

EFFICIENT DATA DISSEMINATION IN VEHICULAR AD HOC NETWORKS

A Thesis submitted in fulfillment of the requirement for
the award of the degree of

DOCTOR OF PHILOSOPHY
IN
COMPUTER SCIENCE AND ENGINEERING

Submitted By

Amit Dua

(Registration No: 901203007)

Under the guidance of

Dr. Seema Bawa

Professor
Computer Science & Engineering
Thapar University,
Patiala (Punjab), India

Dr. Neeraj Kumar

Associate Professor
Computer Science & Engineering
Thapar University,
Patiala (Punjab), India




COMPUTER SCIENCE AND ENGINEERING DEPARTMENT
THAPAR UNIVERSITY, PATIALA – 147004

JUNE 2016

CERTIFICATE

I, Amit Dua, Regn. No. 901203007, hereby declare that the thesis entitled "Efficient Data Dissemination in Vehicular Ad Hoc Networks" submitted to the Department of Computer Science and Engineering at Thapar University, Patiala, Punjab, India is an authenticated record of my own work for the award of the degree of "Doctor of Philosophy" under the supervision of Dr. Seema Bawa and Dr. Neeraj Kumar. This report has not been submitted to any other institution for award of any other degree.

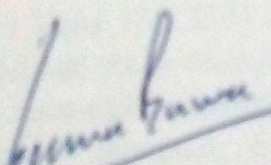

Amit Dua
901203007

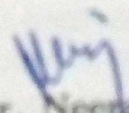
Place: Patiala

Date: OCTOBER 30, 2016

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

Verified by:


(Dr. Seema Bawa)
Supervisor
Professor
Department of CSE
Thapar University,
Patiala (Punjab), India


(Dr. Neeraj Kumar)
Supervisor
Associate Professor
Department of CSE
Thapar University,
Patiala (Punjab), India

ABSTRACT

In recent years, Vehicular ad hoc networks (VANETs) have gained a lot of attention both from academia and industry due to their flexibility to provide uninterrupted services such as entertainment, adaptive route selection, etc., to the end. In VANETs, vehicles interact with other vehicles and to the fixed infrastructures for data dissemination. In VANETs vehicles act as intelligent sensing units having communication and computation capabilities with Application Unit (AU), and On Board Unit (OBU) installed in them. These units can be used in wide range of applications including alert generation, community services, traffic management, etc. and can also impart security, safety and comfort to the on board passengers. With an increasing use of vehicular communications, there may be congestion in the network and quality of service may be compromised. This results in a performance degradation in data dissemination also. A number of research proposals for efficient data dissemination have been laid down since its inception. Most of the existing solution for data dissemination in VANETs were unable to provide a comprehensive scheme to meet the Quality of Service (QoS) parameters. Moreover, the existing schemes were unable to provide reliable communication and the broadcast storm problem was not been solved completely. Hence, there was a need of a new solution that meets the desired QoS parameters and ensures reliable communication.

To address the challenge of meeting the QoS parameters also with changing topology in high mobility scenario, a Quality-Aware Data Dissemination (QADD) scheme has been proposed for VANETs. The protocol was tested for delay incurred, extra messages generated and percent active links with varying vehicle density and speed. QADD successfully overcomes the broadcast storm and gray zone problems and has lowered the generation of extra messages as compared to SOBP [1] and DDOR [2] schemes. The recovery algorithm proposed in this proposal makes it fault tolerant.

To improve the efficacy of data dissemination and to target the problem of heavy congestion, a context aware congestion resolution scheme namely Minimum Calculated Desired Time (MCDT) has been proposed. The scheme is flexible to work in five stages of vehicular state transition and is divided into four phases, i.e., construction, maintenance, message transition, and recovery. Minimum angle method [3] is modified and used as recovery protocol. Links are classified into zones of stability based on the received signal strength. The scheme calculates virtual connectivity, and decides the forwarding vehicle based upon the real-time parameters. The impact of varying speed and density on Packet Delivery Ratio (PDR), End-to-End Delay (E2ED) and overhead is evaluated and compared with GyTAR [4] and A-STAR [5]. The MCDT scheme outperformed the other schemes on probability of successful transmission, average content distribution rate, downloading speed and resource utilization with lower overhead and average load indicating an improvement in efficiency.

Blind flooding of messages in the network especially during emergency causes broad-

cast storm problem which results in reduced PDR and increased delay. Using the game theoretic approach, a Reliability-aware Intelligent Data Dissemination (ReIDD) protocol has been proposed to mitigate this issue. Payoff is calculated for vehicles and weights are assigned to links to calculate reliability. Vehicles with stable links are included in cluster and data is transmitted based on highest cumulative payoff of the possible route. The scheme is executed with varying learning rates of nodes. PDR, Query Response Time (QRT) and reliability are examined and results indicate an increase in performance with lower learning rates. An improvement of 68% in E2ED is observed in the proposed scheme which strengthens its candidature as a solution of broadcast storm problem.

Application of VANETs can be extended to offloading the cellular data in real-time to share the load due to overwhelming growth in mobile data traffic. In Real-time Data Dissemination and Offloading (RDDO) proposal, game theory is applied and utility of each vehicle is calculated by taking connectivity, density, speed and angle of movement of vehicle into account. Utility of WiFi Access Points (APs) is calculated based on the distance from destination, available bandwidth, area of the network and its communication radius. From the results obtained, it is clear that RDDO scheme had an edge over existing state-of-the art protocols in message progress, extra messages exchanged, message dissemination speed, and E2ED.

ACKNOWLEDGMENTS

First and foremost, thanks to almighty God for all his blessings without which nothing of my work would have been possible. I am highly indebted to Prof. (Dr.) Prakash Gopalan, Director, Thapar University, Patiala, Prof. (Dr.) R. S. Kaler, Deputy Director, and Dr. Susheel Mittal, Deputy Director, Thapar University for providing me the opportunity to pursue my course work and research. My deep regards to Dr. O.P. Pandey, Dean of Research and Sponsored Projects for his enormous help in completion of my research work. This thesis would have not been possible without the enabled guidance and keen interest of my supervisors Dr. Seema Bawa, Professor and Dr. Neeraj Kumar, Associate Professor, Department of Computer Science and Engineering, Thapar University, Patiala. The extensive discussions with them have always made me to stay on the right track. They have always been patient and cooperative whenever their guidance and expertise was needed. They helped me not only by sparing their valuable time, but also analytically reviewing my experimental setup, publications, reports and presentation from time to time. The constructive criticism and motivation by my supervisors has groomed me to my present shape. I would also like to express my gratitude to Dr. Deepak Garg, Head, Computer Science and Engineering Department for providing me the continuous feedback throughout my work. I am thankful to my doctoral committee members Dr. Anil Kumar Verma, Dr. Shalini Batra, and Prof. (Dr.) Rajesh Khanna for their constructive suggestions and ensuring the progress of my research work at correct pace. Their critical analysis and encouraging support brought me to this stage of my course. I will go amiss if I forget to thank Dr. Maninder Singh and Dr. Ashwani Kush for their valuable suggestions and motivation throughout the program. I wish to thank all the faculty and staff members of Computer Science and Engineering Department of Thapar University, Patiala for their enormous support. I would like to pay deep gratitude to my parents Mr. B.B. Dua and Dr. Anita Dua, for their unconditional love, affection, and encouragement through all the times. Words can not truly express my feelings and appreciation to all friends and colleagues in lab, Anish, Gagan, Kuljeet, Karanveer, Neenu, Sumedha, Ruby, and Bharath, to make my journey during this work memorable and pleasant. The financial support from Tata Consultancy Services (TCS) in the form of research fellowship is duly acknowledged.

Contents

Certificate	i
Abstract	iii
Acknowledgment	iv
List of Important Abbreviations	xiii
1 Introduction	1
1.1 Evolution of Wireless Networks	1
1.1.1 Types of wireless communication	2
1.1.2 Structure of VANETs	3
1.1.3 Internet of Vehicles (IoV)	4
1.2 Architecture and Components of VANETs	4
1.2.1 Comparison of VANETs with MANETs	5
1.3 Applications of VANETs	7
1.3.1 Alert generations	7
1.3.2 Vehicle maintenance	7
1.3.3 Community services	7
1.3.4 Co-operative collision warning	8
1.3.5 Lane changing warning	8
1.3.6 Intersection collision warning	8
1.3.7 Work zone warning	8
1.3.8 Inter-vehicle communications	8
1.3.9 Electronic toll collection (ETC)	8
1.3.10 Parking lot payment	8
1.3.11 Traffic management	8
1.4 Issues in VANETs	9
1.4.1 Mobility	9
1.4.2 Scalability	11
1.4.3 Channel utilization	11
1.4.4 Security and privacy	11
1.4.5 Data management	12
1.4.6 Clustering	12
1.4.7 Data dissemination	13
1.4.8 Constraints and challenges for data dissemination	13
1.5 Thesis Organization	14

2	Literature Review	16
2.1	Topology based Data Dissemination	16
2.1.1	Proactive techniques	16
2.1.2	Reactive techniques	18
2.1.3	Analysis of topology based protocols	23
2.2	Geographic Data Dissemination	25
2.2.1	Analysis of geographic based protocols	35
2.3	Hybrid Data Dissemination	38
2.3.1	Analysis of hybrid protocols	42
2.4	Clustering based Data Dissemination	43
2.4.1	Analysis of clustering based protocols	47
2.5	Opportunistic Data Dissemination	48
2.5.1	Analysis of opportunistic protocols	50
2.6	Data Fusion based Data Dissemination	51
2.6.1	Analysis of data fusion based protocols	52
2.7	Greedy Data Dissemination	53
2.7.1	Analysis of greedy protocols	54
2.8	Other Schemes used for Data Dissemination	54
2.9	Research Gaps	57
2.10	Problem Formulation	59
2.11	Objectives	59
3	Coordinated QoS-aware Data Dissemination	60
3.1	System Model	60
3.1.1	Mobility model	61
3.1.2	Channel model	61
3.2	Proposed QADD scheme	63
3.2.1	Reward-Penalty (RP) function	63
3.2.2	Intelligent forwarding	64
3.2.3	Weight calculation	64
3.2.4	Construction phase	64
3.2.5	Maintenance phase	68
3.3	Performance Evaluation of QADD Scheme	70
3.3.1	Simulation settings	70
3.3.2	Results and discussion	72
3.4	Comparison of QADD with SOBP and DDOR	74
3.4.1	Connectivity ratio and Delay incurred	74
3.4.2	Extra messages generated and optimal allocated rate	74
3.4.3	Channel access rate and medium usage ratio	76
3.4.4	Load on network	76
3.5	Summary	76
4	Context-aware Congestion Resolution	78
4.1	System Model	78
4.1.1	Network model	78
4.1.2	Mobility model	79
4.1.3	Channel model	79
4.2	Proposed MCDT scheme	84

4.2.1	Construction phase	84
4.2.2	Maintenance phase	85
4.2.3	Message transmission	86
4.2.4	Recovery by minimum angle method	87
4.2.5	Flowchart	87
4.2.6	An illustrative example	88
4.2.7	Algorithm complexity	89
4.2.8	Overhead analysis	89
4.3	Performance Evaluation of MCDT Scheme	91
4.3.1	Simulation settings	91
4.3.2	Results and discussion	91
4.4	Comparison of MCDT with GyTAR and A-STAR	94
4.4.1	Probability and delay	94
4.4.2	Average content distribution rate and overhead	94
4.4.3	Downloading Speed and resource utilization	96
4.4.4	Average load	96
4.5	Summary	97
5	Reliability-aware Intelligent Data Dissemination	98
5.1	System Model	99
5.1.1	Mobility model	99
5.1.2	Application of Game Theory	100
5.1.3	Reliability service model	101
5.2	Proposed ReIDD scheme	102
5.2.1	Setting the game	102
5.2.2	Calculating the Payoff of the players	102
5.2.3	Weight calculation	103
5.2.4	Reliability calculation	103
5.2.5	Belief update	104
5.2.6	Cluster/Coalition formation	105
5.2.7	Cluster/Coalition maintenance	105
5.2.8	Intelligent data dissemination	106
5.2.9	Complexity analysis	107
5.2.10	Servicing the request	110
5.3	Performance Evaluation of ReIDD Scheme	113
5.3.1	Simulation settings	113
5.3.2	Results and Discussion	115
5.4	Comparison of ReIDD with GyTAR and A-STAR	117
5.5	Summary	119
6	Real-Time Data Dissemination and Offloading	120
6.1	System Model	121
6.1.1	Network model	121
6.1.2	Application of game theory	122
6.2	Proposed RDDO scheme	123
6.2.1	Offloading using vehicles	123
6.2.2	Offloading using AP	126
6.2.3	Proposed algorithm	128

6.2.4	Mathematical analysis	128
6.3	Performance Evaluation of RDDO Scheme	130
6.3.1	Simulation settings	130
6.3.2	Results and discussion	131
6.4	Summary	139
7	Conclusion and Future scope	140
7.1	Conclusion	140
7.2	Benefits to the society	141
7.2.1	Smart Cities	141
7.2.2	Real-time alert	142
7.2.3	Alternate means of data transfer	142
7.3	Future research scope	142
7.3.1	Security in data dissemination	142
7.3.2	5G enabled vehicular communication	142
	References	144
	List of Publications	158

List of Figures

1.1	Generalized architecture in VANETs	5
2.1	Classification of Topology based schemes in VANETs	17
2.2	Transmission range and distance from RSU	19
2.3	Classification of Geographic data dissemination schemes in VANETs	25
2.4	GPCR routing along junctions [6]	27
2.5	Restricted Forwarding Algorithm	30
2.6	Selection of next vehicle to forward the packet [7]	32
2.7	Classification of Hybrid data dissemination schemes in VANETs	39
2.8	Routing zone with $\rho=2$ [8]	41
2.9	Classification of Clustering based data dissemination schemes in VANETs	44
2.10	Classification of Opportunistic data dissemination schemes in VANETs	49
2.11	Classification of Data Fusion schemes in VANETs	51
2.12	Classification of Greedy data dissemination schemes in VANETs	53
2.13	Classification of Other schemes for data dissemination in VANETs	55
3.1	(a) Variations in throughput as interference ratio increases (b) Context switching delay with variation in interference ratio	62
3.2	Flowchart for Algorithm 1 of QADD scheme	66
3.3	Shortest path selection using Algorithm 1	67
3.4	Calculation of shortest path selection for Fig. 3.3	67
3.5	Shortest path selection after link breakage	69
3.6	Calculation of shortest path selection for graph used in Fig. 3.5	70
3.7	(a) Patiala city map (b) magnified view of SUMO simulation of Patiala city map	71
3.8	(a) Delay incurred (b) contour representation of delay incurred	72
3.9	(a) Extra messages generated (b) contour representation of extra messages generated	73
3.10	(a) Percentage of active links (b) contour representation of Percentage of active links	73
3.11	Comparison of proposed QADD scheme with SOBP and DDOR for (a) connectivity ratio (b) delay incurred	74
3.12	Comparison of proposed QADD scheme with SOBP and DDOR for (a) extra messages generated (b) optimal allocated rate	75
3.13	Comparison of proposed QADD scheme with SOBP and DDOR for (a) channel access rate (b) medium usage ratio	75

3.14	Comparison of proposed QADD scheme with SOBP and DDOR for (a) load on the network with varying velocity (b) load on the network with increasing number of vehicles in a cluster	76
4.1	Generalized architecture in VANETs	80
4.2	Variation in (a) signal intensity with distance (b) collision probability with increasing number of channels	81
4.3	CDT with increasing velocity and density	82
4.4	LBR with increasing velocity and density	82
4.5	State transition in VANETs	83
4.6	Flowchart of proposed MCDT scheme	87
4.7	Angles of various vehicles from source with East Direction as reference	88
4.8	CDT from source to destination through intermediate vehicles	89
4.9	Patiala city map	90
4.10	(a) PDR of MCDT with beacon interval of 1 second (b)PDR of MCDT with beacon interval of 2 second (c)PDR of MCDT with beacon interval of 3 second (d)E2ED of MCDT with beacon interval of 1 second (e)E2ED of MCDT with beacon interval of 2 second (f)E2ED of MCDT with beacon interval of 3 second	92
4.11	(a) Routing overhead of MCDT with beacon interval of 1 second (b)Routing overhead of MCDT with beacon interval of 2 second (c)Routing overhead of MCDT with beacon interval of 3 second	93
4.12	(a) Probability of successful transmissions (b) Delay in content distribution (ms) (c) Average content distribution rate (d) Average overhead generated (e) Downloading Speed (f) Percentage utilization of resources for content distribution (g) Average load with speed of the vehicles (h) Average load with density of the vehicles	95
5.1	(a) Variation in PDR with increasing density and varying velocity (b) Delay in communication with increasing density and varying velocity	99
5.2	Network model used	100
5.3	Flowchart of the ReIDD scheme	108
5.4	Scenario taken in Example 3	110
5.5	Example Scenario (a) Initial setting (b) Exploring vehicle 2 from Source with payoff of 0.5 (c) Exploring vehicle 3 and payoff from S to V3 is 0.525 (d) Exploring vehicle 5 and payoff from S to V5 is 0.612 (e) Exploring vehicle 6 and payoff from S to V6 is 0.456 (f) Exploring Destination with total payoff from S to D is 0.478	111
5.6	Calculation of payoff for scenario in Fig. 5.5	111
5.7	SUMO map of Patiala city	113
5.8	Variation in PDR with increasing velocity and density (a) with learning rate 0.02 (b) learning rate 0.04 (c) learning rate 0.06	114
5.9	Variation in QRT with increasing velocity and density (a) with learning rate 0.02 (b) learning rate 0.04 (c) learning rate 0.06	115
5.10	Variation in Reliability with increasing velocity and density (a) with learning rate 0.02 (b) learning rate 0.04 (c) learning rate 0.06	116
5.11	Comparison of ReIDD with A-STAR and GyTAR (a) PDR (b) Reliability (c) E2ED	118

6.1	Network model used for RDDO scheme	121
6.2	Total data offloaded and duration of data transfer	123
6.3	(a) Connectivity =1 (b) Connectivity = 2 (c) Connectivity = 3 (d) Con- nectivity = 3	124
6.4	Angle of movement of the vehicle	126
6.5	SUMO map of patiala city	132
6.6	Topologies in the network (a) Sparse connectivity (b) Dense connectivity .	132
6.7	Message progress with varying vehicle density (a) Dense network (b) Sparse network	134
6.8	Message progress with varying source to destination distance	134
6.9	Extra messages exchanged with varying vehicle density (a) Dense network (b) Sparse network	135
6.10	Message dissemination speed with varying vehicle density (a) Dense net- work (b) Sparse network	136
6.11	E2ED with varying vehicle density (a) Dense network (b) Sparse network .	136
6.12	E2ED with varying (a) Source to destination distance (b) Simulation time	137

List of Tables

1.1	Relative comparison of mobility models	11
2.1	Relative comparison of Proactive Data Dissemination schemes in VANETs	23
2.2	Relative comparison of Reactive Data Dissemination schemes in VANETs .	24
2.3	Relative comparison of Geographical Data Dissemination schemes in VANETs	36
2.4	Relative comparison of Hybrid Data Dissemination schemes in VANETs . .	42
2.5	Relative comparison of Clustering based Data Dissemination schemes in VANETs	47
2.6	Relative comparison of Opportunistic Data Dissemination schemes in VANETs	50
2.7	Relative comparison of Data Fusion based schemes in VANETs	53
2.8	Relative comparison of Greedy Data Dissemination schemes in VANETs .	54
3.1	Simulation setting parameters for QADD scheme	72
4.1	Simulation setting parameters for MCDT scheme	90
4.2	Performance comparison of MCDT with GyTAR and A-STAR	97
5.1	Simulation setting parameters for ReIDD scheme	113
5.2	Performance comparison of ReIDD, A-STAR and GyTAR	119
6.1	Test data generated from SUMO	132
6.2	Simulation settings parameters for RDDO scheme	133
6.3	Performance comparison of RDDO, GyTAR and GPCR	138

LIST OF IMPORTANT ABBREVIATIONS

Acronym	Meaning
AANET	Aeronautical Ad hoc Networks
AG	Angle
AP	Access Point
Ar	Area of Network
A-STAR	Anchor-based Street and Traffic Aware Routing
AU	Application Unit
bps	bit per second
BSN	Body Sensor Network
CC	Channel Capacity
CDT	Calculated Desired Time
CH	Cluster Head
Con	Connectivity
CP	Computation Power
CRL	Certificate Resolution List
CSMA	Carrier Sense Multiple Access
D	Destination
DARPA	Defense Advancement Research Project Agency
DDOR	Destination Discovery Oriented Routing
DHT	Distributed Hash Table
DSRC	Dedicated Short Range Communication
E2ED	End-to-End Delay
ETC	Electronic Toll Collection
FI	Jain's Fairness Index
FSPL	Free Space Path Loss
GHz	Giga hertz
GPS	Global Positioning System
GPCR	Greedy Perimeter Coordinator Routing
GyTAR	Greedy Traffic Aware Routing
ID	Identity

IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	Intelligent Forwarding
IoV	Internet of Vehicles
IP	Internet Protocol
ITS	Intelligent Transport System
Kbps	Kilo bits per second
KDC	Key Distribution Center
Km/hr	Kilometer per hour
LAN	Local Area Network
LBR	Link Breakage Rate
LoS	Line of Sight
LTE	Long Term Evolution
LV	Leaving Vehicle
MAC	Medium Access Control
MANET	Mobile Ad Hoc Network
Mbps	Mega bits per second
MCDT	Minimum Calculated Desired Time
MIPS	Million Instructions Per Second
MIPv6	Mobile Internet Protocol Version 6
MS	More Stable
NS-2	Network Simulator 2
OBU	On Board Unit
OR	Opportunistic Routing
P2P	Peer-to-Peer
PC	Personal Computer
PDA	Personal Digital Assistant
PDR	Packet Delivery Ratio
PKI	Public Key Infrastructure
PRNET	Packet Radio Network
PS	Peak Stable
QADD	QoS Aware Data Dissemination
QoS	Quality of Service
QRT	Query Response Time
RA	Relative Acceleration
RD	Receiver Driven
RDDO	Real-time Data Dissemination and Offloading
ReIDD	Reliability-aware Intelligent Data Dissemination
RERR	Route Error

RF	Reward Function
RP	Reward Penalty
RREQ	Route Request
RRP	Route Repair
RS	Relative Speed
RSU	Road Side Unit
RT	Request Time
S	Source
SBM	Special Beacon Message
SD	Sender Driven
SNR	Signal-to-Noise Ratio
SOBP	Sender-designated Opportunistic Broadcast Protocol
SS	Small Stable
SUMO	Simulation of Urban mMobility
SURAN	Survivable Radio Network
TDMA	Time Division Multiple Access
TT	Total Time to Serve Request
TTL	Time To Live
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VANET	Vehicular Ad Hoc Network
VC	Virtual Connectivity
WAN	Wide Area Network
WAVE	Wireless Access for Vehicular Environment
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network
\aleph	Message speed
α, β, γ	Constants
χ	Threshold value for RF
λ	Request arrival rate
μ	Weight factor/ payoff
ν	Velocity
ϕ	Threshold time
ρ	Density
τ	Distance
Θ	End-to-end delay
θ	Angle
Υ	Message progress
\varkappa	AP range
ϖ	Objective function
ξ	Data size

Ξ	Extra messages generated
ξ^{obj}	Objective function
ζ	Vehicle range
Acc_i	Acceleration
D	Distance
$distance[]$	Cumulative weight from source to destination
DSS_i	Change in Signal strength received from v_i
e_{ij}	Link between v_i and v_j
$IF_{i,j}$	Intelligent forwarding of link
$k_1 - k_5, \phi, \zeta$	Constants
k	ratio of energy
loc_x	x coordinate of vehicle
loc_y	y coordinate of vehicle
L	Length of path
min	minimum
max	maximum
M_{S-D}	Number of messages from S to Recipient
N	Number of vehicles
p	Penalty
$parent[]$	Array used to calculate the best path
r, p	Reward and Penalty
Ret	Retardation
R	Range
$SBMD_i$	SBM Database for vehicle i
t	Time
Thr	Throughput
$Thrs$	Threshold of Signal Strength
U	Utility
v_{rel}	relative velocity between vehicles
vel_x	x coordinate of velocity
vel_y	y coordinate of velocity
V	List of Vertices

Chapter 1

Introduction

From the past few decades, there has been a revolution in communication technology which has changed the lifestyle of common people. Now far flung people are interconnected to share information with one another over the Internet. Internet is the inter-connection of different networks in which various entities such as Personal Computers (PCs), smart phones, sensors, laptops are connected with one another and follow predefined rules and regulations for conversation with one another. These set of rules and regulations are known as the protocols. The protocols are specific to the type of networks used. The networks are broadly classified into two categories namely-wired and wireless networks. Wired networks have fixed infrastructure in which dedicated servers, switches, routers are deployed in particular regions to support various users/clients. In contrast to the wired networks, wireless networks generally do not have any fixed infrastructure. They have mobile clients to whom connectivity is provided by mobile routers and Access Points (APs). A brief account of history and journey of evolution of wireless networks is given in the following segment.

1.1 Evolution of Wireless Networks

The use of wireless networking can be traced back to 500 B.C. when a Persian emperor, Darius I, applied an innovative technique to communicate the messages from the capital city to remote places. Darius I placed a series of men on the top of tall buildings separated at the distance enough to hear the adjacent men voice. These men shouted and the series of communication resulted in delivery of messages and news to intended destination. The scheme was at least 25 times faster than messengers carrying the message. Some other kings used series of repeaters of drums, trumpets, etc., for wireless voice communication.

The evolution of modern ad hoc networks started in 1970, when Norman Abramson invented ALOHAnet for single hop wireless communication to connect together universities of Hawaiian islands. The ALOHAnet was implemented originally for fixed single-hop wireless networks. This successful implementation of ad hoc networks led to further research in this field. A project named Packet Radio NETwork (PRNET) funded by Defense Advancement Research Project Agency (DARPA) led to the development of Ethernet by Robert Metcalfe over years 1973-1976. The development of Ethernet was used mainly for military applications having a centralized control. However, the application soon spread to larger geographic areas with distributed multi-hop wireless communication system. The widespread acceptance and overwhelming use was mainly because of the use of single

channel, support of mobility, and simpler channel management technique. To access the shared radio channel, Carrier Sense Multiple Access (CSMA) scheme was used.

The main requirements for ad hoc network scheme were self organization, self configuration, and dynamic operation without the involvement of any fixed infrastructure. However, the PRNET had certain limitations. These include obtaining and maintaining the network topology information, error & flow control, and inability to recover from mobility of nodes that resulted in paths breakage. To overcome these limitations, the SURvivable RAdio Networks (SURAN) project was started with an aim of providing scalable ad hoc networking. An extension of the work carried on by Internet Engineering Task Force (IETF) that standardized the protocols for ad hoc wireless networks and named it Mobile Ad hoc NETWORKS (MANET).

Further development took place in 1994, when Ericsson developed Bluetooth protocol for short-range, low power communication amongst heterogeneous devices. Bluetooth made possible ubiquitous connectivity among inexpensive devices which was implemented by all major telecommunication vendors including Intel, IBM, Nokia, Microsoft, etc. Bluetooth helps exchange of voice or data by forming a group of nodes within smaller geographical regions. The communication can further be extended by the formation of piconets, scatternets, and the progress is still in progress.

1.1.1 Types of wireless communication

There are various types of wireless communication. Some of the prominent ones are discussed as follows.

- i) Mobile Ad hoc NETWORKS (MANETs): MANETs are the infrastructure-less network with self-configuring mobile nodes communicate among each other. The devices in MANET move independently in any direction with peer-to-peer communication. As the nodes move randomly, the network topology changes frequently. The communication amongst nodes takes place using IEEE 802.11 standards. These networks are independent, but some of the nodes can also have Internet connectivity.
- ii) Sensor networks: In this type of wireless networks, the autonomous sensors sense the environmental conditions like temperature, pressure, etc., and communicate the information to a centralized location using the wireless network. The sensor nodes consist of several parts including a radio transceiver, a micro-controller, and an energy source in the form of a battery. The sensor nodes are also constrained with size and cost, where the cost varies according to the complexity of application. Apart from size and cost, the sensor nodes are constrained on resources namely-memory, energy, communication bandwidth and computational speed. The topology of sensor networks varies according to the nature of application. It can be star or mesh topology.
- iii) Vehicular Ad hoc NETWORKS (VANETs): VANETs are special class of MANETs which are different from MANETs in the sense that former may have infrastructure support while later do not have. There are a large number of applications of VANETs, e.g., environment sensing and monitoring, intelligent transport systems (ITS), safety messages alerts in case of emergency, etc., which have been/being developed over the years using VANETs. Various government and private agencies

have invested a lot of money in a number of different projects in this area with an aim to provide safety and comfort to the passengers sitting in the vehicle. In all these applications, messages are broadcasted from source to the destination for information dissemination [9, 10].

The vehicles on the road communicate with each other either in Peer-to-Peer (P2P) manner or by using the existing infrastructure. In the former case, the communication is called as Vehicle-to-Vehicle (V2V) while in the later, it is called as Vehicles-to-Infrastructure (V2I). The infrastructure support is provided by the nearest Road Side Units (RSUs) which may act as an intelligent router to control all the activities of the vehicles on the road. If the vehicles are within the range of RSUs then messages are forwarded to them directly otherwise, these are passed to nearest RSUs of the vehicles. But, due to the high mobility and sparse distribution of the vehicles on the road, data dissemination among the vehicles always remains a challenging task which may cause a long message delivery delay. The message delivery in VANETs follows store and forward strategy in which messages are kept at some of the intermediate nodes till the best forwarding node (vehicles/RSUs) is found [11]. This strategy may cause long delay, but such delay may affect the performance of many of applications in VANETs.

1.1.2 Structure of VANETs

Among the aforementioned wireless networks, VANETs is the one which has gained a lot of popularity due to its flexibility to provide uninterrupted service to the end users during mobility. These have emerged as a new promising technology which can be used in wide areas of applications. A numbers of applications which have been developed both by academia and industry using VANETs are described in [12–15]. The ultimate goal of developing all these applications is to provide comfort and safety to the on-board passengers. A number of options are available for the safety of passengers in the vehicles during driving using embedded hardware (sensors) & software, and communication technology. Passengers in the vehicles can take smart decisions by transferring/receiving the data by plugging remote key-less entry devices, Personal Digital Assistants (PDAs), laptops or mobile telephones in the vehicles. The integration of communication technology in vehicles with all the modern equipments led to multiple advantages such as-the safety of passengers [16]. The data may also be collected by the sensors from the objects located outside the vehicles. For example, sensors may be used in receiving the signal and waves from human body and transmit them to distant locations for medical examination. VANETs equipped with sensor nodes can be used for various critical applications such as generating alarms to nearest police station or fire control office in case of some emergency calls in a living community. In such a case, houses in the community are equipped with APs for transferring and receiving the data from the vehicles and generating the alarms/events to the desired locations. Similarly, the data collected by the vehicles can also be used for other applications such as for finding an optimized routing path in dense and sparse regions.

Vehicle to sensor communication can take place either using short range or long range techniques. Short range techniques such as Bluetooth, Infrared and ZigBee are commonly used for transmission between vehicles and sensors. Bluetooth works within 10 meter range and can transfer data at the rate of 2 Mega bit per second (Mbps). Infrared

has wavelengths ranging from 700 nanometer to 1 millimeter and can work only on line of sight with maximum transmission distance of 10 meter. Zigbee uses less power for communication and can result in extended battery life. Apart from these, long range communication techniques like 4G broadband, WiFi, worldwide interoperability for microwave access (WiMAX) and long term evolution (LTE) can be used. 4G and WiMax use IEEE 802.16e and IEEE 802.16m standards for communication. LTE can provide 100 Mbps downstream and 30 Mbps upstream data rates. It can use IEEE 802.11 a/b/g or IEEE 802.11p standards that work on 2.4 GHz to 5.9 GHz band [17–19].

In this scenario, the information is shared among all the vehicles in the range without the use of existing infrastructure. For V2I, vehicles use the nearest APs generally called as road side units (RSUs) which provide seamless connectivity to all the moving vehicles on the road. These RSUs may be deployed in an optimized manner at different locations alongside the road to maintain the coverage and connectivity to all the moving vehicles [10-13].

1.1.3 Internet of Vehicles (IoV)

A major advancement in communication took place with the realization of Internet [20]. According to a recent prediction, 50 billion of devices will be connected to the Internet by 2020 [21]. One of these are vehicles which form Internet of vehicles (IoV). In IoV, each vehicle has multi-sensor equipments capable to sense the environment in real-time. Apart from sensing, vehicles are also having high computation, processing, and storage capabilities with IP based connectivity to Internet and other vehicles. IoV is a paradigm that enables communication between intra-vehicle devices, vehicles and vehicles, vehicles and roads, vehicles and people, and other types of communication that require Internet. IoV allows sensing data from heterogeneous geographical locations by intelligent vehicles. The sensed data is of versatile nature, offering safety and providing numerous applications to drivers and passengers.

Vehicular ad hoc network (VANET) is a special category of IoV where vehicles are intelligent sensing units having communication and computation capabilities. The vehicles are installed with application unit (AU) and on board unit (OBU) that enable them to communicate amongst each other and to the fixed infrastructure, RSUs. These RSUs are connected to each other and to the centralized Internet connection. However, there are situations where the RSUs might not be available within communication range of vehicles.

1.2 Architecture and Components of VANETs

For communication, vehicles may contain some units which can be used to establish the connection with other vehicles or to the infrastructure. Typically, following are the three major components of VANET architecture: AUs, OBUs, and RSUs. RSUs may act like a router which provides services to the moving clients [22], while OBUs and AUs are the consumer for those services. The communication among OBUs and AUs with RSUs can be done using wireless standards such as IEEE 802.11p, IEEE 802.11 a/ b/g. The vehicles generally have OBUs installed on board of the vehicles which can be used for providing communication with other OBUs or with RSUs. Moreover, OBUs also provide communication with AUs. OBUs are used for congestion control, IP mobility management, data collection and processing [22]. AUs are the sophisticated devices which

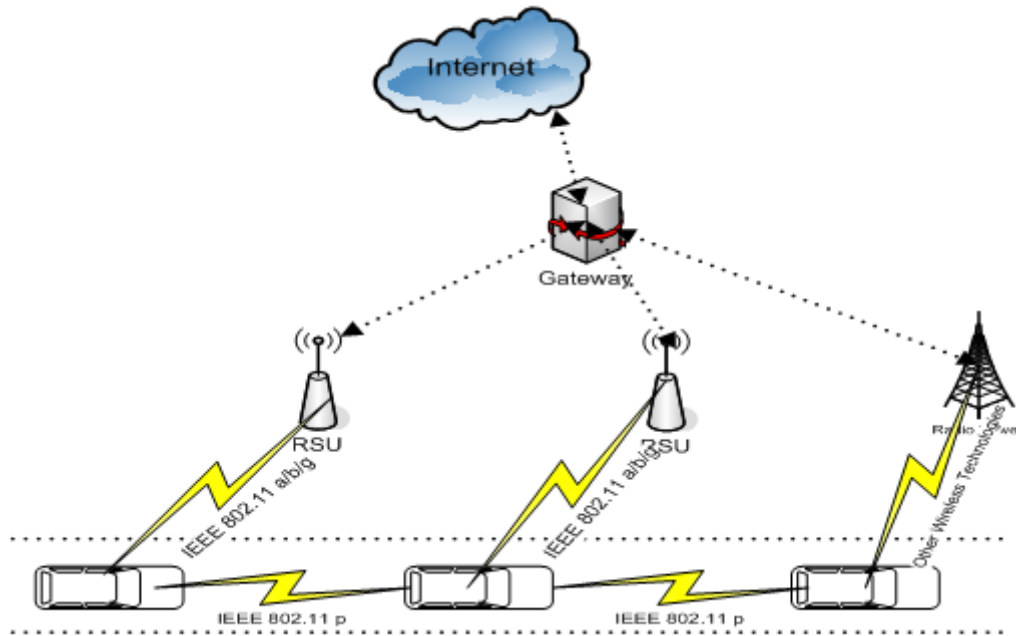


Fig. 1.1: Generalized architecture in VANETs

provide safety applications and communicate to RSUs by using OBUs. These may be separate units or may be integrated with OBUs as a single unit. RSUs are deployed as fixed units alongside the road in an optimized manner so as to preserve the coverage and connectivity to all the vehicles. They provide communication among the vehicles using dedicated short range communication (DSRC) or with the other RSUs and OBUs using IEEE 802.11 a/b/g. Fig. 1.1 shows various components of the generalized architecture used in VANETs.

1.2.1 Comparison of VANETs with MANETs

There are many properties of VANET that make it a unique one. Because of these properties, VANETs have large number of challenges and hence need exclusively designed protocols [16]. Some of the characteristics that make it unique are discussed below.

- i) As the velocity of vehicles can go as high as one hundred and fifty kilometer per hour, there is frequent change in topology. This results in limited and less time for communication between vehicles. This time is even smaller when the vehicles are moving in opposite direction. The transmission range can be increased to counteract the scarcity of communication time, but this would result in higher collisions of packets. The higher contention rate degrades the throughput of VANET. To improve the efficiency, low latency protocols are required.
- ii) As the speed is high and reaction time is less, the warning messages must be delivered within fraction of seconds. This urgency requirement of communication is intrinsic property of VANETs which is not present in MANETs. To counteract high mobility and delivering the information in time, broadcasting the messages can be one of the solutions in VANETs.
- iii) MANETs can work with predictive routing schemes, but such schemes are not very

successful in VANETs as location changes are very quick and unpredictable. This results in making efficient routing table obsolete in no time or it requires heavy channel utility which may degrade the network efficiency.

- iv) The topology of VANETs changes with the movement of vehicles. Since vehicles move on roads, though this topology changes, these changes are predictable. The movement of vehicles only on fixed roads makes this prediction possible.
- v) In MANETs, one of major objectives is to maximize battery lifespan by minimizing energy usage. However, in VANETs, this is not an issue because in vehicles, battery is charged by fuel and runs for months and even for years. The power delivered by battery of vehicles is sufficient for transmitting even after internal usage, for air conditioner, music player, etc. This is not the case in MANETs where power is always a constraint.
- vi) Initially, when the deployment of VANET is on small percentage of vehicles, then frequent and regular fragmentation of the network may occur. After sometime of deployment when most of the vehicles exchange messages with one another, still there may be fragmentation in the network. Hence the designed protocol must expect and take fragmentation into account.
- vii) For making the VANET technology acceptable, privacy and security must be given a priority. If the daily activity of vehicles, monitored by centralized authority is leaked, this may lead to breach in person's privacy which is not acceptable. Any malicious third party user can use this information for illicit purposes that may harm the security of users.
- viii) Misuse of VANET can be done by raising a false alarm of accident by tampering with the messages propagated. Such type of misuses must be dealt seriously and strong mechanisms should be designed for making VANET more secure.

Hence, the main characteristics of VANETs can be summarized as follows.

- a) Mobility of nodes is very high.
- b) The topology can be predicted.
- c) Latency requirement is critical for safety applications.
- d) Power is not an issue.
- e) Fragmentation possibility is high.
- f) Migration rate is low.
- g) Security and privacy are critical factors.

Centralized infrastructure connected to Internet can be deployed at the roads. But, because the number of roads are exponential in size, deploying RSUs at every road is not possible. Hence, RSUs can be deployed at strategic locations at regular intervals. These RSUs can efficiently communicate with the fast moving vehicles and can increase the rate of communication with reduced latency. As these units offer services without any charge

and does not require any heavy centralized infrastructure, it makes VANET a reality. In general, VANETs are special case of MANETs used for communication among vehicles and fixed RSUs. The applications of VANETs are discussed in the following Section.

1.3 Applications of VANETs

The applications of VANETs can be broadly classified into three categories namely-safety, transport efficiency, and infotainment [22]. Fast message dissemination and collision avoidance can be categorized under safety application. Under transport efficiency, major applications are dynamic route scheduling and real-time traffic monitoring. Other applications like asking for nearest gas filling station, seats available in a restaurant or movie timings in nearby movie hall which are not critical but can improve comfort of passengers are categorized as infotainment applications. Some of the major applications of VANETs are discussed as follows.

1.3.1 Alert generations

- i) RSUs gather, process and analyze information of the vehicles moving towards intersection. Depending on the analysis, if there is any possibility of collision/accident, RSU generates alert and informs approaching vehicles and allowing them to take appropriate actions [22].
- ii) In case of emergency, all the vehicles which are coming on that path are informed, so that they can give way to the emergency vehicles [23]. These emergency vehicles can be ambulance, military vehicle, or vehicle of a high security dignitary, etc.
- iii) Even in the case, when an accident has occurred, the vehicles approaching that area are informed so that they can take alternate paths.
- iv) RSUs are placed in specific areas like hospitals, schools, animal passing area, etc., to send alert messages to vehicles approaching that area.

1.3.2 Vehicle maintenance

- i) Event driven notification messages are sent to vehicles when the driver has set a reminder for recall or when there is a fault in the vehicle. In case of a fault, the OBU sends a message to the infrastructure using V2I communication. The support center replies back to the vehicle and provides instructions to it.

1.3.3 Community services

- i) Co-operative downloading: A file is divided into pieces and these are available for download from the neighbors. The car selects the best peer for download. The cooperative assembly of file is encouraged because of limited availability and capacity of access points. This cooperative downloading is possible through BitTorrent or CarTorrent.

1.3.4 Co-operative collision warning

- i) In case of collision, warning messages must be broadcasted to nearby vehicles. This can not only save time for vehicles but can also ensure the safety of passengers.

1.3.5 Lane changing warning

- i) Whenever a vehicle changes its speed or lane abruptly making it dangerous for other approaching vehicles, it must be warned to these vehicles. Broadcast must be performed to dissipate warning message to the approaching vehicles.

1.3.6 Intersection collision warning

- i) Warning messages can be generated by intersection RSU rather than vehicles. RSU broadcasts the warning messages to notify approaching vehicles. They can take preemptive actions either by applying brakes or changing the direction.

1.3.7 Work zone warning

- i) Whenever a construction or any other maintenance work is carried on the roads, vehicles are informed and they change the route. This saves precious time and avoids traffic jams.

1.3.8 Inter-vehicle communications

- i) Vehicles communicate amongst themselves either directly using OBUs or through RSUs.

1.3.9 Electronic toll collection (ETC)

- i) OBUs are charged and as soon as it passes through a toll collecting RSU. The charge is deducted from the OBU. This charge is done by the driver of vehicle through centralized infrastructure by paying the required amount.

1.3.10 Parking lot payment

- i) Similar to a toll collection, parking lot payment can be done. Instead of RSUs, toll collecting infrastructure can deduct the amount from pre-charged OBUs.

1.3.11 Traffic management

- i) Real-time traffic monitoring can be performed by interaction of OBUs with the RSUs. This can be used for taking an appropriate path having minimum traffic. Also, in case of any accident, traffic can be managed smoothly.

1.4 Issues in VANETs

Although there are a number of issues which influence the applications of VANETs, but following are the main concerns which are having direct impact on the performance of any solution in VANETs.

1.4.1 Mobility

The mobility of vehicles depends on the density of vehicles on the roads. Higher density roads have less mobility. Density may vary according to different time of the day. The office rush hours in morning and evening have more density and hence less mobility on roads. The weekends have less number of the vehicles on the roads and mobility is high.

Different mobility models can be used in VANETs, i.e., Manhattan, freeway, etc. In cities, where the roads are straight and cut each other at right angles, the most suitable mobility model is Manhattan mobility model. Some models take movement of vehicles as random and any vehicle can take any path. These vehicles follow freeway mobility model. There is no restriction on the movement of vehicles in this model.

Within any mobility model considered, there can be two scenarios namely: highway and city scenario. In highway scenario, vehicles are sparsely distributed and speed is very high. While in city scenario, the vehicles are densely distributed and velocity is low. Various mobility models have been proposed for VANETs. Following is the description of various mobility models used in VANETs.

1.4.1.1 Mobility models for data collection

The movement pattern of mobile nodes including variation in location, velocity and acceleration with time, is described in the mobility models. Mobility models play an important role in deciding the efficiency of protocol, so proper mobility model must be selected according to the scenario under consideration. Few important mobility models studied are discussed as below.

- i) Random waypoint mobility model: Johnson and Maltz [24] proposed the random waypoint model. The mobile node moves in a particular direction for certain time and pauses for a limited period. After the pause, node starts moving with a random speed between minimum and maximum permissible speed [V_{min} and V_{max}] in a random direction. After moving for newly selected direction for certain amount, the node again pauses and the process is repeated.
- ii) Random walk mobility model: In this model, nodes change their direction and speed after moving for a fixed time. The new direction $\theta(t)$ can take values from $(0, 2\pi]$ and new speed follows Gaussian or uniform distribution. There is no pause between change of velocity and direction and this is the only difference between random waypoint and random walk mobility model. Both these models are very easy to understand and implement but have some limitations like these do not consider the previous or current velocity while deciding the velocity at next moment resulting in sudden acceleration, stops and turns. This limitation is called the temporal dependency of velocity.
- iii) Gauss-Markov mobility model: The temporal dependency of velocity is overcome in this model as current velocity is dependent on previous velocity. The velocity

is modeled as Gauss-Markov stochastic process and is assumed to be correlated over time. For two dimensional simulation field, Gauss-Markov stochastic process is represented as follows.

$$v_t^x = \alpha v_{t-1}^x + (1 - \alpha)v^x + \sigma^x \sqrt{1 - \alpha^2} w_{t-1}^x \quad (1.1)$$

$$v_t^y = \alpha v_{t-1}^y + (1 - \alpha)v^y + \sigma^y \sqrt{1 - \alpha^2} w_{t-1}^y \quad (1.2)$$

α is the parameter reflecting randomness of Gauss-Markov process.

If $\alpha = 0$, the model is memory less and the equations derived show that it is same as random walk model.

In mobility models discussed so far location, speed and movement direction is not affected by the nodes in the neighborhood. Reference point group mobility model takes this into account and is discussed below.

- iv) Reference point group mobility model: In this model, there are two types of nodes; group leader node and group member nodes. The movement of entire group is determined by the movement of the group leader. This is useful in practical scenario when in a freeway motion on roads, vehicles cannot exceed the speed of approaching vehicles otherwise, there might be a collision. Other utility is in the battle field and disaster relief team where group members follows group leader.

In the mobility models, the nodes can move in any direction but in a real scenario, these are constrained by the buildings, obstacles and road directions. Mobility model with geographic restriction takes into consideration the environmental conditions also. One of such model is Manhattan mobility model as discussed below.

- v) Manhattan mobility model: Mobile nodes traverse on roads in horizontal or vertical direction constrained to the urban map. The Manhattan model follows a probabilistic approach to for vehicles selection at intersection. With a certain probability, vehicle turns left or right. With the remaining probability (after subtracting the probability of turns from unity) the vehicle keeps moving in same direction. Relative comparison of various mobility models is shown in Table 1.1 The comparison is done against temporal dependency, spatial dependency, and geographic restriction.

1.4.1.2 Data collection with mobility in VANETs

It is quite challenging task to collect real-time data for processing and analysis in VANETs due to high mobility. Following methods are used for collecting the data in VANETs.

- i) Triangulation Method
- ii) Vehicle re-identification
- iii) GPS based method
- iv) Sensor based methods

Table 1.1: Relative comparison of mobility models

	Temporal Dependency	Spatial Dependency	Geographic Restriction
Random waypoint model / Random walk model	No	No	No
Gauss-Markov mobility model	Yes	No	No
Reference point group model	No	Yes	No
Freeway mobility model	Yes	Yes	Yes
Manhattan mobility model	Yes	No	Yes

1.4.2 Scalability

Solution for small scenario may not work for a larger scenario. Various constraints must be considered before extending the smaller model applicable for a larger network. Firstly, the density and mobility of vehicles may not follow the same pattern. The weather conditions and behavior of driver are the other factors that need to be incorporated before extending the model. In smaller networks, the number of packets exchanged between vehicles is limited which increases exponentially as the number of vehicles increases. Many problems like broadcast storm problem can emerge because of the higher collision and contention of packets as we increase the scalability of the network. Hence, the above mentioned factors must be taken into account while considering the scalability issues in VANETs.

1.4.3 Channel utilization

Cognitive radio based scenario must be used in VANETs. In this scenario, one vehicle acts as primary user and other acts as secondary user. When primary user is accessing the channel the secondary user **cannot** use it and vice-versa. If both of them are using the same channel, then some contention resolution policy must be used. As there are numerous channels, this scheme enhances the battery life and improves the bandwidth usage. This improves the PDR, channel utilization and throughput of the network [25,26].

If more vehicles use this cognitive based scheme, the allotment of primary vehicle and hence the channel allocation is done on a priority basis.

1.4.4 Security and privacy

Security is one of the key issues [27,28]. Public key infrastructure (PKI) system is used to ensure the security of vehicles. In a PKI system, a centralized key distribution center (KDC) exists which distributes the keys based on the ID of the vehicles. Before entering into the system, vehicles must register themselves to KDC. KDC generates the keys and distributes them to the vehicles which is used for secure communication. If any vehicle

misuses the key, its key is revoked.

When a vehicle changes the domain, mobile Internet protocol version 6 (MIPv6) is used for secure message communication among vehicles. Home domain is the domain where the vehicle has registered itself. The foreign domain is the new domain where vehicle enters. Time stamping is used to ensure security. After every time stamp, Certificate Resolution List (CRL) is updated with misbehaving vehicles identification and the next time stamp revokes the misbehaving nodes.

1.4.5 Data management

Data management is the biggest challenge in VANETs. There is varying density at different locations. Not only at different locations but at different times and days of week, there is variation in density which makes management of data difficult. Sensed data has its challenges, because it depends upon the deployment position and intensity of sensors. Also, the management of data depends on spatial locality. There is no centralized location except cloud which can store the sensed data from the vehicles. Even in V2V system, there is problem in data dissemination when the vehicle moves out of range. Hence, the management of data needs to be efficiently taken care for predicting the movement of vehicle and eliminating the risk of accidents.

1.4.6 Clustering

There are two methods to implement the communication between vehicular networks and the backbone Internet. The first one is that mobile nodes directly communicate with the Internet and the second one employs both wireless WAN and wireless LAN in a cluster structure. The above two methods indicate two different ways to organize the vehicular network. The first method views the vehicular network as a flat topology. Wireless WAN and wireless LAN work in parallel. No matter whether a Wireless LAN exists or not, the communication can be implemented. The second method provides a cluster structure to the network. The cluster structure generates a hierarchical vehicular network [29].

1.4.6.1 Existing clustering algorithms for VANETs

VANET, as a special type of MANET is an important part of Intelligent transportation system (ITS). VANET aims to provide an efficient communication between the vehicles to get the vehicles' state information (speed, direction and acceleration) and the real-time traffic information from each other (safety alert messages). In clustering strategy of data transmission, Cluster Head (CH) is selected as a representative for each cluster. The CH is responsible for relay of data and control packets inside and outside the cluster. Clustering approach was initially proposed for MANETs. However, VANET has its own characteristics when compared with MANET as discussed earlier, i.e., frequent topology change, trajectory constraints, energy efficiency, use of GPS and other equipments, etc. Consequently, the traditional clustering algorithms proposed for MANET may not be applied to VANET directly. The features of VANET should be considered in clustering strategy for higher cluster stability and more efficient communication thereafter.

These days, research in the field of clustering for VANETs is going on in the direction to make cluster as much stable as possible and for efficient communication. Many researchers have used different techniques to form stable cluster such as using signal strength received

by the node, position of the node from the cluster head, velocity, direction and destination of node. Various proposal based on clustering algorithm are discussed in Chapter 2 in detail.

1.4.7 Data dissemination

Data dissemination is the transfer of messages/ information from any location in VANETs to its final destination. It can be performed either in one step from source to destination or using store and forward strategy in multi hop manner. Data dissemination depends upon a number of factors such as-velocity, density, direction of motion of the vehicles, etc. Vehicles can be source or destination during the process of data dissemination and various standards have been built to accomplish the task of data dissemination. As VANETs have been used in a wide range of applications, data dissemination becomes an important part of designing protocols for VANETs.

1.4.7.1 Need for data dissemination

With the growing number and demands of the users to access various resources during mobility, efficient techniques are required from user satisfaction perspectives. The ultimate goal of data dissemination in VANETs is to provide safety and comfort to the users sitting in the vehicles. Some of the applications where the necessity of data dissemination is felt are-intelligent transport systems (ITS), generating alarms in case of emergency on the road/ community, on-line diagnosis of patients, weather forecasting, surveillance systems etc.

Researchers have been recently working in many new areas to provide various facilities to the end users in VANETs. Key functionalities and promises of data dissemination technology for VANET include

- i) To increase the safety of traveler
- ii) To enhance the mobility of traveler
- iii) To decrease the traveling time
- iv) To protect the environment and conserve energy
- v) To efficiently magnify transportation system
- vi) To increase the luxury of traveler

Apart from the increasing uses of this new fast growing technology, there are various other challenges such as-frequent topological changes, varying density, and security, etc., which need to be addressed by the research community working in this domain.

1.4.8 Constraints and challenges for data dissemination

Due to the dynamic nature of VANETs, data dissemination in VANETs has various challenges as described below.

- i) Frequent topological changes due to high mobility of the nodes

- ii) Varying density and velocity of the vehicles on the road
- iii) Sparse distribution of vehicles in some geographical regions leading to poor connectivity and performance degradation of the network
- iv) Improving cluster efficiency and selection of CH based upon some predefined criteria
- v) Intrusion detection and security

Based upon the above defined constraints and challenges, number of research proposals have been formulated in literature. Keeping in view the above properties and constraints, work is in progress to improve the data dissemination in VANETs for achieving the major goals of increasing transport efficiency and improving road safety.

1.5 Thesis Organization

The thesis here onwards is organized as follows:

In Chapter 2, a description of existing research solutions on data dissemination have been presented. The schemes in literature have been classified into seven broad categories namely-topology based, geographic, hybrid, clustering, opportunistic, data fusion, and greedy data dissemination strategies. The analysis of strategies in each category is presented by highlighting their advantages and disadvantages. The schemes are compared on several key parameters for their effectiveness.

In Chapter 3, a coordinated Quality of Service (QoS)-Aware Data Dissemination (QADD) scheme has been proposed to improve the QoS parameters during data dissemination in vehicular environment. System mode, detailed scheme, simulation settings and performance evaluation of the QADD scheme are described in this chapter. Results obtained are analyzed and compared with pre-existing schemes for the efficacy.

In Chapter 4, a solution to the problem of congestion in VANETs has been proposed called as Minimum Calculated Desired Time (MCDT) scheme. The chapter presents the system model, mobility model and channel model. The proposed solution has four phases, i.e., construction phase, maintenance phase, message transmission and recovery in case local maxima. These are described in detail in this chapter. The results obtained after simulation and the comparison with existing schemes are discussed in this chapter.

In chapter 5, the challenge of broadcast storm due to blind flooding, which was a major problem in VANET, has been addressed. Data dissemination needs to be reliable and fast. To address this issue, a reliability aware intelligent data dissemination (ReIDD) scheme has been put forward. The chapter presents the mobility model and the application of game theory technique to solve the broadcast storm problem. The proposed scheme has been described in detail with algorithm and flowchart. Complexity analysis and the appropriate examples for the algorithms have been presented. The results obtained are analyzed and a comparative study of the proposed scheme has been documented in this chapter.

Chapter 6 describes a solution to the problem of increasing network usage, through offloading using VANETs and Wi-Fi Access points (APs). The proposed real-time data dissemination and offloading (RDDO) scheme using a game theoretic approach has been described along with the mathematical analysis. Simulation results and comparison with existing scheme have been discussed in this chapter.

Finally, in Chapter 7, the conclusion provides the overall contribution of the research work. The major issues for data dissemination in VANETs that are solved during the course of Ph.D. work have been summarized in this chapter. The problems that are yet to be solved along with the future directions have also been discussed.

Chapter 2

Literature Review

There are various schemes proposed for efficient data dissemination in VANETs. The prominent proposals published in literature are discussed in this chapter. The proposals are classified into seven major categories, i.e., topology based, geographic, hybrid, clustering, opportunistic, data fusion, and greedy strategies. Some research proposals that do not fall in any of the above categories are discussed separately at the end of this chapter. The proposals are compared and analyzed for their advantages and disadvantages.¹

2.1 Topology based Data Dissemination

There are many proposals for data dissemination which exploit the topology of the network. These proposals are further classified into proactive and reactive based data dissemination techniques and are explained as follows.

