An Efficient Routing Protocol for VANET

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

DOCTOR OF PHILOSPHY

By

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Certificate

I hereby certify that the work which is being presented in the thesis entitles " An Efficient Routing Protocol for VANET" in partial fulfillments of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Computer Science and Engineering of Thapar Institute of Engineering and Technology, Patiala is an authentic record of my own work carried during the period from January 2011 to December 2017 under the supervision of Dr. Anil K. Verma, Professor, CSED, Thapar Institute of Engineering and Technology, (Deemed to be University), Patiala.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute/ university.

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Date: 20-08-2018 Prof. (Dr.) Anil K. Verma

Abstract

A report by World Health Organization (WHO) affirms that 1.2 million people die because of road accidents every year (World Health Organization, 2015). This is an alarming situation and requires immediate action to improve the safety measures in the vehicular industry. Intelligent transportation system (ITS) can link the gap between the traditional and the current vehicular industry by automating interactions between vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). Following the direction of ITS, vehicle manufacturing industry has initiated the invention of vehicles with improved technologies such as GPS navigation system, processing units, and the wireless interface. Further, by implementing these technologies, the vehicles can communicate either directly or through road side units (RSUs) and form a network known as vehicular Ad hoc network (VANET). In today's scenario, the VANET is considered as one of the best networking systems offering improved safety measurements for passengers as well as pedestrians. In VANET, each vehicle can act as a router to pass the messages to other vehicles moving in its range. Apart from the safety applications, VANET can also provide a number of services such as availability of parking space and information about traffic jams. The concept of smart cities along with ITS makes the VANET a vital topic of research nowadays. However, the high speed of vehicles, larger network size, and dense/sparse network connectivity make the VANET a challenging class of Ad hoc network.

There are several open issues in VANETs and routing is one of the important aspects of concern. A number of routing protocols have been presented from the commencement of VANET in this study. Most of the protocols follow the greedy forwarding technique to forward the data without considering the fact of interference, which may result in performance degradation on the real test bed. Usage of the infrastructure is also restricted in the existing protocols. Thus, an efficient routing protocol must ensure the solution of data forwarding challenges in VANET. In this thesis, three protocols namely, A Junction Based Infrastructure Assisted Routing Protocol for VANET: JIP"; Street Based Forwarding Protocol: SBFP; and Static Infrastructure Assisted Road Based Forwarding Protocol: SRBF have been proposed.

In protocol JIP, the presence of the infrastructure is considered in the network and it has been extensively used to improve the connectivity of the vehicles. In SBFP, the interference among different street segments is implemented to make the network scenario more realistic. This protocol has tested for packet delivery ratio, packet delivery time and network overhead with Greedy Perimeter Stateless Routing protocol and Contention Based Forwarding routing protocol. The proposed model has exhibited the potential to reduce the problem of the local maximum. The speed of vehicles and percentage of interference are the chief factors to affect the performance of protocols. Taking into account these factors, protocol SRBF is established. It has been evaluated and compared with its peer protocols, Contention Based

Forwarding with Multi Hop Connectivity in Vehicular Ad hoc Networks (TOPOCBF) and A Map Based Stateless VANET Routing (GeoSVR). Our analysis shows that SRBF performs better on packet delivery ratio and network overhead parameters.

KEYWORDS: VANET; Routing; JIP; SBFP; SRBF.

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Table of Contents

List of Figures

List of Tables

List of Important Abbreviations

AATR: Adaptive Allocation of Transmission Range

APU: Application Processing Unit

C2C-CC: Car-to-Car Communication Consortium

CAR: Connectivity Aware Routing

CBF: Contention Based Forwarding

CH: Cluster Head

CRN: Congested Road Notification

CW: Cluster Gateway

DID: Destination Static Node ID

DiRCoD: Distributed and Real-Time Communication Road Connectivity Discovery Scheme

DOT: Department of Transportation

DSRC: Dedicated Short-Range Communications

EBW: Electronic Break Warning

ETX: Expected Transmission Count

FCC: Federal Communication Commission

GeoSVR: A Map-Based Stateless VANET Routing

GPCR: Greedy Perimeter Coordinate Routing

GPS: Global Positioning System

GPSR: Greedy Perimeter Stateless Routing

GPSR+AGF: Greedy Perimeter Stateless Routing with Advance Greedy Forwarding

GyTAR: Greedy Traffic Aware Routing Protocol

IEEE: Institute of Electrical and Electronics Engineers.

iTETRIS: Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions

ITS: Intelligent Transportation System

IVW: Intersection Violation Warning

JIP: A Junction Based Infrastructure Assisted Routing Protocol for VANETs

KEL: Known Edge List

LLT: Link Life Time

m/s: Meter Per Second

MANET: Mobile Ad hoc Network

MGRP: Mobile Gateway Routing for Vehicular Networks

MIBR: A Mobile Infrastructure Based VANET Routing Protocol in the Urban Environment

MMV: Monitoring of Malicious Vehicles

NJ: Nearest Junction

NJC: Nearest Junction Coordinates

NSN_ID: Nearest Static Node's ID

OBU: On Board Unit

OEMs: Original Equipment Manufacturers

OTW: Oncoming Traffic Warning

PAN: Parking Availability Notification

PassCAR: A Passive Clustering Aided Routing Protocol for Vehicular Ad hoc Network

PC: Passive Clustering

PDR: Packet Delivery Ratio

PID: Packet ID

RBF: Road Based Forwarding

RID: Road ID

RIVER: A Reliable Inter Vehicular Routing Protocol for Vehicular Ad hoc Network

RSU: Road Side Unit

RTVB: Real Time Video Broadcast Notification

SADV: Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks

SAN: Service Announcement Notification

SBF: Street Based forwarding

SBFP: An Advanced Forwarding Routing Protocol for Urban Scenarios in VANETs

SID: Street ID

SNAR: Static Node Assisted Routing

SRBF: Street Based Forwarding Protocol

TOPOCBF: Contention Based Forwarding with Multi-Hop Connectivity Awareness in Vehicular Ad hoc Networks

V2I: Vehicle to Infrastructure

V2V: Vehicle to Vehicle

VANET(s): Vehicular Ad hoc Network(s)

VSW: Vehicle Stability Warning

VWCA: An Efficient Clustering Algorithm in Vehicular Ad Hoc Networks

WAVE: Wireless Access in Vehicular Environment

WSN: Wireless Sensor network

IVC: Inter-Vehicle Communication

SNs: Sensor Nodes

Chapter 1

Introduction

Nowadays Communication technology has become the part and parcel of everyone's day to day life. In earlier days, it was very complicated to send the information to remote places, but nowadays people share the information using latest communication technologies available. Internet is a mean to connect among different networks in which various devices such as mobiles, laptops, desktops, sensors are connected and allow to communicate among themselves (Dua *et al.*, 2016; Renzo *et al.,* 2017). These networking devices follow certain rules and regulations, which are called protocols. These protocols are designed according to the underlying network. The networks can be broadly classified into wireless network and wired network[1].

The wired network uses fixed infrastructure and cables to connect devices, where, switches, servers, and routers deployed in a specific region to make the communication possible. Whereas in a wireless network, radio waves are used to establish a connection among different

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[1] The contents of the chapter are partially published in:

Kumar, S., & Verma, A. K. (2015). Position based routing protocols in VANET: A Survey. Wireless Personal Communications, 83(4), 2747-2772. (Springer, SCIE Indexed, IF 0.951) computing devices. Further, the wireless network can be categorized in personal area network, local area network, metropolitan area network, wide area network and Ad hoc networks. Additionally, wireless Ad hoc network can be grouped in mobile Ad hoc networks and vehicular Ad hoc networks (Singh and Verma, 2017; Osseiran *et al.*, 2014).

A brief account of mobile Ad hoc networks, and vehicular Ad hoc networks will be discussing in the following sections.

1.1 Mobile Ad hoc Networks

A temporary or an Ad hoc arrangement of wireless nodes which possesses the high level of mobility, decentralized nature and do not utilize any infrastructure is known as Mobile Ad hoc Networks (MANET's) (Singh *et al.,* 2014; Sankaran *et al.,* 2009). Wireless nodes in MANET's supposed to have equal processing capabilities, high processing power and high battery capacities which can be charged as well (Pal and Singh, 2013; Lian *et al.,* 2006). Figure 1.1 illustrates the communication paradigm of Mobile Ad hoc Networks.

The characteristics of MANET's can be briefly summarized as:

- Nodes in MANETs exhibit distributed operation.
- MANETs are Infrastructure-less and possess the property of self-organization.
- The highly dynamic behavior of MANET's leads to increased network traffic overhead.

- Network topology maintenance, QoS and scalability enhancement are critical issues in MANETs.
- Infrastructure-less nature of MANET's make it easy to configure/ establish. However, it has limited coverage.

Nodes in MANET's show symmetric properties as they can behave as host or router as well.

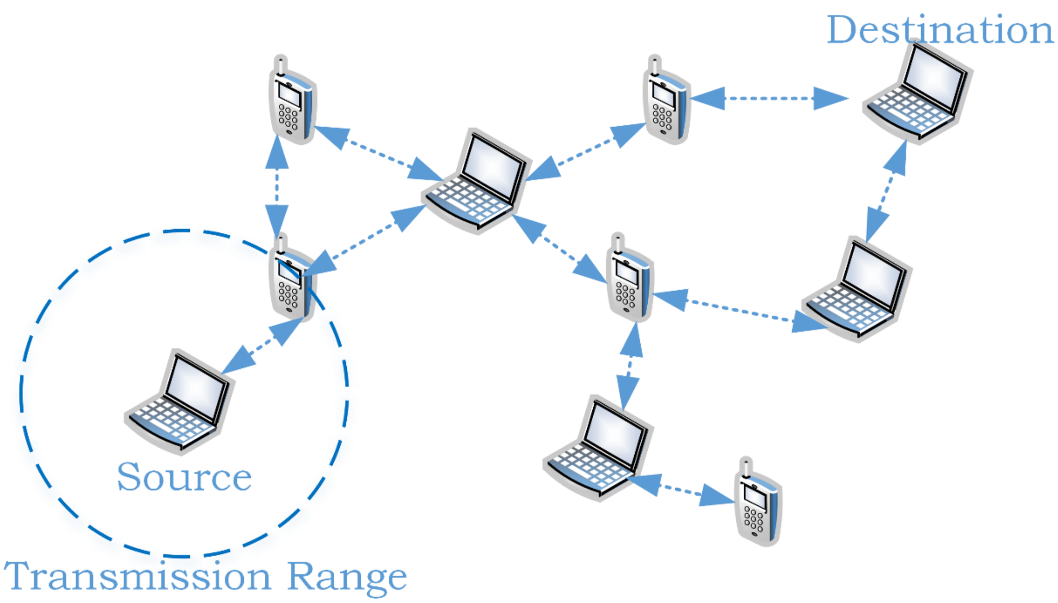

Figure 1. 1 Mobile Ad hoc Networks

1.2 Vehicular Ad hoc Networks

The research community, as well as automotive industry, has drawn their attention to improving inter-vehicle communication providing intelligent transportation system (ITS) to drivers and passengers (Cheng *et al.*, 2010; Chen *et al.*, 2009). Vehicular Ad hoc Network (VANET) is the wireless network that exists in between moving vehicles equipped with wireless interfaces and nearby fixed road side equipment which are supported by homogeneous or heterogeneous technologies, thus to allow short and medium range communication (Sultan *et al.,* 2014; Singh and Sharma, 2018; Sambariya *et al.,* 2016). The vehicles and fixed road side equipment in VANET can be public, private or may belong to any government or private organization.

It is a novel class of Wireless Ad hoc network to provide the advantages to drivers in safety and comfort (Nagaraj *et al.,* 2011; Zemouri *et al.,* 2015). In VANETs vehicles act as mobile nodes and these nodes can form a network with vehicles which come in the range of each other (Vegni and Loscr, 2015). Each vehicle is equipped with several sensors to collect the information of surroundings. VANET assists the drivers to communicate and to coordinate in order to avoid any critical situation such as traffic jams, accidents, unseen obstacles etc. Beside safety applications, VANETs provide comfort applications to users like internet accessing, mobile commerce, parking space, the location of nearest mall etc. (Zeletin *et al.,* 2010; Cheng *et al.,* 2011; Amadeo *et al.,* 2012).

Undeniably, VANETs are also capable to offer dissimilar communication services to pedestrians, passengers and drivers (Liang *et al.,* 2014; Cai *et al.,* 2014; Toor *et al.,* 2008). Thus, VANETs are getting significant interest from the automotive industry, researchers and as well as from government organizations. In this framework of VANETs, dedicated short-range communications (DSRC) with 75 MHz of licensed spectrum at 5.9 GHz was granted by the U.S. Federal Communication Commission (FCC) in 2003 (Chang, 2015). Apparently, to enhance the road safety measurements, car manufacturers and automotive original equipment manufacturers (OEMs) had initiated the Car-to-Car Communication Consortium (C2C-CC) (Baldessari, 2007). For Safety-related applications, the European Commission has allocated radio spectrum in the 5875-5905 MHz frequency. In Japan, 5.8 GHz spectrum is extensively using for electronic toll collection. Thus, it is also proposed to use 5.8 GHz for Vehicle to Infrastructure (V2I) based applications and 700 MHz spectrum is allocated for Vehicle to Vehicle (V2V) based applications. The Intelligent transportation systems with V2V and V2I were supported by the United States, Department of Transportation (DOT) (CICAS, 2009). Currently, IEEE 802.11p standard is used for the Physical and Medium Access Control address portion of the DSRC (IEEE 802.11 Working Group, 1999; Krishnan *et al.,* 2010). The four standards have been introduced by IEEE for wireless access in the vehicular environment (WAVE) (Carpenter, 2013; IEEE draft guide for Wireless Access in Vehicular Environments) are as follows:

I. IEEE P1609.1, which is known as WAVE resource manager, it describes the application platform and contains the read/write protocol between Onboard unit (OBU) and Road side unit (RSU).
II. IEEE P1609.2 is known as WAVE Security Services and outlines the 5.9-GHz DSRC Security, anonymity, authenticity, and confidentiality.
III. IEEE P1609.3 is known as WAVE networking services and outlines the services of network and transport layers including

secure data transfer with routing, iv) IEEE P1609.4, known as WAVE multichannel operations, manages DSRC frequency band coordination.

1.2.1 VANET Communication Architecture

The recent advancement in Ad hoc networking technologies allows a variety of deployment architectures for VANETs in different scenarios, such as rural, urban and highway. It can be deployed either with the support of government agencies or private service providers. These architectures allow communication between vehicles and the infrastructure or RSUs deployed at the road side. Communication in VANET can be facilitated by three types of its architecture (Lee *et al.,* 2010; Karagiannis *et al.*, 2011; Li and Wang, 2007): pure cellular, pure Ad hoc and hybrid.

In pure cellular architecture, the communication among vehicles is possible only with the assistance of RSUs (Figure 1.2). The pure cellular architecture supports V2I communication applications (Kumar and Verma, 2017).

The pure Ad hoc architecture (Figure 1.3) is an Infrastructure-less network in which vehicles communicate directly with the help of sensors. This is V2V kind of communication application (Yousefi *et al.,* 2006).

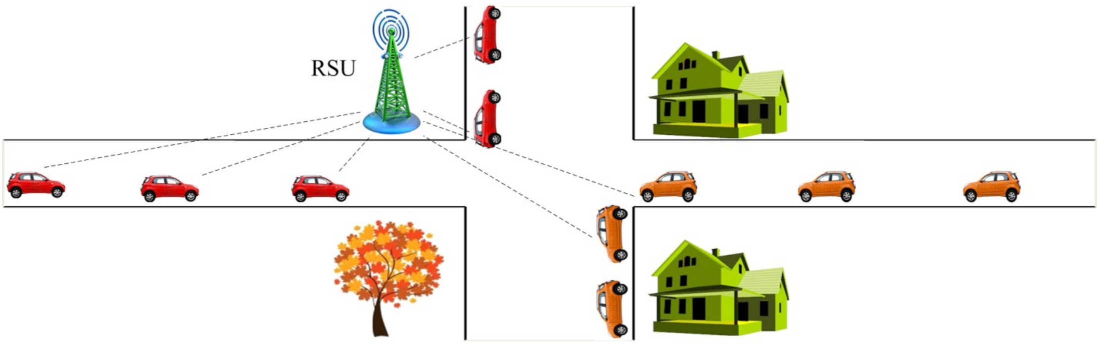

Figure 1. 2 Pure Cellular Architecture

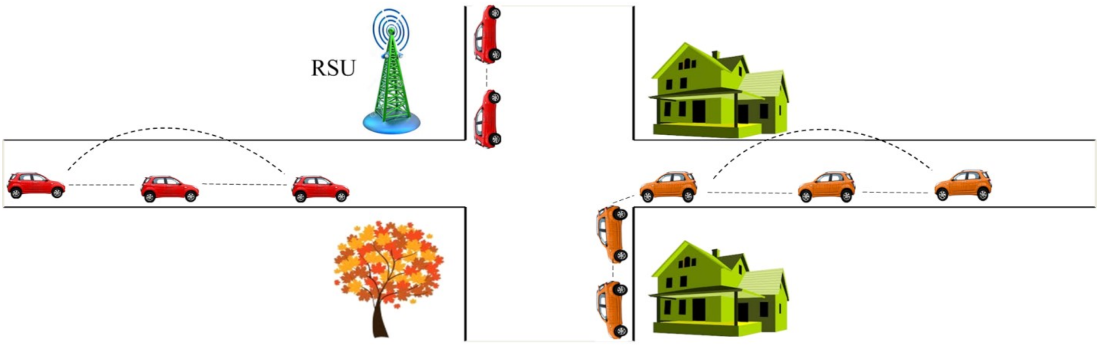

Figure 1. 3 Pure Ad hoc Architecture

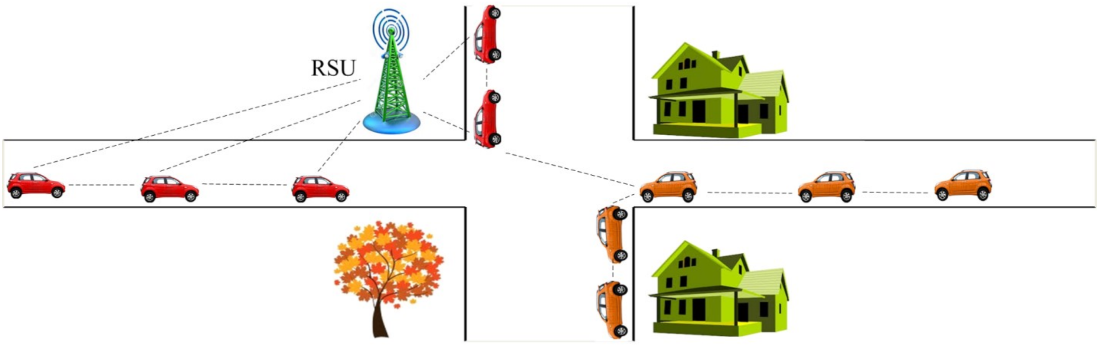

Figure 1. 4 Hybrid Architecture

The Hybrid architecture of VANET is the combination of both cellular and Ad hoc architecture (Figure 1.4). Here, if RSU is available then vehicles make use of it or else direct communication can take place. In this architecture vehicles do not use RSUs in constant behavior, however, RSUs are used to improve the performance or to use the services provided by VANET.

1.2.2 Characteristics of VANET

VANET have special characteristics and features making it special from the other existing Ad hoc networks (Jakubiak and Koucheryavy, 2008; Li and Wang, 2007). In assessment with other existing Ad hoc networks it has following unique striking features, as discussed in following paragraphs (Nekovee, 2005; Moustafa, 2009; Li and Wang, 2007; Yang *et al.,* 2008):

- **Limitless Transmission Power**

The Wireless Sensor Networks (WSNs) and Mobile Ad hoc networks (MANETs) have limited source of power, but in the case of VANETs, vehicles contain a huge source of power, thus OBU and the application processing unit (APU) can get continuous power supply for computation and communication (Wan *et al.,*2013; Lin *et al.,* 2012; Zhang *et al.,* 2013).

- **Advanced Computational Capacity**

Vehicles in VANET can carry high computational devices, which are capable to perform complex operations within a short amount of time. These computing devices allow vehicles to perform efficiently in the complex vehicular environment.

- **Predictable Moving Pattern**

In Contrast to Mobile Ad hoc networks, where nodes movement is not predictable, VANET offers to predict the vehicles' movement. The movement of vehicles is bound to certain traffic rules and road topology (Zhang *et al.,* 2013). The Global positioning system (GPS) is making available a lot of information like the average speed of a road segment, roadmap, current position of the vehicle. With the help of this provided information, the future position of vehicles can be predicted (Yong *et al.,* 2014, Michael *et al.,* 2007).

Apart from the above discussed special characteristics, VANETs have to deal with certain challenges as follows (Blum *et al.,* 2004; Jakubiak and Koucheryavy, 2008; Li *et al.,* 2017):

- **Large Network Size**

Unlike to MANETs or Sensor networks that have limited network size, VANETs can include a wide road network with many vehicles making it denser (Chen *et al.,* 2011).

- **Highly Mobile in Nature**

Vehicular Ad hoc network can work in the highly dynamic environment and a vast kind of scenarios. In the urban scenario, the vehicular network can be highly dense with 50 to 60 km/h vehicles' speed. Conversely, on highways, VANETs have the sparse network of vehicles traveling with very high speed (Mauve and Scheuermann, 2009).

Disconnected Network

VANETs supports highly dynamic environment which can lead to frequent network gaps in the network. Owing to network disconnection, several Ad hoc networks are formed among different vehicle clusters.

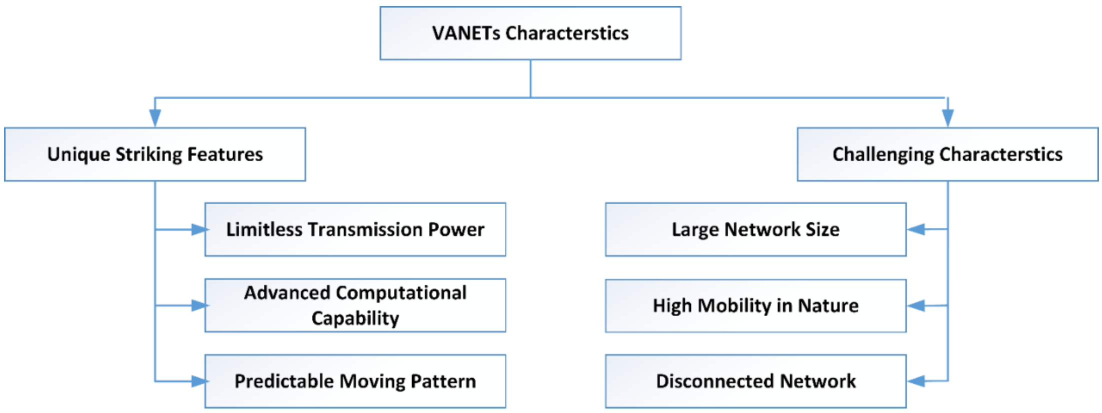

Figure 1. 5 Characteristics of VANETs

1.2.3 Application of VANET

The VANET application can be grouped mainly into three classes: Convenience oriented applications, Safety oriented applications (Willke *et al.*,2009; Chaqfeh *et al.*, 2014), and Commercial oriented applications (Emmelmann *et al.*, 2010; Watfa, 2010) (Figure 1.10). This categorization of VANET applications is based on the end-user perspective. Though all three applications have their own importance, the safety-oriented applications are given higher preference than others, as it can minimize the fatalities and the infrastructure (Dua *et al.*, 2014; Kumar and Verma, 2015).

Safety Oriented Applications

The Safety oriented applications executed by observing the vehicular environment which consists speed of vehicles, road conditions, vehicle density, and status of traffic lights. The role of OBU and APU are to make the communication possible among vehicles to exchange vehicular environment information. The provided information can be beneficial for the drivers to take quick decision. Further, some sort of actions can perform by the vehicle automatically. In the following section, some of the significant safety-oriented applications are discussed.

- **Intersection Violation Warning (IVW)**

IVW application alerts the drivers about the traffic signals with the help of RSU if they are close to the intersection (Hartenstein *et al.*, 2010). An RSU located near junction can broadcast the traffic signal information to nearby vehicles. This information can benefit those drivers who fail to notice the traffic signal. This situation is shown in Figure 1.6a, if the white car coming from left side missed the red traffic signal then there is a probability of collision. However, with the IVW application (Figure 1.6b), the driver of the white car is alerted by RSU and he can control his car before the junction.

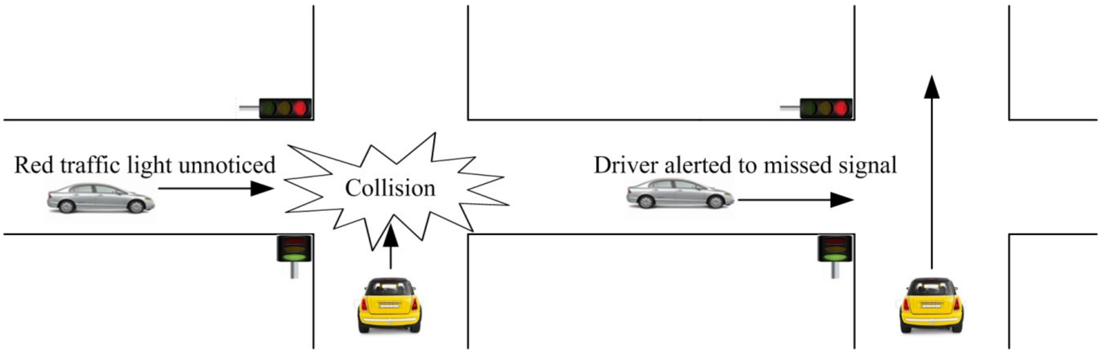

Figure 1. 6 a. Scenario without IVW application b. Scenario with IVW application

Electronic Break Warning (EBW)

EBW application is useful if the driver of a preceding vehicle applies sudden break and the view of this vehicle is blocked by another vehicle. Figure 1.7 is illustrating this situation, here (Figure 1.7a) yellow colored vehicle applies sudden break and view of this car is blocked for the white car by the blue truck. In the absence of EBW application, such a condition may lead to an accident (Figure 1.7b). This kind of miss-happening can be avoided if the vehicles are supported by EBW, where the white car get timely alerted (Figure 1.7c).

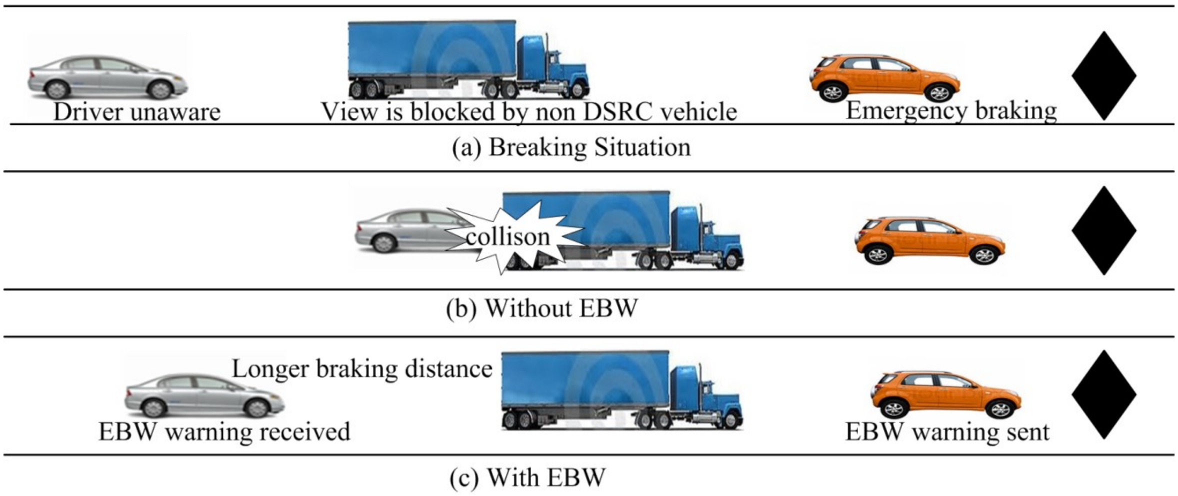

Figure 1. 7 EBW Application. a Braking Situation. b Without EBW. c With EBW

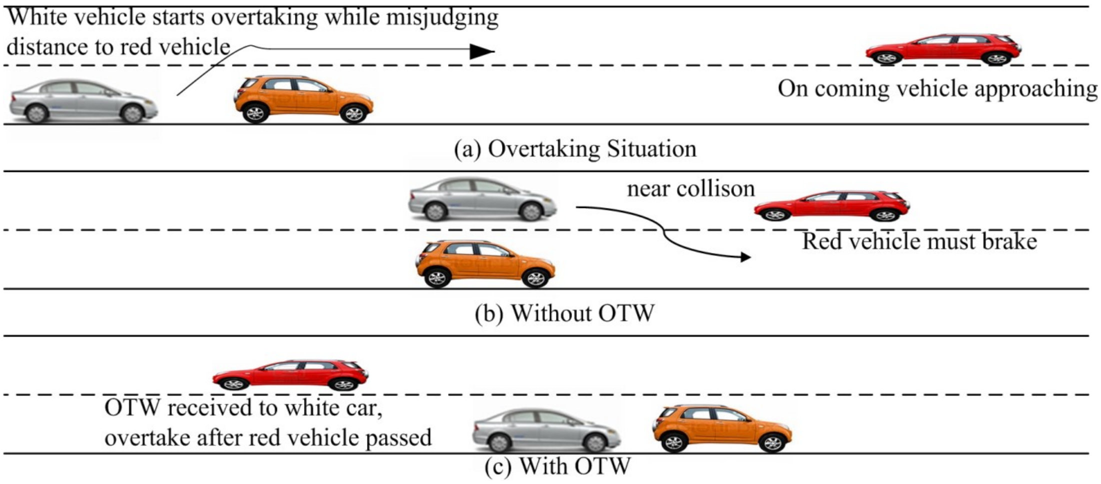

Figure 1. 8 OTW Application. a Overtaking Situation. b Without OTW. c With OTW

Oncoming Traffic Warning (OTW)

OTW application alerts the drivers in overtaking situations. In Figure 1.8a, the white vehicle wants to overtake the yellow vehicle whereas it misjudges the distance to the red car which was coming from opposite direction. In this circumstance, the vehicle can end up with a disaster (Figure 1.8b). However, with the help of OTW white vehicle will overtake only after passing the red vehicle (Figure 1.8c) (Wan *et al.*, 2011).

