

RESOURCE ALLOCATION IN COOPERATIVE COMMUNICATION
USING COALITIONAL GAME THEORY

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Submitted by

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DECLARATION

I Rajneet Kaur hereby declare that the work presented in this thesis entitled RESOURCE ALLOCATION IN COOPERATIVE COMMUNICATION USING COALITIONAL GAME THEORY is fulfilment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Department, Thapar University, Patiala is an authentic record of work carried out under supervision of Dr. Sanjay Sharma (Professor, Dept of ECE, Thapar University) from 2015 to 2017. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

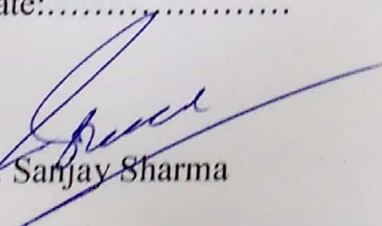
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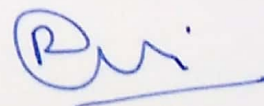
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ABSTRACT

The propagation of radio waves for communication purpose through the wireless medium is affected by lot of impediments on their way. Among other impediments, fading is one such experience which has been an area of significant interest among the research fraternity in order to evaluate the performance of a digital communication system. Among the various techniques, Diversity is one of the leading techniques to deal with the severity of fading induced in a signal transmitted over a channel. The goal for a system designer is to reach at a unified set of mathematical models characterized by diversity combining techniques. Spatial diversity is a well known method to generate autonomous communication paths between the source and the destination through the use of several antennas at the source and/or destination. Cooperative communication in recent times makes use of the mobile users in a network to relay the original source signal to the destination which creates a virtual form of multiple-input and multiple-output (MIMO) antenna array system.

In cooperative communication multiple users in a mobile radio environment share their antennas in order to achieve transmit diversity creating a virtual MIMO scenario. Because of its inherent advantages, cooperative diversity is a burgeoning field in wireless network communication systems. The main purpose behind cooperative communication is to improve outage probability, symbol or bit error rate. Besides this reliability improvement, cooperative diversity communication also improves transmission rate.

Sometimes the source node can't realize reliable communication with the help of only single relay node, so in order to achieve desired quality of service some relay nodes would like to form a group to transmit cooperatively. The transmit power of every selected relay node thus can be reduced. Thus the relays have incentive to form coalitions to relay the data of relay nodes.

The SNR allocation of the selected relay node based on the Shapley value, which divides the payoff among relay nodes in a fair and equitable way, can lead to the least power consumed for relay nodes. As a result there is much interest shown by the research fraternity in coalition in cooperative communication. The coalitional games provide proof to be a very powerful tool for designing robust, fair, efficient and practical cooperation strategies in communication networks.

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LIST OF ABBREVIATIONS

AF	Amplify-and-Forward
DF	Decode and forward
CR	Cognitive Radio
GC	Grand Coalition
MANET	Mobile Ad hoc Networks
MIMO	Multiple Input Multiple Output
NBS	Nash Bargaining Solution
NE	Nash Equilibrium
IC	Interference Channel
TDMA	Time Division Multiple Access
UE	User Equipment
RF	Radio Frequency
WANET	Wireless Ad hoc Network
WBAN	Wireless Body Area Network
ERC	Equal ratio combining
FRC	Fixed ratio combining
MRC	Maximal ratio combining
BER	Bit error rate
SER	Symbol error rate

CHAPTER 1

INTRODUCTION

1.1 RADIO PROPAGATION

In the era of globalisation, the increase in use of the wireless technologies in the current times for the purpose of communication between devices/hosts is inevitable. With this ever increase in use of wireless communication undeniably; efficient system performance and security of data are the prerequisites. Communication using wireless technologies suffers from several impairments, fading among them being the prominent one, as it affects both the reliability of the system and the quality of signal transmitted over a mobile radio channel. [1].

This phenomenon of fading, affecting the transmission of data has been a major challenge for the research fraternity engaged in the field of wireless communication technologies. Owing to huge dependence on wireless technologies, counter fading methods are gaining much attention. There are many developments in the field of counter fading that led to the improvement in overall communication performance in mobile radio environment [1].

1.2 CONCEPT OF FADING

In the transmission system, the signal transmitted from base station propagates via a channel in order to reach the receiver in mobile communication system. During this journey, the signal propagating generally experiences three phenomena of propagation reflection, diffraction and scattering [2]. These phenomena results in propagation of different signals because of the several obstructions, both natural and manmade, such as different weather conditions at different locations, hills, forests, tall buildings etc. Due to this the receiver receives resultant signal that varies in the amplitude, frequency and phase characteristics. The multipath signal versions at the destination have both the chances of combining usefully as well as belligerently to give a randomly varying resultant signal [2]. These variations in the final received signal give rise to phenomenon of fading. Fading is, thus, a result of the interference between the different multipath versions of the transmitted signal, also referred to as the multipath waves. The relative time of propagation, allocation of intensity of signal strength and the bandwidth of these multipath waves affects the nature of variations in the consequential signal at the receiver.

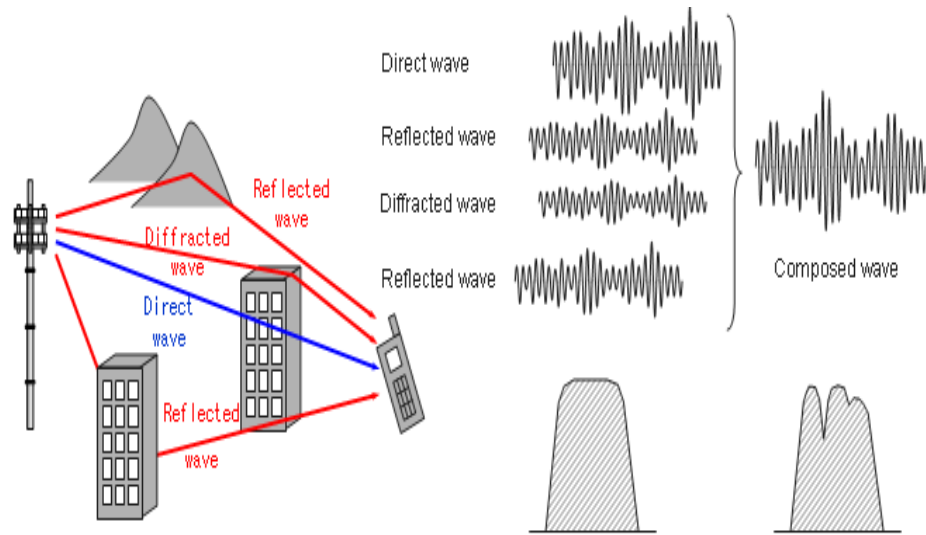


Figure 1.1 Propagation of wave in mobile radio environment [3]

When a signal is arrived over a fading channel, there are few changes in the signal parameters like phase, frequency and envelope over time. In case of systems employing coherent modulation schemes, the phase fluctuations caused by fading can unfavourably affect the performance unless suitable instruments are taken to quash these undesirable effects at the receiver [2]. Thus, in the study of such modulation schemes incorporating systems it is supposed that the phase variations resulted by fading are plausibly corrected to achieve the ideal coherent demodulation at the receiver. On the other hand, a non coherent modulation scheme does not require the phase information at the destination node and thus phase variations due to fading will not distort the system performance. Therefore, the act scrutiny of both the coherent and non coherent modulation schemes requires only the knowledge of the fading envelope information [4].