2.1.1 Proactive techniques

A list of destination is maintained by nodes in proactive data dissemination protocols. In this type of protocols, all the links are computed by exchanging beacon messages. The routing tables are distributed periodically throughout the network. The advantage of this technique is that alternate routes are known beforehand in case of link failure. It has many disadvantages as it consumes heavy bandwidth for maintaining the routes. Fig. 2.1 depicts various proactive and reactive data dissemination protocols.

In a Prediction-Based Routing (PBR) for VANETs, the vehicles used Wireless Local Area Network (WLAN) and Wireless Wide Area Network (WWAN) as mobile gateways to connect to the Internet while traveling on road [30]. The main challenge to use this type of service is the frequent link breakage because of highly dynamic topology. Although the vehicles on road have high velocity and change the direction rapidly but still their motion is predictable. PBR used this predicted routes to preemptively suggest new routes before the existing routes fail. PBR has achieved satisfactory results as compared to existing proactive and reactive protocols. To minimize the adverse effects of route length and mobility patterns, high gateway density has been recommended in PBR protocol. The results [30] proved that the PBR offered reduction in route failures and an improved

¹The contents of the chapter are partly published in Amit Dua, Neeraj Kumar, Seema Bawa, "A systematic review on routing protocols for vehicular ad hoc networks," *Vehicular Communications*, vol. 1, no. 1, pp. 33-52, 2014. (*Elsevier*) (*ESCI Indexed*).

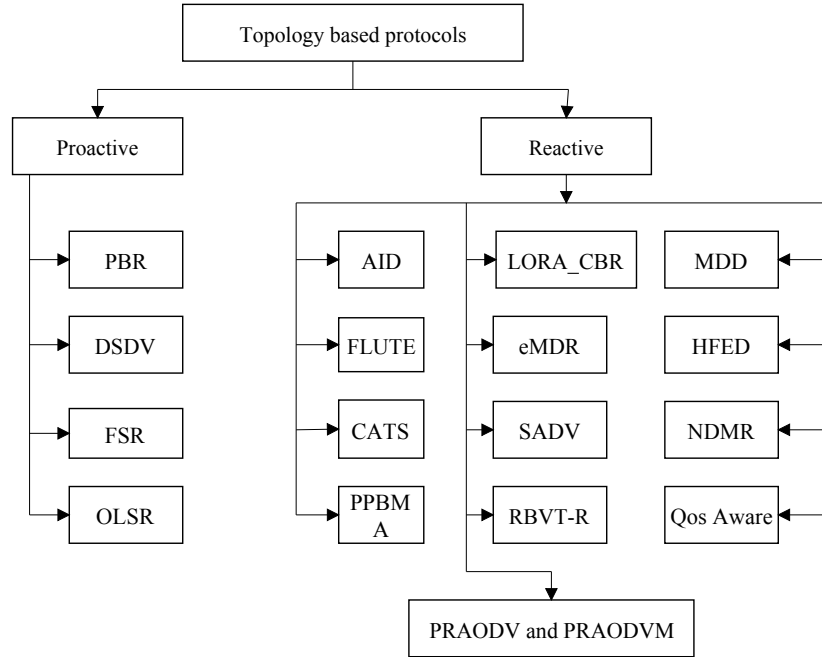


Fig. 2.1: Classification of Topology based schemes in VANETs

PDR. The overhead of checking and predicting routes has been also very less and within tolerable limits. In Destination Sequence Distance Vector (DSDV) routing protocol, two routing tables are maintained at each node namely routing table and setting time table [31]. The routing table has the list of addresses of all other nodes in network. Also, it has the address of next hop, route metric, destination sequence number, etc. The setting time, i.e., the time for update advertisement, for each destination is maintained in setting time table. Routes with later sequence number were selected. If sequence numbers are same, then the decision was made on smallest metric. DSDV ensured loop free routes. DSDV has some limitations such as-it has unidirectional link problem and induced route fluctuation.

In Fisheye State Routing (FSR) protocol, the nodes maintained accurate information of their immediate neighbors and lesser information and details of the nodes as the distance increased [32]. Nodes exchanged information with neighboring nodes and maintained Link State (LS) information. The messages containing information are exchanged by neighbors periodically rather than flooding the network when there was any change in topology. This periodic exchange of messages reduced the control message overhead. The nearest neighbors exchanged messages most frequently, the nodes two hop away exchanged less frequently, and farthest nodes exchanged least frequently. A full topology map was maintained at each node and the shortest paths were computed from this map. Simulations have been performed using random waypoint model. LS routing protocol has less inaccuracy as it reacts fast to topology changes. As the network size increased the control overhead also increased. The higher the radius the less was inaccuracy but more was overhead. The routing accuracy of FSR is comparable to ideal LS routing with minimum routing overhead.

In Optimized Link State Routing (OLSR) protocol, the optimization problem is defined with an optimal parameter setting by using an automatic optimization tool [33].

OLSR is a routing protocol which follows proactive routing strategy which does periodic flooding of control information using special nodes that act as Multi Point Relays (MPRs). In this scheme, the status of the links was immediately known which allowed the hosts to know in advance the quality of network routes. There was an easy integration into existing operation systems and devices without changing the format of header of IP messages. OLSR is well suited for high density networks and is appropriate for networks with applications that require short transmission delays. Because of the capability of managing multiple interface addresses of the same host, VANET nodes could use different network interfaces and act gateways to other possible network interfaces and devices. The functionality of OLSR has been performed mainly by three different types of messages namely-hello messages, Topology Control (TC) and Multiple Interface Declaration (MID) messages. Meta-heuristic algorithms have been studied to find an optimal configurations of the routing protocol. These algorithms were Particle Swarm Optimization (PSO), Differential Evolution (DE), Genetic Algorithm (GA) and Simulated Annealing (SA). The simulation results had following findings.

- i) SA has been best ranked after Friedman test, so it outperformed other algorithms in solving the defined optimization problem.
- ii) PSO offered the best trade-off between performance and execution time requirements.
- iii) The use of optimized configurations reduced the routing load generated by OLSR.
- iv) It has been proved from validation experiments that optimized configurations reduced the network workload.
- v) PSO achieved the best tradeoff between QoS and routing overhead.
- vi) Automatically tuned OLSRs have been more scalable than the standard version as they were less likely to be affected by medium access and congestion problems.

2.1.2 Reactive techniques

This type of protocols find a route on demand using the propagation and reply from route request packets. The problem of heavy bandwidth consumption has been overcome but these are slower than proactive routing in which the links are available instantaneously. These protocols also have slower reaction for restructuring and failures. The prominent protocols of this category are analyzed as follows.

In an adaptive Approach for Information Dissemination (AID) in VANETs, each node takes help of local information gathered from neighboring nodes [34]. This information includes the number of neighbors and the distance between each other. The values of local parameters have been adjusted dynamically. The proposed approach has been evaluated with respect to various metrics such as Saved ReBroadcasts (SRB), awareness and latency. The simulation results proved the supremacy of AID scheme as compared to other state-of-art protocols. The authors have proposed a rebroadcasting algorithm that works as follows.

Initially, when a node receives a message, it initiates counters c and s . As the time passes, the counter t goes down. If the message is heard again before counter expires, the counter c is incremented by 1. After the counter t expires, if c is less than or equal to zero then rebroadcast the message. If the message is heard again after counter t expires

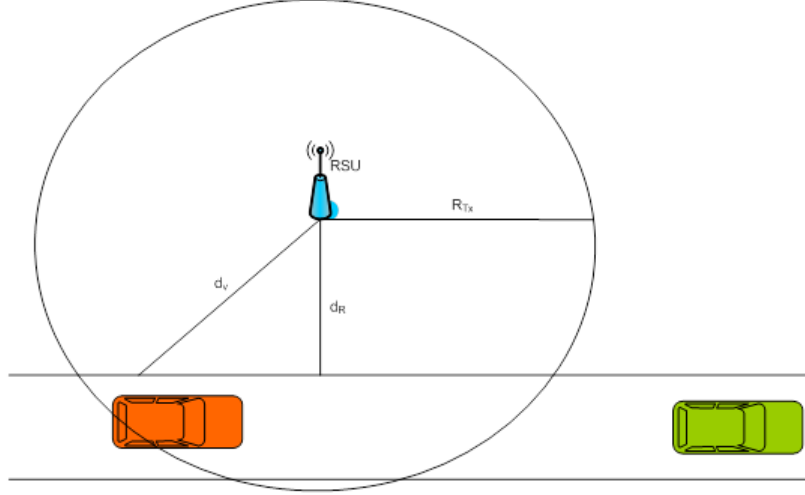


Fig. 2.2: Transmission range and distance from RSU

and threshold value is greater than zero then counter s is decremented by 1 and if the threshold value is less than or equal to zero the counter s is incremented by 1. The initial time is known as t_a and the time at which message is heard again is known as t_b . Threshold value of time is defined as follows.

$$\frac{t}{c - (t_a - t_b)} \quad (2.1)$$

In another scheme, a content delivery system for a robust content broadcasting system has been proposed [35]. The scheme uses the delivery of multimedia-based advertisement information to passing-by vehicles in urban environments. The optimal packet size value could be determined regardless of actual speed of the different vehicles. In order to make the content distribution more robust, reliable and fast, the system integrated the File Delivery over Unidirectional Transport and named it FLUTE. In the proposed FLUTE protocol messages are broadcasted as follows.

First, the data file to be transmitted is opened in the binary mode. After the creation of File Delivery Table (FDT) there has been decomposition into source blocks. So, there was decomposition into encoding symbols of source symbols only with Forward Error Correction (FEC) [36]. After adding the redundancy through FEC, there has been construction and transmission of FLUTE packets. At the receiver, the reverse operation was carried out. As soon as the FDT is received, the related parameters were saved and incoming data packets are stored. After analyzing the received packets, data encoding has been done. When the data was fully received, it was handed by the application layer. To maximize the throughput at the receiver, the following formula has been used to calculate L_o (the optimal packet size).

$$\theta(L_o) \cdot \delta(L_o, d_v) \geq \theta(L_i) \cdot \delta(L_i, d_v) \quad (2.2)$$

$$\forall L_o, L_i, \in N : L_{min} \leq L_i, L_o \leq L_{min}, L_o \neq L_i \quad (2.3)$$

where d_v is the distance of vehicle from RSU and L_i is the packet size. Fig. 2.2 shows how these parameters are computed in this scheme. Simulation tests have been carried out in two different vehicular scenarios, static and dynamic, and results indicated the efficacy of

Raptor FEC scheme.

A traffic signal system named CATS based on car-to-car communication which dynamically adjusted the timing patterns according to traffic demands has been proposed [37]. The cycle time has been calculated based on estimated density of vehicular traffic which helped in reducing the waiting time for vehicles at intersection and made this proposed solution collision free at intersection. The authors proposed an algorithm for election of CH and cluster formation. At start, when the cluster ID was NULL, it checked for the timer to expire. When timer expired, if the reply was received from the node whose distance is less than the threshold distance, that node which is farthest from header and within the threshold distance is elected as the CH.

Inter-green interval, i.e., the time which allowed the vehicles that are already beyond the point-of-no-return to continue through the intersection safely has been proposed. The vehicles at far distance from lights had enough time to react and stop. The vehicles in between are caught in dilemma and do not have enough time to react and stop or cross. Safe Stopping Distance (SSD) is the minimum distance away from the intersection that enabled the vehicles to stop at intersection without causing collisions. SSD has been computed as follows.

$$SSD = 1.47 \times v \times t + \frac{v^2}{30 \times (f + g)} \quad (2.4)$$

where, v = velocity with which vehicle was moving when it approached the intersection, f = coefficient of friction, g = gradient of the road. Based on above calculations, the inter-green interval has been calculated.

$$Inter - green\ interval = \frac{SSD + L + W}{1.47 \times v} \quad (2.5)$$

where, L = length of vehicle, W = width of the intersection.

This model is efficient enough to compute an effective cycle time within a given time frame. The simulation of the proposed algorithm has been done against the classic pre-timed system and adaptive fuzzy logic system. The results obtained depicted that CATS performed better than other schemes.

Privacy Preventing Broadcast Message Authentication (PPBMA) protocol for VANETs used message authentication code functionality and hash operations to authenticate the messages instead of performing asymmetric verification [38]. In order to avoid message losses, the protocol used two levels of key hash chain. The key features of this protocol are that it is time efficient privacy authentication protocol for secure communication and is capable of providing the conditional privacy and prevents anonymity. The protocol also has lower message latency and higher efficiency in terms of computational and communication resources. The base station acts as sink and broadcasts the Commitment Distribution Messages (CDM). CDM has been used by each node to authenticate the low level hash. The simulations have been done in two scenarios namely-city driving and two lane highway communication. The protocol has been compared with Time efficient and Secure Vehicular Communications (TSVC) with privacy preventing scheme, PPBMA, and Time Efficient Stream Loss-tolerant Authentication (TESLA). The simulation parameters were average packet delay with number of vehicles and fraction received packets with number of vehicles. The results obtained showed that PPBMA has considerable improvement as compared to other existing protocols.

A cluster based flooding protocol called LORA_CBR has been proposed and evaluation of performance of routing protocols for VANETs has been done [39]. The nodes were classified into cluster members, gateways and CHs with one CH in every cluster. Gateways nodes were connected to more than one clusters. CH maintained information of members and gateways of cluster. Packets were routed to destination node in a greedy manner. In case the location of destination was unavailable, the source sent the Location REQuest (LREQ) packets. The responsibility of dissemination of LREQ and Location REPLY (LREP) messages was assigned to the CH. The protocol is similar to AODV [40] but the difference is that only CH disseminated the messages. Simulations have been done for both urban and highway scenarios. Results clearly showed that network mobility and size affect the performance of AODV and DSR more than LORA_CBR.

In a message dissemination scheme, enhanced Message Dissemination based on Roadmaps (eMDR), road maps were used to increase the percentage of informed vehicles and reduce the notification time [41]. The proposed protocol worked successfully in urban scenarios where the density of vehicles is high and buildings absorbed radio waves making the communication only possible for vehicles in the line-of-sight. Vehicles operated in two modes, normal and warning. The default behavior was normal mode but when vehicle detects a dangerous condition, it starts working in warning mode. Two separate algorithms have been proposed for sending and receiving messages. In case of sending, for the vehicle in warning mode, the message priority was set accordingly and the message was broadcasted. The gap between consecutive sending messages has also been set. In case of receiving, the warning message, if the distance between sender and receiver was greater than threshold distance or both vehicles were in different streets then the message was re-broadcasted. If any of above four cases failed the message was discarded. The simulations have been performed and compared with existing protocols namely the location based scheme and distance based scheme [42] on following metrics.

- i) Percentage of vehicles informed
- ii) Warning notification time
- iii) Number of packets received per vehicle
- iv) Reception overhead

With respect to all the above metrics, eMDR performed better than the compared protocols. This protocol also mitigated the problem of broadcast storm which is common in urban scenarios. SADV protocol that depends upon the static nodes placed at intersections has been proposed [43]. Vehicle carried a packet when it had no vehicles to forward. The packet was forwarded to static node when the vehicle was within its range. The static node stored the packet and transmitted it when the optimal path was available. These static nodes measured the delay of forwarding between each other to adapt to changing vehicle densities. In this protocol, multipath routing mechanism has been used to reduce the data delivery delay but in-turn increased the overhead of the system. In Road Based Vehicular Traffic Reactive (RBVT-R) routing protocol which combined geographic forwarding and route discovery, to discover a path to Destination (D), source (S) broadcasted a Route Request (RR) packet [44]. Once D received RR , it replied with Route Reply (RP) containing the connected path to S . When all the vehicles from S to D were connected, there was no need of store and forward. But if in broken link, the intermediate vehicle carried packet for a specific time λ .

PRAODV and PRAODVM are two prediction protocols based on AODV scheme [45]. In AODV scheme, there is frequent breakage of routes because of dynamic nature of mobility. Authors predicted the life time of links based on speed and location information of nodes. AODV chose alternate route when there was a link failure but in PRAODV, the new route was constructed before the end of route's estimated life-time. PRAODVM unlike AODV selected the shortest path with maximum predicted life-time. Simulations showed slight improvement in PDR. The method depended heavily on the accuracy of the prediction method. A bidirectional traffic model studied how the Message Delivery Delay (MDD) in VANETs is affected by two factors namely message delivery distance and density of vehicles [46]. It has been found that MDD depends on message delivery distance linearly, i.e., larger the distance, more was the delay. As the density of vehicles and their velocity increased, the delivery delay decreased, but there has been an upper bound on this linear relationship.

Hindering False Event Dissemination (HFED) scheme proposed proof-of-work mechanism to address the problems like illusion, collusion and Sybil attack [47]. Normally, when any warning message is to be propagated by any vehicle, there is no check and the sender sends wrong messages leading to confusion for the receiver. The authors have proposed a mechanism in which the sender sending Event Warning Messages (EWM) have to do some negligible computation. This computation cost, called Proof-Of-Work (POW) was enough to discourage the dishonest vehicles from flooding the wrong message in the network. The imposed POW, depends on the following factors.

- i) The capability of On Board Unit (OBU)
- ii) The immediacy required for communication between the vehicles

The warning messages included a structure called Event Warning Certificate (EWC) which contained the event along with the non-repudiable proof attesting that the POW has been performed. The RSUs did the following tasks.

- i) They produced POWs and deployed them in case non-interactive POW scheme has deployed, or produced on-demand POW in case interactive POW scheme was used.
- ii) They stored and transmitted EWM and worked on-line and off-line whenever EWMs are available.
- iii) They collected evidence whenever any vehicle tried to threaten security and informed vehicles of their penalties in case any illegal action has been committed.

Node-Disjoint Multipath Routing (NDMR) protocol is studied for the behavior of node-disjoint paths and the effect of mutual interference [48]. Simulation results showed that if there was careful path selection and node disjoint path, there has been an improvement in terms of PDR and E2ED as compared to single path routing. Also, there has been an improvement if both the paths were used to transfer packets. The energy efficiency of single path routing has been higher than energy consumption of node-disjoint path routing without redundancy. If both paths were used, the energy consumption was more than single path routing.

An improvement in QoS is reported in QoS aware protocol for VANET [49] that used Multi-Protocol Label Switching (MPLS). MPLS forwarded the packet to next hop by viewing the label of the packet and searching in the routing table. MPLS by using Traffic Engineering (TE) determines the best route but that route may not be the shortest. The

Table 2.1: Relative comparison of Proactive Data Dissemination schemes in VANETs

	No. of vehicles	PDR	Latency	Network Load	Route Length	Gateways	Control/Routing Overheads	Bandwidth Usage	Route failure	Feasibility
PBR [30]	M	H	ND	ND	L	L	H	H	M	M
DSDV [31]	M	H	H	ND	ND	ND	M	ND	L	M
OLSR [33]	L	M	M	M	ND	ND	H	H	H	L

L = Low; M = Medium; H = High; ND = Not Determined.

protocol assumed that base stations were connected with wired network named Roadside Backbone Network (RBN). For wireless transfer, the protocol used AODV. QoS parameters compared with normal ad hoc protocol showed an improvement in throughput and decrease in E2ED and packet loss.

2.1.3 Analysis of topology based protocols

This section provides comparative analysis of various topology based routing approaches. Tables 2.1 and 2.2 provide the relative comparison of various topology based routing schemes. In these tables, route length is the length of the path from source to destination. Latency is the interval of time when first broadcast started to the time last host finished its broadcasting. Latency is the cumulative sum of various delays including buffering, queuing, transmission and propagation delays. In PBR, due to multihop capability of wireless ad hoc networks, there has been a decrease in number of gateways required with an increase in number of nodes. The adverse effect of randomness was smaller at high gateway density. PBR has been better than other proactive protocols in terms of percentage of dropped packets because PBR predicted the routes breakage to adjust the route creation interval, which results in the decrease in the route failure probability. In PBR, larger node density improved connectivity, but route failures were unaffected as higher density did not decrease the route length [30]. DSDV failed to converge if vehicles did not pause for at least 300 seconds during movement. At higher rate of mobility in DSDV, the PDR ranged from 70-92%. There was packet loss because of stale entries in network [31]. By using optimized configurations, network load has been reduced significantly and thus PDR of 100% was achieved in OLSR because of an optimal parameter tuning of OLSR [33]. AID protocol gave best results when the speed was 25 m/s and number of nodes was up to 100 because the AID scheme increased the number of SRB. Hence, congestion and latency are less [34]. Raptor FEC was more flexible and allowed almost any recovery packet to contribute to the original message reconstruction and its file transfer time was also less [36]. But, the average packet delay increased in almost all these scheme, as the number of vehicles increased to a high value. As the traffic density increased, mean buffer size decreased because when there were more vehicles around, there were more chances for the packets in buffer to be delivered [42]. eMDR performed better than other protocols as percentage of vehicles receiving the warning messages was highest and warning notification time was lowest. 95% of the vehicles received the warning message using eMDR [41]. In

Table 2.2: Relative comparison of Reactive Data Dissemination schemes in VANETs

	No. of vehicles	PDR	Latency	Route Length	Vehicle density	Warning notification time	Speed	Bandwidth consumed	Feasibility
AID [34]	H	M	L	ND	M	ND	M	M	L
FLUTE [35]	M	M	ND	ND	L	M	L	L	M
eMDR [41]	H	H	M	ND	H	M	H	L	H
SADV [43]	H	L	H	M	H	ND	M	ND	L
RBVT-R [44]	M	M	L	H	M	ND	M	M	M
PRAODV & PRAODVM [45]	M	L	ND	ND	M	H	M	M	L
MDD [46]	M	ND	L	H	M	ND	M	H	M
NDMR [48]	M	M	M	L	M	ND	ND	M	M
QoS Aware [49]	L	ND	L	ND	L	L	L	L	L

L = Low; M = Medium; H = High; ND = Not Determined

complex road map, reachability was lower as compared to when the streets were longer and mostly arranged in Manhattan Grid Style which favored the wireless signal propagation. So, in later the percentage of vehicles receiving warning messages was high. RBVT-R has higher PDR than other schemes because of its integration of real-time knowledge of vehicular traffic on roads [44].

There was a decrease in gateway connectivity with decrease in gateway density. Path lifetime increased with decrease in node and gateway density. On an average, there was 80-85% gateway connectivity across different node densities [45]. The reason is that when node density decreased, there were fewer nodes in close proximity to connect and form fewer paths, which led to an increase in path lifetime. As the node density increased, the number of paths formed were more with some of paths forming between distant nodes, so more path breakages [45]. As the vehicle density increased, delay/distance ratio decreased because with high vehicle density, the probability of two successive vehicles being connected was also high which resulted in faster message delivery [46]. It has been proven that the delay/distance (sec/m) decreases with an increase in the vehicle velocity. Message delivery delay is also linearly related to the message delivery distance in bidirectional traffic model [46].

Error probability in E2ED increased as the number of packets is increased from 1 to 100 [48]. A decrease in packet loss was observed by using MPLS as compared to AODV [49]. It has been proven that packet loss is decreased by improving reception of data at destination and minimizing the probability of link breakages [49]. For short distances, node disjoint paths achieved same performance as the single path because node disjoint paths **did not** diverge significantly from shortest path. For longer distances, node disjoint paths improved PDR as compared to single path [48].

2.2 Geographic Data Dissemination

The Geographic routing protocols use the position information of source and destination. This information is acquired either through beacon messages or through GPS. The knowledge of position of source and destination helps the protocol to directly route the messages to destination even without having the knowledge of topology of the network. Figure 2.3 shows various geographic based data dissemination proposals. Their description is presented in the following section.

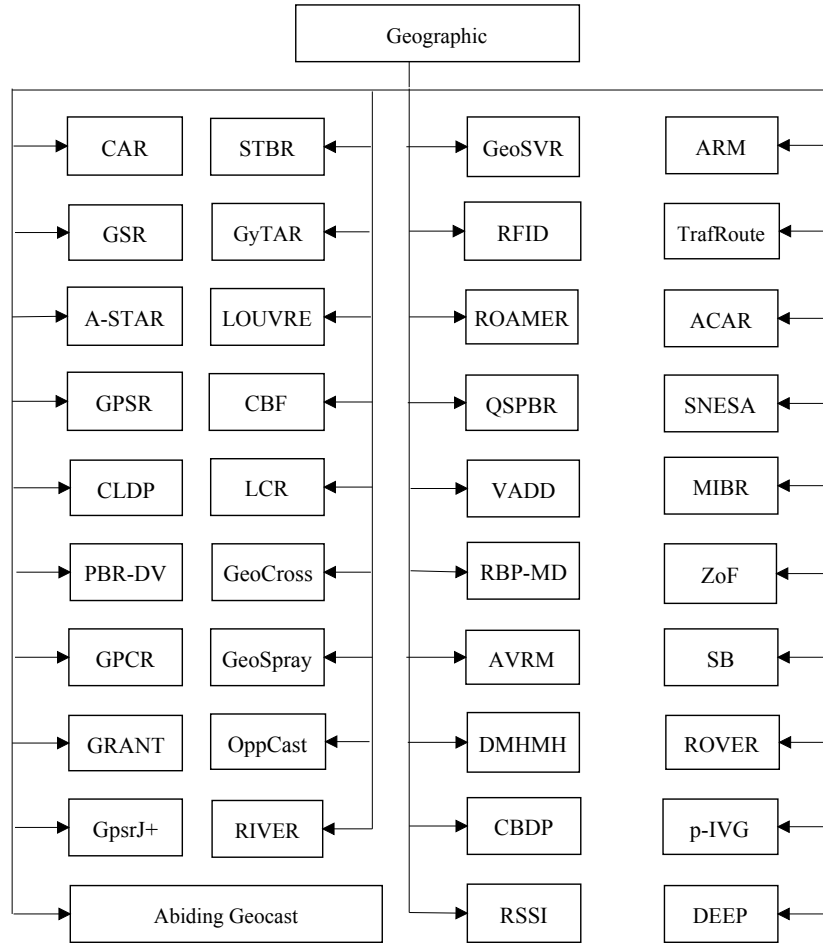


Fig. 2.3: Classification of Geographic data dissemination schemes in VANETs

Connectivity Aware Routing (CAR) protocol for VANETs used AODV based path discovery and authors in [50] proposed Preferred Group Broadcast (PGB) to find routes for limited broadcast. For forming the routes, the scheme neither record nodes and nor used backward learning, instead recorded the nodes near the crossing or road curve. The nodes recorded at crossing or road curve are called anchor points. Another characteristics was that, its velocity vector was different and not parallel to previous node. A path having better connectivity and lower delay has been chosen to disseminate the packet. The packets are routed to destination through anchor points using Advanced Greedy Forwarding (AGF) protocol. On receiving the reply, source node recorded the path to the destination and started transmitting. Following greedy manner, the data packets have been forwarded

towards the destination through the set of anchor points. Guards were used to handle the mobility to destination and track the location of destination node. Guarding node redirected packets or added information to the packets to be delivered to destination. CAR was compared to GPSR and GPSR +AGF. As CAR ensured shorter paths to destination, the PDR has been higher than GPSR and GPSR +AGF. The overhead of CAR has been reduced by using PGB protocol. There was minor increase in overhead because of storing guards. This increase was in beacon messages which were very small in size. Only 2-3 beacon guards were used for node broadcasts, hence the beacon overhead was not very high.

A Geographic Source Routing (GSR) strategy for city environment used Reaction Location Service (RLS) and street maps to acquire the destination location and city topology [51]. In order to acquire the junctions, the scheme used Dijkstra's shortest path algorithm. Position based strategy was used for forwarding between junctions. GSR provided promising routing strategy by combining topological knowledge from street maps and geographic routing. GSR is compared with DSR and AODV. Results showed an improvement in PDR, bandwidth consumption, and latency for GSR. The drawback of this scheme was that it was useful only for the city scenarios.

Another protocol for data dissemination in city scenarios was the position based data dissemination, and is called Anchor-based Street and Traffic Aware Routing (A-STAR) [5]. The protocol used street maps for computing anchors or junctions. The message packets were routed through these anchors to destination. Traffic cognizance was used for computing anchor paths. Statistically related or dynamically related maps were used to identify high connectivity anchor paths. Statistically related maps were used to find the city bus routes while dynamically related maps were used for monitoring the latest traffic condition. In order to save the packet from being completely lost in the local recovery state, the packet has been traversed to new anchor path. In case other packets are not lost in void area, an "out of service" label was assigned to the street at which local minimum occurred. Out of service streets were functional only after the time out duration and before that these streets were not used for computation. A-STAR delivered 40% more packets as compared to GSR.

Karp *et al.* [52] proposed a scheme that forwarded the packets to geographically separated nodes towards destination and named it Greedy Perimeter Stateless Routing (GPSR). While forwarding, there may occur a state of local maximum. In this state, the distance of destination from current node was lesser than distance of destination from neighbors. In such cases, GPSR used right-hand rule to recover. The right hand rule works as follows.

When node P (say) gets stuck at local maximum, it chooses the node Q which is in counter clock wise direction to line joining P and destination D . The next hop Z is also in counter clock wise direction to the edge joining node Q and node P . If edge PD and QS intersects, the next node R is chosen to be counter clock wise direction to QS . The drawback to this protocol is that routing loops occurred if the graph has cross-edges and is not planar.

An attempt has been made to overcome this issue of routing loops in Cross Link Detection Protocol (CLDP) [53]. In this scheme, there is recursive and repeated probing of adjacent links to check for cross links. CLDP used the similar right hand rule for the proposed node as used in GPSR but with additional recording of cross links. After probing, if there are cross links, the scheme decides the link to remove for avoiding fur-

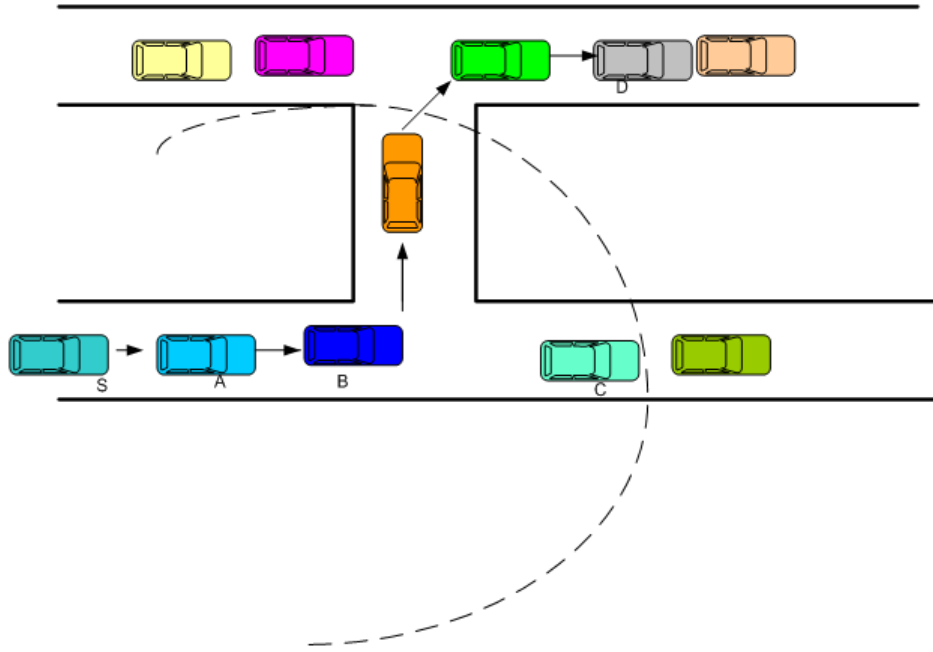


Fig. 2.4: GPCR routing along junctions [6]

ther partitioning of the network. The affected nodes are informed and the cross links are not considered for further routing. This scheme is less scalable and has high complexity. Moreover, the convergence time is very high. The convergence time has been 4 minutes which is not suitable for VANET where the mobility is very high and topology keeps changing constantly.

The solutions to critical problem of local maximum were proposed by various researchers. One such solution is Position Based Routing with Distance Vector Recovery (PBR-DV) in which flooding was used to find nearest node to destination [54]. The nodes nearest to destination were replied back to be used for routing. As the scheme used flooding as the basis for routing, there was higher bandwidth consumption. But, the protocol has not been compared with any other protocol, so its performance can not be analyzed.

A study was carried out using perimeter mode to forward the packet to destination vehicle and greedy strategy was used in which it was found that planar graph can be formed by urban street maps [6]. In Greedy Perimeter Coordinator Routing (GPCR), there has been considerable reduction in distance that packets travel as it followed perimeter mode. This is depicted in Fig. 2.4. Vehicle A forwarded packets to vehicle B, although vehicle C was in range because B was at junction. The node stopped at junction where decision about turn was to be taken. To know whether the node was at junction two strategies were proposed. In the first strategy, nodes exchanged beacon messages and if the node x had two neighbors y and z but both did not have each other in their neighbor list, then node x was at junction. The second strategy used correlation coefficient that relates neighbor to the node. If the co-efficient was 0, it signified that there was no relationship between the node at junction and the position of the neighbors. A marked improvement has been observed in PDR of GPCR as compared with GPSR [52].

Another strategy has been proposed by Schnauffer *et al.* [55] in which data of next n hop neighbors was maintained by each node. For selecting the next hop neighbor N , each

node S computed metric containing the multiplication of distance between N and S , the distance between N and Destination D , and the change per hop for multi-hop neighbors. The next hop neighbor which offers minimum metric was selected. The GRANT scheme separated plane into areas so that there was only one neighbor per area. As the current node received a beacon, it computed the distance between broadcasting node and the neighbor node into respective areas and categorized into different hops. The propagation model took into account the buildings that absorbed the radio waves. Simulation results proved that there has been a reduction in path length when compared with traditional routing protocols. In simulation the n hop neighbors were assumed to be available which is not always possible. There has been large beacon overheads and inaccuracy in calculation which have not been taken into consideration.

An improvement of GPCR has been proposed in GpsrJ+ in [56]. Two hop neighbor beaconing was used by GpsrJ+ to predict the route taken by junction node. If it was predicted that different direction at junction would be taken, then the packet was forwarded to junction node, otherwise it was forwarded to furthest neighboring node. Simulations results indicated an improvement in PDR of GpsrJ+ when compared to GPCR. Also, the results proved a reduction in number of hops as compared to GPSR.

Street Topology Based Routing (STBR) checked the geographic location and distance of the street of destination [57]. In STBR, a junction was selected as master to check for availability of the links. The information was shared amongst masters. The broadcast by master contained link information of all the neighboring nodes. Greedy Traffic Aware Routing (GyTAR) worked on information of connectivity of roads [4]. The connectivity of roads was determined by RSUs by computing the number of vehicles per road. A greedy approach was followed and the next junction node was selected to forward the message. The proposed GyTAR strategy took into account the road connectivity and used shortest path routing. Simulation results showed an improvement in PDR when compared with GSR. However, the scheme has not been compared with any other existing schemes.

Landmark Overlays for Urban Vehicular Routing Environment (LOUVRE) used the sequence of overlaid nodes [58]. The LOUVRE scheme used the fact that links remain connected whenever the vehicle density is above threshold, regardless of vehicular distribution. Most of the routes used the same overlay links. It reduced delay for establishing overlay routes and global route optimality has also been guaranteed. The determination of road connectivity and density was done in peer-to-peer manner. Density of all the connected roads was known. With road density above threshold, Dijkstra shortest path road was built. Since LOUVRE has global knowledge of density distribution, it performed better than GPSR and GPCR. LOUVRE scheme did not use recovery as it rarely encountered local maxima, hence the hop count and delay were less. The scheme has a constraint of not being scalable. A Contention Based Forwarding (CBF) scheme was proposed by Fubler *et al.* [59] in which data packets were broadcasted to all the neighbors. The scheme worked on precise calculation of distance between current node and destination. The scheme also calculated the distance between previous node (from which the message has been received) and the destination. Both the distances were used to select the next forwarding node. Simulations infer that PDR is higher for CBF for beacon interval of 0.25 seconds as compared to GPSR. As the beacon interval increased, PDR of GPSR dropped even further.

Lazy Crosslink Removal (LCR) scheme reduced message complexity by removing only the loop-inducing cross links [60]. The scheme initially detected the cross links in looped

walk. If no cross links were found, the scheme searched the adjacent faces. As the cost increases with an increase in number of nodes in the network, it incurs higher overheads. The overhead increased even further as the vehicles had high mobility. Simulation results depict an improvement in PDR in LCR as compared to CLDP. Use of the planar nature of street maps was proposed in GeoCross [61]. In GeoCross, three fields have been used namely-probe, Unroutable Roads (UR), and Visited Faces (VF). The record of road segments and junctions was maintained by probe while UR recorded the road segments that were unroutable. GeoCross has higher PDR as compared to GPSR and GPCR. Another Geographic routing scheme named GeoSpray, used GPS services to determine the location of nodes [62]. A combination of multiple copies and single copy routing scheme was used in GeoSpray. Alternate paths were exploited by multiple copies scheme. Additional opportunities were explored by single copy scheme. Extensive simulations have been performed and an improvement in PDR and decrease in delay is observed. Also, the scheme resulted in reduction in dropped packets and overhead as compared to other schemes with respect to similar parameters. Backward ACKnowledgments (BACK) was exploited in Opportunistic broadcast protocol (OppCast) [63]. The scheme used BACK, and unnecessary and redundant rebroadcasts could be minimized. Following problems were addressed in the protocol.

- i) Nodes made forwarding decisions based on guesses if the packet has been received or not. The reliability requirement of Warning Messages (WM) propagation had not been considered and no optimization had been done.
- ii) In coordination mechanism, implicit acknowledgments were subjected to channel fading and collisions.

In this protocol, these two problems were solved by

- i) Minimizing the number of rebroadcasts to satisfy a given PRR requirement.
- ii) Sending out BACK before each WM's rebroadcast that has higher communication range than the normal WMs.

Simulations results showed an improvement in PDR and dissemination rate as compared to other state-of-the-art protocols. OppCast was extended to handle disconnected VANET scenarios by characterizing optimal threshold density to switch between normal dissemination and store-carry-and-forward scheme. A trade-off and intricate interplay was recorded between WM reception reliability, dissemination rate, and overhead.

Reliable Inter-VEhicle Routing (RIVER) explored the representation of street layout as an undirected graph [64]. The graph had vertices as road intersections and street segments represented the edges. In another scheme, Geographic Stateless VANET Routing (GeoSVR) also addressed the issue of local maximum [65]. The scheme also tackled the issues of sparse connectivity which occurred when forwarding path to destination was calculated by using maps. But, because of low vehicle density there is packet dropping and the unreliable wireless channel in which the relay node runs out of communication range. The excessive distance between the two relays led to communication breakdown. Two algorithms have been proposed namely-optimal forwarding path algorithm and restricted forwarding algorithm, to address these three problems. The authors described the definition of optimal forwarding path as the shortest connected path with the highest probability of having most of the vehicles between the source and destination. According

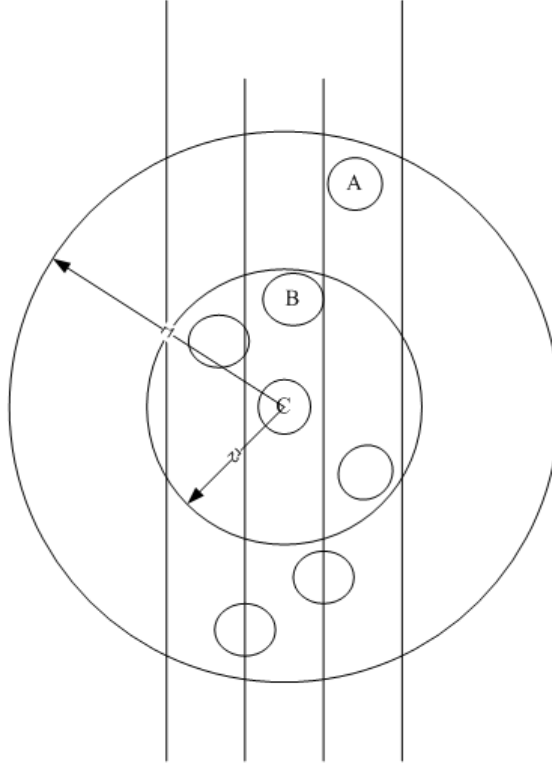


Fig. 2.5: Restricted Forwarding Algorithm

to the algorithm, the optimal forwarding path was calculated based on the location of the source and digital map by providing a global directive. The algorithm also considered the vehicle density on every road thus avoided local maximum problem and sparse connectivity. The map was used as weighted graph and Dijkstra algorithm was used to find the shortest path with minimum weight as optimal forwarding path. In the restricted forwarding algorithm, a neighbor was chosen for forwarding packets. As shown in the Fig. 2.5, restricted forwarding algorithm finds the next-hop closer to r_2 , to reduce the interference of an unreliable wireless channel. Free Space Path Loss (FSPL) in dB is calculated [65] as follows.

$$FSPL = 20\lg d + 20\lg f + 118 \quad (2.6)$$

where d is communication distance in meters and f is frequency in Hz

$$d = \frac{10^{\frac{FSPL}{20} - 5.9}}{f} \quad (2.7)$$

By using this algorithm, the number of hops was increased but the results were positive in terms of PDR and latency. AODV and GPSR have been compared with GeoSVR by considering urban and mobile scenarios. The results showed that in GeoSVR and GPSR, the latency is less than 0.1 second while it is as high as 1 second in AODV. The PDR has also been better in GeoSVR than other compared protocols such as AODV and GPSR. There has been a reduction in latency despite an increase in number of hops.

An accurate method of determining the position of vehicles by using Radio Frequency

Identification (RFID), used electromagnetic waves runs without battery and had two components, RFID tag and RFID reader [66]. RFID reader emits Radio Frequency (RF) waves eliciting a signal back from the tag. Upon receiving the radio waves, the tag absorbs energy and pump back the waves modulated with its own ID signature. Earlier, the RFID were used in the following two ways.

- i) RFID tag attached to a vehicle and RFID reader installed on the road side.
- ii) RFID reader attached in the vehicle and RFID tag on the road side or under the pavements.

Vehicles used in the existing proposals are supposed to be equipped with RFID tag and reader and named it RFID GPS or RF-GPS. RF-GPS calibrated GPS error and vehicle could know its exact position. Even if a vehicle did not have a GPS receiver or can not use the receiver temporarily, it can accurately calculate its position with the single peer localization scheme. Extensive simulations and real-world experiments have verified and proved that this protocol could be applied to fast moving vehicles to calculate the position accurately.

To route the messages to distant locations ROAdside unit MESSage Routers in VANETs (ROAMER) protocol [67] used three algorithms. The first algorithm searches for RSU in range and sends the packet to the nearest RSU. If there is no router in range, then it passes the packet to that vehicle which is nearest to the RSU. The packet is sent to the vehicle nearest to the destination in the second algorithm. When it receives the packet and calculates the region of radius around the destination, it finds the best road and sends the packet to all the vehicles in that radius. If the vehicle is outside the estimated area it searches the packet within the estimated area (circle around the calculated radius). If no such packet exists, it sends the packet to a vehicle nearest to the area. Once the packet reaches within the estimated area the vehicle looks for its neighbors if the destination exists otherwise, it searches for the vehicles within whose neighborhood the destination exists.

Fonseca *et al.* [68] have done Qualitative Survey of Position Based Routing (QSPBR) protocols for VANET in highway and urban environment. The topology based protocols are compared to position based protocols. Various position based routing protocols like A-STAR, GPSR, GPCR, GyTAR, and MOPR have been studied and findings showed that there is no single protocol that is best for both urban and highway environment. GPCR and GyTAR are best for urban scenario while GPSR and MOPR meet up to the expectations in highway environments. It is not easy to define when to make transitions between these protocols. It was suggested by the authors to propose a new hybrid protocol to cater the requirements of both environments.

To address the issue of delay tolerant applications in sparsely connected vehicular networks, Vehicle-Assisted Data Delivery (VADD) has been proposed [7]. As VADD uses a carry-and-forward technique, following basic principles are considered in it.

- i) As much as possible, transmit through wireless channels.
- ii) If there is no neighbor moving and packet has to be carried through the road, then choose higher speed road.
- iii) Dynamic path selection should be executed continuously throughout the packet forwarding process.

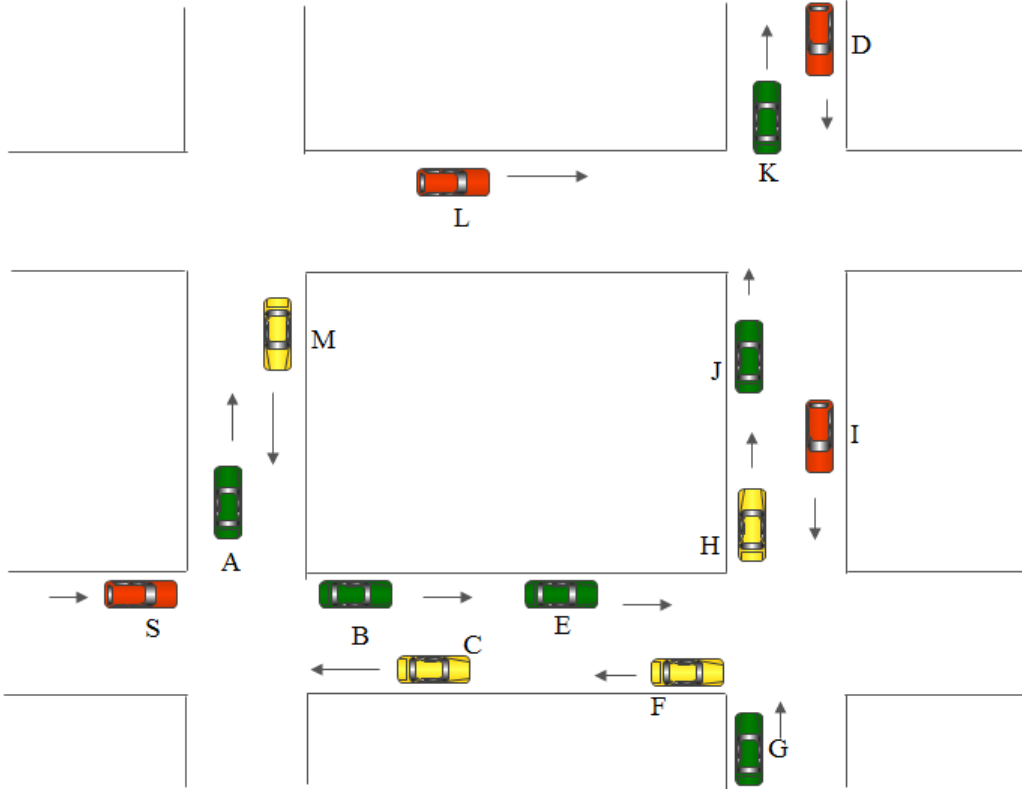


Fig. 2.6: Selection of next vehicle to forward the packet [7]

Fig. 2.6 shows the scenario in VADD protocol. Vehicle S wants to forward the packet to vehicle D which is situated in North-East direction. According to Location First Probe (L-VADD), the packet is forwarded to the vehicle closest towards the direction. Hence, it selects the vehicles C , and F as the next hop in East direction. At vehicle F , it forwards the packet to vehicle G in East direction. Vehicle G could in-turn forward to vehicle F that is in North direction resulting in a loop. Hence, L-VADD may result in routing loops. However, Direction First Probe (D-VADD) overcome from falling in routing loops by selecting the vehicle that is moving towards the selected direction. It selects vehicles B and E as they are moving towards East direction. E selects vehicle G that is moving towards North direction. However, G won't select E , rather would select vehicle H moving towards North. Consequently, the packet is forwarded towards D via, vehicles, J and K without any loop. Another protocol Hybrid Probe (H-VADD) combined the benefits of both protocols. At the intersection, H-VADD behaved like L-VADD with loop detection. As the loop was detected, it used D-VADD until it exited the current intersection. The simulation work compared the proposed protocol with DSR, the epidemic routing protocol and GPSR, which was simple carry and forward protocol. The simulation results proved that VADD protocols outperform these protocols in terms of PDR, data packet delay and protocol overhead. Amongst the VADD protocols, H-VADD performed best. But the power control with varying transmission range depended upon vehicle density, which needs further investigation [7].

For efficient message dissemination, a Relative Position Based Message Dissemination (RPB-MD) protocol has been proposed [69]. RPB-MD considered all vehicles in Zone of Radius(ZoR) as destinations of messages. It also assumed that vehicles obtain relative

distance between neighbors through GPS position information. To make the candidate nodes hold the message with high reliability and to ensure high PDR and low delivery overhead, a Directional Greedy Broadcast Routing (DGBR) was proposed. The time parameters were designed adaptively based on message attributes and local vehicular traffic density which guaranteed efficiency. The protocol was robust to traffic density and relative distance accuracy. This protocol has been applicable only to highway scenario and needs to be revised to ensure real-life working in urban city scenario.

Augmenting Vehicle to Roadside connectivity in Multi-channel (AVRM) VANETs covered up the sparse RSU [70]. This work proposed to design techniques by supporting the spreading of network initialization advertisements from RSUs jointly considering the features and constraints of WAVE. To improve the efficiency and robustness of network advertisement procedure, the scheme used the space, time, and channel diversity. The solution exploited the repetition of Basic Service Set (BSS) advertisements during the Common Control Channel (CCH) interval. It used the low overhead and flexible WAVE-mode Short Message Protocol (WSMP) packets. With slight modifications in it, the protocol used packets already available to CCH also. Simulations have been carried out with different parameters like RSU density, vehicular networking technology, penetration rate, data rate and packet size to show the efficiency and effectiveness of the proposed solution. Use of WSMP packets could reduce the overhead and increase the reliability of the link, but has not been explored to its full potential.

A scheme namely Disseminating Messages among Highly Mobile Hosts (DMHMH), based on inter-vehicle communication is a simple geocast scheme [71]. The receiving vehicle waited for sometime before forwarding the message. The waiting time depended upon the distance of vehicle from the sending vehicle. As the distance increased, time was reduced and was minimum for more distant vehicles. Therefore, it is intuitive that vehicle at the edge of communication radius participated more as compared to other vehicles. If the vehicle did not receive the same message within the waiting time, i.e., there was no other vehicle in the communication radius. Hence, it broadcasted the message. The scheme limited the hop count to restrict the excessive flooding. The major advantages of this protocol have been that it could avoid packet collision and reduce the number of rebroadcasts. An Abiding Geocast scheme was claimed to be time-stable protocol [72]. In this scheme, the authors proposed a protocol where the packets were delivered to all the vehicles that were inside the geocast destination region during their geocast lifetime. The characteristics of this proposal are as follows.

- i) Server stores the geocast messages.
- ii) An elected node inside geocast region stores the messages.
- iii) For the packets destined to its location, each node stores all the geocast packets and also keeps the neighbor information.

A Content Based Dissemination Protocol (CBDP) considered the relevance of data based on encounter probability to decide when re-diffusion is needed [73]. The protocol set appropriate weights to different types of events in the network. It allowed dissemination of different types of events, i.e., both static and mobile events occurring in VANETs were supported. The messages which were not necessary for specific users were dropped by re-diffusion. It not only saved time but minimized the network usage. The proposed protocol could be deployed to any kind of vehicular network if the following attributes were communicated as part of information of the events.

- i) Current Position
- ii) Direction Reference Position
- iii) Mobility Reference Position
- iv) Last diffusion position
- v) Hop number

This information takes only few bytes and can be easily set. The proposed protocol was implemented in Vehicular Event Sharing with mobile Peer-to-peer Architecture (VESPA) [74–76]. It allowed sharing among vehicles and also applied data management techniques in VANETs. The simulations performed in both urban and highway scenario, showed that vehicles received the information of interesting events well before meeting them. Though there were overheads in this protocol but these were limited. In application level Role Mobility (ARM) framework, nodes shared assignments and associated application level roles [77]. The handover of role has been done according to the mobility patterns of vehicles. The framework did two tasks namely-the dissemination of information to traveling cars and collecting data from RSUs. For each application, a dedicated role handover has been provided. ARM selected the node which was best suited to accomplish a particular task. ARM has successfully performed the required operations in fully distributed way. The operations were performed without any need of fixed infrastructure or dedicated nodes. There was overhead involved but low and under tolerable limits.

In another scheme, TrafRoute divided the network into sectors [78]. A single RSU has been deployed within each sector where vehicles registered when they entered into that sector. The intersections were called Forwarding Points (FPs). The path has been computed from FP nearest to sender to the FP nearest to the destination. The packet moved along this computed path was finally broadcasted to the destination. This protocol is best suited for dense scenarios. An Adaptive Connectivity Aware Routing scheme (ACAR) proposed an optimal multi-hop communication to the destination [79]. The scheme used a cell and cluster based connectivity model along with the on-the-fly density calculator in their calculation. But, there is a trade-off between the large transmission and the low error-rate, a minimum packet error rate path was used to commute to the destination. In case of non-availability of neighbors, the ACAR algorithm used the store-carry-forward technique. A strategy to overcome the connectivity and scalability problem in VANETs is presented in a Smart NExt hop Selection Algorithm (SNESA) in which source vehicle multi-casted the request for knowing the destination [2]. The destination on receiving the request replied back with its position. The SNESA algorithm incorporated the changes in direction of destination and updated the procedure accordingly. The extensive simulations on NS2 [80] proved the effectiveness of the scheme.

In a geographic routing protocol with selected intersection points as next hop neighbors, the selection of path is auto adjustable and sub-path is dynamically computed [81]. This protocol used a technique for dense urban scenarios with Manhattan type network layout. Infrastructure assisted geographic routing protocol for VANETs used RSUs as the relaying agents [82]. In this protocol, the RSUs assisted the multi-hop communication in vehicular environment. Another scheme used the concept of buses as the backbone for communicating the messages [83]. The buses were chosen as they have higher communication range and larger storage capabilities. The scheme named Mobile Infrastructure Based VANET Routing (MIBR), aimed to overcome the need of store-carry-forward technique

and increased the PDR in lesser time. The scheme has higher throughput as compared to GPSR technique.

A scheme for efficient data dissemination improved the Zone of Relevance (ZoR) to Zone of Forwarding (ZoF) [84]. ZoR is the area where the vehicles have the information about the other vehicles. This approach might not work at the times when some of the vehicles loose the contact with others in ZoR. To correct and improve this, ZoF was used, where the vehicles were having connectivity with each others. The geographic zones were classified based on the communication ranges of the vehicles. Effectiveness of the scheme has been proven through simulation on NCTUns simulator [85]. Smart Broadcast (SB) protocol aimed to maximize the progress of the message and minimize the rebroadcast delay [86]. The protocol is position aware and claimed to disseminate messages in fast and reliable manner. To achieve the goals, the contention window size was optimized according to the vehicle density. The claim of the authors has been supported by mathematical calculations and simulation results.

A scheme for the dissemination of warning messages using vehicular networks [87] used the sensors in each vehicle, which were activated as there was a detection of emergency situation. The scheme ensured that alarm messages were received in minimum hops. The scheme also worked under asymmetric communication and with variable vehicular transmission ranges. Simulations performed on GTNetS simulator [88] have proved the claim of the authors. The trade-off between fast data dissemination and reliable communication has been studied [89]. For fast data dissemination the authors presented Distributed Reliable Geocast (DRG) protocol. The protocol has less overhead and high scalability. The RObust VEhicular Roting (ROVER) protocol met end-to-end quality of service parameters for reliable communication. ROVER formed multi-cast trees using geographical addressing. The on-demand formation of tree helped in communication of messages within ZoR. Both the protocols had different aims and fulfilled the requirements.

The inter-vehicle geocast protocol was improved to probabilistic Inter-Vehicle Geocast (p-IVG) protocol [90], and the messages were probabilistically forwarded depending upon the vehicle density. The scheme showed an improvement in reception rates, channel contention and PDR. An efficient deployment of RSUs on vehicles and an algorithm for location determination of vehicles showed an improvement over time based method and Angle of Arrival (AOA) method [91]. After studying the received signal strength method, author suggested the deployment of RSUs on both sides of the road. The application of algorithm could ensure the determination of position of vehicles with higher accuracy. Using the geographic condition of the network and Density aware Emergency message Extension Protocol (DEEP), the emergency messages were transmitted reliably well before time so that the drivers had enough time to take alternate route [92].

Table 2.3 provides a relative comparison for various geographical based protocols.