Vehicle Stability Warning (VSW)

In the VSW application when a vehicle observes a risky driving state through the vehicle stability control system (VSC), it broadcast the vehicle stability warning to all the neighbor vehicles. This application alerts the vehicle drivers to be prepared for any hazardous situation such as the icy or greasy road. In Figure 1.9, the vehicle A observe the icy road situation and VSC system sends the VSW warning to vehicle

C, resulting vehicle C crosses the icy road with slow speed. On contrary the absence of VSW, such a site can lead to the crash of vehicle B and C.

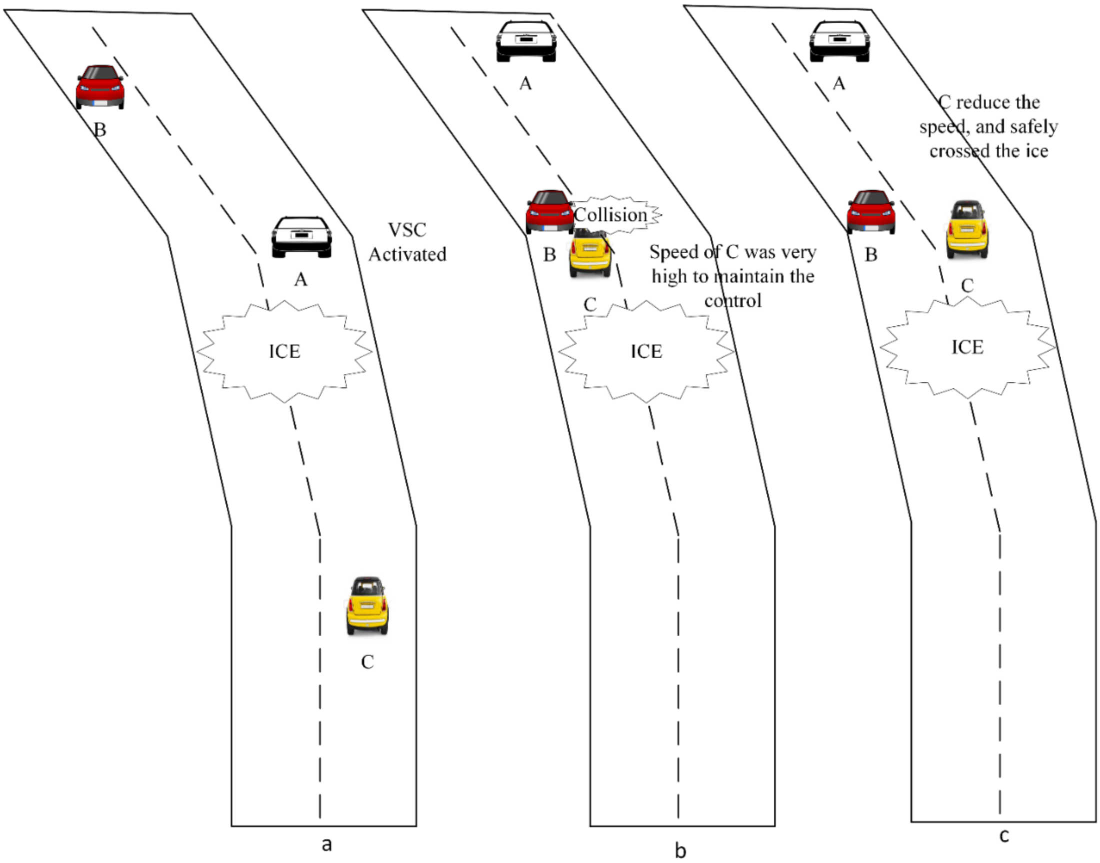

Figure 1. 9 VSW Application. a Icy Road situation. b Without VSW. c With VSW

Convenience Oriented applications

Convenience-oriented applications are used to increase the convenience of drivers, passengers, and pedestrians. This application enhances the ease of driving by sending information like traffic condition, road conditions, alternate paths in case of traffic jams.

- **Congested Road Notification (CRN)**

In the dense vehicular network, vehicles generate a CRN message, with the intention to inform other vehicles to avoid congested road and to use any other alternate route.

- **Parking Availability Notification (PAN)**

This notification is very useful for the vehicle drivers. Whenever a driver looking for a parking space, he or she sends a request to the neighbor vehicle or RSU and if they own any information regarding the available parking space they respond back to the requesting vehicle with PAN. In the case of more than one parking slots, the vehicle can select any desired slot according to its convenience.

Commercial Oriented Applications

VANET is also useful for commercial applications. It can improve the productivity of drivers as well as the business houses. A driver or passenger can use entertainment services and vehicle maintenance services information from their neighboring area. Moreover, a businessman can use RSUs to advertise about his product and services to increase the reachability up to nearest customers.

- **Service Announcement Notification (SAN)**

The service announcement notifications are useful for the drivers looking for specific services like restaurants, petrol pump, workshop etc. Similarly, this service helps the service providers to advertise their services to the customers directly.

- **Real-Time Video Broadcast Notification (RTVB)**

RTVB notification is used when a driver wishes to perform the live streaming of some specific circumstances like traffic roadblock, any road accident etc. Such live streaming can be made available to all the neighbor vehicles through multi-hop broadcast method.

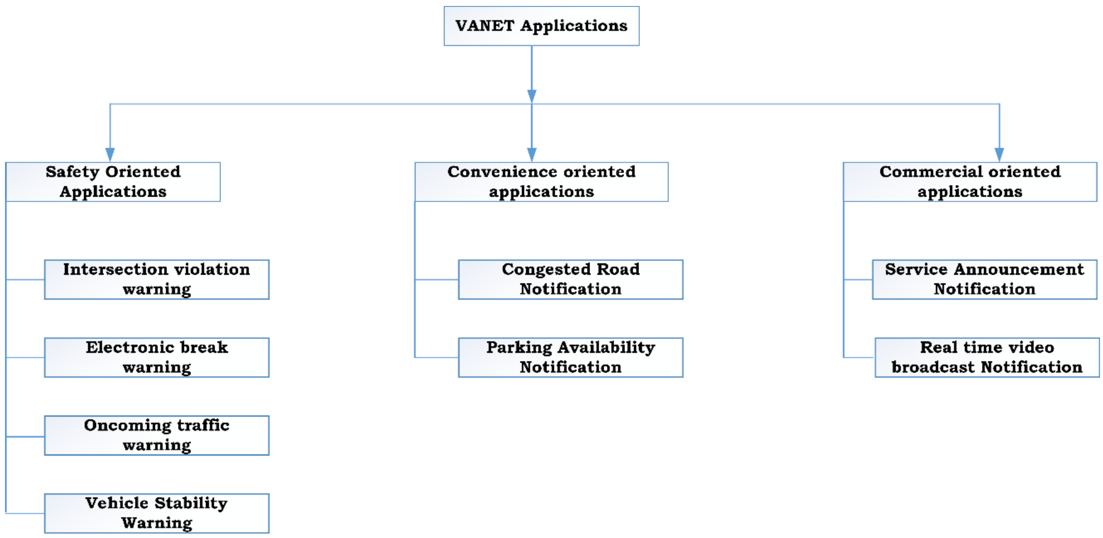

Figure 1. 10 VANET Applications

1.3 Vehicular Communication Regimes

The vehicular communication regimes can be classified according to the vehicular applications and the technology required to facilitate the communication among vehicles (Popescu *et al.,* 2010). The application based vehicular communication architectures are already discussed in the previous section 1.2.1. To support the V2V and V2I communication architecture, the available position based and bidirectional transmission schemes can be used.

The bidirectional regime allows to set up the connection to facilitate the unicast communication between V2V or V2I. It comprises four stages: i) Discovery, ii) Connection, iii) Data sending and iv) Ending. In the first stage, when any vehicle wants to send some data, initially it will look for the available neighbor vehicles. After the discovery stage, source vehicle initiates a connection stage to set up the connection with neighbor vehicle or RSU. The connection may be rejected or accepted by neighbor vehicle. In the third stage, the vehicle starts sending the data. Subsequently, in the ending stage, any of the two vehicles agree to terminate the connection.

The position based regime spreads the data within a specific geographic location. It can be performed by vehicle or RSU. It contains discovery and the flooding phase. In the discovery phase, sender searches for destination and flooding phase allows delivering the date to the recipient within a geographical area. The position based communication scheme can also be used to deliver the data packet to the destination which is multi-hop away. To deliver the packet to the destination which is not in the direct communication range of source vehicle, a routing algorithm is required.

1.4 Thesis Organization

This thesis contains six chapters and the second chapter onwards are organized as follows:

The chapter two covers a review of existing routing protocols of VANETs. The position based VANET routing schemes have been categorized into infrastructure-less and infrastructure-equipped categories. Further the infrastructure-less protocols are divided into basic and advance category. A comparative study is also done with the protocols of similar class and presented in the tabular form. This chapter made the foundation for gap analysis, problem formulation and objectives for this research work.

In the direction of achieving the objectives, in chapter 3, "A Junction Based Infrastructure Assisted Routing Protocol for VANET: JIP", is presented. This protocol exploits the infrastructure available at junctions. JIP is evaluated and compared with GPSR and CBF on different parameters.

The chapter four takes into the account of interference among different road segments and presented a street based forwarding technique to improve the packet delivery ratio and network overheads. The proposed, "Street Based Forwarding Protocol for VANET: SBFP" is evaluated by comparing with its peer protocols.

The chapter five comprises a "Static Infrastructure Assisted Road Based Forwarding Protocol for VANET: SRBF". This protocol contains the functionality of both JIP and SBFP. In addition to this, SRBF considered the problem of sparse connectivity and proposed a solution for it.

The last chapter concludes the work done, proposes the limitation and future scope of proposed three protocols.

Chapter 2

Literature Survey

Routing is the process of forwarding data from source to a destination via multi-hops (Ghebleh, 2017; Rahim *et al.*, 2017). Routing protocols are responsible to determine the path from source to destination, to send the packet to the destination and to form an alternate path after a failure (Chen and Cai, 2005; Giang *et al.,* 2013; Boukerche, 2005). These protocols can be further divided into proactive, reactive, and position based routing protocols (Palma and Vegni, 2013; Paul *et al.,* 2012; Altayeb and Mahgoub, 2013). Proactive routing protocols maintain routing information all the time even if the routing path is not in use. On the other hand, reactive routing protocols implement route discovery phase only on demand or need basis and maintain only those routes which are in current use[2].

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[2] The contents of the chapter are partially published in:

Kumar, S., & Verma, A. K. (2015). Position based routing protocols in VANET: A survey. Wireless Personal Communications, 83(4), 2747-2772. (Springer, SCIE Indexed, IF 0.951).

Kumar, S., & Verma, A. K. (2013, November). Performance evaluation of reactive routing protocols in VANET. In Proceedings of 2nd international conference on computing sciencesWILKES100 (pp. 242–252). (Elsevier)

Whereas position-based routing protocols require physical location of nodes in order to facilitate the communication (Viriyasitavat *et al.,* 2015). Location of neighbors can be obtained by the beaconing method and destination's position can be obtained by location discovery services such as GPS (Joilson and Emilio, 2016). Route establishment and route maintenance are not the part of position based routing protocols (Zhu *et al.,* 2016; Katsaros *et al.* 2016; Zhang and Wolff, 2008). The position-based routing protocols are categorized as infrastructure-less and infrastructure-equipped routing protocols (Figure 2.1). Further, infrastructure-less routing protocol are categorized into basic and advanced routing protocols. In the following section, a brief overview of basic routing protocols and detailed summary of all other protocols is presented (Table 2.1).

2.1 Pure Ad hoc Routing Protocols/Infrastructure-less Routing Protocols

In the infrastructure-less routing protocols, vehicles can communicate with the assistance of sensors and they don't require any infrastructure to send messages. Various basic and advanced routing protocols which use vehicle to vehicle (V2V) method to forward the packet to next node or destination are discussed below.

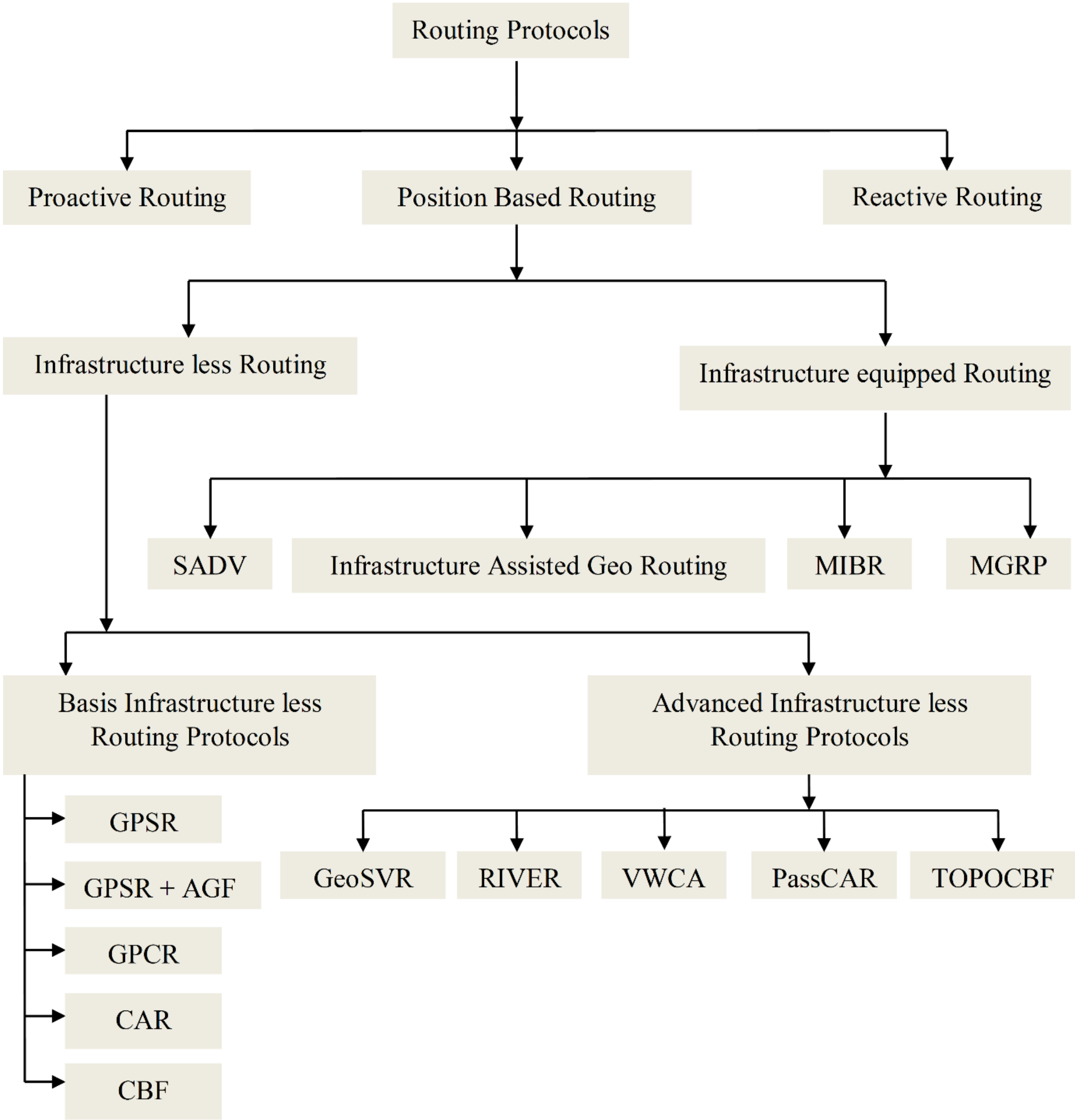

Figure 2. 1 Taxonomy of Routing Protocols

2.1.1 Greedy Perimeter Stateless Routing (GPSR)

GPSR considered as an efficient routing algorithm which uses the location of destination and intermediate nodes to take the forwarding decisions. It uses the greedy approach to select a node from its immediate neighbors as a next forwarding node (Figure 2.2) (Karp and Kung, 2000). The beaconing method is used to expose the location of neighbors. In Figure 2.2, dotted circle shows the range of node A and dotted arc is showing that the distance from node B to the destination is less than to any other neighbor of node A. Node A receives a packet for destination D. So, in this case, node A will select node B as a next forwarding hop as B owns less distance from any other neighbor of A. This process repeats till the packet reaches the destination. If there is no other node available with lesser distance to the destination than the current packet holding node, then the packet reaches to a condition known as the local maximum. Planarized graph method is used to recover from this situation (Karp and Kung, 2000).

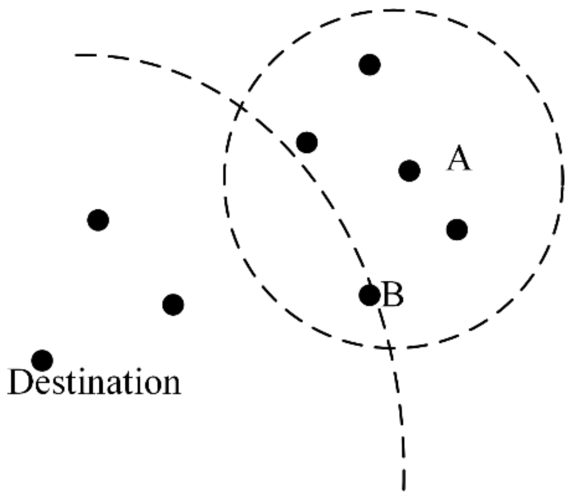

Figure 2. 2 Greedy Forwarding

2.1.2 Greedy Perimeter Coordinate Routing (GPCR)

Packets in greedy forwarding based algorithms (GPSR, GPSR+AGF) sometimes fall into local maximum, then these algorithms implement repair strategy to recover from local maximum. This repair strategy does not perform well in city scenarios because this kind of algorithms relies on a distributed algorithm to planarize the graph (Lochert *et al.,* 2003).

This algorithm takes the advantage of the fact that roads and junctions form planner graph and thus the no additional algorithm is required to construct the planner graph. GPSR consists of two main elements, restricted greedy forwarding, and the repair strategy. According to Lochert *et al.* "Actual routing decisions take place only at junctions". By considering this fact they proposed that the data packet should forward to nodes on the junctions in the greedy manner (Lochert *et al.,* 2003). Nodes located on junctions are called coordinator (Figure 2.3). In Figure 2.3, red nodes are coordinator nodes. Node S wants to send a packet to node D. According to restricted greedy forwarding, S tries to deliver the packet to nearest junctions. Initially, S will deliver the packet to A and A can either select node E according to the greedy forwarding or coordinator nodes following the restricted greedy forwarding algorithm. If A select E as a next forwarding hop then it will be stuck in local maximum but if it selects any coordinator node then the packet can reach to destination D without falling in the local maximum. Despite all this excellent forwarding strategy if the packet gets stuck in the local maximum then the right-hand rule can be used to recover from the local maximum (Lochert *et al.,* 2003).

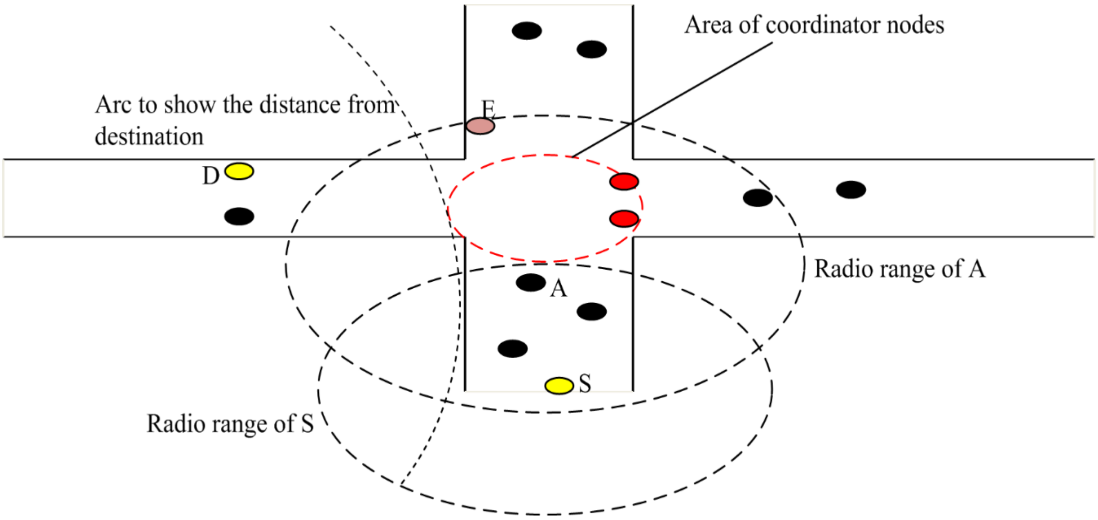

Figure 2. 3 Forwarding in GPCR

2.1.3 Connectivity Aware Routing (CAR)

CAR is a novel routing protocol which can locate the position of destination as well as the paths between source and destination (Naumov and Gross, 2007). This protocol uses realistic mobility traces to validate its performance. Routing protocols GPSR+AGF, GPCR and A-STAR (Seet *et al.*, 2004) consider the uniform distribution of nodes in the rectangular area which is the favorable condition for these routing protocols. Most of the geographic routing protocols proposed for VANET, perform on the basis of the fact that the position of destination is known. If routing protocols are evaluated with this assumption, then it may hide several overheads. To overcome this problem and to validate the routing protocols more accurately, the connective aware routing protocol (CAR) is proposed. This protocol consists of destination location, path discovery, data packet forwarding, path maintenance and error recovery modules. The adaptive beaconing method is used in CAR, in which frequency of hello beacons depends upon the number of neighbors. This method reduces the network overheads. Here preferred group broadcasting method (Naumov and Gross, 2007) is employed for destination location discovery. During path discovery, any node can add itself as an anchor if its velocity vector is different from the previous forwarder. After path discovery, 'CAR' forwards, the packed in a greedy manner on the anchored path. The concept of Guard is used for path maintenance in 'CAR'. Guard initiator node is known as guarded node and the neighbors of guarded node are called as guarding nodes. Two types of guard used in this protocol. The first one is a standing guard which is an entry in hello beacon and contains velocity vector of the guarded node and tied to a geographical area. Second is a traveling guard which contains velocity vector, position, and radius of the guarded node. If an end node changes its direction then it initiates a standing guard. Whenever a guarding node receives a data packet for guarded node it calculates the location of the guarded node with the help of velocity vector and adds this information into the packet header. On the other hand, the traveling guard is used when guarded node starts traveling in opposite direction of communication. To remove the routing errors, timeout algorithm with active waiting cycle and walk-around error recovery methods is used (Naumov and Gross, 2007).

2.1.4 Contention Based Forwarding (CBF)

Unlike CAR, CBF is not following the beaconing method to know the neighbor's location. In most of the greedy based forwarding, location of neighbors is made available by the beaconing method. But as the presence of high-speed vehicles in VANET make it to a highly dynamic and the beacons can provide the inaccurate position of vehicles. To avoid this situation, the frequency of beacons can be increased nevertheless it can result in a higher load on the network. Under such a situation CBF get renewed importance as it can cope up with the described problem (Fu¨ßler *et al.,* 2004). CBF follows greedy forwarding with all available neighbors participating in the next forwarding hop selection process, is based on the actual position of neighbor nodes and is known as the distributed contention process. In this protocol, each forwarding node broadcast the packet with last hop ID, destination ID, and packet ID to all of its neighbors. After receiving a packet, neighbor nodes start a timer. A node whose timer expires early will suppress all other competing nodes. This timer depends on the progress making by node towards destination i.e. node which is having less distance to the destination will select as a next forwarding hop. Progress toward destination can be defined as follows:

$$Progress = max\left\{0, \frac{dist\ (s,d) - dis(c,d)}{range}\right\}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where t is the timer and s, d, c are the positions of the source, destination and current node respectively (Fu¨ßler *et al.,* 2004).

In the contention process the timer is used according to the following equation:

$$t(Progress) = T\,(1\text{-}Progress), \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

where T is the maximum forwarding delay and node with the smaller value of t will suppress all other participant nodes.

In CBF, there are chances of packet duplication. For two nodes having timer t1 and t2 and if the difference between these timers is less than the time interval of suppression then both the node will broadcast the packets. To avoid the packet duplication, proposed three different type of algorithms namely, basic suppression algorithm, area-based suppression algorithm and active selection suppression algorithms (Fubler *et al.*,2003).

2.1.5 A Map-Based Stateless VANET Routing (GeoSVR)

The geographic routing is perturbed by local maximum, sparse connectivity and wireless channel conditions. GeoSVR is a routing which considers these problems. This routing protocol combines two algorithms: optimal forwarding path selection and restricted forwarding algorithms (Xiang *et al.,* 2013). Optimal forwarding path selection algorithm overcome the problem of local maximum and sparse connectivity. On the other hand, restricted forwarding algorithm avoids the impact of the unreliable wireless channel.

Xiang et al. (Xiang *et al.,* 2013) defined the optimal path as the shortest connected path with the highest probability of increased vehicles density between the source and the destination. To calculate the vehicle density on roads algorithm Acar (Yang *et al.,* 2008) can be used. In this algorithm, the width of the road is directionally proportional to the density of vehicles on the roads i.e. higher width of road results with the higher probability of increased vehicles density. Further, the GeoSVR used "road type" as an entity in the graph and assigned values to this entity i.e. lower value to roads of higher width and higher values to the roads of smaller widths.