1.3 DIVERSITY

In wireless communication, diversity is defined as a technique in which a random signal is transmitted to the destination through two or more communication paths lying between the sender and the destination receiver to improve the consistency of the message signal. At the destination node, different signals from different paths are added to get average of all the signals strength received from different channels. The probability of two signals travelling via different channels affecting by same amount of fading is very less. Thus the combination of signals can be achieved at the destination by using diversity combining techniques. Diversity-combining is in use to lessen the effects of fading caused by the different channels [6]. The sovereign signals are combined in a way that the resultant signal is minimum affected by disturbances causing fading. This can happen when two transmitting antennas are located

satisfactorily at a distance from each other, and then it is implausible that the paths offered by the two antennas result in the deep fade concurrently [6].

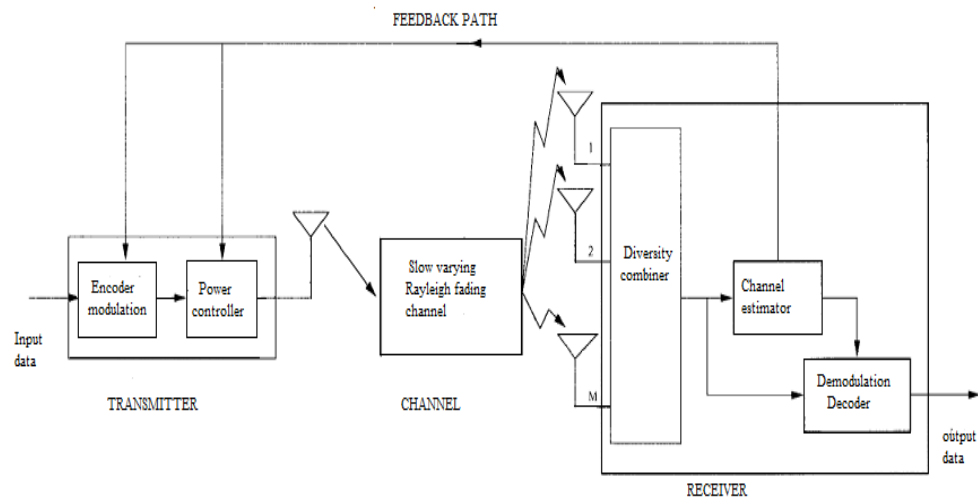


Figure 1.2 Transmission system block diagram.

Types of diversity are as follow:

a. Frequency diversity

Frequency diversity results when the different channels use multiple frequencies at the same time to transmit a signal to prevail over the unwanted effects of multipath fading. Hence, the use of multiple frequencies creates different and uncorrelated fading characteristics [2].

b. Time diversity

Time diversity is a phenomenon in which same signal is sent at different time instances such that difference between these time instances is more than the coherence time and the signal sent are uncorrelated. The channel condition in this time gap is different from each other. Time diversity can also be achieved by addition of a redundant error correcting code in which the error bursts are spread in time by the use of bit-interleaving [2].

c. Spatial diversity

Spatial diversity makes use of multiple antennas at the transmitter or the receiver to achieve independent paths to combat fading in a wireless communication system. The elements of the antenna array are spatially separated from one another. The optimum separation between the antennas depends on environmental conditions around the antennas. To obtain transmit spatial diversity, the transmit power is divided among the

multiple antennas in the array. The parting between the different receiving antennas should be such that the fading amplitudes for each path are nearly independent of each other [2].

1.4 DIVERSITY COMBINING TECHNIQUES

The different fading paths formed by the use of more than one antenna are combined at the destination to give a resultant signal which is passed for detector at the demodulation. There are different types of diversity combining techniques which are of different complexity [6].

a. Selection Combining

In the selection combining (SC) technique, the branch with highest SNR will be considered as the output at the receiver side. The technique needs only single receiving antenna at the destination that is switched to the antenna branch with the highest SNR and thus only one branch is used actively. A dedicated receiver may be required at each antenna branch such that the SNRs on each antenna branch are continuously monitored. This technique does not require co-phasing of the branches because the output of only highest SNR carrying branch is considered [6].

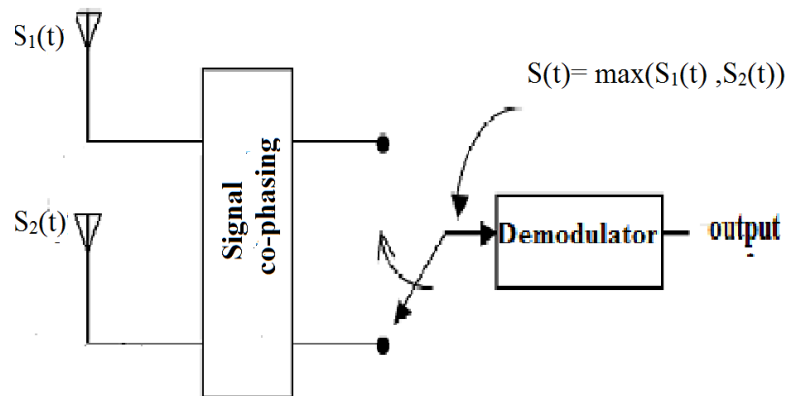


Figure 1.3 Selection combining technique [6].

b. Maximal Ratio Combining

In this combining technique, the instantaneous voltage-to-noise ratios are used to weigh the independent signals. The independent branches have phase before combining at the receive side so the different branches being added up possess same phase to achieve diversity gain. The different summed up signals are then used as the final received signal. This combining technique has the advantage of improving the final received signal when all the branches are correlated. The performance of MRC scheme is significantly better than both the SC scheme and EGC technique as it is an optimum combiner. The information on all channels is used to get a more reliable signal at the receiver point [6].

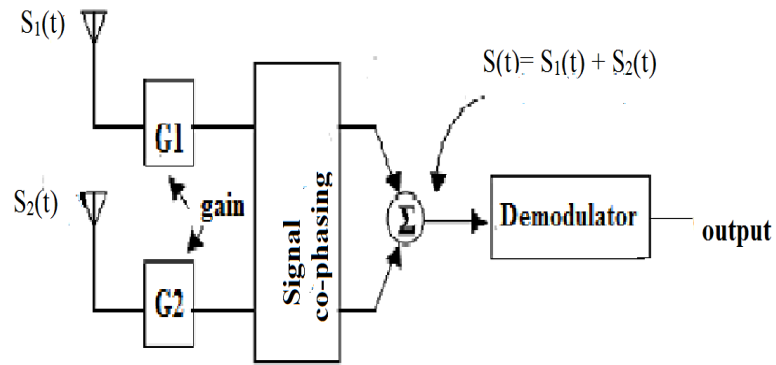


Figure 1.4 Maximal ratio combining technique [6].

c. Equal Gain Combining

EGC is somewhat similar to that of MRC technique. The only exception is that of equal gains used by this technique. In this combining technique all the branches possess equal gains and they remain constant throughout the data transmission. The branch signals are multiplied by the equal amount of branch gain as shown in the figure 1.5. EGC is less complicated in comparison to MRC. In terms of performance, EGC is nearly alike to MRC. EGC is a comparatively simpler method as unlike MRC; it does not need the knowledge of the SNR (changing with time) for every branch as this is hard to compute [6].