2.2.1 Analysis of geographic based protocols

Position based routing approach performed better in PDR and latency as compared to AODV and DSR but loss of connectivity in path selected by algorithm led to the failure of GSR [51]. By traffic awareness A-STAR selected paths with higher connectivity hence PDR could be improved by 40% [5]. Since GSR used recovery strategies to bypass dropped node, it selected longer routes and reduced packet drop rate but DSR being more aggressive, used the node with largest progress and led to more packet drops. GPSR

Table 2.3: Relative comparison of Geographical Data Dissemination schemes in VANETs

	Vehicle density	Speed	PDR	Latency	No. of hops	Distance	Packet Loss	Throughput	Bandwidth	Feasibility
CAR [50]	M	M	L	H	ND	H	ND	L	L	L
GSR [51]	H	ND	M	M	L	H	ND	ND	L	M
A-STAR [5]	M	M	L	ND	H	M	L	ND	ND	M
GPSR [52]	L	L	H	M	L	M	M	ND	L	M
CLDP [53]	M	ND	H	H	H	L	M	L	ND	M
GPCR [6]	H	ND	L	ND	H	H	ND	ND	M	L
GRANT [55]	H	M	L	ND	H	L	ND	ND	ND	L
GpsrJ+ [56]	H	M	M	H	M	L	ND	ND	ND	M
GyTAR [4]	M	M	L	M	L	ND	ND	M	M	M
LOUVRE [58]	L	ND	L	H	H	ND	H	L	ND	L
CBF [59]	H	ND	H	ND	H	H	ND	ND	ND	L
LCR [60]	H	ND	ND	ND	L	H	ND	L	ND	L
GeoCross [61]	M	L	M	L	H	M	ND	ND	ND	H
GeoSpray [62]	M	M	L	L	ND	ND	L	ND	H	L
RIVER [64]	M	L	ND	M	M	ND	ND	L	M	M
GeoSVR [65]	M	M	H	M	H	H	L	ND	ND	M
ROAMER [67]	M	M	L	ND	ND	H	ND	ND	L	M
VADD [7]	H	H	M	L	M	H	ND	ND	L	M
RPB-MD [69]	H	H	H	M	ND	ND	ND	H	M	H
AVRM [70]	H	M	M	H	ND	M	M	ND	H	M
DMMH [71]	L	H	M	H	ND	H	H	L	L	L
Abiding Geo-cast [72]	H	M	M	H	L	H	H	ND	M	M
CBDP [73]	ND	H	M	M	ND	M	ND	ND	ND	M
ARM [77]	H	M	H	L	ND	ND	L	H	H	H
ACAR [79]	ND	M	M	H	ND	L	L	L	ND	M
SNESA [2]	L	M	M	M	ND	M	ND	ND	M	M
MIBR [83]	M	L	L	ND	ND	L	ND	M	M	L
ZoF [84]	M	L,M	M	M	ND	L	ND	M	ND	L
SB [86]	L	ND	L	ND	L	M	ND	ND	L	L
ROVER [89]	H	H	H	L	ND	H	L	M	H	H
p-IVG [90]	L,M,H	L	L	M	M	L	M	ND	ND	L
RSSI [91]	ND	M	ND	H	ND	L	H	ND	ND	M
DEEP [92]	L	H	M	L	L	H	ND	ND	H	M

L=Low; M = Medium; H=High; ND = Not Determined

route the packets nearer to the destination, hence achieved higher data packet delivery up to 97% as compared to 85% with DSR [52]. GPSR performed well on connectivity graphs without planarization. Since it removed all the links witnessed by planarization, it incurred higher stretch whereas CLDP outperformed GPSR by removing fully cross links [53].

GPCR has higher PDR but at the expense of higher number of hops and higher latency as compared to GPSR [55]. GRANT is able to find more routes without recovery than greedy routing. The performance is better than greedy routing with junction detection also. The recovery in GRANT was scarcely used and did not increase the average path length considerably [55]. As the density of the nodes in network increases, the network becomes more connected resulting in the increase in PDR in GpsrJ+ [56]. There was smoother decrease in hop count in GpsrJ+ than GPCR because in GpsrJ+, nodes did not have to go necessarily through junction nodes [56]. The E2ED in GyTAR has been much less than by GSR in all configurations. This is because number of hops taken by GyTAR is much less than GSR. The route from source to destination is searched progressively and no end-to-end route is maintained by GyTAR [4]. The hop count and delay of LOUVRE is very less because the probability of encountering a local maxima in LOUVRE is less, therefore it does not have to use recovery mode [58]. The CBF scheme has high PDR because it only required retransmissions to resolve collisions which occurred when two nodes selected same MAC slot [59].

LCR with lazy removal of cross links reduced message overhead up to three times less than CLDP. Message overhead per node has been relatively insensitive to network size in LCR [60]. GeoCross used greedy scheme on top of geographical routing. When the greedy mode failed GeoCross switched to recovery mode. Because of this, GeoCross yielded sub-optimal paths which led to higher hop count and low packet delivery [61]. GeoSpray encountered low bundle drop rates inspite of initiating more transmissions across all simulation scenarios. The reason for this is the dedicated bundle clearing module used by GeoSpray [62].

Average packet delay decreased with an increase in car density from 2 to 6 second in city and 2.5 to 5.5 second in highway scenario using CAR. CAR performed even better than combination of CAR+GPSR [50] whereas, much lower latency has been observed with GeoCross where it was about 250 milliseconds (ms) and further decreased to 100-120 ms as number of nodes increased from 180-200. As the number of nodes increased, the connectivity to the destination increased. GeoCross takes larger strides towards destination in perimeter mode, which decreased latency [61]. The packet throughput of RIVER was up to 222% higher than GPSR and up to 39% better than STAR as it used optimal greedy strategy [64]. The latency of GeoSVR was less than 0.1 second whereas it was as high as 1.0 second in AODV. The low latency of GeoSVR is because of stateless routing. AODV used restrictive routing and had to establish a stable route to destination before forwarding the packets hence had high latency [65]. ROAMER was able to maintain low delay even when the number of vehicle density was less since ROAMER does not require route recovery phase to the RSU before sending data packets [67].

A decrease in average delay has been reported with an increase in traffic density up to 0.02 vehicle/m.lane [68]. An increase in traffic density to 0.05 vehicle/m.lane had no effect on average delay although RPB-MD kept very high network reachability by adjusting its parameters accordingly to different scenarios. A very high data delivery ratio (95%) at traffic density 0.01 vehicle/m.lane to 0.05 vehicle/m.lane using RPB-MD has

been reported [69]. RPB-MD maintained high data delivery ratio, which decreased from 0.98 to 0.88 as data sending rate increased from 0.2 to 1.0 because only message head broadcasted the message [69]. A similar trend of decrease in data delivery ratio with an increase in data sending rate using epidemic protocol has been reported. However, loop detection by H-VADD protocol prevented some packets being sent to loop vulnerable neighbors and an almost constant level of 0.8 was obtained when data sending rate was increased up to 1.0 [7]. Using MP-Best protocols, node disjoint path routing achieved the same PDR as single path routing for short distance source-destination pair because intra flow contention dominates. PDR of node disjoint path was double than that of single path when packet rate was more than 40 packets per second and source to destination distance is 7 hops. Data packet dropped up to 0.1% using VADD when data sending rate was 1 or less [42]. Average E2ED has been maintained at a constant low level of around 30 seconds when data sending rate is up to 1 [7]. However, an increase in average E2ED was observed as packet sending rate was increased from 1 to 100 per second. The best node disjoint paths showed lowest average delay since node disjoint paths were far away enough and transfer packets with less contention and offset the retransmission delay due to lossy links. Packet loss has been reduced five times with H-VADD as compared to L-VADD with loop [7].

The RSU detection capability decreased as the penetration rate increased because for any number of RSU, there was higher congestion on CCH caused by beacons [70]. With an increase in number of nodes, network load increased because distance between sender and geocast destination region became large [72]. Normally, all the vehicles were informed before encountering the event using CDBP and most of these vehicles had enough time to react to warning message received but in case of mobile events it was difficult to warn the vehicle far away, since the probability of two vehicles meeting was not very high [73].

ARM was highly accurate by using speed and direction in selecting carrier as compared to distance based strategy protocols [77]. Campolo *et al.* [70] explored the flexible WAVE-mode Short Message Protocol (WSMP) packets and could reduce the overhead and increase the reliability of the link, which has not been explored to its full potential. The power control with varying transmission range depends upon vehicle density, which needs further investigation [7]. There is a need to investigate ways to design an advanced cross-layer between MAC and routing layer to solve the problem of interference, scalability and connectivity in VANETs [69].

2.3 Hybrid Data Dissemination

These protocols are designed to take the best of both Topology based and Geographic based data dissemination schemes. Some of major hybrid protocols are categorized in Fig. 2.7 and discussed in this section.

In Topology based schemes, the link state information has been used for packet forwarding. In these protocols, the performance degraded as the network size increased. In Geographical based schemes, the forwarding decision was based on the position of destination vehicle and position of one hop neighbors. The most important issue in geographic routing was the location error [93]. Hybrid Location-based Ad hoc Routing (HLAR) is a scalable hybrid routing protocol for VANETs in which a combination of location based geographic routing and reactive routing schemes was used [94]. The HLAR protocol combined AODV and Expected Transmission Count (ETX) metric to find the

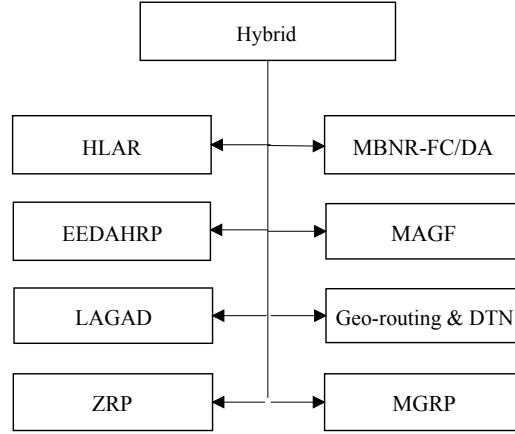


Fig. 2.7: Classification of Hybrid data dissemination schemes in VANETs

best quality route. The route discovery was done at on-demand basis. If the source knew the route to the destination, the source in Route REQuest (RREQ) included the location coordinates of both itself and destination. Then it looked at its neighbor table to find any vehicle closer to the destination. If the closer vehicle was available, the RREQ packet was forwarded, but in case of void region where no closer neighbor was available, the packet was flooded to all the neighbors. In this way the RREQ packet reached the destination, following the same procedure at all the intermediate vehicles. The source node inserted a Time To Live (TTL) field, which was decremented whenever the intermediate vehicle could not use the location information in forwarding decision. The destination replied if any of three conditions were satisfied, either the destination received the RREQ from the source for the first time or if the RREQ packet had higher source sequence number, or else if the new packet had better quality route available. Another important feature of this protocol was that the broken links were allowed to be repaired locally through Route Repair (RRP) packets. In case of broken links, the intermediate vehicle looked its neighbor table and found a vehicle closer to the destination. If a closer neighbor was not available, the intermediate vehicle flooded the RRP packets with TTL set to the number of hops remaining to the destination. If still the problem was not sorted, the Route Error (RERR) packet was sent to the source. The authors categorized the routing overhead rate O_{ov} into three categories.

- i) Initiating overhead rate O_i
- ii) Maintenance overhead rate O_{mn}
- iii) Beacon overhead rate O_b

O_i for both AODV-ETX and for HLAR was calculated. Following equation was used for calculating O_i for AODV-ETX.

$$O_i = \frac{N_i S_p}{t} \quad (2.8)$$

where, N_i = total number of routing overhead packet transmission for initiating communication pairs, S_p = control packet size. Two scenarios namely highway and urban environment were used and the comparison has been made with AODV-ETX and Minimum Traffic Load (MTL). In both urban and highway scenarios, the routing overhead

rate has been lower for HLAR than MTL and the overhead for AODV-ETX was much higher. This proved that HLAR is more scalable than AODV-ETX.

In E2ED Assessment and Hybrid Routing Protocol (EEDAHRP) [95], the end-to-end delay (E2ED) is given as

$$EEdRDT = RREQT_{tot} + TotMACLd + Tot\mu \quad (2.9)$$

Where, $RREQT_{tot}$ is total time spent on route discovery processes and $TotMACLd$ is total delay at MAC Layer. If source and destination were separated by n hops, total propagation delay, i.e., $Tot\mu$ was the product of number of hops and average delay per hop, i.e., μAvg ,

$$Tot\mu = n \times \mu Avg \quad (2.10)$$

According to this protocol, the source node S, sent packet to Destination node D, by unicast if these were in range of each other, otherwise multicast message was sent to far neighbor of S till it reached to D.

Location-Aided Gateway Advertisement and Discovery (LAGAD) scheme [96] has following key features.

- i) It is built on top of network layer.
- ii) It uses channel diversity.
- iii) It is based on location aided adaptation of the advertisement zone of the gateway.

According to this scheme, given the set of gateways and assuming that each car and each base station was aware of its position, the protocol let each gateway requester car discover nearby gateways and gain sufficient information to route the packets toward the closest gateway while guaranteeing network scalability. The protocol required no prior configuration and could perform in ad hoc manner. LAGAD had considerably lower overhead than proactive, reactive and other hybrid approaches. LAGAD exhibited highest PDR with low E2ED and permitted duplicate and ordered data packet reception at the destination gateway. Among all the strengths, LAGAD has weakness in determining efficient radius of gateway advertisement zone.

In Zone Routing Protocol (ZRP) [8], zones contained the nodes that were at most ρ hops away. Nodes were classified as interior, peripheral and external nodes. The nodes that were less than ρ hops were interior nodes. Peripheral nodes were exactly ρ hops away. The nodes that were farther than ρ hops and did not lie in the zone were termed external nodes. As shown in Fig. 2.8 the routing zone with $\rho=2$ centered at S , the nodes A to H were situated within two hop distance from S hence are interior nodes. But nodes I, J and, K were outside the zone because they could not be reached within 2 hops. Proactive routing component IntraZone Routing Protocol (IARP) maintained the up to date routing table within the zone. Using route request and route replied InterZone Routing Protocol (IERP) routes outside the zone were discovered. IARP and IERP were not specific protocols but were family of proactive and reactive routing protocols. When global route discovery was needed Bordercasting Routing Protocol (BRP) was used. Using BRP, nodes at the border of zone were directly queried. ZRP used Neighbor Discovery protocol (NDP) provided by Medium Access Control (MAC) Layer to detect new nodes and link failures. NDP regularly exchanged beacon messages to update its neighbor table.

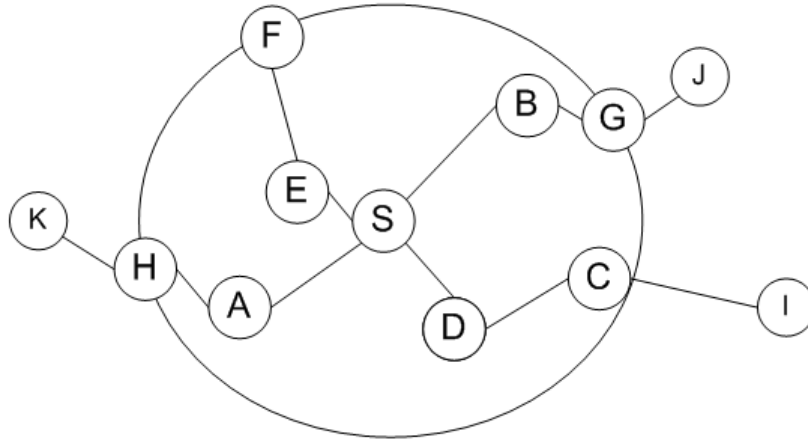


Fig. 2.8: Routing zone with $\rho=2$ [8]

After specific time, if no beacon message was received from a node, it was removed from the table. The protocol performance could be optimized by regulating the number of nodes in a zone and by adjusting the transmission power of nodes.

Mobile Backbone Network Routing with Flow Control and Distance Awareness (MBNR-FC/DA) dynamically elected backbone capable nodes to form mobile backbone (Bnet) [97]. MBNR-FC/DA selectively flooded the route discovery messages across Bnet. This reduces the routing control overhead. In order to further improve the performance, the traffic was guided to traverse less congested areas. The protocol used both backbone centered and global route discovery processes. The backbone paths were used only where Bnet was unable to cover the whole network area to limit the throughput capacity. To improve the overall throughput capacity of links located away from Bnet, flows that use distance less than threshold distance could use non-backbone routes. In order to efficiently utilize the network capacity resources, global route discovery process was invoked. MBNR-FC/DA had good delay-throughput performance under different backbone coverage levels.

Movement Aware Greedy Forwarding (MAGF) strategy [98] used the position, velocity, and direction information of the neighbors to compute the next best vehicle for communication. The simulation results were compared with GPSR. In another work, a hybrid geographic routing scheme, Geo-routing and DTN forwarding has been used [99]. This scheme claimed to work for both connected and partitioned networks. In case of non-availability of forward nodes, the scheme used store-carry-forward technique.

In an another hybrid data dissemination protocol for highway scenarios in VANETs, a combination of sender and receiver-based techniques was used [100]. The scheme aims to eliminate the broadcast storm problem. In case of unavailability of vehicles and RSUs the scheme used store-carry-forward technique till the next best node for communication is available. In another technique, Pan *et al.* [101] presented a Mobile Gateway Routing Protocol (MGRP) that combined vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technique for data dissemination. The concept of gateways was introduced where gateway vehicle had the capability of communication using 3G technique or IEEE 802.11 protocols. In case a vehicle was not equipped with OBUs the vehicle could contact the gateway vehicle which in-turn disseminated the message to the intended vehicles. This hybrid architecture has been proven to work better than GPSR technique.

Table 2.4: Relative comparison of Hybrid Data Dissemination schemes in VANETs

	Vehicle Density	Speed	PDR	Latency	Throughput	Bandwidth	Feasibility
HLAR [94]	M	M	M	L	ND	M	H
EEDAHRP [95]	M	ND	M	M	L	H	M
LAGAD [96]	ND	ND	M	M	M	ND	M
MBNR-FC/DA [97]	ND	L	H	L	H	L	H
MAGF [98]	L	L	M	M	ND	ND	M
Georouting [99]	L	L	M	M	ND	M	M
MGRP [101]	M	M	M	H	ND	ND	L

L = Low; M = Medium; H = High ; ND = Not Determined

Table 2.4 gives the relative comparison of various hybrid Data Dissemination schemes in VANETs.

2.3.1 Analysis of hybrid protocols

A number of protocols had been proposed to achieve optimal connectivity for rapid and reliable routing in VANETs in urban and highway scenarios. While using different protocols for highway and urban environment, it was not easy to define when to make transition between the two protocols. A new type of hybrid protocol was needed to be designed aimed to adapt itself to the type of environment and solve the protocol transition issue.

The routing overhead rate of HLAR grew slowly with the increase in network size and network density than other compared protocols proving that HLAR is scalable [94]. With the increase in vehicle density, PDR of HLAR increased because with the increase in density it was easier to establish and repair routes [94]. Route discovery time increased with increase in number of nodes in EEDAHRP but this increase was smaller than that in AODV, mainly because of using E2ED delay assessment and using the mechanism that relayed the destination node to closer neighbors [95]. Due to low route discovery time and end-to-end data transfer time, EEDAHRP had fast setting up connection link and average packet loss rate was low, so suited better to rapid changing topology and high mobility in VANETs. Similarly, a low end-to-end delay was observed in LAGAD up to 700 nodes [96]. Advertisement in zone adaptation mechanism in LAGAD resulted in 96% success rate. LAGAD succeeded in maintaining order of sent data packets. Optimal radius for ZRP was independent of node density [8]. The geographic routing protocols outperformed ZRP [97]. Delay-Threshold performance did not change under different levels of backbone coverage in MBNR-FC/DA [97]. Non-hybrid schemes because of having distance threshold equal to 0 have lower throughput capacity than MBNR-FC/DA.

Message delivery delay was linearly co-related to message delivery distance, i.e., larger the distance more was the delay. As the density of vehicles and their velocity increased the delivery delay decreased, but there was an upper bound on this linear relationship [94]. Optimal deployment of RSU was still to be achieved in high density scenario and on highways, where velocity limit was higher. VANET is characterized by high speed of nodes and fast changing topology. Geographic protocols used the position of destination to send messages whereas hybrid protocols combined the use of reactive routing with geographic routing. But how to maintain link stability with rapidly changing topology is still to be

answered.

2.4 Clustering based Data Dissemination

In these type of Data Dissemination schemes, vehicles moving within a particular geographical area form a cluster. One of the vehicles is elected/selected as cluster head (CH) and other vehicles are cluster members. However, there arises a situation where one vehicle situated at the boundary is a member of more than one clusters. Such vehicles are called border nodes. Different data dissemination schemes have different methods of selecting the CH and vary in the process of communicating the message to intended destination. Some of the prominent protocols in this category are depicted in Fig. 2.9 and described in this section.

Yvonne *et al.* [29] were the first to introduce clustering scheme for Medium Access Control (MAC) with the objective of fairer medium access and to reduce the effects of hidden station problem. To track changes in the topology, each node maintains two tables, one for neighboring nodes and the other for adjacent cluster. Every node sends the data in its own time slot only. These time slots are allotted according to the amount of data that the nodes want to transmit. The authors simulated the proposed protocol and evaluated its functionality. They fixed some of the simulation parameters like Time Division Multiple Access (TDMA) frames and slots. The results obtained depict good cluster stability and successful data transmission rate in different traffic scenarios with varying traffic densities. The proposed protocol works well in low and medium traffic densities but in rush hours of traffic, only low data rate communication is possible.

Due to faulty components between service provider and service requester there are dropped connections and decrease in service request satisfaction. This decrease in connections and service request satisfaction can be improved by fault tolerant techniques. In a service discovery protocol for VANETs, Fault Tolerant Location based Vehicular Service Discovery Protocol (FTLocVSDP) [102] requester specified the region of interest within the request. The protocol used discovery of location based services. In the region of vehicular network, the protocol used infrastructure support consisting of clusters of roadside routers. In order to improve the service discovery efficiency, the service discovery messages were integrated into network layer and used channel diversity. Earlier version of LocVSDP relied on wireless backbone or roadside routers but in enhanced version roadside routers were clustered around the service providers, the congested areas of vehicular networks and discontinuous areas. In the simulation of enhanced LocVSDP and FTLocVSDP the three metrics were used namely success rate, average response time and bandwidth usage. Comparing with protocol which did not consider fault tolerant techniques in the roadside router, there has been an improvement of 50% in communication link failure scenario.

Using directional data dissemination, Simple and Robust Dissemination (SRD) protocol performed well in both dense and sparse networks [103]. But, the major problem in dense networks is broadcast storm and the SRD approach dealt with it by using optimized broadcast suppression technique. For sparse networks where there were not many vehicles, the protocol used store-and-carry-forward communication technique. The protocol assumed that there were no RSUs available. Vehicles were classified in two states, cluster tail and non-tail. In the tail state, the vehicle broadcasted the received message with the tail flag in the message, set to true. The vehicles in the tail state stored all the messages. If there is no connectivity, the tail is responsible to propagate the message in store-carry-

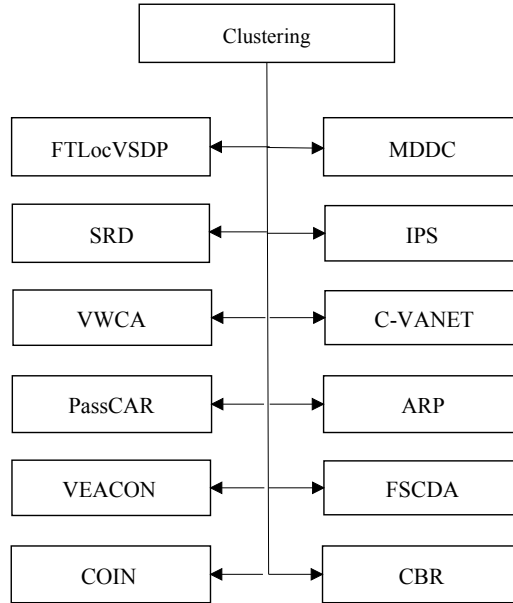


Fig. 2.9: Classification of Clustering based data dissemination schemes in VANETs

forward mechanism. When a vehicle did not receive a message from the vehicle farther, then it migrated from non-tail state to tail state. In the non-tail state all the messages coming from tail were stored. In order to reduce the redundant transmissions, non-tail vehicle rebroadcasted the received messages with Optimized Slotted 1-Persistence technique. According to Optimized Slotted 1-Persistence technique, vehicles could only cancel the rebroadcasts when the vehicle received an echo from any of the vehicle further in the message direction. From the results of simulations in OMNeT++4.1 [104], it was evident that SRD outperformed DV-CAST for delivery ratio. SRD also achieved lower load in the network. In highly dynamic scenario, where the vehicles moved frequently to different roads, SRD performed better with respect to robustness also.

VWCA, an efficient clustering algorithm took into consideration various parameters including the direction of vehicles, the number of neighbors, the distrust parameters and the entropy [105]. This algorithm selected CH, increased stability, improved connectivity, and reduced the overhead in the network. Using VWCA, the communication overheads required for joining to a new cluster in network, decreased because the membership duration for each vehicle increased. Since, for communication vehicles should be located in each other's transmission range, an algorithm for an Adaptive Allocation of Transmission Range (AATR) was designed. In AATR algorithm, minimum and maximum transmission range were defined, because a vehicle might not be located in the range of neighbors and messages might not arrive on their destination on-time. The vehicle started with minimum transmission range and looked to find a neighbor. If it did not exist, it iteratively increased the transmission range till the range was equal to maximum range or vehicle finds a neighbor. VWCA used distrust value in weighted sum operation which was calculated from Monitoring Malicious Vehicle (MMV) algorithm. MMV detected abnormal vehicle in the system and monitored behavior of vehicles in the network. Three algorithms namely-VWCA, AATR and MMV have been good only in highway scenario and their adaptability in city scenario is questionable.

In passive clustering based routing protocol named PassCAR, a cluster has one CH

and multiple clusters were connected through gateways [106]. PassCAR worked in three phases namely route discovery, route establishment and data transmission. During the route discovery phase, suitable nodes were selected which became gateway and CH. These nodes forwarded RREQ packets. For route establishment, the protocol used multi-metric election strategy and considered the links reliability, stability and sustainability. Protocol quantified the links based on metrics of node degree, expected transmission count and link lifetime. Once the route was discovered the destination node replied the RREP packet to the source node. The data transmission has been done through the established path. PassCAR has been superior to other protocols as it has better PDR and network throughput.

Vehicular ACCident ONtology (VEACON) was proposed to improve the safety on roads [107]. For different entities involved in transportation system, there needed to be a standard structure that enabled data interoperability. The protocol combined the information available at the site of accident and data accessible from General Estimates System (GES) accidents database. The reliability crash tests on NS-2 inferred that both nearby vehicles and RSUs have been correctly notified about the accident within short time. This increased emergency services notification effectiveness. In an another scheme, a Clustering algorithm for Open IVC Networks (COIN) has been proposed by Blum *et al.* [108]. In this scheme, the CH was elected based on the driver's intentions and vehicular dynamics. Algorithm also takes into consideration the oscillatory nature of the inter-vehicle distances. Simulation results proved that COIN produced a stable structure for VANETs. The overhead has also been minimal and within tolerable limits. Average life time of cluster has been increased by at least 192% and there is reduction in cluster membership by at least 46%.

By taking into account the parameters such as-vehicle direction, speed, the degree of connectivity to other vehicles, and mobility pattern, a Multiagent Driven Dynamic Clustering (MDDC) of vehicles in VANETs has been proposed [109]. The scheme formed a moving dynamic cluster between the two intersections. The scheme integrated mobile and static agents to deliver a rapid response for dynamic clustering. The proposal has been analyzed for cluster formation time, cluster member selection time, CH selection time, and control overhead. Results have been compared with existing clustering schemes and found that MDDC performed better in all aspects. However, after crossings and the lane intersections were not considered in this scheme. Noisy environments, traffic lights, signs at the intersection, more number of lanes per road are some other factors that can influence effectiveness of such system.

Little *et al.* [110] proposed an Information Propagation Scheme (IPS) based on clustering to improve scalability, but has some limitations too. As the size of VANETs grew and because of high mobility, there have been lots of overheads involved in the formation and maintenance of the clusters. A Cooperative Communication Aware Link Scheduling for Cognitive VANET (C-VANET) [111] has been investigated for the throughput maximization in C-VANET under multiple constraints.

- i) Cognitive Radio (CR) devices' inherent single-ratio constraint
- ii) The availability of licensed spectrum
- iii) Transmission mode selection
- iv) Link scheduling

The scheme classified the links into general or cooperative links. According to the availability of bands at different extended links, extended band pairs were defined and a 3-D cooperative conflict graph was formed. The end-to-end throughput maximization problem was mathematically formulated and solved by linear programming. Due to NP-Completeness of finding all independent sets, the cooperative communication aware link scheduling algorithm was proposed. The simulations showed that CR capability provided more opportunities for using cooperative communications. The performance of link scheduling with properly selected transmission mode has been better than the one in which the transmission relied on one transmission mode.

Li *et al.* [112] proposed Adaptive Role Playing (ARP) strategy to enable the nodes in each hop to contend to perform the basic functions. Even in the case of existing malfunctioning and misbehaving nodes, reliable and faithful data packet relaying was still achievable. The authors also proposed a Lightweight Reliable and Faithful Packet Relaying Framework (LEAPER), which enabled the nodes in each hop to securely and efficiently follow ARP strategy. LEAPER has been resistant to the malfunctioning nodes with security threshold k . Authors defined the constraints on security threshold k as follows.

$$k \leq \lambda \times L \times nl \quad (2.11)$$

k must be fewer than the number of nodes in a trust group determined by λ , L , and nl . λ = node density; L = length of trust group; nl = number of lanes

$$(k + 2)\tau m + (2k + 2)\tau v + 3\tau s \leq Td \quad (2.12)$$

τm MAC access time; τs signature creation time; τv signature verification time; T_d per-hop latency.

The total delay caused by one data packet, $(\tau m + \tau v + \tau s)$, k trust tokens and $(k\tau m + k\tau v + \tau s)$ total trust token $(\tau m + (k + 1)\tau v + \tau s)$ must be shorter than T_d .

$$Pr\{\text{Less than } k + 1 \text{ misbehaving nodes in a hop}\} \quad (2.13)$$

More than $k + 1$ misbehaving nodes in a trust group could plan to relay a tampered data packet to the next hop. Hence, k must be big enough to make it impossible to have $k + 1$ misbehaving nodes in a trust group. k must be set to any value within ranges determined by the above three factors. With $k = 1$, LEAPER was able to countermeasure the misbehaving nodes, discarding the tempered data packet and enabling the authentic data packets to be relayed. With $k = 1$, LEAPER could ensure both reliable and faithful data packet relaying in the face of up to 30% misbehaving and malfunctioning nodes. With k set to higher values, LEAPER could handle the plans among the misbehaving nodes better and remove any tempered data packets from VANETs. A Fundamental Scalability Criterion for Data Aggregation in VANETs (FSCDA) [113] showed that for any aggression scheme, its bandwidth profile must be $o(\frac{1}{d^2})$, to be considered scalable. It has also been proven that for arbitrary θ a bandwidth profile in $\Omega(\frac{1}{d^{2+\theta}})$ can be achieved. Where, d is distance between source of information and interested vehicle.

Cluster based routing protocol (CBR) has exhibited a decline in routing overhead, E2ED in the scenario when the number of vehicles is increased [114]. The scheme could overcome the problem of routing loop in VANETs. The Traffic Infrastructure Based Cluster Routing Protocol with Hand-off (TIBCRPH) has used existing infrastructure

Table 2.5: Relative comparison of Clustering based Data Dissemination schemes in VANETs

	Vehicle density	Speed	PDR	Scalability	Throughput	Cluster lifetime	Bandwidth	feasibility
FTLocVSDP [102]	L	ND	M	H	H	H	H	H
SRD [103]	H	H	H	M	H	M	H	M
VWCA & AATR [105]	M	H	H	H	ND	H	H	H
PassCAR [106]	H	H	L	ND	M	M	L	L
COIN [108]	M	M	M	L	L	H	L	M
MDDC [109]	M	L	M	M	M	H	H	M
IPS [110]	M	H	ND	L	ND	H	ND	M
C-VANET [111]	L	H	ND	H	M	M	H	M
LEAPER [112]	H	M	L	M	L	ND	H	L
FSCDA [113]	M	M	M	M	M	M	M	M
CBR [114]	L	L	L	L	M	ND	L	L

L= Low; M = Medium; H = High; ND = Not Determined

and various clustering techniques to efficiently solve the problem of data dissemination [115]. Hand-off similar to cellular network was used and compared with existing schemes. Simulation on NS-2 proved the effectiveness of proposed scheme. Use of cluster chains proposed in cluster construction, cluster merging and cluster repair algorithms [116]. The distance was used as a metric for electing the CH. The cluster merging and cluster repair algorithms enhanced the stability of cluster chains. The number of CHs has been minimized and accuracy in routing was achieved.

Table 2.5 describes the relative comparison of various clustering schemes in VANETs.

2.4.1 Analysis of clustering based protocols

The performance of LocVSDP was affected adversely by the roadside router failures. This was because of interruption of service requests during the location based request propagation phase and also due to interruption of service messages during reply propagation phase. The problem **did not** occur in FTLocVSDP due to the use of channel diversity, so the success rate in FTLocVSDP was 70% up to 100 nodes, which was 50% higher than LocVSDP. But, the bandwidth usage and response time was higher at the same time [102]. In other routing protocols, the collisions became severe and resulted in low PDR in low density scenario [103].

PassCAR improved PDR by an average of 45% as compared to other protocols because of the usage of node degree as routing metric, which increased the probability of forwarding RREQ packets per hop. This in turn increased the discovery of routing path [106]. AATR improved network connectivity and increased message transmission probability.

SRD being simple protocol put lower load on the network and has higher delivery ratio. SRD coped up well with simultaneous broadcasts in low density scenario and hence has higher PDR. The clustering protocols improved throughput of the network, but there was a decrease in PDR as the number of vehicles increased. In PassCAR there was a decrease in PDR and throughput with increase in velocity. PDR was around 80% for 250 vehicles and which reduced to 70% for 350 vehicles in PassCAR [106]. The clustering protocols have very long connectivity in urban areas and can strengthen security on highways. The COIN protocol imparted stability in clustering protocols [108]. In COIN, there was slow rate of cluster creation therefore, in other schemes the number of CH forming exceeds COIN [108]. As the number of vehicles increased, CH selection time gradually increased, because stable clustering scheme requires more packet buffering while forwarding a packet [109].

Maximum propagation rate is the sum of vehicle velocity and speed of message propagation in dense traffic conditions whereas minimum propagation rate is speed of carrier vehicle in sparse condition because it is difficult to form data path in such conditions [110]. The deviation of vehicle speed in C-VANET caused performance degradation of link scheduling because speeding up or slowing down led to change in network topology of C-VANET [111]. There was a decrease in gateway connectivity with decrease in gateway density. Path lifetime increased with decrease in node and gateway density. The reason being that when node density decreased, there were fewer nodes in close proximity to connect and form fewer paths, hence increase in path lifetime.

The VWCA protocol was designed to improve security of the network [105]. Resistant to malfunctioning nodes with any security threshold k in LEAPER ensured reliable data packet relaying [112]. Integration of mobile agents and static agents delivered a rapid response for dynamic clustering [109]. However, the lane intersection, noisy environments, traffic lights, signs at the intersection, more number of lanes per road can also influence effectiveness of such system. Directional routing protocol for vehicular environments [103] used power control mechanisms to decrease the network load in dense scenarios, but needs improvement for better performance with regard to E2ED. There is a need to reduce the number of communications and provide aggregate information to the drivers.

2.5 Opportunistic Data Dissemination

In these schemes, nodes join dynamically to exploit the resources of separate networks according to the needs of specific application tasks. In these schemes, opportunities are intermittent, network is partitioned and continuous end to end paths do not exist [117]. Some of opportunistic data dissemination schemes are mentioned in Fig. 2.10 and their brief description is provided in this section.

COperative Traffic congestion detECTION (CoTEC) scheme detected road traffic congestion [118] without the deployment of any infrastructure nodes. CoTEC could accurately characterize the length and intensity of traffic jam. Hence, for road management and to detect and characterize road congestion conditions, CoTEC offered efficient and cost-effective solution. CoTEC has been evaluated using iTETRIS simulation platform and compared to V2V and infrastructure based detection solutions. CoTEC could accurately and successfully detect congestion conditions.

Traffic information was gathered by relying on static sensors placed at specific road locations or vehicles reported their location, speed, and travel time [119]. The realistic

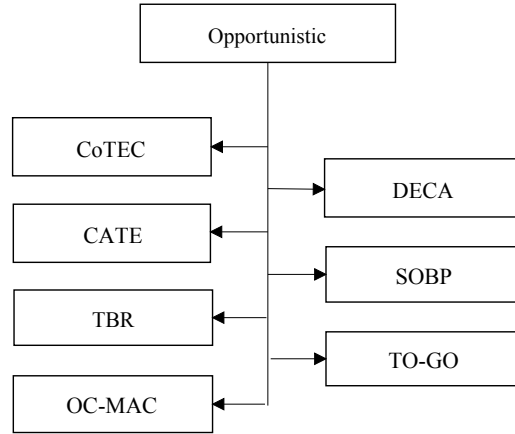


Fig. 2.10: Classification of Opportunistic data dissemination schemes in VANETs

effectiveness of the later case was studied. For this, they designed a system in which vehicles gathered information in ad hoc manner and dynamically rerouted based on the collected traffic information. The system called Computer-Assisted Traveling Environment (CATE), has traffic-sensing module in which every vehicle became a traffic sensor. The architecture had disseminating module, traffic estimation, and dynamic routing module. To evaluate CATE, a tool was designed by integrating QualNET and mobility simulator, MobiDense. This newly designed tool was implemented to simulate both dynamic vehicular navigation and the VANET dissemination. A decentralized approach reduced traffic congestion in realistic scenarios. The gossip scheme performed very well, both in terms of vehicular traffic and telecommunications traffic overhead. The average travel time decreased marginally when nodes were provided with full information about the traffic with no delay.

Trajectory Based Routing (TBR) took knowledge of other vehicle's trajectory using the services implemented at RSUs for rural scenario [120]. By knowing the future knowledge of trajectory of vehicles, the source computed route to forward packet to destination. Simulations proved that TBR performed with higher PDR than other opportunistic schemes without increasing the latency. The scheme assumed RSUs installed properly in rural conditions which has not been achieved practically till date.

In OC-MAC protocol, the neighboring nodes exchanged data while the recovering node was not active [121]. The sender node transferred the data to its neighboring node and went to sleep. By the time receiver node woke up, the data was with neighboring node which transferred to its intended destination. OC-MAC used opportunistic cooperation to reduce the waiting time of the sender. OC-MAC had lowered E2ED as it decreased packet collisions and retransmissions. OC-MAC has no additional overhead. The condition for using OC-MAC was that there should be multiple neighboring active senders.

An opportunistic technique for data dissemination that used only one hop neighbor information, has extended the concept of opportunistic routing from uni-casting to multi-casting to achieve the higher PDR and lower E2ED [122]. An effective beaconing scheme was proposed to gather the information of neighbors with minimum message exchange [123]. The proposed density-aware reliable broadcasting scheme (DECA) selected the next hop having the maximum density and maximized the number of nodes that receive the messages. The authors failed to mention the procedure for calculation of density,

Table 2.6: Relative comparison of Opportunistic Data Dissemination schemes in VANETs

	Vehicle density	Speed	PDR	Latency	Distance	Throughput	Bandwidth	Feasibility
CoTEC [118]	L,M,H	L,M,H	M	M	M	ND	ND	M
CATE [119]	H	M	M	M	H	M	ND	M
TBR [120]	L	L	M	M	L	M	ND	M
OC-MAC [121]	L	L	M	M	M	L	L	L
DECA [123]	L,M,H	L, M	M	M	M	M	M	M
SOBP [1]	L, M	L, M	M	L	M	M	H	M
TO-GO [124]	M	M	M	M	L	M	M	M

L = Low; M = Medium; H = High; ND = Not Determined

although the simulation results have highlighted the efficiency of the proposed scheme.

Sender-designated Opportunistic Broadcast Protocol (SOBP) claimed to reduce the effects of slow reaction problem and local broadcast storm problem [1]. In slow reaction problem, the nearby nodes of communicating vehicle, reacted slowly and had higher delay. On the contrary, in local broadcast storm problem, the channel was congested because of the frequent broadcasts by nearby nodes. Both were due to the extreme situations and resulted in performance degradation. The SOBP protocol used opportunistic routing and took advantage of linear topology of vehicles in VANET. With assigning fixed priorities to the candidate vehicle, the collision was minimized and use of only uni-cast message communication solved both the addressed problems. The SOBP scheme has maintained constant performance even in high density scenarios.

The Topology assisted Geo-Opportunistic routing (TO-GO) [124] exploited the knowledge acquired from 2-hop beaconing and used opportunistic forwarding to select the next best node for data dissemination. The scheme was implemented on VanetMobim and achieved better result as compared to other opportunistic forwarding technique. Exploiting coding based mobile data offloading for heterogeneous networks, a mobile offloading scheme that used opportunistic vehicular networks [125] was put forward. Opportunistic network was employed to propose a solution of the increasing use of mobile data usage problem [126]. Three algorithms namely-greedy, heuristic and random were framed for the data offloading, and mobile social networks were used as an alternate means for communication. Opportunistic protocol was used to put forward a subscribe-and-send architecture for the user on content service providers [127]. A survey and discussion on the options for mobile offloading has been presented [128]. The survey discussed offloading through Wi-Fi via femtocells, using WiMax and by IP flow mobility. The relative comparison of Opportunistic Data Dissemination scheme is presented in Table 2.6.

2.5.1 Analysis of opportunistic protocols

CoTEC protocol has improved congestion detection probability on the road with vehicle density 10-15 vehicles/km/lane. Using CoTEC, congestion signal could be successfully classified for intensity and length. Success rate of the protocol has been 70-80%. Because the vehicles collecting traffic information diverted from highly congested area to less con-

gested area, around 34% vehicles saved up to 20% time. In total, 64% of vehicles saved time. About 13% vehicles took more time using CATE due to diversion of traffic into smaller roads which became busier [119].

Congestion estimation error in CoTEC increased as the separation distance between inductive loops increased, due to the decrease in traffic information available to estimate traffic congestion [118]. TBR has global knowledge of vehicles' trajectories and the performance of TBR was independent of vehicle density [120]. Cooperative communication reduced the E2ED and the time of idle listening and hence the average duty cycle in OC-MAC [121] was redundant. But, nodes closer to destination consumed more energy because they relayed more packets.

2.6 Data Fusion based Data Dissemination

Data fusion can be distributed into network and executed on nodes which reduce data from redundant nodes. It fuses the information from complementary nodes to get complete view from cooperative nodes. Consequently only the inference of interest is sent. Some of data fusion schemes having applicability in data dissemination are categorized in Fig. 2.11 and are discussed in this section.

The data fusion problem was studied in driver-in-the-Loop Vehicular Cyber-Physical Systems (VCPS) in which the message was composed of Data Elements (DE) [129]. This message had flexible structure. The message was divided into two parts namely

- i) Essential part
- ii) Auxiliary part

The essential part consisted of DEs without which the message is of no use. All the DEs must reach the driver for whom the message was generated. The auxiliary part contained DEs that were beneficial if and only if the essential part was available to the driver. Hence, there was limited transmission capacity and limited number of messages to be sent. With these constraints, the target was to maximize the total utility of complete or partial messages that reach the receiver. The authors have formulated a new Driver-in-the-loop Data Fusion Problem (DDFP) and have proved DDFP to be NP-Complete. An algorithm for ideal and lossy communication networks has been proposed. Large simulations have been performed and the algorithm has been found out to be efficient. Problem for the Multi Sender Single Receiver and Single Sender Multiple Receiver models have been addressed

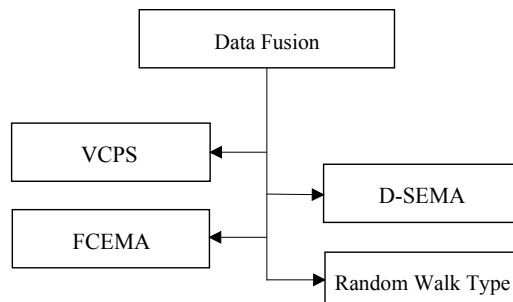


Fig. 2.11: Classification of Data Fusion schemes in VANETs

and the algorithm to deal with practical issues has been extended.

Zhang *et al.* [130] have proposed a multilevel information fusion approach for road congestion detection in VANETs. The proposed approach combined the feature level information fusion with decision level information fusion. By using Fuzzy Clustering based Message Aggression (FCMA) local atomic messages were classified into different message clusters and abnormal feature was extracted. Event probability prediction and message credibility was defined and Basic Probability Assignment (BPA) was calculated. This BPA value of evidence was an abnormal aggregation message. To detect the road congestion event, the modified BPA based Dempster-Shafer (D-S) evidence reasoning method was used. The highlight of FCMA was that it could exactly distinguish different traffic conditions in adjacent two way lanes. Another algorithm named D-S Evidence Message Aggression (D-SEMA) has removed the false abnormal feature information caused by the traffic lights. The multilevel information fusion approach has achieved high accuracy of road congestion and reduced traffic load in the network significantly.

The condition under which information could be sustained in a system was studied with focus on a random walk type mobility model [131]. The direction of each step is random and step size has been assumed which follows an exponential distribution. The nodes were assumed to move in straight line. The authors studied the case when all nodes moved with the same velocity. The transport equation was calculated as

$$\begin{aligned} \frac{d}{ds}\varphi(r(s), \theta(s)) + \sigma\varphi(r(s), \theta(s)) &= \frac{\sigma}{2\pi} \int_0^{2\pi} \varphi(r(s), \theta')d\theta' \\ &+ \int_0^{2\pi} \varphi(r(s), \theta')\sqrt{2 - 2\cos(\theta(s) - \theta')}d\theta' \end{aligned} \quad (2.14)$$

The angular flux $\varphi(r, \theta)$ depended only on the distance r from the center of the disk and the angle θ between the line of the flow and the radius vector pointing from the center to the point of consideration; s denoted the position of the point on the line, i.e., distance from a reference point; r and θ are functions of s . The initial condition for the equation was $\varphi = 0$ at the entry into disk. The threshold value of the

- i) Product of the node density
- ii) Interaction width
- iii) Radius of the disk

was found as the smallest eigenvalue of the transport equation. The asymptotic behavior of the function is determined by diffusion theory. The accurate rational approximation for the function in the whole range has also been established. Shortening the mean step size lowered the critical threshold because the zig-zag path of a node in the anchor zone became more chaotic (longer) which increased the possibility for information exchange. A Relative comparison of Data fusion based schemes in VANETs is given in Table 2.7.

2.6.1 Analysis of data fusion based protocols

An increase in total utility using FFCS and FCS protocols with an increase in the percentage of auxiliary content of message has been observed. FFCS performed better than

Table 2.7: Relative comparison of Data Fusion based schemes in VANETs

	Vehicle Density	Speed	Bandwidth	PDR	Scalability	Feasibility
DDFP [129]	M	M	L	H	H	H
FCEMA & DSEMA [130]	H	L	M	L	H	M

L=Low; M = Medium; H = High; ND = Not Determined

FCS and KPS by delivering more messages to the receiver. This is because FFCS fully exploits the flexible structure of each message and has more fine grained control over the insertion of auxiliary part. As FFCS had best control over type and size of each message that was picked, its performance has been highest [129]. Using FCMA, an improvement in average message aggregation efficiency from 92% to 98% has been achieved with an increase in message aggregation time from 300 seconds to 800 seconds [130]. With low number of left messages and high average message aggregation efficiency, FCMA has successfully detected road congestion [130].

In an extremely loaded situation, a huge amount of data is to be transmitted, so collision of messages is large. How to efficiently route the urgent data to all the destined nodes in minimum time needs to be explored further. The use of proxy mobile router also needs further investigation. No study could be found which used vehicular traces from different scenarios with different node densities to evaluate feasibility and limitations. To the best of our knowledge, there is no research proposal which does comprehensive scalability analysis.

2.7 Greedy Data Dissemination

The strategies to use the furthest nodes in the communication range are categorized as Greedy strategy. Some of Greedy schemes having applicability in Data Dissemination are categorized in Fig. 2.12 and are described in this section.

A hop-greedy algorithm that worked with uni-casting on zone-wise partitioned city network, named BAHG [132] used backbone nodes for void and regions having non-availability of forwarders. In this work, network maps from OpenStreetMap [133] and SUMO [134] network simulator were used for evaluating the scheme and comparing it

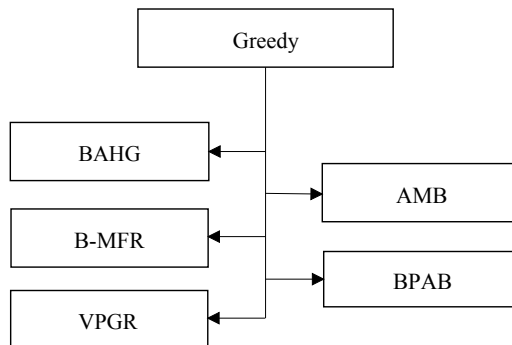
**Fig. 2.12:** Classification of Greedy data dissemination schemes in VANETs

Table 2.8: Relative comparison of Greedy Data Dissemination schemes in VANETs

	Vehicle density	Speed	PDR	E2ED	Distance	Throughput	Bandwidth	Feasibility
BAHG [132]	M	L	M	L	M	ND	M	M
B-MFR [135]	L,M	M	ND	M	M	ND	L	L
VPGR [136]	ND	L, M	M	M	L	M	M	L
AMB [137]	M	L	M	M	M	M	L	M
BPAB [138]	M, H	M	M	M	M	M	ND	M

L = Low; M = Medium; H = High; ND = Not Determined

with GPCR [6] and GyTAR [4]. An improvement in the Most Forwarding within Radius (MFR), Border MFR (B-MFR) scheme used GPS technique and selected the node on border of the communication radius towards the destination [135]. In another scheme, a vertex based predictive greedy routing (VPGR) protocol has been proposed by Shrestha *et al.* [136]. The VPGR scheme used the predicted vehicles in the area of interest, from source node to forward the message to the RSU which was used for further communication to the destination. The scheme was best applicable for city environment. The simulations performed on NS-2 suggest VPGR's supremacy as compared to AODV and GPSR protocols. In another proposal, two schemes for data dissemination namely Adhoc Multi-hop Broadcast (AMB) and Urban Multi-hop Broadcast (UMB) have been suggested [137]. These schemes selected the furthest vehicle within the communication range for communication. The schemes addressed the problems of broadcast storm, hidden node and reliability. The schemes have worked efficiently even without the infrastructure support, unless the line of sight was blocked by obstacles. In case of obstacles, the repeaters have been used by UMB protocol to successfully communicate the message.

The problem of broadcast storm and hidden terminal was addressed in a Binary Partition Assisted Broadcast (BPAB) protocol also [138]. The protocol divided the transmission area into narrow segments and chose the farthest vehicle for data dissemination. The scheme worked successfully irrespective of density of vehicles in the network. NS-2 based simulations have been done to prove the efficiency of the proposed scheme. The relative comparison of Greedy Data Dissemination schemes is presented in Table 2.8.

2.7.1 Analysis of greedy protocols

UMB protocol has much higher success percentage as compared to 802.11 random protocols at high packet loads. In Geocast routing protocols, vehicles only in the specified geographical area called Zone of Relevance (ZoR) were destination nodes and vehicles outside ZoR were not, hence unnecessary hasty reactions have been avoided.

2.8 Other Schemes used for Data Dissemination

Some of other data dissemination schemes are explained in the following section. These schemes are categorized in Fig. 2.13 and are discussed as follows.

Location-and Mobility Aware (LMA) protocols for VANETs used directional antennas [139], adopted predictive location and mobility of the vehicles using the directional beams to provide robust communication links. The proposed algorithm addressed the

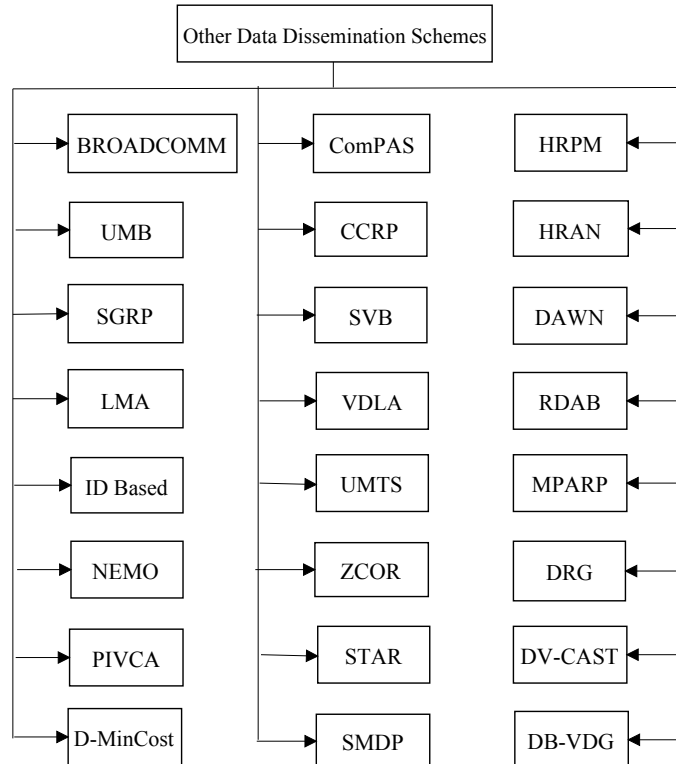


Fig. 2.13: Classification of Other schemes for data dissemination in VANETs

deafness problem using the directional listen mechanism. Even as the direction and speed of vehicles changed, the proposed algorithm used directional beacons and enhanced the reliability. In order to compare the performance with 802.11 and DMAC algorithm NS-2 simulator has been evaluated. The throughput, E2ED and control packet overhead metrics were used. LMA had higher throughput and lower E2ED, but the control packet overhead was higher than other compared protocols.

A scheme for sharing files among vehicles on the move using consistent hashing with ID of vehicles and ASCII code of first letter of message achieved tolerable overhead and acceptable scalability [140]. The rate of file sharing has been improved with reduced file download time. A multi-cast routing scheme that was an improvement of AODV scheme applicable for VANETs has been proposed [141]. The proposed algorithm presents an application of an ant colony optimization that used mobility prediction for tree based multi-cast routing. The output paths have been an improvement in terms of lifetime of links and have smaller hop counts as compared to paths returned by MAODV scheme. Another highlight of the protocol is the use of cooperation beacon messages that reduced the number of beacon messages to be exchanged to maintain and know the state of the system.

NEMO is another scheme that overcame the problems of packet loss and hand-off which were caused due to the fast movement of vehicles [142]. By applying the NEMO scheme the vehicle moving on road could dynamically acquire the IP address of the vehicle in communicating range and disseminate the message. The vehicle in front initiated the pre-handoff procedure to acquire the IP address of vehicles moving in opposite direction. The scheme, tested on NS-2 simulator and compared with FNENO, BUS and virtual-BUS

schemes, has performed well.

An architecture for inter-vehicle communication for vast variety of applications named PIVCA has been proposed [142]. PIVCA ensured multi-hop communication of messages in relatively less time. The architecture reduced the number of transmissions and adapted its functionality to the network traffic. An analytical model for the dissemination of warning messages has been presented [143]. The mathematical model could be used to compute the message delivery delay, the probability of destination be informed, and the number of duplicate messages that the destination would receive. The network connectivity has been the key to reliable communication. To ensure connectivity, the transmission range of the vehicle and the forwarding probability of message were focused in this proposal. Another finding of the protocol was that the collisions affected the number of duplicate messages received. It is evident that for effective communication the transmission range of vehicles is important.

The collection of data by vehicles in a time bound manner has been studied [144]. The protocol presented a delay bound vehicular data gathering scheme called DB-VDG that managed the collection and forwarding of data towards the RSUs. The scheme helped in deciding the vehicle whether to keep carrying the data or forward it to next vehicle. DB-VDG scheme helped in lowering the overall bandwidth utilization mainly for urban scenario. The problem of excessive packets exchanged for maintaining the network and to monitor traffic systems is addressed in D-Greedy and D-MinCost [145]. These two strategies delivered the messages to nearest RSU or base station and used local information and global traffic knowledge for forwarding the message and minimizing the communication packets exchanged. This scheme has been an improvement over epidemic routing.

In another work, a strategy with the use of Wi-Fi for transferring the data has been presented [146]. It is a hand-off and data transfer strategy for quick connection establishment and faster data transfer. A mathematical framework for mobile data offloading in different data interests has been presented [147]. The heterogeneity of data in terms of size and lifetime is also on records. Delay-Aware Wi-Fi offloading and Network selection (DAWN) algorithm with the aim of delivering the data using Wi-Fi AP within the required time has been presented [148]. The algorithm used minimum cost to deliver the data to destination when the time was not a critical factor.