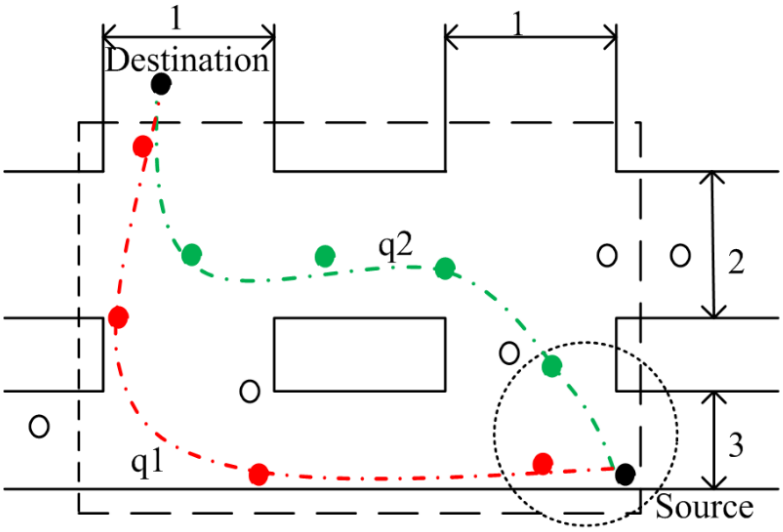

Figure 2. 4a Optimal Forwarding Path Selection

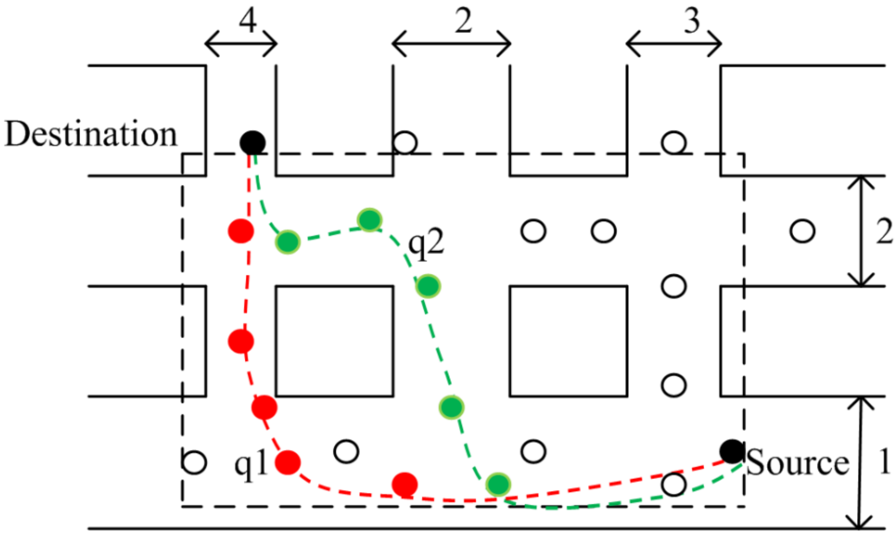

Figure 2.4b Optimal Forwarding Path Selection

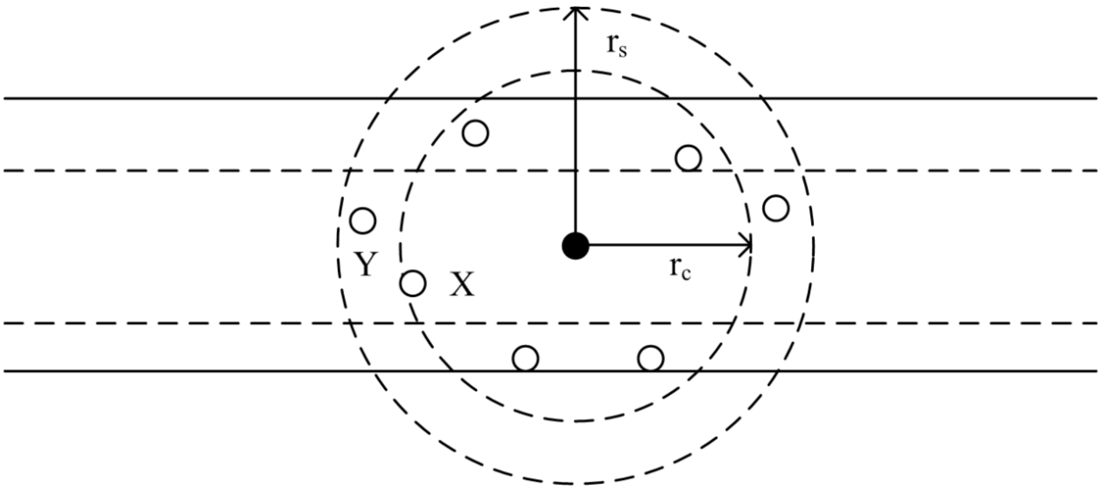

Figure 2. 5 Restricted Forwarding

$$t_{total} = \sum_{q_i=q_1}^{q_n} t_{q_i} \quad (q_i \in R) \text{ .... } (2.3)$$

where qi is the road from q_1 to q_n and t_{total} is the sum of road type in this path. But the above equation can provide more than one path for the same distance. To overcome this problem following equation is used in GeoSVR:

$$\sigma(t_a) = \sqrt{\frac{1}{n}\sum_{q_i=q_1}^{q_n}(t_{q_i} - t_a)^2} \quad (q_i \in R) \text{ .... } (2.4)$$

where r(ta) is the calculation of optimal path, t_a is the average of road types and n is the number of roads in the path.

The working of this algorithm is described in Figure 2.4a, b.

In Figure 2.4a sum of path q2 is less than q1, therefor q2 is an optimal forwarding path. In Figure 2.4b sum of q1 and q2 is same then according to Eq. 2.4 q2 is an optimal path. After selecting the optimal forwarding path, the restricted forwarding algorithm is applied to select the next neighbor. GeoSVR selects the next hop as a forwarding hop within a constrained range which results to an increased number of hops and higher latency. It benefits to reduce the probability of packet loss. This fact can be understood by Figure 2.5 where r_s and r_c are the actual transmission and restricted transmission range of the sender respectively. According to the restricted forwarding algorithm, the sender will send the packet to node 'X' because it is in the constrained range of sender, on the other hand, GPSR will select 'Y' as a next hop to forward the packet.

The authors (Xiang *et al.,* 2013) considered NS-2 for performance evaluation by taking packet delivery ratio and network latency as the evaluation parameter. They performed simulation in Line, urban, static and mobile scenarios and implemented AODV and GPSR to compare the performance of GeoSVR. Line and urban scenario are synthetic scenarios, on the other side static and mobile scenarios are realistic scenarios. In Line scenario, it could confirm that packet delivery ratio for AODV and GPSR is approximately 60 % and for GeoSVR is 95 %. Static scenario proved that GeoSVR can provide low latency within the communication range. With the help of mobile scenario and the urban scenario, it was concluded that GeoSVR performs better than AODV and GPSR (Xiang *et al.,* 2013).

2.1.6 RIVER: A Reliable Inter Vehicular Routing Protocol for Vehicular Ad hoc Network

RIVER uses the undirected graph and assigns reliability ratings to streets through some mechanisms (Bernsen and Manivannan, 2012). With the help of this rating, RIVER selects the street as a forwarding path. Unlike other routing protocols RIVER uses real time traffic information to assign reliability ratings to streets. Due to real time traffic information, there are fewer chances of network gaps in RIVER. This is a position-based routing protocol which forwards the packet in greedy manner up to nearest anchor point. The position of neighbors is identified through beacon messages and it also uses preloaded street maps to identify the location of anchor points and destination. RIVER does not allow broadcast or network flooding to propagate the street reliability information instead it uses piggybacking to distribute the traffic information (Bernsen and Manivannan, 2012). To take the benefit of real time traffic information during transmission this routing protocol recalculates the forwarding path at anchor points. A probe message is used to check out the connectivity of path. Unlike unicast messages, RIVER sends a probe message to the unknown network to check the reliability of path.

RIVER allows two type of traffic monitoring: active and passive monitoring. Probe message is used for active traffic monitoring and on the other hand, passive monitoring is performed by each vehicle which is receiving packets. To find out whether a message can be delivered to a particular route a probe message is used. A node which is near to a street vertex can send a probe message to next hop node to a street which is indented on the same vertex. Probe message which traverses a street edge will be received by a node close to another vertex. At the same time, a return probe is sending back to its original sender so that the sender becomes aware of the connected path. Each node in RIVER checks edge connectivity by passively snooping into packets (Bernsen and Manivannan, 2012).

In this protocol, routing can be performed after distributing the information regarding connectivity of edges. When a node X on vertex Vx receives a message from a node Y of an edge which is incident to Vx, then it resets the weight of edge from node X to node Y to the minimum value, which shows that traversed edge is connected. When a node sends a packet, it includes the edge weight along with the time stamp. This timestamp represents the time when the reliability value was updated. When a node receives a packet and it is not a final recipient then it processes the packet and also updates the reliability value of the path. In this protocol beacon or probe contains known edge list. This known edge list contains endpoint of edges and reliability information. When a node receives a routing packet it selects an edge from known edge list (KEL) on the basis of reliability information and the KEL get updated.

A crucial component of RIVER is reliability and hence each node assigns weight to every known edge with the help of active and passive monitoring. A small weight to an edge shows higher reliability, large weight indicates the unreliable path and a maximum weight shows path is not traversable. Dijkstra's (Dijkstra, 1959) least weight path algorithm is used to calculate the most reliable path. RIVER also considers the length of the path, if the reliability of two paths is same then it would select a path with the lesser number of edges. This protocol also provides the feature of route recovery and route recalculation.

To evaluate the performance of RIVER Bernsen et al. simulated the protocol on NS-2 simulator where 6.05 km2 area used for the simulation with 100–300 nodes traffic density. The River was compared with STAR (Giudici and Pagani, 2005), GPSR (Karp and Kung, 2000), and a shortest path routing protocol. Data throughput, forwards per route and transit time parameters were used for comparative study. After the simulation, they found that RIVER gave packet throughput of 222, 75, and 39 % better than GPSR, shortest path algorithm and STAR routing protocol respectively. Delivery delay of RIVER calculated as up to seven times, four times, and twice the delay of GPSR, STAR and shortest path algorithm respectively. Delay of RIVER increasing because of an average data packets in this protocol using 84, 45, 40 % more hops than GPSR, STAR and short path respectively.

2.1.7 VWCA: An Efficient Clustering Algorithm in Vehicular Ad hoc Networks

There are several challenges in VANET, scalability is one of them (Nuri and Nuri, 2010). Clustering can be used as a solution for scalability problem (Daeinabi *et al.,* 2011; Hande and Muddana, 2016; Ashour *et* *al.,* 2016). VWCA is a clustering algorithm and it is the combination of three algorithms; vehicular clustering based on weighted clustering, adaptive allocation of transmission range (AATR), and monitoring of malicious vehicles (MMV).

Three types of vehicles are considered in VWCA; honest, abnormal and malicious (Daeinabi *et al.,* 2011). A vehicle which forwards packet correctly and behaves normally is called honest one, which propagates false information in the network in the limited number of time is called abnormal one and if the abnormal vehicle propagates the false information beyond the limit then it is called a malicious one.

Vehicular Clustering Based on Weighted Clustering

This algorithm is proposed to optimize the process of cluster head election. In the process of clustering, the selected cluster should not be very large or very small. A very large cluster can result in network congestion and a very small cluster can increase the process of re-affiliation. In this algorithm, cluster head election process is based upon the distrust value of vehicles. Initially, each node in the cluster declares itself as a cluster head, but after getting information from its neighbor nodes would decide whether to change its status or not. This algorithm uses following five steps to choose cluster head:

Step 1: Create neighbor list.

Step 2: Determine the priority of vehicles based on their distrust value.

Step 3: Determine the Vehicle’s Direction.

Step 4: Calculate entropy (Wang and Bao, 2007)

Step 5: Calculate weighted clustering values.

After getting information from above four steps a vehicle V can calculate its weighted sum (WV) with the help of following formula (Daeinabi *et al.,* 2011):

$$W_{V}= w_1 T_d + w_2 (- H_v) + w_3 (- D_v) + w_4 (- M_{u,v}) \ldots\ldots\ldots\ldots\ldots (2.5)$$

where T_d is distrust value, Hv is entropy value, Dv is the number of neighbor and $M_{u,v}$ is direction measure of vehicle V. w_1, w_2, w_3, and w_4 are weighing factors. The weighing factors are greater than 0 with $w_1+w_2+w_3+w_4 = 1$. After calculating W_v, vehicles broadcast this value to their neighbors and a vehicle which is having smaller value will be elected as the cluster head.

Adaptive Allocation of Transmission Range (AATR)

Due to the high speed of vehicles, VANET topology changes very frequently. Vehicles leave a cluster and join another one very frequently. Considering this nature of VANET the algorithm AATR is framed so that vehicles in VANET can adjust their transmission range based on their surroundings. According to DSRC standards, vehicles can increase their transmission range up to 1000 m. Three steps are required to execute AATR which are:

Step 1: Determining the Maximum and Minimum Transmission Ranges.

Minimum transmission range of vehicle V depends on the number of neighbors of V. If the number of neighbors within the circle of radius

100 m of vehicle V is more than the threshold value then minimum transmission range was fixed as 100 meters otherwise it was varied between 300 and 400 meters (Lee, 2008).

Step 2: Forwarding Message.

After applying AATR the vehicle V can transmit the message with the help of vehicles of the neighbor table. If there is no vehicle in the neighbor table then V broadcast a hello message. If V gets a reply within a time period then it updates its neighbor table and forwards the message. Within the desired time if V doesn't get a reply then it will increase its transmission range and repeats the above process.

Step 3: Decrease the Transmission Range.

High transmission range can be fruitful only in the case of low vehicle density. If the vehicle density is increasing then high transmission range can result in network congestion and collision. Therefore (Daeinabi *et al.,* 2011) proposed a technique to decrease the transmission range according to vehicular density.

Monitoring of malicious vehicles (MMV)

There is no central unit in VANET to ensure the security so that vehicles should cooperate with each other to ensure the same. A vehicle V uses distrust value of neighbor vehicles to update its black and white list.

To calculate the value of threshold (σ), the value of "number of the average vehicle" (N_v) is required and on the basis of following eqn. 2.6, σ can be calculated (Daeinabi *et al.,* 2011):

$$\sigma = e^{a} \qquad 0 <= a <= N_v - 1 \quad \text{.............................(2.6)}$$

This equation is used to put the vehicle either in a black or white list.

Daeinab et al. compare VWCA with four different algorithms, the direction base clustering algorithm (Fan, 2007), D-lowest ID, D-highest ID and WCA (Chatterjee, 2002). Evaluation of this algorithm is done based on the parameters' average membership duration and average cluster head duration. It is observed that the performance of VWCA was better than all these algorithms. VWCA also improves the security of network and percentage of selecting a malicious vehicle as CH is very low in VWCA.

2.1.8 PassCAR: A Passive Clustering Aided Routing Protocol for Vehicular Ad hoc Network

Passive clustering (PC) does not use any protocol specific beacons/signals to form a cluster (Wang and Lin, 2013). On the other hand, in the traditional clustering routing protocol, all the available nodes in the network advertise their existence with cluster related information (Kwon and Gerla, 2002). This mechanism reduces the overheads of route discovery and maintenance. First declaration wins (FDW) and Gateway selection heuristic are two mechanisms of PC to select Cluster Head (CH) and Cluster gateway (CW). In FDW a node which claims itself as a CH dominates another node within its transmission range. Gateway selection heuristic is to find out the minimum number of gateways to ensure the connectivity. Problem with traditional PC mechanism is that it can select a node as a CH with the fewer number or no neighbors. To remove this problem PassCAR is proposed.

The basic idea behind this protocol is to find out the appropriate CH and gateway to forward the data packets. To form an efficient cluster structure this protocol considers node degree, transmission count, and link lifetime metrics. These metrics are used to measure reliability, stability, and sustainability of link.

The number of nodes in the communication range of node N is called its degree. Link stability can be measured with the help of expected transmission count (ETX) (Couto, 2005; Rozner, 2009) and degree of the node. Wang and Lin (Wang and Lin, 2013) used link lifetime (LLT) as a metric to measure link sustainability, which is the time interval when two nodes remain close to each other. Based on these three metrics, priority is calculated to select CH and CG.

PassCAR mechanism contains three phases; route discovery, route establishment and data transmission. When a node A wants to transmit a data packet then it checks its routing table first, if a path is available then 'A' forward the packet to next hop otherwise 'A' initiates the route discovery phase and find out the CH and CG to forward the packet.

Any of the "On demand routing protocol" can be associated with PassCAR. MOVE and NS-2 are used to compare PassCAR with original PC mechanism. Path discovery ratio, throughput, path lifetime and packet delivery ratio metrics were used to evaluate the performance of PassCAR. This protocol improved the path discovery ratio by 45 % than

PC mechanism. It is also observed that the expected transmission count and LLT are caused to improve network throughput and path lifetime respectively.

2.1.9 Contention Based Forwarding with Multi-Hop Connectivity Awareness in Vehicular Ad hoc Networks (TOPOCBF)

Most of the proposed position-based routing protocol (Karp and Kung, 2000; Fubler *et al.*,2003; Tian, 2003) in VANET has employed the greedy approach to forward the packet. This approach can result in the selection of nodes with weak forwarding links and thus to decreasing the packet delivery ratio. Protocols (Seet *et al.*, 2004; Zhao and Cao, 2008; Ding and Xiao,2010; Jerbi *et al.,* 2006) considered the traffic density to select their routing path i.e. roads with higher vehicular traffic selected as the forwarding path. Nevertheless, this approach can increase network traffic load, resulting congestion and the same problem which arise in greedy approach.

To overcome these problems Rondinone and Gozalvez have presented Road Topology-Aware Contention-Based Forwarding (TOPOCBF) algorithm, this scheme dynamically selects road segments based on the multi-hop connectivity (Rondinone and Gozalvez, 2013). A road segment is called multi-hop connected if there are the sufficient number of nodes available to deliver a packet from one to another end of the road segment. TOPOCBF uses Distributed and real-time communication road connectivity discovery scheme (DiRCoD) (Rondinone and Gozalvez, 2010). DiRCoD uses beaconing method to calculate the virtual distance. The virtual distance metric is required to find out the multi-hop connectivity of a road segment. DiRCoD's concept can be understood with the help of Figure 2.6, here every road segment is divided into the number of sections. The length of each section is equal to the transmission range of the vehicle. Consider the road segment from intersection I_1 to intersection I_2. A vehicle entering the road at I_1 needs to be informed about the connectivity status of the segment. In all the sections between I_1 and I_2 there are vehicles and hence this segment is a multi-hop connected. To understand the "partial multi-hop connected status" of a segment, consider road segment I_1–I_3, this path is partially connected and hence the virtual distance metric is required to calculate to estimate the remaining distance to reach intersection I_3. Vehicle at I_1 will obtain value of the virtual distance 2 as there is no vehicle in section 1 and 2 (Rondinone and Gozalvez, 2010).

Like CBF (Rondinone and Gozalvez, 2013), TOPOCBF also uses the broadcast greedy approach to forward a packet. After receiving a packet, node starts its "forwarding timeout" timer, when it gets expires node re-sends the packet. "forwarding timeout" duration is inversely proportional to the progress towards the nearest junction in the direction of destination, i.e. node nearest to the junction towards destination re-transmits the packet first and other nodes cancel their forwarding attempt. Working of TOPOCBF can understand as follows:

a vehicle entering at intersection I1 wants to send a packet to destination situated at intersection I4. There are two paths available from I_1 to the destination; I_1–I_3–I_4 and I_1–I_2–I_4. TOPOCBF would select the most appropriate path by considering the following three properties:

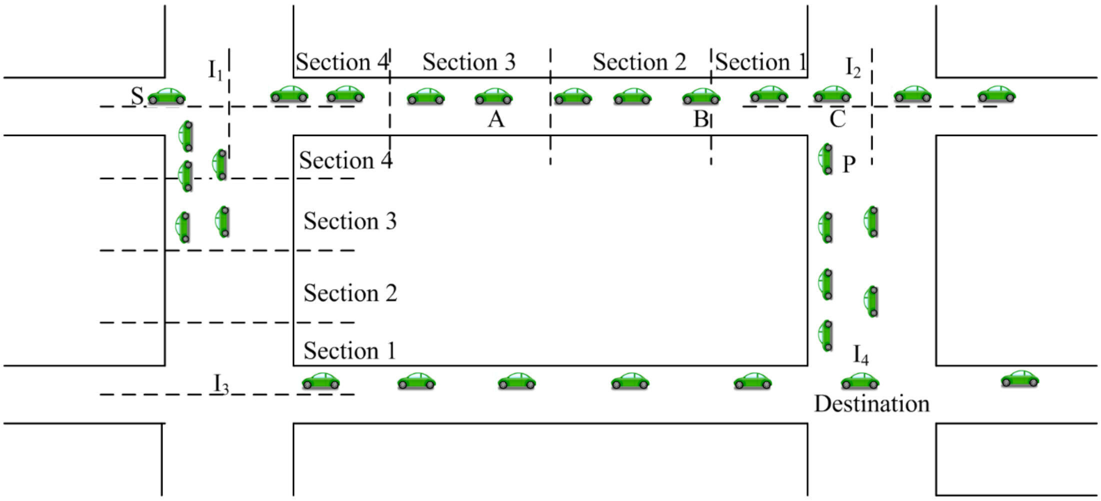

Figure 2. 6 Urban Scenario

<u>Property 1</u> Progress towards the final destination: TOPOCBF considers only those intersections which provide progress towards the destination. Hence, in this case, it can use both the available paths.

<u>Property 2</u> Freshness of road connectivity information: Vehicles at intersection continuously process the received beacons to find out the connectivity status of adjacent road segments. If a received beacon is older than the threshold value, then the sender assumes that the respective road segment does not ensure the guarantee of multi-hop connectivity.

<u>Property 3</u> If more than one road segment satisfies the above two properties then the sender vehicle will select the road which is providing lower virtual distance.

In Figure 2.6, the sender will select I_1–I_2 as a next forwarding segment since it is providing less virtual distance than I_1–I_3. After selecting next forwarding road segment sender will broadcast the packet with its coordinate. Contention process allows only one node to rebroadcast the packet to reach the next intersection.

TOPOCBF does not use CBF's duplicate packet discarding policy. In CBF if any node receives a packet with the same ID then it discards the packet. In Figure 2.6, if a packet is moving towards the junction I_2 and vehicle P along with vehicle C receive the packet then C will rebroadcast the packet to the destination. When C broadcasts the packet then P will again listen the broadcast and according to CBF, it will discard the packet because in the previous broadcast it has received the packet with same ID. Thus, to avoid this problem TOPOCBF uses packet ID and next intersection field to discard the packet.

However, TOPOCBF cannot completely discard the packet duplication, for this Rondinone et al. propose eTOPOCBF in which packet contains two intersections fields and packet ID. First intersection field contains the position of the current targeted intersection while other contains the position of the previous intersection.

Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions (iTETRIS) was used to simulate TOPOCBF. Four scenarios are used to compare TOPOCBF, eTOPOCBF and Greedy traffic aware routing protocol (GyTAR). Two variants of GyTAR used for the comparative study. GyTAR a (first variant) removes a node from its neighbor table only if none of the beacons is received in the last 1.5 s. In GyTAR b (second variant), node resides in neighbor table till 5 s and a node will be selected as a next forwarding node if at least 2 beacons are received from it in the last 4 s and the last beacon should not be older than 1 s. TOPOCBF and eTOPOCBF outperform than GyTAR a, GyTAR b on the packet delivery ratio and the average overheads parameters. In TOPOCBF, eTOPOCBF value of average end to end delay, average number of hops and average hop length received were greater than GyTAR a and GyTAR b.

2.2 Hybrid Routing

As its name suggests it is the combination of pure cellular and pure Ad hoc routing. In this kind of routing, vehicles use either vehicle or RSU to forward the packet depending on which one is providing the best path. Hybrid routing is also known as the Infrastructure-equipped routing (Emmanuel *et al.,* 2016; Liu *et al.,* 2013). Various infrastructure based routing protocols will be discussing in this section.

2.2.1 Static-Node-Assisted Adaptive Data Dissemination in Vehicular Networks (SADV)

SADV is proposed to improve the data delivery with the help of static nodes; these static nodes are deployed at each intersection of roads (Ding and Xiao, 2010). Since the actual routing decision takes place at the junctions, each intersection should have a static node which can store data packets in its buffer till then it does not get any other vehicle which is providing the best delivery path to the destination. As illustrated in Figure 2.7, vehicle 1 wants to send a packet to a remote location. Vehicle 1 forwards the packet to vehicle 2 which will calculate the shortest path to the destination. If the shortest distance path is in the east direction (E) and vehicle 2 is moving towards the south direction (S) and if the static nodes are not deployed, then the packet will be carried out by vehicle 2 in south direction, which is not the shortest path. But if the static nodes are deployed then vehicle 2 will forward the packet to the static node, which will store the packet in its buffer till vehicle 3, which is moving towards East direction approaches the intersection.

The simulation results explain that SADV performs better than other data dissemination multi-hop routing protocols in sparse networks (Ding and Xiao, 2010) like Vehicular Assisted Data Delivery routing protocol (VADD). In VADD there are two reasons for the performance degradation (Zhao and Cao, 2008):

- VADD selects the best available path at each intersection. But for any certain moment of time due to the disconnection in the network, the forwarding node may select a wrong path, which can result in performance degradation.
- In VADD packet forwarding delay is based on some statistical data but vehicle density may vary with time. Therefore, if the forwarding node is not having any current data regarding vehicular density, then there are chances of wrong path selection.

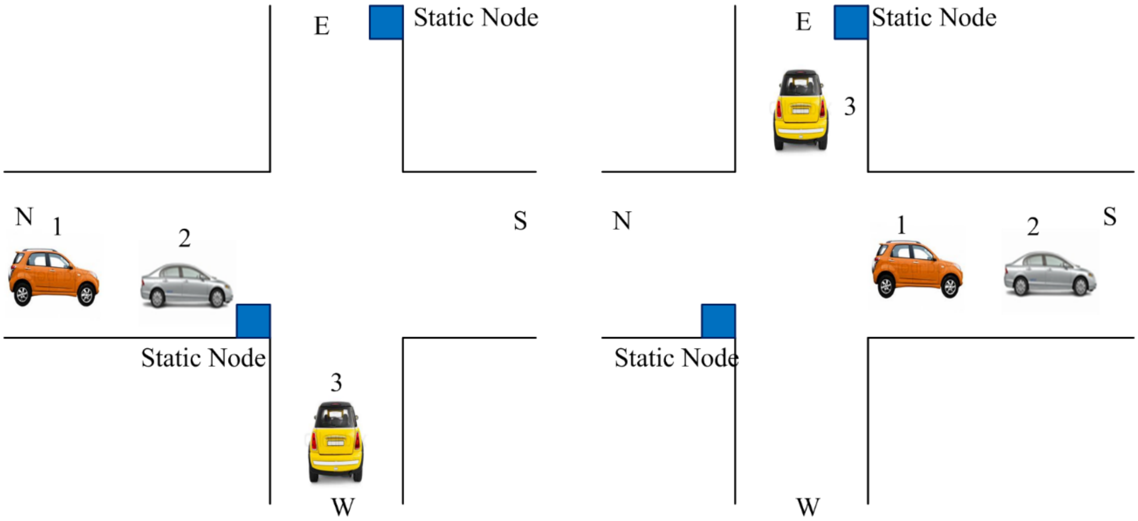

Figure 2. 7 Routing Assisted by Static Node

To avoid such performance degradation problems the protocol SADV has been proposed. For the better performance and to avoid the problems which arise while dealing with VADD, Ding et al. proposed to deploy static nodes at each intersection. These static nodes can store the packet in buffer till a vehicle approaches the intersection, which will be moving towards the best path. The concept of link delay update and multipath dissemination is proposed to avoid the second problem.

SADV contains three modules:

i. SNAR (static node assisted routing)

ii. Link delay update

iii. Multi path dissemination

i. SNAR

SNAR works in two modes: a road mode and an intersection mode. In Road mode, the vehicles use the greedy forwarding to deliver the packet to the next intersection (static RSUs) whereas, in intersection mode, RSU at each intersection uses the delay matrix to find out the next forwarding node (Ding and Xiao,2010).

ii. Link Delay Update

Delay matrix can provide outdated information to RSUs, which can result in wrong path selection. In order to obtain more accurate information for delay matrix, Ding et al. introduce the concept of link delay update. In link delay update, each static node propagates the packet forwarding delay to other RSUs. Every static node can update its delay matrix on the basis of link delay update and thus it can select the best available path to deliver the packet.

iii. Multi Path Data Dissemination

If it is not possible to calculate the accurate delay between the static nodes then the multi path data dissemination will be employed. However, this technique can result in network overheads. Thus, it was suggested that this technique can be beneficial only if the network is not highly loaded.

The Simulation result of (Ding and Xiao,2010) presented that SADV works better than VADD. Moreover, if all the modules of SADV and if all the modules of SADV combined then it works better than any single module of SADV (Ding and Xiao,2010).

2.2.2 Infrastructure Assisted Geo-Routing for Cooperative Vehicular Networks

The authors (Borsetti and Gozalvez, 2010) used geographic routing to deliver the packet to static nodes. Infrastructure Assisted Geo Routing suggests two types of advantages by using RSUs:

1. The higher height of antenna provides higher communication range for V2I communication as compared to V2V communication.
2. Unlike SADV, RSUs should be connected as a backbone network and distance among these will be treated as zero.

Infrastructure Assisted Geo routing introduces a new graph representation, referred as the network graph. In network graph, a node is considered as either an anchor point or a static node. Since RSUs are connected through higher bandwidth network, the distance among all the RSU's is considered as zero. In the network graph (Figure 2.8c), all the nodes which are representing the RSUs can be merged into a single node, which is referred as backbone gate. Figure 2.8 a, b and c are illustrating this routing protocol. Figure 2.8 a display a road topology in which two RSUs are deployed. To send a packet from source (s) to the destination (D), the traditional GSR routing protocol uses the shortest path (S-3-2-D) (Figure 2.8b). However, if RSU 1 and RSU 2 are interconnected through higher bandwidth network as shown in Figure 2.8c, then this routing protocol will adopt another path (S-RSU-D).

The performance of this routing protocol with 2 RSU and 4 RSU is compared with CBF, GSR, and GPSR. The packet delivery ratio, overhead, wireless hops and geographic routing parameters were used to evaluate the performance. The Infrastructure Assisted Geo routing protocol with 2 RSUs achieved the same performance as of other compared protocols and outperforms with 4 RSUs.