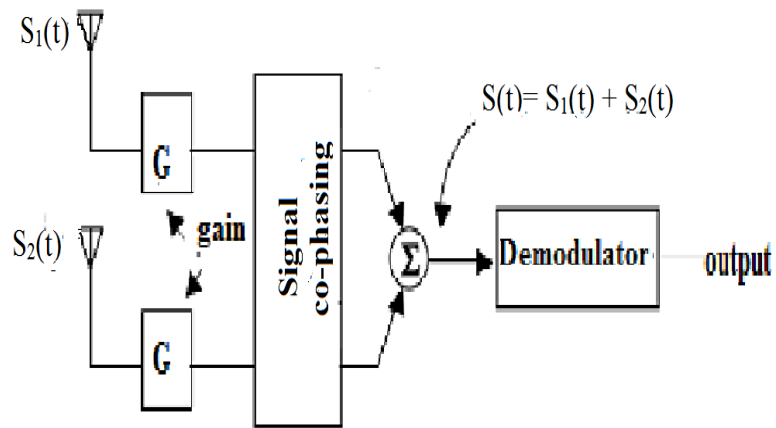


Figure 1.5 Equal gain combining technique [6]

1.5 COOPERATIVE DIVERSITY

The transmit diversity scheme uses a number of antennas at the transmitter to create independent fading paths. On the other hand wireless devices use only one antenna at the device terminal because of constraint in the size or the complexity of hardware. So in order to overcome this problem a new method called cooperative diversity communication was introduced. In cooperative communication multiple users in a mobile radio environment share their antennas in order to achieve transmit diversity creating a virtual MIMO scenario.

Because of its inherent advantages, cooperative diversity is a burgeoning field in wireless network communication systems [7]. The network performance can be enhanced by taking benefit of wireless transmission surroundings. The main purpose behind cooperative communication is to improve outage probability, symbol or bit error rate. Besides this reliability improvement, cooperative diversity communication also improves transmission rate.

The MIMO systems are being included into the wireless technologies because of their many rewards such as high data rates, enhanced spectral efficiency and minimum probability of error [7]. However, in certain cases, a MIMO system may not be practical due to limitations in size, hardware, cost or the inability of a wireless agent to allow multiple antennas at its source terminal. Thus, cooperative communication systems offer an alternative to MIMO systems (virtual MIMO) as they can tap the benefits of the MIMO systems in a virtual manner [7].

1.5.1 Cooperative Diversity Model

In communication wireless networks, a signal is broadcast in all directions such that the entire nearby node can overhear the signal sent by a source. This property of broadcast communications in wireless network is used in cooperative diversity. In the cooperative model the signal broadcasted by the source can be heard by relay(s) which can further forward the signal to destination. When signal is transmitted from source, it can follow two paths, one from S to D direct and another from S to D through R . The relays R receive the signal from source and retransmit it to D .

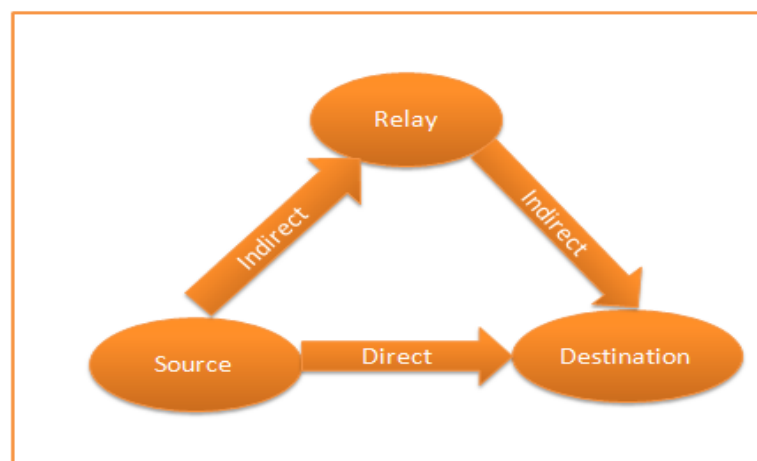


Figure 1.6 Cooperative diversity model.

The figure 1.6 illustrates a basic cooperative communication system model. It shows a source node, a destination node and a relay node. In cooperative communication the transmission is carried out in two phases:

a. Direct transmission phase

In this phase the signal is transmitted directly to destination node without asking for the help of relay node. During this transmission relay overhears the signal transmitted by the source. The relay node follows certain procedure for the received signal.

b. Cooperative transmission phase

In the cooperative transmission phase, the signal is overheard by relay in earlier time slot is transmitted by relay node to destination node. This will help in improving the SNR at the destination.

Thus, because of the presence of statistically independent fading paths, spatial diversity is achieved in a virtual manner.

1.5.2 Elements Of Cooperative Communication

The basic parts of cooperative communication are Source, Relay and Destination. All the elements follow certain characteristics which are different from the non-cooperative model elements.

a. Source

The source has the duty to transmit the new message signal to the receiver as well as to the relay(s) nodes in the pre determined initial phase of transmission process. Continuing, in second phase of transmission, the relay(s) forward(s) the message signal sent by the source antenna to the receiver based on a particular predetermined cooperative signalling protocol.

b. Relay

The node(s) acting as the relay(s) overhear signal broadcast by the source node in first phase of the total transmission and then retransmit it to the receiving node called receiving antenna after following certain protocol like Amplify and Forward (AF) or Decode and Forward (DF) etc. The procedure followed by the relay node depends on system features .In Amplify and forward relay act as a

repeater because it only regenerates the signal that is it just amplify the signal without demodulating the signal received at the relay node. But it will also amplify the noise, which is its drawback. While in decode and forward protocol of relaying, the signal received at the relay node which acts as an intermediate destination is first decoded using an encryption decryption method and then forwarded to the actual destination node. If the relay node is incapable to decode, the received signal, the signal sending to destination is denied. The other protocol viz. compress and forward relaying compress signal at relay node and then forward to destination node.

c. Destination

The antenna present at destination node receives signal from both source node and the relay node in different forms based on the protocol employed. If the signal from source is sufficient enough of giving proper information at destination, it will inform relay not to forward the signal implementing non cooperative mode of communication instead of cooperative one. The signals at the destination node are combined using various combining techniques eg., maximal ratio combining (MRC), equal gain combining (EGC) and fixed ratio combining (FRC).

The channel in the communication process is considered to have additive white Gaussian noise, path loss and Rayleigh fading. Considering thermal noise to be, $N_{s,d}[m]$ and path loss is calculated using path loss exponent $\sigma_{s,d}^2$ is white Gaussian random variable. Suppose we have a symbol $S_s[m]$ which we have transmitted and $Y_d[m]$ at destination are received, $Y_d[m]$ where can be described as:

$$Y_d[m] = d_{s,d} \cdot a_{s,d}[m] \cdot S_s[m] + N_{s,d}[m], \quad (1.1)$$

If overall attenuation can be written as $h_{s,d}$ then Equation (1.1) can be expressed as

$$Y_d[m] = h_{s,d} \cdot S_s[m] + N_{s,d}[m], \quad (1.2)$$

The signal received at relay node can be written as $Y_r[m]$

$$Y_r[m] = h_{s,r} \cdot S_s[m] + N_{s,r}[m], \quad (1.3)$$

Equation (1.2) and (1.3) represents the first phase where $d_{s,d}$ being the path loss factor, $a_{s,d}[m]$ is the fading coefficient and $h_{s,d}$, $h_{s,r}$ is overall attenuation factor. The signal received at relay is retransmitted to destination.

1.6 COOPERATIVE RELAYING PROTOCOLS

The cooperative communications, which are helpful in relaying data to the destination either follows decode and forward (DF) or amplify and forward (AF) protocol. There is a variety of a lesser amount of complex cooperative diversity protocols such as fixed relaying (FR), selection relaying (SR), and incremental relaying (IR) in wireless communication technologies. In fixed relaying, the relay nodes when amplify received signals from the broadcast by the source node is said to employed amplify and forward protocol, whereas when relay node decode, re-encode, and retransmit the signal the protocol is called decode and forward protocol [5]. Selection relaying decides its behaviour to cooperate or not based on SNR between source, relay and destination. Incremental relaying allows cooperation only when it is required thus improving spectrum efficiency [5].