To manage increasing usage of mobile data, managing peak hours and increasing yield along with data offloading, techniques were suggested [149]. The techniques discussed offloading including Wi-Fi offloading and use of smart cell. In another work Kang *et al.* [150] also agreed to the fact that Wi-Fi can be used to offload mobile data because of the provision of high data transmission rate in Wi-Fi. Successive interference calculation (SIC) technique has been used to offload the mobile data. Different cases have been considered for the availability and non-availability of SIC at AP. Various optimal solutions for both the cases have also been presented. A mobile offloading technique that used IP mobility has been put forward [151]. The highlight of this protocol was that it used distributed mobility anchors and provided selective data offloading.

To offload the mobile data, another iterative double auction mechanism has been forwarded [152]. The auction mechanism considered the benefits for mobile service providers and AP's offloading cost. Various challenges including the interference of APs have been considered. In a similar approach, authors presented a bargaining approach which included mobile network operators and AP owners. Two different bargaining protocols namely-sequential bargaining and concurrent bargaining have been presented. The sce-

nario is used when multiple APs form a group and Nash bargaining theory was applied to find a solution with benefit to mobile operators and group of AP owners.

Some challenges for network selection and their solution with game theoretic approaches have been analyzed [153]. The existing game theoretic approaches are compared and outlined the probable problems wireless networks will face in future. Addressing the issue of increase in the mobile traffic in years to come, the alternative means for data transfer by using Wi-Fi and LTE have been discussed and suggested for better efficiency [154].

Relative Degree Adaptive flooding Broadcast (RDAB) algorithm solved the broadcast storm problem by using the current situation of the network and taking the relative degree of nodes into consideration [155]. According to the relative degree of nodes, next forwarding node was selected. Mobility Pattern Aware Routing Protocol (MPARP) that was intended for heterogeneous vehicular networks has been put forward [156]. It took advantage of IEEE 802.11 and IEEE 802.16 standards by combining both technologies. It assumed that vehicles have both wireless interfaces for communication between vehicles and with base station using IEEE 802.11 and IEEE 802.16 respectively. Base station gave path to be followed for transmitting the data and vehicles followed that path using IEEE 802.11. In case of failure, vehicles forward data through the base station and use IEEE 802.16.

Some other proposals using distance or categorized zones for mitigating broadcast storm also exist in literature. In this category, Distributed Robust Geocast (DRG) [157], which reduced redundant broadcasts used a distance based back-off algorithm and defined fixed Zone of Forwarding (ZoF). DRG overcame temporal network fragmentation through periodic retransmissions. The proposed solution worked well in case of network fragmentations and topology changes. The optimal computation of ZoF must be done to avoid wastage of channel resources and temporal network fragmentations which occurred because of larger and smaller ZoF area respectively. ZoR area has been defined within which all vehicles received messages that were routed through mobicast protocol [158]. The store-and-forward strategy has been applied in this scheme. The scheme aims to disseminate messages that were time insensitive applications. Though carry-and-forward strategy reduced the problem of network partitioning but in turn increased the delay. Both these protocols worked on the principle of Zone formation which might not be possible always.

A Distributed Vehicular BroadCAST (DV-CAST) strategy that worked well in extreme traffic conditions has been proposed [159]. Broadcast suppression technique and store-carry-forward strategy has been used for connected and disconnected scenarios respectively. The scheme has worked satisfactorily in rush hours as well as in very light traffic scenarios and claimed to solve the problem of broadcast storm and network partition. The limitation of DV-CAST is that protocol worked with beacon messages whose optimal value has not been calculated. Moreover, the implementation of DV-CAST has been done on simple highway topologies only.

2.9 Research Gaps

As observed in literature survey, many research proposals have been reported covering various issues in VANETs, but still there are a number of research gaps that need further investigation in this emerging technology. Some of these are as follows.

- i) Various researcher have worked to achieve optimal connectivity for rapid and reliable data dissemination in VANETs in urban and highway scenarios, by using different protocols for highway and urban environment. There is a need for a comprehensive scheme that works well in both the conditions.
- ii) Campolo *et al.* [70] proposed the flexible WAVE-mode Short Message Protocol (WSMP), to reduce the overhead and increase the reliability of the link. Still, there is a scope of improvement in link reliability and overhead reduction in VANETs.
- iii) For the integration of mobile and static agents a scheme has been put forward by Kakkasageri *et al.* [109]. The proposed scheme used dynamic clustering to achieve the efficient communication. However, the authors have not considered the intersection of lanes. Noisy environments, traffic lights, signs at the intersection are some other factors which may influence the effectiveness of data dissemination.
- iv) Message delivery delay is proportional to message delivery distance. As the density of vehicles and their velocity increases the delivery delay decreases but there is an upper bound on this linear relationship [94]. Optimal deployment of RSU in high density scenario and on highways, where velocity limit is higher is still to be achieved.
- v) Namboodiri *et al.* [30] proposed Prediction Based Routing (PBR) for preemptively selecting the routes. But the absence of vehicles in the remote areas, may cause connectivity problem that needs to be addressed for effective data dissemination. Moreover, the power control with varying transmission range depends upon vehicle density [7] which needs further investigation.
- vi) In order to decrease the load on the network Schwartz *et al.* [103] proposed a scheme that used power control mechanism. The number of communications need to be reduced further and provide aggregate information to the drivers. There is a need to improve the performance, especially to reduce the delay.
- vii) VANET is characterized by high speed of nodes and fast changing topology. Geographic protocols used the position of destination to send the messages, hybrid protocols combined the use of reactive routing with geographic routing. But how to maintain link stability with rapidly changing topology is still to be answered.
- viii) In an extremely loaded situation, there will be a huge amount of data to be transmitted. This may to collision of messages. There is a need of a solution to disseminate the prioritized data within constrained time. Also, the use of proxy mobile router seeks further investigation.
- ix) No study could be found which used vehicular traces from different scenarios with different node densities to evaluate feasibility and limitations.
- x) To improve the QoS and security of the network, various components of VANETs are still to be explored to full potential [33].
- xi) A cross-layer solution is required for reducing the interference and increasing the connectivity [69].

2.10 Problem Formulation

As VANETs are highly dynamic in nature, so mobility management for data dissemination is one of the core issues which needs inspection from all prospective. As discussed above, there are still many research gaps in the existing proposals for data dissemination in VANETs, so there is a requirement of more formulized approach for the same. So keeping in view of the above, the problem formulation for the current proposal consists of following steps:

- i) A System model has been constructed which contains different components such as estimation of density and mobility of the nodes along with various costs associated during the mobility of the clients. The requirement from support of infrastructure has been identified and included in the model.
- ii) A bidirectional movement of the nodes is included in the model in which procedure for calculation of direction of motion of vehicles has been identified which shows the relative motion of the vehicles with respect to different RSUs deployed.
- iii) Identification of different strategies for estimation of density of the vehicles on highway or community regions. The density of the nodes need not be same during various hours of the day, e.g., it may be different during the early and late hours of the day and during weekends. Hence keeping in view of the same, a variable is identified which has different thresholds during these hours.
- iv) By combining all these factors, efficient algorithms are designed for data dissemination in VANETs

2.11 Objectives

Based upon the above observations, the proposal is laid with the following objectives.

- i) To study and review various data dissemination techniques available in VANETs.
- ii) To propose an efficient data dissemination scheme covering the aspects like QoS, varying density etc.
- iii) To design and implement the proposed data dissemination scheme.
- iv) To test and validate the proposed scheme in different scenarios with respect to various metrics like packet delivery ratio, latency, overhead, throughput, etc.

Chapter 3

Coordinated QoS-aware Data Dissemination

There are several issues identified that need to be addressed for improving the data dissemination in the VANETs. One of the important requirements is satisfying the QoS while disseminating the data in vehicular environment. To achieve this, a coordinated QoS-Aware Data Dissemination (QADD) scheme in VANETs has been proposed ¹.

Wireless communication among vehicles is an increasing focus of research for providing safety and comfort to driver and passengers. Vehicles **do not** remain just electro-mechanical machines but are becoming intelligent system carriers in modern era. All thanks to revolution in automobile and communication industry which makes vehicles connection to wireless networks. Vehicles from all leading companies are getting equipped with GPS, digital maps and wireless interfaces so that user can access various resources from the Internet with an ease.

3.1 System Model

Although many state-of-the-art protocols are available for routing in VANETs, but these solutions are not adequate to provide QoS to various applications in these networks. This is because of high mobility of nodes in VANETs which leads to constant topological changes. A novel solution is required which will efficiently deliver the messages to their final destination within the prescribed time and associated constraints.

Keeping focus on all the above points, a novel routing algorithm that is quickest to route the packets to the destination from any source has been proposed. The protocol works successfully for both sparse and dense regions in VANETs. The main objective here is to achieve high PDR in shortest time with minimum overhead. The protocol overcomes broadcast storm problem and gray zone problem which exist in most of the earlier solutions. Also, the proposed QADD scheme recovers quickly in case of link failures to avoid fault tolerance issue.

¹The contents of the chapter are partly published in Amit Dua, Neeraj Kumar, Seema Bawa, "QoS-aware data dissemination for dense urban regions in vehicular ad hoc networks," *Mobile Networks and Applications*, vol. 20, no. 6, pp. 773-780, 2015. (*Springer, IF 1.05*) (*SCI/SCIE*).

3.1.1 Mobility model

In the mobility model, the roads are bidirectional and each direction has 2 lanes. There are N vehicles in the network following Freeway mobility model. The constraints considered are as follows.

Vehicles are following binomial distribution with a probability of taking a left turn or right turn at intersection being equal, i.e., p . The probability of moving in a straight line is $1 - 2p$. Each vehicle Veh_x has velocity component v_x and angle component θ_x . Before moving further, we will prove the following lemmas.

Lemma 1: Vehicles moving in opposite direction have least communication time.

Proof: Two vehicles Veh_x and Veh_y are moving in communication range at an angle θ_x and θ_y have relative velocity as

$$\begin{aligned} v_{rel} = & (v_x \cos(\theta_x) - v_y \cos(\theta_y))\hat{i}, \\ & (v_x \sin(\theta_x) - v_y \sin(\theta_y))\hat{j} \end{aligned} \quad (3.1)$$

The exact value of relative velocity is given as

$$|v_{rel}| = \sqrt{v_x^2 + v_y^2 - 2v_x v_y \cos(\theta_x - \theta_y)} \quad (3.2)$$

Let range of vehicle x is R_x and range of vehicle y is R_y . Maximum covered area where two vehicles can be communicating is $R_x + R_y$. Maximum time t_{max} , for which Veh_x and Veh_y exchange messages is

$$t_{max} = \frac{R_x + R_y}{|v_{rel}|} \quad (3.3)$$

When the vehicles are moving in opposite direction, difference between their angles, i.e., $\theta_x - \theta_y = \pi$ and $\cos(\pi) = -1$, so Eq. (3.2) becomes

$$|v_{rel}| = \sqrt{v_x^2 + v_y^2 + 2v_x v_y} \quad (3.4)$$

For calculating maximum communication time t_{max} from Eq. (3.3), the denominator calculated from Eq. (3.4) is maximum, making t_{max} as minimum. Hence, the vehicles moving in opposite direction have least communication time.

Lemma 2: Vehicles moving in same direction have maximum communication time.

Proof: When Veh_x and Veh_y move in same direction, the difference of their angle, i.e., $\theta_x - \theta_y = 0$ and $\cos(0) = 1$. The value of relative velocity from Eq. (3.2) becomes

$$|v_{rel}| = \sqrt{v_x^2 + v_y^2 - 2v_x v_y} \quad (3.5)$$

which is minimum. By substituting this value in Eq. (3.3) for calculating t_{max} , as the denominator is minimum, the t_{max} is maximum.

3.1.2 Channel model

IEEE 802.11a supports 8 data rates with a maximum of 54 Mbps and minimum of 6 Mbps. It supports 12 non-interfering channels while IEEE 802.11b has 3 non interfering

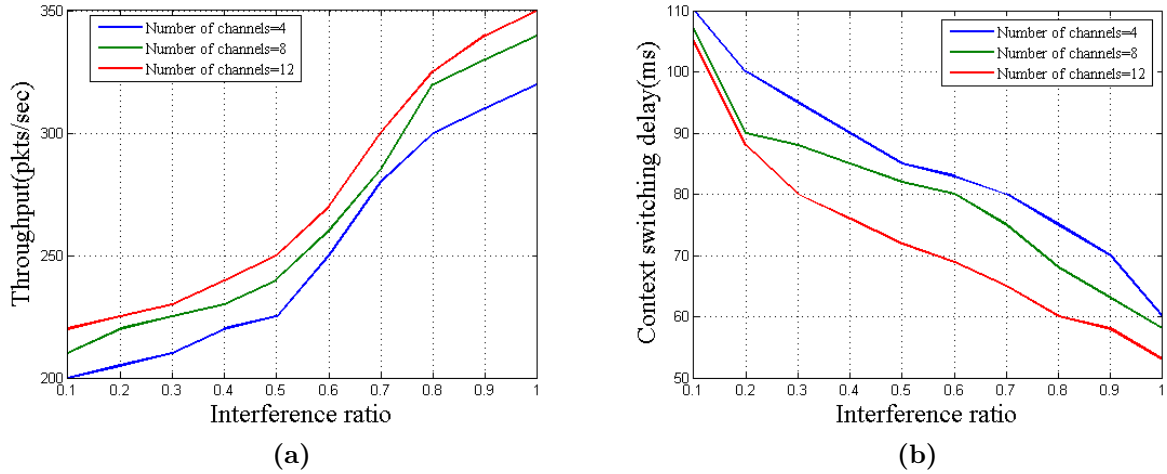


Fig. 3.1: (a) Variations in throughput as interference ratio increases (b) Context switching delay with variation in interference ratio

channels with four data rates varying from 1 Mbps to 11 Mbps. Each vehicle has necessary infrastructure to use multiple interfaces from these standards. Interference ratio is the ratio of utilized link to available links. As shown in Fig. 3.1 (a,b), with increase in interference ratio the throughput increases and context switching delay decreases which is because of better utilization of the network.

There are various challenges for maintaining QoS for data dissemination from source to destination in VANETs, e.g., in case of proactive protocols, the route maintenance overheads are very high while in case of geographic routing protocols, the frequent disconnections amongst vehicles are the major challenges. These disconnections in the path are because of high speed of vehicles and rapidly changing topology. The selection of shortest route based on the least number of hops has poor link quality of intermediate hops because of which there is higher packet error rate. The calculation of density may be erroneous because of inaccuracy in statistical data. Not even this, the obstructions in the network because of buildings, roundabouts, traffic lights does not allow line of sight communication.

For safety applications using broadcasting of emergency messages, there is a requirement of high reliability and efficiency. The problem with broadcasting is that there are no acknowledgments or medium reservation and packet retransmission makes network even more congested. For broadcasting, there are two schemes available, either select the next hop on the fly or decide the next hop before the transmission. The former is receiver driven (RD) and later is termed as sender driven (SD). In RD protocols, nodes collaborate to find the next node to forward the packet and make full use of broadcast nature of wireless propagation. The RD protocols assume that connection range is fixed and do not consider node density. In most of cases, these result in broadcast storm problem. The SD protocols can adapt to rapidly changing network conditions and reduce redundant forwarding. The constraint is that they do not take transmission speed into account. As there are no retransmissions they may be unreliable.

Opportunistic Routing (OR) works successfully for unicast as well as broadcast in VANET. They require global topology and link state to select the best next hop vehicle. This knowledge of topology is challenging because of high mobility of vehicles and fast

changing positions. For working of sparse networks, the use of efficient QoS mechanism is must as the connectivity between vehicles is not guaranteed. Apart from above mentioned constraints, there are various other challenges for developing a QoS aware routing protocol. Various issues to maintain QoS are illustrated as below.

- i) Broadcast storm problem and flooding: In order to find the desired destination, some protocols suggest blind or restricted flooding which causes congestion in the network.
- ii) Gray zone problem: Normally the farthest vehicle is selected as next hop but that vehicle may leave the network or acquire a position that is not optimal for forwarding.
- iii) Scalability: With an increase in the node density and speed of vehicles, the protocol must be scalable also.

3.2 Proposed QADD scheme

Based upon the above issues and challenges, this section illustrates the proposed QADD solution to the problems. Every node is assumed to have GPS installed to know its position. Though GPS is not accurate, the nodes exchange beacon messages in order to know their speed, direction in which they are moving and exact location. The node keeps data in Distributed Hash Table (DHT) and $\langle key, value \rangle$ pair is stored for fast searching. The repository is maintained and shared in P2P manner amongst other vehicles. The proposed solution consists of various phases such as calculation of reward-penalty, intelligent forwarding, weight calculation, construction and maintenance, which are described in detail in coming section.

3.2.1 Reward-Penalty (RP) function

The concept of reward-penalty for efficient transmission from source to destination which is used as follows.

When a new node enters into the network, the link connecting to other node is having RP value of 0.5. Vehicles exchange beacon messages while moving to know the neighbors, their location and velocity. For the vehicles within the transmission range of other vehicles, the time taken for successful delivery of hello packet determines whether vehicle gets a reward or a penalty using following function.

$$RewardFunction_{i,j} = \frac{Distance_{i,j}}{LinkSpeed_{i,j}} \quad (3.6)$$

If the Reward Function (RF) value, i.e., $RF_{i,j} \leq \zeta$, then there is a reward of 10% to current $RP_{i,j}$. If $RF_v > \zeta$, then there is a penalty of 10% to current RP_v . The next $RF_{i,j}$ is calculated after ϕ time interval and if $RF_{i,j} \leq \zeta$, there is a reward else a penalty of 10% . As the vehicles move, links will be broken and after some time RP_v for that link becomes very low. Following condition is tested for the same.

$$0 \leq RP_{i,j} \leq 1 \quad (3.7)$$

If the link persists with good speed and less distance, then $RP_{i,j}$ goes higher. According to Eq. (3.2), the $RP_{i,j}$ must be less than 1. So the $RP_{i,j}$ approaching to 0 is considered as very poor link and the link whose $RP_{i,j}$ tends to be 1 is considered reliable and trusted link for data transmission.

3.2.2 Intelligent forwarding

There are four factors on which the next link is selected.

- i) Link stability: the link must have maximum bandwidth.
- ii) Distance: The maximum distance from the destination.
- iii) Speed: The vehicle having maximum speed towards destination is given priority.
- iv) Density: the vehicle moving in more vehicle density area is given preference over vehicle moving in less dense area.

Based upon the above four parameters, calculations are defined.

$$IF_{i,j} = IF_{Max} \times \left(\frac{\alpha}{LinkStability} + \frac{\beta}{Distance} + \frac{\gamma}{Speed} + \frac{\delta}{Density} \right) \quad (3.8)$$

3.2.3 Weight calculation

The routing is done according to weight computed for each link. Each link has some RP_v as computed and has a IF as computed in Eq. (3.8). The weight for each link is directly proportional to IF and inversely proportional to RP_v . The calculation of weight for link between vertex i and vertex j is as follows:

$$Weight_{i,j} = \frac{IF_{i,j}}{RP_{i,j}} \quad (3.9)$$

Using the value of the variable in Eq. (3.9), we have sent the packets to their final destination.

3.2.4 Construction phase

Every vehicle calculates the weight of link according to Eq. (3.9). These links are exchanged by vehicles along with hello messages. When source vehicle (S) decides to transmit a message to a particular destination (D), it has the complete knowledge of the position and weights of links between vehicles. It uses the modified Dijkstra's algorithm to compute the shortest path based upon weights calculated by the $\langle Reward, IF \rangle$ value. As described in Algorithm 1, first the distance of S is assigned zero as it is the origination vehicle, rest all links are assigned very high value. All the links are added to a priority Queue Q and covered nodes are included into array u . For each adjacent vertex of v , the vehicle having minimum weight is assigned u . The combined weight of its parent in v and the weight of vertex is assigned X . If this X is less than the distance of u , then distance of u is assigned to X and parent of u is assigned to v . This process continues until destination is reached. Once destination is reached, the distance vector and parent vector are returned from which the path from source and destination is computed.

Algorithm 1 Shortest path from Source to Destination**Input:** List of Vertices (V), Source (S), Destination (D), Weight of Connecting Edges**Output:** Shortest path from S to D

```

1: distance[S] = 0
2: for (i = 0 to V - 1) do
3:   if (vi ≠ S) then
4:     distance[i] = ∞
5:     parent[i] = Null
6:   end if
7:   Create a priority Queue Q for all vertex according distance[ ]
8: end for
9: v = Extract minimum from Q
10: while (Q ≠ ∅ && v ≠ D) do
11:   Create a Queue (Q2) of adjacent vertex of v
12:   while (Q2 ≠ ∅) do
13:     u = Extract a vertex from Q2
14:     X = distance[v] + weight(u,v)
15:     if (X < distance(u)) then
16:       distance[u] = X
17:       parent[u] = v
18:     end if
19:   end while
20:   v = Extract minimum from Q
21: end while
22: return distance[ ] and parent[ ]

```

3.2.4.1 Flowchart

Flowchart for construction phase is depicted in Fig. 3.2. The procedure described for flowchart is the same as explained above for Algorithm 1.

3.2.4.2 Complexity analysis

The first phase (line number 1), i.e., for V vertices takes $\log(V)$ time.

The second phase, i.e., decrease key operation takes $O(V\log(V))$ time.

The first and second phase are in loop and are repeated for V number of vertices.

For finding distance and parent of V vertices takes $O(V)$ time.

The first phase (lines number 1-8), i.e., updating the distance and parent for all the vertices take $O(V)$ time. Line number 9 takes $O(\log(V))$ time. While loop from line 10 to 20 runs for all the vertices, i.e., V times. Line number 11 takes $O(1)$ time and it is being in while loop runs for V times. While loop from line number 12-19 again runs for V iterations. Within it is decrease key operation which takes $O(\log V)$ time. Extract minimum operation in line number 19 takes $O(\log(V))$ time, which is repeated V times as it is in while loop.

So, the total complexity of the Algorithm 1 is as follows.

$$Complexity = O(V) + O(\log(V)) + V (O(\log(V)) + O(V\log(V))) \quad (3.10)$$

$$= O(V + \log(V) + V\log(V) + V^2\log V) \quad (3.11)$$

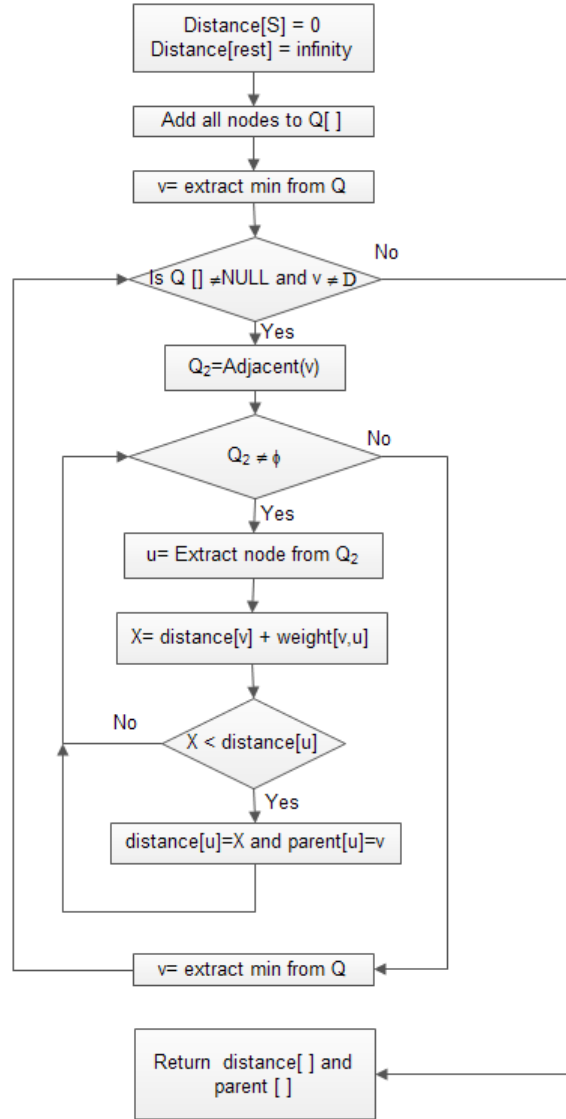


Fig. 3.2: Flowchart for Algorithm 1 of QADD scheme

as $E = V \times (V - 1)$
 $E = O(V^2)$. $O(V)$ is very small as compared to $O(V^2)$ hence neglecting it and putting the value in Eq. 3.11.

$$O(V + (V + E)(\log V)) \quad (3.12)$$

$$O((V + E)(\log V)) \quad (3.13)$$

Hence the total complexity is $O((V + E)\log V)$ as computed in Eq. 3.13.

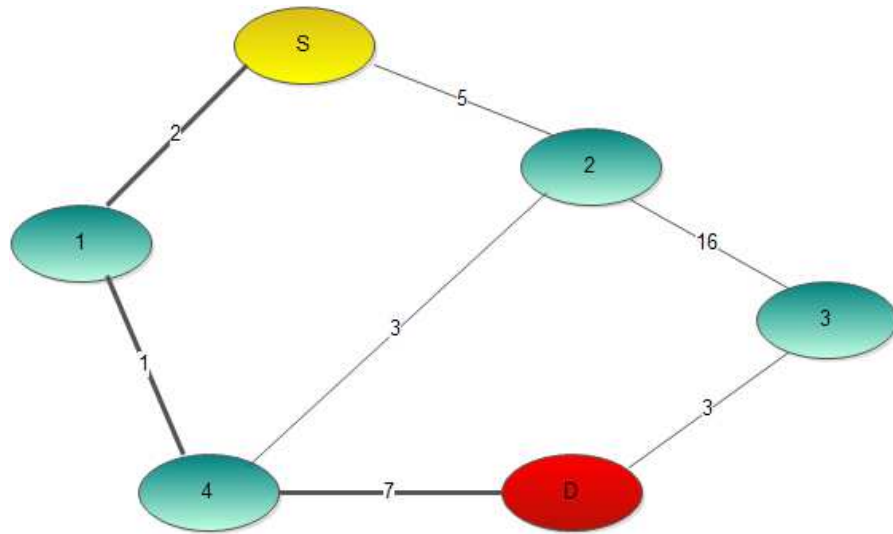


Fig. 3.3: Shortest path selection using Algorithm 1

	S	1	2	3	4	D
	0 N	∞ N	∞ N	∞ N	∞ N	∞ N
S		2 S	5 S	∞ N	∞ N	∞ N
S 1	0 N	2 S	5 S	∞ N	3 1	∞ N
S 1 4	0 N	2 S	5 S	∞ N		10 4
S 1 4 2	0 N	2 S	3 1	5 S		10 4
S 1 4 2 D	0 N	2 S	3 1	5 S	10 4	

Fig. 3.4: Calculation of shortest path selection for Fig. 3.3

3.2.4.3 Example 1

Consider a scenario shown in Fig. 3.3, where source S (marked in yellow) has to transmit message to destination D (marked in red). The weight metrics calculated according to Eq. (3.9) are marked on each edge. The step by step calculation according to Algorithm 1 is depicted in Fig. 3.4. Each node has been marked with two parameters as: its distance from source and its parent. Initially all vehicles, except source, are having distance ∞ and parent as *Null*. In second step, source distance is minimum with *Null* as its parent. The distance of other vehicles from reached vehicle, i.e., is calculated. In the third step,

vehicle 1 is having minimum distance whose parent is S. Similarly in fourth step, vehicle 4 with parent 1 and in fifth step vehicle 2 with parent as source are selected. In last step, Destination vehicle, D, is reached with distance 10 and vehicle 4 as parent. Now by calculating parent $D \rightarrow 4 \rightarrow 1 \rightarrow S$, the route is constructed.

Algorithm 2 Shortest path after link breakage

Input: Shortest path from source till node previous to (LV)

Output: Shortest path from source to destination

- 1: Calculate the shortest path from node previous to LV to destination using Algorithm 1
 - 2: ($distance_1[S, D] = distance[S, LV] + distance[LV, D]$)
 - 3: recalculate $distance_2[S, D]$ from Source using Algorithm 1
 - 4: **if** ($distance_1[S, D] < distance_2[S, D]$) **then**
 - 5: Use $distance[] = distance_1[S, D]$
 - 6: **else**
 - 7: Use $distance[] = distance_2[S, D]$
 - 8: **end if**
 - 9: return distance[]
-

3.2.5 Maintenance phase

There are two conditions that have been considered in this phase.

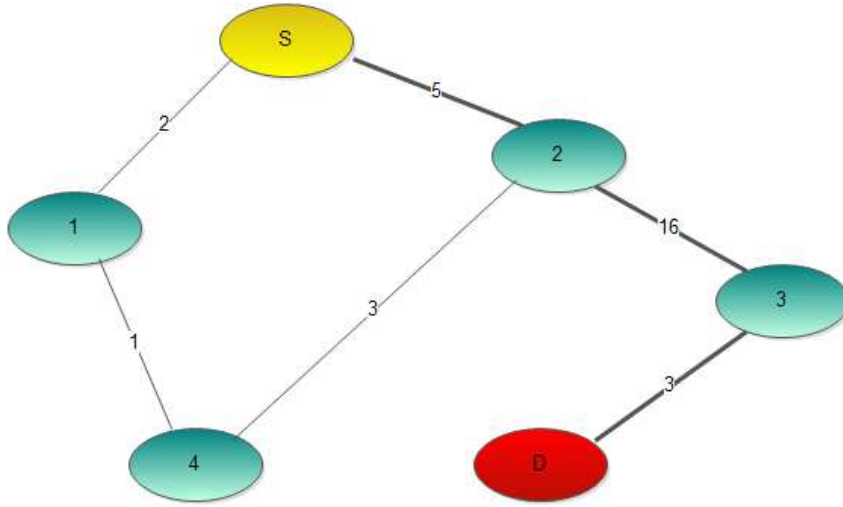
- i) When an intermediate vehicle in the shortest path leaves the network or because of any reason one link breaks.
- ii) A better path than the existing path is available.

In the first case, when an intermediate vehicle leaves the network or link breaks, the path from the source to the vehicle previous to the leaving vehicle (LV) is the shortest. The shortest path is calculated from LV to destination using Algorithm 1. It may also be possible that an alternate path from source to destination is shorter. So whichever of the two paths is shorter the packets are sent through that path. The Algorithm for the same is explained in Algorithm 2.

In second case, when there is a better path available, the source checks the optimal path after every ψ time and follows the best resultant path explained in Algorithm 3.

Algorithm 3 Updation of shortest path**Input:** Existing path $distance_{ex}[S, D]$ **Output:** Shortest path from Source and Destination

- 1: Calculate shortest path $distance_{new}[S, D]$ from Algorithm 1 after every ψ time
- 2: **if** ($distance_{new}[S, D] < distance_{ex}$) **then**
- 3: $distance[] = distance_{new}$
- 4: **else**
- 5: $distance[] = distance_{ex}$
- 6: **end if**
- 7: return distance []

**Fig. 3.5:** Shortest path selection after link breakage**3.2.5.1 Complexity analysis**

Algorithm 2 and Algorithm 3 directly use the Algorithm 1. Calculation of the complexity of Algorithm 2 is as follows.

Line number 1 uses Algorithm 1, whose complexity is already calculated in Eq. (3.13), i.e., $O((V + E)(\log V))$. Line 2 is normal assignment and takes $O(1)$ time. Line 3 again uses Algorithm 1 and its complexity is $O((V + E)(\log V))$. Line number 4 to 9 takes constant computation time. So, total complexity of Algorithm 2 is

$$Complexity = O((V + E)(\log V)) + O(1) + O((V + E)(\log V)) + 4 \times O(1) \quad (3.14)$$

$$Complexity = 2 \times O((V + E)(\log V)) + 5 \times O(1) \quad (3.15)$$

$$= O((V + E)(\log V)) \quad (3.16)$$

Calculation of complexity of Algorithm 3 is as follows.

First step takes $O((V + E)(\log V))$ time and rest all steps takes constant time. Hence, complexity of Algorithm 3 is as follows.

$$Complexity = O((V + E)(\log V)) \quad (3.17)$$

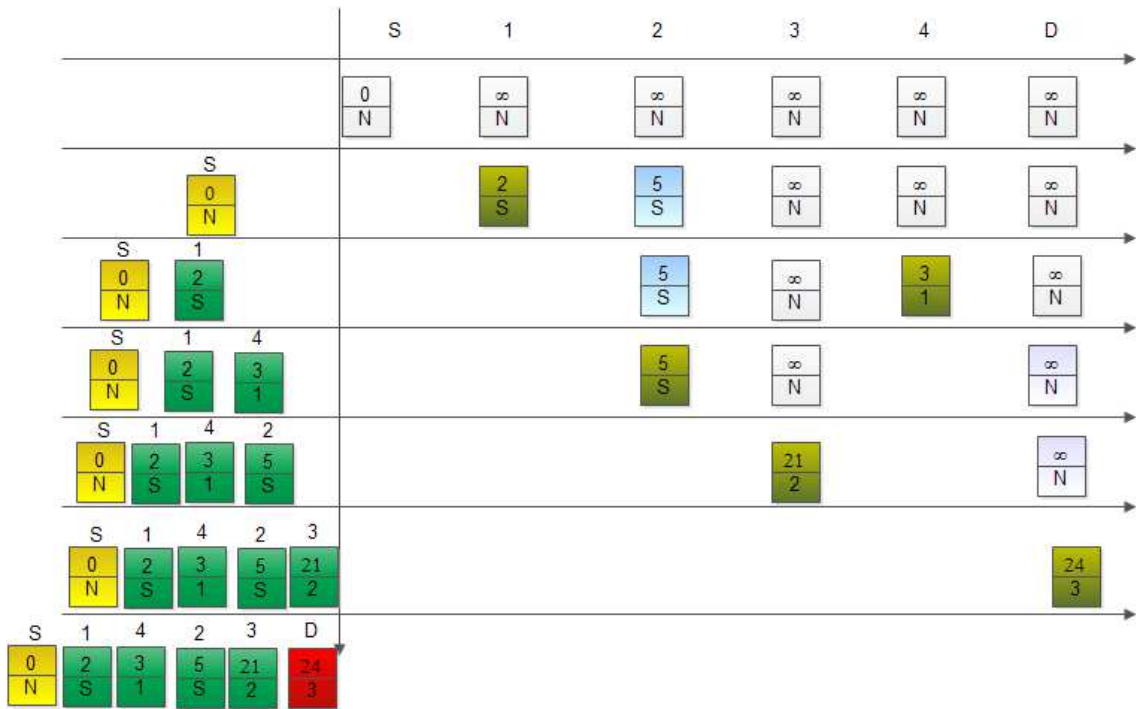


Fig. 3.6: Calculation of shortest path selection for graph used in Fig. 3.5

3.2.5.2 Example 2

The same scenario of Fig. 3.3 is taken in Fig. 3.5 but now link between 4 and D is broken. Initially, vehicle 4 finds shortest path according to Algorithm 2 and will route packet from $r \rightarrow 2 \rightarrow 3 \rightarrow D$. But on next iteration using Algorithm 3, the better path is calculated after ψ time. Rest of procedure is same as in example 1. The final parents array now are $S \rightarrow 3 \rightarrow 2 \rightarrow D$.

3.3 Performance Evaluation of QADD Scheme

This section outlines the simulation settings and discusses the results obtained after exhaustive simulations.

3.3.1 Simulation settings

To test the performance of the proposed QADD scheme, extensive simulations are done using NS2.35 [80] and SUMO [134]. The area used is roads of Patiala city of India as shown in Fig. 3.7. The map of 6 Km \times 4 Km is taken from OpenStreetMap [133] and SUMO [134] is used to generate vehicle movements. Each road is bidirectional and all major roads are having two lanes in each direction. The vehicle moves with a velocity ranging from 10 Km/hr to 100 Km/hr with a data rate of 2 Mbps. The number of vehicles in a cluster varies from 100 to 500 which takes care of both sparse and dense scenarios. There are 623 intersections and 1534 number of road segments. Each simulation runs for a total of 900 seconds. The QADD scheme is compared with DDOR [2] and SOBP [1]

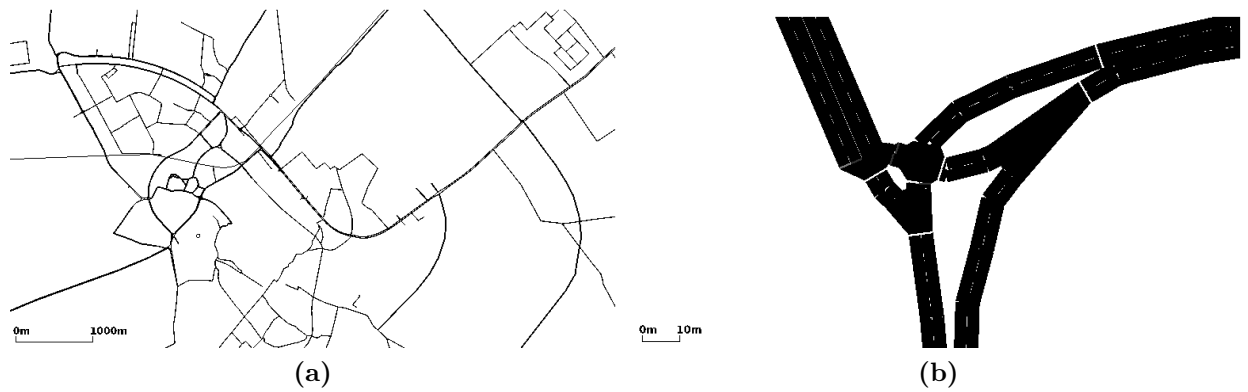


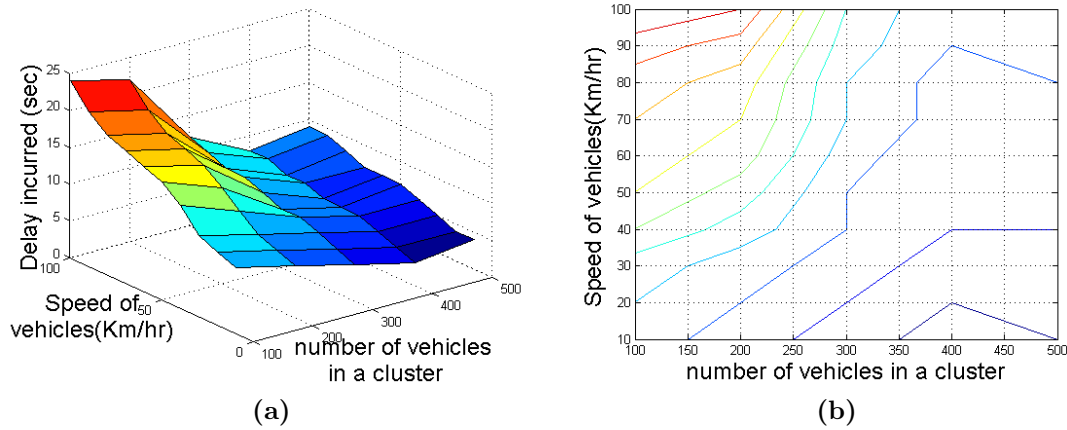
Fig. 3.7: (a) Patiala city map (b) magnified view of SUMO simulation of Patiala city map

because both of these protocols have considered similar conditions as used in the proposed QADD scheme. Following are the routing metrics against which the QADD scheme is compared and evaluated.

- i) Delay incurred: This is the amount of time a packet takes from generation at source to reception at destination.
- ii) Extra messages generated: It indicates the control messages generated which includes beacon messages and lost messages during transmission. It is calculated as difference between messages generated and useful messages received at the destination.
- iii) Percentage of active links: This parameter indicates the percentage of active links to total links during transmission.
- iv) Connectivity ratio: This parameter indicates the ratio of vehicles reachable from a particular source to the total vehicles in the network. The value ranges between 0 and 1.
- v) Optimal allocated rate: The data rate used by the vehicle for transmitting message to destination vehicle is 2 Mbps.
- vi) Medium usage ratio: This parameter indicates the fraction of total amount of medium used. The better the utility of medium, the higher the medium usage ratio.
- vii) Load on network: This parameter indicates the average load of all the links in the network. Table 3.1 describes various parameters used in the simulation.

Table 3.1: Simulation setting parameters for QADD scheme

Parameter	Value
Simulation Area	6 Km \times 4 Km
Minimum number of vehicles in cluster	50
Maximum number of vehicles in cluster	500
Minimum velocity of vehicle	10 Km/hr
Maximum velocity of vehicle	100 Km/hr
Number of intersections	623
Number of road segments	1534
Data Rate	2 Mbps
Simulation time	900 second

**Fig. 3.8:** (a) Delay incurred (b) contour representation of delay incurred

3.3.2 Results and discussion

Figs. 3.8–3.10 illustrate the variation of delay incurred, extra messages generated and percentage of active links which is measured with changing speed of vehicles and number of vehicles in a cluster. Figs. 3.11-3.12 show the comparison of SOBP [1] and DDOR [2] with the proposed QADD scheme.

3.3.2.1 Delay incurred

With an increase in speed of vehicles, delay incurred increases mainly because of frequent breakage of links and changing topology. As density increases, the delay incurred decreases showing the importance of availability of routes with better link quality. The delay incurred is as low as only 3 second when number of vehicles in a cluster is 400 and speed of vehicles is 10 Km/hr which goes as high as 24 second when the network is sparse and speed of vehicles is 100 Km/hr. The variation of delay incurred is depicted in Fig. 3.8.

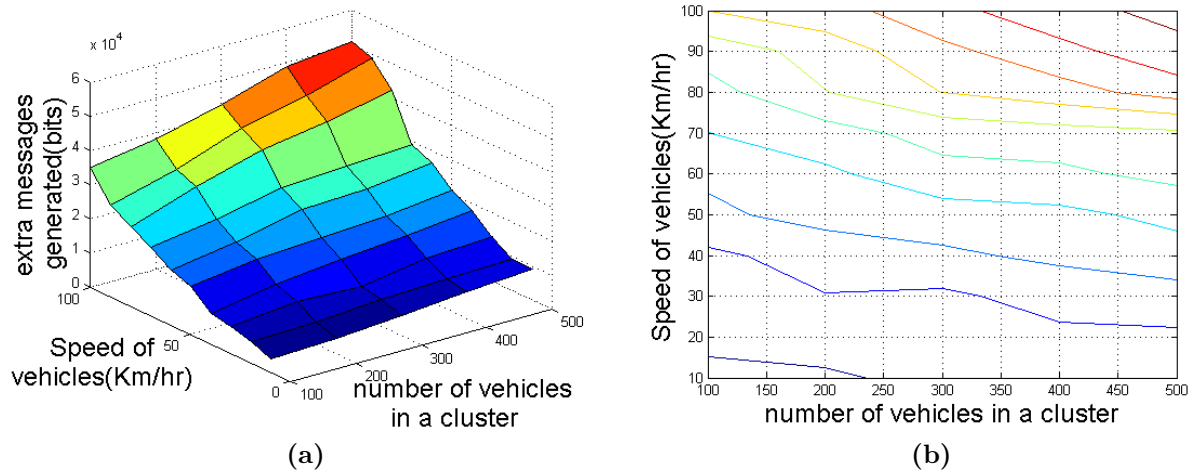


Fig. 3.9: (a) Extra messages generated (b) contour representation of extra messages generated

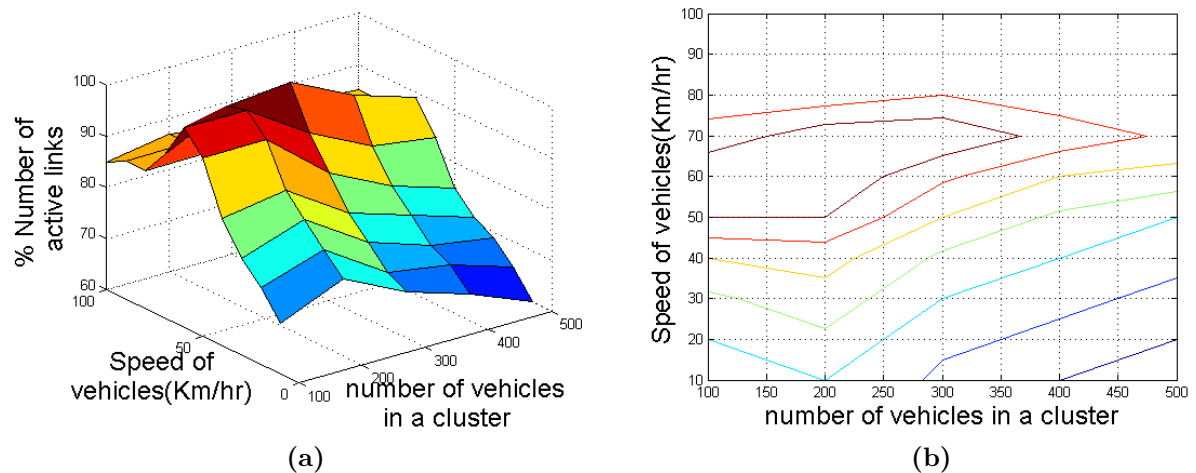


Fig. 3.10: (a) Percentage of active links (b) contour representation of Percentage of active links

3.3.2.2 Extra messages generated

Simulation results show that extra messages generated are very high in dense network with vehicles having high speed. This is because of large number of links in dense scenario and frequent breakage of links when the speed of vehicles increases. When the number of vehicles in cluster is 500 and the speed of vehicles is 100 Km/hr, the extra messages generated are of the order of 5×10^4 bits, but is as low as 4×10^3 bits when velocity and number of vehicles in cluster is low. The variation of extra messages generated with an increase in number of vehicles in a cluster and increasing speed of vehicles is shown in Fig. 3.9.

3.3.2.3 Percentage of active links

As illustrated in Fig. 3.10, the percentage of active links is low with very less number of vehicles in cluster. Since, most of the vehicles use store-carry-forward mechanism, the number of active links is low. As the speed and number of vehicles increases, the percentage of active links also increases which attains a saturation 99% at 70 Km/hr speed and 300 vehicles beyond which it again decreases because of increased turbulence in the network. Percentage of active links decreases to 85%, when there are 500 vehicles in cluster and speed is 100 Km/hr.

3.4 Comparison of QADD with SOBP and DDOR

The proposed QADD scheme is compared with existing protocols namely SOBP [1] and DDOR [2]. The results are discussed in following sections.

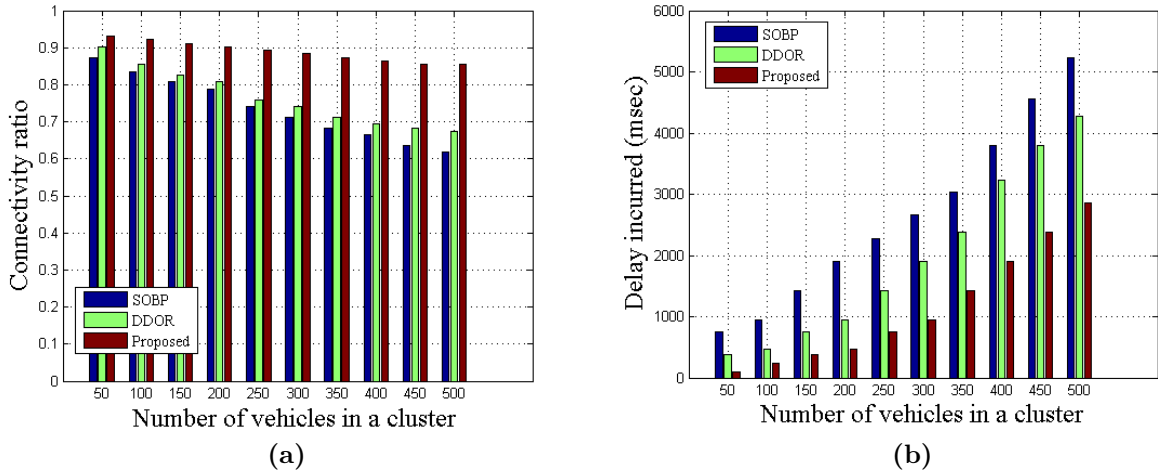


Fig. 3.11: Comparison of proposed QADD scheme with SOBP and DDOR for (a) connectivity ratio (b) delay incurred

3.4.1 Connectivity ratio and Delay incurred

Fig. 3.11 shows that with an increase in number of vehicles, connectivity ratio decreases and delay incurred increases because of frequent changes in topology and more number of link breakages. When compared with SOBP and DDOR, the proposed QADD scheme has higher connectivity ratio of 0.88 at 300 vehicles and delay incurred of 1000 ms which is better than SOBP and DDOR in the same situation. The proposed QADD scheme solves the gray zone problem. Instead of selecting the farthest vehicle, proposed QADD scheme uses newly defined metric to find the optimal path due to which the connectivity ratio increases and delay incurred decreases as shown in the figure.

3.4.2 Extra messages generated and optimal allocated rate

Extra messages generated are increased with an increase in number of vehicles in cluster because of more number of links created and beacon messages exchanged. Also, the rate

of data transfer decreases because of more interference between links which results in more number of collisions. From Fig. 3.12, it is clear that extra messages is only 94 bps and optimal allocated rate is 950 Kbps, when number of vehicles is low for proposed QADD scheme, which is a clear advantage over SOBP and DDOR under similar conditions. The broadcast storm problem is eliminated in the proposed QADD scheme as the messages are forwarded to the vehicle according to the weight of link computed. Hence, the extra messages generated in proposed QADD scheme is considerably less than the other compared protocols.

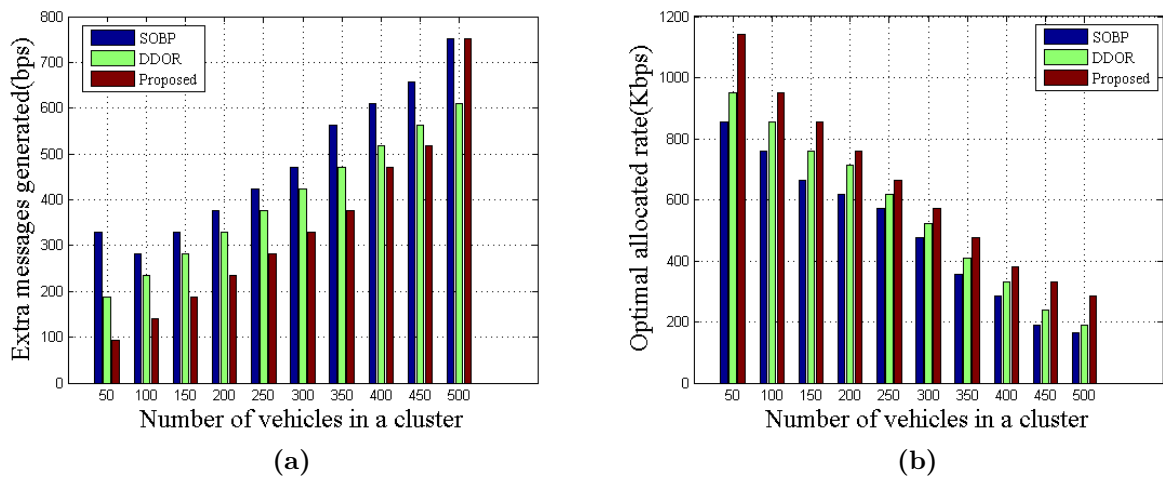


Fig. 3.12: Comparison of proposed QADD scheme with SOBP and DDOR for (a) extra messages generated (b) optimal allocated rate

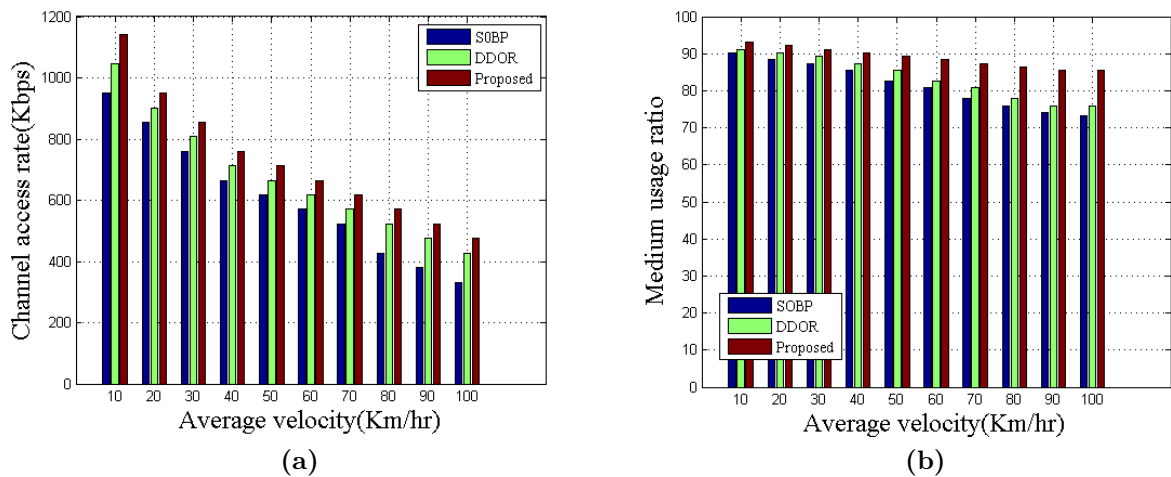


Fig. 3.13: Comparison of proposed QADD scheme with SOBP and DDOR for (a) channel access rate (b) medium usage ratio

3.4.3 Channel access rate and medium usage ratio

As shown in Fig. 3.13, it is clear that both channel access rate and medium usage ratio decreases as the average velocity increases. The proposed QADD scheme works better because of using metrics that takes link stability and speed into account before forwarding the message to next hop. Channel access rate for SOBP is 617.5 Kbps, for DDOR it is 665 Kbps while the proposed QADD scheme has channel access rate of 712.5 Kbps at 50 Km/hr average velocity. Medium usage ratio is 86% for proposed QADD scheme at 80 Km/hr average velocity but it is less than 80% for both SOBP and DDOR.

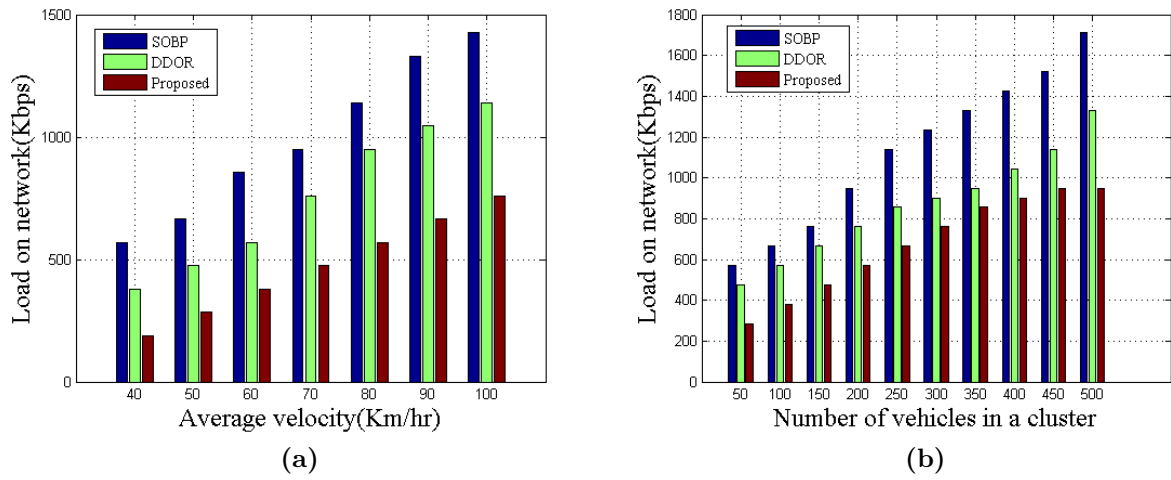


Fig. 3.14: Comparison of proposed QADD scheme with SOBP and DDOR for (a) load on the network with varying velocity (b) load on the network with increasing number of vehicles in a cluster

3.4.4 Load on network

Load on the network increases with increase in the average velocity and number of vehicles in cluster. But the load is considerably lower in the proposed QADD scheme as it uses link stability, velocity, density and distance while calculating the weight of a link for transmitting the message. The load is 1425 Kbps for SOBP and 1140 Kbps for DDOR when average velocity is 100 Km/hr which is much higher than 760 Kbps of proposed QADD scheme at similar conditions. The load of proposed QADD scheme is 950 Kbps when there are 500 vehicles in cluster but load is 1710 Kbps and 1330 Kbps for SOBP and DDOR respectively in same conditions. The variations of load on the network are illustrated in Fig. 3.14.

3.5 Summary

Although wireless technology is growing very fast, users are still demanding high data rates for most of the applications they are using especially, when they are going from one place to another. In this regard, it is a challenging task to maintain the QoS for various applications in vehicular adhoc networks (VANETs). To address this issue, a new coordinated QADD scheme for VANETs has been proposed. As the safety messages are

the most important messages in these types of networks, so to choose the best route from a source to destination, a new intelligent forwarding mechanism is proposed. Based upon this newly defined metric, new algorithms for route construction and maintenance are designed in the proposed QADD scheme. Finally, performance evaluation of the proposed QADD scheme is done using extensive simulations with respect to various metrics. The results obtained show that the proposed QADD scheme is effective in maintaining QoS, because it is faster in message delivery and reduces the load on the network.