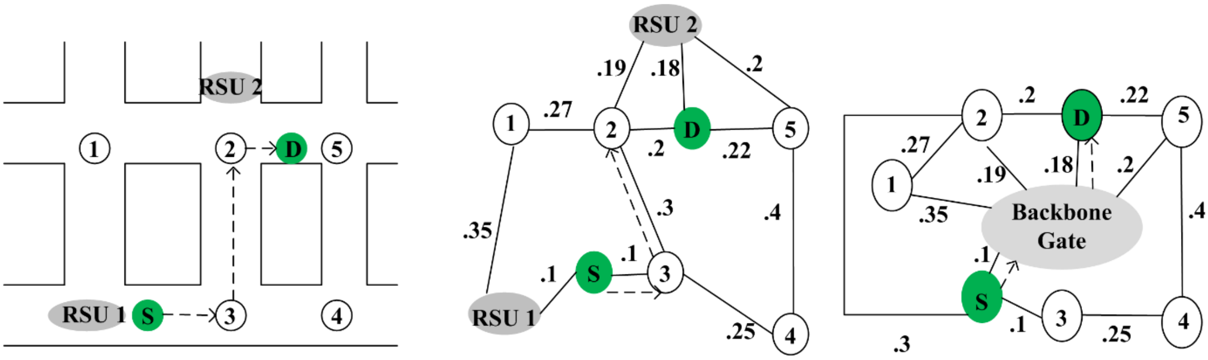

Figure 2. 8 a Road Path Followed by GSR. b Graph Representation of Road Topology in GSR. c Network Graph Representation in Infrastructure Assisted Geo Routing

2.2.3 A Mobile Infrastructure Based VANET Routing Protocol in the Urban Environment (MIBR)

After analyzing the unique characteristics of urban VANET that ordinary roads can have two types of vehicles like buses and cars, (Luo *et al.*, 2010) proposed MIBR routing protocol. Generally, vehicles move in the form of clusters due to traffic lights and to improve the connectivity of the road segments, buses used as mobile infrastructure, which are big in size and can easily carry the transmission equipment.

In city scenario, vehicles movement is governed by traffic lights. Red traffic light stops vehicles at junction and green traffic light allows vehicles to start moving which results in cluster formation, as shown in Figure 2.9.

The number of buses on roads is 20 % of total vehicles (Luo *et al.*, 2010), hence the transmission range of buses is increased to three times than that of cars' for better transmission. MIBR is a location based reactive routing protocol which uses GPS, digital street map and location service. Each bus contains two interfaces, one for the bus to bus communication and another for the bus to car communication. On the other hand, each car contains only one interface for both kinds of communication. This protocol contains two parts, selection of the optimal path and efficient forwarding of the packet (Luo *et al.*, 2010). MIBR uses road segment based routing approach. Where road segments are chosen in such a way that it can provide a path to the destination with the lesser number of hop count. MIBR also proposed a formula (Luo *et al.*, 2010) to estimate the hop count for each road segment, which depends on the number of buses and transmission range of vehicles. To estimate the shortest path, Dijkstra algorithm was used in this protocol.

Whenever a vehicle at a junction receives a packet, it checks its route table and considers the probability of buses to select the next road segment. After selecting the next road segment "bus first strategy" is used to forward the packet. Figure 2.10 is illustrating the concept of packet forwarding in MIBR.

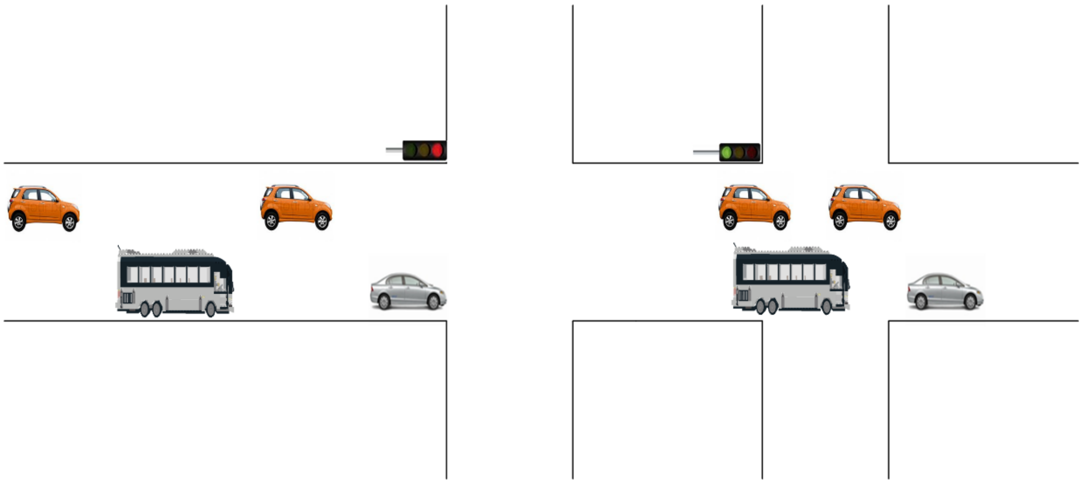

Figure 2. 9 Cluster Formation due to Traffic Lights

In Figure 2.10 source node wants to send a packet to the destination. Source node first forwards the packet to car 1 which is in its transmission range located at the next road segment. Here the (case 1) source node doesn't select bus as the next hop because MIBR gives preference to the vehicle of next road segment. After receiving the packet, car 1 forwards the packet to vehicle 2 which is a bus. In case 2 MIBR gives the preference to bus over the car in the same road segment. In the last case, vehicle 2 will forward the packet to vehicle 4 of next road segment which will further forward the packet to the destination.

Luo et al. compared the performance of MIBR with GPSR, one channel interface MIBR and two channel interface MIBR on throughput and packet delivery ratio parameters. In one channel interface buses have only one interface for communication and in two channel interface buses have two interfaces, one for the bus to car communication and another for the bus to bus communication. Both one channel and two channel algorithms have used the greedy forwarding approach for the next hop selection. Thus, simulation analysis brief that one channel performs better than GPSR, two channels better than one channel while MIBR performs better than all these three routing protocols.

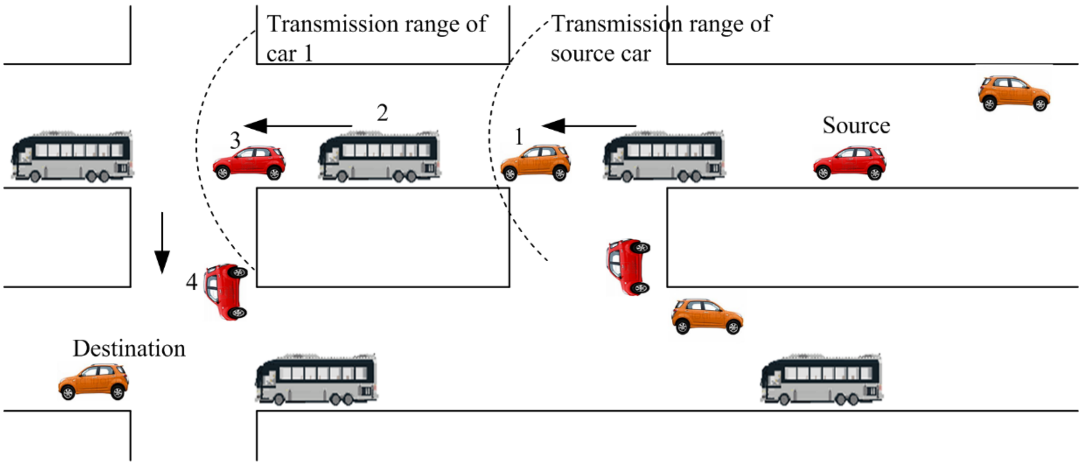

Figure 2. 10 Routing in MIBR

2.2.4 Mobile Gateway Routing for Vehicular Networks (MGRP)

MGRP is based on MIBR. Unlike MIBR, MGRP uses vehicles such as taxis as mobile gateways. MIBR proposed to use buses as mobile gateways however due to the fixed route of buses it can result in limited connected areas (Pan *et al.,* 2011; Namboodiri *et al.,* 2004). Therefor Pan et al. proposed to use taxis as mobile gateway. Gateway vehicles contain two interfaces, IEEE 802.11 interface for V2V communication and 3G interface to communicate with a base station. While any other ordinary vehicles (except mobile gateway vehicles) have only IEEE 802.11 interface.

An ordinary vehicle initially sends the packet to the destination, if it is unable to send the packet to destination vehicle directly, then they will choose the Mobile gateway. After receiving the packet from gateway vehicles, base station forwards the packet to the gateway controller which will further forward the packet to a nearby vehicle of the destination. Architecture of MGRP is shown in Figure 2.11.

Like AODV protocol, MGRP uses RREQ and RREP method to find out the path to destination. Unlike AODV, it restricts the TTL value to three hops as RREQ message can lead to following three situations:

Case 1: There is no neighbor, in such a condition the sending vehicle carries the packet till then any other vehicle is not coming in its range. After then it will forward the packet to this neighbor. In Figure 2.12, there is no neighbor for car A, thus it will carry the packet until to find any other vehicle in its range.

Case 2: There are more than one neighbor vehicles, but none of them have a path to gateway or destination. In this case, the sender will forward the packet on the road with higher vehicular density. In Figure 2.12, car S1 require to send a packet to car D1, and there is no vehicle available with a path to the destination, in this case, S1 will select the car of Road 1 as the next forwarding node since this road possesses high vehicular density than Road2.

Case 3: There are more than one routing paths are available. In this case, the sender will select a path with longest lifetime. Path lifetime is the smallest lifetime of a link in the same path. As shown in Figure 2.12, car S2 wants to send a packet to car D2. There are two routing paths are available through road 3 and 4. As the path lifetime of road 3 is greater than road 4, S2 will select the vehicle of road 3 as next forwarding hop.

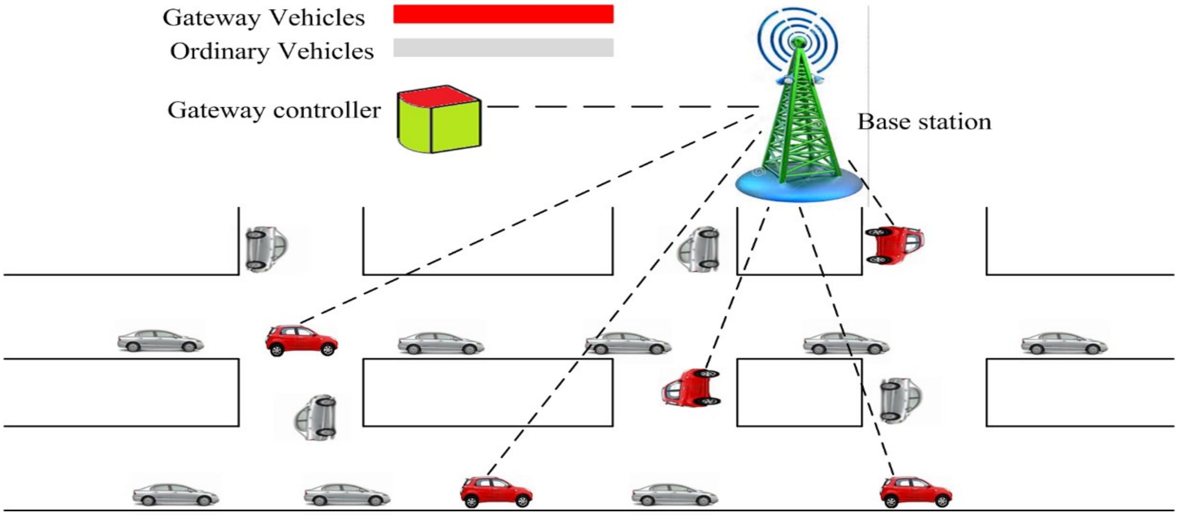

Figure 2. 11 Architecture of MGRP Protocol

After receiving the packet, gateway vehicle will send the packet to the base station which will further forward the packet to gateway controller. Gateway controller will forward the packet to all those vehicles which are within the 500 meters of destination. It will increase the probability of packet delivery. Still, if there is no vehicle within 500 meters of destination then the gateway controller will drop the packet.

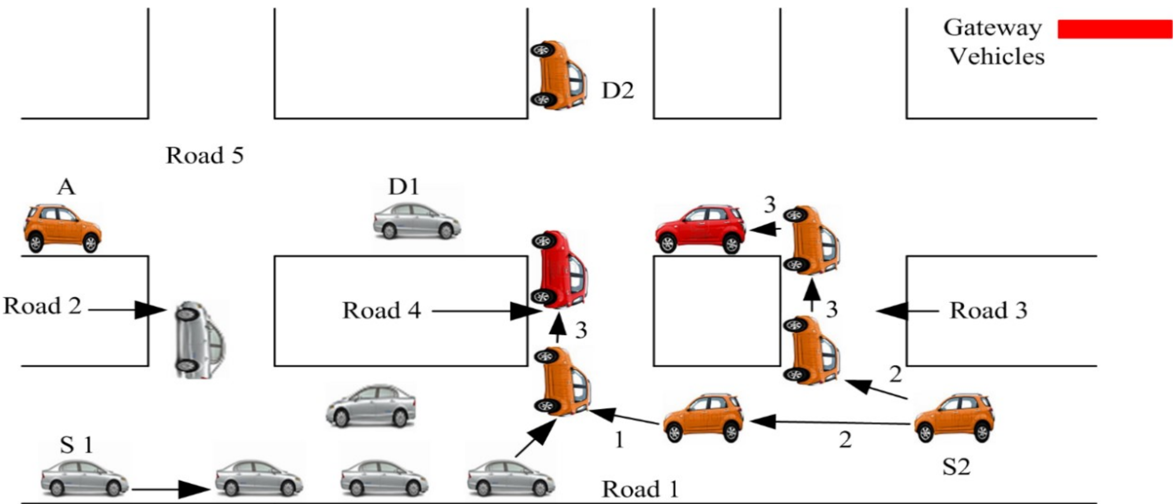

Figure 2. 12 Different Scenarios of Packet Forwarding

The performance of this routing protocol was compared with GPSR on packet delivery ratio, average hop count, and packet overhead parameters. MGRP performed better than GPSR on packet delivery ratio and average hop count parameter. When the speed of the vehicles is increased more than 85 km/h then the packet delivery ratio of GPSR exhibits better performance than MGRP, because the MGRP has to maintain the routing table more frequently. Due to routing table overhead, packet overhead in GPSR was fewer than MGRP.

Table 2. 1 Comparison of Position Based Routing Protocols

PROTOCOLS	COMMUNICATION TYPE	FORWARDING STRATEGY	ANCHOR PATH COMMUTATION	TRAFFIC AWARENESS	PROTOCOL USED FOR COMPARISON
GPSR	V2V	Greedy forwarding	No	No	DSR
GPSR+AGF	V2V	Advanced greedy forwarding	No	Yes	AODV, AODV+PGB, GPSR
GPCR	V2V	Restricted greedy forwarding	Yes	Yes	GPSR
CAR	V2V	Advanced greedy forwarding	Yes	Yes	GPSR, GPSR+AGF, CAR+WA
CBF	V2V	Greedy Forwarding based on contention	No	No	B-PBR
GEOSVR	V2V	Restricted greedy forwarding	Yes	Yes	AODV, GPSR
RIVER	V2V	Optimized Greedy Forwarding	Yes	Yes	GPSR, Short-path, STAR
VWCA	V2V	Directional forwarding to CH	No	Yes	D- highest degree, D-lowest ID, WCA
PASSCAR	V2V	Forwarding to next cluster in path	No	No	Passive clustering mechanism
TOPOCBF	V2V	Greedy forwarding based on connectivity of road segment	Yes	Yes	eTOPOCBF, GyTAR
SADV	V2I	Greedy forwarding	Yes	No	VADD
INFRASTRUCTURE ASSISTED GEO ROUTING	V2I	Greedy forwarding to RSUs	Yes	No	GSR, GPSR, CBF
MIBR	V2I	Greedy forwarding to buses	Yes	Yes	GPSR, one channel and two channel MIBR
MGRP	V2I	Greedy forwarding to mobile gateways	No	Yes	GPSR

2.3 Gap Analysis

Throughout the previous sections, various routing protocols for VANETs have been classified and reviewed. Although a number of research works have been proposed, most of the studies referred improvement in its functioning. It is expected that vehicular communication will dominate the market in the coming years. After reviewing and evaluating these algorithms following gaps are identified:

2.3.1 Forwarding Strategy

Most of the reviewed protocol follows the traditional geographic routing to select the next hope in a route. It can lead to difficulties in the following manners:

Geographic routing towards a destination selects a vehicle as a next hope which is nearest to the destination node. If the real wireless network conditions are considered where attenuation and noise make the communication challenging, this strategy is not suitable as the probability of signal reception decreases with distance.

There is another drawback with this forwarding strategy; forwarding node (farthest known neighbor from the source and nearest to destination) is likely to be out of range when actual forwarding occurs. It can happen because of driver's fast driving, traffic light or crossing which can increase the distance in between source node and next forwarding hope.

2.3.2 Higher Layer Traffic Awareness

The protocols studied in this chapter are concerned with delay tolerant networks. Some of the protocols deliver the packet as soon as it receives. Nevertheless, there is a large variety of requirements, depending on which the Routing protocol decide which kind of traffic should be given high priority and which one should be considered in the last.

2.3.3 Network Conditions Adaptability

One of the most important characteristics of vehicular communication is the variability. Mobility pattern of vehicles and traffic density vary a lot during the traveling because of the behavior of the driver, road condition, area (rural, city, highway) and several other factors. So, Routing protocols must be designed in a way such that they can deal with most of these situations.

2.3.4 Infrastructure Exploitation

One of the most important types of Vehicular network is a hybrid network, in which vehicles can take the help of road side infrastructure for communication. However, most of the reported protocol neglects the existence of road side units. Whereas, routing protocols could benefit many ways from those devices, which could act as buffers and routers. Moreover, the vehicle could get the useful information of traffic from these units, resulting in enhanced performance of the routing algorithm.

2.4 Problem Formulation

One of the major issues that affect the performance of VANET is the way of routing implemented in a network. Routing protocols used in the conventional wired networks cannot be used in VANET considering its inability to tune to the dynamic topology nature of the vehicular environment as the connections among vehicles are established in Ad hoc manner. Vehicular topology varies very frequently due to the high mobility of vehicles and abundant network size.

To realize the real-world applications of VANETs, efficient routing protocols are required which can adjust themselves with the changing topology and successfully deliver the packets to the destination while maintaining the high performance.

As mentioned earlier, VANETs and MANETs have many similarities, e.g., self-organization, self-management, low bandwidth, and short radio transmission range, whereas VANET differs from MANET by its highly dynamic topology. A number of studies have been done to simulate and compare the performance of routing protocols in different traffic conditions in VANETs (Wang and Lin, 2013; Kwon and Gerla, 2002; Couto, 2005; Artimy *et al.,* 2004; Artimy *et al.,* 2005). The simulation results showed that traditional Ad hoc routing protocols for MANETs (e.g., AODV and DSR) suffer from highly dynamic nature of node mobility as they tend to have poor route convergence and low communication throughput (Kaur *et al.,*2009).

Node movement in VANETs usually restricted only to the bidirectional movement which is constrained along roads and streets. Thus, routing strategies that practice geographical location information obtained from street maps, traffic models, or even more prevalent navigational systems onboard, the vehicles make sense. This fact receives support from a number of studies that compare the performance of topology-based routing (such as AODV and DSR) against the position-based routing strategies in urban as well highway traffic scenarios (Kwon and Gerla, 2002; Rozner, 2009). Therefore, the geographic routing (position-based routing) has been identified as a more promising routing paradigm for VANETs. Several protocols which are based upon the position-based routing technique were introduced in recent years for the efficient communication in VANET.

2.5 Objectives

On analyzing the gaps in various routing protocols in VANET and after formulating the problem, the following objectives have been laid down.

1. To study and review various routing protocol available with respect to Vehicular Ad hoc network.
2. To design and develop a routing protocol for VANET.
3. To verify and validate the proposed protocol.

The following three chapters present three different routing protocols for VANETs.

Chapter 3

A Junction Based Infrastructure Assisted Routing Protocol for VANETs: JIP

Various routing protocols for VANETs have been proposed by researchers' world wide and after carefully disseminating these protocols, this chapter presents a novel routing protocol for VANETs. A good number of the Geography based routing protocols in VANET ((Gonçalves *et al.,* 2016; Oliveira *et al.,* 2017; Liu *et al.*, 2017; Bhagyavathi *et al.,*2017; Bhagyavathi *et al.,* 2017), some have been extended by implemented the greedy forwarding method to forward the packet. GPSR (Karp and Kung, 2000), GPSR+AGF (Lochert *et al.,* 2003), the CBF (Fu¨ßler *et al.,* 2004) are few of the prominent protocols which follow greedy forwarding method[3].

GPSR has been considered as a novel routing protocol which has introduced the concept of greedy forwarding (Karp and Kung, 2000). It uses beaconing method to acquire the position of neighbor vehicles. In greedy forwarding technique, the vehicle uses the position of

[3] The contents of the chapter are partially published in:
Kumar, S., & Verma, A. K. (2017). A Junction Based Infrastructure Assisted Routing Protocol for VANETs: JIP, International Journal of Artificial Intelligence and Knowledge Discovery, 07(4), 01-10. (IF .50).

destination and neighbor vehicles to determine the next vehicle which can act as the carrier for further packet forwarding (Zeadally, *et al.*, 2012). In this method, a vehicle which is having the smaller distance to a destination than any other neighbor of the packet sender could be selected as the next packet forwarder. However, this distance measuring technique may not be suitable in urban scenarios, since the transmission power of vehicles can be affected by interference available on the roads. The beaconing method used in GPSR can also lead to higher network load in the highly dense network (Yousefi and Fathy, 2008; Chang *et al.,*2015; Abdou *et al.,* 2015).

Most of the position-based routing protocols use beaconing method to acquire the information of neighbors. As discussed above, the beaconing method can lead to the outdated neighbor table and increased network load. By considering these facts CBF protocol uses greedy forwarding technique with the broadcasting approach to forward the packet from source to destination (Fu¨ßler *et al.,* 2004). In CBF, when a vehicle wants to send a packet, it simply broadcast and the packet will be received by the neighbor vehicles. All the receivers apply equation 3.1 to calculate their progress towards the destined vehicle and make use of equation 3.2 to start a timer. A vehicle which provides more progress than any other neighbor will be selected as the next forwarding vehicle and it will broadcast the same packet, suppressing all other vehicles which were the part of packet forwarding process.

$$Progress = max\left\{0, \frac{dist\ (s,d) - dis(c,d)}{range}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$t(Progress) = T\,(1\text{-}Progress)\ldots\ldots\ldots\ldots(3.2)$$

where d, c, and s, are the positions of destination, current node and source respectively and T is the maximum forwarding delay (Fußler *et al.,* 2004).

3.1 Proposed Protocol: JIP

JIP is a position-based routing protocol which has used digital maps and GPS system to locate road side units (RSUs) and moving vehicles (Bazzi *et al.,* 2016). Since any traffic or accident related information can be useful for a specific region, thus in this protocol we have not chosen any vehicle as a destination, instead, a random location is selected as the destination region. As shown in Figure 3.1, a 50 meter circular region of any selected destination coordinates is treated as the destination region. If a vehicle wants to send a message to any destination region, it broadcast the packet. This broadcast will be listened by all the neighbor vehicles (Tomar *et al.,* 2010; Hartenstein *et al.,* 2008). When a source node initiates a packet sending process it adds its ID (source ID), the position of destination region and nearest RSU's location. After broadcasting the packet following cases can occur:

Case a: The packet is reached in the destination region.

Case b: The packet is received by RSU, which is not mentioned in the packet header.

Case c: The packet is received by RSU, which is mentioned in the packet header.

Case d: The packet is received by neighbor vehicles.

Figure 3.1 is used to exemplify the above-discussed cases and the functioning of JIP. In this diagram, the dotted circle shows the circular transmission range of vehicles. To improve the connectivity of the vehicles, RSUs are deployed at each junction.

In the given scenario case a can be understood as follows; vehicle 1 makes the first move to send the data packet for destination region 1. Within the first attempt of broadcast, the data packet reaches the vehicle 2, which was moving in the destination region 1. As vehicle 2 is the only vehicle available within the transmission range of vehicle 1, it will broadcast the packet further by updating the value of a flag such that the same packet need not to broadcast, given that it has already reached to its destination.

In the proposed protocol, source and destination pairs are selected randomly. Before sending the packet, source vehicle adds the id of nearest RSU into the packet header using digital map. The idea behind adding the id of nearest RSU to the packet header was for the selection of shortest path, which can lead to improvement in the packet delivery time. If the broadcasted packet reaches to RSU which was not refer to, then the packet will be discarded. As shown in Figure 3.1, the vehicle 3 initiates a packet sending process for destination region *2.*

RSU 2 is nearest RSU to vehicle 3 on the destined path. Vehicle 3 broadcasts the packet, which will be listened by vehicle 4 and RSU 1. However, the packet was not destined for RSU 1, thus it will discard the packet (case b).

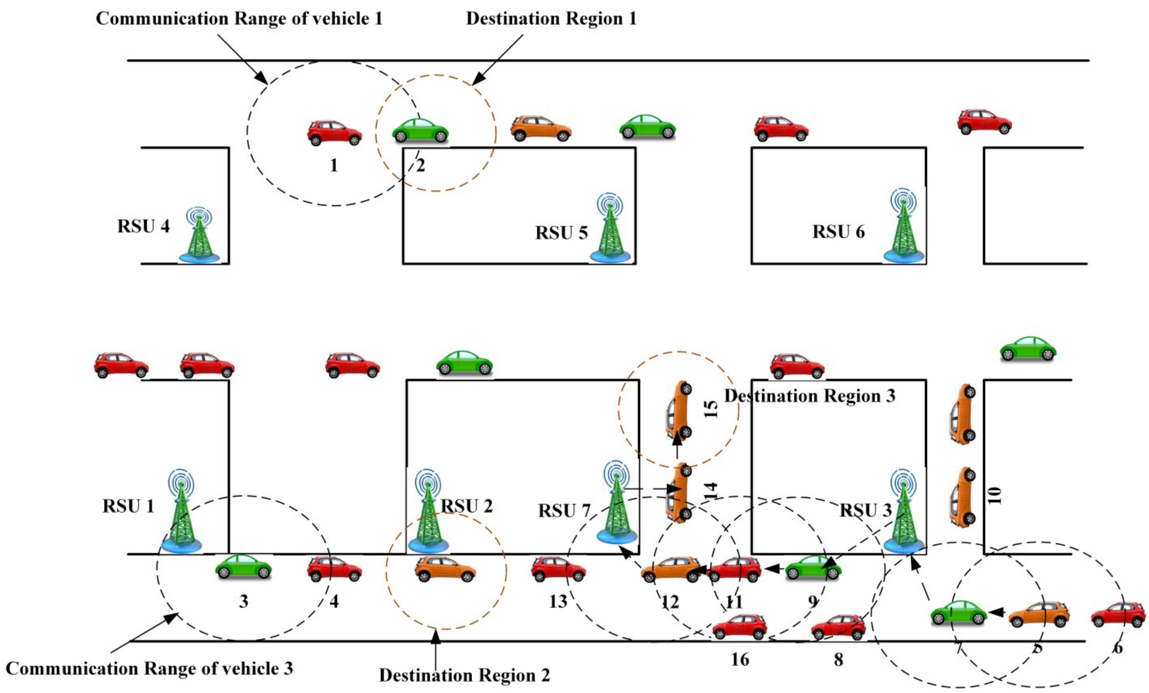

Figure 3. 1 Scenario to Illustrate the Working of JIP

If the receiver is RSU which is mentioned in the packet header (case c), then the RSU will apply Dijkstra's shortest path algorithm (Dijkstra, 1959) to find the location of next RSU through which the packet can be forwarded. This will also suppress other participating vehicles to further forward the packet. This RSU will broadcast the packet by adding its ID and next RSU's ID in the packet. In Figure 3.1, vehicle 5 initiates the packet sending process for destination region *3* by adding the id of nearest RSU 3 in the packet header. The broadcasted packet of vehicle 5 will be received by vehicle 6 and 7 (case d). Both the vehicles will apply equation 3.3 to calculate their progress towards RSU 3. In this circumstance, vehicle 6 will provide zero progress, subsequently, it will stop further broadcasting. The vehicle 7 will apply equation 3.2 to start a timer, after the expiry of timer it will broadcast the packet again, which can be received by vehicle 5 and RSU 3 (case c). Since the packet was destined for RSU 3, it will apply Dijkstra's algorithm to find out the shortest path from the current position to the destination region. RSU 3 will specify the id of RSU 7 in the packet header and it will broadcast the packet which can be received by vehicle 9 and 10. Similarly, vehicle 9 will broadcast the packet which can be received by vehicle 8, 11 and 16. After calculating the progress, vehicle 11 and 16 will start the timer (equation 3.2). The timer of vehicle 11 will expire earlier than vehicle 16. Once the timer expires, vehicle 11 will broadcast the packet and suppress the broadcasting process of vehicle 16. In the same way, the data packet will reach to RSU 7 and from RSU 7 to the destination region. The complete path from the source vehicle to destination region is shown in Figure 3.1 using dotted arrows.

$$Progress = max\left\{0, \frac{dist\ (p,RSUJ)-dis(c,RSU)}{range}\right\}, \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

where c, p, and RSU are the position of the current vehicle, previous packet sender vehicle and RSU respectively.