1.6.1 Fixed Relaying: This type of relaying involves following two protocols:

- a. Amplify and forward protocol (AF): During the broadcast phase of the cooperative communication, the signal received at the intermediate relay node is amplified under power constraint to certain extend. The received signal $Y_r[n]$ is amplified which contain original signal as well noise component incorporated due to different channel and environment constraints. Thus while amplifying the signal, the noise is also amplified which is a shortcoming to this protocol. This protocol is used when computing time requirement for the relay node is less as decode and forward protocol (DF) takes high time. The received signal at receiver side can be written as $S_r[n]$. The achievable capacity in AF protocol from source to destination can be mathematically expressed as:

$$Cap_{AF}(s, r, P_r, d) = \frac{W}{2} \log_2 \left(1 + SNR_{sd} + \frac{SNR_{sr}SNR_{rd}}{SNR_{sr} + SNR_{rd} + 1} \right), \quad (1.4)$$

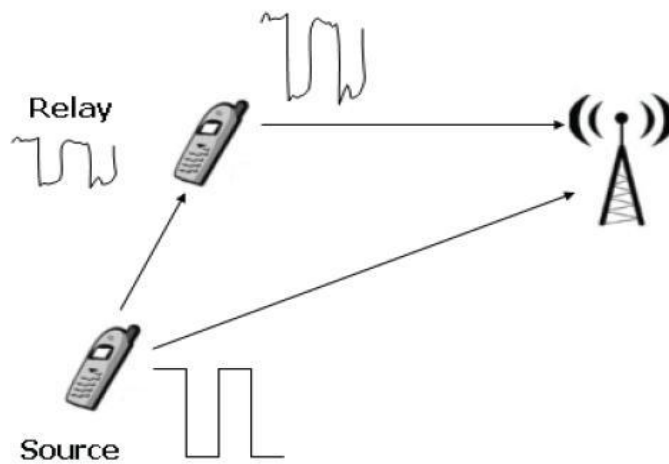


Figure 1.7 Amplify and forward protocol.

- b. Decode and forward protocol: (DF) method is mostly used because of the more usage digital modulation technique in wireless communication which gives an adequate amount of computing power required to implement decode and forward (DF) protocol. The received signal is first decoded and then re-transmitted to actual destination after re-encoding the signal at the intermediate level [5]. The signal can only be decoded absolutely if relay has a sufficient amount computing power or it can decode the signal symbol by symbol. The suitable decoding option can be chosen according to complexity of the system. The achievable capacity of decode and forward can be written as:

$$Cap_{DF}(s, r, P_r, d) = \frac{W}{2} \{ \log_2(1 + SNR_{sr}), \log_2(SNR_{sr} + SNR_{rd} + 1) \} \quad (1.5)$$

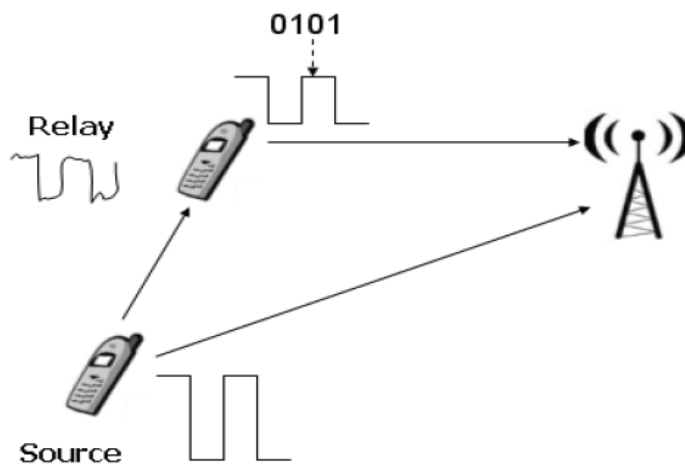


Figure 1.8 Decode and forward protocol.

1.6.2 Selection Relaying

Selection relaying is based on a system model of decision taking. Fixed relaying protocol is restricted by transmission between source and the relay. The decision making is due to fading coefficients of the channel that can be measured by the receivers at high precision such that they can decide whether cooperation is required or not [9]. If the signal to noise ratio between intermediate/ relay and destination node is below pre determined threshold level of signal to noise ratio, the system works prefers to employ non-cooperative mode of communication that is the relay node will not provide help to the source for relaying it's the signal. The source to destination path is sufficient for proper reception of data at destination [9]. On the other hand if the measured SNR is above threshold value of the ratio, the system employs cooperative mode that the signal is transmitted by relay and the receiver processes both the source and relay signal using diversity combining techniques [9].

1.6.3 Incremental Relaying

Incremental relaying is used in communication model where there is limited response such as single bit communication, and this type of relaying show better result as compared to selection relaying. This protocol is an extension to incremental automatic-repeat-request (ARQ) as in incremental relaying data is transmitted when there is distorted reception of the signal at the receiver. In this relaying protocol the signal is transmitted to destination node in broadcast phase only. The destination node will send an acknowledgement to the source as well as relay node if the received signal is of accurate quality signal. The relay then does not have to retransmit the signal. Thus the protocol helps in saving spectrum thus incremental relaying is spectral proficient. If the signal quality is below threshold the signal is send by relay as well [9]. The destination then combines both signal from source and relay. Thus signal is saved from deep fade.

1.7 RELAY SELECTION

Cooperative communication is a means by which performance of wireless communication has been enhanced to a great extent. This is believed by the research fraternity that by the use of cooperative communication they are able to build energy resourceful communication models which will use less amount of power. Relay selection is an important part of the entire cooperative models. The efficient relay selection will make the communication process more spectral efficient and will be able to exploit the diversity gain [10]. The full diversity gain can be achieved by using single best relay in DAF cooperative model as is achieved in simple

cooperative models which use all the relays [11]. The main challenge in relay selection model is the dynamic nature of the wireless model. Thus selecting optimal or the best relay becomes complicated. Thus an adaptive nature of relay selection scheme is employed in dynamic wireless networks. Generally in cooperative model employing adaptive relay selection, the relay is selected in two phases. And transmission in cooperative model of communication is accepted out in two phases [10].

The two phases of relay selection are:

- a. Phase 1: Relay candidate selection.
- b. Phase 2: Relay assignment.

1.7.1 Relay Candidate Selection Scheme

To choose best among many relays best depend on a variety of criteria. Basically there are two different types of relay selection schemes.

- a. Pre-assigned selection scheme

This scheme promotes the relays selection prior to communication connection. The relaying candidates are being selected while making multi hop mesh structure [10]. Before the communication begins the route is discovered and established. This is a simplest way of relay candidate selection scheme [6]. This scheme does not work in dynamic channel environment because dynamic channel keeps on changing the position of relay nodes ultimately leading to the change in topology of the network. Thus making relay selection process ineffective for wireless communication which is actually very dynamic in nature. The pre-assigned selection scheme can add to an operating cost as the relay information is collected before transmission. Thus though being simplest of all schemes, it is least favoured for selecting relays as candidate.