In the next chapter, the problem of congestion in vehicular environment while disseminating the data is discussed. A solution proposed for this problem is discussed in detailed in next chapter.

Chapter 4

Context-aware Congestion Resolution

The communication between vehicles and RSU's is broadcast in nature, so everyone can listen to the messages. The drawback of this is that data can be monitored, altered and forged easily. On top of that, there is no privacy because vehicles move in an open physical space which leads to exposure of position and travel route information of vehicles. Moreover, drivers identity and license plate can also be compromised. The communication amongst vehicles is multicast in nature, though more secure, still can be manipulated and private information can be extracted. Due to the above scenarios, one of the most common issues existing in VANETs is broadcast storm problem in which source node broadcasts the packet to the destination nodes and all intermediate nodes also broadcast, resulting in heavy congestion in the network. Hence, there is a requirement of contextual aware information dissemination between different nodes in VANETs to overcome the issue of heavy congestion. Also, there may be obstacles in the medium in the form of buildings, electric lamp posts, and trees which cause the wireless signal to fade with the distance within the medium called as channel fading. Keeping in view of the above issues and challenges, a new context aware congestion resolution protocol named Minimum Calculated Desired Time (MCDT) for intelligent data dissemination in VANETs has been proposed ¹.

4.1 System Model

In this section, the components of network model, mobility model, and channel model are described.

4.1.1 Network model

There are three main components in VANET architecture: Application Units (AUs), On Board Units (OBUs) and RSUs. RSUs provide services to the moving client act like a router while OBUs and AUs are consumer to those services. The communication among

¹ The contents of the chapter are partly published in Amit Dua, Neeraj Kumar, Seema Bawa, Joel JPC Rodrigues, "An intelligent context-aware congestion resolution protocol for data dissemination in vehicular ad hoc networks," *Mobile Networks and Applications*, vol. 20, no. 2, pp. 181-200, 2015. (*Springer, IF 1.05*) (*SCI/SCIE*).

OBUs and AUs with RSUs can be done using wireless standards such as IEEE 802.11p, IEEE 802.11 a/ b/g. Vehicles can use centralized Long Term Evolution (LTE) architecture for communication where the message is passed through infrastructure node in core network. This core network would intercept the message and redistribute it to desired vehicles. This supports enhanced security but takes more time.

Vehicles have OBUs installed that can be used for providing communication amongst other OBUs or with RSUs or with AUs. OBUs have many utilities and can be used for congestion control, data collection, data processing, and IP mobility management. AUs communicate with RSUs using OBUs and provide safety applications. These may be integrated with OBUs as a single unit or may be separate units. RSUs provide communication among the vehicles using Dedicated Short Range Communication (DSRC). They can also provide communication with OBUs or other RSUs using IEEE 802.11a/b/g. Fig. 4.1 illustrates the detailed components of system model. As shown in the figure, vehicles communicate with each other using IEEE 802.11p and communicate with RSU using IEEE 802.11a/b/g. The Peak Stable(PS) Zone of each vehicle is marked with dotted circles.

IEEE 802.11b supports four different data rates, i.e., 1, 2, 5.5 and 11Mbps. IEEE 802.11a supports eight data rates from 6 to 54Mbps. IEEE 802.11a has 12 non-interfering channels and IEEE 802.11b supports three non-overlapping channels. It is assumed that each node is equipped with multiple interfaces using these standards.

4.1.2 Mobility model

The mobility model used is similar to Freeway mobility model [41]. The roads are random having 2 lanes on every path. There are N vehicles, each moving with a velocity between V_{min} and V_{max} .

$$V_{min} \leq V_i \leq V_{max}; i \in N \quad (4.1)$$

Vehicles arrive with Poisson distribution with mean request arrival rate λ . Each vehicle maintains a minimum distance d_{min} from others. Each vehicle $V_i \in N$ accelerates with probability p and de-accelerates with the same probability. The rate of acceleration and retardation is a . The vehicle moves with constant velocity with probability $1 - 2p$. If two vehicles are in same lane and are coming closer to each other with distance between them being less than d_{min} , then either of following takes place.

- i) The vehicle following de-accelerates with retardation $-a$, so that the final velocity becomes $V_i(t + 1) = V_i - at$ making sure that following holds $V_i(t + 1) \geq V_{min}$.
- ii) Either of two vehicle changes lane making sure that in other lane, the distance between two vehicles is greater than d_{min} .
- iii) Combination of above two can take place, i.e. , vehicle can change lane and also changes its velocity.

4.1.3 Channel model

There are two types of communication as V2V and V2I. Both of these can use the same channel for transmission. Hence, there is a probability of collision of messages. For communication, both the sender and receiver must be in Line of Sight (LOS). The antenna of

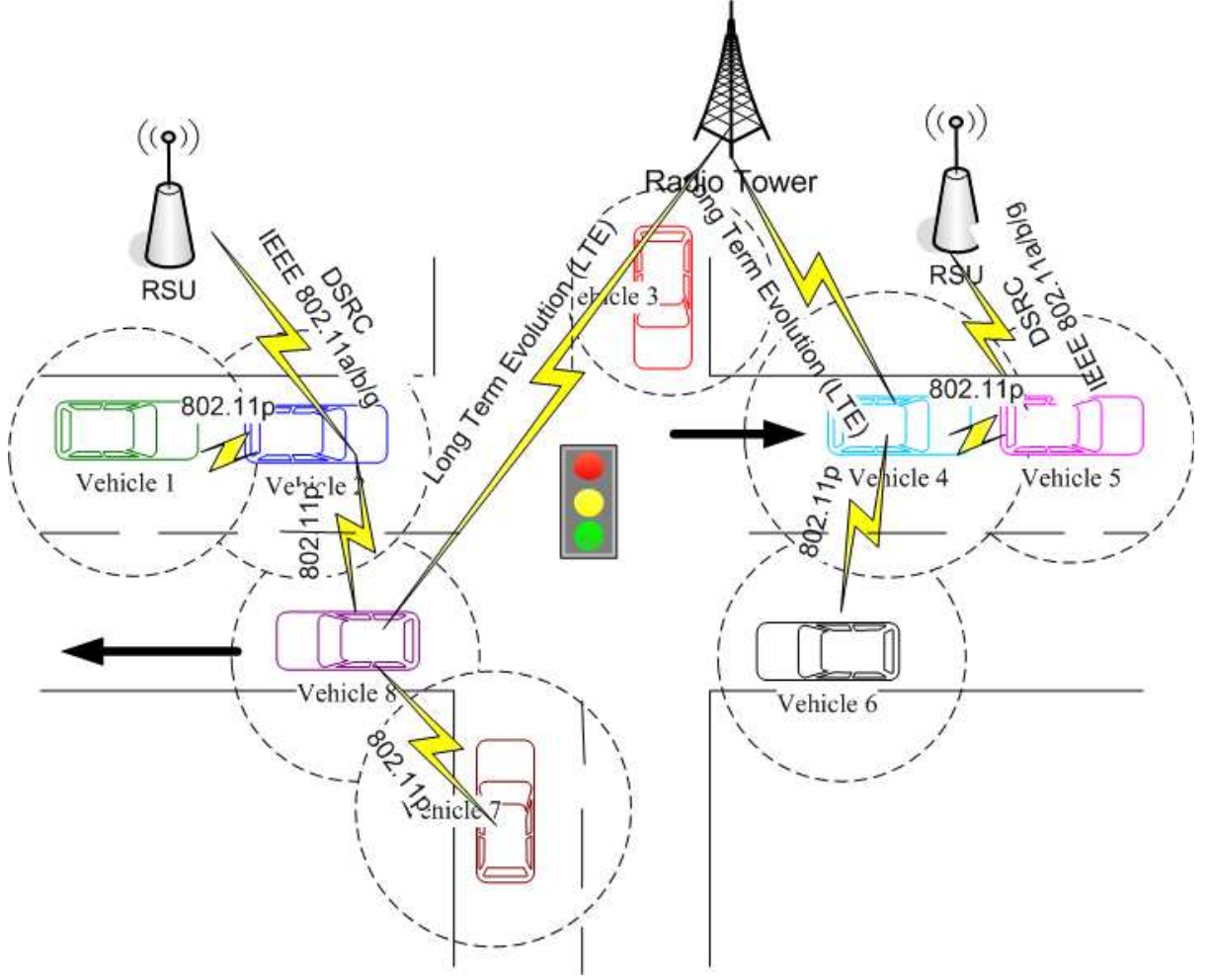


Fig. 4.1: Generalized architecture in VANETs

RSU is generally very high, ensuring that LOS exists for vehicles communicating within the range of RSU. But there is severe shadowing for communication between vehicles (in V2V type) because of which there is a great loss of signal strength, hence the communication is possible only between vehicles in Peak Stable(PS) Zone (explained in the coming sections). It is assumed that vehicles in PS Zone are in LOS of each other. Vehicles are equipped with different radio interfaces that can access different channels. Channel switching is also possible.

Time slots with size T are divided for transmission. For small scale fading, Rician model is adopted. The channel capacity (CC) between two vehicles $i, j \in N$ at slot t is as calculated in [60] as given below.

$$CC_{i,j}(t) = \begin{cases} B \log_2(1 + SNR|r|^2 d_{ij}^{-4}(t)) & \text{within PS Zone} \\ 0 & \text{otherwise} \end{cases} \quad (4.2)$$

where $CC_{i,j}$ describes the maximum data transmitted between the vehicles (i, j) in slot t , B is the channel bandwidth, SNR is signal-to-noise rate, $d_{i,j}$ is the distance between vehicles i and j and r is the Rician channel gain [160] calculated as follows.

$$r = \sqrt{\frac{k}{k+1}} e^{j\theta} + \sqrt{\frac{1}{k+1}} g \quad (4.3)$$

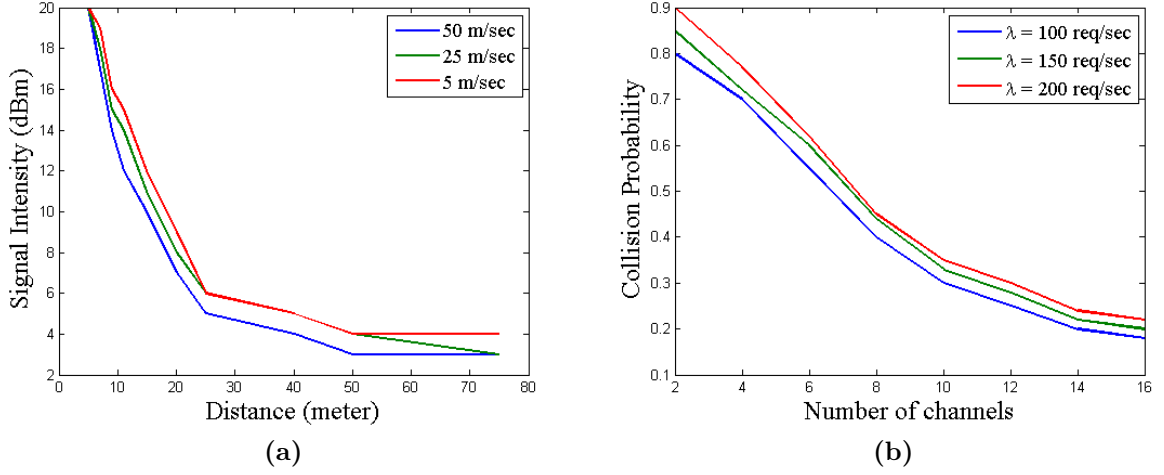


Fig. 4.2: Variation in (a) signal intensity with distance (b) collision probability with increasing number of channels

where k is the ratio of energy in the PS Zone path to the energy in the scattered paths, $\theta \in [0, 2\pi]$ is a random variable and g is a complex Gaussian random variable whose mean is 0 and variance is 1. Fig. 4.2(a) shows the variations of signal intensity with increasing distance between the vehicles. As the distance between the vehicles increases, the intensity drops down exponentially. The drop is more with higher speed. Fig. 4.2(b) shows the variation in collision probability as the number of channels increases. According to the channel model used, if the number of channels increases there is a drop in collision as messages have alternate means to reach the destination. If the requests arrival rate is high the collision is also high.

To calculate the time the $vehicle_i$ remains in PS Zone of $vehicle_s$, it is assumed that position of $vehicle_i$ is pos_x, pos_y and its velocity is vi_x, vi_y . Similarly, the position of $vehicle_s$ is P_x, P_y and velocity is vs_x, vs_y . Their relative velocity is $vi_x - vs_x, vi_y - vs_y = vel_x, vel_y$. Relative position of $vehicle_i$ with respect to $vehicle_s$ at time t is,

$$Y^2(t) = (pos_x + vel_x \times t - P_x)^2 + (pos_y + vel_y \times t - P_y)^2 \quad (4.4)$$

$$Y^2(t) = (pos_x - P_x)^2 + (vel_x \times t)^2 + 2 \times (pos_x - P_x) \times (vel_x \times t) + (pos_y - P_y)^2 + (vel_y \times t)^2 + 2 \times (pos_y - P_y) \times (vel_y \times t) \quad (4.5)$$

$$2 \times Y \frac{dY}{dt} = 2 \times vel_x^2 t dt + 2 \times (pos_x - P_x) \times vel_x + 2 \times vel_y^2 t dt + 2 \times (pos_y - P_y) \times vel_y \quad (4.6)$$

To calculate time t for which $vehicle_i$ remains in PS Zone of $vehicle_s$, is computed by

putting $\frac{dY}{dt} = 0$ in Eq. (4.6), to get

$$t = \frac{-(pos_x - P_x) \times vel_x - (pos_y - P_y) \times vel_y}{vel_x^2 + vel_y^2} \quad (4.7)$$

by differentiating Eq. (4.6) again, i.e., $\frac{d^2Y}{dt^2}$

$$\frac{d^2Y}{dt^2} = 2 \times vel_x^2 + 2 \times vel_y^2 \quad (4.8)$$

This value is positive showing that there is a minima at this point. Hence in Eq. (4.7), when the value of t is negative, it shows the vehicles are approaching towards each other otherwise, these are moving away from each other.

By putting the value of $Y(t) = Thr_s$ in Eq. (4.5), the time duration, when the vehicle s is in PS Zone to vehicle i , is achieved.

Fig. 4.3 shows that initially the message is carried in store-carry-forward way, so with increase in velocity Calculated Desired Time (CDT) marginally decreases, but as velocity further increases the CDT increases rapidly. CDT reduces significantly when the velocity increases more than 80 Km/hr because more vehicles are in PS zone.

As shown in Fig. 4.4, Link Breakage Rate (LBR) increases exponentially with an increase in velocity and density. This is due to the fact that more links are broken as topology changes with increase in velocity and density. LBR reduces with very high density as more vehicles are in PS zone and less move out of this zone.

To overcome the local minima, a five phase flexible mobility model is proposed similar to [160], in which seven phase model was proposed for Aeronautical Ad hoc Networks (AANET). In this proposal AANET has been modified for VANETs according to vehicular motion on the road. As shown in Fig. 4.5, these phases are acceleration phase, steady movement phase, deceleration phase, turn phase and pause phase.

- i) Acceleration phase: The vehicle determines a target velocity $V_A < V_{max}$ and achieves this velocity in t_A time. The acceleration of vehicle a_A is given by

$$a_A = \frac{V_A}{t_A} \quad (4.9)$$

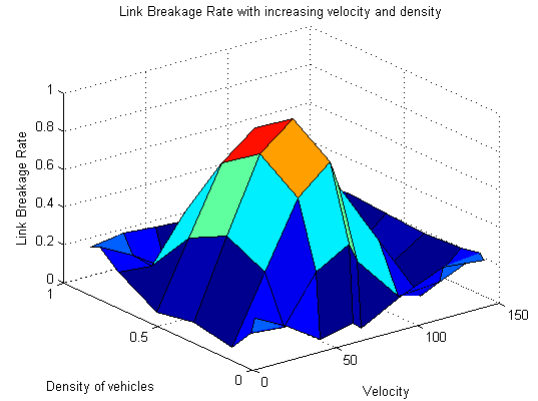
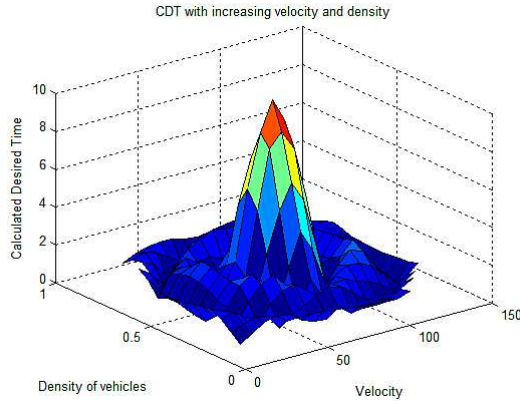


Fig. 4.3: CDT with increasing velocity and **Fig. 4.4:** LBR with increasing velocity and density

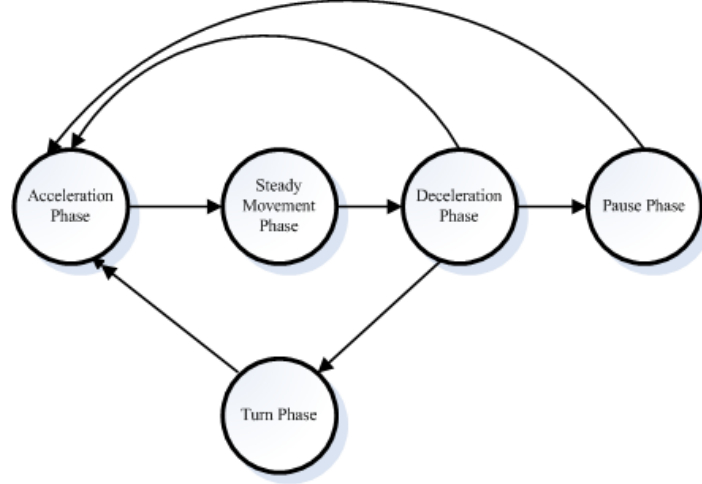


Fig. 4.5: State transition in VANETs

- ii) Steady movement phase: After achieving the target velocity, the vehicle moves at constant velocity $V_S = V_A$ for t_S time.
- iii) Deceleration phase: Before stopping or taking a turn, the vehicle reduces its speed. This phase can be categorized into two cases namely when the final velocity has some fixed value, i.e., $V_D > 0$ and when finally the vehicle intends to stop in that case it is $V_D = 0$. The vehicle takes t_D time and then accelerate with a_D .

$$a_D = \frac{V_D - V_S}{t_D} \quad (4.10)$$

After this phase either vehicle takes turn or accelerates again.

- iv) Turn phase: In Manhattan network, all the crossings are at 90 degrees but in practical scenario, sometimes the vehicle has to turn at some angle θ_T .
- v) Pause phase: The vehicle stops for time t_P before going to Acceleration phase again. The pause may take very long time $t_P \rightarrow \infty$, if the destination has been reached.

IEEE 802.11b supports four different data rates, i.e., 1,2,5.5 and 11Mbps. IEEE 802.11a supports eight data rates from 6 to 54Mbps. Different links have different lengths and have different channels available. For each link, total throughput is

$$Thr_{Total} = \sum_{i=1}^K Thr_i \quad (4.11)$$

Balanced Throughput is calculated by multiplying total throughput with Fairness Index (FI) as calculated in [161].

$$F.I. = \frac{(\sum_{i=1}^K Thr_i)^2}{K \times \sum_{i=1}^K (Thr_i)^2} \quad (4.12)$$

$$Thr_{Bal} = Thr_{Total} \times F.I. \quad (4.13)$$

Better the Balanced Throughput, better is the quality of the link using different channels. By using the Thr_{Bal} and Length of the path (L), CDT is computed as follows.

$$CDT = \frac{L}{Thr_{Bal}} \quad (4.14)$$

Lower CDT is desirable for the link upto the next node. It is assumed that the link lies in PS Zone of the sending node and $VC = 0$. If $VC \neq 0$, then

$$CDT = CDT_{VC} + \frac{Distance_{VC}}{Speed_{VC}} \quad (4.15)$$

where $CDT_{VC} = CDT$ till the vehicle where $VC = 0$ and $Distance_{VC}$ is the distance from that vehicle till the nearest vehicle and $Speed_{VC}$ is speed of the carrying vehicle.

When the source node desires to send any message, it calculates the CDT to not only the nearest nodes but to the destination including the intermediate nodes from all possible paths. Hence, it can be defined as:

$$CDT_{Total} = \sum CDT_i \quad \forall i \in (1, k) \quad (4.16)$$

where k is the number of vehicles on that path from source to destination.

4.2 Proposed MCDT scheme

The proposed minimum calculated desired time (MCDT) scheme is divided into four phases as: construction phase, maintenance phase, message transmission and recovery phase. These are discussed in detail in the following sections.

4.2.1 Construction phase

This phase describes that how the construction of tree is done in the proposed MCDT scheme. Packets will be lost if signal strength is not good. This is due to environmental factors like obstacles, noise and wireless interferences [162]. Different vehicles have different signal strength. So, in the proposed scheme, based on signal strengths, three zones are considered. Liu *et al.* [69] also used the concept of ZoR but they neither classify them and nor used signal strength for construction of different zones. There are two thresholds $Thrs_1$ and $Thrs_2$. If the signal strength received from vehicle is greater than $Thrs_1$, the vehicles are classified in Peak Stable (PS) Zone. On the other hand, if the signal received is equal to or less than $Thrs_1$ but is greater than $Thrs_2$ and vehicles are approaching the receiving vehicle, then these are classified to be in More Stable (MS) Zone. Lastly, if the source vehicle is going away and its change in signal strength is greater than threshold μ , then the vehicles are in Small Stable (SS) Zone, otherwise the vehicles are in unstable zone. The detailed mechanism is presented in Algorithm 4.

A road segment is multihop connected if it contains sufficient number of vehicles and forward the packets from one end of road segment to the other end. Virtual Connectivity (VC) is the number of road segments between destination and closest vehicle to destination that can be reached from source through multihop transmission. Lesser the VC, more is connectivity within that road segment. The vehicle at destination intersection is at $VC=0$, if there are vehicles in PS Zone till the destination, i.e., there is proper connectivity till

Algorithm 4 Calculation of Link Stability

Inputs: $e_{ij}, SS_{cum_i}, DSS_j$ **Output:** Zone for e_{ij}

```

1: if ( $SS_{cum_i} > Thr_{s1}$ ) then
2:    $e_{ij}$  is Peak Stable
3: else
4:   if ( $(SS_{cum_i} > Thr_{s2})$ ) then
5:     if  $DSS_j > 0$  then
6:        $e_{ij}$  is More Stable
7:     else
8:       if  $DSS_j > \mu$  then
9:          $e_{ij}$  is Small Stable
10:      end if
11:    end if
12:  end if
13: end if
14:  $e_{ij}$  is Unstable
15: Return  $e_{ij}$ 

```

destination. If not, the algorithm checks the vehicle at one hop from destination, its VC = 1. If there is a vehicle within PS Zone of vehicle having VC = 0, that vehicles VC also becomes 0 otherwise if it is in PS Zone of vehicle having VC = 1, its VC becomes 1. If no vehicle is nearer to current vehicle within the PS Zone to the destination intersection its VC is equal to the number of hops to reach destination intersection. The VC_{source} is the minimum hops that it had to traverse to reach destination if it is not fully connected. If the road is fully connected and there are vehicles all the way through, $VC_{source} = 0$. The pseudo code for the calculation of VC is presented in Algorithm 5. Authors in [163] have also used a similar concept to calculate the connectivity which they called virtual distance, but they have calculated the distance till nearest intersection by taking predefined transmission range of each vehicle. Later case is not practical as each vehicle has its own transmission range. The calculation till intersection is not sufficient when the distance till destination can be considered, as all vehicles know about other vehicles in their PS zone as described in next section.

4.2.2 Maintenance phase

A Special Beacon Message (SBM) is a message transferred from one vehicle to another vehicle. By SBM, vehicle knows which vehicle has moved out of PS Zone or which vehicle has entered PS Zone. All the SBMs received by $Vehicle_i$ are stored in SBM Database $SBMD_i$. A SBM is exchanged regularly but immediately disseminated under following circumstances.

- i) A vehicle moves from PS zone to MS or SS zone.
- ii) A new vehicle appears in PS range.

A SBM has 5 attributes: $Vehicle_{id}$: position; velocity; PS zone radius and time. Authors in [163] have also used a similar method where they have exchanged report which

Algorithm 5 Calculation of VC**Inputs:** Vehicle in PS Zone from source to destination**Output:** VC_{source}

```

1: if ( $Vehicle_i$  is at throughout connected to destination) then
2:    $VC_i = 0$ 
3: else
4:   if ( $Vehicle_i$  is at one hop from destination) then
5:      $VC_i = 1$ 
6:   else
7:     if ( $Vehicle_i$  is at two hop from destination) then
8:        $VC_i = 2$ 
9:     end if
10:  end if
11: end if
12: if ( $Vehicle_j$  is in PS Zone of  $Vehicle_i$  and closer to destination ) then
13:    $VC_j = VC_i$ 
14: end if
15: if ( $Vehicle_k$  is in Peak Stable Zone of  $Vehicle_j$  and closer to destination) then
16:    $VC_k = VC_j$ 
17: end if
18: Process continues till vehicle at source
19: Return  $VC_{source}$ 

```

has parameters: $vid, loc_x, loc_y, vel_x, vel_y, t$. The proposed approach is different, as [164] did not take PS Zone radius into consideration while transmitting report. This PS zone radius is important in calculating the number of vehicles in communicating radius in future as described here. By knowing the current movement of $vehicle_i$ and its PS zone radius from $SBMD_i$, its future movement can be predicted [7]. It can be predicted till how long the $vehicle_i$ will remain connected.

4.2.3 Message transmission

For transmitting the message from source to destination, it is assumed that vehicles are equipped with GPS and through constant exchange of SBM, the position of source and destination is known. Following attributes are considered for transmission.

- i) The path having minimum CDT_{Total} is chosen.
- ii) The route having minimum VC is to be used.
- iii) The route having maximum vehicles in PS Zone is considered. if the vehicles are not in MS Zone, then SS Zone is considered.

For message transmission, following objective must be met

$$\min \left(CDT_{Total} = (VC + 1)^\alpha \times (E2ED)^\beta \times \left(\frac{100}{PDR} \right)^\gamma + \phi \right) \quad (4.17)$$

when minimum CDT is taken, the value of VC and E2ED will be minimized and PDR will be maximized. The flowchart depicting the working of MCDT scheme is presented in Fig. 4.6.

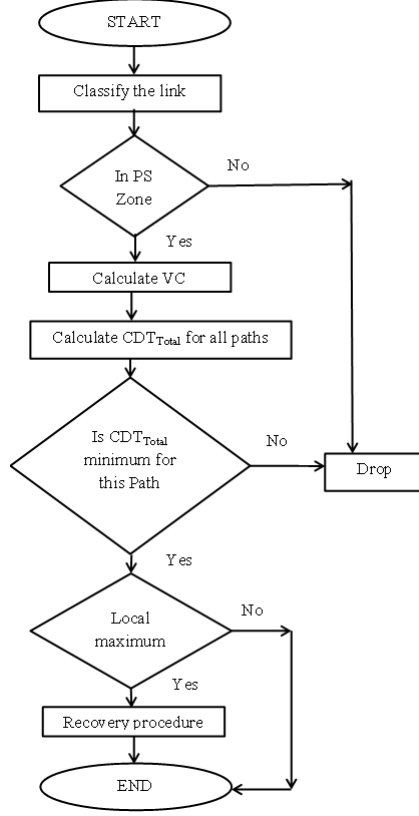


Fig. 4.6: Flowchart of proposed MCDT scheme

4.2.4 Recovery by minimum angle method

S = Node at local maxima or at link breakage

D = destination vehicle

$N_i \in \{N_1, N_2, N_3 \dots N_K\}$ are vehicles in PS Zone. If D is in South direction to S , take West direction as reference to calculate the angle difference between $\angle SD$ and $\angle N_i$, otherwise take East direction as reference. The vehicle for which this angle is minimum is selected as node for recovery. Tsiachris *et al.* [3] also considered minimum angle method for recovery but when the vehicle is in South direction to source, then their recovery procedure was not suitable for VANETs. This error is removed in proposed MCDT scheme by taking reference as West direction when the destination in South direction.

As shown in Fig. 4.7, the destination is in South direction to source, hence West direction must be taken as a reference. $\angle SD$ comes out to be 60. $\angle SN_2 = 25$, $\angle SN_3 = 70$ and $\angle SN_4 = 105$. N_1 is not in PS zone so, it is not taken into consideration. From above discussion, it is evident that $|\angle SD - \angle SN_3| = 10$ which is minimum. Hence, vehicle N_3 must be the next node.

4.2.5 Flowchart

As shown in Fig. 4.6, first of all there is classification of links in PS, MS, SS and Unstable. If the link is in PS Zone, then calculate the VC (Virtual Connectivity) and CDT_{Total} . If the CDT_{Total} is minimum for this path, then start transmission on this path. In case there is local maximum, Start recovery according to Algorithm 6. Continue the procedure till the topology changes or there is no more message to transmit.

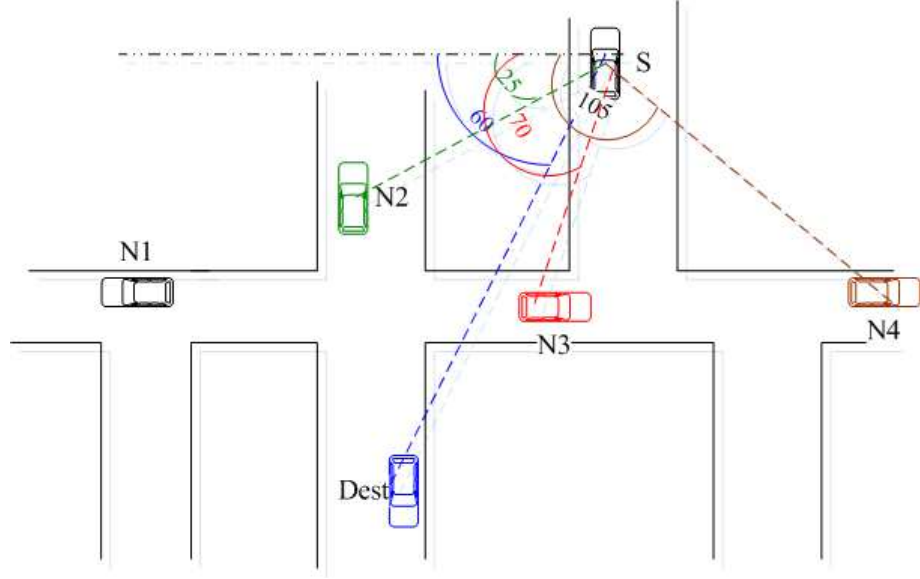


Fig. 4.7: Angles of various vehicles from source with East Direction as reference

Algorithm 6 Recovery algorithm

Input: Direction of S , D and vehicles in range of S

Output: Vehicle N_i to transfer message

- 1: Calculate angle between S and D.
 - 2: **if** D is in East, North or West Direction to S **then**
 - 3: take East as reference direction
 - 4: **else**
 - 5: **if** (D is in South Direction to S) **then**
 - 6: take West as reference direction
 - 7: **end if**
 - 8: **end if**
 - 9: Calculate $\angle SN_i \forall N_i$ in PS Zone of S
 - 10: Calculate $\angle Diff_{N_i} = |\angle SD - \angle SN_i|$
 - 11: return N_i for which $\angle Diff_{N_i}$ is minimum
-

4.2.6 An illustrative example

In Fig. 4.8, there are three paths available from source to destination. First, there is calculation of CDT for one hop. As shown in 4.8(a), the CDT of A is 5, CDT of P is 4 and CDT of L is 6. The first choice would be to transmit packet to P whose CDT is minimum, i.e., 4. But before transmitting, the second hop CDT is calculated. Then CDT is calculated for third hop and so on till all the paths are exploited. Path 1, i.e., Src-A-B-Dest has $CDT_{Total} = 8$, Path 2, i.e., Src-P-Q-Dest has $CDT_{Total} = 11$ and Path 3, i.e., Src-L-M-N-Dest has $CDT_{Total} = 17$. So Path 1 having minimum CDT_{Total} is the best path amongst the three.

Algorithm 7 Efficient data dissemination procedure

- 1: Calculate Vehicles in PS Zone
- 2: Calculate connectivity to destination
- 3: Calculate Thr_{Total} and Thr_{Bal} from eqn (11) and (13)
- 4: Calculate CDT_{Total} for various paths
- 5: Choose the path with minimum CDT_{Total}
- 6: In case of link breakage or local maximum follow recovery

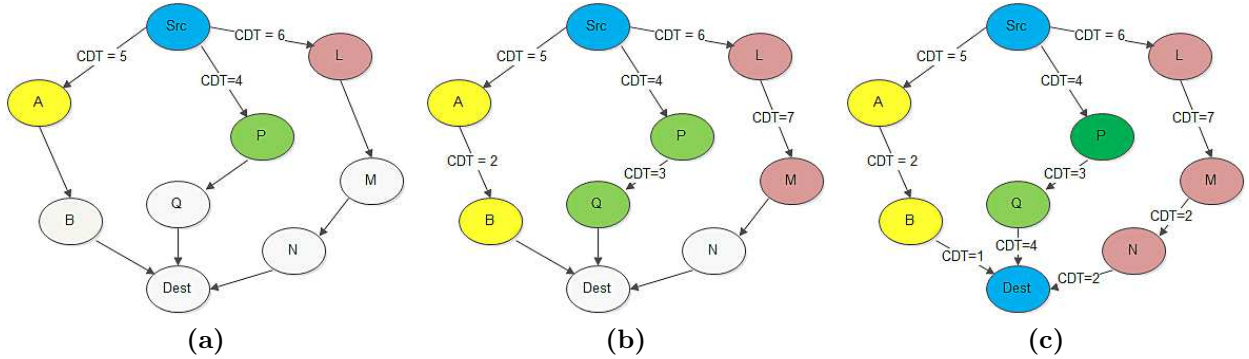


Fig. 4.8: CDT from source to destination through intermediate vehicles

4.2.7 Algorithm complexity

In Algorithm 4, there are three checks to calculate the zone. In the best case it takes $O(1)$. Because there are constant number of comparisons which take fixed time, in the worst case it takes $O(1)$ for each vehicle.

For Algorithm 5, the vehicles have to calculate the VC starting from destination and moving towards the source. The complexity varies from the number of intermediate vehicles in PS Zone hop by hop from source to destination. It takes $O(1)$ time for each vehicle.

$$Complexity = O(1) + O(1) + \dots + O(1)$$

$$Complexity = O(n)$$

where n is the number of intermediate vehicles.

In Algorithm 6, to calculate recovery, there is a need to calculate the angle for each vehicle which takes $O(n)$ time. Then comparison with destination also takes $O(n)$ time. In total, the Algorithm takes $O(n)$ time.

Algorithm 7, Step 1 takes $O(1)$ time, step 2 takes $O(n)$ time. For calculating threshold in step 4, constant amount of time is consumed. To calculate CDT, time taken will be the number of vehicles in each path which again is of $O(n)$. Step 5 also takes $O(n)$ time and step 6 takes $O(n)$ time as calculated in Algorithm 6. Hence,

$$TotalComplexity = O(1) + O(n) + O(1) + O(n) + O(n) + O(n)$$

$$TotalComplexity = O(n)$$

4.2.8 Overhead analysis

MCDT is well suited for both sparse as well as dense networks because the implementation enables the efficient utilization of bandwidth and helps in increasing the success rate of message transmission. MCDT is efficient even where all the vehicle are not connected

**Fig. 4.9:** Patiala city map**Table 4.1:** Simulation setting parameters for MCDT scheme

Parameter	Value
Simulation Area	3Km × 3Km
Number of road segments	2854
Number of intersections	974
Number of lanes	4
Number of vehicles	100–500
Velocity of vehicles	10-100 Kmph
Data rate	2 Mbps
Periodic Beacon Interval	1–3 second
Simulation time	700 second

to each other or to RSU. Overhead depends on the number of vehicles and assumes that RSU deployment is sparse.

Scalability of MCDT can be established from the fact that with increase in service requests the overhead remains just $O(n)$.

Lemma 1: The message overhead of MCDT in worst case is $O(n)$.

Proof: For calculating the zones, hello messages are exchanged and vehicles come to know the intensity of messages from nearby vehicles. Then, these are classified into different zones. For construction phase, message overhead is $O(n)$.

For calculating the VC, control messages are exchanged whose number is directly proportional to number of vehicles. For calculating VC, message overhead is $O(n)$.

For calculating CDT, the overall path's CDT has to be found out. This has to be done for all the paths possible from source to destination. For traversing the tree from top to bottom, the best case is $O(\log(n))$ and worst case is $O(n)$. Hence, the worst case message overhead is $O(n)$.

Calculating the error recovery node requires only few messages to be exchanged whose number is directly proportional to n^χ , where $0 < \chi < 1$. The message overhead is $O(n^\chi)$. Overall message overhead in worst case is

$$O(n) + O(n) + O(n) + O(n^\chi) = O(n). \quad (4.18)$$

4.3 Performance Evaluation of MCDT Scheme

This section evaluates the performance of the proposed scheme in comparison with the other schemes with respect to various metrics such as PDR, E2ED and Routing Overhead. The results are compared by varying beacon intervals.

4.3.1 Simulation settings

The implementation is done in NS-2.35 [80] simulator in Ubuntu 12. The simulation area is 3 Km \times 3 Km with 4 lanes. The minimum velocity considered is 10 Km/hr and gradually increments to 100 Km/hr with step size of 10 Km/hr. The number of vehicles varies from 100 to 500. The data rate of 2Mbps is utilized with beacon interval varying from 1 second to 3 second. For each simulation scenario, 50 iterations were performed and average was taken. In simulation, Patiala city map is used which is illustrated in Fig. 4.9. Table 4.1 lists various parameters. Following parameters are chosen for result analysis.

- i) PDR (%): It is the ratio of total number of packets received at the destination to the total number of packets generated by the source.
- ii) Average E2ED: It is average time taken for each received packet.
- iii) Routing overhead: It signifies the total number of routing packets in the entire simulation period.

4.3.2 Results and discussion

Figs. 4.10 and 4.11 illustrate the variations in PDR, E2ED and routing overhead over variable velocity and number of vehicles.

4.3.2.1 PDR

In Fig. 4.10(a)-(c), the PDR of proposed MCDT protocol is calculated by varying the speed and number of nodes. Fig. 4.10(a)-(c) demonstrate PDR with beacon intervals of 1, 2 and 3 second respectively. Initially the PDR is low as there are not enough nodes that can propagate the message. The messages are mostly propagated with store-carry-forward technique where there is heavy loss hence we have observed low PDR. As the velocity of nodes increases, the PDR increases and reaches its maximum at speed of 60 Kmph. Then, PDR decreases slightly because of overheads and fast changing topology and comes to a stable value of 90 %. With an increase in beacon interval, the PDR is improved by constant factor.

4.3.2.2 E2ED

Fig. 4.10(d)-4.10(f) shows the variation of E2ED with increasing velocity and number of vehicles. When the velocity is low and number of vehicles is less, then E2ED is very high because the communication is mainly in store-carry-forward way. For beacon interval of 1 second, when velocity is 10 Km/hr and 100 vehicles, the E2ED is 25 ms. As the number of vehicles increases the E2ED decreases but there is limit to it. When the number of vehicles is 350 the E2ED is 5 ms. This value increases and becomes stable to 8 ms with

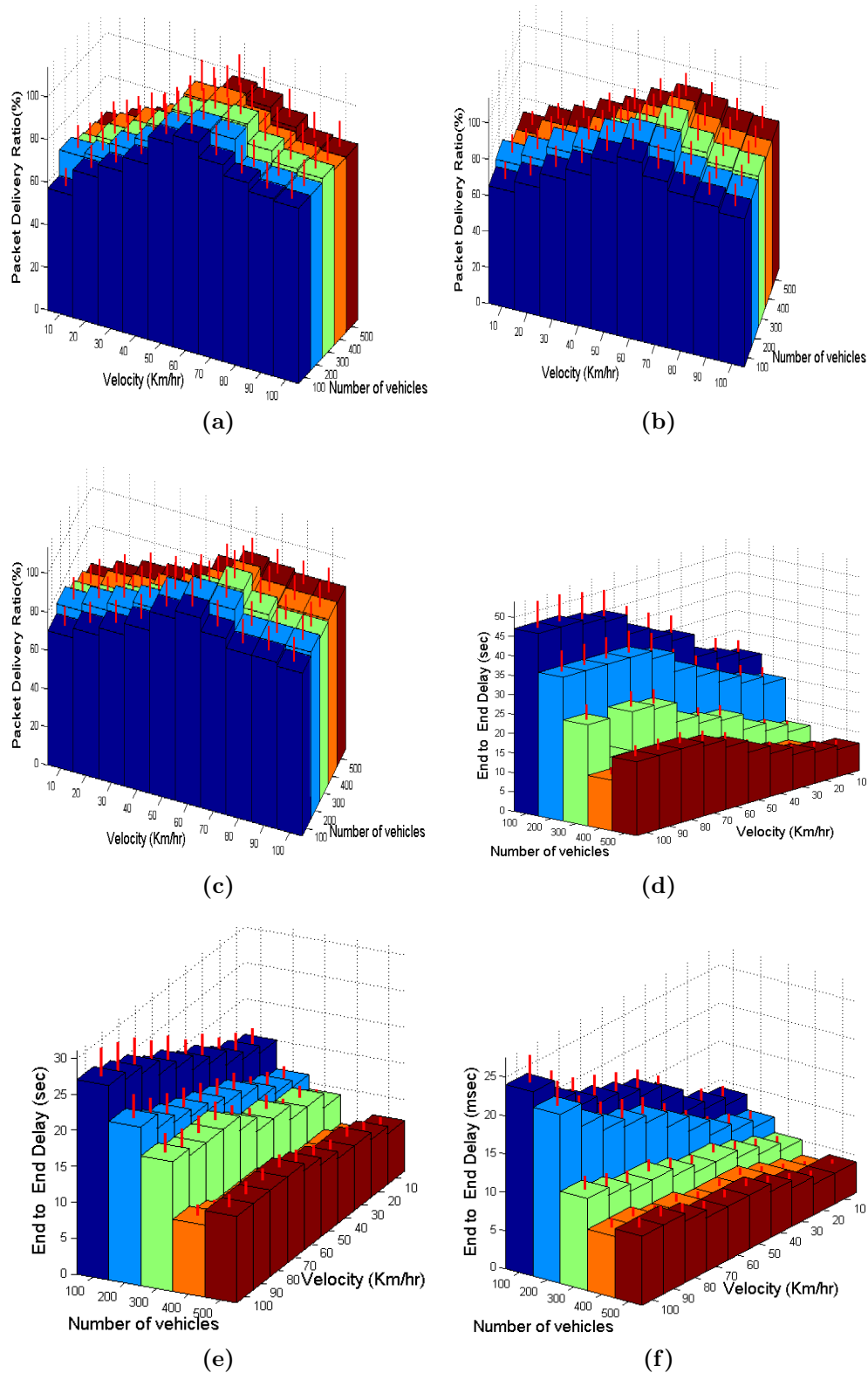


Fig. 4.10: (a) PDR of MCDDT with beacon interval of 1 second (b)PDR of MCDDT with beacon interval of 2 second (c)PDR of MCDDT with beacon interval of 3 second (d)E2ED of MCDDT with beacon interval of 1 second (e)E2ED of MCDDT with beacon interval of 2 second (f)E2ED of MCDDT with beacon interval of 3 second

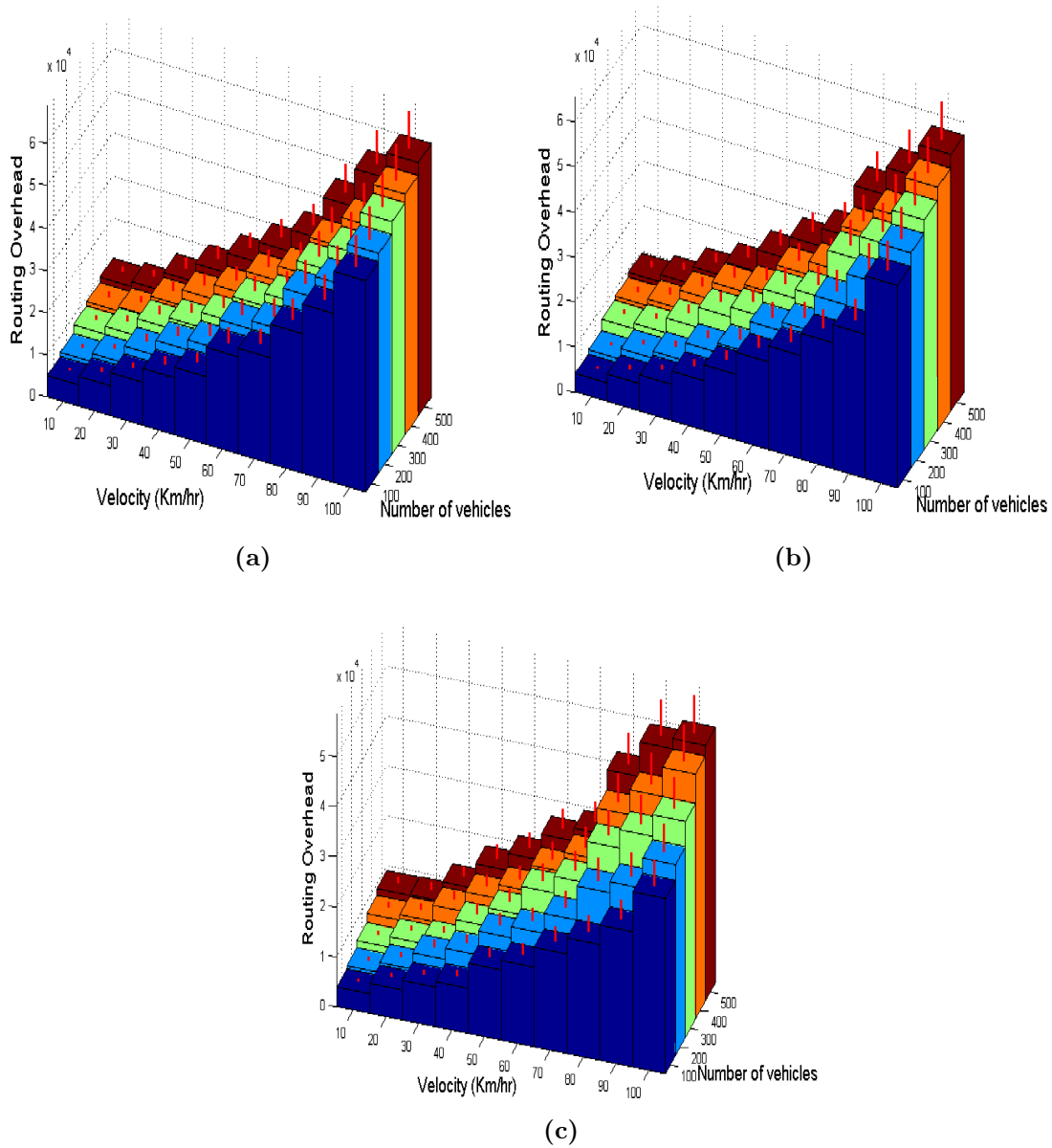


Fig. 4.11: (a) Routing overhead of MCDT with beacon interval of 1 second (b) Routing overhead of MCDT with beacon interval of 2 second (c) Routing overhead of MCDT with beacon interval of 3 second

further increase in number of vehicles. As beacon interval increases from 1 to 2 second, the E2ED reduces which further reduces on increasing the beacon interval to 3 second. The congestion due to regular exchange of beacon interval reduces which results a decrease in E2ED. E2ED is 3 ms when beacon interval is 3 second and number of vehicles is 400.

4.3.2.3 Routing overhead

As is clear from Fig. 4.11 that routing overhead keeps on increasing with increase in velocity and number of vehicles. The increase is because of an increase in number of messages exchanged. The value of routing overhead though decreases when the beacon interval increases as shown in Fig. 4.11(b, c). The overhead is 39000 bits for 300 vehicles at velocity of 80 Km/hr when the beacon interval is 1 second but keeping rest same the value decreases to 37878 bits for beacon interval of 2 second and to 35090 bits when the beacon interval increases to 3 second.

4.4 Comparison of MCDT with GyTAR and A-STAR

The proposed MCDT is compared with existing protocols namely GyTAR [4] and A-STAR [5]. The results obtained are shown in Fig. 4.12.

4.4.1 Probability and delay

With an increase in density of vehicles, the probability of successful transmission decreases. The decrease is much higher in GyTAR and A-STAR as compared to MCDT. As shown in Fig. 4.12(a), when the density of vehicles is 300, the probability of MCDT is 0.93 where as that of GyTAR and A-STAR are 0.75 and 0.78 respectively. This is mainly because of the fact that the channel diversity considered in A-STAR is single while the multi-channel diversity is used in MCDT which reduces the chances of collision. The average probability for MCDT is 0.936 and there is an improvement of 15.54 % as compared to other protocols examined. The delay in content distribution increases exponentially with an increase in density in case of GyTAR and A-STAR, but, the delay growth is linear in MCDT as shown in Fig. 4.12(b). With an increase in number of vehicles, the control messages exchanged increases hence there is an increase in delay. The delay is 4 second in case of GyTAR, when the density is 400 nodes. At same parameters the delay is 3.40 second for A-STAR but for MCDT delay is just 2 second. This is because MCDT calculates the best path out of many paths based on CDT value and transmits messages only through the best bath. Unnecessary messages are prevented and best route is chosen, hence the delay is least.

4.4.2 Average content distribution rate and overhead

Fig. 4.12 (c) shows the variation in content distribution rate with increase in density. The distribution rate is highest for MCDT. When the density is 100, the content distribution rate is 800 Kbps for GyTAR, 900 Kbps for A-STAR and 1000 Kbps for MCDT. Multi-channel diversity is used for MCDT whereas other schemes used a single channel. There is an improvement of 18% in content distribution of MCDT as compared to others. The overhead increases with an increase in density of vehicles. This is because as the packets

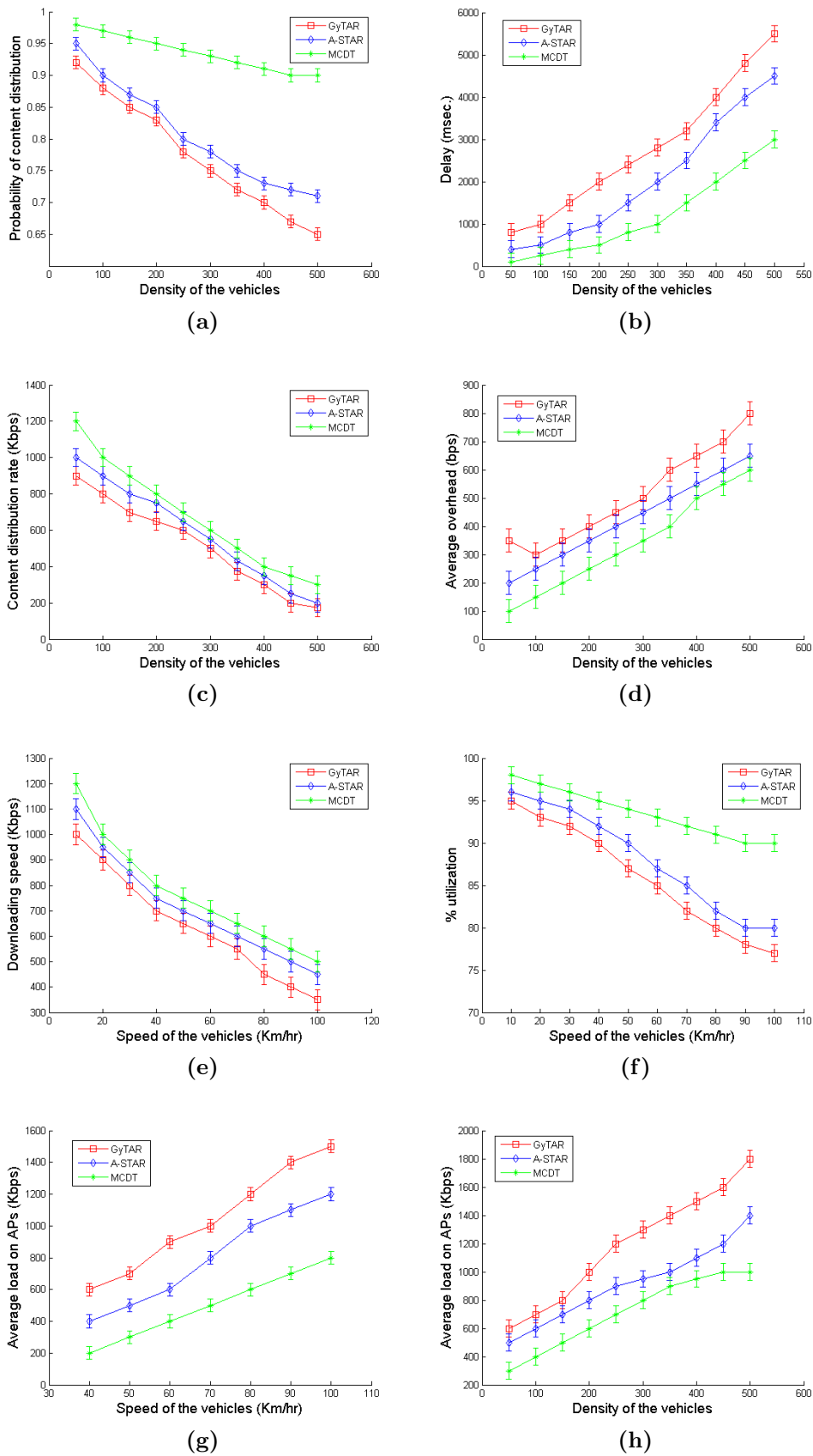


Fig. 4.12: (a) Probability of successful transmissions (b) Delay in content distribution (ms) (c) Average content distribution rate (d) Average overhead generated (e) Downloading Speed (f) Percentage utilization of resources for content distribution (g) Average load with speed of the vehicles (h) Average load with density of the vehicles

exchanged increases, the bandwidth consumption increases and there are more errors while delivering messages with an increase in number of vehicles. As illustrated in Fig. 4.12(d), the overhead for 250 vehicle density is 450 bps, 400 bps and 300 bps for GyTAR, A-STAR and MCDT respectively. The error recovery in rest of protocols is partial, i.e., there are still chances of loops or failures but the error recovery in MCDT is complete. Also, the bandwidth consumption does not increase so high because of use of multi-channel diversity in MCDT. There is a decrease in overhead of 16% in MCDT as compared to other schemes evaluated.

4.4.3 Downloading Speed and resource utilization

The download speed reduces with an increase in speed of vehicles. This is due to fact that there are frequent link breakages with an increase in speed. Also, the destination and intermediate vehicles change positions making the download speed lesser. The download speed is highest for MCDT because the path chosen for transfer has highest link speed and the multi-channels are used for transfer. From Fig. 4.12(e), it is clear that at speed 80 Km/hr, the download speed is 450, 550 and 600 for GyTAR, A-STAR and MCDT respectively which verifies the better performance of MCDT. The performance of MCDT is 11.75% better for download speed as compared to other schemes. From Fig. 4.12(f), it is evident that the percentage resource utilization of MCDT is highest and the difference between MCDT and other schemes keeps on increasing with an increase in velocity. This is because of earlier detection of best route and use of best error recovery mechanism. When the velocity is 80 Km/hr, the percentage utilization is 80% for GyTAR, 82% for A-STAR and 91% for MCDT. The resource utilization is improved by 7% in MCDT as compared to other protocols examined here.

4.4.4 Average load

With an increase in speed, the average load increases, but this increase is much more in GyTAR and A-STAR as compared to MCDT. From Fig. 4.12(g), it is clear that the speed of vehicles is 70 Km/hr and the load is 1000 Kbps for GyTAR and 800 Kbps for A-STAR, but it is only 500 Kbps for MCDT. This is due to the fact that multi-channels are used for MCDT and best path is chosen based on least CDT value at the earliest, resulting in least load. Average load increases with increase in density. From Fig. 4.12(h), it is evident that the average load is least for MCDT. It is because with an increase in density, the overhead of exchanging messages and overhead due to loss of packets is least in MCDT. With increasing density, there is an improvement of 47% in average load of MCDT as compared to others.

Table 4.2 shows the comparative analysis of various schemes and percent improvement in the proposed scheme as compared to other schemes of its category.