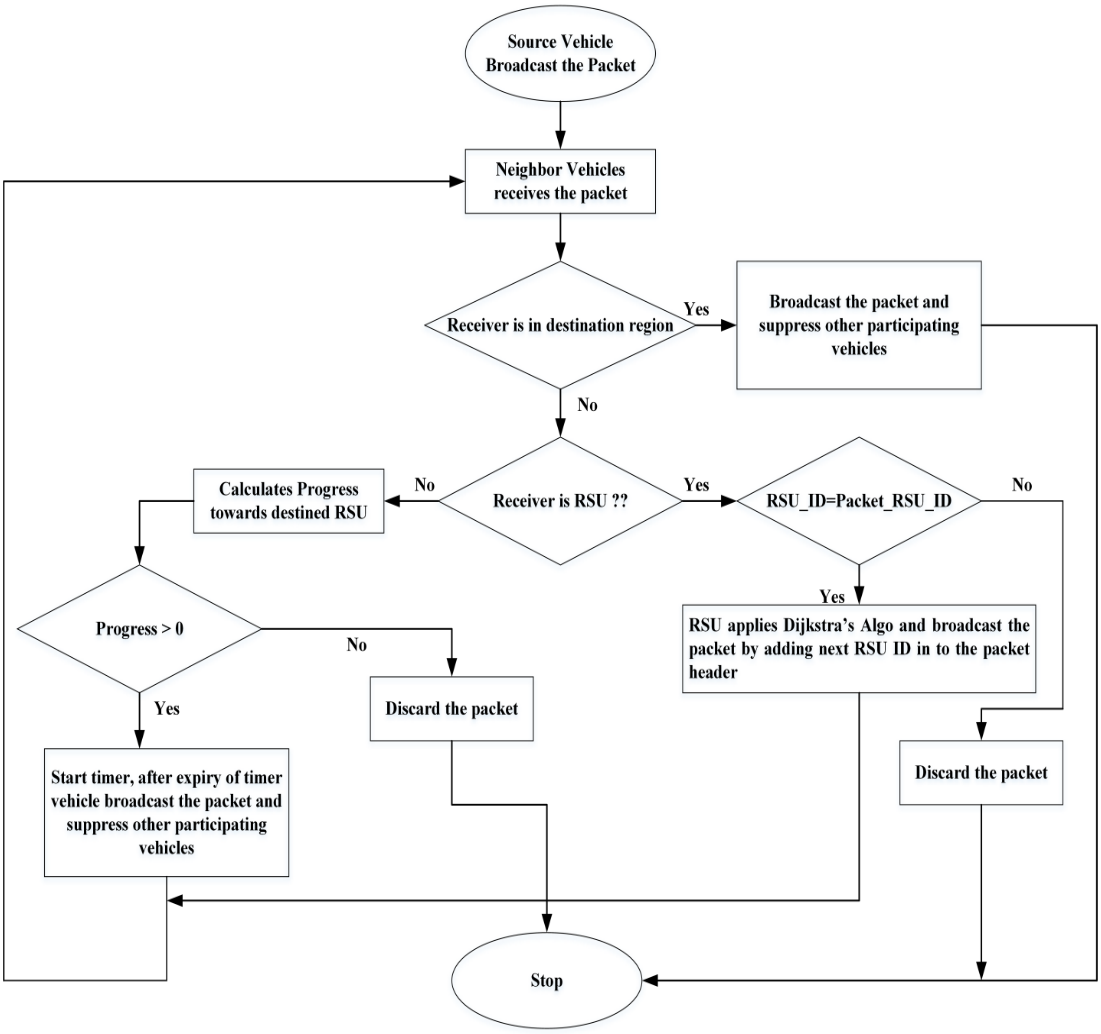

Figure 3. 2 Architecture of JIP

3.2 Simulation

3.2.1 Simulation Environment

To evaluate the performance of JIP an artificial scenario is created using SUMO and MOVE tool (https://sourceforge.net/projects/sumo/files/latest/download;Behrisch *et al.*, 2011; Lämmel, 2017). The Qualnet simulator (QualNet Documentation, 2006) is used to implement JIP, CBF, and GPSR. GPSR protocol uses beaconing method, therefore it is simulated on three beacon forwarding interval as 0.5, 1 and 1.5 seconds. The road map of

Table 3. 1 Simulation Parameters: JIP

SIMULATION PARAMETERS:

SIMULATOR USED	Qualnet 6.1, Sumo and MOVE
PROTOCOL USED FOR COMPARISON	GPSR, CBF
TERRAIN SIZE	5000 X 5000 meter
NUMBER OF JUNCTIONS	30
BEACON FORWARDING INTERVAL	0.5, 1, and 1.5 seconds
VEHICLE DENSITY	100, 150, 200, 250, and 300
VEHICLE SPEED	5 m/s to 15 m/s and 16m/s to 30 m/s
SIMULATION TIME	100 Seconds
PACKET SIZE	512 Bytes
EVALUATION PARAMETERS	Packet Delivery Ratio, Average Broadcast v/s Average number of Beacons sent, Network Latency

size 5000 m X 5000 m with 30 junctions is created by Sumo and Move tool. To analyze the performance in different scenarios, vehicle numbers are varied from 100 to 300. Vehicles' speed can affect the performance of protocols, for that reason two set of simulation is carried out, in the first set the vehicles' speed has been varied between from 5 m/s to 15 m/s and in the second set it has ranged 16 m/s to 30 m/s. During the

Simulation, each vehicle sends 5 packets to any randomly selected destination region. Simulation time period was fixed as 100 seconds.

3.2.2 Evaluation Metrics

To evaluate the performance of JIP, following metrics were used:

Packet Delivery Ratio (PDR)

To evaluate the successfully delivered packet in ratio to sent packets, this metric is used. It can be calculated as follows:

PDR (=Total Packet Received)/(Total Packet Sent)..................(3.4)

Average Broadcast v/s Average number of Beacons sent

Following equation are used to estimate the network overhead due to beaconing method and broadcasting technique:

Average Broadcast = (Total number of Broadcast)/(Total number of vehicles)

................(3.5)

Average Beacons Sent = (Total number of Beacon Sent)/(Total number of vehicles)

................(3.6)

Network Latency

To estimate the end to end delay in packet delivery, network latency parameter is used.

3.2.3 Performance evaluation

JIP is evaluated and compared with the modified version of CBF and GPSR protocols. Based on the vehicles' speed, two sets of simulations have been carried out. Packet delivery ratio of GPSR for different vehicles' speed with diverse traffic densities and different beacon interval is shown in Figure 3.3, Fig 3.4, Table 3.2 and Table 3.3. As the number of vehicles increases with reduced beacon interval, the PDR found to be improved. Moreover, it can also observe that the packet delivery ratio decreases with increasing the speed of vehicles (Figure 3.3 and Figure 3.4).

Table 3. 2 Packet Delivery Ratio of Modified GPSR with Vehicle Speed 5 m/s to 15 m/s

Beacon Forwarding Interval (Seconds)	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
0.5	0.4	0.42	0.49	0.55	0.6
1.0	0.36	0.4	0.45	0.48	0.5
1.5	0.3	0.32	0.36	0.37	0.4

Table 3. 3 Packet Delivery Ratio of Modified GPSR with Vehicle Speed 16 m/s to 30 m/s

Beacon Forwarding Interval (Seconds)	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
0.5	0.28	0.3	0.35	0.43	0.48
1.0	0.24	0.28	0.32	0.35	0.39
1.5	0.19	0.21	0.23	0.25	0.3

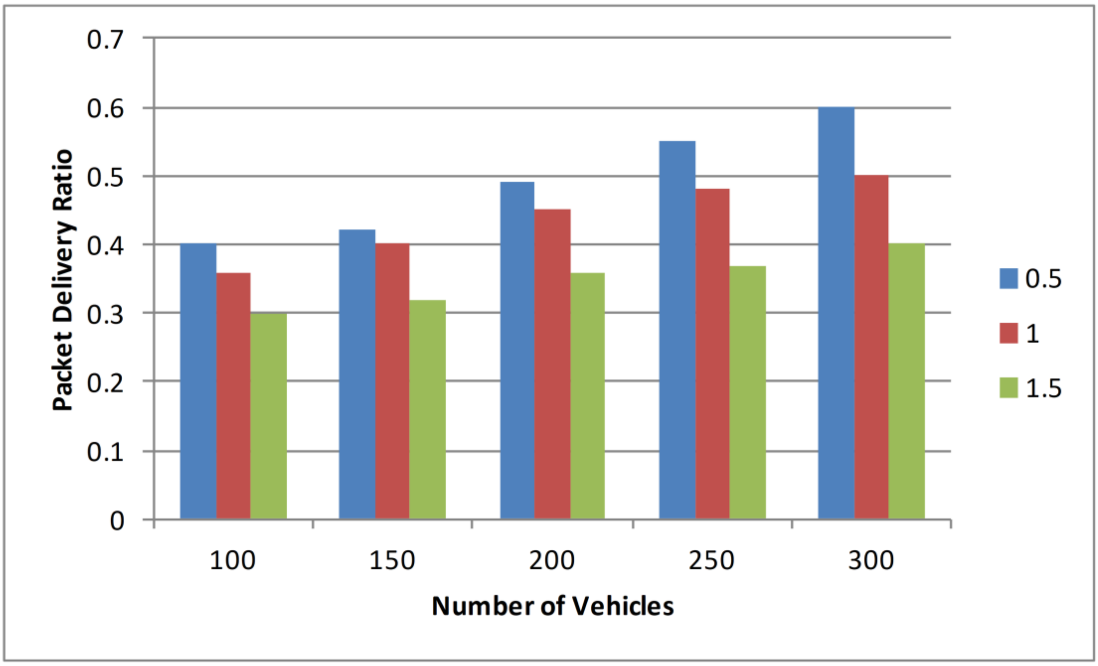

Figure 3. 3 Packet Delivery Ratio of Modified GPSR with Vehicle Speed 5 m/s to 15 m/s

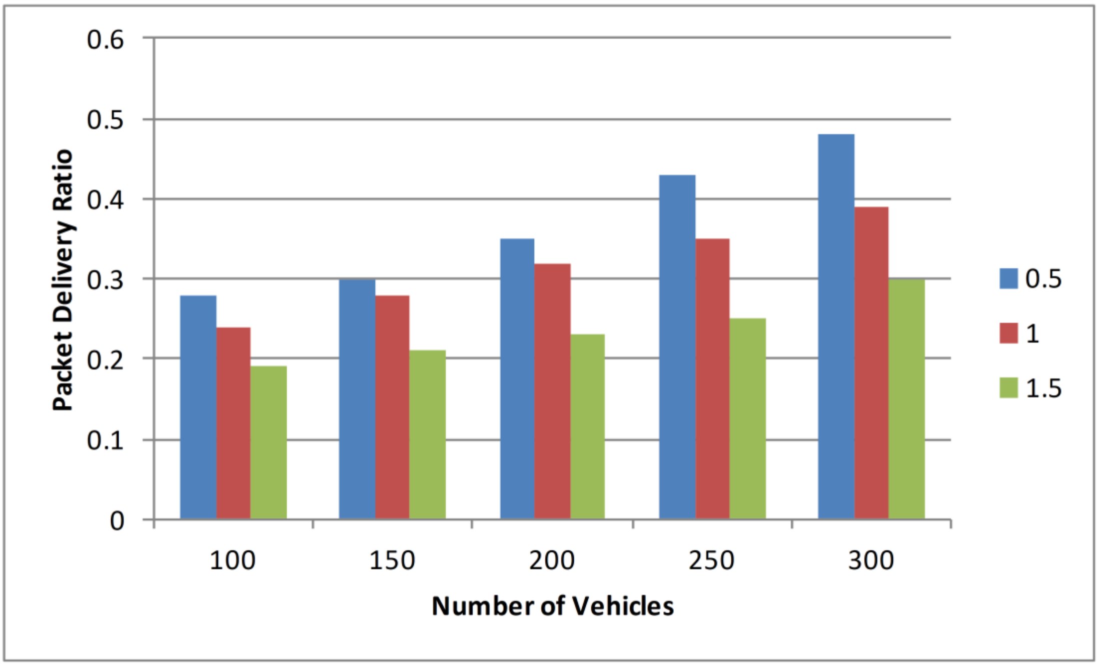

Figure 3. 4 Packet Delivery Ratio of Modified GPSR with Vehicle Speed 16 m/s to 30 m/s

Further, to evaluate and compare the performance of JIP with GPSR and CBF protocols, the average PDR of GPSR was calculated by taking the mean at different beacon intervals. Sometimes, the beaconing method in GPSR can provide inconsistent information of neighbors, which may cause to increase the probability of packet drop. Consequently, JIP performs better than GPSR and CBF on packet delivery ratio parameter. On the other hand, CBF protocol offers the better result than GPSR, since CBF follows the packet broadcasting mechanism (Table 3.4 and 3.5).

Table 3. 4 Packet Delivery Ratio with Vehicle Speed 5 m/s to 15 m/s

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
GPSR	0.35	0.38	0.43	0.46	0.5
CBF	0.43	0.58	0.7	0.79	0.8
JIP	0.5	0.6	0.72	0.81	0.82

Table 3. 5 Packet Delivery Ratio with Vehicle Speed 16 m/s to 30 m/s

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
GPSR	0.23	0.26	0.3	0.34	0.39
CBF	0.38	0.5	0.6	0.7	0.77
JIP	0.45	0.52	0.65	0.74	0.79

Furthermore, the results of simulation show that as the number of vehicles increase in the network, all the three protocols offer better PDR. Figure 3.5 and 3.6 demonstrate that the scenario with the increased number of slow moving vehicles offers enhanced packet delivery ratio.

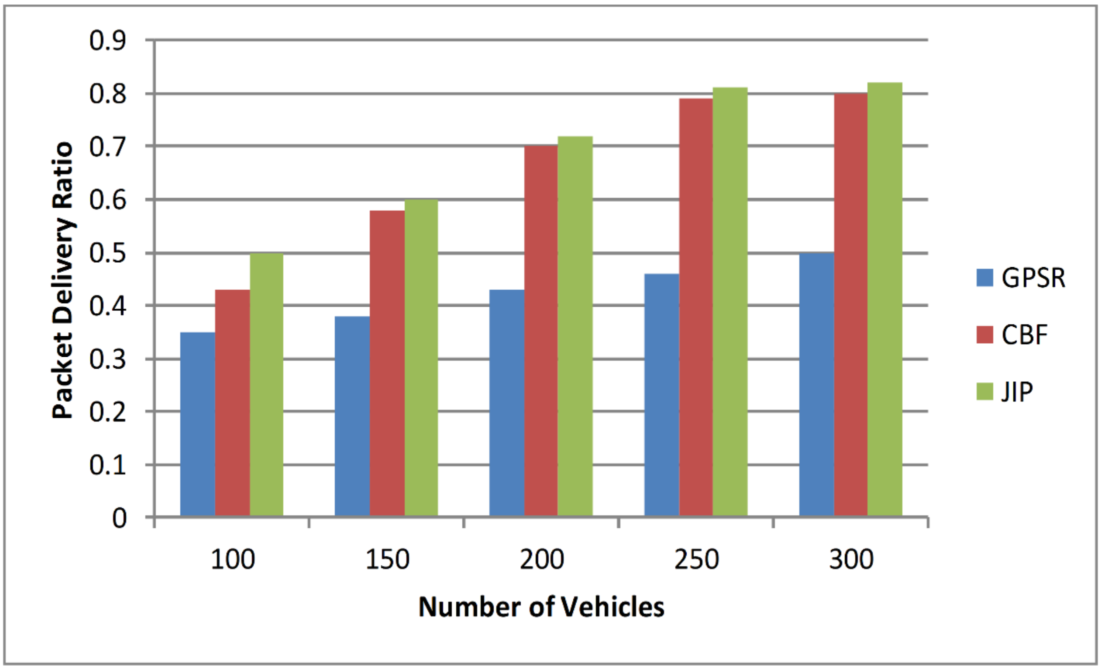

Figure 3. 5 Packet Delivery Ratio with Vehicle Speed 5 m/s to 15 m/s

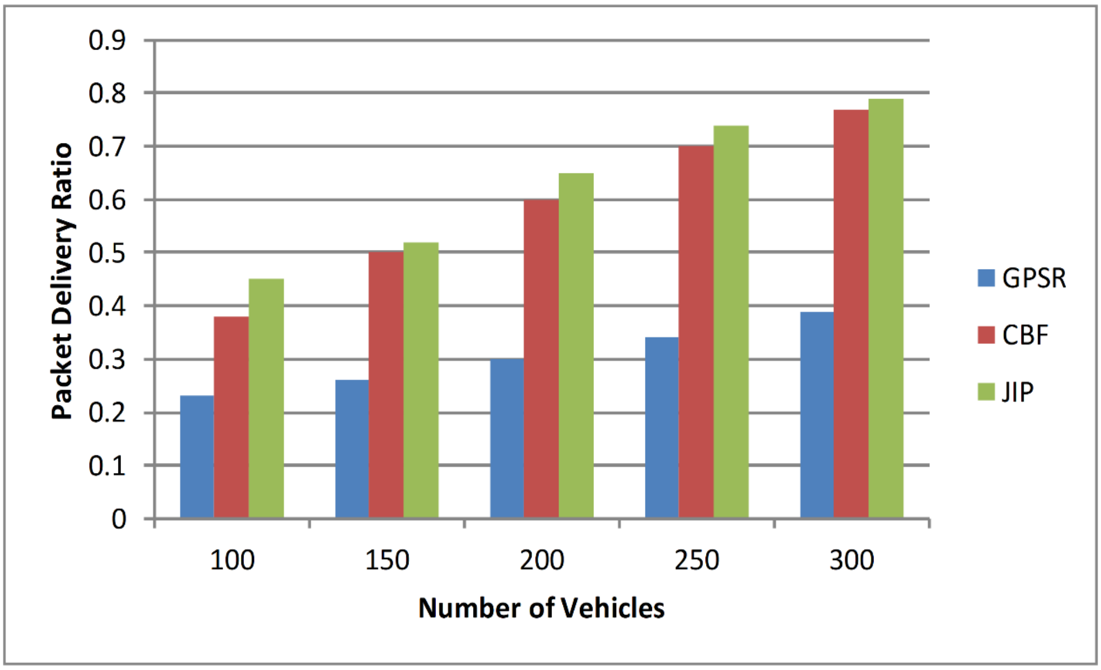

Figure 3. 6 Packet Delivery Ratio with Vehicle Speed 16 m/s to 30 m/s

Table 3. 6 Average Number of Broadcast/ Beacon

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
GPSR	122.22	122.22	122.22	122.22	122.22
CBF	25.4	30.1	35.3	37.3	40.1
JIP	30.3	35.7	39.4	42.1	43.2

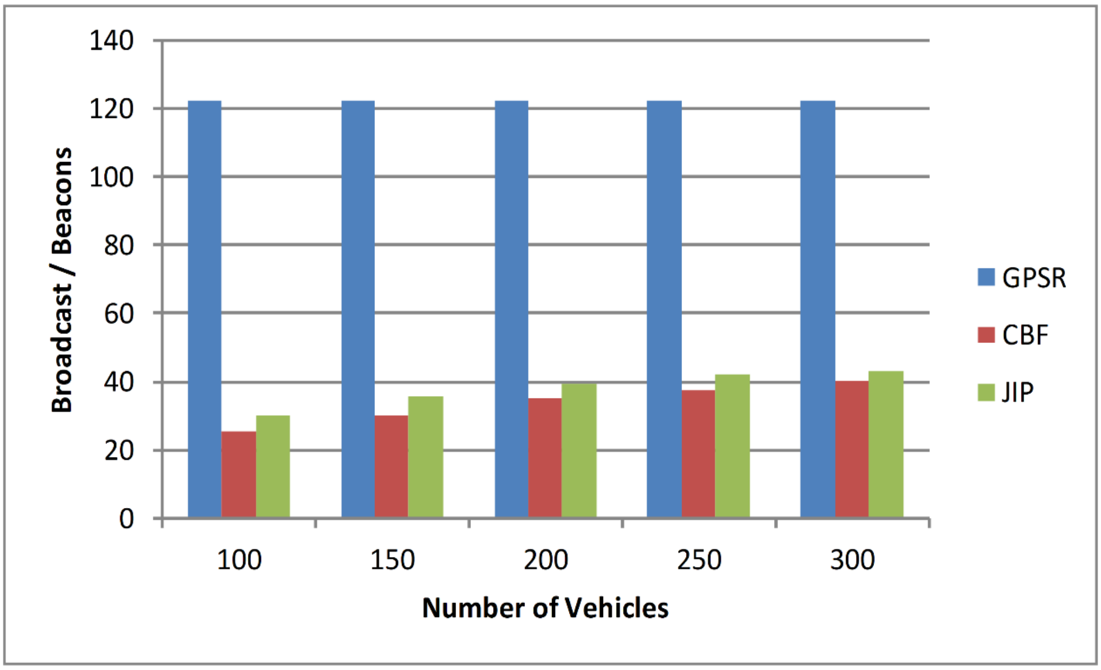

Figure 3. 7 Average Number of Broadcast/ Beacon

In the JIP and CBF, vehicles broadcast the packets, when it is required, while in the GPSR protocol, vehicles send the beacons to neighbor vehicles proactively. To estimate the total number of beacons sent by vehicles, Beacons sending time interval and total simulation time are used as an input metric. Conversely in JIP and CBF, "the total number of the source to destination pairs" along with the total number of packets sent were used to calculate the average number of broadcasted packets by a vehicle. From the Figure 3.7 and Table 3.6, it can be observed that the average beacons sent in GPSR protocol by vehicles are at least three times more than the average number of the packet broadcast send by the vehicles in JIP and CBF. Moreover, as the result of enhanced PDR value, the average number of broadcasts made by JIP is higher than CBF.

Packet delivery time of protocols is shown in Figure 3.8 and Table 3.7. It is obvious that the JIP takes a longer time to deliver the packet as compared to its peer protocols since it utilizes RSU and junctions to send the packets from source to destination. Moreover, JIP may not work well in terms of latency, though it provides lower network overhead and good packet delivery ratio than GPSR and CBF protocols.

Table 3. 7 Packet Delivery Time

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
GPSR	0.015	0.017	0.018	0.0165	0.019
CBF	0.018	0.019	0.02	0.025	0.027
JIP	0.034	0.035	0.036	0.035	0.037

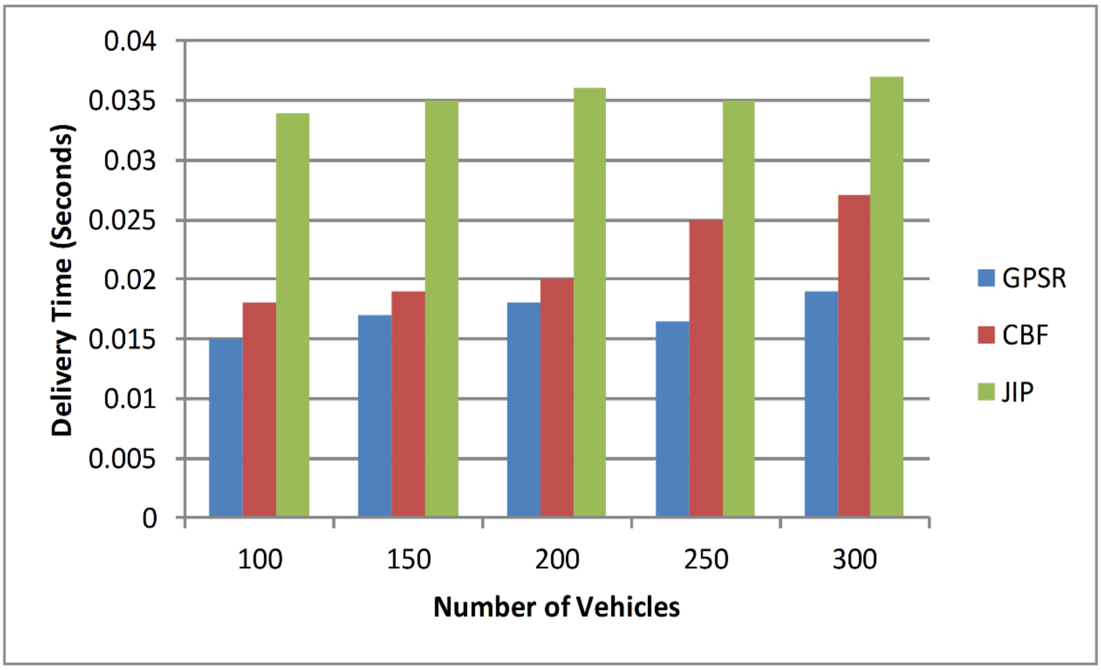

Figure 3. 8 Packet Delivery Time

3.3 Summary

An efficient routing protocol named A Junction Based Infrastructure Assisted Routing Protocol for VANET: JIP, is proposed in this chapter. To make the scenario and simulation more realistic, SUMO and MOVE tool has been extensively practiced. In JIP, data packets have passed from source to the destination through RSUs, which are deployed at the junctions. In urban scenarios, the distance between source and distance cannot be calculated directly due to the presence of several interferences, consequently, in JIP this distance has been calculated through junctions. To reduce the network overhead, which usually occurs with beaconing method (Ruiz *et al.,* 2010; Kumar and Dave, 2016), the broadcasting method is implemented in the present protocol. The performance evaluation of proposed protocol as compared with other peer protocol such as CBF and GPSR illustrate that JIP gives better packet delivery ratio with the lesser number of broadcasts than GPSR.

The distance measuring technique used in JIP, GPSR, and CBF may not be suitable in urban scenarios since the streets are separated by various obstacles such as buildings and towers. One of the major limitation of the proposed JIP protocol is that the interferences among different street segments is not considered. To overcome this limitation another protocol is presented in the next chapter.

Chapter 4

An Advanced Forwarding Routing Protocol for Urban Scenarios in VANETs: SBFP

As discussed, one of the most important characteristics of vehicular communication is changeability (Cristiano *et al.,* 2017; Fuentes *et al.,* 2014; Vegni and Loscri, 2015). The mobility pattern of vehicle and traffic density varies a lot during traveling because of the behavior of driver, road condition, area (rural, city, highway) and several other factors (Araniti *et al.,* 2013; Halim *et al.,* 2017; Seo *et al.,* 2017). Thus, Routing protocols must be designed in a way to handle most of these situations.

In this direction, for the efficient data dissemination in VANETs, a street-based forwarding protocol (SBFP) has been proposed[4]. The interferences among different street segments are considered and a unique street-based forwarding concept is introduced to reduce the local maximum problem. In this protocol, the greedy forwarding concept along with the broadcasting mechanism and suppression technique is

[4] The contents of the chapter are partially published in:
Kumar, S., & Verma, A. K. (2017). An advanced forwarding routing protocol for urban scenarios in VANETs. International Journal of Pervasive Computing and Communications, 13(4), 334-344. (ESCI and SCOPUS Indexed, IF 0.68).

implemented to minimize the overhead created in the regular beacons forwarding processes (Lipman *et al.,* 2009; Panichpapiboon and Pattara, 2012).

4.1 Data Forwarding Challenges in VANET

Greedy forwarding is a very popular technique among position-based routing protocols (Karp and Kung, 2000; Füßler *et al.*, 2004; Naumov *et al.*, 2006; Naumov and Gross, 2007; Xiang *et al.*, 2013; Pan *et al.*, 2011). In this technique, the coordinates of vehicles are used to calculate the distance from a vehicle to the destination vehicle (Eze *et al.,* 2014). In the urban scenario, streets are separated by various obstacles such as buildings and towers. Therefore, the methods used to calculate the distance between two vehicles in greedy forwarding are not suitable for such a scenario. Alternatively, in highway scenario, this distance-measuring technique is appropriate, as highways are generally free from transmission hurdles. Vehicular network is known for its high speed, which results in rapid alteration of the vehicle's position. Consequently, the neighbor table maintained by the vehicles may be outdated, which can result in wrong forwarding hop selection. This issue can be addressed by higher beacons frequency; nevertheless, this solution can also lead to higher network load. Lochert et al. (2003) said: "actual routing decisions take place only at junctions". If the vehicular network is dense, then vehicles available at the junction can easily forward the packet to the next forwarding hop, however, if the network is sparse, the packet may be dropped or forwarded to a vehicle that is moving in a different direction. Figure 4.1 illustrates the data forwarding challenges of GPSR and CBF.