- b. Adaptive selection scheme

As the name suggests adaptive selection scheme is a dynamic relay selection scheme best match to the dynamic nature of the wireless communication. The burden is reduced by integrating it in multiple access control protocol. The integration of selection scheme with the multiple access protocol (MAC) is done by integrating it with request to send signal [12]. This way relay realises that it lies in between sending node and receiving node and will be a part of the cooperative model of communication [11]. On receiving multiple requests from the sending node to send messages, the relay node starts competing with the other relays to get selected in cooperation process to help the source and get paid off by

the same. In [13] the selection of relays is suggested by sharing messages between multiple sources and relays. Ad hoc on demand distance vector routing protocol has been used in [13] according to which relay think itself to be a part of cooperative model on receiving a route request from source node and route repeat request from destination node. Due to less overhead as compared to pre-assigned selection scheme and more adherences with wireless system, this selection scheme is preferred.

1.7.2 Relay Assignment

When the relay nodes are selected as candidates for the cooperative transmission model, then in the next step the relay assignment phase is executed. The best or the optimal relay is selected based on various criterions as discussed below.

a. Pre-defined or Random relay assignment

This is the one of the simplest criteria because the relay node which is going to be a part of cooperative model is pre-assigned. The relays are selected prior to communication [14]. This becomes the easiest way of assignment of relay but networks because of the dynamic nature of the wireless communication it performs incompetently in wireless communication.

b. Distance based relay assignment

The optimal relay selection is done on the basis distance criteria between relay to source and destination. The relay node in multiple relay scenarios, which is closer to source, is chosen as best relay for relaying the source data. In [15] the back off timer algorithm is used by the source node for relay assignment. The relay near to source will deteriorate its back off timer sooner than the other relays and thus will be having high chance of selection as an optimal relay. The selected relay will now send an acknowledgement to the source node to send signal to relay nodes for relaying it towards the destination. Although this is an easier way of assignment but distance cannot be considered as an important measurement because the relay which is closer to destination or source may have substandard signal to noise (SNR) value or can have nastiest fading effects. Thus more appropriate criteria are required for best relay assignment to the source node.

c. SNR Based Relay Assignment

For satisfactory communication both paths from source to relay and relay to destination must have good path link quality. Thus having SNR as the criteria for relay assignment is intellectual choice. The relay having highest signal to noise ratio must be selected as the best relay.

d. Game Theory Based Relay Assignment

In the new emerging communication era in the world of globalization, Game theory is a concept which provides us the tools by which an interaction can be formulated between decision makers based on their mutual benefiting interests. These decision makers are the players in the game in the same way as there are market players in share market etc. which has a mutual impact of their decisions on one another on one another. In the analogous situation the wireless network consists of nodes that compete with one another for resources such as time slots, spectrum etc. And they all have to make choices suitable for their interests. The research fraternity in wireless communication have been curious to use the economics concept of game theory in the communication technology also. They have utilized the decision making criteria for the selection of optimal relays out of relaying candidates selected in phase 1 of two phase's communication process between the source node and the destination node. The intermediate candidates are mimicked as the players which compete with each other for getting selected as the best possible relay to help out the source node. The relaying nodes acting as players compete with one another in distributed manner on the basis of the payoff it achieves while competing with other relays. The payoff is difference between benefit that a relay can get by acting as best relay and cost that is power in wireless communication, used for relaying the data. The relays in order to achieve high payoff act rationally and follow certain predetermined set of strategies. In [16] the author proposed a buyer seller game in which both the relay and source nodes work together in a game to mutually earn maximum payoff. They proposed a two level Stackelberg game. The Stackelberg leadership model is a strategic game in economics in which the leader firm moves first and then the follower firm's move in succession following the leader. In game theory terms, the players of this game act as a leader and a follower and they compete for scarce resources. The Stackelberg leader is also sometimes referred to as the Market Leader. If the

follower could commit to a Stackelberg leader action and the leader knew this, the leader's best response would be to play a Stackelberg follower action.

1.8 GAME THEORY ANALYSIS

Game theory is a process which is aimed at modelling different circumstances in which decision makers have mutual, possibly conflicting interests. Though, it originally developed by the researchers in the economics field, it has also been applied to wireless communication network designing in the past several years. Because of the competitive environment in wireless networks, it lends itself logically to a game theoretic formulation [17].

Game theory is a collection of tools that help us in predicting results when decision makers cooperate with one another for their common gains. It has three parts.

- Players set
- Actions set
- Preferences set

A set of players are the decision makers that will interact with one another in the considered system model. In wireless communication networks, these players are the nodes- source, relay and destination present in the networks. The actions are the set of strategies taken into consideration by the players. These actions may assume the type of modulation technique used, coding rate, power, bandwidth etc. The actions or the strategies that the players choose decide their result outcomes [18]. The preferences are described by the utility function which will assigns a value to every outcome. Wireless communication can show interest for such strategies which provide higher signal to noise ratio, low power consumption etc [18].

The research area of wireless communication networks has witnessed an incredible growth in past years and it has emerged to become one of the fastest mounting segments of the telecommunications industry. Various wireless communication systems, such as adhoc, cellular, mesh networks as well as WLAN (Wireless Local Area Network) are widely used and have become an indispensable tool people across the world in everyday life. However, the relevance of mathematical tools to the study of wireless networks has been able to achieve only some degree of success because of the difficulty of mobility and traffic models. Among all those theories applied to study wireless networks, game theory is the most adequate one since it offers a substantial amount of tools that may be used successfully in building the contact among individual nodes in wireless networks [19].

But since most of the literature in the field of wireless communication revolves around the informal network which is a multi-hop network, decentralised and have no central authority. Ad hoc network is distributed in nature and are power and energy constrained [18]. The present and the evolving wireless communication model have many features in common with ad hoc network. As game theory is a study of contact among independent agents, this theory can thus be utilized to analyse the nature of growing wireless networks. But game theory can be applied to the wireless models having difficult optimization problems.

1.8.1 Component Mapping For Wireless Communication

A game consists of three major components:

- **Players:** The decision makers in the game are called players, denoted by a finite set $N = \{1, 2, \dots, n\}$.
- **Strategy:** Each player $i \in N$ has a strategy set S_i to maximize its gain or profit. Each player would adopt different strategy to lead in the game. A strategy profile S consists of strategies of all the players, i.e. $s_i = (s_1, s_2, \dots, s_n)$.
- **Utility/payoff:** The utility of any player i amongst different players is a measurement function, denoted by $u_i S \rightarrow R$, on the probable result is measured by the strategies of different players, where R is the set of real numbers.

The mapping of elements in a game to the components in cooperative communications is:

Game Theory elements	Cooperative Communication elements
Players	<ul style="list-style-type: none"> • Source nodes and/or intermediate nodes
Strategy	<ul style="list-style-type: none"> • To control power • Radio allocation • Source node(s) or Relay node(s) • Price
Utility/payoff	<ul style="list-style-type: none"> • Data rate • Gain, e.g., revenue generated minus cost

Table 1.1 Mapping of components.

1.8.2 Game Types

A game involves different players like source, destination in case of game in communication networking. Based on the information of the players of each other's strategies, payoffs games can be subdivided into different categories. On the basis of the number of players, a game can be divided into 2-player game or n-players where $n > 2$. While on the basis of cooperation level, information about the different players available and the strategy of moves of the individual players, the games for cooperative communication can be broadly divided into following categories.