Table 4.2: Performance comparison of MCDT with GyTAR and A-STAR

	GyTAR [4]	A-STAR [5]	Proposed MCDT	
			Actual Value	Improvement(%)
Probability	0.775	0.806	0.936	15.54
Delay	2800	2060	1205	90
Content Distribution	520	588	675	18
Overhead	510	425	360	16
Download Speed	640	710	765	11.75
Percentage utilization	85.9	88.1	93.6	7
Load with speed	1042	800	500	84
Load with density	1190	915	715	47

4.5 Summary

With the evolution of Internet and related technologies, Vehicular Adhoc Networks (VANETs) have been used in wide areas of applications for collecting and processing the contextual data. But due to high velocity and sparse distribution of vehicles on the road, routing of this collected data to the final destination is one of the core issues which needs special attention. Keeping it in the view, a new intelligent scheme named MCDT has been proposed for processing the contextual data with varying the velocity and density of the vehicles on the road. The proposed MCDT scheme is evaluated with respect to various performance metrics in comparison to the other state-of-the-art existing schemes. The results obtained show that the proposed scheme performs better than the other schemes on the parameters studied.

In the next chapter, the protocol that aims to overcome the broadcast storm problem has been presented.

Chapter 5

Reliability-aware Intelligent Data Dissemination

The urgency of communication is an important property of VANETs for which flooding is the most commonly used technique. The communication in VANETs is achieved by the usage of shared wireless medium. If the safety messages are flooded blindly in the medium, they may collide with one another and may result in the packet drop. This phenomenon may cause contention and large bandwidth consumption which ultimately leads to reduced PDR and increased delay. This problem is named as the Broadcast Storm problem. A common practical scenario of the dense network is shown in Fig. 5.1 (a,b), where flooding occurs for transmitted messages. Fig. 5.1 (a,b) show that there is 20% drop in PDR, and an increase in delay by six times due to broadcast storm problem ¹.

For communication of safety messages, an efficient data dissemination to the vehicles is required in VANETs. But, lack of proper routing measures leads to broadcast storm problem. Millions of lives could be saved if the emergency messages are reached to the driver on time. In a study [92], it has been found that 60% of road accidents could have been avoided, had the driver got the warning information at least half a second prior to the collision. So, there is requirement of efficient techniques to mitigate the broadcast storm problem.

Game theory has been used in various fields to solve the real-time problems [165–167]. The solutions to real-life problems can be designed efficiently using game theoretic approach. In this proposal, the concept of game theory is used to form different coalitions among the players. The concept of coalition has also been used in VANETs in past [168]. Using the game theory, calculations are performed based on which the coalition amongst vehicles is formed. The coalition formation depends on the movement of vehicles at different relative velocity, acceleration, etc. The next node is selected based on the Dijkstra algorithm using the intelligent algorithm as described in Section 5.2.8. The time to exchange messages among vehicles in coalition can be reduced to a great extent which increases the ratio of successful packets delivered with reduced delay.

In the past, many researchers have used geographical information, and zone formation to mitigate the broadcast storm problem. In the Reliability-aware Intelligent Data Dis-

¹The contents of the chapter are partly published in Amit Dua, Neeraj Kumar, Seema Bawa, “ReIDD: Reliability-aware Intelligent Data Dissemination Protocol for Broadcast Storm Problem in Vehicular Ad Hoc Networks,” *Telecommunication Systems*, In Press. DOI 10.1007/s11235-016-0184-0. (*Springer, IF 0.705 (SCI/SCIE)*)

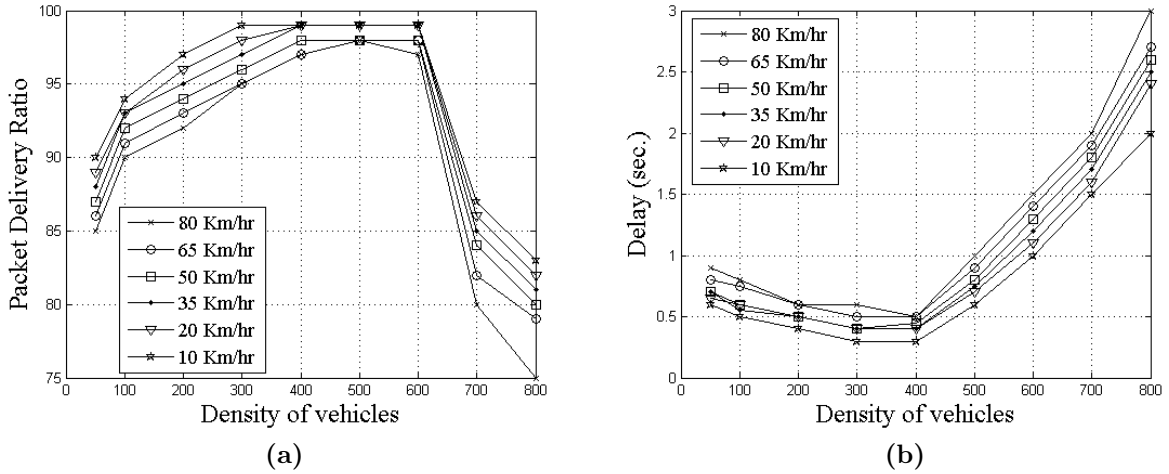


Fig. 5.1: (a) Variation in PDR with increasing density and varying velocity (b) Delay in communication with increasing density and varying velocity

semination (ReIDD), an intelligent approach has been used to address the broadcast storm problem by computing the reliability of routing the messages to their final destination.

5.1 System Model

This section illustrates the mobility model, application of game theory, reliability service model, problem formulation, and the constraints. Brief description of scenario used in the network model is as follows.

Each vehicle is having an AU, and OBU which is necessary for communication amongst each other and for interaction with RSU. Hybrid scenario is considered where vehicles can communicate with each other and with RSU. The RSUs themselves are interconnected. There are n types of vehicles and the classification is based on communication range, storage, and computation capabilities. In the network model considered, n as two, consisting of ordinary cars having moderate communication range with less storage and computational capabilities, is used. The other types of vehicles are relay vehicles, which consist of buses, trucks, and other heavy vehicles that have large storage and very high computational capability. These relay vehicles can offer assistance in storage and information retrieval. Inter-vehicle communication takes place using the IEEE 802.11p wireless standard. RSUs are deployed at regular interval and these RSUs are connected to one another using LTE and wired/wireless communication techniques. Fig. 5.2 shows the network model used here.

5.1.1 Mobility model

The vehicles are considered to be moving randomly in the network and following the free-way mobility model. It is assumed that vehicles are having location determination devices like GPS installed on them. Vehicles enter the network according to Poisson distribution and inter-arrival time varies according to exponential distribution. The movement of vehicles is restricted by the rules of the road. Each vehicle must be within the permissible

speed limits.

$$V_{min} \leq v_i \leq V_{max} \tag{5.1}$$

The roads are having multiple lanes and each lane has its permissible speed limits. The vehicle retards and takes appropriate lane before taking a turn. The initial and final speeds of vehicles must be within the permissible speed limits according to Eq. (5.1). The vehicles that are having common interests form a cluster. The election of cluster head is similar to ALCA [169]. The maintenance and expansion of cluster is explained in proposed work in Section 5.2. As the vehicles communicate amongst themselves, their reliability increases and they form a resource center where a particular type of request can be served by any vehicle within that cluster. The information about the clusters and their interests are known to the RSU within whose proximity the cluster head falls. As the RSUs are interconnected, they virtually have knowledge about different clusters that may or may not be within their direct range.

$$v_{ifinal} = v_{iinitial} - ret \times t \tag{5.2}$$

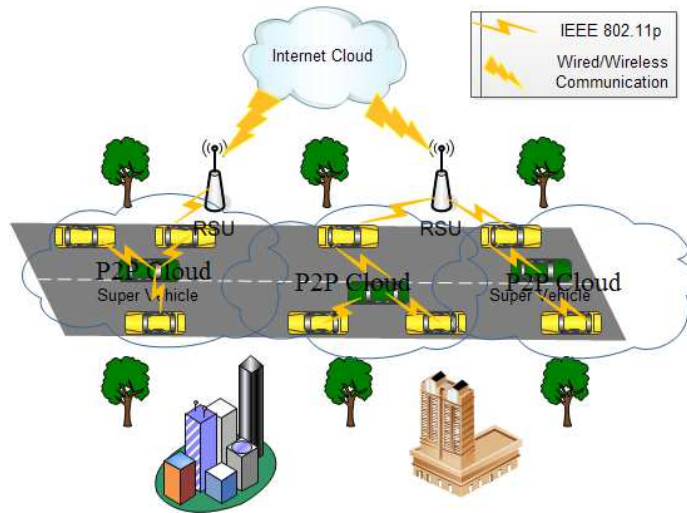


Fig. 5.2: Network model used

5.1.2 Application of Game Theory

The game theory has wide applicability and has been used for data dissemination in the proposed work. There are three main components in game theory namely-players, strategy space, and actions. In the proposed scheme, vehicles are the players. The payoffs of the players depend upon the actions of the players. In the proposed scheme, there are three factors based on which the initial payoff is calculated. These factors are communication range, storage resources and computation power. The payoff of the players is updated regularly based upon the reliability calculations. The actions of the players affect the reliability and in-turn their payoffs. These actions are their relative speed, relative acceleration and angle. Based upon the movement, the reliability and

in-turn the payoffs are updated according to which the clusters/coalitions are formed. These coalitions make it easier to exchange the messages between the vehicles within the coalition. Examples 1, 2, and 3 illustrate the initial payoff calculation, updation of the payoff and formation of coalitions based on the payoff of the players.

5.1.3 Reliability service model

A number of reliability service models are described in literature. To increase accuracy of approximation a Monte Carlo based reliability model [170] and two cellular automata based models [171] were presented. The time and energy spent in recalculations for analysis of reliability could be reduced. To increase the accuracy, k-terminal reliability problem was solved and simulation time was reduced [172]. Monte Carlo based approximation method was extended to mobile networks [173, 174]. Based on the techniques proposed [174] for calculation of reliability, real-time parameters viz. the velocity, acceleration and distance are used in this proposal, the ReIDD scheme.

The vehicles in the network have high mobility, but still there exists a pattern according to which they move. Different vehicles approaching the same destination have common resource requirements. This fact can be utilized to serve other vehicles that demand similar services. These vehicles can form a cluster and satisfy the needs of not only cluster members but also the other vehicles. If a request is not satisfied within the cluster, vehicles can approach the cluster head and the RSU. RSU has the knowledge about the cluster that can satisfy the request. The objective of the proposed scheme is to maximize PDR, and to minimize the Request Time (RT)

$$\xi^{obj} = (\max(PDR), \min(RT))$$

with respect to the constraints listed below.

$$\left\{ \begin{array}{l} V_{min} \leq V_i \leq V_{max} \\ d \geq d_{min} \\ R_N \leq R_R \\ Ret_i \geq k \times (V_{min} - V_i) \times (V_{min} + V_i) \\ Acc_i \leq k \times (V_{max} - V_i) \times (V_{max} + V_i) \end{array} \right. \quad (5.3)$$

The constrains defined in Eq. (5.3) are as follows. The velocity of vehicles is limited within the maximum and minimum values. The distance between vehicles must be greater than minimum permissible limit. Transmission range of normal vehicle is less than the transmission range of relay vehicles. Moreover, minimum retardation must be greater than threshold value and maximum acceleration must not exceed the limits. These limits are subject to different road conditions.

$$Acceleration_i = \frac{V_i^2 - U_i^2}{2d} \quad (5.4)$$

$$Acc_i \propto (V_{max} - U_i)(V_{max} + U_i) \quad (5.5)$$

$$Ret_i \propto (V_{min} - U_i)(V_{min} + U_i) \quad (5.6)$$

As the minimum distance is limited hence, the value of acceleration and retardation is also constrained. These values are specified in Eq. (5.3).

5.2 Proposed ReIDD scheme

The proposed ReIDD scheme consists of following phases-setting of the game, calculating the payoff and weight, updating the beliefs of the players, and intelligent data dissemination.

In normal scenario, there are different types of vehicles moving on road. They differ in communication range, storage capacity, and computation power. We have broadly classified the vehicles in two categories-The first is the normal vehicle including cars and other vehicles that have average communication range, storage and other attributes. The other category is of heavy vehicles or relay vehicles like buses, trucks, and commercial vehicles with higher computation power, and range. These vehicles are considered as the relay nodes in the networks. The normal and relay vehicles are considered as the players in the game.

5.2.1 Setting the game

Various vehicles which are assumed as the players in the game move according to Poisson distribution and inter-arrival time is distributed according to exponential distribution. Different players form clusters among themselves. This enhances their service time and helps them for data dissemination. Players can change their coalition dynamically, and there is addition and deletion of new member in coalition. For each member in coalition, payoff is calculated based on various factors as discussed in following Section.

5.2.2 Calculating the Payoff of the players

The payoff of the vehicles can be calculated according to three parameters.

- i) Maximum communication range
- ii) Storage resources
- iii) Computation power

For vehicle i , the payoff can be calculated according to the Eq. (5.7)

$$\mu_i = \alpha \times Range_i + \beta \times Storage_i + \gamma \times CP_i \quad (5.7)$$

where, μ_i is the payoff and CP_i is the Computation Power of $vehicle_i$.

Distributed Hash Table (DHT) has been used for storing the payoffs of the players (vehicles). The values of payoffs are hashed and sorted in ascending order in the DHT. In this scheme the vehicle with the highest payoff is returned and selected for calculation of reliability, the selection of next node, and further computations.

5.2.2.1 Example 1

In practical scenario, the computation power is measured in Million Instructions Per Second (MIPS). Normal vehicle can compute two MIPS and relay vehicles can perform 10 MIPS. The maximum communication range of normal, and relay vehicles is 300 meters and 500 meters respectively. Their storage is of the order of 2×10^{30} bytes, and 32×10^{30} bytes

respectively. After randomly selecting the value of α, β and γ as 2000^{-1} , $(100 \times 2^{30})^{-1}$ and 50^{-1} , we get the value of μ_i from Eq. (5.7), as follows.

$$\begin{aligned} \mu_N &= 2000^{-1} \times 300 + (100 \times 2^{30})^{-1} \times 2 \\ &\quad + 50^{-1} \times 2 \end{aligned} \tag{5.8}$$

$$\mu_N = 0.21 \tag{5.9}$$

$$\begin{aligned} \mu_R &= 2000^{-1} \times 500 + (100 \times 2^{30})^{-1} \times 32 \\ &\quad + 50^{-1} \times 10 \end{aligned} \tag{5.10}$$

$$\mu_R = 0.77 \tag{5.11}$$

μ_N comes out to be 0.21 and μ_R gives 0.77 value where μ_N, μ_R is the payoff for normal and relay vehicles respectively.

5.2.3 Weight calculation

Whenever any vehicle enters the network, its initial payoff is calculated according to Eq. (5.7). Soon after it begins communicating with other vehicles and starts exchanging hello messages. Based on these hello messages, it estimates the distance, relative speed, acceleration, and angle with the other vehicles. These parameters at any time determine the weight of the link between two vehicles. The parameters for computing the weight are as follows.

- i) Distance (D)
- ii) Relative Speed (RS)
- iii) Relative Acceleration (RA)
- iv) Angle (AG)

The weight at a particular time t , i.e., W_t is calculated according to Eq. (5.12)

$$W_t = D_t \times k_1 + RS_t \times k_2 + RA_t \times k_3 + AG_t \times k_4 \tag{5.12}$$

It is to be noted that the higher value of D, RS, RA, AG denotes more turbulence or weaker connection which is undesirable. So, k_1, k_2, k_3 , and k_4 are considered the constants that take into account the turbulence and forms the weight that gives exact reflection of type of link.

5.2.4 Reliability calculation

Another important factor used in the proposed scheme is the reliability of the link. The initial value of reliability is calculated in Eq. (5.13)

$$R_t = 1 - W_t \tag{5.13}$$

The value of R_t is computed in the Algorithm 8 as follows. The vehicles exchange hello messages at regular interval. The vehicle expects a message after every ϕ unit of time. If the message is received in time, the value of reliability is increased by a constant k_5 .

Algorithm 8 Value of R_t

```

1: calculate  $weight_t$  of  $link_{i,j}$  according to (5.12)
2: if ( $weight_{i,j} > 1$ ) then
3:    $R_t = 0$ 
4: else
5:    $R_t = 1 - weight_t$ 
6: end if
7: Return  $R_t$ 

```

Otherwise, it is reduced by same constant value k_5 . The final value of reliability at time t , R_t is computed in Eq. (5.14)

$$R_t = \begin{cases} R_{t-1} + k_5 & \text{if } Message_{success} \\ R_{t-1} - k_5 & \text{if } Message_{failure} \end{cases} \quad (5.14)$$

The reliability value exists between 0 and 1. If it crosses the limit, the crossing limit is considered the final value as described in Eq. (5.16).

$$0 \leq R_t \leq 1 \quad (5.15)$$

$$R_t = \begin{cases} 0 & \text{if } R_t < 0 \\ 1 & \text{if } R_t > 1 \\ R_t & \text{otherwise} \end{cases} \quad (5.16)$$

5.2.5 Belief update

The vehicle forms a belief for the other vehicle based on the reliability value and wight of the link. When hello packet is received in time, the reliability is increased. Otherwise, its value is decreased as explained earlier. The belief is calculated by updating the payoff value according to Eq. (5.17)

$$\mu_{t+1} = \mu_t + \left[\frac{R_{t+1} - R_t}{R_t} \times |1 - W_{t+1}| \right]. \quad (5.17)$$

The payoff at time $t + 1$ depends upon the payoff at time t . It also depends upon the variation in reliability and current weight of the link. If there is an increase in reliability, the payoff also increases.

The equilibrium is achieved after few steps as the payoff value for a link increases or decreases. The final value depends upon the reliability and weight calculation for the link. The stable value is close to either 0 or 1 which suggests that equilibrium has been attained.

5.2.5.1 Example 2

Initially, the distance (D) between two vehicles is 200 meters, their relative speed (RS) is 10 Km/hr, relative acceleration (RA) is 10 Km/hr^2 , and the angle (AG) between them is 25 degrees. The values of k_1, k_2, k_3, k_4 as 0.0033, 0.01, 0.00003, 0.00278 respectively are

used for calculations.

$$\begin{aligned} W_t &= 200 \times 0.66 + 10 \times 0.10 \\ &\quad + 25 \times 0.07 + 10 \times 0.003 \\ W_t &= 0.8303 \end{aligned} \tag{5.18}$$

$$\begin{aligned} R_t &= 1 - W_t \\ &= 0.17 \end{aligned} \tag{5.19}$$

Using these values in Eq. (5.12), the value of weight (W_t) computed is 0.8303. Using Eq. (5.13), the initial value of Reliability R_t is 0.17. After some time either the vehicles move closer to each other or move away. In first scenario, the distance between them reduces to 150 meters and in second scenario the distance increases to 250 meters.

$$\begin{aligned} W_t &= 150 \times 0.66 + 10 \times 0.10 \\ &\quad + 25 \times 0.07 + 10 \times 0.003 \\ W_t &= 0.6703 \end{aligned} \tag{5.20}$$

$$R_t = 0.33 \tag{5.21}$$

Considering rest of the parameters same, value of weight decreases to 0.6703 in first case and increases to above 1, i.e., 1.02 in second case signifying the instability of the link.

$$\begin{aligned} W_t &= 250 \times 0.66 + 10 \times 0.10 \\ &\quad + 25 \times 0.07 + 10 \times 0.003 \\ W_t &= 1.02 \end{aligned} \tag{5.22}$$

$$R_t = 0 \tag{5.23}$$

The above calculations verify the Eq. (5.12) and the analysis discussed above.

5.2.6 Cluster/Coalition formation

When a vehicle enters the network and has same interests as of the cluster members, it communicates with the nearby vehicles by sending hello messages. These hello messages (or beacon messages) are exchanged after a fixed interval. After exchange of first hello message, the neighboring vehicle knows when the next hello message would be transmitted. If neighboring vehicle receives the hello message within the predefined time limit, i.e., within ϕ time units, the link gets a reward and its weight value is increased by constant amount (ζ). Otherwise, there is a penalty for every miss of hello message. If either the number of messages transmitted or the time interval exceed the limit with weight of the link below 0.99, then that link is considered unstable. Otherwise, the link is considered as a stable link. The vehicle having stable link is included in the cluster and all the cluster members are informed about the new member in the cluster. The steps for cluster formation are explained in Algorithm 9.

5.2.7 Cluster/Coalition maintenance

When vehicle has exchanged minimum hello messages and the link is stable, still the hello messages are exchanged at regular interval as before. As these hello messages are

Algorithm 9 Cluster/Coalition formation

```

1: set the weight of link according to Eq. (5.12)
2: while (termination condition is not satisfied) do
3:   Send hello message after finite interval
4:    $N_{msg}++$ 
5:   if (message received within time  $< \phi$ ) then
6:     increase value of r by  $\zeta$ 
7:   else
8:     increase value of p by  $\zeta$ 
9:   end if
10: end while
11: if  $\left( (time > 1000 \times \phi \mid N_{msg} \geq 1000) \&\& \left( \frac{r}{p} \not\geq 0.99 \right) \right)$  then
12:    $link_{i,j}$  is considered unstable
13: else
14:    $link_{i,j}$  is considered stable
15:   Include vehicle in cluster
16:   Communicate to other vehicles in cluster about new link to vehicle
17: end if

```

of very small size, they will not generate any extra overhead in the network. The value of weight does not exceed its limit from 1 and is always greater than 0. Suppose after some time, one vehicle leaves the network, then the neighboring vehicle stops receiving any hello messages further. After every expected receiving time of hello message there is a penalty on every failure in communication. As the $\frac{r}{p}$ value goes below 0.99, the link is declared unstable and the update is communicated to other members of the cluster. The pseudo code of vehicle leaving the cluster is given in Algorithm 10. Whenever a vehicle enters or leaves the cluster, as explained in Algorithm 9, and Algorithm 10 respectively, the other members of cluster are informed immediately. After regular time interval, the cluster head updates the RSU about the vehicles in cluster. This exchange keeps RSU updated about the clusters having vehicles with specific common interests. The pseudo code is provided in Algorithm 11.

5.2.8 Intelligent data dissemination

After calculating the weights, the initial reliability of the link is determined from Algorithm 8. As the vehicles move and communicate messages, the reliability changes according to Eqs. (5.14 and 5.16). At periodic intervals, the beliefs get updated according to the Eq. (5.17). For routing the message from S to destination, modified Dijkstra algorithm is used. In Dijkstra algorithm, the minimum distance is calculated between any two nodes, while in ReIDD scheme, the maximum payoff is taken.

Initially, two vectors namely *Payoff* and *Prev*, which stores the payoff and previous vehicle of all other nodes are set. The *Prev* (previous) vector stores the path from S to the current node. A priority queue is created which adds vertex in order of payoff, with maximum value at top. The top value is extracted and compared with each of its neighbors. The payoff to the neighbor is mean of payoff from S till the node and payoff of link connecting the neighbors. Unique metric is used in the algorithm which is defined in

Algorithm 10 Vehicle leaving the cluster

```

1: while ( $\frac{r}{p} > 0.99$ ) do
2:   regularly exchange hello packets
3:   if (no reply wihting time  $\phi$ ) then
4:      $p = p + \zeta$ 
5:     calculate  $\frac{r}{p}$ 
6:   else
7:      $r = r + \zeta$ 
8:   end if
9: end while
10: if ( $\frac{r}{p} < 0.99$ ) then
11:   Vehicle out of coverage area
12:   Drop the connection
13:   Notify the other vehicles about the update
14: end if

```

Algorithm 11 Cluster/Coalition maintenance

```

1: if ((New link in the cluster)|| (vehicle leaves the cluster)) then
2:   Update the neighbor table
3:   Share the updated table with neighbors
4: end if
5: if (Vehicle is Cluster Head) then
6:   After every regular interval
7:   Exchange the neighbor table with RSU
8: end if

```

line number 14 of Algorithm 12. Based upon this metric, maximum value is calculated. The final payoff and path from S to D (prev vector) is returned to the S node. The pseudo code is provided in Algorithm 12.

If the route from S to D is not connected, nearest RSU is approached from where Store-Carry-Forward technique is used. The flowchart of ReIDD scheme is provided in Fig. 5.3. For data dissemination, ReIDD selects the route to the D intelligently rather than by blind flooding. By selecting the path having maximum reliability, ReIDD not only saves time but consumes less bandwidth and prevents frequent contention. Thus, broadcast storm problem is eliminated by following the proposed scheme.

5.2.9 Complexity analysis

The following section gives the complexity in terms of both time and space.

5.2.9.1 Time complexity

This section describes the complexity analysis of the above algorithm. Step 3 to step 7 are repeated for all V vehicles, hence, it takes $O(V)$ time. For creating a priority queue and adding vertex takes $O(V)$ time. Extracting the maximum value takes $O(\log V)$ time. Steps 11-21 run for V iterations. The inner *for* loop updates the priority queue and after updating queue is arranged with maximum value at top. The whole operation takes V

Algorithm 12 Routing of message from S to D

Input: S, D, N, Payoff's of adjacent Links

Output: Reliable shortest route with payoff from S to D

```

1: Payoff[S]  $\leftarrow \mu_s$ 
2: Prev[S]  $\leftarrow$  NULL
3: for ( $i = 0; i < N; i++$ ) do
4:   if ( $V_i \neq S$ ) then
5:      $payoff[V_i] \leftarrow 0$ 
6:      $prev[V_i] \leftarrow NULL$ 
7:   end if
8:   Create a priority Queue Q and add vertex according to payoff[ ]
9: end for
10:  $u \leftarrow$  Extract vertex with max payoff from Q
11: while ( $u \neq NULL$ ) do
12:   Remove u from Q
13:   for Each neighbor v of u do
14:      $max \leftarrow (Payoff[u] + Payoff[u, v]) / 2$ 
15:     if ( $max > Payoff[v]$ ) then
16:        $Payoff[v] \leftarrow max$ 
17:        $prev[v] \leftarrow u$ 
18:     end if
19:   end for
20:    $u \leftarrow$  Extract vertex with max payoff from Q
21: end while
22: Return Payoff[ ] and prev[ ]

```

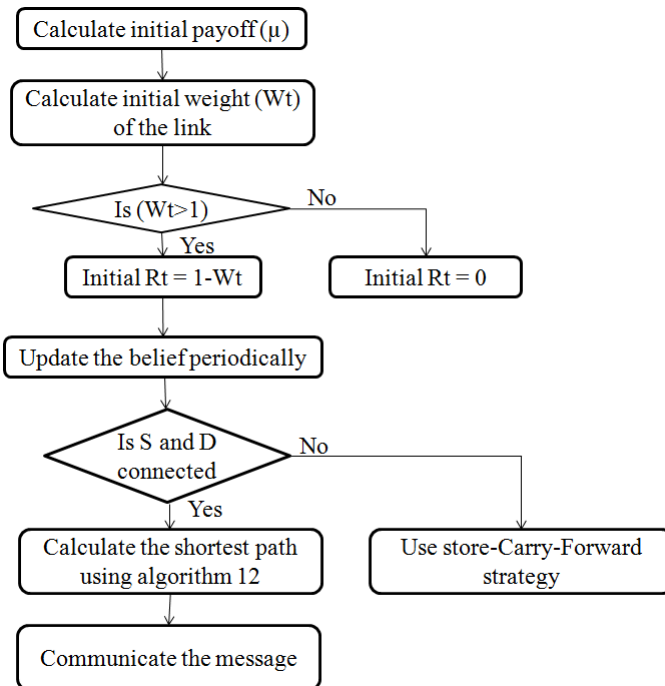


Fig. 5.3: Flowchart of the ReIDD scheme

time since it can be repeated to a maximum of V vehicles. Extraction and arrangement of queue in step 20 takes $(\log V)$ time. As stated earlier the step number 12-21 are repeated for maximum of V vehicles. Hence, total time complexity of the designed algorithm is as follows.

$$\begin{aligned} \text{Time_Complexity} &= O(V) + O(V) + O(\log V) + \\ &\quad V \times (O(V) + \log(V)) \end{aligned} \tag{5.24}$$

$$= O(V) + V \times O(V) + O(\log V) \tag{5.25}$$

$$\text{TimeComplexity} = O(V(V + \log V)) \tag{5.26}$$

Time complexity of Algorithm 12 is $O(V(V+\log V))$ as calculated in (5.26)

5.2.9.2 Space complexity

Initially, payoffs of all the vertex and links which takes $O(V^2)$ space are stored. Calculation and assignment takes constant space. Creating a priority queue takes $O(V)$ space where, V is the maximum size of queue. Extraction, assignment, and comparison takes constant space; when performed in loop still takes constant space hence, the space complexity of the designed algorithm is as follows.

$$\text{SpaceComplexity} = O(V^2) + O(V) + O(1) \tag{5.27}$$

$$= O(V^2) \tag{5.28}$$

The space required in Algorithm 12 is of the order of V^2 .

5.2.9.3 Example 3

A practical scenario that how cluster are structured in the proposed scheme for mitigation of broadcast storm problem is considered in Fig. 5.4, where there are 9 vehicles in the network. Source S, vehicles V_1, V_2 are in same cluster. Vehicles V_4 and V_5 are part of second cluster while, vehicles V_6, V_7 and destination D form third cluster. Vehicle V_3 is a relay vehicle and is not a part of any cluster. The payoff of V_1 with respect to S is 0.4, and the payoff of V_2 with respect to S is 0.5. The payoff of V_3 with respect to $V_2 = 0.55$. Similarly, payoff of V_4 with respect to V_3 is 0.6, and V_5 with respect to V_3 is 0.7. The payoff of V_6 with respect to V_5 is 0.3, and of D with respect to V_6 is 0.5. Source S wants to route message to destination D. In its neighborhood, $S - V_2$ link has maximum payoff

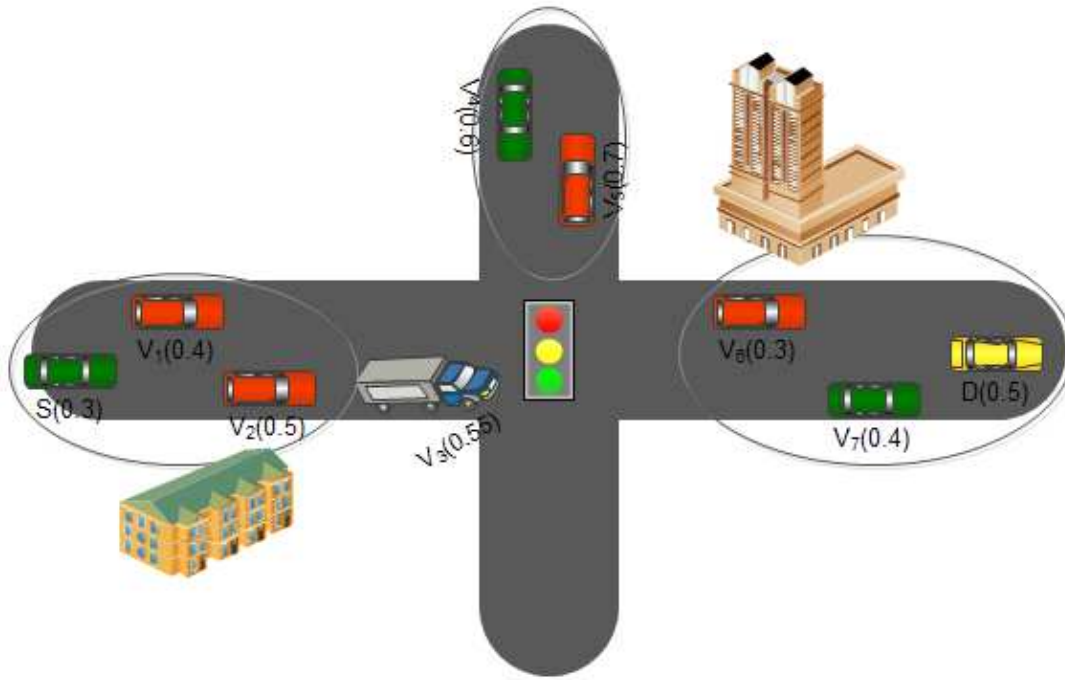


Fig. 5.4: Scenario taken in Example 3

of 0.5. The initial selection is Vehicle 2 from S .

$$\begin{aligned}\mu_{S-V_3} &= \frac{0.5 + 0.55}{2} \\ &= 0.525\end{aligned}\tag{5.29}$$

$$\begin{aligned}\mu_{S-V_5} &= \frac{0.525 + 0.7}{2} \\ &= 0.612\end{aligned}\tag{5.30}$$

$$\begin{aligned}\mu_{S-V_6} &= \frac{0.612 + 0.3}{2} \\ &= 0.456\end{aligned}\tag{5.31}$$

$$\begin{aligned}\mu_{S-D} &= \frac{0.456 + 0.5}{2} \\ \mu_{S-D} &= 0.478\end{aligned}\tag{5.32}$$

After that payoff of $S - V_3$ is mean of payoff of $S - V_2$ and $V_2 - V_3$ which is 0.525. After V_2 , V_3 is taken as the next hop. Similarly, the payoff of $S - V_5$ is greater than $S - V_4$. As both V_4 and V_5 are in range, so V_5 is the next hop. Payoff of $S - V_6$ comes out to be 0.456 as V_6 is in range of V_5 . V_7 does not come in range of V_5 , so V_6 is the next hop. Finally, the payoff of $S - D$ comes to be 0.478. The detailed calculations are shown in Eqs. (5.29)-(5.32) and in the Fig. 5.6.

5.2.10 Servicing the request

To serve a request, first of all vehicle searches within the current cluster where the other vehicles are of same interest. Whenever, such a request comes, it is served immediately. For some request from outside the cluster, the vehicle first approaches the current cluster

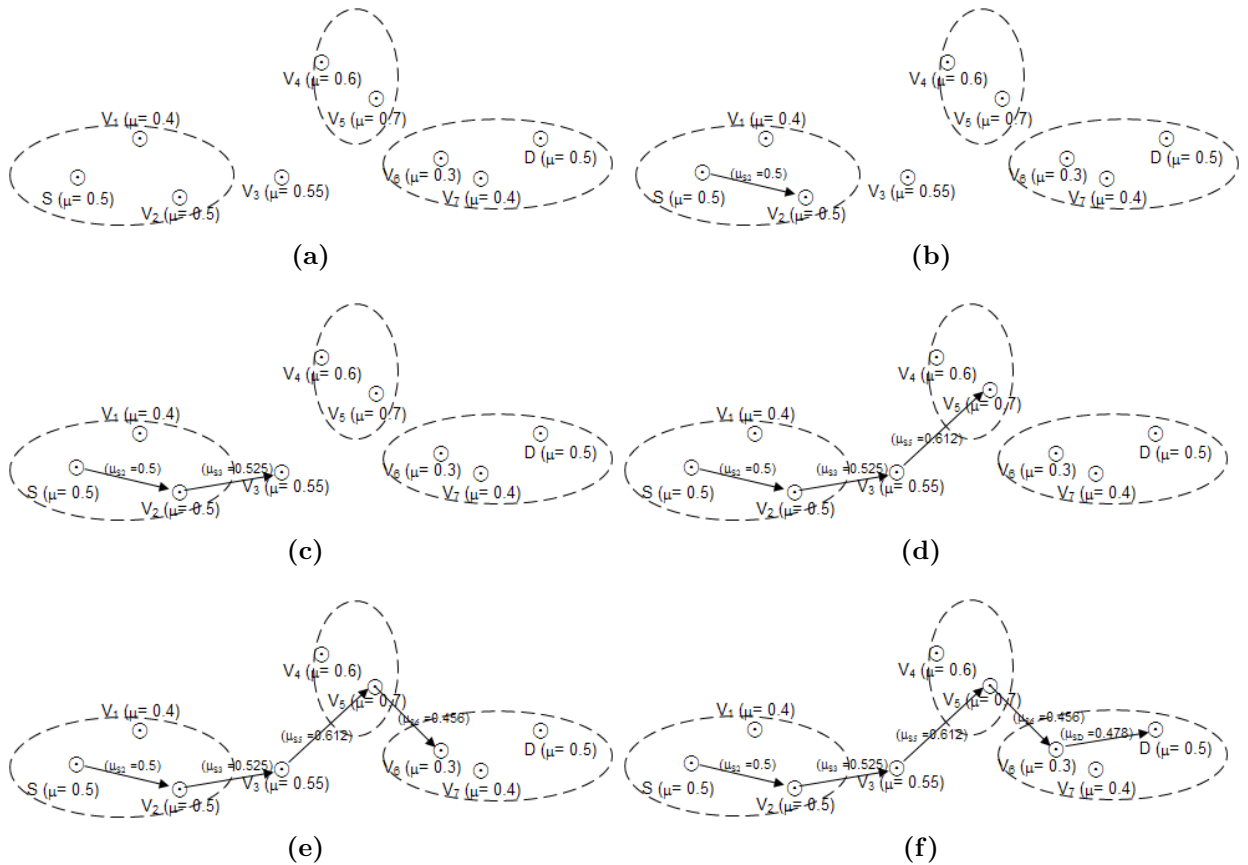


Fig. 5.5: Example Scenario (a) Initial setting (b) Exploring vehicle 2 from Source with payoff of 0.5 (c) Exploring vehicle 3 and payoff from S to V3 is 0.525 (d) Exploring vehicle 5 and payoff from S to V5 is 0.612 (e) Exploring vehicle 6 and payoff from S to V6 is 0.456 (f) Exploring Destination with total payoff from S to D is 0.478

head, the cluster head contacts the RSU which directs the request to the appropriate cluster where it is served and replied back to the vehicle. The pseudo code for request service is explained in Algorithm 13.

	S	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇	D
S	0.5	0.4	0.5	0	0	0	0	0	0
S V ₂	0.5	0.4	0.5	0.525	0	0	0	0	0
SV ₂ V ₃	0.5	0.4	0.5	0.525	0.562	0.612	0	0	0
SV ₂ V ₃ V ₅	0.5	0.4	0.5	0.525	0.562	0.612	0.456	0	0
SV ₂ V ₃ V ₅ V ₆	0.5	0.4	0.5	0.525	0.562	0.612	0.456	0.428	0.478
SV ₂ V ₃ V ₅ V ₆ D	0.5	0.4	0.5	0.525	0.562	0.612	0.456	0.428	0.478

Fig. 5.6: Calculation of payoff for scenario in Fig. 5.5

Algorithm 13 Servicing the request

-
- 1: **for** Requests within cluster **do**
 - 2: Satisfy the requests immediately
 - 3: **end for**
 - 4: **if** Request from outside the cluster **then**
 - 5: Reach cluster head of current cluster
 - 6: Cluster head reaches to RSU
 - 7: RSU contacts destined cluster to satisfy the request
 - 8: **end if**
 - 9: Return the reply to request
-

Theorem 1: The ReIDD scheme serves the requests in order of request time.

Proof: The vehicle v_i is part of cluster C_j , where i varying from 1 to n is the number of vehicles in the cluster C_j . The vehicle first requests the cluster neighbors which are having maximum probability of satisfying the request as they have common interests. Time taken to serve request is the time to exchange the message and is computed as follow.

$$t_{request} = D_{ij} \times PS \quad (5.33)$$

$$t_{reply} = t_{request} \quad (5.34)$$

$$TT = 2 \times D_{ij} \times PS \quad (5.35)$$

In case the neighbors do not have any answer, the clusterhead approaches the RSU. The RSU forwards the request to intended cluster that satisfies the request. The reply is answered back through the same channel as the request.

$$t_{CH} = t_{request} \quad (5.36)$$

$$t_{RSU} = t_{request} \quad (5.37)$$

$$TT_{request} = 3 \times t_{request} \quad (5.38)$$

$$TT_{reply} = TT_{request} \quad (5.39)$$

$$TT = TT_{request} + TT_{reply} \quad (5.40)$$

$$TT = 6 \times t_{request} \quad (5.41)$$

In the worst case, total time taken is equal to six times the time required to transmit a message from one vehicle to other vehicle.

Theorem 2: Broadcast Storm problem is solved by using the ReIDD scheme

Proof 2: Any message to be transmitted is propagated to the RSU which transmits them to the intended cluster heads. The cluster heads have the knowledge of members in the cluster. The information is then unicasted to the vehicles rather than broadcasted. Number of messages required to propagate the information to the intended vehicles is calculated as follows.

$$M_{S-R} = M_{S-RSU} + M_{RSU-CH} + M_{CH-R} \quad (5.42)$$

M_{S-R} is the number of messages from S to recipient, M_{S-RSU} , M_{RSU-CH} , and M_{CH-R} is number of messages from S to RSU, from RSU to cluster head and from cluster head to

recipient respectively. As all these types of messages are unicasted, so the network is not flooded. This saves the network from broadcast storm problem.

Table 5.1: Simulation setting parameters for ReIDD scheme

Parameter	Value
Simulation Area	5 Km \times 5 Km
Density of vehicles	100 - 500
Velocity of vehicles	10 - 100 Km/hr
Data Rate	2Mbps
Learning rate	0.02,0.04, 0.06
Simulation time	1000 second
Number of repetition of each trial	50

5.3 Performance Evaluation of ReIDD Scheme

This section presents the simulation work done on NS2.35 [80] and SUMO [134]. The simulation settings, followed by results obtained on various parameters viz. PDR, QRT, reliability and their comparison with the other schemes are described as follows.

5.3.1 Simulation settings

A real scenario of Patiala city is considered, where vehicles enter the system according to Poisson distribution and their inter-arrival time is distributed according to Exponential distribution. An area of 5 Km \times 5 Km is taken with most of roads being bidirectional as shown in Fig. (5.7). Various simulation setting parameters along with their values are described in Table 5.1. Following parameters are evaluated in the proposed scheme.



Fig. 5.7: SUMO map of Patiala city

- i) PDR: It is the ratio of number of successful packets received at the D vehicle to the number of packets generated from S .
- ii) Reliability: It is inversely proportional to number of link breakage and is given by Eq. (5.43) as described in Section 5.3.2.3.
- iii) E2ED: E2ED is computed as the average time taken by messages originating from S to reach to the D vehicle.
- iv) QRT: It is the total time taken from origin of the query to get response from vehicles in cluster or RSU.

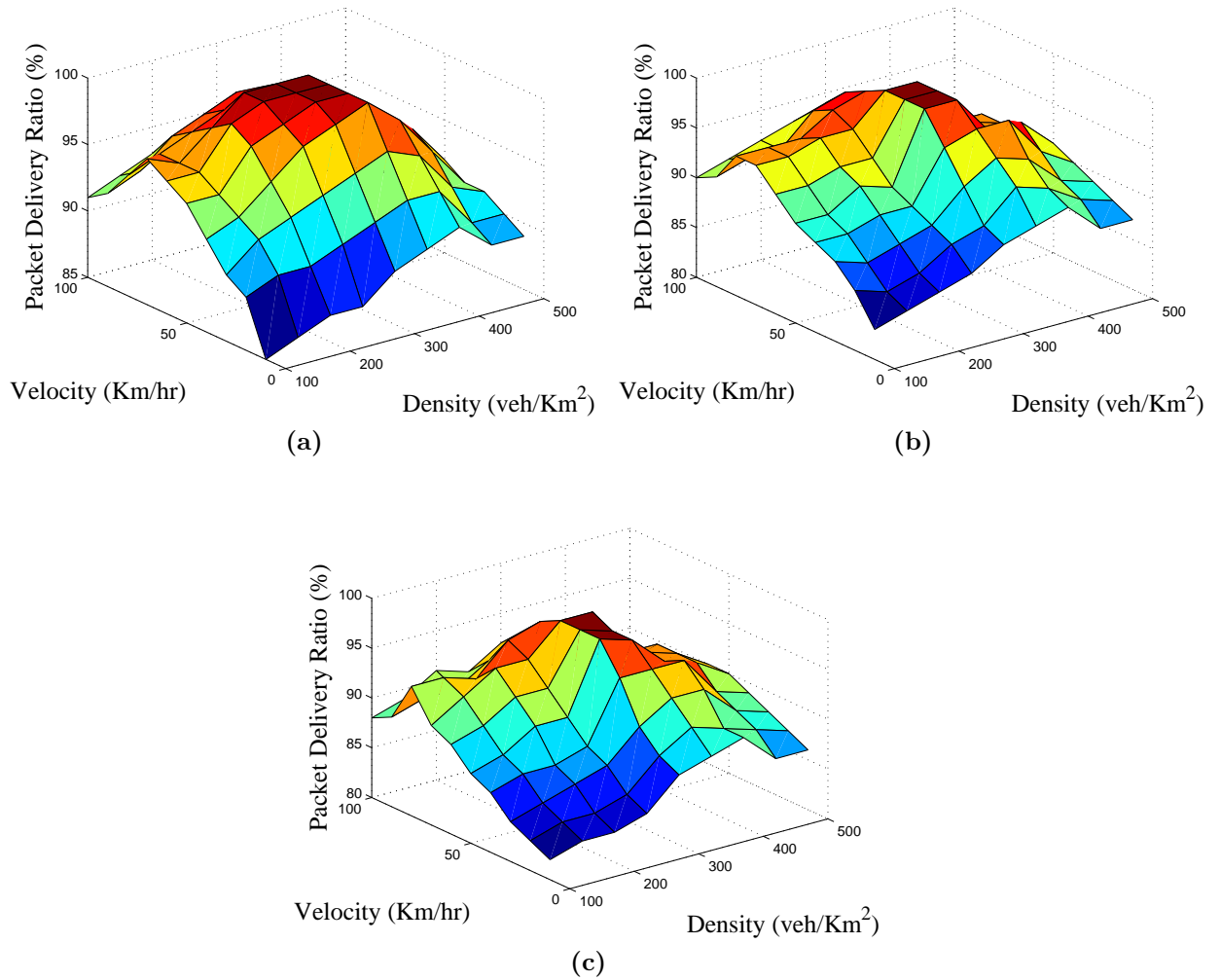


Fig. 5.8: Variation in PDR with increasing velocity and density (a) with learning rate 0.02 (b) learning rate 0.04 (c) learning rate 0.06

Each test run was repeated 50 times and an average was taken for producing the results. The simulations were performed in two phases. The ReIDD scheme is executed in three different scenarios, i.e., with learning rate of players as 0.02, 0.04, and 0.06. The results are compared with GyTAR [4], and A-STAR [5].

5.3.2 Results and Discussion

Figs. 5.8, 5.9, and 5.10 depict the results obtained on changes in PDR, QRT and reliability as velocity and density of vehicles change.

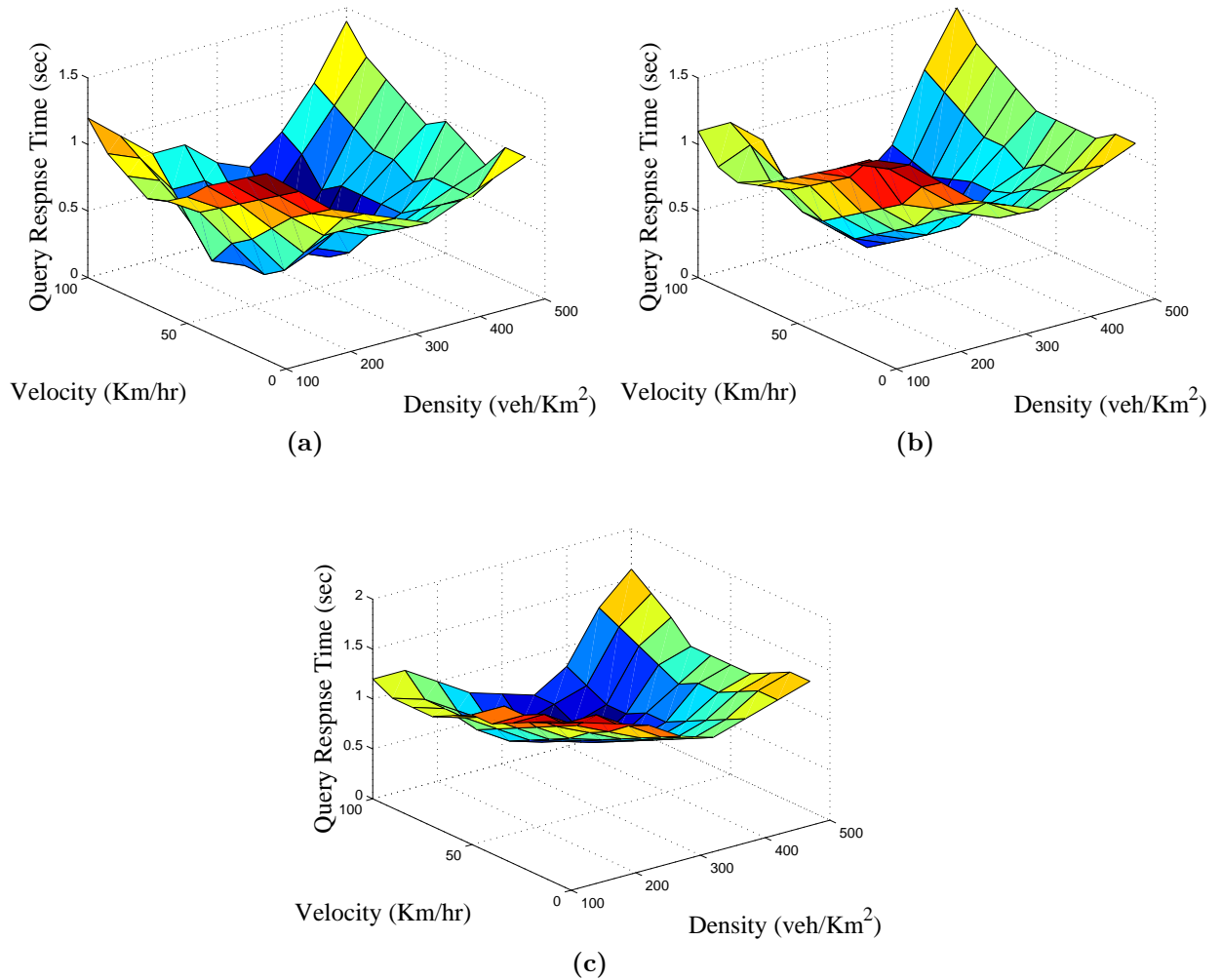


Fig. 5.9: Variation in QRT with increasing velocity and density (a) with learning rate 0.02 (b) learning rate 0.04 (c) learning rate 0.06

5.3.2.1 PDR

The variations in PDR with changes in velocity and density in the scenario are depicted in Fig. 5.8. When the velocity and density of vehicles is low, there are not enough vehicles to carry the message from S to D . This leads to lower PDR. When the velocity and density increases, there is gradual increase in PDR. But, when the density and velocity is very high, there are frequent collisions of packets resulting in regular packet drop. This condition also leads to lower PDR. As the learning rate increases from 0.02 to 0.04, the system takes more time to learn and adjust. This leads to lower PDR. When the learning rate further increases to 0.06, there is decrease in PDR because of the same reasons. When the velocity is 70 Km/hr and density is 300 vehicles/Km², the PDR is maximum.

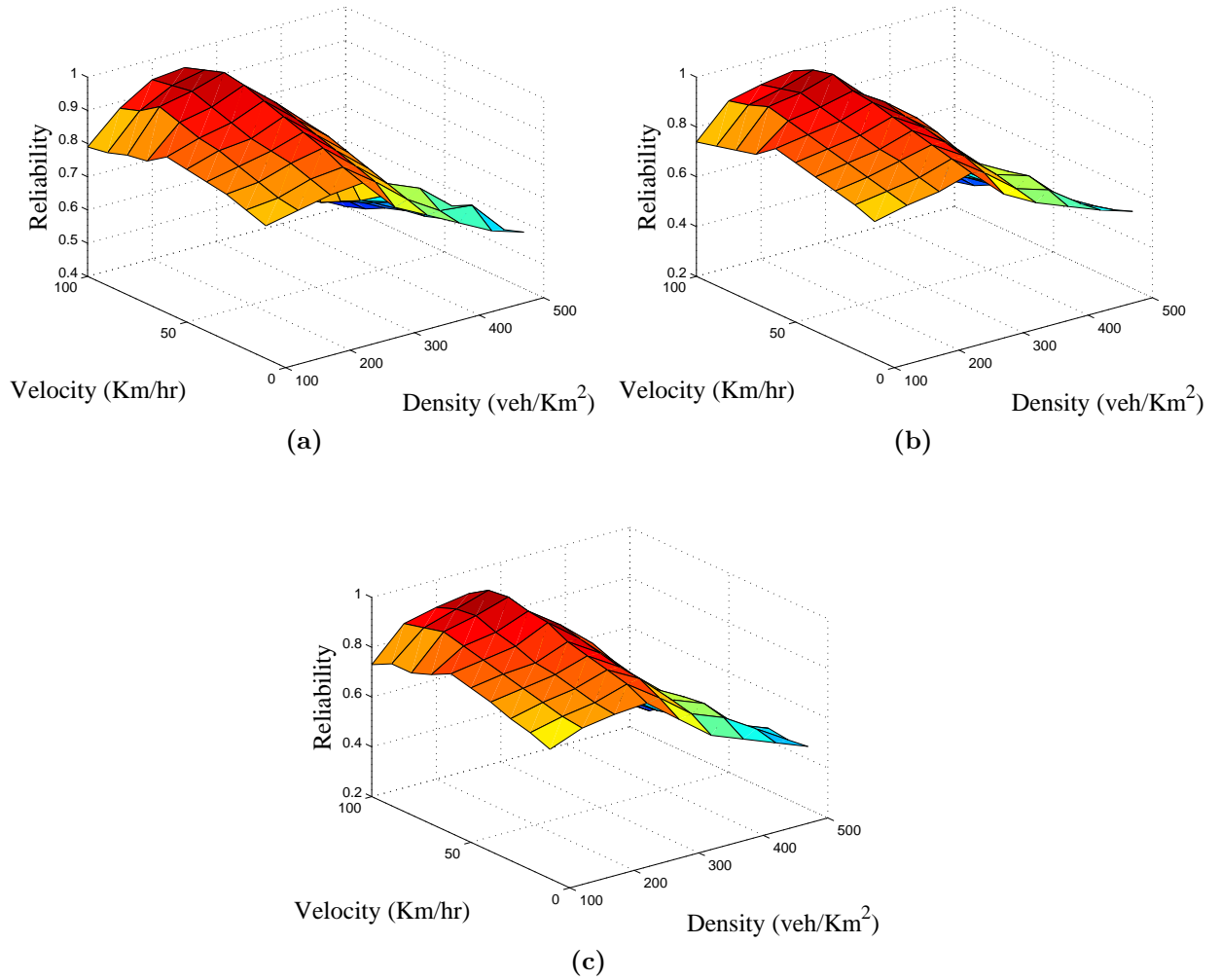


Fig. 5.10: Variation in Reliability with increasing velocity and density (a) with learning rate 0.02 (b) learning rate 0.04 (c) learning rate 0.06

The PDR at specified density and velocity is 99% with 0.02 learning rate. However, the PDR reduces to 95% with 0.04 learning rate at average vehicular speed of 40 Km/hr and density of 300 vehicles/Km², because the time is taken to form the coalition. This may result in some dropped packets. Another reason for reduced PDR is the drop in packets because of low average speed of the players which results in taking higher time for communication and lower PDR. Similarly, the PDR reduces even further at 0.06 learning rate to 90% at average vehicular speed of 30 Km/hr and density of 300 vehicles/Km².

5.3.2.2 Query response time

When a vehicle wants a service, it sends a query to its neighbors in cluster. If the required result is available with the cluster member, the response is sent to the S vehicle who has generated a request for the desired service. Otherwise, the query is sent to the cluster head who contacts the RSU and serves the request. Fig. 5.9 shows the effect of velocity and density on QRT. Initially, when the density and velocity is less, there is higher QRT,

because of not enough nodes in cluster to reply the service. With increasing density and velocity, QRT decreases. However, at higher turbulence, the links in cluster become fragile and break often. Also, the collision rate is high resulting in higher QRT. As the learning rate increases, the QRT also increases because of more time required to learn and adjust. The vehicles acting as players take more time to form the coalitions, hence resulting in increased time to exchange messages. The minimum value of QRT is at learning rate of 0.02, is observed at density of 250 vehicles/Km² and velocity of 60 Km/hr. Similarly, minimum QRT is obtained at density of 300 vehicles/Km² and velocity of 80 Km/hr for learning rate of 0.04, and 0.06 respectively.

5.3.2.3 Reliability

Reliability is inversely proportional to Link Breakage Rate (LBR). Lower the LBR, the higher will be reliability. The exact equation used is given in 5.43. The reliability first increases then decreases as the number of messages exchanged increases, the links become unstable. The variation in reliability at learning rate 0.02, 0.04 and 0.06 is shown in Fig. 5.10. At density of 250 vehicles/Km² and velocity of 80 Km/hr, the reliability is 0.99, 0.98 and 0.97 for learning rate of 0.02, 0.04 and 0.06 respectively.

$$R = e^{-\lambda \times LBR} \quad (5.43)$$

An increase in learning rate leads to increase in calculation and updation of payoff. This causes reduction in reliability with increase in learning rate.