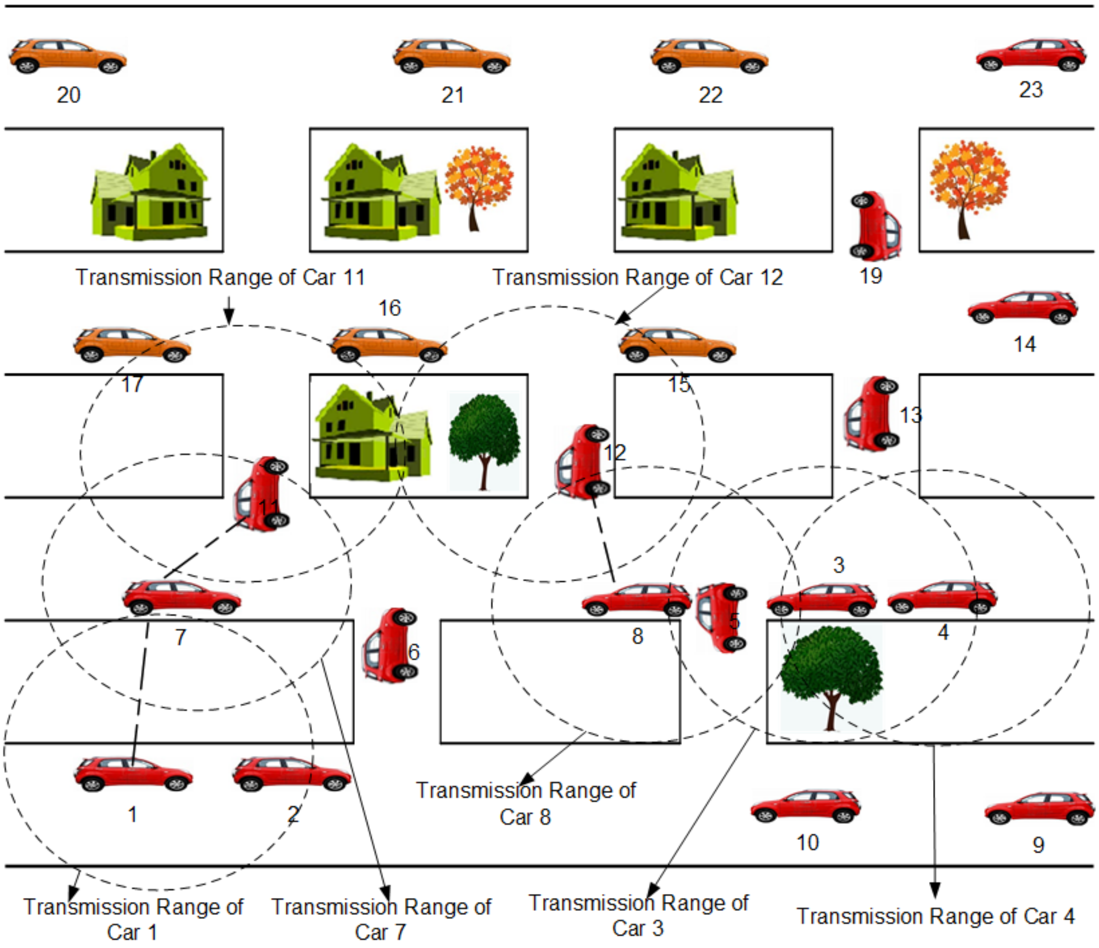

Figure 4. 1 Forwarding Mechanism of GPSR and CBF

Scenario 1 (GPSR): Car 1 needs to send the packet to Car 23. Cars 2 and 7 are the neighbors of Car 1; however, Car 7 will be selected as a next forwarding hop, as it is having less distance to the destination as compared to Car 2. Further, based on the distance to the destination of Car 7's neighbors, Car 11 will become the next forwarding vehicle. Subsequently, considering the transmission range of Car 11, Cars 16 and 17 can be its neighbors. As shown in Figure 4.1, Car 16 may not receive the beacons from Car 11 as a consequence of an existing building in between them. Next, Car 17 cannot be selected as a next forwarding hop, as the previous sender (Car 11) is having less distance to the destination than Car 17. Here, the packet will be stuck in the local maximum, and the right-hand rule will be used to recuperate this situation. In the urban locality, this kind of situation arises repeatedly. Increased frequency of beacons can reduce the numbers of local maximum situations and lead to further higher network load.

Scenario 2 (CBF): Car 4 needs to send the packet to Car 20, so it will broadcast the packet, possibly which can be received by all its neighbors. In this case, (Figure 4.1) Car 3 is the only neighbor of Car 4 thus it can receive the packet. If Car 3 receives the packet, it will again broadcast the packet, which can be received by Car 5 and 8. Both the receivers will use equations 4.1 and 4.2 to calculate progress and value of timer (t). According to equation 4.2, the timer of Car 8 may expire early and suppress further broadcasting of Car 5. Subsequently, Car 12 will receive the data packet from Car 8 and will rebroadcast it. However, Car 16 may not be able to listen to this broadcast because of the presence of the tree and the building. On the other hand, Car 15 is not making any progress toward Car 20, and now the packet gets stuck in the local maximum situation.

The main advantage of CBF over GPSR is that it can reduce the network load, which usually occurs in the beaconing method. Scenarios 1 and 2 depict the situation of a general urban situation, where the beaconing method and broadcasting mechanism have been used for sending a packet to the next neighbor nodes. However, these techniques are not perfectly suitable for a highly dynamic urban scenario because of the presence of towers, buildings and other obstacles.

$$Progress = max\left\{0, \frac{dist\ (s,d) - dis(c,d)}{range}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

$$t(Progress) = T\ (1\text{-}Progress) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

where d, c, and s, are the positions of destination, current node and source respectively and *T* is the maximum forwarding delay ((Holger *et al.*, 2004*)*.

4.2 Proposed Protocol: SBFP

In the proposed protocol SBFP, the solution of all the above-discussed challenges are incorporated. In SBFP, a destination zone is selected within the radius of 50 meters of randomly selected coordinates. Here, a digital map is used to obtain the position of junctions and street ID (SID) on which the vehicle is moving. The source vehicle sends a packet with its source id, location, nearest junction coordinates (NJC) and destination location to the packet header using the global positioning system (GPS). In most of the position-based routing protocols, beaconing method was used to get the neighbors' position, whereas, in SBFP, the broadcasting method has been used to forward the packet.

The forwarded packet will be received by all the neighbor vehicles of the sender. After receiving the packet, the following cases can occur:

Case 1: Receiver is in the destination zone.

Case 2: Receiver is not in the same street segment.

Case 3: Receiver is in the same street segment, making progress towards the nearest junction (NJ) or destination.

Case 4: Receiver is in the NJ zone, and it has been mentioned in the packet header.

If the packet is received by the vehicles of destination zone (case 1), then the receiver can suppress the broadcasting process of other neighbor nodes. In the proposed protocol, a new data-forwarding technique, street-based forwarding (SBF), is offered. In this technique, communication can occur among vehicles moving only on the same street segment (vehicles having same SID). Instead, if the packet is received by the vehicle having different SID, then the receiver will discard the packet (case 2).

In case 3, the packet will be received by neighbor vehicles on the same street segment. All the receiver vehicles will apply equation 4.3 to calculate their progress toward the NJ. Vehicles providing no progress will not participate in the contention process. Remaining receivers will be using equation 4.2 to start a timer. A vehicle with the smaller value of timer can broadcast the suppression message and the packet.

If the vehicle selected for further forwarding process in case 3 lies in the NJ zone mentioned in the packet (case 4), then it will apply Dijkstra’s shortest path algorithm (Dijkstra, 1959) to find out the shortest path from the current position to the destination. Before broadcasting the packet, this node will add next junction's coordinates in the NJC field of the packet. If Dijkstra's algorithm finds more than one path for the same distance, then any of the shortest paths can be selected for further forwarding.

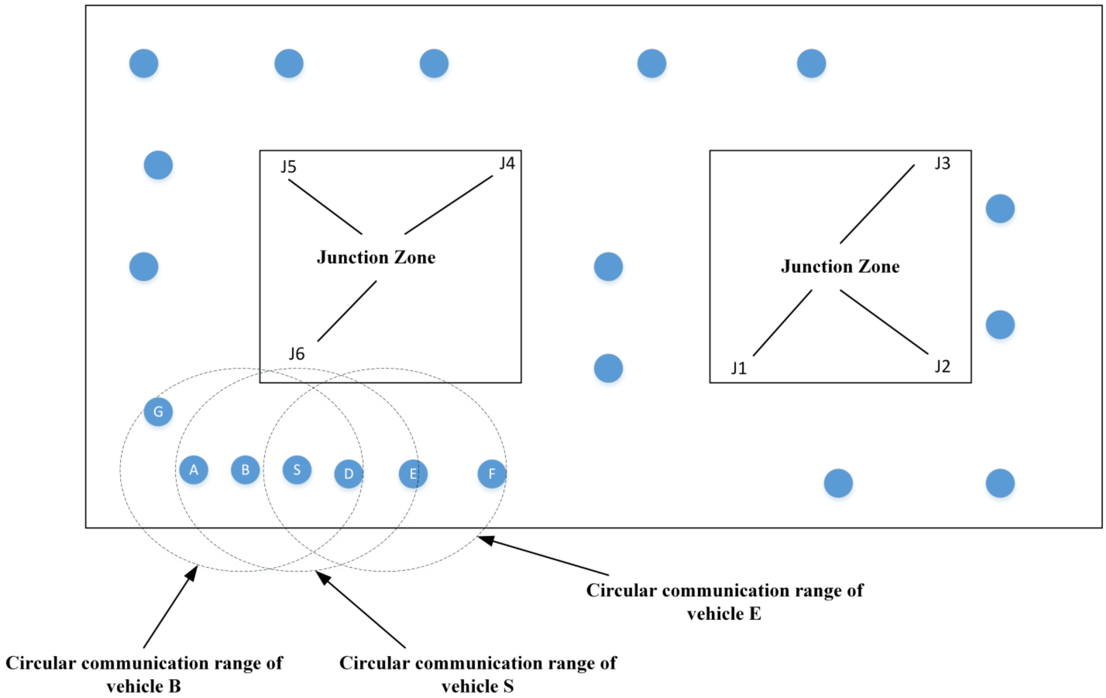

Figure 4. 2 Suppression Technique in SBFP

In the proposed SBF protocol, the suppression technique can be understood as follows (Figure 4.2): any vehicle which initiates a packet-sending process, adds its ID and packet ID into the packet. In the present case, the packet-sending process is initiated by Vehicle S, which write its unique ID, coordinates of J1 (NJC) and packet ID into the packet header. Vehicle A, B, D, and E can hear this broadcast. As Vehicle E will be providing maximum progress toward J1, its timer will expire early. Further, Vehicle E can suppress the response of Vehicle D, as it is residing within its communication range. Vehicle A and B will not broadcast the same packet, as both the vehicles provide zero progress toward J1. The flow chart of SBFP is shown in Figure 4.3.

$$Progress = max\left\{0, \frac{dist\ (s,NJ) - dis(c,NJ)}{range}\right\}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

where c, s, and NJ are the position of the current node, source, and nearest junction respectively, and T is the maximum forwarding delay (Yong et al., 2013).

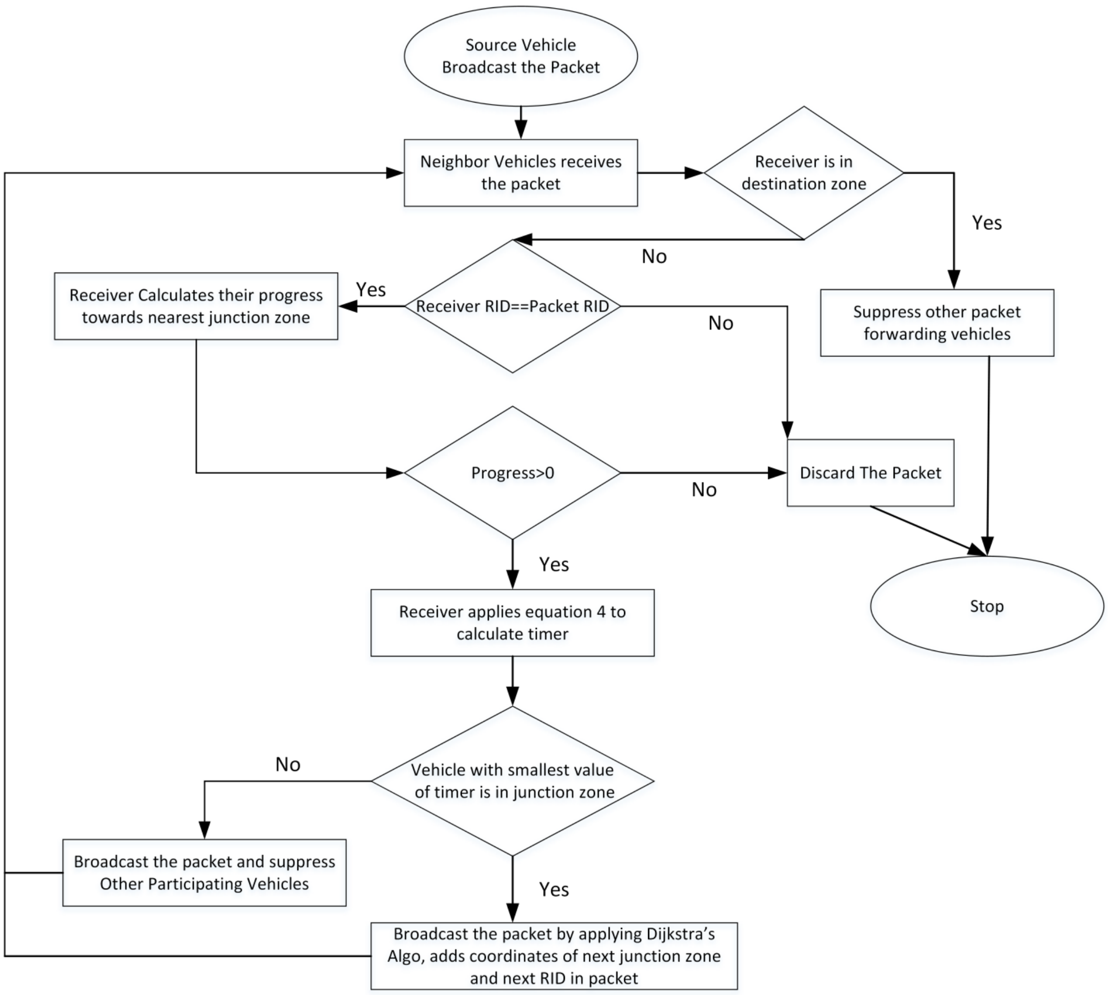

Figure 4. 3 Architecture of SBFP

Table 4. 1 Simulation Parameters: SBFP

SIMULATION PARAMETERS:

SIMULATOR USED:	Qualnet 6.1, Sumo and MOVE
PROTOCOL USED FOR COMPARISON	GPSR, CBF
TERRAIN SIZE	5000 X 5000 meter
NUMBER OF JUNCTIONS	30
BEACON FORWARDING INTERVAL	0.5, 1, and 1.5 seconds
VEHICLE DENSITY	100, 150, 200, 250, and 300
VEHICLE SPEED	5 m/s to 15 m/s and 16m/s to 30 m/s
SYNTHETIC INTERFERENCE	30%, 50% and 70%
SIMULATION TIME	100 seconds
PACKET SIZE	512 Bytes
EVALUATION PARAMETERS	Packet Delivery Ratio, Average Broadcast v/s Average number of Beacons sent, Network Latency

4.3 Simulation

4.3.1 Simulation Environment

A synthetic scenario was created to evaluate the performance of the proposed protocol. QualNet simulator (QualNet Documentation, 2006) was used to implement SBFP, CBF, and GPSR. To create the vehicle's movement pattern and network topology, SUMO and MOVE tools (https://sourceforge.net/projects/sumo/files/latest/download) were used. For GPSR protocol, beacons forwarding period was selected as 0.5, 1 and 1.5 s. The network topology of size 5,000 X 5,000 m with 30 junctions was populated by SUMO and MOVE tool. The traffic density has been varied by changing the number of vehicles from 100 to 300. The speed of vehicles varied from 5 to 30 m/s. To present the scenario as more realistic, streets were divided on the basis of interference from 30 to 70 percent. Because of this interference, vehicles moving on different street segment were not able to communicate directly. Simulation time period was fixed as 100 s, and during this period, each vehicle sent five packets to any randomly selected destination zones.

4.3.2 Evaluation Metrics

Following metrics are used to evaluate the performance of SBFP:

Packet Delivery Ratio

Passengers' safety is one of the major applications of ITS. In critical situations, the routing protocols should be able to deliver the maximum packet delivery ratio (PDR). It can be calculated as follows:

$$PDR = Total\ packet\ received/Total\ packet\ sent \ldots\ldots\ldots \quad (4.4)$$

Average Broadcast vs Average Number of Beacons Sent

To compare the overheads because of the number of beacons sent and broadcasted with contention, following equations have been used:

Average Broadcast = (Total Number of Broadcast)/(Total Number of Vehicles)

……………(4.5)

Average Beacons Sent = (Total Number of Beacon Sent)/(Total Number of Vehicles)

…………….(4.6)

Network Latency

To measure the packet delivery time, the network latency metric has been implemented. This is also known as the end-to-end delay.

4.3.3 Performance Evaluation

Performance of SBFP was evaluated and compared with modified CBF and GPSR. Two sets of simulations have been created by varying the speed of vehicles. In the first set, the speed of vehicle ranges from 5 to 15 m/s, and in the second set, it ranges from 16 to 30 m/s. To calculate the PDR of basic GPSR, the beacon interval and interference among streets are varied. PDR of GPSR for different traffic densities is shown in Figure 4.4, 4.5 and Table 4.2, 4.3. As the network becomes denser with reduced beacon interval, PDR improves. Furthermore, variations in interference affect the PDR. GPSR gives better PDR in 30 percent interference than in 50 percent interference, which can be understood as follows. In 50 percent interference, the packet reaches to local maximum very frequently. On the other hand, it performs better in 70 percent interference than in 50 percent interference, as the vehicles are not able to receive the beacons of another street segment. Moreover, the speed of vehicles also affects the PDR. From Figures 4.4 and 4.5, it can be concluded that high-speed vehicles give low PDR.

Table 4. 2 Packet Delivery Ratio for Basic GPSR with Vehicle Speed 5 m/s to 15 m/s

Synthetic Interference	***Beacon Forwarding Interval (Seconds)***	***Number of Vehicles***				
		100	**150**	**200**	**250**	**300**
30 %	**0.5**	0.39	0.4	0.47	0.53	0.58
	1.0	0.35	0.36	0.42	0.46	0.5
	1.5	0.29	0.31	0.34	0.35	0.39
50 %	**0.5**	0.34	0.39	0.4	0.5	0.53
	1.0	0.3	0.32	0.35	0.4	0.45
	1.5	0.27	0.29	0.3	0.34	0.38
70 %	**0.5**	0.38	0.4	0.44	0.51	0.56
	1.0	0.3	0.33	0.36	0.42	0.48
	1.5	0.25	0.3	0.32	0.35	0.36

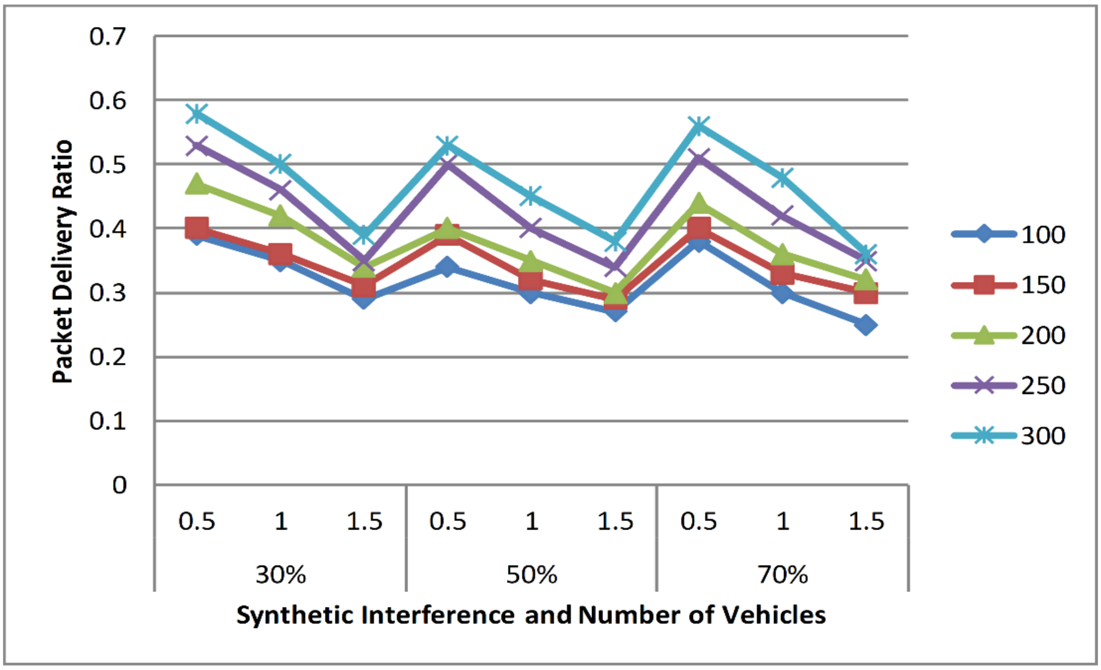

Figure 4. 4 Packet Delivery Ratio for Basic GPSR with Vehicle Speed 5 m/s to 15 m/s

Table 4. 3 Packet Delivery Ratio for Basic GPSR with Vehicle Speed 16 m/s to 30 m/s

Synthetic Interference	***Beacon Forwarding Interval (Seconds)***	***Number of Vehicles***				
		100	**150**	**200**	**250**	**300**
30 %	**0.5**	0.26	0.29	0.34	0.41	0.45
	1.0	0.22	0.26	0.28	0.33	0.37
	1.5	0.18	0.2	0.23	0.23	0.29
50 %	**0.5**	0.23	0.29	0.3	0.38	0.4
	1.0	0.2	0.22	0.25	0.27	0.39
	1.5	0.14	0.15	0.18	0.2	0.25
70 %	**0.5**	0.25	0.28	0.33	0.39	0.43
	1.0	0.19	0.21	0.23	0.28	0.35
	1.5	0.16	0.19	0.2	0.21	0.22

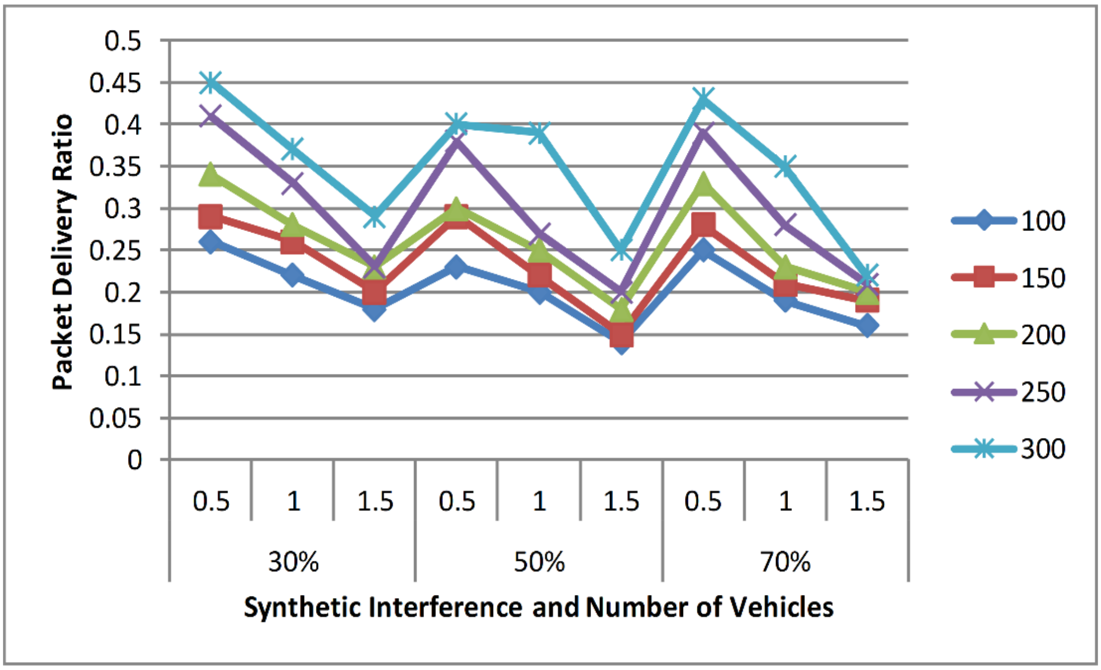

Figure 4. 5 Packet Delivery Ratio for Basic GPSR with Vehicle Speed 16 m/s to 30 m/s

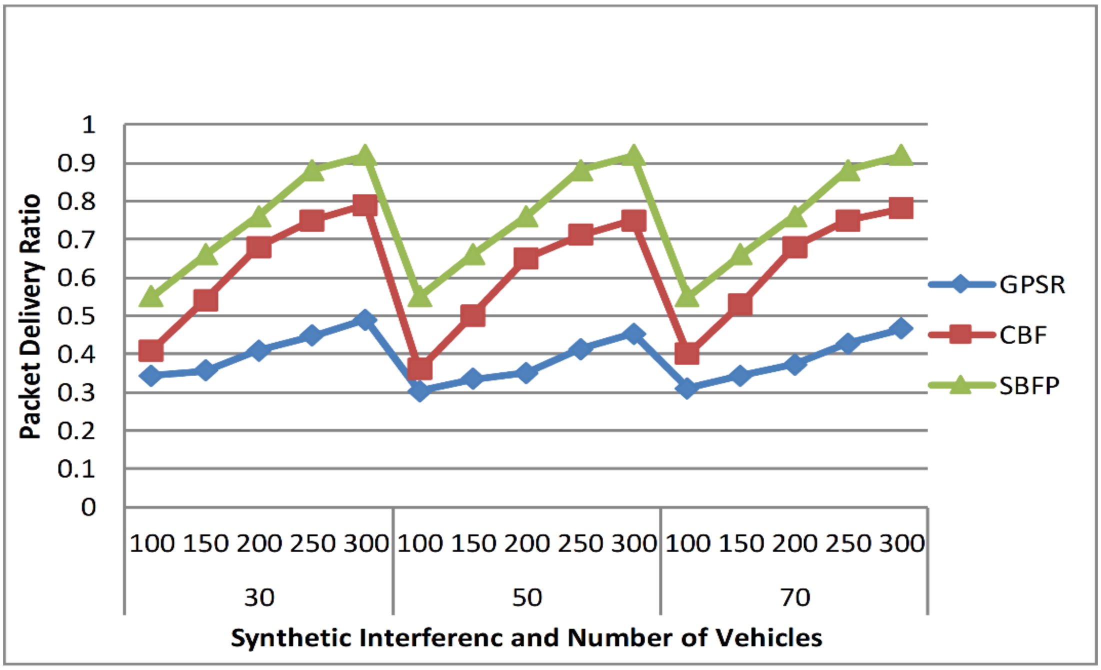

Figure 4. 6 Packet Delivery Ratio with Vehicle Speed 5 m/s to 15 m/s

Next, to compare and evaluate the performance of SBFP with GPSR and CBF, the average PDR of GPSR in all the three synthetic interferences has been calculated. Different synthetic interferences cannot affect the performance of SBFP, as it follows the SBF mechanism (Figures 4.6 and 4.7). For a while, beacons in GPSR can provide outdated information of neighbor vehicles, which can increase the chances of packet drop. Moreover, SBFP performs better than GPSR and CBF in terms of PDR. Conversely, CBF gives better result than the GPSR, as it follows the packet broadcasting mechanism (Table 4.4 and 4.5.

Table 4. 4 Packet Delivery Ratio with Vehicle Speed 5 m/s to 15 m/s

Synthetic Interference	***Routing Protocols***	***Number of Vehicles***				
		100	**150**	**200**	**250**	**300**
30 %	**GPSR**	0.343	0.356	0.41	0.446	0.49
	CBF	0.41	0.54	0.68	0.75	0.79
	SBFP	0.55	0.66	0.76	0.88	0.92
50 %	**GPSR**	0.303	0.333	0.35	0.413	0.453
	CBF	0.36	0.5	0.65	0.71	0.75
	SBFP	0.55	0.66	0.76	0.88	0.92
70 %	**GPSR**	0.31	0.343	0.373	0.426	0.466
	CBF	0.4	0.53	0.68	0.75	0.78
	SBFP	0.55	0.66	0.76	0.88	0.92

Furthermore, the simulated results demonstrate that all the three protocols offer better PDR with increased vehicular density. From Figure 4.6 and 4.7, it can also be observed that higher vehicular density and slower vehicles give improved PDR.