- Cooperative and non-cooperative games.
 - Sequential and Simultaneous Move Games.
 - Zero-Sum and Non-Zero Sum Games.
 - Games having Perfect and Imperfect Information.
 - Games possessing Complete and Incomplete Information.
- a. Non-Cooperative and Cooperative Games

In these games, the unit under consideration is always the individual player rather than group of players in non-cooperative games, as each player acts for his own benefit and tries to maximize its own utility only. The players tend to have selfish behaviours – i.e., they always try to amplify their own gains without bothering of other player's payoffs involved in the game. So, these games involve competitive nature of the players where their sole aim to increase their own benefits by adopting different set of strategies [19]. While on the other hand in cooperative games, the groups of players take part as an entity rather than being an individual and hence they tend to improve their payoffs as a group. The applications can be seen in groups forming situations, called coalitions, [19].

b. Sequential and Simultaneous Move Games

The games in which different players involved take their decisions in succession are called sequential move games. These games possess basic attribute of knowing about the strategies of other players in the circumstance. On the other hand simultaneous games are the games in which players implement strategy concurrently or simultaneously without the prior knowledge of the strategy adopted by other players taking part in the decision making process. Basically the sequential move games are the one where players decide its strategy according to the other player's strategy [17]. In sequential move game the player do not have

the complete knowledge of the player's strategy as they know only the present strategy not all the strategy of the game.

c. Zero-Sum and Non Zero Sum Games

The players participating in this type of game makes profits equal to zero at the end of the game [17]. These games present the total win-total loss situation the players in a game. There are many examples of the Zero-Sum games in the real world, winning of one team leads to the loss of the other team. But on the other hand in the Non-Zero sum game, each and every player participating in the game gets some share of the total profit or some loss at the end of the game. The only difference is that in Zero-Sum games, the participants have no familiar interest and in Non-Zero-Sum games, participants have sometimes contradictory and sometimes similar interests.

d. Games with Perfect and Imperfect Information

When each player has prior knowledge of exactly about all the decision of other players during his turn, then this is called as the game with complete information. Sequential games are the example of games of complete information. In other cases, when there is no information about other players past strategies then the game is called of imperfect information. All simultaneous move games are examples of games of imperfect information.

e. Games with Complete and Incomplete Information

When all the participant players have the knowledge of all the factors involved in the game, such games fall under the category of games of complete information. These games are perfectly competitive and the moves of the players are exceptionally strategic. While the games having the limited knowledge of players' strategies and payoffs are called games of incomplete information [19]. In the symmetric incomplete information, the deficiency of knowledge is equivalent for all the players. For example, in a sealed bid auction all players are uniformly ignorant about the strategies of other players and the outcome associated with each. In the case of asymmetric incomplete information, some players know more than the other players. For example, the game of poker where each player has only biased knowledge about the cards held by the other players.

1.8.3 Utility Function

Utility function in the game theory approach can be defined as a function which allocates a value to all the possible outcomes or results of the player in a game. The incentive given to the players to be a part of the game is represented by utility function. The higher the value rewarded by an outcome more preferable is that outcome. Let S is the set of strategy from which the players want to choose a particular the strategy and X is the set from which the decision makers want to choose the outcomes [18]. Let Q be the relation on X and let x and y be the elements of the Q , then x is less preferable than y if $x \geq y$ [18]. In wireless communication the basic preference characteristics for the nodes are spectrum, power control, rate, bandwidth etc. The utility function is not unique.

1.8.4 Solution Concepts In Game Theory

a. Nash Equilibrium

The term Nash Equilibrium was first coined by John Nash and this is being used widely in behavioural ecology and economics. It is an equilibrium in which the outcome of the player is most favourable and no player move away from its present adopted strategy considering the strategy adopted by other players. The players suppose that its fellow players will not change its strategy and thus does not diverge from its present strategy as it may receive no incremental benefits by deviating. A game can have many Nash Equilibriums.

We can solve a game in many ways once we express it in strategic form. By solving we mean predicting strategy by assuming that the players are rational. One of the simplest ways is to depend on iterative strict dominance solution [17]. Mathematically, the strategy profile S of different players is called as Nash Equilibrium such that:

$$U_i(S_i, S_{-i}) \geq U_i(S'_i, S_{-i}) \forall i \in N, \quad \forall S'_i \in S, \quad (1.6)$$

Where S_i is the present strategy of player i against the strategies adopted by different players and S_{-i} S'_i are all other strategies of player i . This means that a strategy profile S i.e. combination of different strategies of all the players will give Nash Equilibrium if and only if the condition in the Equation (1.6) satisfies for all the players.

b. Pareto Optimality

Pareto Optimality is defined as “A situation is held to be Pareto optimal if there is no way to reorganize things to make at least one person superior off without making anyone inferior off [17]. If such a strategy is adopted by any player in order to boost its payoff by varying its present strategy without compromising with the payoffs of other players, and then the outcome is not Pareto optimal. It is not always obligatory for the Nash Equilibrium outcome of a game to be the Pareto optimal one. Mathematically, it can be expressed that a strategy profile will be Pareto optimal if and only if:

$$U_i(S'_i) \geq U_i(S_i) \quad \forall i \in N, \quad \forall S'_i \in S, \quad (1.7)$$

And for any $j \in N$, for any $S'_i \in S$,

$$U_j(S'_j) \leq U_j(S_j), \quad (1.8)$$

1.9 COALITIONAL GAME THEORY

Coalition in general terms means group of items or in the words of wireless communication, it is defined as the grouping of the different nodes in order to gain maximal possible outcome. The coalitional game theory concept deals with the configuration of cooperative groups. As a result there is much interest shown by the researchers in coalition in cooperative communication. The coalitional games provide evidence to be a very influential tool for designing fair, robust, proficient and practical cooperation strategies for the communication networks. For this purpose, it is of strong interest to:

- Provide an engineering oriented preface to coalitional game theory that can unify the different aspects of coalitional games and
- Propose advanced applications for coalitional games in wireless networks. This thesis will tackle both points thoroughly as will be seen in the next sections.

The two main apparatus that a coalitional game requires are the players set, which is represented by $N = \{1, \dots, N\}$, and the coalition value of each player. The set N defines the players that act together in order to create groups which are cooperative in nature, in the form of coalition in order to improve their place in the game. Thus, a coalition $S \subseteq N$ defines an arrangement between the members of S to act as a single entity in a given game. Framing coalitions or alliances is persistent in many disciplines such as politics, economics, and, more recently, wireless networks as it helps to consolidate the position of individual eg., coalitions of political parties after the elections. The definition of the value can be defined by the pair (N, v) .

The characteristic form of a coalition is the most important concept of game theory literature [20]. The worth or utility of any coalition $S \subseteq N$ does not depend on group formed by the players outside S , i.e., the players in $N \setminus S$. Thus, a value of a coalition S in characteristic function depends solely on the members of that coalition. In any coalitional game there are two concepts: the value of the characteristic function of coalition and the profit received by a participant for its contribution in the game. The value obtained as a result of coalition gives the amount of utility that a coalition, can obtain. In contrast, the payoff or utility of a player gives the amount of dividend that a player on being the member of a certain coalition will obtain. Depending on the method of giving value is mapped into payoffs, the coalitional game can be classified in two forms *viz.* transferable utility (TU) or non-transferable utility (NTU). A TU game implies that the total dividend/utility obtained by any coalition $S \subseteq N$ can be divided in any manner amongst the members of S .

A coalitional game having characteristic form (N, v) , with transferable utility is said to be superadditive if for any two disjoint coalitions $S_1, S_2 \subset N$, $S_1 \cup S_2 = \emptyset$, $v(S_1 \cup S_2) \geq v(S_1) + v(S_2)$. Superadditivity implies that if coalition $S_1 \cup S_2$ forms, then it can give its members any allocations they can achieve when acting in S_1 and S_2 separately.