5.4 Comparison of ReIDD with GyTAR and A-STAR

The variations in PDR of ReIDD scheme are compared with the other existing schemes namely-GyTAR [4], and A-STAR [5] as shown in Fig. 5.11(a). The PDR of ReIDD is higher than A-STAR and GyTAR because ReIDD uses intelligent data dissemination. For routing the messages, most stable path based on the reliability of links is chosen. Neither A-STAR nor GyTAR have taken reliability into account. Hence, there is high collision of the packets and frequent contention which leads to broadcast storm problem in these schemes. Also, the use of game theory for the formation of coalitions has improved the communication speed and accuracy of ReIDD scheme. Formation coalitions based on computations of real-time parameters, has increased the probability of successful message transmission in ReIDD. The formation of coalitions on the basis of game theory is not taken into account by GyTAR and A-STAR scheme. This resulted in improved PDR for the ReIDD scheme. It has been validated from Fig. 5.11 that ReIDD successfully overcomes the broadcast storm problem.

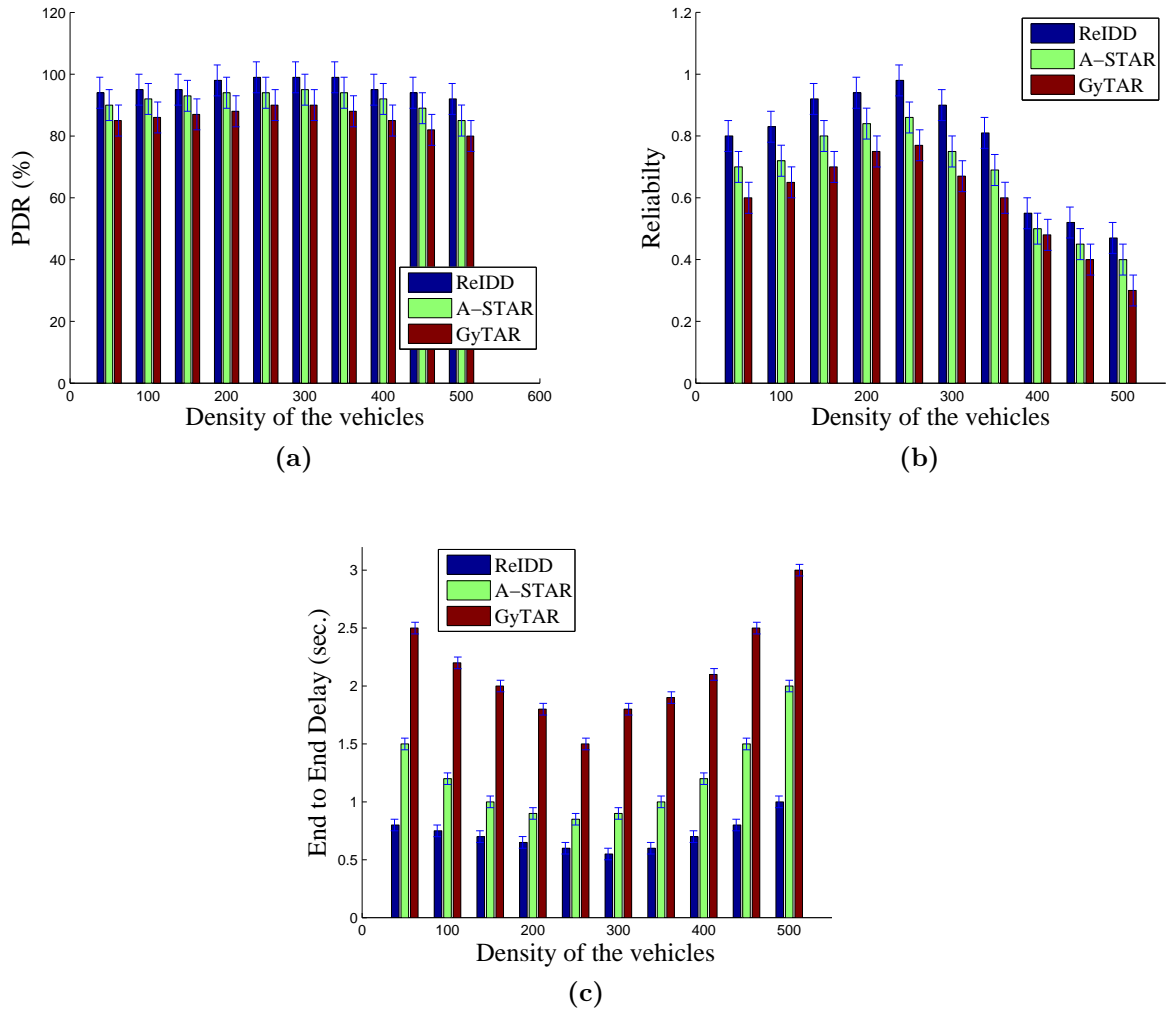


Fig. 5.11: Comparison of ReIDD with A-STAR and GyTAR (a) PDR (b) Reliability (c) E2ED

Similarly, the reliability and E2ED are also better in ReIDD. In pre-existing schemes flooding strategy is used for data dissemination, resulting in collision of messages. These messages have to be resent for successful transmission. Also, the chosen path in pre-existing schemes is not stable which increases the E2ED and reduces the reliability. As shown in Fig. 5.11 (b), the reliability is improved in ReIDD by 13% and 23% as compared to A-STAR and GyTAR respectively. The E2ED in ReIDD is lowered by 68% as compared to A-STAR and 80% when compared with GyTAR.

Table 5.2 shows the relative comparison of the proposed scheme with the other pre-existing schemes namely-A-STAR [5], and GyTAR [4] using various metrics. The results obtained clearly indicate that the proposed scheme out performs the other pre-existing schemes of its category.

Table 5.2: Performance comparison of ReIDD, A-STAR and GyTAR

Parameter	Percent improvement compared to	
	A-STAR [5]	GyTAR [4]
PDR	5%	10%
Reliability	13%	23%
End to End Delay	68%	80%

5.5 Summary

Vehicular Ad Hoc Networks (VANETs) have been used in wide range of applications in recent years. One of the biggest challenges in this environment is the blind flooding of the messages to the recipient nodes which leads to the broadcast storm problem and affects the overall functionality of the network. To address this issue, the concept of game theory for intelligent forwarding of the packets to the recipient nodes has been used. Vehicles are assumed as the players of the game and they form a cluster among themselves using the payoff function, the value of which is computed and updated at regular intervals. To mitigate the broadcast storm problem, an intelligent data dissemination algorithm is designed in the proposed scheme. The efficacy of the ReIDD scheme is evaluated and compared with pre-existing schemes, with respect to various performance evaluation metrics. The results obtained confirm the effectiveness of the proposed scheme in terms of higher PDR and reliability along with lower E2ED as compared to other state-of-the-art protocols.

In the next chapter, the problem of increasing burden on cellular network is addressed. A real-time data dissemination and offloading scheme using vehicular infrastructure and Wi-Fi access points has been described.

Chapter 6

Real-Time Data Dissemination and Offloading

There has been ever increasing demand for communicating the data to the intended recipients. The data can be either text, audio, image, video or a combination of two or more of these. The most common mode of communication is through mobile networks which have penetrated to even the remotest of locations. However, the increasing use of mobile communication can pose several challenges. According to the forecast by Cisco, the traffic in mobile communication will increase ten times and global monthly data traffic will exceed 24.3 exabytes by 2019 [175]. Owing to such a massive increase, mobile users will face call drops, unreliable coverage and limited bandwidth. Even the quality of service (QoS) experienced by users may reduce owing to such data traffic expansion [176].

One of the possible solutions is to increase the number of deployment of base stations across the network and increase the cellular capacity [177]. But, the patterns of increasing demands suggest that it will soon surpass the network capacity even if more infrastructure is deployed. The existing trends for increasing use of cellular data will leave the mobile companies in a state of bother even if they upgrade their technologies. Hence, there is an eminent need of using some alternate means for transmitting the data. For this, emerging vehicular ad hoc network (VANET) and existing Wi-Fi can be the tools for off-loading the cellular data in real-time. A study reveals that more than 50% of cellular data can be transferred using Wi-Fi when it is available [177–179].

The general intuition for offloading is to select the local best Wi-Fi or vehicle that can transfer the cellular data but the selected node might not be the globally best node. Hence, there is a trade-off between local best offloading and meeting the global QoS parameters. The existing offloading proposals focus mainly on local best solutions and compromising on global QoS parameters. However, the end users are concerned with global QoS parameters for a better experience. Hence, there is a need of a scheme that meets the global QoS parameters while using either Wi-Fi or vehicles to offload the cellular data in real-time. The proposed Real-time Data Dissemination and Offloading (RDDO) scheme ¹ aims to fulfil these requirements.

¹The contents of the chapter are partly published in Amit Dua, Neeraj Kumar, Seema Bawa, “Game Theoretic approach for Real-Time Data Dissemination and Offloading in Vehicular Ad hoc Networks,” *Journal of Real-Time Image Processing*, Minor revision submitted. (*Springer, IF 2.02*) (*SCI/SCIE*).

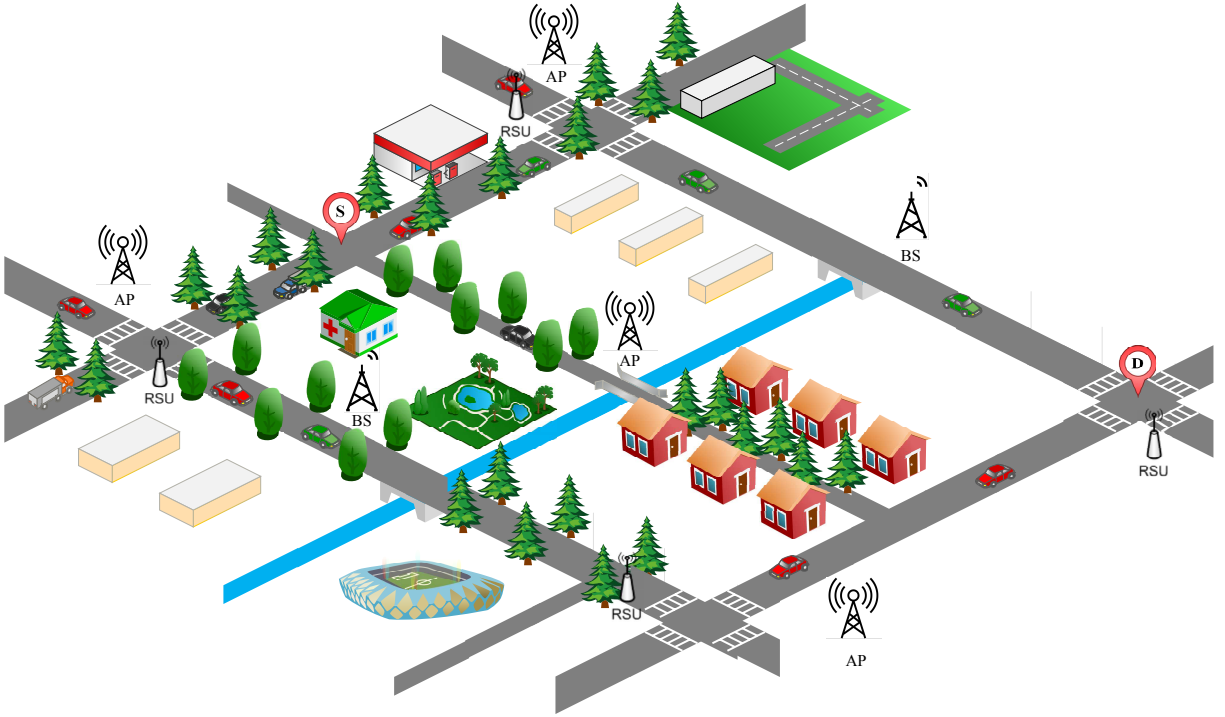


Fig. 6.1: Network model used for RDDO scheme

6.1 System Model

The following Section discusses the network model used in the proposed work. The problem is described with associated constraints.

6.1.1 Network model

Vehicles are assumed to move in the network according to Poisson distribution and inter arrival time is distributed according to Exponential distribution [180,181]. As depicted in Fig. 6.1, the mobile data has to be transferred from source, S , to destination, D . Due to heavy congestion in the network, there is a possibility that the data might not reach the intended receiver on time. The problem becomes even more severe in peak hours. Hence, the alternate means to communicate the data are depicted in the figure. There are two possibilities to communicate the data namely-through Wi-Fi APs and through vehicular network. The APs and RSUs are assumed to be already deployed in the network and need no further infrastructure installation. The communication through vehicular network is possible using IEEE 802.11 a/b/g and IEEE 802.11p or WAVE protocols. Additionally, there are various DSRC protocols defined for the efficient transfer of information amongst vehicles and between vehicles and RSUs.

The mobile phones are assumed to be equipped with GPS sensors which impart them the knowledge of the network. This knowledge allows the mobile devices to locate the nearest vehicle, RSUs and APs. The various parameters are used for calculating the pay-off of the vehicle and nearest AP. The pay-off or utility of the vehicle or AP and in-turn the value of the parameters decides which next node is to be chosen for offloading. One of the parameters is the area of the network. There are two types of network areas-sparse and dense. The network area is sparse if there are less than κ vehicles in the square unit area surrounding the origin of message.

The vehicles considered in the proposed scheme are equipped with OBUs to communicate with other vehicles and RSUs. The GPS devices and modern navigation equipments are assumed to be installed in the network to assist the vehicles in communication. Also, the vehicle are having high computation and storage capabilities for offloading the mobile data in real-time. As the batteries in vehicles are charged by fuel, there is no constraint of the energy of the vehicles. The network considered in this proposal consists of both sparse and dense regions. Hence, the scheme is practically applicable in both the environments.

6.1.2 Application of game theory

The game theory has wide applicability and has been used for offloading mobile data using VANETs. There are three important components in game theory namely-the players, the strategy space and the actions [167]. In the proposed scheme, there are two players, i.e., vehicles and APs. The utility or payoff function is associated with each player whose value depends upon the actions taken by all the players. In the proposed scheme the utility of vehicle depends upon five factors namely-the connectivity, the density, the distance from destination, the speed and the direction of the movement. However, the utility of AP depends on four factors namely-the distance between destination and AP, the bandwidth available, the area of the network and the communication range of AP. The detailed description on how these factors affect the utility is explained in Section 6.2.

The strategies and strategy space are stored in distributed hash table (DHT) for faster access and computation of utilities for the players. It is assumed that the players in the game are rational and selfish. The rational behavior implies that the players take decision based on the knowledge of the information of other players. However, the selfish behavior means that the players want to maximize their utility.

This section discusses the constraints and challenges used in formulating the problem. There are constraints for the movement of the vehicle, the communication range of the vehicles and the location of APs. Additionally, there is a constraint in the size of data that can be offloaded by vehicles. These constraints are defined in following equations.

$$0 \leq \nu \leq \nu^{max} \quad (6.1)$$

$$0 \leq \zeta \leq \zeta^{max} \quad (6.2)$$

$$0 \leq \varkappa \leq \varkappa^{max} \quad (6.3)$$

$$0 \leq \xi \leq \xi^{max} \quad (6.4)$$

Eqs. (6.1)-(6.4) emphasize that values for the velocity, vehicle range, AP range and the data size must not exceed the maximum permissible limits. Moreover, in order to have the best user experience, the offloaded data must satisfy the quality of service (QoS) parameters namely the message must not be dropped and it should reach the destination with minimum E2ED. These constraints are defined in the objective function as follows.

$$\varpi = \min \{ \Theta + \Xi + \Upsilon^{-1} + \aleph^{-1} \} \quad (6.5)$$

The objective function defined in Eq. (6.5) emphasizes that the E2ED and the generation of extra messages must be minimized, at the same time message speed and message progress must be maximized. There are several constraints and challenges for achieving this objective. A practical scenario of data offloading is depicted in Fig. 6.2. It is evident

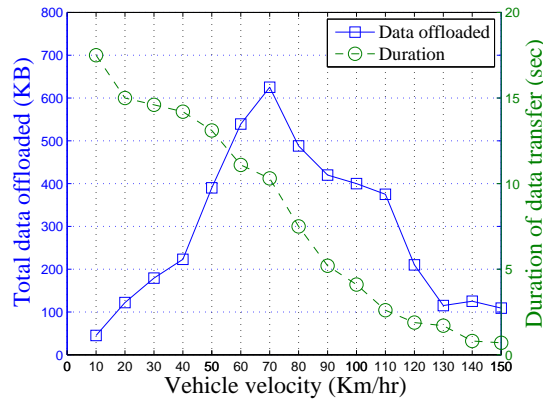


Fig. 6.2: Total data offloaded and duration of data transfer

from the figure, that the duration of data transfer decreases with an increase in the velocity. The decrease is expected because the time for the availability of the communication link decreases with an increase in the velocity of the vehicle. Moreover, the total data offloaded increases initially with the mobility of the vehicle because the higher velocity vehicle has larger communication range and can communicate large data to the destination. However, when the vehicle velocity increases beyond 70Km/hr, the communication link becomes unstable and **cannot** communicate larger data.

Hence, there is a requirement of a new solution that can exploit the existing infrastructure of vehicular and Wi-Fi AP. The solution must take into account the real-time parameters and meeting the QoS requirements. The proposed real-time data dissemination and offloading (RDDO) scheme aims at satisfying the objective function and the requirements using the game theoretic approach.

6.2 Proposed RDDO scheme

The proposed RDDO scheme, takes intelligent decision whether to offload the cellular data and which AP or vehicle to be used in disseminating the data. The decision to choose next node depends upon the utility of the nearby nodes. There are two types of offloading namely—offloading using vehicles, using Wi-Fi, and combination of both of these. The following segment describes the various factors used to take decisions about offloading.

6.2.1 Offloading using vehicles

The vehicles are considered a good option for offloading because of their high computational, communication and storage capabilities. There is no need to deploy additional network apart from RSUs which can be used for data dissemination. Even if the RSUs are not in proximity, still IEEE 802.11 p standard can be used to communicate using V2V communication. The source S has to decide which vehicle to be used to offload the data based on the utility of each vehicle in the vicinity. The factors on which utility of vehicles in VANET is decided are as follows.

- i) Connectivity to the destination

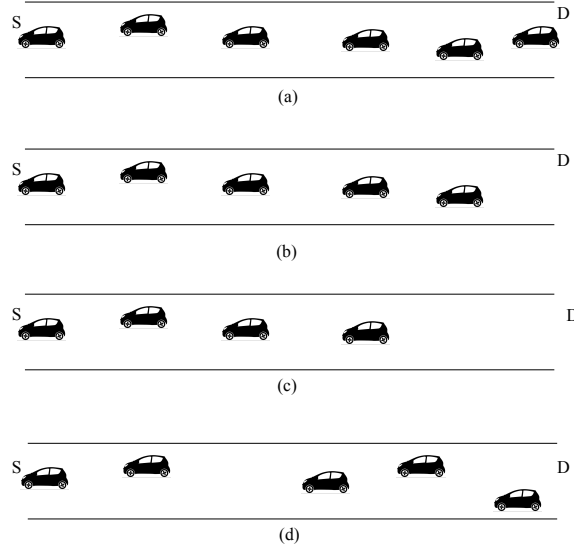


Fig. 6.3: (a) Connectivity =1 (b) Connectivity = 2 (c) Connectivity = 3 (d) Connectivity = 3

- ii) Density of the vehicles
- iii) Distance from the destination
- iv) Speed of the vehicle
- v) Angle of movement of the vehicle

6.2.1.1 Connectivity to the destination

The connectivity to the destination is decided based on the distance to be traveled in store-carry-forward way. If the path to the destination is reachable from the current position of the vehicles, then the connectivity is considered as 1 [182]. However, if the vehicle has to move before being able to transfer the message to the vehicle which carries to the destination, the connectivity is non-unity. Hence, the lesser the value of connectivity, the better chances for vehicle to meet the QoS requirements.

A diagram depicting the calculation of connectivity of the vehicle is presented in Fig. 6.3. As shown in the figure, the S having throughout communication to the destination is having connectivity value of 1. Second and third scenarios depicted in Fig. 6.3(b,c) are not having full communication connection to the destination. In second scenario, the closest vehicle to the destination is expected to move the distance on unit communication range in store-carry-forward way. This incurs additional time to transfer the data and experiences connectivity value of two. In the third scenario, a distance of two communication range has to be covered by store-carry-forward way, hence, the connectivity is three. In fourth scenario, the intermediate vehicle has to travel two unit distance and once the data is communicated to next vehicle, there is availability of communication nodes after that. This makes the connectivity of three. The usage of connectivity for calculating the utility of vehicle has to be scaled down using a constant factor α . As, connectivity (Con) is inversely proportional to the utility of vehicle (U_v), i.e., higher connectivity denotes lesser

utility, its contribution is as follows.

$$U_v \propto \frac{\alpha}{Con} \quad (6.6)$$

6.2.1.2 Density of the vehicles

Density of vehicles is another important factor which affects the time taken to communicate the data to the destination. The density of vehicles, is determined by the average number of vehicles in unit cross section in the path from source to destination. Higher the density, higher is the probability to disseminate the message. Low density, signifies that the message is likely to be communicated in store-carry-forward manner. This consumes extra time and is undesirable for offloading. Hence, the utility of vehicle is directly proportional to the density of vehicles (ρ). A scaling factor β is multiplied for normalization of utility of vehicle (U_v).

$$U_v \propto \beta\rho \quad (6.7)$$

Eq. (6.7) signifies that the utility of the vehicle is directly proportional to the density of the vehicles in the concerned area.

6.2.1.3 Distance from the destination

The distance from the destination gives an estimate of minimum time that is required to communicate the data. The smaller distance implies that if all other parameters are constant, the time taken would be lesser than time taken by vehicle having larger distance. Hence, utility of vehicle is inversely proportional to the distance ($Dist$) of vehicle from destination. A scaling factor γ is multiplied to normalize the impact of $Dist$ on the utility.

$$U_v \propto \frac{\gamma}{Dist} \quad (6.8)$$

Eq. (6.8) signifies that the utility of the vehicle is inversely proportional to the distance of the vehicle from the destination.

6.2.1.4 Speed of the vehicle

The speed of vehicle is used for communicating the message to the other situated vehicle when the other vehicle is not in communication range. The other important situation when speed of vehicle is crucial factor is the condition of sparse distribution of vehicles. In such situations, the message is communicated in store-carry-forward manner and higher speed vehicles are an advantage. Even in regular density, the speed plays a crucial role in offloading the mobile data. Intuitively, the payoff of vehicle is directly proportional to the speed of the vehicle (ν). A constant factor δ is multiplied to normalize the impact of speed for calculation of utility.

$$U_v \propto \delta\nu \quad (6.9)$$

Eq. (6.9) signifies that the utility of the vehicle is directly proportional to the speed of the vehicle.

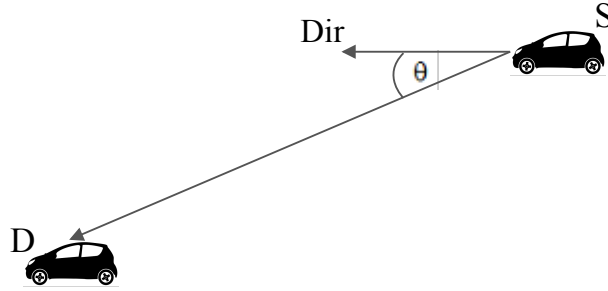


Fig. 6.4: Angle of movement of the vehicle

6.2.1.5 Angle of movement of the vehicle

The angle of movement is a complementary factor to the speed of vehicle. Higher speed must be in conjunction with the movement forward in right direction. The angle of movement is measured by taking reference to the imaginary line joining the vehicle and the destination (D). If the vehicle is moving towards the D , the angle would be less and vehicle moving away from the destination have larger angle. The calculation of angle is depicted in Fig. 6.4, where S , D , and Dir are source, destination and direction of the movement of the source vehicle. The D can be a vehicle or can be a general mobile device or any smart-phone. If the D is a mobile device or a vehicle its instantaneous position is taken as a reference. The angle made by the moving direction of S vehicle to the reference is θ . Utility of vehicle is inversely proportional to θ , i.e., the lesser the value of θ the higher the utility. A constant χ is used for normalization.

$$U_v \propto \frac{\chi}{\theta} \quad (6.10)$$

Eq. (6.10) signifies that the utility of the vehicle is inversely proportional to the angle of the vehicle to the destination. The angle θ would be zero when the vehicle is moving in the direction of the D . To cater this, the minimum value of θ is considered as unity.

$$\theta = \begin{cases} 1 & \text{if } \theta = 0 \\ \theta & \text{otherwise} \end{cases} \quad (6.11)$$

To summarize, U_v is directly proportional to density and the speed of moving vehicle. But, it is inversely proportional to the connectivity, distance from destination, and angle made with the destination. The normalization factors α , β , γ , δ , and χ are used for connectivity, speed, distance, speed and angle respectively. The following equation denotes the utility of the vehicle in the proposed solution..

$$U_v = \frac{\alpha}{Con} + \beta\rho + \frac{\gamma}{Dist} + \delta\nu + \frac{\chi}{\theta} \quad (6.12)$$

6.2.2 Offloading using AP

Wi-Fi access points (APs) are assumed to be located at major locations of cities. These can be utilized for sharing the burden of mobile data towers, especially during peak hours. This segment elaborates the possibilities of offloading using AP and the calculation of utility associated with each AP. There are various factors on which the utility of AP is dependent upon. These are summarized as follows and discussed in detail.

- i) Distance of destination from AP
- ii) Bandwidth available
- iii) Area of the network
- iv) Communication radius of AP

6.2.2.1 Distance of destination from AP

The distance of AP from the destination is a parameter for deciding the estimated time in delivering the message. Lesser is the distance better is the assurance of meeting QoS parameters. If all the parameters are same, the AP nearer to the destination is selected for offloading. Hence, the utility of AP (U_{AP}) is inversely proportional to the distance to destination ($Dist_{AP}$). A scaling factor η is used for normalization.

$$U_{AP} \propto \frac{\eta}{Dist_{AP}} \quad (6.13)$$

Eq. (6.13) signifies that the utility of the AP is inversely proportional to the distance of the AP from the destination.

6.2.2.2 Bandwidth available

Another important factor for calculating the utility is the available bandwidth. Different AP will be having different maximum bandwidths. In a vicinity if all the nearby AP are having same maximum bandwidth still the available bandwidth varies. This is because each AP might be serving different nodes, hence the bandwidth available might be different at various times of the day. Higher availability of bandwidth allows faster communication between source AP (S_{AP}) and progressive AP or to the D . Hence the utility is directly proportional to the available bandwidth (B). A constant factor ξ is used for normalization.

$$U_{AP} \propto \xi B \quad (6.14)$$

Eq. (6.14) signifies that the utility of the AP is directly proportional to the bandwidth available.

6.2.2.3 Area of the network

The area of the network can be sparse or dense depending upon the location and time of the day. A network can be dense in peak rush hours and can be sparse during night times or off-peak hours. However, there is no concrete classification that the network is dense or sparse. So, the value of the area of the network varies from 0.1 to 1. The higher the density of nodes in the network is assigned the value is closer to one. The less dense network will have value closer to 0.1. The lesser dense network are desirable because it gives higher probability for AP to communicate in less time. In the more dense networks, there are chances of other nodes seeking the service of the AP. Hence, the utility of AP is inversely proportional to the area of the network (Ar). A constant factor ϱ is used for normalization.

$$U_{AP} \propto \frac{\varrho}{Ar} \quad (6.15)$$

Eq. (6.15) signifies that the utility of the AP is inversely proportional to the area of the network.

6.2.2.4 Communication radius of AP

It is assumed that all AP are having same communication range. The actual communicable distance may be less than maximum because of the fading and interference due to surrounding buildings, trees, lamp posts, or other constructions. The obstructions are quantified by the impact on the communication radius. Hence, higher obstructions are undesirable and inversely affect the QoS factors. The utility is directly proportional to the communication radius (R) of the AP. A scaling constant factor ψ is used for normalization.

$$U_{AP} \propto \psi R \quad (6.16)$$

Eq. (6.16) signifies that the utility of the AP is directly proportional to the communication radius of the AP.

To summarize, U_{AP} is directly proportional to the bandwidth available and communication radius and inversely proportional to the distance from destination and the area of the network. Hence, following equation holds.

$$U_{AP} = \frac{\eta}{Dist_{AP}} + \xi B + \frac{\rho}{Ar} + \psi R \quad (6.17)$$

6.2.3 Proposed algorithm

The sequence of steps for the proposed scheme is presented in Algorithm 14. In order to offload the data, the best node is selected in the real-time. The nearest vehicle and AP are known to the user using GPS. The mobile device probes the nearest vehicle and AP for various parameters and computes their utility. The vehicle or AP having higher utility is selected and the current utility is updated. If the current utility is greater than threshold, the node is selected to offload the data. The selected AP or vehicle calculates the nearby nodes for their payoffs and selects the node having higher utility. The same procedure is followed and the vehicle or AP having higher utility is selected in the direction to the destination. This process continues till the destination is reached and the intermediate nodes are returned to the source. The source decides whether to do offloading depending upon the QoS requirements fulfilled by the offloaded route by adjusting the threshold of current utility.

The step by step description of Algorithm 14 is presented in following segment. The algorithm takes the source (S) and destination (D) as inputs and returns the offloaded path. The function *Moff* is created (line 1), which takes the S and D as input variables. The vehicles in range of S are calculated (line 2) following which the maximum utility for vehicle is assigned as 0 (line 3). The algorithm calculates the utility of each vehicle and maximum utility is assigned to U_{vmax} (lines 5-12). The ID of vehicle having maximum utility is stored in variable p . Similarly, the AP having maximum utility is calculated and stored in U_{APmax} (lines 16-23). The maximum utilities of vehicle and AP are compared (line 24). If vehicle (V_p) is having higher utility (U_{Vp}) and the destination is not reached the current utility is updated (Lines 24-27). If the current utility is greater than threshold, function *Moff* is called recursively (lines 29-36). Similarly the *Moff* function is called (lines 37-48) if AP (AP_q) is having higher utility (U_{APq}) than threshold. The procedure continues recursively and the path from S to D is returned (line 50).

6.2.4 Mathematical analysis

As the data is offloaded, two quantities are quantified by numerical analysis namely

Algorithm 14 Mobile offloading in real-time**Input:** S, D **Output:** $Path_{SD}$

```

1: Function Moff(S,D)
2: Calculate  $V \in \{V_1, V_2, \dots, V_n\}$  in range
3:  $U_{vmax} \leftarrow 0$ 
4:  $p \leftarrow 1$ 
5: for ( $i = 1; i \leq n; i++$ ) do
6:   Calculate  $Con_i, \tau_i, \rho_i, \nu_i$ , and  $\theta_i$ 
7:   Calculate  $U_{vi}$  using Eq. (6.12)
8:   if ( $U_{vi} \geq U_{vmax}$ ) then
9:      $U_{vmax} \leftarrow U_{vi}$ 
10:     $p \leftarrow i$ 
11:   end if
12: end for
13: Calculate  $AP \in \{AP_1, AP_2, \dots, AP_m\}$ 
14:  $U_{APmax} \leftarrow 0$ 
15:  $q \leftarrow 1$ 
16: for ( $j = 1; j \leq m; j++$ ) do
17:   Calculate  $\tau_j, B_j, Ar_j$ , and  $R_j$ 
18:   Calculate  $U_{APj}$  using Eq. (6.17)
19:   if ( $U_{APj} \geq U_{APmax}$ ) then
20:      $U_{APmax} \leftarrow U_{APj}$ 
21:      $q \leftarrow j$ 
22:   end if
23: end for
24: if ( $U_{Vp} \geq U_{APq}$ ) then
25:   Store p
26:   if ( $p \neq D$ ) then
27:      $U_{cur} \leftarrow U_{Vp}$ 
28:     if ( $U_{cur} > \phi$ ) then
29:       Function Moff(p,D)
30:     else
31:       No offload
32:     end if
33:   else if
34:     thenBreak
35:   end if
36: else if
37:   thenStore q
38:   if ( $q \neq D$ ) then
39:      $U_{cur} \leftarrow U_{APq}$ 
40:     if ( $U_{cur} > \phi$ ) then
41:       Function Moff(q,D)
42:     else
43:       No offload
44:     end if
45:   else if
46:     thenBreak
47:   end if
48: end if
49: EndFunction
50: Return path from  $S$  to  $D$ 

```

- i) The maximum data that can be communicated (Λ).
- ii) The time the communication link remains active for offloading (Ω).

The inter-arrival time of vehicles is distributed according to exponential distribution. The vehicles arrive at a rate of λ per unit time. Hence, the probability density function is computed by Eq. 6.18.

$$f(t) = \begin{cases} \lambda e^{-\lambda t} & t \geq 0 \\ 0 & t < 0 \end{cases} \quad (6.18)$$

In order to communicate Λ units of data the link must be active for that time. Assuming rest of the parameters remain stable, the probability that at least Λ units is communicated within t time is

$$\int_0^t f(x) = \int_0^t \lambda e^{-\lambda x} \quad (6.19)$$

$$= 1 - e^{-\lambda t} \quad (6.20)$$

$$\Lambda = 1 - e^{-\lambda t} \quad (6.21)$$

where, t is the communication time.

In order to offload the data while achieving the minimum QoS standards, the link must be active till the next vehicle arrives in the network. Suppose the vehicle i is moving with ν_i velocity and the communication range is ζ . In order to successfully offload the data to the vehicle j at x distance apart by moving at ν_j velocity, vehicle i has limited time.

$$t = \begin{cases} t_1 = \frac{\zeta+x}{\nu_i-\nu_j} & i, j \text{ in same direction} \\ t_2 = \frac{\zeta-x}{\nu_i-\nu_j} & i, j \text{ in opposite direction} \end{cases} \quad (6.22)$$

$$t_2 \leq t \leq t_1 \quad (6.23)$$

Hence, the probability that there is successful offloading of the data in the scenario with λ as exponential arrival rate.

$$P(t_2 \leq t \leq t_1) = \int_{t_2}^{t_1} f(x) = \int_{t_2}^{t_1} \lambda e^{-\lambda x} \quad (6.24)$$

$$= [1 - e^{-\lambda t}]_{t_2}^{t_1} \quad (6.25)$$

$$= e^{-\lambda t_2} - e^{-\lambda t_1} \quad (6.26)$$

6.3 Performance Evaluation of RDDO Scheme

To evaluate the performance of the proposed scheme, extensive simulations were performed. The detailed description of the simulation settings and results obtained are described in this section.

6.3.1 Simulation settings

An area of 10 Km \times 5 Km of Patiala city was taken on which 5 APs and 10 RSUs were deployed at different locations. Vehicles were assumed to move in the area with vehicle

density varying from 50 to 650. The speed of vehicles were confined in the limit of 10 Km/hr to 100 Km/hr. The mobile data was offloaded using APs and vehicles. The standards used were IEEE 802.11 b and IEEE 802.11 p with frequency of 2.4 GHz. The maximum data rate used for communication was 11 Mbit/s. The simulations were allowed to run for 650 second and each test run was repeated 50 times and an average was taken for producing the results. Two different topologies were considered for evaluation of the proposed scheme namely-dense and sparse. The dense topology has higher connectivity from S to D while sparse topology is intermittently connected.

Following parameters are evaluated to check the effectiveness of the proposed scheme.

- i) Message progress: It is the average additional area covered in one hop. It is calculated as the fraction of total distance between S and D to the number of hops.

$$\text{Message Progress} = \frac{D_{SD}}{N_{hop}} \quad (6.27)$$

- ii) Extra messages exchanged: It is the number of hello packets and acknowledgment packets exchanged in the duration of starting of the transmission of data till the data is received at D .
- iii) Message dissemination speed: This quantity signifies the distance traveled by the data in unit second. An average distance traveled from S to D is taken for calculating the speed.

$$\text{Message dissemination speed} = \frac{D_{SD}}{\text{time}_{SD}} \quad (6.28)$$

- iv) E2ED: It is the time taken for transmission of data from S to D . It is an important QoS factor and must be minimized for success of a scheme.

6.3.2 Results and discussion

The following segment describes the results of simulations performed under various metrics. Every result is compared with the two state-of-the-art protocols namely-GyTAR [4] and GPCR [6].

6.3.2.1 Message progress

As described earlier, message progress describes the fraction of area covered as the data traverses from S to D . In the case of dense network, when the vehicle density is low, the message progress is low. It increases sharply with the vehicle density which is justified from the fact that higher density of vehicles allow more radius of area to be covered by the transmitted data. As the density reaches to 500 vehicles, the rise in message progress is impeded. The similar trend is observed by GPCR and GyTAR (Fig. 4.6). However, the proposed scheme has higher message progress as compared to other two schemes. When the density is around 100 vehicles, the message progress is 75%, 76%, and 77% for GPCR, GyTAR and the RDDO scheme respectively. It increases to 87% when density is 250 vehicles and 92% when density is 400 vehicles for the RDDO scheme. However, progress is 80% and 84% for density of 250 vehicles and 86% and 90% at the density of



Fig. 6.5: SUMO map of patiala city

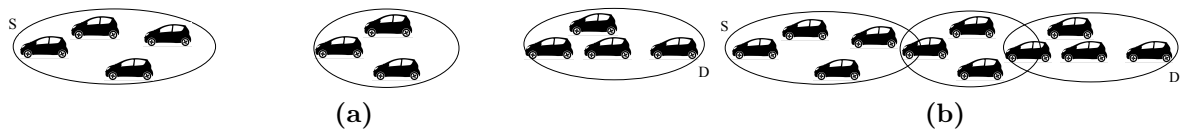


Fig. 6.6: Topologies in the network (a) Sparse connectivity (b) Dense connectivity

Table 6.1: Test data generated from SUMO

Data ID	Size of data	Vehicle ID	Vehicle Utility	AP ID	AP utility	Next hop	Time (sec)
D1	45	V3	0.63	A19	0.2	V3	0.3
D3	105	V9	0.81	A5	0.7	V9	12
D4	31	V17	0.69	A3	0.91	A3	91
D5	65	V14	0.72	A12	0.51	V14	31
D6	29	V1	0.45	A7	0.89	A7	45
D7	67	V6	0.22	A16	0.92	A16	103
D9	89	V19	0.68	A1	0.83	A1	29
D11	79	V21	0.91	A6	0.71	V21	146
D14	82	V18	0.15	A13	0.65	A13	179
D15	29	V42	0.62	A11	0.54	V42	215
D17	62	V31	0.33	A15	0.77	A15	3.4
D19	32	V25	0.95	A23	0.31	A23	19
D23	29	V28	0.81	A5	0.29	V28	54
D62	62	V37	0.45	A2	0.82	A2	109

Table 6.2: Simulation settings parameters for RDDO scheme

Parameter	Value
Simulation area	10 Km \times 5 Km
Minimum vehicle density	50
Maximum vehicle density	650
Minimum vehicle speed	10 Km/hr
Maximum vehicle speed	100 Km/hr
Wi-Fi standard	IEEE 802.11 b
Vehicular communication standard	IEEE 802.11 p
Frequency	2.4 GHz
Data Rate	11 Mbit/s
Number of AP	5
Number of RSU	10
Simulation time	650 second
Number of repetitions	50

400 vehicles for GPCR and GyTAR respectively. The progress stabilizes to 90%, 92%, and 93% respectively at the density of 500 vehicles and marginally increases to 92%, 93%, and 95% for GPCR, GyTAR and RDDO scheme at the density of 650 vehicles. The graph depicts the variation in message progress for dense network is presented in Fig. 6.7(a).

In case of sparse network, the message progress is low which is due to the fact that less number of vehicles are available to carry forward the data. The message progress is as low as 57%, 67%, and 71% for GPCR, GyTAR and RDDO scheme at density of 100 vehicles. The increase is marginal for GPCR which ultimately reaches maximum of 66% at the density of 650 vehicles. The trend for GyTAR and RDDO scheme is different where progress rises to 79% and 82% respectively at density of 300 vehicles and further increases to 84% and 89% respectively at density of 500 vehicles. The progress of GyTAR however increases marginally to 85% at 550 vehicle density and then reduces to 83% at the density of 650 vehicles. The same trend is observed for the RDDO scheme where the progress drops to 86% at density of 650 vehicles. This is because large number of extra packets are generated and the packet drop reduces the progress. Fig. 6.7 (b) depicts the variation in message progress for sparse networks.

A comparison showing the message progress with initial S to D distance is presented in Fig. 6.8. Figure depicts that the progress is nearly same for GPCR, GyTAR and proposed schemes when the initial distance is 500m but decreases sharply for GPCR and GyTAR as the distance increases. This is because of the fact that lesser distance is traversed in fewer hops and covering larger percentage of area. The uncovered area increases with the increase in S to D distance for GPCR and GyTAR. The progress for GPCR reduces to 80% with distance of 1000m and further reduces to 65% as the distance approaches 2000m. The progress ultimately reaches below 60% with increase of distance to 3000m. In a similar trend, GyTAR experiences progress of 84% at 1500m distance and 75% at 2500m distance. The RDDO scheme maintains progress above 90% throughout the simulation, because of use of higher payoff vehicles to communicate the data. This not only reduces the number of hops but increases the coverage also.

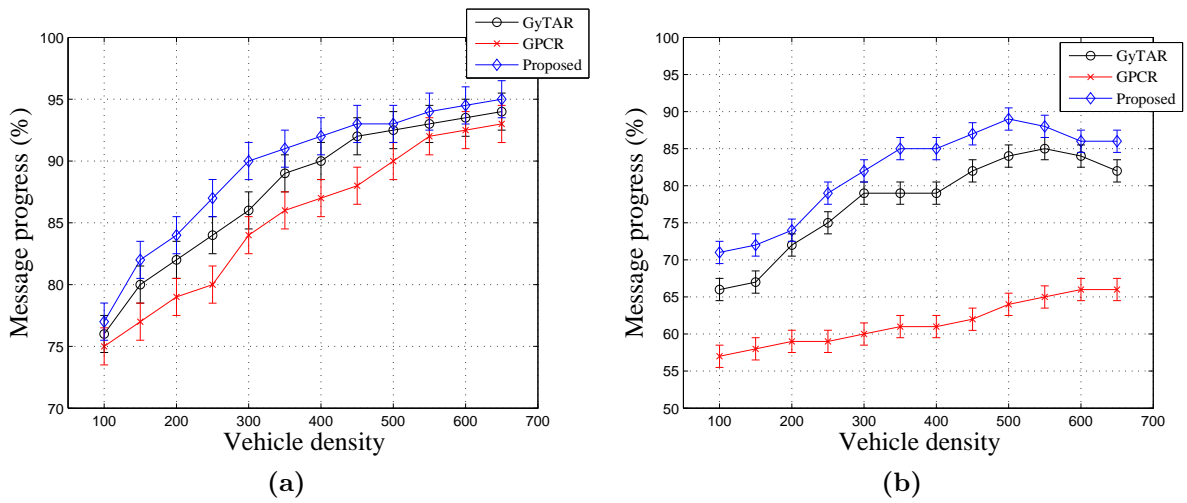


Fig. 6.7: Message progress with varying vehicle density (a) Dense network (b) Sparse network

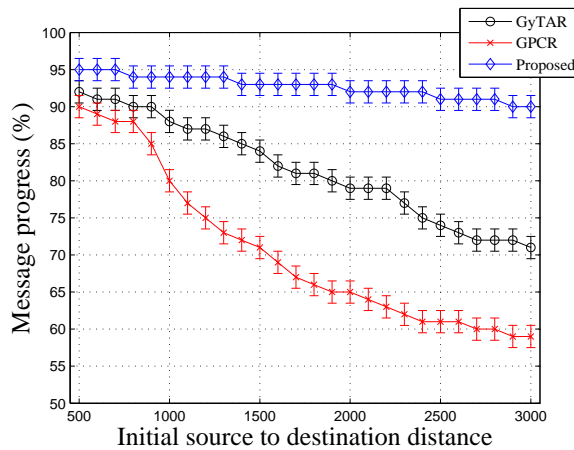


Fig. 6.8: Message progress with varying source to destination distance

6.3.2.2 Extra messages exchanged

There are several messages exchanged in the course of transfer of data from S to D . These include hello packets for getting the information about the neighboring nodes and maintaining the network. Another important type of extra message is acknowledgment message which notifies the S about the reception of data at the D . Fig. 6.9 depicts the number of extra messages exchanged from starting of data dissemination till reception of data at the D . In dense network, the messages exchanged by GyTAR increases with density while messages exchanged by GPCR decreases with increase in vehicle density as evident from Fig.6.9 (a). This is because of the property of these schemes that GyTAR exchanges more extra messages with higher density of vehicles while GPCR exchanges less extra messages. The RDDO scheme exchanges nearly same extra messages with increase of vehicle density. The extra messages exchanges by RDDO scheme are less because the location of nearby vehicle is known using GPS and only favorable vehicles having

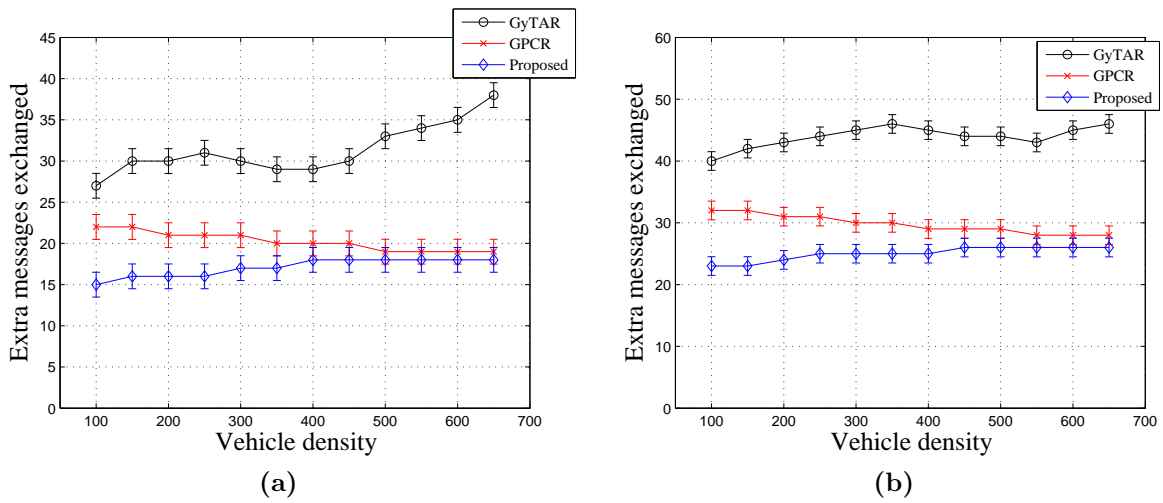


Fig. 6.9: Extra messages exchanged with varying vehicle density (a) Dense network (b) Sparse network

higher utility are probed for communicating the data. This does not increase rapidly with increase of vehicle density. In case of dense networks, the GyTAR exchanges 27 messages and GPCR exchanges 22 messages when vehicle density is low. At moderate vehicle density of 300 vehicles the messages exchanged are 21 and 30 for GPCR and GyTAR respectively. This increases to 19 and 37 for GPCR and GyTAR respectively, at high vehicle density of 650 vehicles. The extra messages exchanged for proposed RDDO scheme was found to vary between 15 messages to 18 messages throughout the vehicle density variations.

Fig. 6.9 (b) shows that the trend remains the same even in sparse networks although the absolute values of message exchange are higher, because the underlying schemes are the same. There is an increase in number of messages exchanged because of intermittently connected networks in sparse environment. To counter the intermittent nature, extra messages are exchanged. The extra messages exchanged by GyTAR is 40 for vehicle density 100 and increase to 45 with vehicle density 350. There is a drop in the number of messages exchanged in GyTAR scheme because of reaching an optimal situation at 550 vehicles in the network. At this density, the number of packets exchanged drops to 42 which again increases to 46 at vehicle density of 650. The extra messages exchanged by GPCR is 31 when density is low and gradually reduces to 29 when vehicle are high in the network. The RDDO scheme exchanges 21 messages at low distribution of network and gradually increases to exchange 26 messages at 400 vehicle density. After this, there is no significant impact on extra messages exchanged in proposed scheme with the increase in vehicles in the network. The extra messages exchanged remains 26 at vehicle density of 650.

6.3.2.3 Message dissemination speed

The distance traversed by vehicles in unit second is signified by the message dissemination speed. The message dissemination speed for dense networks is depicted in Fig. 6.10 (a). The proposed RDDO scheme selects the vehicles or AP which have highest payoff and are moving in the direction of the destination. Hence, the scheme is able to prop-

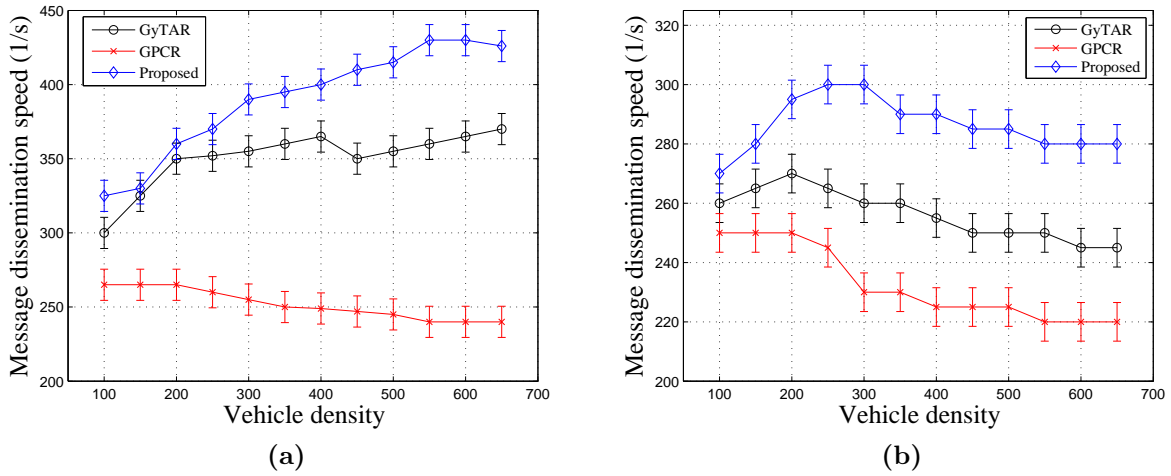


Fig. 6.10: Message dissemination speed with varying vehicle density (a) Dense network (b) Sparse network

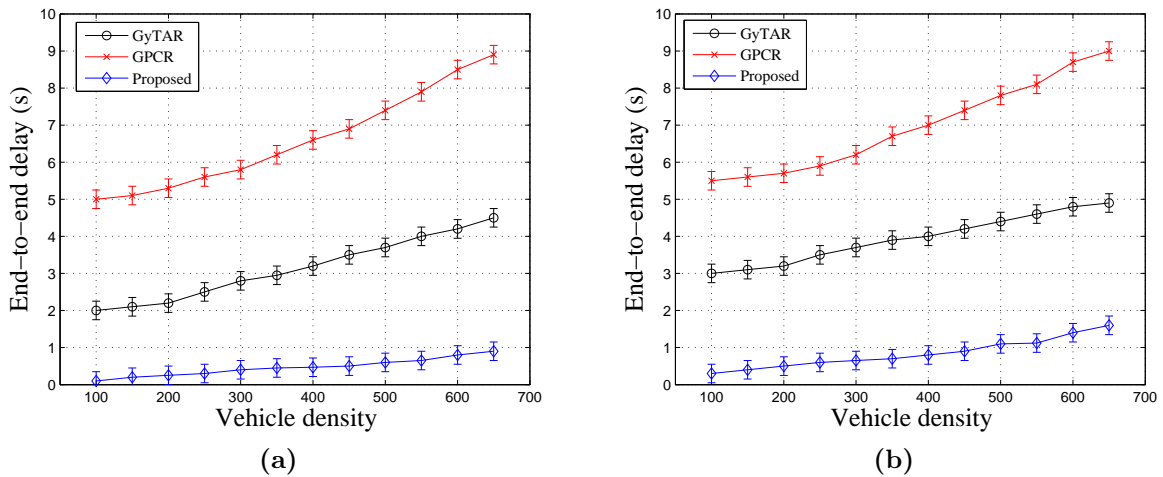


Fig. 6.11: E2ED with varying vehicle density (a) Dense network (b) Sparse network

agate the largest distance in smallest time. The message dissemination speed increases for RDDO scheme as density increases because there are more vehicles available and a choice is presented to select the best vehicle to traverse the distance towards the destination. A similar reason justifies the increase in message dissemination speed for GyTAR as a choice is presented to select the best vehicle to move larger distance in least time. However, the message dissemination speed parameter decreases with increase in vehicle density for GPCR because there is higher hand-off in transmitting the data from one vehicle to another. For dense networks, the distance traversed by GPCR, GyTAR and RDDO is 260, 300, and 325 meter/second respectively for 100 vehicles in network. The values for GPCR, GyTAR and RDDO at 300 vehicle density are 255, 355, and 380 meter/second respectively. The message dissemination speed achieves a value of 425 m traversed in one second by RDDO at a vehicle density of 650 vehicles. However, at same density the values of message dissemination speed are 235 and 370 meter/second for GPCR and GyTAR

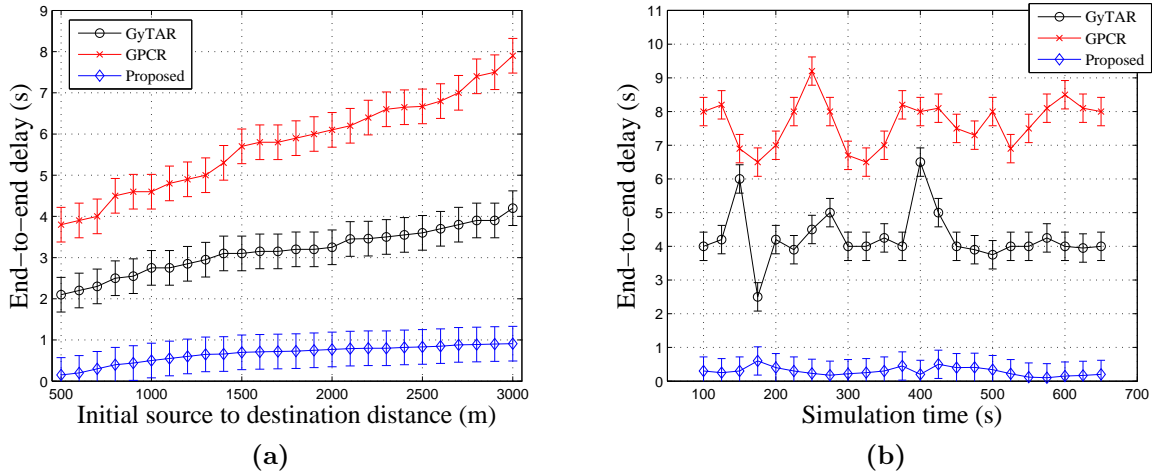


Fig. 6.12: E2ED with varying (a) Source to destination distance (b) Simulation time

respectively.

When the network is having sparse connectivity the message dissemination speed decreases after certain vehicular density. This is because of the fact that too many messages are getting dropped in the network and intermittent connections result in reduction of message dissemination speed. The parameter attains a value of 250, 260 and 272 meter in unit second for GPCR, GyTAR and RDDO when the vehicle density is 100 vehicles. This value increase for proposed scheme and reaches a maximum of 300 meter/second at 300 vehicle density, reduces to 280 meter/sec at 450 vehicle density and remains constant at this speed thereafter. A similar trend is observed for GyTAR, for which the speed attains a maximum of 270 meter in unit second at a density of 200 vehicles, and the value of message dissemination speed reduces gradually to 245 meter/second at the density of 650 vehicles. The parameter value for GPCR reduces from 250 meter/second to 220 meter/second as the vehicle density increases from 100 vehicles to 650 vehicles. The variations in message dissemination speed with vehicle density are depicted in Fig. 6.10.

6.3.2.4 E2ED

E2ED increases with the increase in vehicle density. This is because of extra messages exchanged to maintain the network which results in frequent drop in the packets and thus higher delay. The delay is even higher when the network is sparsely connected and there is not enough connectivity. The variation in E2ED is depicted in Fig. 6.3.2. When the scenario is dense, at the density of 100 vehicles the delay is 2 and 5 second for GyTAR and GPCR respectively. The delay increases to 3.2 and 6.5 second for GyTAR and GPCR respectively at the density of 400 vehicles. This value increases exponentially thereafter to reach 4.5 and 9 second respectively at density of 650 vehicles. The delay value for the RDDO increases gradually but is always less than 1 second even when the density is 650 vehicles. The delay is less for the proposed scheme because only selected vehicles and APs are used in communication. The selected vehicles and APs are having highest utility and thus the scheme incurs least delay in transmitting the message from S to D .