Table 4. 5 Packet Delivery Ratio with Vehicle Speed 16 m/s to 30 m/s

Synthetic Interference	Routing Protocols	Number of Vehicles				
		100	150	200	250	300
30 %	GPSR	0.22	0.25	0.32	0.323	0.37
	CBF	0.36	0.48	0.59	0.68	0.75
	SBFP	0.45	0.6	0.7	0.8	0.89
50 %	GPSR	0.19	0.22	0.32	0.283	0.346
	CBF	0.33	0.46	0.6	0.68	0.7
	SBFP	0.45	0.6	0.7	0.8	0.89
70 %	GPSR	0.2	0.226	0.253	0.293	0.333
	CBF	0.36	0.5	0.65	0.7	0.71
	SBFP	0.45	0.6	0.7	0.8	0.89

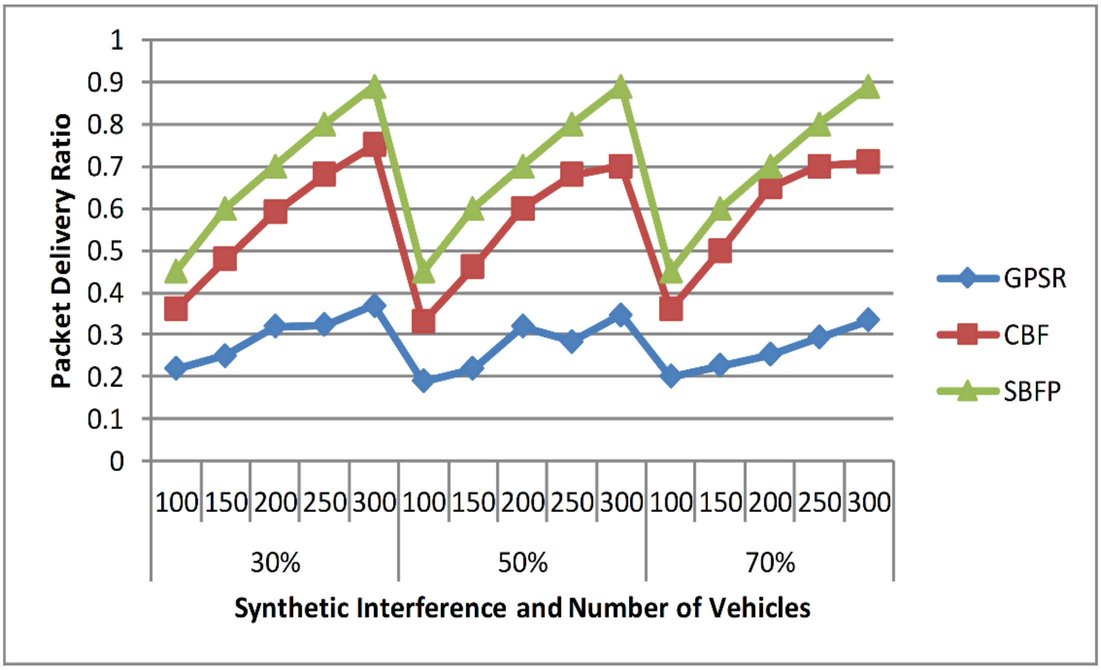

Figure 4. 7 Packet Delivery Ratio with Vehicle Speed 16 m/s to 30 m/s

In the proposed protocol and CBF, vehicles start broadcasting only in the required condition, whereas, in GPSR, vehicles continuously send the beacons to neighbor vehicles. Simulation time and beacon interval are the two factors to calculate the average number of beacon sent by a vehicle. In SBFP and CBF, “the total number of source to destination pairs” is the key to measure the average broadcast made by a vehicle. From Figure 4.8 and Table 4.6, it can be observed that beacons sent by vehicles in GPSR are at least two times more than the number of broadcasts made by vehicles in SBFP and CBF. Here, the number of broadcasts incurred in CBF is lesser than the broadcasts created in SBFP. It happens because SBFP gives better PDR, which results in more number of broadcasts than CBF.

Table 4. 6 Average Number of Broadcast/ Beacon

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
GPSR	122.22	122.22	122.22	122.22	122.22
CBF	25.3	30	35.1	36.6	39.9
JIP	35.2	39.9	44.8	45.1	46.92

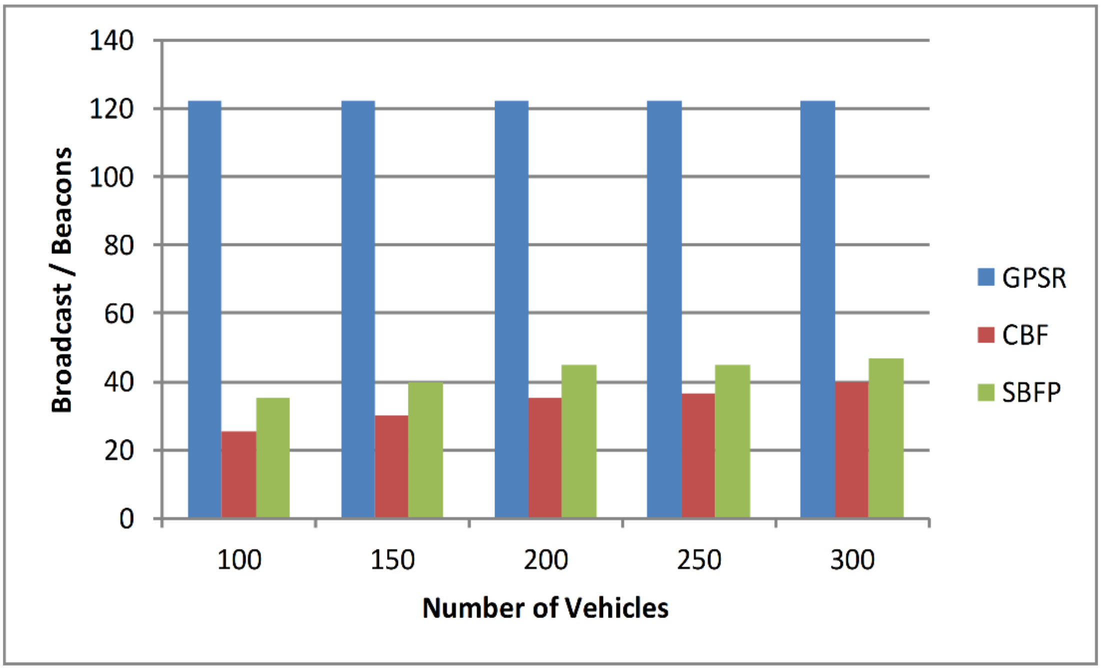

Figure 4. 8 Average Number of Broadcast/ Beacon

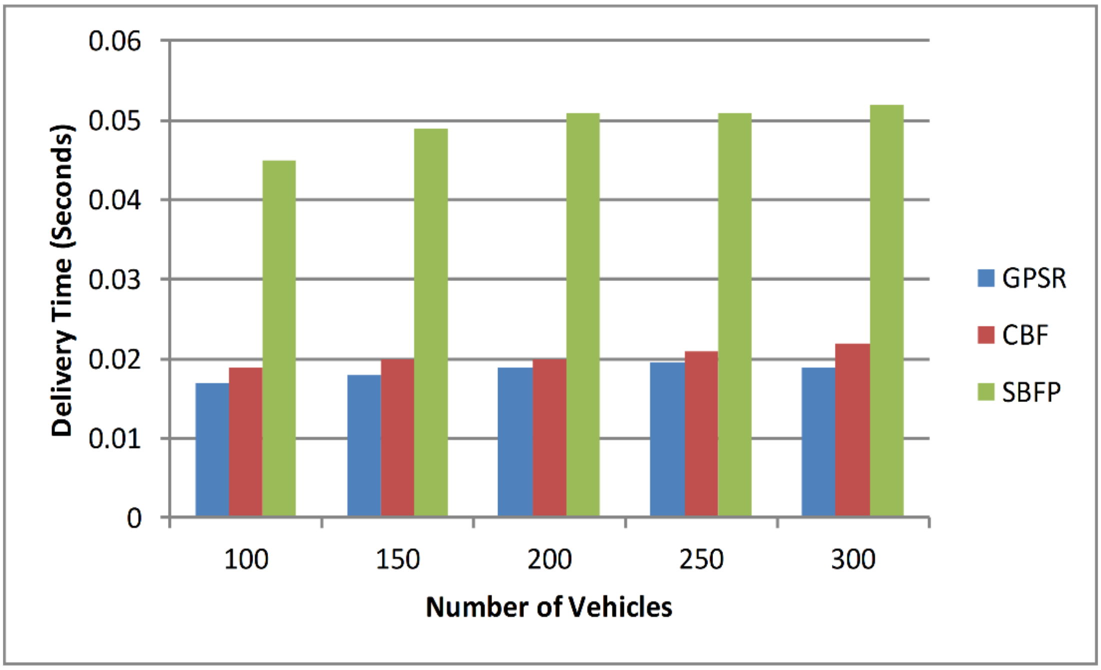

Figure 4. 9 Packet Delivery Time

Packet delivery time of protocols is shown in Figure 4.9 and Table 4.7. As SBFP sends packets through the junction to junction, it may require more time than CBF and GPSR. SBF technique results in delayed packet delivery time; however, it gives higher PDR and less network overhead than its peer protocols.

Table 4. 7 Packet Delivery Time

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
GPSR	0.017	0.018	0.019	0.0195	0.019
CBF	0.019	0.02	0.02	0.021	0.022
JIP	0.045	0.049	0.051	0.051	0.052

4.4 Summary

In this chapter, an efficient protocol for VANETs with street-based forwarding technique is proposed. The interferences during packet forwarding have been considered to illustrate the scenario as more realistic. In this proposed protocol, the packet can be forwarded through junctions and vehicles running on the same street segment. This SBF technique improved PDR in urban scenarios. The broadcasting method is used to reduce the unwanted network overheads in packet delivery process. The outputs of the proposed protocol are evaluated by comparing with its peer protocols such as CBF and GPSR in a synthetic scenario. The simulated results demonstrated improved PDR with the minimum average number of broadcast by each individual vehicle in SBFP than GPSR. Nevertheless, our method takes the more time to deliver the packet than peer protocols. Thus, the proposed protocol can be further improved by overcoming this issue.

The sparse network connectivity may result in performance degradation of VANET in SBFP. In this direction “A Static Infrastructure Assisted Road Based Forwarding Protocol for VANETS: SRBF “is presented in the next chapter. SRBF also takes the advantage of RSUs to improve the connectivity of vehicles.

Chapter 5

A Static Infrastructure Assisted Road Based Forwarding Protocol for VANETS: SRBF

In this chapter, the position-based routing protocols and their issues while employing it in the urban scenario are discussed. Further to address these challenges, a "*Static Infrastructure Assisted Road Based Forwarding Protocol*" *(SRBF)* is proposed[5]. In this protocol, road side units (RSUs) are used to minimize the problem of local maximum (Alessandro and Alberto, 2016; Karagiannis *et al.,* 2011; Mershad *et al.,* 2012). SRBF is a hybrid position-based routing protocol which uses the greedy forwarding technique to select the next hop neighbor. Instead of using the beaconing process to know the location of next suitable sender, the data packet is broadcasted to all the neighbors of the sender. The broadcasting method can heavily increase the network load, therefore to resolve this shortcoming the contention mechanism (Meneguette *et al.,* 2014; Hossain, *et al.,* 2010) is used in the proposed protocol. In this protocol, it is assumed that the roads in the urban scenario can be separated by the interference of buildings, trees, towers

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[5] The contents of the chapter are under review in:

Kumar, S., & Verma, A. K. A Static Infrastructure Assisted Road Based Forwarding Protocol for VANETS: SRBF. Vehicular Communication. (Under Review, SCIE Indexed, IF 5.108).

etc., and can influence the transmission range of vehicles (Zhang and Wolff, 2008; Liu *et al.,* 2016). By considering this fact, a novel road based forwarding (RBF) method has been proposed. A simulative study is carried out to evaluate the performance of SBFP with its peer protocols, GeoSVR: A Geographic Stateless VANET Routing and Contention Based Forwarding with Multi-Hop Connectivity Awareness in Vehicular Ad Hoc Networks (TOPOCBF).

5.1 Data Forwarding Challenges in GeoSVR and TOPOCBF

In GeoSVR, the packet forwarding route has been selected before sending the packet thus road width is the key parameter to choose the path. This protocol does not consider the real-time traffic density to select next neighbor hop, which usually leads to frequent local maximum situations. On the other hand, restricted greedy forwarding algorithm has employed to reduce the packet drop probability which can give rise to latency and number of the intermediate vehicle during packet forwarding process.

Figure 5.1 portrays the problems which may occur in the GeoSVR protocol. In this scenario (Figure 5.1) there are three paths available from the source to destination. The sum of path 1 is lesser than the sum of other two paths. In path 1, car C cannot see any car in its range to forward the packet further. Consequently, packet reaches the local maximum situation. Furthermore, the sum of path 3 is more than any available path from source to destination, nevertheless, it is the only path which can send the packet to the destination.

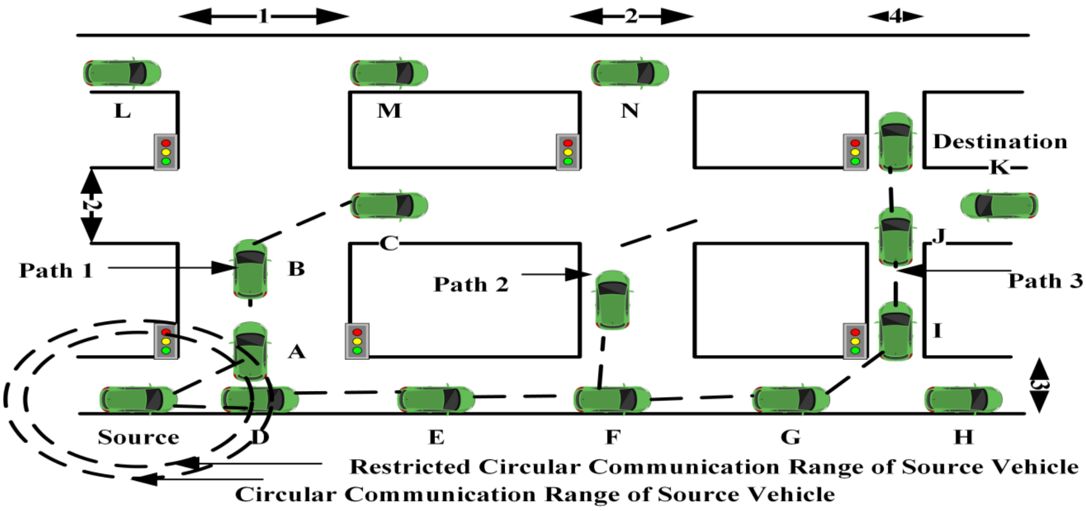

Figure 5. 1 GeoSVR Routing Scenario

In Topology-Aware Contention-Based Forwarding (TOPOCBF) algorithm, the broadcasting mechanism has been implemented to forward the packet in the greedy manner along with the beaconing algorithm to identify the connectivity status of road segment (Rondinone and Gozalvez, 2013). The uses of both unicast and multicast techniques in TOPOCBF may result improvement in the packet delivery performance although it can lead to increased network load. As shown in Figure 5.2, a vehicle entering to intersection I_1 wants to send a packet to destination vehicle D at intersection I_4. There are two paths available from I_1 to intersection I_4, I_1- I_2- I_4 and I_1- I_3- I_4. Since there is no vehicle available in section 2 of I_1 to I_3 path, further, section I_1 to I_2 is multi-hop connected (Figure 5.2), it could be chosen as the next forwarding pathway. However, I_2 to I_4 path is partially connected, consequently, the packet may reach to the local maximum situation in the vehicle P. In such a circumstance, the packet may not be delivered to destination D. Thus, the problem of local maximum has not been addressed in the algorithm TOPOCBF.

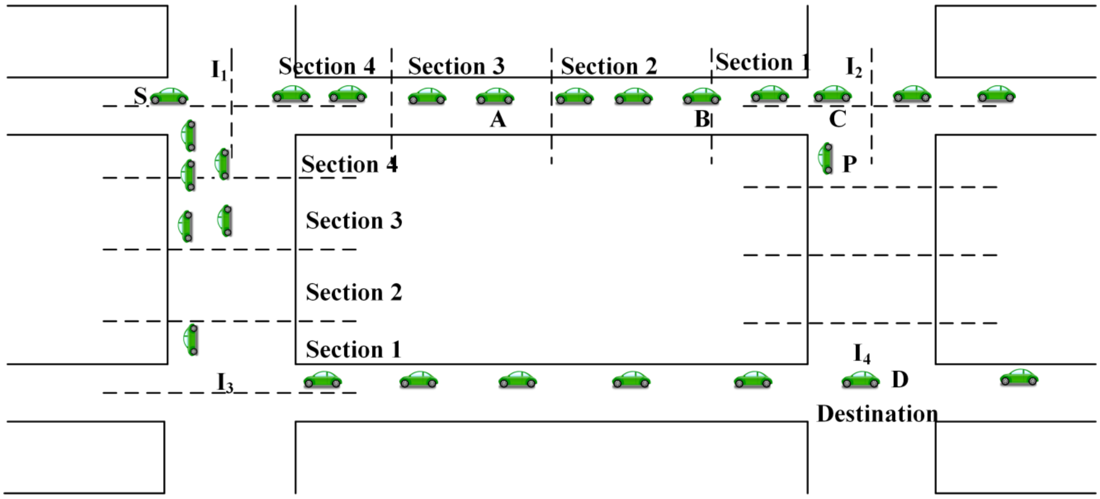

Figure 5. 2 TOPOCBF Routing Scenario

5.2 Proposed Algorithm: SRBF

In SRBF, all the above discussed "data forwarding challenges" are incorporated, thus offer an excellent way of overcoming those challenges. In VANETs any information can be useful for their targeted audience. Following are the examples:

a) *Information about an accident should be forwarded to the nearest hospital.*

b) *Messages regarding traffic should be forwarded to a limited zone so that the vehicles available in this zone can take an alternate path.*

Focusing on these two examples, in the proposed protocol, rather selecting a vehicle as the destination, a zone will be selected as the destination. It is assumed that vehicles can communicate with each other within a wireless communication range of 300 meters. Here the data packet header contains information like source vehicle ID (SID), source location, packet ID (PID), current road ID (RID), nearest static node's ID (NSN_ID), and destination static node ID (DID) etc. Moreover, the vehicles are equipped with digital maps, through which they can get the position of destination. In SRBF, static nodes are used to improve the packet delivery ratio. These static nodes deployed at each intersection and are meant to calculate the shortest connected path using vehicular density.

The SRBF protocol comprises three algorithms: 1. Selection of a suitable vehicle to broadcast the data packet, 2. Calculation and selection of the shortest connected path by the static node and 3. Re-forwarding of data packets in the sparse networks.

Algorithm 1: Selection of a Suitable Vehicle to Broadcast the Data Packet.

When a source vehicle initiates a data forwarding process, it adds above-discussed information like SID, PID, RID, NSN_ID and DID to packet header. Along with this information, the packet sender also adds its distance to the nearest static node into the packet header. Unlike most of the position-based routing protocols, SRBF does not use beaconing method to know its neighbor's location, while it directly broadcast the packet and these forwarded packets will be received by all the neighbors of the sender. After broadcasting the packet, following cases can occur:

Case 1: Receiver is in the destination zone.

Case 2: Receiver is a vehicle or a static node which is not on the same road segment.

Case 3: Receiver is on the same road segment.

Case 4: Receiver is a static node, which is mentioned in the packet header.

Figure 5.3 illustrates the case 1 in which vehicle S1 broadcast the packet for destination D1. The dotted circle shows the circular transmission range of S1. The broadcasted packet will be received by vehicle 2. After receiving the packet, the receiver applies equation 5.1 to calculate its distance to destination. If the distance between the receiver and destination is less than 50 meters, then the receiver will broadcast the packet and other receivers of the same packet will get suppressed. In the scenario of Figure 5.3, car 2 lies in the destination zone (an area within the 50 meters of circular communication range of the destination), hence it will broadcast the packet which can be received by the destination.

dis_c=sqrt(pow((static_nodes_coordinates[b_Pkt->DID][0]-position.common.c1),2) + pow((static_nodes_coordinates[b_Pkt->DID][1]-position.common.c2),2))............(5.1)

dis = sqrt(pow((junction_coordinates[b_Pkt->NSN_ID][0]-position.common.c1),2)+ pow((junction_coordinates[b_Pkt->NSN_ID][1]-position.common.c2),2)).............(5.2)

where b_Pkt is the broadcasted packet, DID is the destination static node id, position.common function is used to get the coordinates of current packet holder vehicle, dis_c denotes the vehicle's distance to destination, and 'dis' denotes the distance between the current vehicle to the static node.

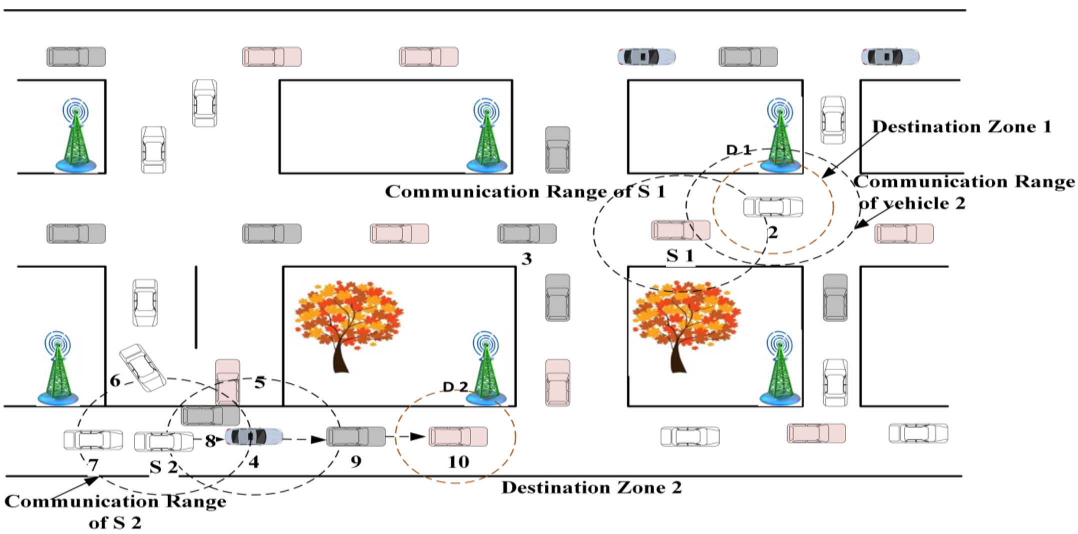

Figure 5. 3 Scenario to Illustrate the Working of Algorithm 1

The case 2 and 3 of Algorithm 1 is depicted in Figure 5.3; here vehicle S2 initiates a packet forwarding process for destination D2. The broadcasted data packet will be listened by vehicle 4, 5, 6, 7 and 8. All the receivers will check for their presence in the destination zone, however, in this scenario, none of the data packet receivers qualifies for the same. In SRBF, a "road based forwarding" (RBF) technique is used. RBF is a mechanism where only the vehicles of the same road segment (vehicles having same RID) can communicate. If a vehicle receives a packet from the vehicle of different road segment then the packet will be discarded by the receiver. In this case, car 5 and 6 are moving on the different road segment, hence they will not participate in the packet sending process and will discard the packet. Remaining vehicles 4, 7 and 8 will apply equation 5.2 to calculate their distance to the nearest static node which is mentioned in the packet header. After receiving a packet, all the recipients having same RID, calculate their "progress" towards the NSN and then it will start a timer. A vehicle whose timer expires early again broadcasts the packet and suppresses other nodes. Equation 5.3 and 5.4 are used to calculate the progress and timer. Vehicle 7 provides no progress towards NSN; thus, it will not participate in the broadcasting process. Vehicle 4 and 8 will apply equation 5.3 to calculate their progress. A timer will be started by both the vehicles (equation 5.4). In this scenario vehicle 4 is providing more progress than vehicle 8, consequently, its timer will expire early. After the expiry of the timer, vehicle 4 will broadcast the packet. This broadcast will suppress the broadcast of vehicle 8. In this fashion vehicle 9 will receive the packet, further, it will be delivered to the vehicle 10, which is moving in the destination zone.

$$Progress = max\left\{0, \frac{(b\_Pkt{-}{>}p\_dis) - dis)}{range}\right\} \text{ ....(5.3)}$$

$$t(Progress) = T\ (1\text{-}Progress)\text{........... ....(5.4)}$$

where b_Pkt->p_dis denotes the distance between previous packet sender to the nearest static node.

The case 4 of algorithm 1 is discussed in detail in algorithm 2.

Algorithm 2: Calculation and Selection of the Shortest Connected Path by Static Node.

In the proposed protocol, static nodes are empowered with beacon sending mechanism to obtain the information of neighbor vehicles. The acquired information is used to compute the vehicular density on a specific road segment. The vehicular network often suffered by low vehicular density, therefore static nodes can select the appropriate density path to deliver the packet to the destination.

Figure 5.4 illustrates the working of algorithm 2. Every time a packet reaches to a static node which is mentioned in the packet header (case 4, algorithm 1), it applies Dijkstra's shortest path algorithm (Dijkstra, 1959) to calculate the shortest path from the current static node to the destination. Selection of suitable path and next RSU leads to the following cases in SRBF:

Case 1: The "Dijkstra's shortest path algorithm" provides a shortest path among all the available paths from the current static node to the destination.

Case 2: Out of all the available paths, if there are two or more routes with equal distance, and at the same time shorter than the other available paths.

In continuation with case 4 of algorithm 1, a packet is initiated by S1 for destination D1 (Figure 5.4), which will be received by static node 8 through vehicle 2 and 3. Since the packet reached to the static node which was mentioned in the packet header, it will use Dijkstra's algorithm to find out the shortest path from its position to the destination. In this scenario (Figure 5.4), there is only one shortest path available (SN 8 – SN 9 – D1). Hence the value of RID and NSN_ID in the packet header will be changed by static node 8. Further static node 8 will broadcast the packet for static node 9. In this way, the packet will reach to the destination zone of D1.

The main idea behind the algorithm 2 of SRBF is to select a shortest connected path. In the view of this direction, the static nodes periodically send the beacons to acquire the information about their surrounding vehicles. The acquired information is useful to compute the vehicular density on a specific road segment. After receiving the packet, static nodes calculate the shortest path, however, before selecting the shortest path, the static node will check for the vehicular density of shortest path. It will be chosen only if it satisfies the threshold value of traffic density, or else static node will discard this path and will check for another.

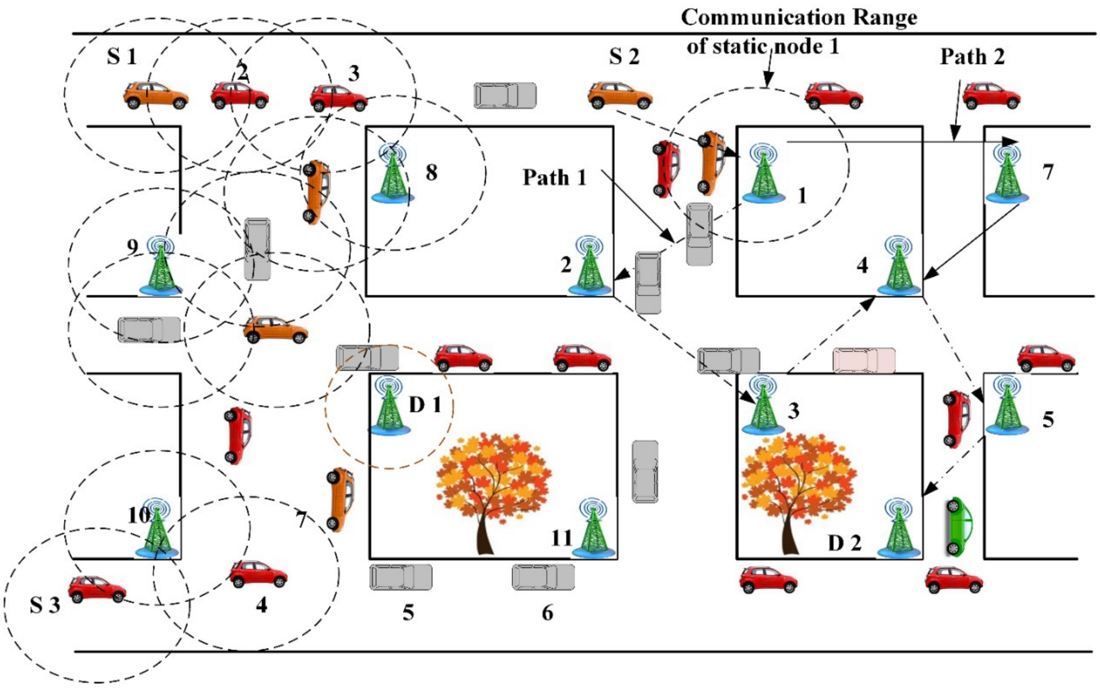

Figure 5. 4 Scenario to Illustrate the Working of Algorithm 2 and Algorithm 3

In Figure 5.4, vehicle S2 broadcast the packet for destination D2. When the packet reaches to static node 1, it will check for available shortest paths. In this scenario, there are two paths available from static node 1 to destination D2. The dotted arrows show path1 (SN 1- SN 2- SN 3- SN 4- SN 5-D2) and solid arrows show path 2 (SN 1- SN 7- SN 4- SN 5-D2) in Figure 5.3. However, the path 1 is denser than path 2, thus path 1 will be selected as the next forwarding path by static node1.

Algorithm 3: Re-Broadcasting of Data Packets in the Sparse Networks.

The algorithm 3 of SRBF is designed by considering the fact that a data packet can be stuck in the sparse network during the forwarding process. To improve the packet delivery ratio, vehicles can re-broadcast their broadcasted packet, if they don't receive the broadcast of the next forwarding vehicle of the same packet. The process of re-broadcasting of the data packet will lead to an overhead on the network, however, it can cause to increase the packet delivery ratio (Schoch *et al.,* 2008).

Figure 5.4 is used to explain the working of algorithm 3, where vehicle S3 starts packet sending process for the destination D2. The static node 10 comes in the range of vehicle S3, hence it will receive the data packet sent by S3. Further, the static node 10 will broadcast the packet by adding NSN_ID and RID in the packet header. The vehicles S3 and 4 will receive the packet sent by the static node. If the vehicle S3 received the same packet which was sent by S3 itself, it confirms that the packet has reached to the next node. On the other hand, vehicle 4 is making progress towards the next static node, therefore it can be the part of packet broadcasting process. However, there is no vehicle moving in the range of vehicle 4 to receive the packet. Subsequently, after the maximum forwarding delay, if vehicle 4 does not receive the same packet, it will re-broadcast the same packet. This rebroadcasting mechanism will recursively repeat till the packet reaches to the next suitable vehicle or packet forwarding vehicle moves on another road segment. Consequently, still, there is the probability of packet loss in the highly sparse network.