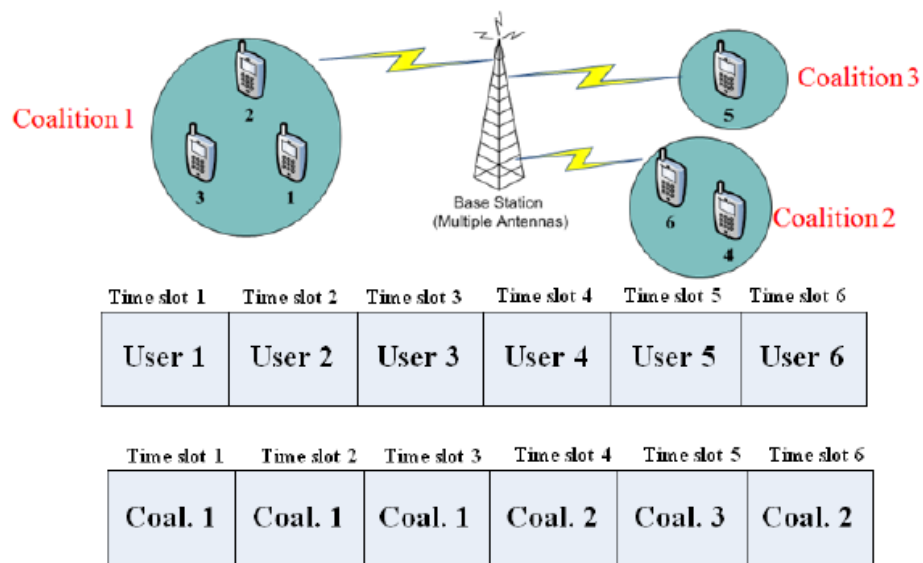


Figure 1.9: Different coalitions in different time slots.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY FOR GAME THEORY IN COOPERATIVE COMMUNICATION

- **Todd E. Hunter *et al.*** [4] in 2002 investigated the use of cooperative communication using coded cooperation technique. Each code word of the signal is divided into two subsets that will be transmitted from user and relay antenna respectively. Coded cooperation achieves high gain and maintains bandwidth, data rate and transmits power.
- **Sendonaris *et al.*** [6] in 2003 investigated a new spatial diversity form, which is based on achieving the diversity gains due to the cooperation between the different mobile users. He further explained that the noisy channel condition puts limited impact on the signal strength when there is cooperation between the mobile users; cooperation will lead to amplify the signal strength and will provide a more robust system to achieve rates less vulnerable to channel variations.
- **J. N. Laneman *et al.*** [23] in 2004 developed and analyzed models of low-complexity protocols employing cooperative diversity that help in combating fading added by multiple paths adopted by the propagating signal in wireless networks by exploiting space diversity accessible through cooperating terminals that relays signals for each other. The protocol were the blend of selection, incremental, fixed relaying. Outage probability of the model was analyzed for all type of relaying in cooperative communication.
- **A. S. Ibrahim *et al.*** [24] in proposed a new cooperative communication protocol in which source use relay which has maximum harmonic mean function of its source –relay and relay –destination. This protocol shows a significant increase in bandwidth efficiency.
- **Mark Felegyha zi *et al.*** [28] 2006 explained how the game theory can be applied on wireless networks. In wireless network the channel is shared among the nodes. They introduced the concept of non-cooperative game theory and made a simple analyzation on main factors of game theory.
- **Dusit Niyato *et al.*** [25] 2008 analysed and compared the processes of Competitive, Cooperative Pricing and Market-Equilibrium, for Spectrum Sharing in Cognitive Radio Networks. In case of radio resources trading, incentives and

prices are the key issues of interest to resource sellers as well as to secondary resource buyers. The author investigated different pricing models for radio resource trading in a radio environment. The distributed algorithms can achieve the pricing solutions for different pricing models and can also analyze stability for the distributed algorithms.

- **Yingda Chen *et al.*** in [31] 2008 analysed a game theoretical decode and forward cooperative communications in additive white Gaussian noise (AWGN) and Rayleigh fading channels. Cooperative communications is modelled as a repeated game in which the two participating terminals are selfish and seek to maximize their own payoff, a general utility function that monotonically increases with Signal-to-noise ratio. A Nash Equilibrium in which users mutually cooperate can be obtained for AWGN channels when strict power control is enforced and users care about future payoff.
- **C.K. Tan *et al.*** [27] 2010 explained about the resource allocation in wireless communication using Fair power control and game theory along with pricing scheme. But to alleviate selfishness problem, a payment-based scheme to control the power can be adopted so that each user gets different compensation paid for their own share of performance. The authors treat the problem of lack of motivation among users to give their due share using a Prisoner's Dilemma game.
- **S. S. Ikki *et al.*** [26] 2010 investigated the performance of amplify and forward protocol using best relay selection scheme. Regardless of number of relay available only two channels are used for diversity. Best relay selection not only maintain same diversity order but also reduces the amount of resource required. The scheme proposed usage of cooperative group which is consists of $M + N$ terminals, where M the managing is relay and N is the assisting relay. Managing relay manages the channel state information of the neighbouring relay. Out of these terminal only terminals having high SNR is selected and is encoded.
- **Y. A. Chau *et al.*** [28] 2011 proposed simple switch based relay selection scheme in which signal to destination channel is examined at starting of transmission and the relay is used only if channel gain is lesser than threshold. The channel gain of source to relay and relay to destination is compared with threshold, if it is lesser than threshold then that relay is not used instead another relay channel is compared. This is practiced for all L number of relay. The signal is combined using maximum ratio combining.

- **B. Wang, Z. Han *et al.*** [29] 2012 proposed a game-theoretical framework which is distributed in nature to achieve most favourable relay selection and to allocate power to them without knowledge of CSI. A two-level Stackelberg game is adopted to jointly take into consideration the reimbursement of the relay and source nodes considering the source node as buyer as relay node as seller. The game is proved to congregate to a unique optimal equilibrium. The author further explained that, the proposed allocation of radio resources with the distributed game can achieve comparable performance to that employ centralized schemes.
- **Dan Wu *et al.*** [29] in 2014 put forward an auction based relay power allocation scheme over multi relay network which provide energy efficiency by helping source nodes. They have presented three goals which are- to efficiently use the relay resources with maximum pay off given to them, to insure competitive fairness among competing users and to assure distributed execution with relaxation of limitations on complete private knowledge and precise assessments of convergence.

2.2 LITERATURE SURVEY ON COALITION OF RELAY NODES

- **Juan M. *et al.*** [32] 2002 investigated a new approach for allocation of radio resources method among the electric market participants. Both collaboration and antagonism are defined as the leading ways to fair solutions and competent cost allocation. The method is based their rational behaviour, the formation of different coalitions, and cooperative game theory resolution mechanisms. The author successfully concluded that adequate solutions are achievable in a decentralized atmosphere with open access to networks.
- **Sahas Mathur, *et al.*** [30] 2008 study about the coalition formation in cooperative communication using coalitional game theory. The stable coalition of relay nodes, from where the buyer has no incentive to get away depends on the manner in which the rate profits are apportioned among the cooperating users. Furthermore the stability of the grand coalition (GC) depends on the detector when receivers cooperate using linear multiuser detectors (non-transferable) and there are two cases of wholly cooperating transmitters and under a partial decode-and-forward strategy.
- **Omid Namvar Gharehshiran *et al.*** [31] 2009 proposed the coalition formation on random basis to get effective and efficient for the wireless sensor network (WSN). The sleep time allocation problem is designed as a non-convex

cooperative game and the concept of the core in Shapley value theorem is used to solve this problem. Further an algorithm is proposed based on a best-reply rule which converges to the core with probability of one if the core of the game is non empty.