The delay for sparse network is higher as compared to dense networks. When delay of GyTAR in sparse network is compared with that of dense scenario, the delay is initially

3 second as compared to 2 second. As the vehicle density increases, the delay also increases and reaches 4 second at 300 vehicle density in sparse network as compared to 2.9 second in dense network. Similarly, the delay reaches 5 second in sparse networks when vehicle density is 650, but delay is 4.5 second at same density in dense scenario. Not only GyTAR, GPCR and RDDO also experience higher delay in sparse scenario as compared to dense scenario. The proposed RDDO scheme has delay of 0.5 second when density is 300 and 1 second when the density is 500 vehicle. The delay value reaches 1.5 second at density of 650 vehicles but still the delay is far less than GyTAR and GPCR under similar conditions.

The variations in E2ED with increasing initial S to D distance is depicted in Fig. 6.12 (a). When the distance between S to D increases, the delay also increases because the data has to traverse larger distance. The increase is less in the proposed RDDO scheme in which the E2ED remains under 1 second even when the distance increases to 3000 m. The other schemes namely GyTAR and GPCR face higher delay and encounters a delay as high as 4.4 and 8 second respectively at 3000m initial distance. The delay experienced by GyTAR and GPCR is high, i.e., 2s and 4s even when the distance is only 500 m.

In another experiment data of constant size are transmitted from S to D throughout the simulation time. The end-to-end delay is recorded at each instant of time and plotted in Fig. 6.12 (b). There is a variation of more than 3 second delay in GyTAR and GPCR schemes at different instances of time, while the proposed scheme maintains delay of less than 1 second throughout the simulation time. The variations in GyTAR and GPCR is because of network settlement, availability of forwarding vehicles and drop of packets because of either less vehicles or excess of vehicles in the network. The proposed RDDO scheme is least affected by these factors and hence is most reliable in terms of delay incurred from S to D .

Table 6.3: Performance comparison of RDDO, GyTAR and GPCR

Parameter	% improvement	
	GyTAR [4]	GPCR [6]
Message progress (dense network)	1.70	4.08
Message progress (sparse network)	4.16	20.5
Message progress (S-D distance)	11.26	22.34
Extra messages exchanged (dense network)	14.25	3.16
Extra messages exchanged (sparse network)	18.91	4.75
Message dissemination speed (dense network)	11.26	54.94
Message dissemination speed (sparse network)	11.70	23.11
End-to-end delay (dense network)	32.03	73.58
End-to-end delay (sparse network)	78.71	87.94
End-to-end delay (S-D distance)	78.94	88.45
End-to-end delay (simulation time)	93.23	96.26

It is evident from table 6.3 that the proposed RDDO scheme is an improvement as compared to GyTAR and GPCR. Hence, the proposed scheme achieves the QoS factors like time and progress better than other existing state-of-the-art schemes.

6.4 Summary

The data exchange using mobile networks is increasing and may increase many fold in the years to come. A novel solution to solve this problem using data offloading by vehicles and Wi-Fi AP is presented here. The proposed RDDO solution uses the game-theoretic approach to calculate the utility of the nearby vehicles and APs based on the real-time parameters. The calculated utility is used to select the most favorable node for data offloading. Results indicate that the higher message progress and dissemination speed is achieved by the proposed scheme. Important QoS parameters are met with minimum end-to-end delay and extra packets generated. The scheme is compared with existing state-of-the-art protocols and found to perform better results in real-time.

Chapter 7

Conclusion and Future scope

This chapter concludes the research work on efficient data dissemination in VANETs presented in this thesis. It also discusses open research problems along with a number of future research scope.

7.1 Conclusion

With an exponential growth in the Internet and related technologies, now it is possible for the moving vehicles to access various resources from anywhere. As technology is changing at rapid pace, more number of vehicles are equipped with navigation and communication devices now a days, which provide an ultimate comfort to the passengers. The dissemination of important information to the intended destination not only save time but precious lives also. Due to the constant topological changes, there is high probability of link breakage between the vehicles which may lead to a performance degradation of any implemented solution in this environment. In this context, disseminating the data to the recipients vehicles is one of the most difficult tasks to be performed. In [92], the importance of dissemination of messages was revealed to such an extent that if the information of approaching accident site is communicated to the drivers even half a second faster, more than 60 percent road accidents could have been avoided. This thesis has proposed and implemented a novel techniques for efficient data dissemination in VANETs.

The existing research work in the field of data dissemination has been studied. After careful analysis of these existing proposals, these were classified into seven categories. The advantages and disadvantages of each broad categorical strategy along with relative advantages and disadvantages of each scheme are presented. Moreover, a comparative analysis of the performance of the different schemes with respect to various parameters has been done. Based on the requirements for a particular application, a scheme from one of the broad categories can be selected for its real-time practical implementation.

The exhaustive literature survey has helped in identifying the critical issues and problems which were not addressed for efficient data dissemination in VANETs. One of the major requirement for communication in VANETs is to satisfy the QoS parameters. The QADD scheme has been presented specifically to address this issue. The scheme decides the next forwarding node based on the weights assigned to the links. The proposed scheme has less time and space complexity which makes it appropriate to be implemented in real-time scenarios. The proposal has been simulated on Patiala city in India using SUMO [134] simulator. The efficiency of the scheme has been tested on practical param-

eters. Simulation results illustrate better connectivity ratio with lower delay and lesser extra messages generated. The proposed scheme recorded a reduction of 39 percent and 21 percent in the load on the network as compared to SOBP [1] and DDOR [2] schemes respectively. The proposed QADD scheme is quick in message delivery, recovers efficiently from link failures and overcomes broadcast storm and gray zone problems.

Another prominent problem in VANETs is the congestion in the network because of the dissemination of any data sensed. To address this problem, a context-aware congestion resolution protocol, MCDT has been proposed. The proposed scheme uses the signal strength of the existing links and determines the optimum path. There may be a situation when the disseminated data has a local maxima situation and there is no better node for the progress towards the destination. To overcome this, a dedicated recovery algorithm has been presented which is based on the minimum angle method. The proposed scheme has been tested on NS-2.35 [80] and analyzed for several parameters including PDR, E2ED and routing overheads. An improvement in probability of transmission and network utilization with reduced delay incurred and overhead as compared to [5] and GyTAR [4] is obtained. A description of the scheme is provided in Chapter 4.

Extending this work and specifically focusing on one of the major issues in data dissemination, i.e., the broadcast storm problem, a novel ReIDD scheme has been proposed. The problem exists because of the blind flooding strategy applied for communicating the data. In sparsely connected networks, where there are less vehicles, flooding can produce satisfactory results. But, as the vehicles and number of messages exchanged increase, this causes higher collision, contention, and retransmissions leading to poor results. To address this issue, a novel scheme has been proposed that uses reliability as a metric for the formation of clusters/coalitions. The scheme utilizes payoff metric for the selection of the route the data has to traverse till destination. The schemes have been implemented on SUMO simulator and an improvement in PDR, reliability and E2ED has been observed as compared to existing state-of-the-art schemes.

Concepts of game theory are applied further to solve the practical problem of increasing load on cellular networks. A RDDO scheme has been presented that uses existing infrastructure of VANETs and Wi-Fi Access points. The offloading decision is done based on the payoff value calculated using the real-time parameters. The results prove that the data can be disseminated successfully using VANETs. More specifically, the proposed scheme has an improvement of 20 percent in message progress, 3 percent in extra messages exchanged, 54 percent in message dissemination speed and 73 percent in E2ED when compared with GPCR [6] scheme. Similar improvements were observed when the proposed scheme is compared with GyTAR [4] scheme.

7.2 Benefits to the society

There are various areas where the work carried out can be applied. Some of the benefits of the work to the society are discussed as follows.

7.2.1 Smart Cities

Government of India and other countries are investing for realizing the smart cities. One of important component of smart cities is smart transportation system. The schemes presented can work efficiently for choosing the best path for transportation. This helps

in traffic management and in turn saves fuel and time of citizens. not only this the air pollution is minimized which can have a positive effect on the environment.

7.2.2 Real-time alert

Alerts can be communicated to the vehicles approaching a cross section about the vehicles coming from different directions. This can help in minimizing the accidents and help drivers in low visibility conditions and blind turns.

Not only this, the real-time alerts can also be communicated about the patient traveling inside the vehicles to the hospitals using the techniques proposed in this work. Any abnormality can be detected and immediate treatment can be provided to the patients while on the move. This can help save precious lives of patients.

7.2.3 Alternate means of data transfer

The RDDO scheme presented can be used to offload the mobile data using alternate means including vehicular communication or WiFi networks. As the number of mobile users are increasing using alternate means of communication while maintaining the QoS parameters can help reduce the burden on mobile service providers at the same time satisfy the communication requests from the customers.

7.3 Future research scope

Despite substantial contributions of the current thesis in efficient data dissemination in VANETs, there are still a number of open research challenges that need to be addressed.

7.3.1 Security in data dissemination

The messages exchanged between vehicles must satisfy the security requirements, i.e., authenticity, integrity and confidentiality. When one of the nodes in the network is compromised, then it can lead to catastrophic consequences. Though there are several schemes proposed by researchers to ensure security, still there is scope for a better and more comprehensive technique.

7.3.2 5G enabled vehicular communication

As the communication technology is advancing, more and more avenues are opening for better and safer movement while remaining connected to each other. The 5G enabled communication aims for one such step forward. For communication amongst vehicles there are various networks available. These include LTE, Wi-Fi, Cellular, 5G, IEEE 802.11 a/b/g and IEEE 802.11p. Vehicle has the option to choose any of these networks. The RDDO proposed tests on two options and achieves satisfactory results. However, this can be extended to other network options including 5G. There is a trade-off between service availability and resource utilization. The work presented in this thesis uses optimal strategy for utilizing the bandwidth.

The Software Defined Networks separates the data plane from the control plane. All the softwares can be changed at the control plane while the underlying hardware remains

the same. The schemes presented in this thesis can be applied at the control plane. This allows the applications to work without any modification. For application in 5G, MIMO strategy is used which uses the channel more efficiently. Moreover, the collaboration of VANETs with 5G technology can open new doors for excellence and efficiency. This has not been explored much and can be one of the core research areas in the years to come.

References

- [1] G. Li, W. Wang, X. Yao, and W. Chen, “SOBP: a sender-designated opportunistic broadcast protocol for vanet,” *Telecommunication Systems*, vol. 53, no. 4, pp. 453–467, 2013.
- [2] P. K. Sahu, E. H.-K. Wu, J. Sahoo, and M. Gerla, “DDOR: Destination discovery oriented routing in highway/freeway vanets+,” *Telecommunication Systems*, vol. 50, no. 4, pp. 267–284, 2012.
- [3] S. Tsiachris, G. Koltsidas, and F.-N. Pavlidou, “Junction-based geographic routing algorithm for vehicular ad hoc networks,” *Wireless personal communications*, vol. 71, no. 2, pp. 955–973, 2013.
- [4] M. Jerbi, S.-M. Senouci, R. Meraihi, and Y. Ghamri-Doudane, “An improved vehicular ad hoc routing protocol for city environments,” in *IEEE International Conference on Communications, 2007. ICC’07*. IEEE, Glasgow, Scotland, 24-28 June 2007, pp. 3972–3979.
- [5] G. Liu, B.-S. Lee, B.-C. Seet, C.-H. Foh, K.-J. Wong, and K.-K. Lee, “A routing strategy for metropolis vehicular communications,” in *Information networking. networking technologies for broadband and mobile networks*. Springer, 2004, pp. 134–143.
- [6] C. Lochert, M. Mauve, H. Füßler, and H. Hartenstein, “Geographic routing in city scenarios,” *ACM SIGMOBILE mobile computing and communications review*, vol. 9, no. 1, pp. 69–72, 2005.
- [7] J. Zhao and G. Cao, “VADD: Vehicle-assisted data delivery in vehicular ad hoc networks,” *IEEE Transactions on Vehicular Technology*, vol. 57, no. 3, pp. 1910–1922, 2008.
- [8] N. Beijar, “Zone routing protocol (ZRP),” *Networking Laboratory, Helsinki University of Technology, Finland*, pp. 1–12, 2002.
- [9] A. Dua, N. Kumar, and S. Bawa, “A systematic review on routing protocols for vehicular ad hoc networks,” *Vehicular Communications*, vol. 1, no. 1, pp. 33–52, 2014.
- [10] N. Kumar and J.-H. Lee, “Peer-to-peer cooperative caching for data dissemination in urban vehicular communications,” *IEEE Systems Journal*, vol. 8, no. 4, pp. 1136–1144, 2014.

- [11] N. Kumar, S. Misra, and M. S. Obaidat, "Collaborative learning automata-based routing for rescue operations in dense urban regions using vehicular sensor networks," *IEEE Systems Journal*, vol. 9, no. 3, pp. 1081–1090, 2015.
- [12] N. Kumar, S. Tyagi, and D.-J. Deng, "LA-EEHSC: Learning automata-based energy efficient heterogeneous selective clustering for wireless sensor networks," *Journal of Network and Computer Applications*, vol. 46, pp. 264–279, 2014.
- [13] N. Kumar, R. Iqbal, S. Misra, and J. J. Rodrigues, "An intelligent approach for building a secure decentralized public key infrastructure in VANET," *Journal of Computer and System Sciences*, vol. 81, no. 6, pp. 1042–1058, 2015.
- [14] N. Kumar, S. Misra, J. J. Rodrigues, and M. S. Obaidat, "Coalition games for spatio-temporal big data in internet of vehicles environment: a comparative analysis," *IEEE Internet of Things Journal*, vol. 2, no. 4, pp. 310–320, 2015.
- [15] N. Kumar, J. J. Rodrigues, and N. Chilamkurti, "Bayesian coalition game as-a-service for content distribution in internet of vehicles," *IEEE Internet of Things Journal*, vol. 1, no. 6, pp. 544–555, 2014.
- [16] R. Kumar and M. Dave, "A comparative study of various routing protocols in VANET," *arXiv preprint arXiv:1108.2094*, 2011.
- [17] R. S. Bali, N. Kumar, and J. J. Rodrigues, "Clustering in vehicular ad hoc networks: taxonomy, challenges and solutions," *Vehicular communications*, vol. 1, no. 3, pp. 134–152, 2014.
- [18] A. Dua, N. Kumar, and S. Bawa, "QoS-aware data dissemination for dense urban regions in vehicular ad hoc networks," *Mobile Networks and Applications*, vol. 20, no. 6, pp. 773–780, 2015.
- [19] N. Kumar and J. Kim, "Probabilistic trust aware data replica placement strategy for online video streaming applications in vehicular delay tolerant networks," *Mathematical and Computer Modelling*, vol. 58, no. 1, pp. 3–14, 2013.
- [20] A. Paul and S. Rho, "Probabilistic model for M2M in iot networking and communication," *Telecommunication Systems*, pp. 1–8, 2015.
- [21] D. Evans, "The internet of things: How the next evolution of the internet is changing everything," *CISCO white paper*, vol. 1, pp. 1–11, 2011.
- [22] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, "A comprehensive survey on vehicular ad hoc network," *Journal of network and computer applications*, vol. 37, pp. 380–392, 2014.
- [23] C.-C. Lin and D.-J. Deng, "Optimal two-lane placement for hybrid VANET-sensor networks," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 12, pp. 7883–7891, 2015.
- [24] D. B. Johnson and D. A. Maltz, "Dynamic source routing in ad hoc wireless networks," in *Mobile computing*. Springer, 1996, pp. 153–181.

- [25] T. K. Mak, K. P. Laberteaux, and R. Sengupta, "A multi-channel vanet providing concurrent safety and commercial services," in *Proceedings of the 2nd ACM international workshop on Vehicular ad hoc networks*. ACM, Cologne, Germany, September 02, 2005, pp. 1–9.
- [26] M. Van Eenennaam, W. K. Wolterink, G. Karagiannis, and G. Heijenk, "Exploring the solution space of beaconing in VANETs," in *IEEE Vehicular Networking Conference (VNC), 2009*. IEEE, Tokyo, Japan, 28-30 Oct, 2009, pp. 1–8.
- [27] S. Yu, W. Zhou, and R. Doss, "Information theory based detection against network behavior mimicking ddos attacks," *IEEE Communications Letters*, vol. 12, no. 4, pp. 318–321, 2008.
- [28] R. Singh and T. P. Sharma, "A secure wlan authentication scheme," *IEIE Transactions on Smart Processing & Computing*, vol. 2, no. 3, pp. 176–187, 2013.
- [29] Y. Günter, B. Wiegel, and H. P. Grossmann, "Cluster-based medium access scheme for vanets," in *IEEE Intelligent Transportation Systems Conference, ITSC 2007*. IEEE, 2007, pp. 343–348.
- [30] V. Namboodiri and L. Gao, "Prediction-based routing for vehicular ad hoc networks," *IEEE Transactions on Vehicular Technology*, vol. 56, no. 4, pp. 2332–2345, 2007.
- [31] C. E. Perkins and P. Bhagwat, "Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers," in *ACM SIGCOMM computer communication review*, vol. 24, no. 4. ACM, London, UK, Aug 31 - Sep 2, 1994, pp. 234–244.
- [32] G. Pei, M. Gerla, and T.-W. Chen, "Fisheye state routing: A routing scheme for ad hoc wireless networks," in *IEEE International Conference on Communications, ICC 2000*, vol. 1. IEEE, New Orleans, LA, 18-22 June, 2000, pp. 70–74.
- [33] J. Toutouh, J. García-Nieto, and E. Alba, "Intelligent OLSR routing protocol optimization for VANETs," *IEEE Transactions on Vehicular Technology*, vol. 61, no. 4, pp. 1884–1894, 2012.
- [34] M. Bakhouya, J. Gaber, and P. Lorenz, "An adaptive approach for information dissemination in vehicular ad hoc networks," *Journal of Network and Computer Applications*, vol. 34, no. 6, pp. 1971–1978, 2011.
- [35] C. T. Calafate, G. Fortino, S. Fritsch, J. Monteiro, J.-C. Cano, and P. Manzoni, "An efficient and robust content delivery solution for ieee 802.11 p vehicular environments," *Journal of Network and Computer Applications*, vol. 35, no. 2, pp. 753–762, 2012.
- [36] T. Paila, "Unidirectional ip-based mass file delivery protocol," in *1st International Symposium on Wireless Communication Systems, 2004*. IEEE, Mauritius, 20-22 Sep, 2004, pp. 235–239.

- [37] N. Maslekar, J. Mouzna, M. Boussedjra, and H. Labiod, "CATS: An adaptive traffic signal system based on car-to-car communication," *Journal of Network and Computer Applications*, vol. 36, no. 5, pp. 1308–1315, 2013.
- [38] B. Ying, D. Makrakis, and H. T. Mouftah, "Privacy preserving broadcast message authentication protocol for VANETs," *Journal of Network and Computer Applications*, vol. 36, no. 5, pp. 1352–1364, 2013.
- [39] R. A. Santos, A. Edwards, R. Edwards, and N. L. Seed, "Performance evaluation of routing protocols in vehicular ad-hoc networks," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 1, no. 1-2, pp. 80–91, 2005.
- [40] R. Kumar and K. Arya, "A modified approach for route maintenance using alternate path in AODV," in *2011 International Conference on Computational Intelligence and Communication Networks (CICN)*. IEEE, Gwalior, India, 7-9 Oct, 2011, pp. 37–41.
- [41] M. Fogue, P. Garrido, F. J. Martinez, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Evaluating the impact of a novel message dissemination scheme for vehicular networks using real maps," *Transportation Research Part C: Emerging Technologies*, vol. 25, pp. 61–80, 2012.
- [42] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The broadcast storm problem in a mobile ad hoc network," *Wireless networks*, vol. 8, no. 2-3, pp. 153–167, 2002.
- [43] Y. Ding, C. Wang, and L. Xiao, "A static-node assisted adaptive routing protocol in vehicular networks," in *Proceedings of the fourth ACM international workshop on Vehicular ad hoc networks*. ACM, Montreal, Canada, 10 Sept, 2007, pp. 59–68.
- [44] J. Nzouonta, N. Rajgure, G. Wang, and C. Borcea, "VANET routing on city roads using real-time vehicular traffic information," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 7, pp. 3609–3626, 2009.
- [45] V. Namboodiri, M. Agarwal, and L. Gao, "A study on the feasibility of mobile gateways for vehicular ad-hoc networks," in *Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*. ACM, Philadelphia, USA, 1st Oct, 2004, pp. 66–75.
- [46] Y. Liu, J. Niu, J. Ma, L. Shu, T. Hara, and W. Wang, "The insights of message delivery delay in vanets with a bidirectional traffic model," *Journal of Network and Computer Applications*, vol. 36, no. 5, pp. 1287–1294, 2013.
- [47] E. Palomar, J. M. de Fuentes, A. I. González-Tablas, and A. Alcaide, "Hindering false event dissemination in VANETs with proof-of-work mechanisms," *Transportation Research Part C: Emerging Technologies*, vol. 23, pp. 85–97, 2012.
- [48] X. Huang and Y. Fang, "Performance study of node-disjoint multipath routing in vehicular ad hoc networks," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 4, pp. 1942–1950, 2009.
- [49] M. Fathy, S. GholamalitabarFirouzjaee, and K. Raahemifar, "Improving QoS in VANET using MPLS," *Procedia Computer Science*, vol. 10, pp. 1018–1025, 2012.

- [50] V. Naumov and T. R. Gross, “Connectivity-aware routing (CAR) in vehicular ad-hoc networks,” in *26th IEEE International Conference on Computer Communications INFOCOM 2007*. IEEE, Anchorage, Alaska, USA, 6-12 May, 2007, pp. 1919–1927.
- [51] C. Lochert, H. Hartenstein, J. Tian, H. Fussler, D. Hermann, and M. Mauve, “A routing strategy for vehicular ad hoc networks in city environments,” in *IEEE Intelligent Vehicles Symposium, 2003*. IEEE, Ohio, USA, Jun 9-11, 2003, pp. 156–161.
- [52] B. Karp and H.-T. Kung, “GPSR: Greedy perimeter stateless routing for wireless networks,” in *Proceedings of the 6th annual international conference on Mobile computing and networking*. ACM, Boston, MA, USA, 6-11, Aug, 2000, pp. 243–254.
- [53] Y.-J. Kim, R. Govindan, B. Karp, and S. Shenker, “Geographic routing made practical,” in *Proceedings of the 2nd conference on Symposium on Networked Systems Design & Implementation-Volume 2*. USENIX Association, Berkeley, CA, USA, 2nd May, 2005, pp. 217–230.
- [54] K. C. Lee, U. Lee, and M. Gerla, “Survey of routing protocols in vehicular ad hoc networks,” *Advances in vehicular ad-hoc networks: Developments and challenges*, pp. 149–170, 2010.
- [55] S. Schnauffer and W. Effelsberg, “Position-based unicast routing for city scenarios,” in *International Symposium on a World of Wireless, Mobile and Multimedia Networks, WoWMoM 2008*. IEEE, Newport Beach, CA, USA, 23-26 June, 2008, pp. 1–8.
- [56] K. C. Lee, J. O. Häerri, U. Lee, and M. Gerl, “Enhanced perimeter routing for geographic forwarding protocols in urban vehicular scenarios,” in *IEEE Globecom Workshops, 2007*. IEEE, Washington DC, USA, 26-30 Nov, 2007, pp. 1–10.
- [57] D. Forderer, “Street-topology based routing,” *Master’s thesis, University of Mannheim*, 2005.
- [58] K. C. Lee, M. Le, J. Häerri, and M. Gerla, “LOUVRE: Landmark overlays for urban vehicular routing environments,” in *68th IEEE Vehicular Technology Conference, 2008. VTC 2008-Fall*. IEEE, Calgary, Canada, 21-24 Sep, 2008, pp. 1–5.
- [59] H. Füßler, H. Hartenstein, M. Mauve, W. Effelsberg, and J. Widmer, “Contention-based forwarding for street scenarios,” in *1st International workshop in intelligent transportation (WIT 2004)*, no. LCA-CONF-2004-005, Hamburg, Germany, 23-24 Mar, 2004.
- [60] Y.-J. K. R. Govindan, B. Karp, and S. Shenker, “Lazy cross-link removal for geographic routing,” in *Proceedings of the 4th international conference on Embedded networked sensor systems*. ACM, Boulder, CO, USA, 1-3 Nov, 2006, pp. 112–124.
- [61] K. C. Lee, P.-C. Cheng, and M. Gerla, “GeoCross: A geographic routing protocol in the presence of loops in urban scenarios,” *Ad Hoc Networks*, vol. 8, no. 5, pp. 474–488, 2010.

- [62] V. N. Soares, J. J. Rodrigues, and F. Farahmand, “GeoSpray: A geographic routing protocol for vehicular delay-tolerant networks,” *Information Fusion*, vol. 15, pp. 102–113, 2014.
- [63] M. Li, K. Zeng, and W. Lou, “Opportunistic broadcast of event-driven warning messages in vehicular ad hoc networks with lossy links,” *Computer Networks*, vol. 55, no. 10, pp. 2443–2464, 2011.
- [64] J. Bernsen and D. Manivannan, “RIVER: A reliable inter-vehicular routing protocol for vehicular ad hoc networks,” *Computer Networks*, vol. 56, no. 17, pp. 3795–3807, 2012.
- [65] Y. Xiang, Z. Liu, R. Liu, W. Sun, and W. Wang, “GeoSVR: A map-based stateless vanet routing,” *Ad Hoc Networks*, vol. 11, no. 7, pp. 2125–2135, 2013.
- [66] E.-K. Lee, S. Y. Oh, and M. Gerla, “RFID assisted vehicle positioning in VANETs,” *Pervasive and Mobile Computing*, vol. 8, no. 2, pp. 167–179, 2012.
- [67] K. Mershad, H. Artail, and M. Gerla, “ROAMER: Roadside units as message routers in VANETs,” *Ad Hoc Networks*, vol. 10, no. 3, pp. 479–496, 2012.
- [68] A. Fonseca and T. Vazão, “Applicability of position-based routing for VANET in highways and urban environment,” *Journal of Network and Computer Applications*, vol. 36, no. 3, pp. 961–973, 2013.
- [69] C. Liu and C. Chigan, “RPB-MD: Providing robust message dissemination for vehicular ad hoc networks,” *Ad Hoc Networks*, vol. 10, no. 3, pp. 497–511, 2012.
- [70] C. Campolo, H. A. Cozzetti, A. Molinaro, and R. Scopigno, “Augmenting vehicle-to-roadside connectivity in multi-channel vehicular ad hoc networks,” *Journal of Network and Computer Applications*, vol. 36, no. 5, pp. 1275–1286, 2013.
- [71] L. Briesemeister, L. Schäfers, and G. Hommel, “Disseminating messages among highly mobile hosts based on inter-vehicle communication,” in *Proceedings of the IEEE Intelligent Vehicles Symposium, 2000. IV 2000*. IEEE, 2000, pp. 522–527.
- [72] C. Maihöfer, T. Leinmüller, and E. Schoch, “Abiding geocast: time-stable geocast for ad hoc networks,” in *Proceedings of the 2nd ACM international workshop on Vehicular ad hoc networks*. ACM, Cologne, Germany, 2 Sep, 2005, pp. 20–29.
- [73] N. Cenerario, T. Delot, and S. Ilarri, “A content-based dissemination protocol for VANETs: Exploiting the encounter probability,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 771–782, 2011.
- [74] T. Delot, N. Cenerario, and S. Ilarri, “Estimating the relevance of information in inter-vehicle ad hoc networks,” in *Ninth International Conference on Mobile Data Management Workshops, 2008. MDMW 2008*. IEEE, Beijing, China, 27-30 Apr, 2008, pp. 151–158.
- [75] N. Cenerario, T. Delot, and S. Ilarri, “Dissemination of information in inter-vehicle ad hoc networks,” in *IEEE Intelligent Vehicles Symposium, 2008*. IEEE, Eindhoven, Netherlands, 4-6 June, 2008, pp. 763–768.

- [76] T. Delot, N. Cenerario, and S. Ilarri, “Vehicular event sharing with a mobile peer-to-peer architecture,” *Transportation Research Part C: Emerging Technologies*, vol. 18, no. 4, pp. 584–598, 2010.
- [77] D. Borsetti, M. Fiore, C. Casetti, and C.-F. Chiasserini, “An application-level framework for information dissemination and collection in vehicular networks,” *Performance Evaluation*, vol. 68, no. 9, pp. 876–896, 2011.
- [78] R. Frank, E. Giordano, P. Cataldi, and M. Gerla, “TrafRoute: A different approach to routing in vehicular networks,” in *IEEE 6th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), 2010*. IEEE, Niagara Falls, Canada, 11-13 Oct, 2010, pp. 521–528.
- [79] Q. Yang, A. Lim, S. Li, J. Fang, and P. Agrawal, “ACAR: Adaptive connectivity aware routing for vehicular ad hoc networks in city scenarios,” *Mobile Networks and Applications*, vol. 15, no. 1, pp. 36–60, 2010.
- [80] The Network Simulator - ns-2 www.isi.edu/nsnam/ns/ Last accessed on: 31st January, 2016.
- [81] Y.-S. Chen, Y.-W. Lin, and C.-Y. Pan, “DIR: diagonal-intersection-based routing protocol for vehicular ad hoc networks,” *Telecommunication systems*, vol. 46, no. 4, pp. 299–316, 2011.
- [82] D. Borsetti and J. Gozalvez, “Infrastructure-assisted geo-routing for cooperative vehicular networks,” in *IEEE Vehicular networking conference (VNC), 2010*. IEEE, New Jersey, USA, 13-15 Dec, 2010, pp. 255–262.
- [83] J. Luo, X. Gu, T. Zhao, and W. Yan, “A mobile infrastructure based vanet routing protocol in the urban environment,” in *International Conference on Communications and Mobile Computing (CMC), 2010*, vol. 3. IEEE, Shenzhen, China, 12-14 Apr, 2010, pp. 432–437.
- [84] Y.-S. Chen, Y.-W. Lin, and S.-L. Lee, “A mobicast routing protocol in vehicular ad-hoc networks,” *Mobile Networks and Applications*, vol. 15, no. 1, pp. 20–35, 2010.
- [85] S.-Y. Wang and C.-C. Lin, “Nctuns 6.0: a simulator for advanced wireless vehicular network research,” in *IEEE 71st Vehicular Technology Conference (VTC 2010-Spring), 2010*. IEEE, 2010, pp. 1–2.
- [86] E. Fasolo, A. Zanella, and M. Zorzi, “An effective broadcast scheme for alert message propagation in vehicular ad hoc networks,” in *IEEE International Conference on Communications, 2006. ICC’06*, vol. 9. IEEE, Istanbul, Turkey, 11-15 Jun, 2006, pp. 3960–3965.
- [87] M. Rocchetti, G. Marfia, and A. Amoroso, “An optimal 1d vehicular accidentwarning algorithm for realistic scenarios,” in *IEEE Symposium on Computers and Communications (ISCC), 2010*. IEEE, Riccione, Italy, 22-25 Jun, 2010, pp. 145–150.
- [88] The Georgia Tech Network Simulator (GTNetS), www2.ece.gatech.edu/research/labs/MANIACS/GTNetS/, Accessed on [31st January, 2016].

- [89] M. Kihl, M. Sichitiu, and H. Joshi, "Design and evaluation of two geocast protocols for vehicular ad-hoc networks," *Journal of Internet Engineering*, 2008.
- [90] K. Ibrahim, M. C. Weigle, and M. Abuelela, "p-IVG: Probabilistic inter-vehicle geocast for dense vehicular networks." in *VTC Spring*, 2009.
- [91] C.-H. Ou, "A roadside unit-based localization scheme for vehicular ad hoc networks," *International Journal of Communication Systems*, vol. 27, no. 1, pp. 135–150, 2014.
- [92] M.-C. Chuang and M. C. Chen, "Deep: Density-aware emergency message extension protocol for vanets," *IEEE Transactions on Wireless Communications*, vol. 12, no. 10, pp. 4983–4993, 2013.
- [93] S. Kumar and R. B. Mishra, "A hybrid model for service selection in semantic web service composition," *International Journal of Intelligent Information Technologies (IJIIT)*, vol. 4, no. 4, pp. 55–69, 2008.
- [94] M. Al-Rabayah and R. Malaney, "A new scalable hybrid routing protocol for VANETs," *IEEE Transactions on Vehicular Technology*, vol. 61, no. 6, pp. 2625–2635, 2012.
- [95] Y. MingChuan, G. Qing *et al.*, "End-to-end delay assessment and hybrid routing protocol for vehicular ad hoc network," *IERI Procedia*, vol. 2, pp. 727–733, 2012.
- [96] K. Abrougui, A. Boukerche, and R. W. N. Pazzi, "Location-aided gateway advertisement and discovery protocol for VANETs," *IEEE Transactions on Vehicular Technology*, vol. 59, no. 8, pp. 3843–3858, 2010.
- [97] X. Huang, I. Rubin, and H. Ju, "Mobile backbone network routing with flow control and distance awareness (MBNR-FC/DA)," in *IEEE Military Communications Conference, MILCOM*, vol. 4, Atlantic City, NJ, USA, 17-21 Oct, 2005, p. 2048.
- [98] N. Brahma, M. Boussedjra, J. Mouzna, and M. Bayart, "Adaptative movement aware routing for vehicular ad hoc networks," in *Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly*. ACM, Leipzig, Germany, 21-24 June, 2009, pp. 1310–1315.
- [99] P.-C. Cheng, K. C. Lee, M. Gerla, and J. Härri, "GeoDTN+ nav: geographic dtm routing with navigator prediction for urban vehicular environments," *Mobile Networks and Applications*, vol. 15, no. 1, pp. 61–82, 2010.
- [100] G. Maia, A. L. Aquino, A. Viana, A. Boukerche, and A. A. Loureiro, "HyDi: a hybrid data dissemination protocol for highway scenarios in vehicular ad hoc networks," in *Proceedings of the second ACM international symposium on Design and analysis of intelligent vehicular networks and applications*. ACM, Paphos, AA, Cyprus, 21-25 Oct, 2012, pp. 115–122.
- [101] H.-Y. Pan, R.-H. Jan, A. A.-K. Jeng, C. Chen, and H.-R. Tseng, "Mobile-gateway routing for vehicular networks," in *Proceedings of the 8th IEEE/VTS Asia Pacific wireless communication symposium (APWCS 2011)*, Singapore, 22-23 Aug, 2011.

- [102] K. Abrougui, A. Boukerche, and H. Ramadan, "Performance evaluation of an efficient fault tolerant service discovery protocol for vehicular networks," *Journal of Network and Computer Applications*, vol. 35, no. 5, pp. 1424–1435, 2012.
- [103] R. S. Schwartz, R. R. Barbosa, N. Meratnia, G. Heijenk, and H. Scholten, "A directional data dissemination protocol for vehicular environments," *Computer Communications*, vol. 34, no. 17, pp. 2057–2071, 2011.
- [104] OMNeT++ Discrete Event Simulator, <https://omnetpp.org/>, Accessed on [31st Jan, 2016].
- [105] A. Daeinabi, A. G. P. Rahbar, and A. Khademzadeh, "VWCA: An efficient clustering algorithm in vehicular ad hoc networks," *Journal of Network and Computer Applications*, vol. 34, no. 1, pp. 207–222, 2011.
- [106] S.-S. Wang and Y.-S. Lin, "PassCAR: A passive clustering aided routing protocol for vehicular ad hoc networks," *Computer Communications*, vol. 36, no. 2, pp. 170–179, 2013.
- [107] J. Barrachina, P. Garrido, M. Fogue, F. J. Martinez, J.-C. Cano, C. T. Calafate, and P. Manzoni, "VEACON: A vehicular accident ontology designed to improve safety on the roads," *Journal of Network and Computer Applications*, vol. 35, no. 6, pp. 1891–1900, 2012.
- [108] J. Blum, A. Eskandarian, and L. Hoffman, "Mobility management in IVC networks," in *Proceedings of IEEE Intelligent Vehicles Symposium, 2003*. IEEE, Ohio, USA, 9-11 Jun, 2003, pp. 150–155.
- [109] M. Kakkasageri and S. Manvi, "Multiagent driven dynamic clustering of vehicles in VANETs," *Journal of Network and Computer Applications*, vol. 35, no. 6, pp. 1771–1780, 2012.
- [110] T. D. Little and A. Agarwal, "An information propagation scheme for VANETs," in *Proceedings of IEEE Intelligent Transportation Systems, 2005*. IEEE, Vienna, Austria, 13-15 Sep, 2005, pp. 155–160.
- [111] M. Pan, P. Li, and Y. Fang, "Cooperative communication aware link scheduling for cognitive vehicular networks," *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 4, pp. 760–768, 2012.
- [112] Z. Li and C. Chigan, "LEAPER: A lightweight reliable and faithful data packet relaying framework for vanets," *Ad Hoc Networks*, vol. 9, no. 3, pp. 418–429, 2011.
- [113] B. Scheuermann, C. Lochert, J. Rybicki, and M. Mauve, "A fundamental scalability criterion for data aggregation in VANETs," in *Proceedings of the 15th annual international conference on Mobile computing and networking*. ACM, Beijing, China, 20-25 Sep, 2009, pp. 285–296.
- [114] Y. Luo, W. Zhang, and Y. Hu, "A new cluster based routing protocol for VANET," in *Second International Conference on Networks Security Wireless Communications and Trusted Computing (NSWCTC), 2010*, vol. 1. IEEE, Wuhan, China, 24-25 Apr, 2010, pp. 176–180.

- [115] T. Wang and G. Wang, "TIBCRPH: traffic infrastructure based cluster routing protocol with handoff in VANET," in *19th Annual Wireless and Optical Communications Conference (WOCC), 2010*. IEEE, Shanghai, China, 14-15 May, 2010, pp. 1-5.
- [116] W. Xiaonan and Q. Huanyan, "Constructing a vanet based on cluster chains," *International Journal of Communication Systems*, vol. 27, no. 11, pp. 2497-2517, 2014.
- [117] L. T. Lilien, L. Ben Othmane, P. Angin, A. DeCarlo, R. M. Salih, and B. Bhargava, "A simulation study of ad hoc networking of UAVs with opportunistic resource utilization networks," *Journal of Network and Computer Applications*, vol. 38, pp. 3-15, 2014.
- [118] R. Bauza, J. Gozalvez, and J. Sanchez-Soriano, "Road traffic congestion detection through cooperative vehicle-to-vehicle communications," in *IEEE 35th Conference on Local Computer Networks (LCN), 2010*. IEEE, Denver, USA, 10-14 Oct, 2010, pp. 606-612.
- [119] I. Leontiadis, G. Marfia, D. Mack, G. Pau, C. Mascolo, and M. Gerla, "On the effectiveness of an opportunistic traffic management system for vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 4, pp. 1537-1548, 2011.
- [120] M. Yuksel, R. Pradhan, and S. Kalyanaraman, "An implementation framework for trajectory-based routing in ad hoc networks," *Ad Hoc Networks*, vol. 4, no. 1, pp. 125-137, 2006.
- [121] X. Wang, X. Zhang, G. Chen, and Q. Zhang, "Opportunistic cooperation in low duty cycle wireless sensor networks," in *IEEE International Conference on Communications (ICC), 2010*. IEEE, Capetown, South Africa, 23-27 May, 2010, pp. 1-5.
- [122] B.-J. Chang, Y.-H. Liang, and Y.-D. Huang, "Adaptive message forwarding for avoiding broadcast storm and guaranteeing delay in active safe driving VANET," *Wireless Networks*, vol. 21, no. 3, pp. 739-756, 2015.
- [123] N. N. Nakorn and K. Rojviboonchai, "DECA: density-aware reliable broadcasting in vehicular ad hoc networks," in *International Conference on Electrical Engineering/Electronics Computer Telecommunications and Information Technology (ECTI-CON), 2010*. IEEE, Chiang Mai, Thailand, 19-21 May, 2010, pp. 598-602.
- [124] K. C. Lee, U. Lee, and M. Gerla, "TO-GO: Topology-assist geo-opportunistic routing in urban vehicular grids," in *Sixth International Conference on Wireless On-Demand Network Systems and Services, WONS 2009*. IEEE, Snowbird, UT, USA, 2-4 Feb, 2009, pp. 11-18.
- [125] Y. Li, D. Jin, Z. Wang, L. Zeng, and S. Chen, "Coding or not: Optimal mobile data offloading in opportunistic vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 1, pp. 318-333, 2014.

- [126] B. Han, P. Hui, V. A. Kumar, M. V. Marathe, J. Shao, and A. Srinivasan, "Mobile data offloading through opportunistic communications and social participation," *IEEE Transactions on Mobile Computing*, vol. 11, no. 5, pp. 821–834, 2012.
- [127] L. Xiaofeng, H. Pan, and P. Lio, "Offloading mobile data from cellular networks through peer-to-peer WiFi communication: A subscribe-and-send architecture," *Communications, China*, vol. 10, no. 6, pp. 35–46, 2013.
- [128] A. Aijaz, H. Aghvami, and M. Amani, "A survey on mobile data offloading: technical and business perspectives," *IEEE Wireless Communications*, vol. 20, no. 2, pp. 104–112, 2013.
- [129] A. Wagh, X. Li, R. Sudhaakar, S. Addepalli, and C. Qiao, "Data fusion with flexible message composition in driver-in-the-loop vehicular cps," *Ad Hoc Networks*, vol. 11, no. 7, pp. 2083–2095, 2013.
- [130] L. Zhang, D. Gao, W. Zhao, and H.-C. Chao, "A multilevel information fusion approach for road congestion detection in VANETs," *Mathematical and Computer Modelling*, vol. 58, no. 5, pp. 1206–1221, 2013.
- [131] J. Virtamo, E. Hyttiä, and P. Lassila, "Criticality condition for information floating with random walk of nodes," *Performance Evaluation*, vol. 70, no. 2, pp. 114–123, 2013.
- [132] P. K. Sahu, E. H.-K. Wu, J. Sahoo, and M. Gerla, "BAHG: back-bone-assisted hop greedy routing for vanet's city environments," *IEEE Transactions on Intelligent Transportation Systems*, vol. 14, no. 1, pp. 199–213, 2013.
- [133] OpenStreetMap <https://www.openstreetmap.org/> Last accessed on: 31st January 2016.
- [134] Simulator of Urban MObility www.dlr.de/ts/sumo/en/ Last accessed on: 31st January 2016.
- [135] R. S. Raw and D. Lobiyal, "B-MFR routing protocol for vehicular ad hoc networks," in *International Conference on Networking and Information Technology (ICNIT), 2010*. IEEE, Manila, Philippines, 11-12 Jun, 2010, pp. 420–423.
- [136] R. K. Shrestha, S. Moh, I. Chung, and D. Choi, "Vertex-based multihop vehicle-to-infrastructure routing for vehicular ad hoc networks," in *43rd Hawaii International Conference on System Sciences (HICSS), 2010*. IEEE, Honolulu, HI, 5-8 Jan 2010, pp. 1–7.
- [137] G. Korkmaz, E. Ekici, and F. Özgüner, "Black-burst-based multihop broadcast protocols for vehicular networks," *IEEE Transactions on Vehicular Technology*, vol. 56, no. 5, pp. 3159–3167, 2007.
- [138] J. Sahoo, E. H. K. Wu, P. K. Sahu, and M. Gerla, "BPAB: binary partition assisted emergency broadcast protocol for vehicular ad hoc networks," in *Proceedings of 18th International Conference on Computer Communications and Networks, ICCCN 2009*. IEEE, San Francisco, CA USA, 3-6 Aug, 2009, pp. 1–6.

- [139] K.-T. Feng, “LMA: location-and mobility-aware medium-access control protocols for vehicular ad hoc networks using directional antennas,” *IEEE Transactions on Vehicular Technology*, vol. 56, no. 6, pp. 3324–3336, 2007.
- [140] N. Ahmadifard, H. Nabizadeh, and M. Abbaspour, “ISEFF: An id-based scalable and efficient distributed file sharing technique in vehicular ad hoc networks,” *Wireless personal communications*, vol. 75, no. 2, pp. 821–841, 2014.
- [141] A. B. Souza, J. Celestino, F. A. Xavier, F. D. Oliveira, A. Patel, and M. Latifi, “Stable multicast trees based on ant colony optimization for vehicular ad hoc networks,” in *International Conference on Information Networking (ICOIN), 2013*. IEEE, Bangkok, Thailand, 27-30 Jan, 2013, pp. 101–106.
- [142] Y.-S. Chen, C.-S. Hsu, and C.-H. Cheng, “Network mobility protocol for vehicular ad hoc networks,” *International Journal of Communication Systems*, vol. 27, no. 11, pp. 3042–3063, 2014.
- [143] R. Fracchia and M. Meo, “Analysis and design of warning delivery service in intervehicular networks,” *IEEE Transactions on Mobile Computing*, vol. 7, no. 7, pp. 832–845, 2008.
- [144] C. E. Palazzi, F. Pezzoni, and P. M. Ruiz, “Delay-bounded data gathering in urban vehicular sensor networks,” *Pervasive and Mobile Computing*, vol. 8, no. 2, pp. 180–193, 2012.
- [145] A. Skordylis and N. Trigoni, “Efficient data propagation in traffic-monitoring vehicular networks,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 3, pp. 680–694, 2011.
- [146] P. Deshpande, A. Kashyap, C. Sung, and S. R. Das, “Predictive methods for improved vehicular WiFi access,” in *Proceedings of the 7th international conference on Mobile systems, applications, and services*. ACM, Krakow, Poland, 22-25 Jun, 2009, pp. 263–276.
- [147] Y. Li, M. Qian, D. Jin, P. Hui, Z. Wang, and S. Chen, “Multiple mobile data offloading through disruption tolerant networks,” *IEEE Transactions on Mobile Computing*, vol. 13, no. 7, pp. 1579–1596, 2014.
- [148] M. H. Cheung and J. Huang, “DAWN: Delay-aware wi-fi offloading and network selection,” *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 6, pp. 1214–1223, 2015.
- [149] R. A. Novo, C. J. Davolos, and Z. John Zhao, “Measuring the impact of redirecting and offloading mobile data traffic,” *Bell Labs Technical Journal*, vol. 18, no. 1, pp. 81–103, 2013.
- [150] X. Kang, Y.-K. Chia, S. Sun, and H. F. Chong, “Mobile data offloading through a third-party wifi access point: An operator’s perspective,” *IEEE Transactions on Wireless Communications*, vol. 13, no. 10, pp. 5340–5351, 2014.

- [151] J.-H. Lee, K. D. Singh, J.-M. Bonnin, and S. Pack, "Mobile data offloading: a host-based distributed mobility management approach," *IEEE Internet Computing*, vol. 18, no. 1, pp. 20–29, 2014.
- [152] L. Gao, G. Iosifidis, J. Huang, L. Tassiulas, and D. Li, "Bargaining-based mobile data offloading," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1114–1125, 2014.
- [153] R. Trestian, O. Ormond, and G.-M. Muntean, "Game theory-based network selection: solutions and challenges," *IEEE Communications Surveys & Tutorials*, vol. 14, no. 4, pp. 1212–1231, 2012.
- [154] Y. Choi, H. W. Ji, J.-y. Park, H.-c. Kim, and J. A. Silvester, "A 3W network strategy for mobile data traffic offloading," *IEEE Communications Magazine*, vol. 49, no. 10, pp. 118–123, 2011.
- [155] M. Sheng, J. Li, and Y. Shi, "Relative degree adaptive flooding broadcast algorithm for ad hoc networks," *IEEE Transactions on Broadcasting*, vol. 51, no. 2, pp. 216–222, 2005.
- [156] C.-C. Hung, H. Chan, and E. H.-K. Wu, "Mobility pattern aware routing for heterogeneous vehicular networks," in *Wireless Communications and Networking Conference, WCNC 2008*. IEEE, Las Vegas, Nevada, USA, 31 Mar-3 Apr, 2008, pp. 2200–2205.
- [157] H. P. Joshi, M. L. Sichitiu, and M. Kihl, "Distributed robust geocast multicast routing for inter-vehicle communication," in *Proceedings of WEIRD workshop on WiMax, wireless and mobility*, vol. 921, 2007.
- [158] Y.-S. Chen, Y.-W. Lin, and S.-L. Lee, "A mobicast routing protocol with carry-and-forward in vehicular ad-hoc networks," in *5th International ICST Conference on Communications and Networking in China (CHINACOM), 2010*. IEEE, Beijing, China, 25-27 Aug, 2010, pp. 1–5.
- [159] O. K. Tonguz, N. Wisitpongphan, and F. Bai, "DV-CAST: A distributed vehicular broadcast protocol for vehicular ad hoc networks," *IEEE Wireless Communications*, vol. 17, no. 2, pp. 47–57, 2010.
- [160] T. Wang, L. Song, Z. Han, and B. Jiao, "Dynamic popular content distribution in vehicular networks using coalition formation games," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 9, pp. 538–547, 2013.
- [161] R. Jain, D.-M. Chiu, and W. R. Hawe, *A quantitative measure of fairness and discrimination for resource allocation in shared computer system*. Eastern Research Laboratory, Digital Equipment Corporation Hudson, MA, 1984, vol. 38.
- [162] L. Lei, D. Wang, L. Zhou, X. Chen, and S. Cai, "Link availability estimation based reliable routing for aeronautical ad hoc networks," *Ad Hoc Networks*, vol. 20, pp. 53–63, 2014.
- [163] H. Yoo and D. Kim, "Repetition-based cooperative broadcasting for vehicular ad-hoc networks," *Computer Communications*, vol. 34, no. 15, pp. 1870–1882, 2011.

- [164] M. Rondinone and J. Gozalvez, “Contention-based forwarding with multi-hop connectivity awareness in vehicular ad-hoc networks,” *Computer Networks*, vol. 57, no. 8, pp. 1821–1837, 2013.
- [165] F. Doctor, R. Iqbal, and R. N. Naguib, “A fuzzy ambient intelligent agents approach for monitoring disease progression of dementia patients,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 5, no. 1, pp. 147–158, 2014.
- [166] N. Kumar, N. Chilamkurti, and S. Misra, “Bayesian coalition game for the internet of things: an ambient intelligence-based evaluation,” *IEEE Communications Magazine*, vol. 53, no. 1, pp. 48–55, 2015.
- [167] N. Kumar, R. S. Bali, R. Iqbal, N. Chilamkurti, and S. Rho, “Optimized clustering for data dissemination using stochastic coalition game in vehicular cyber-physical systems,” *The Journal of Supercomputing*, vol. 71, no. 9, pp. 3258–3287, 2015.
- [168] R. S. Bali and N. Kumar, “Secure clustering for efficient data dissemination in vehicular cyber-physical systems,” *Future Generation Computer Systems*, vol. 56, pp. 476–492, 2016.
- [169] N. Kumar, N. Chilamkurti, and J. H. Park, “ALCA: agent learning—based clustering algorithm in vehicular ad hoc networks,” *Personal and ubiquitous computing*, vol. 17, no. 8, pp. 1683–1692, 2013.
- [170] T. Elperin, I. Gertsbakh, and M. Lomonosov, “Estimation of network reliability using graph evolution models,” *IEEE Transactions on Reliability*, vol. 40, no. 5, pp. 572–581, 1991.
- [171] J. A. Moreno *et al.*, “Network reliability assessment using a cellular automata approach,” *Reliability Engineering & System Safety*, vol. 78, no. 3, pp. 289–295, 2002.
- [172] H. Cancela and M. El Khadiri, “The recursive variance-reduction simulation algorithm for network reliability evaluation,” *IEEE Transactions on Reliability*, vol. 52, no. 2, pp. 207–212, 2003.
- [173] J. L. Cook and J. E. Ramirez-Marquez, “Two-terminal reliability analyses for a mobile ad hoc wireless network,” *Reliability Engineering & System Safety*, vol. 92, no. 6, pp. 821–829, 2007.
- [174] J. Cook and J. E. Ramirez-Marquez, “Mobility and reliability modeling for a mobile ad hoc network,” *IIE Transactions*, vol. 41, no. 1, pp. 23–31, 2008.
- [175] S. Jose, “Ca, cisco visual networking index: Global mobile data traffic forecast update, 2012-2017,” *Cisco Public Information*, 2013.
- [176] S. Wang, L. Sun, Q. Sun, X. Li, and F. Yang, “Efficient service selection in mobile information systems,” *Mobile Information Systems*, vol. 2015, 2015.
- [177] F. Rebecchi, M. Dias de Amorim, V. Conan, A. Passarella, R. Bruno, and M. Conti, “Data offloading techniques in cellular networks: a survey,” *IEEE Communications Surveys & Tutorials*, vol. 17, no. 2, pp. 580–603, 2015.

- [178] N. Cheng, N. Lu, N. Zhang, X. S. Shen, and J. W. Mark, "Opportunistic wifi offloading in vehicular environment: A queueing analysis," in *IEEE Global Communications Conference (GLOBECOM), 2014*. IEEE, Texas, USA, 8-12 Dec, 2014, pp. 211–216.
- [179] A. Aijaz, H. Aghvami, and M. Amani, "A survey on mobile data offloading: technical and business perspectives," *IEEE Wireless Communications*, vol. 20, no. 2, pp. 104–112, 2013.
- [180] Y. Li, D. Jin, Z. Wang, L. Zeng, and S. Chen, "Coding or not: Optimal mobile data offloading in opportunistic vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 1, pp. 318–333, 2014.
- [181] A. Dua, N. Kumar, S. Bawa, and N. Chilamkurti, "Efficient TDMA based virtual back off algorithm for adaptive data dissemination in vanets," in *International Symposium on Wireless and Pervasive Computing (ISWPC), 2013*. IEEE, Taipei, Taiwan, 20-22 Nov, 2013, pp. 1–6.
- [182] A. Dua, N. Kumar, S. Bawa, and J. J. Rodrigues, "An intelligent context-aware congestion resolution protocol for data dissemination in vehicular ad hoc networks," *Mobile Networks and Applications*, vol. 20, no. 2, pp. 181–200, 2015.

LIST OF PUBLICATIONS

- (R1) Amit Dua, Neeraj Kumar, Seema Bawa, “QoS-aware data dissemination for dense urban regions in vehicular ad hoc networks,” *Mobile Networks and Applications*, vol. 20, no. 6, pp. 773-780, 2015. (*Springer, IF 1.05*) (*SCI/SCIE*).
- (R2) Amit Dua, Neeraj Kumar, Seema Bawa, “ReIDD: Reliability-aware Intelligent Data Dissemination Protocol for Broadcast Storm Problem in Vehicular Ad Hoc Networks,” *Telecommunication Systems*, DOI 10.1007/s11235-016-0184-0. (*Springer, IF 0.705*) (*SCI/SCIE*)
- (R3) Amit Dua, Neeraj Kumar, Seema Bawa, “Game Theoretic approach for Real-Time Data Dissemination and Offloading in Vehicular Ad hoc Networks,” *Journal of Real-Time Image Processing*, DOI: 0.1007/s11554-016-0615-x. (*Springer, IF 2.02*) (*SCI/SCIE*).
- (R4) Amit Dua, Neeraj Kumar, Seema Bawa, Joel JPC Rodrigues, “An intelligent context-aware congestion resolution protocol for data dissemination in vehicular ad hoc networks,” *Mobile Networks and Applications*, vol. 20, no. 2, pp. 181-200, 2015. (*Springer, IF 1.05*) (*SCI/SCIE*).
- (R5) Amit Dua, Neeraj Kumar, Seema Bawa, “A systematic review on routing protocols for vehicular ad hoc networks,” *Vehicular Communications*, vol. 1, no. 1 , pp. 33-52, 2014. (*Elsevier*) (*ESCI Indexed*).
- (R6) Amit Dua, Neeraj Kumar, and Seema Bawa, “Intelligent Technique for Clustering and Data Acquisition Vehicular Sensor Networks: Challenges and Solutions,” CRC Press, 2016. (*Taylor and Francis*)
- (R7) Amit Dua, Neeraj Kumar, Seema Bawa, “An Energy Efficient Data Dissemination and Information Retrieval Scheme for VANET,” In *IEEE International Conference on Data Science and Data Intensive Systems*, Sydney, Australia, 11-13 December 2015, pp. 427-434.
- (R8) Amit Dua, Neeraj Kumar, Seema Bawa, Naveen Chilamkurti, “Efficient TDMA based virtual back off algorithm for adaptive data dissemination in VANETs,” In *8th International Symposium on Wireless and Pervasive Computing (ISWPC)*, Taipei, Taiwan, 20-22 November 2013, pp. 1-6.