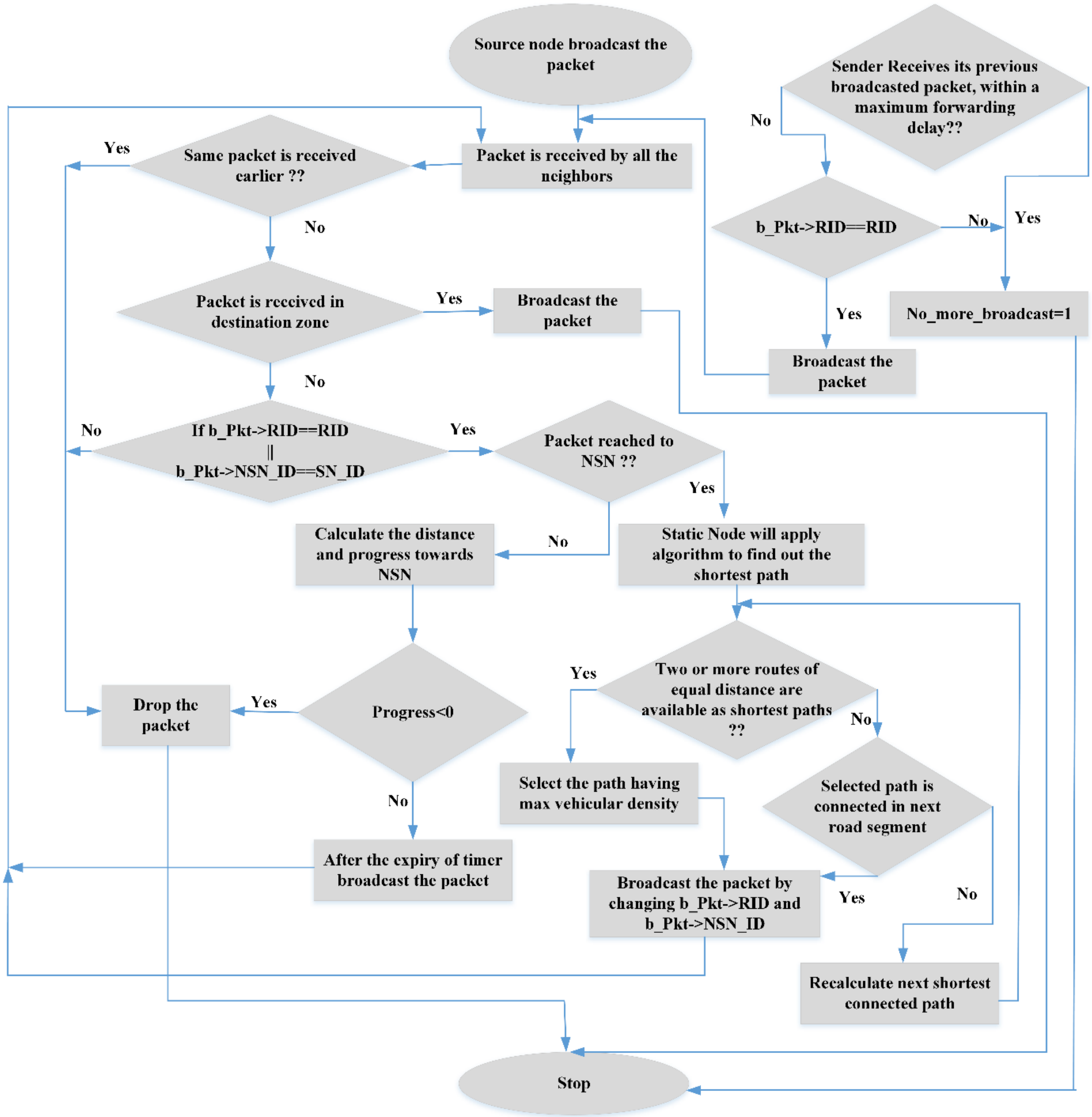

Figure 5. 5 Architecture of SRBF

5.3 Simulation

5.3.1 Simulation Environment

To evaluate the performance of the proposed protocol, a synthetic urban scenario has been created. The simulations were carried out using Qualnet simulator. Here GeoSVR and TOPOCBF are implemented with minor modifications. In the simulation, the TOPOCBF and SRBF use beaconing as well as broadcasting method whereas, GeoSVR uses the beaconing mechanism, thus the beacon forwarding interval is set to 1.0 second. Sumo and Move are extensively implemented to create road topology and vehicles movement pattern. A roadmap size of 5000 m × 5000 m with thirty intersection points is created with Move tool and this road topology is populated with a different traffic density of 100 vehicles to 300 vehicles. Vehicles speed limit is set between 5 m/sec. to 30 m/s. Further, a Synthetic interference has been created among streets. Consequently, vehicles of a different road segment may not be able to listen to the broadcast or beacons. The range of interference has varied from 30% to 70%. Simulation's time limit is set to 1000 seconds such that each vehicle can send 5 packets within this time limit.

In this simulation, 30 static nodes are deployed, one at each intersection to efficiently disseminate the packets. The source vehicles are selected randomly to send the packet and static node as the destination.

5.3.2 Evaluation Metrics

In order to evaluate and compare SRBF with its peer protocols, Packet Delivery Ratio (PDR), Average Broadcast v/s Average number of Beacons sent, and Network Latency parameters are used.

5.3.3 Performance Evaluation

To evaluate the performance of SRBF, the working of this protocol is compared with GeoSVR and TOPOCBF. Two sets of simulation have been carried out on the basis of vehicles' speed. In the first set, the range of vehicles' speed is fixed from 5 m/s to 15 m/s and in the second set 16 m/s to 30 m/s.

Table 5. 1 Simulation Parameters: SRBF

SIMULATION PARAMETERS:

SIMULATOR USED:	Qualnet 6.1, Sumo and MOVE
PROTOCOL USED FOR COMPARISON	GeoSVR, TOPCBF
TERRAIN SIZE	5000 X 5000 meter
NUMBER OF JUNCTIONS	30
BEACON FORWARDING INTERVAL	1 second
VEHICLE DENSITY	100, 150, 200, 250, and 300
VEHICLE SPEED	5 m/s to 15 m/s and 16m/s to 30 m/s
SYNTHETIC INTERFERENCE	30%, 50% and 70%
NO. OF STATIC NODES	30
SIMULATION TIME	100 seconds
PACKET SIZE	512 Bytes
EVALUATION PARAMETERS	Packet Delivery Ratio, Average Broadcast v/s Average number of Beacons sent, Network Latency

From the result as displayed in Figure 5.6, 5.7 and Table 5.2, 5.3, it can be seen that as the number of vehicle increases, the PDR tends to increase. The Synthetic interference also plays a very important role in PDR. When, increase the synthetic interference from 30 percent to 50 percent, the packet reaches to local maximum frequently resulting low PDR. On the other hand, as the synthetic interference increases up to 70%, PDR also improves as the vehicles are not able to receive the beacons of another road segment.

Table 5. 2 Packet Delivery Ratio with Vehicle Speed 5 m/s to 15 m/s

Synthetic Interference	***Routing Protocols***	***Number of Vehicles***				
		100	**150**	**200**	**250**	**300**
30 %	**TOPOCBF**	0.45	0.5	0.55	0.59	0.7
	GeoSVR	0.51	0.55	0.62	0.7	0.8
	SRBF	0.6	0.65	0.75	0.88	0.95
50 %	**TOPOCBF**	0.4	0.43	0.45	0.5	0.52
	GeoSVR	0.43	0.47	0.53	0.62	0.7
	SRBF	0.6	0.65	0.75	0.88	0.95
70 %	**TOPOCBF**	0.42	0.45	0.5	0.53	0.6
	GeoSVR	0.47	0.51	0.59	0.65	0.75
	SRBF	0.6	0.65	0.75	0.88	0.95

To evaluate the performance of SRBF, all three protocols are simulated on 30 %, 50 % and 70 % synthetic interferences. The SRBF performs in the same manner in all the three synthetic interferences, as it follows RBF mechanism (Figure 5.6 and 5.7). The GeoSVR protocol uses beaconing mechanism to select the next forwarding vehicle and "road width" as a selection criterion to select the next forwarding path. The beaconing method can lead to outdated neighbor information and "road width" may lead to the selection of sparse road segment which accounts for low PDR than SRBF (Figure 5.6 and 5.7). Beside the GeoSVR, TOPOCBF also uses beaconing mechanism to calculate the virtual distance metric, resulting in outdated information. Thus, our simulation results clearly illustrate that GeoSVR performs better than TOPOCBF.

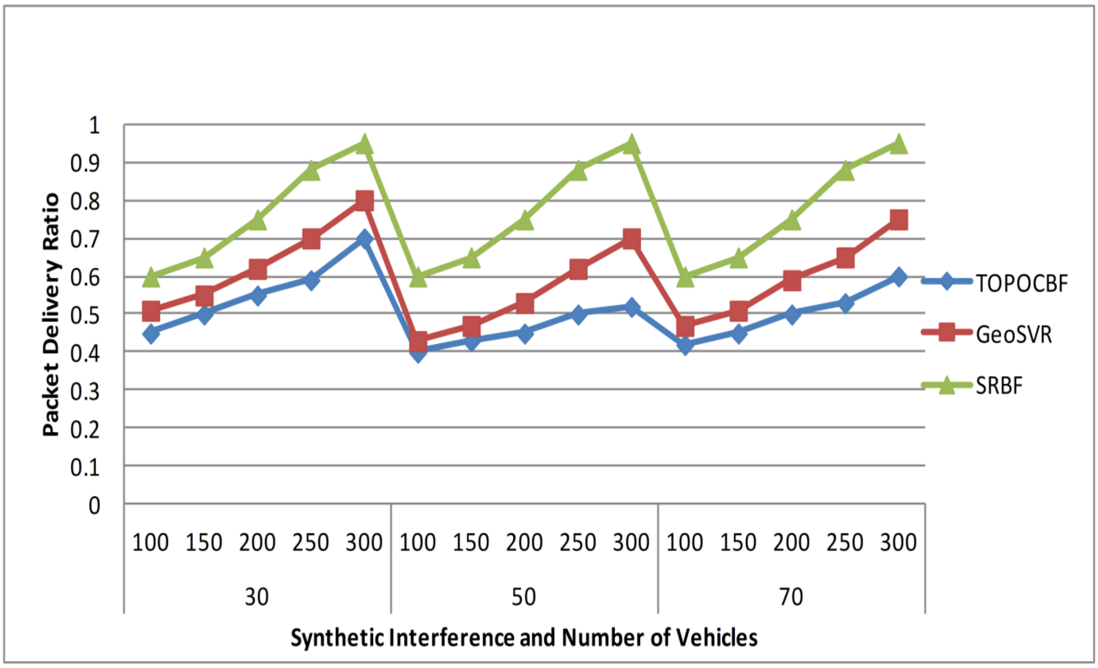

Figure 5. 6 Packet Delivery Ratio with Vehicle Speed 5 m/s to 15 m/s

Whereas the proposed protocol SRBF performs better than GeoSVR and TOPOCBF. Furthermore, all three protocols give improved PDR when the number of the vehicle increases. Vehicles speed and density are the key factors in PDR, from Figure 5.6 and 5.7 it is obvious that all the three protocols offer better performance on higher vehicle density and slower speed.

Table 5. 3 Packet Delivery Ratio with Vehicle Speed 16 m/s to 30 m/s

Synthetic Interference	***Routing Protocols***	***Number of Vehicles***				
		100	**150**	**200**	**250**	**300**
30 %	**TOPOCBF**	0.4	0.44	0.51	0.56	0.62
	GeoSVR	0.45	0.5	0.55	0.62	0.77
	SRBF	0.51	0.6	0.7	0.82	0.91
50 %	**TOPOCBF**	0.38	0.41	0.43	0.49	0.5
	GeoSVR	0.4	0.42	0.5	0.58	0.67
	SRBF	0.51	0.6	0.7	0.82	0.91
70 %	**TOPOCBF**	0.4	0.42	0.46	0.51	0.54
	GeoSVR	0.42	0.48	0.53	0.6	0.71
	SRBF	0.51	0.6	0.7	0.82	0.91

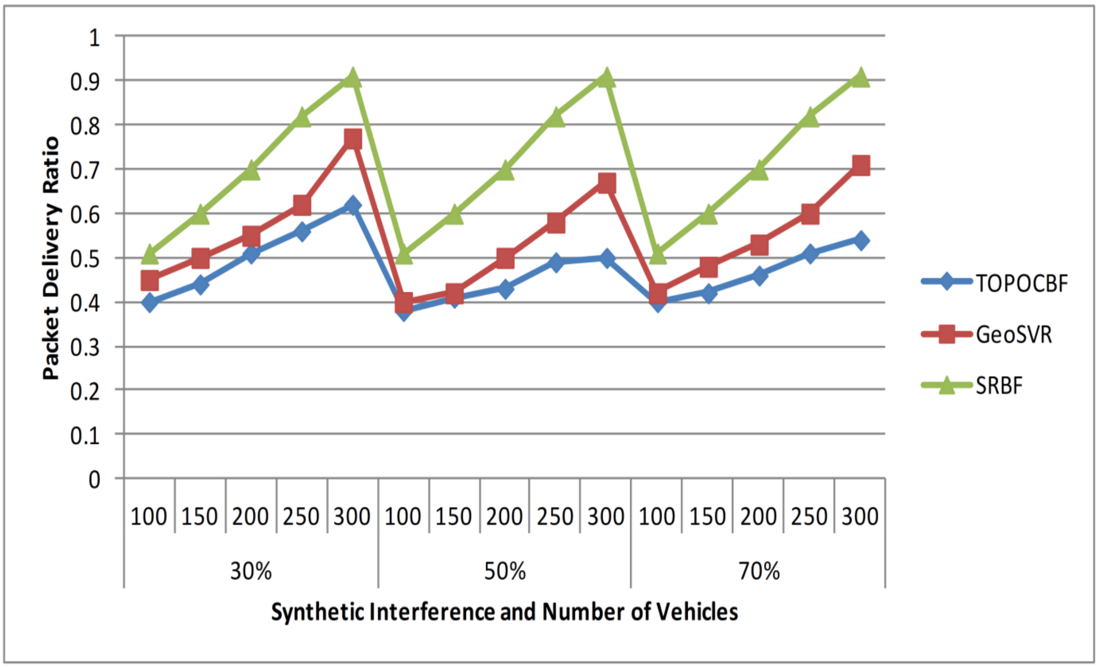

Figure 5. 7 Packet Delivery Ratio with Vehicle Speed 16 m/s to 30 m/s

As discussed in the above section, in SRBF only static nodes are allowed to send beacons to estimate the vehicular density, on the other hand, GeoSVR and TOPOCBF continuously send beacons in the network. Vehicles in SRBF and TOPOCBF broadcast the packet only when it is required. In GeoSVR and TOPOCBF, the average number of beacon sent by each vehicle depends on the simulation time and beacon interval. Alternatively, in SRBF and TOPOCBF one principal factor is "total number of source-destination pair" on which average number of broadcast depends.

To estimate the network overhead occurred due to beacons and packet broadcast, all three protocols are compared. It can be observed from Figure 5.8 and Table 5.4, the network overhead occurred in TOPOCBF are at least 3 times more than the SRBF. In this parameter evaluation, GeoSVR performs better than TOPOCBF, since it uses a unicast technique alternatively, TOPOCBF uses both unicast and broadcast technique.

Table 5. 4 Average Number of Broadcast/ Beacon

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
TOPOCBF	1028.48	1033.61	1038.71	1043.92	1047.2
GeoSVR	1023.52	1027.34	1028.92	1030.24	1033.62
SRBF	330.2	235.4	190.1	165.2	148.3

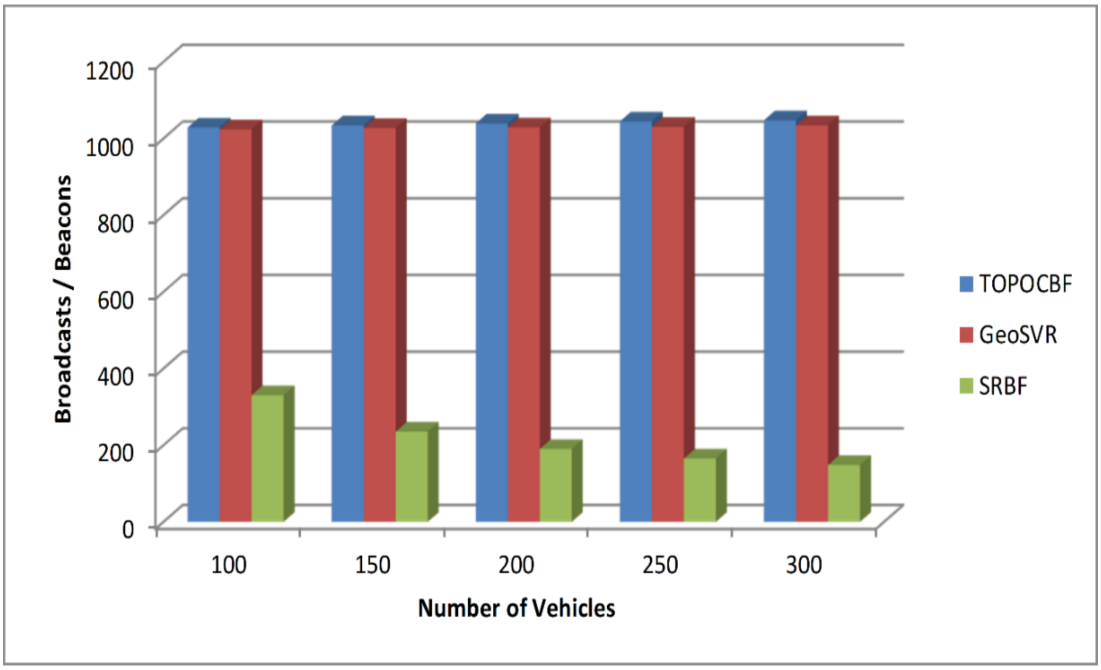

Figure 5. 8 Average Number of Broadcast/ Beacon

The packet delivery time comparison has been shown in Figure 5.9 and Table 5.5. SRBF forwards the packet through static nodes and follows RBF mechanism, thus comparatively it takes a long time to deliver the packet. The packet delivery time of SRBF is at least two and half times more than the time taken by TOPOCBF and GeoSVR. Further, as GeoSVR uses restricted greedy forwarding technique, TOPOCBF offers improved result than it.

Table 5. 5 Packet Delivery Time

Routing Protocols	***Number of Vehicles***				
	100	**150**	**200**	**250**	**300**
TOPOCBF	0.015	0.017	0.018	0.0165	0.019
GeoSVR	0.018	0.019	0.02	0.025	0.027
SRBF	0.046	0.048	0.05	0.051	0.052

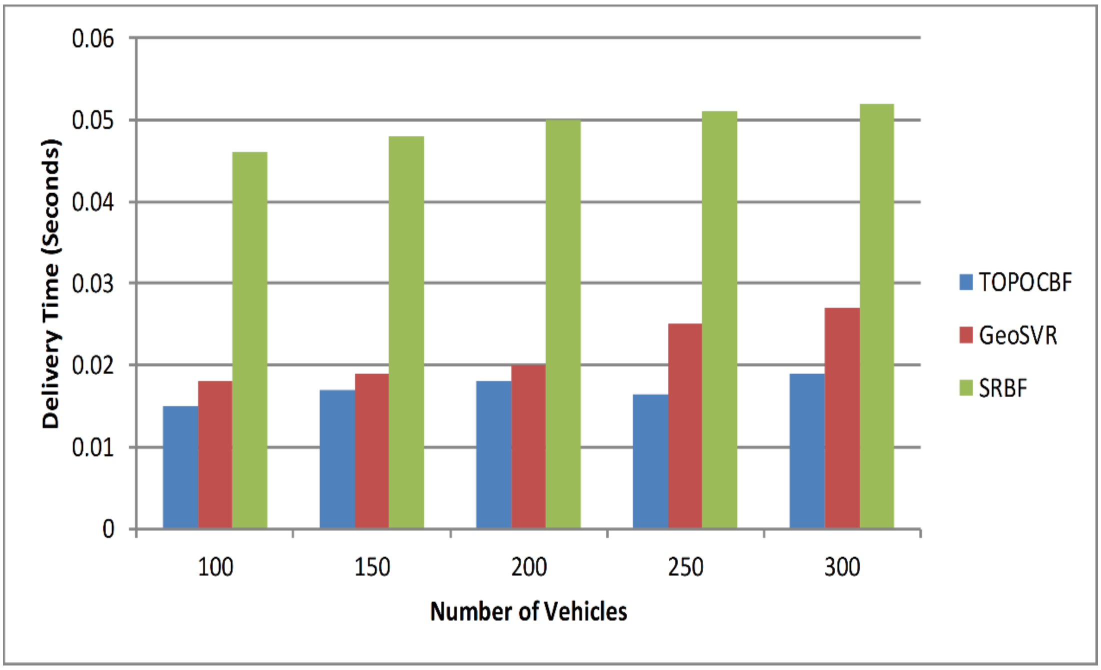

Figure 5. 9 Packet Delivery Time

5.4 Summary

In this chapter, SRBF: Static Infrastructure Assisted Road Based Forwarding Protocol for VANETs has been proposed. It works on the concept of Road Based Forwarding and considers the fact of interferences during packet forwarding. Instead of beaconing method, the broadcasting method is used in the present protocol which reduces the unwanted network overheads. The fact of the sparse network is also taken into consideration to reduce the probability of packet drop in the absence of any vehicle. SRBF is evaluated by comparing it with its peer protocols GeoSVR and TOPOCBF in the synthetic scenarios. The results confirm that the proposed protocol provides improved packet delivery ratio with the lesser average number of broadcast by each vehicle than with its peer protocols. However, SRBF takes more time to deliver the packet than GeoSVR and TOPOCBF. The shortcoming of the proposed protocol can be overcome in the future work.

Further, static nodes can be deployed with buffer capacity thus if no vehicle is found in optimized routes then the packets can be stored in the buffer. VANET is still a new area of research and it is required to evaluate our proposed protocol SRBF on realistic scenarios to offer real-time outcome.

Chapter 6

Conclusion and Future Scope

The chapter 6 provides the conclusion of the research work carried out to develop “An Efficient Routing Protocol for VANET”. The objective of this work was to present efficient protocols which can adjust themselves with the changing topology and successfully deliver the packets to the destination while maintaining high performance.

6.1 Conclusion

In the present traffic scenario, VANETs, are getting considerable attention in wireless networking, as it offers the ability for vehicles to impulsively and wirelessly communicate with other nearby vehicles with improved features. As the automobile industry is vast, the traffic flung and increased number of fatal accidents become common. On focusing human safety in priority base, the research community has drowned their attention on inter-vehicle communication, where vehicles, roads, and drivers are considered as a single entity. VANET is facilitating IVC for the intelligent transportation system and driver assistance for the better driving experience. The foremost requirement for the efficient networking in VANETs is considered as an efficient route between the networking nodes in the specified group must be established. The routing protocol must be integrated with the rapidly changing topology of vehicles in motion to ensure robust data communication.

In this research work, three different routing protocols are implemented and compared and evaluated with their peer protocols. In the literature survey, it was observed that most of the established position-based routing protocols are based on greedy forwarding technique with beaconing method to make the communication possible. In the proposed protocols, greedy forwarding technique for data forwarding is used, however, instead of beaconing method, the broadcasting method has been used. In the urban scenario, streets are separated by various obstacles such as buildings and towers. Therefore, the methods used to calculate the distance between two vehicles in greedy forwarding are not suitable for such scenarios. Thus, in the proposed models a modified distance measuring technique is implemented to calculate the distance up to nearest junction.

The chapter two presented the review of the previously proposed prominent routing protocols of VANETs. Where the position-based VANET routing schemes are grouped into infrastructure-less and infrastructure-equipped categories. In the infrastructure-less category, the working nature of protocols GPSR, GPSR+AGF, GPCR, CAR, CBF, GeoSVR, RIVER, VWCA, PassCAR, and TOPOCBF are analysed. Whereas protocols SADV, Infrastructure Assisted Geo Routing, MIBR, and MGRP include in the infrastructure-equipped group. Further, the infrastructure-less protocols are divided into basic and advance category. In all these protocols the location of neighbors and the destination's position can be obtained by beaconing method and location discovery services. Further, a comparative study of all the protocols of the similar class is carried out. This extensive literature study leads us to identify the issues and challenges while executing these routing protocols. Furthermore, the study is extended to formulate protocols with the solution of identified issues.

In chapter 3, "A Junction Based Infrastructure Assisted Routing Protocol for VANET: JIP", is presented. One of the most important types of Vehicular Network is a hybrid network, in which vehicles can take the help of road side infrastructure for communication. Therefore, this protocol exploits the infrastructure available at junctions. Most of the position-based routing protocols use beaconing method to acquire the information of neighbors. However, the beaconing method can lead to the outdated neighbor table and increased network load. By considering these facts in the proposed protocol the greedy forwarding technique is adopted with the broadcasting approach to forward the packet from source to destination. Further, this protocol employed digital maps and GPS system to locate road side units (RSUs) and moving vehicles. In JIP, vehicles effort to deliver the packet to nearest junction, where shortest path algorithm used to find the next RSU to send the data packet.

JIP is evaluated and compared with the modified version of CBF and GPSR protocols based on the Packet Delivery Ratio (PDR), Average Broadcast v/s Average number of Beacons sent and Packet Delivery time parameters. Our analysis illustrates that JIP offers better packet delivery ratio with the lesser number of broadcasts than GPSR. However, JIP takes more time to deliver the packet from source to destination.

The chapter four takes into the account of interference among different road segments and presented a street based forwarding technique to improve the packet delivery ratio and network overheads. The proposed protocol namely "Street Based Forwarding Protocol for VANET: SBFP" ponders the interference among different road segments and presented a novel road based forwarding technique, in which vehicles of different road segments are not allowed to communicate. Since in SBFP, greedy forwarding of GPSR and suppression technique of CBR are used, hence it is compared with the same protocols. The greedy forwarding concept along with the broadcasting mechanism and suppression technique is implemented to minimize the overhead created in the regular beacons forwarding processes. In SBFP, a destination zone is selected within the radius of 50 meters of randomly selected coordinates. Here, the digital map is used to obtain the position of junctions and street ID (SID) on which the vehicle is moving. The source vehicle sends a packet with its source id, location, nearest junction coordinates (NJC) and destination location to the packet header using the global positioning system (GPS). A synthetic scenario was created to evaluate the performance of proposed protocol and its efficiency was assessed by comparing its performance with modified CBF and GPSR. Different synthetic interferences cannot affect the performance of SBFP, as it follows the SBF mechanism. For a while, beacons in GPSR can provide outdated information of neighbor vehicles, which can increase the chances of packet drop. Moreover, SBFP performs better than GPSR and CBF in terms of PDR. Conversely, CBF gives the better result than GPSR, as it follows the packet broadcasting mechanism. Furthermore, the simulated results demonstrate that all the three protocols offer better PDR with increased vehicular density. While the performance evaluation demonstrated that the proposed protocol exhibits improved PDR with the minimum average number of broadcast by each individual vehicle in SBFP than GPSR.

The chapter five present the functioning of protocol "A Static Infrastructure Assisted Road Based Forwarding Protocol for VANETS: SRBF. This protocol utilizes the concept of infrastructure used in JIP and concept of road based forwarding from SBFP. In addition, the sparse network is also taken into consideration to reduce the probability of packet drop in the absence of any vehicle. Consecutively to evaluate the performance of SRBF, it is compared with GeoSVR and TOPOCBF. Results show that proposed protocol provides improved packet delivery ratio with the lesser average number of broadcast by each vehicle than with its peer protocols. However, SRBF takes more time to deliver the packet than GeoSVR and TOPOCBF.

6.2 Future Research Scope

The presented results are based on simulation, however it would be interesting to observe the behavior of these three protocols (JIP, SBFP, and SRBF) on a real test bed.

Undoubtedly our proposed protocols provide better PDR with lesser network overhead, however, the time taken to deliver the packet is comparatively more than the others. It has certain reasons behind that which are discussed in earlier chapters. Thus, this issue can be considered as one of the future research issues.

Routing in VANETs has been extended to FANETs, it would be interesting to study how these protocols adopt to this environment.

The data packets send among the vehicles must satisfy the security requirements. Since, if any of the vehicles in the network get compromised, it can affect the whole network. Thus, a better security technique for the routing protocols is also required. These security algorithms may also affect the performance of the protocols, which can also be evaluated in the future.

List of Publications

1. Kumar, S., & Verma, A. K. (2013, November). Performance Evaluation of Reactive Routing Protocols in VANET. In Proceedings of 2nd International Conference on Computing Sciences WILKES100 (pp. 242–252). (Elsevier).

2. Kumar, S., & Verma, A. K. (2015). Position Based Routing Protocols in VANET: A Survey. Wireless Personal Communications, 83(4), 2747-2772. (SCIE Indexed, IF .951).

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4. Kumar, S., & Verma, A. K. (2017). An Advanced Forwarding Routing Protocol for Urban Scenarios in VANETs. International Journal of Pervasive Computing and Communications, 13(4), 334-344. (ESCI and SCOPUS Indexed, IF .68).

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