- **Dongming Su *et al.*** [35] 2010 used the concept of coalitional game theory to design and implement new relay selection scheme in multi user wireless networks. The coalition will be a combination of source and the relay nodes in order to improve the transmission capacity and lower the bit error rate (BER) of system and improve the signal to noise ratio. The relays that are considered can form different number of coalitions.
- **H. Khayatian *et al.*** [33] 2010 provided novel concepts based on which source nodes are able to self organize themselves in order to form stable coalitions. Stable coalitions help to achieve significant amount of reduction for energy consumption in order to transmit the data from the source to the receiver side in multi user wireless networks. The purposed scheme helps to achieve better data rates and enhances the capacity of the system.
- **Dan Wu *et al.*** [34], 2011 proposed cooperative selection and stay combining for energy efficient cooperation where relay is not active all the time. In CSSC the channel gain of source to destination and source-relay-destination channel is compared, which so ever channel has high gain is used for transmission. It has lesser complexity than incremental relaying employing MRC. The author proposed an algorithm by using a random coalition formation process for the relay nodes based on best-reply response with trial opportunity to achieve a stable coalition structure with a core allocation.
- **Mohammed S. Bahbahani *et al.*** [36] 2015 studied, the problem related to multi relay selection to form their coalition in case of multiple source relay nodes. The author proposes the coalition formation based on by means of a political coalition of different parties formation game approach. An algorithm of distributed ruling coalition formation is advanced that selects only stable set of relays. A comparison with centralized multi-relay selection shows that the proposed provide comparable network sum rate with the extra advantage of network stability.
- **Fatiha Mokdadl *et al.*** [36] 2015 proposed a new strategy in which the characteristic function (payoff) of the Shapley value theorem represents a method of ranking the players according to their performance index within a coalition of

players. The Shapley value assigned to each feature calculated the value of different relay nodes and ranked them from higher to lower. The best feature selection method is identified on the basis of player providing highest Shapley value.

CHAPTER 3

COOPERATIVE COMMUNICATION AND GAME THEORY

3.1 COOPERATIVE DIVERSITY AND COMBINING TECHNIQUES ANALYSIS

In Cooperative diversity method, the broadcasting nature of the wireless communication is exploited to help the source node for relay data to the destination. The concept of cooperative communication helps to create a virtual MIMO which implements spatial diversity technique to send multiple packets of the data so as to minimize the effect of fading on the signal. The bit error rate (BER) of the signal is improved when relay nodes work cooperative and the performance of the system will get boosted up further with different combining method. Further we will examine as the number of relay increases the bit error rate seems to improve.

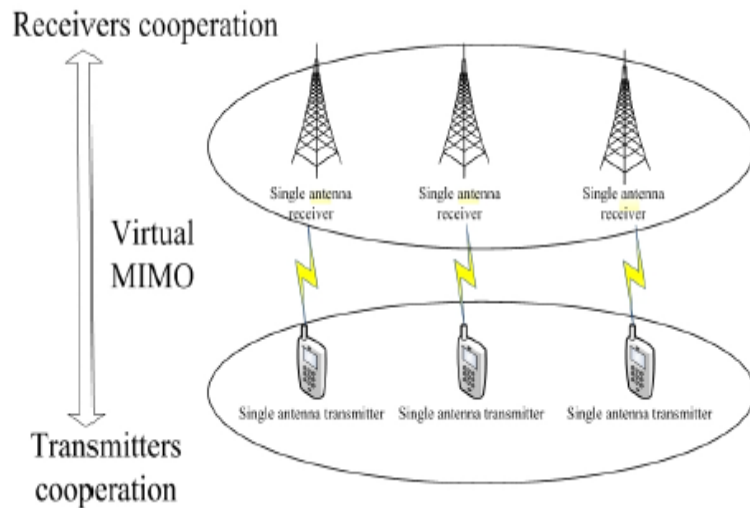


Figure 3.1 An illustrative example of a virtual MIMO system.

3.1.1 System Model For Cooperative Mode

To explain the cooperative mode for communication let's consider a source node, a destination node and a relay model. The channel is assumed to have path loss, and Rayleigh fading and additive white Gaussian noise (AWGN). The path loss exponent is 2. A BPSK signal is transmitted with non-cooperation and a QPSK signal in cooperative model because the QPSK signal is twice of BPSK signal. When we use cooperative model, the communication process takes place in two phases which require two time slots to transmit 2 binary data. In this case a BPSK in non-cooperative model is considered so that 2 bits are transmitted in 2 time slot as in cooperative QPSK model.

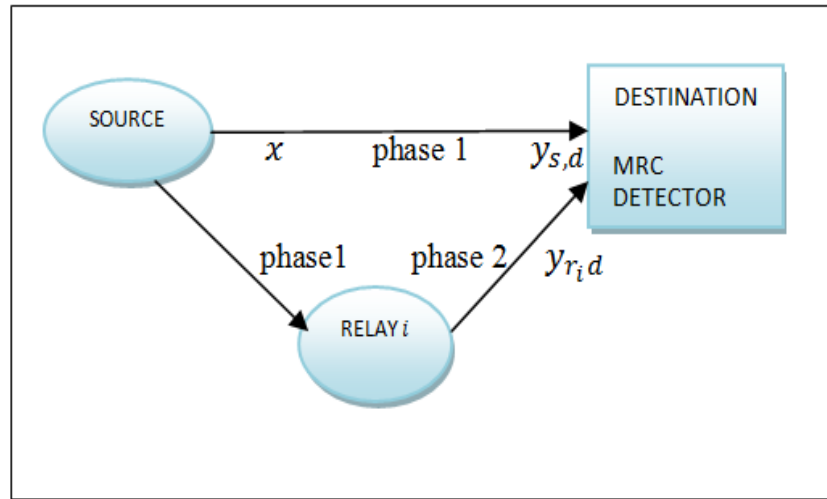


Figure 3.2 Cooperative system model.

In first phase, source node will broadcast its signal which is overheard by relay node and received by destination node. The received signal at the final destination point is given by

$$y_{s,d}[m] = d_{s,d} \cdot a_{s,d}[m] \cdot x_s[m] + n_{s,d}[m], \quad (3.1)$$

$$y_{s,d}[m] = h_{s,d}[m] \cdot x_s[m] + n_{s,d}[m], \quad (3.2)$$

Where $x_s[n]$ transmitted signal is the $d_{s,d}$, is the path loss factor and $a_{s,d}$ is the zero mean Gaussian random variable having variance $\sigma_{s,d}^2$. The factor $n_{s,d}[n]$ is the thermal noise and $h_{s,d}$ is the overall reduction or attenuation and is given by $d_{s,d} \cdot a_{s,d}[n]$. The power of the signal at relay is given by:

$$P[|y_r|^2] = P[|h_{s,r}|^2] \cdot [|x_s|^2] + P[|n_{s,r}|^2], \quad (3.3)$$

In the first way the relay will either first amplify the original signal or decode it the signal received and then retransmit it towards the destination in second phase. If the relay node first amplify then transmit the signal, this is called amplify and forward protocol. In case of decode and forward the data is first decoded and then re-encoded before retransmission. The above model uses amplify and forward (AF) protocol.

In second phase, the relay transmits the amplified or the re-encoded signal received in first phase. The signal received at destination from the relay can be written as.

$$y_{r,d}[m] = h_{r,d}[m] \cdot s_r[m] + n_{r,d}[m], \quad (3.4)$$

3.1.2 Analysis Of Combining Technique

The graph between BER and SNR for QPSK signal in cooperative model with different combining method and BPSK signal in non-cooperative model is shown below. It can be observed from the graph that in case of in non-cooperative communication, for BPSK modulation, BER of .98 with SNR of 14dB. In case of cooperative model used for QPSK transmission with ERC combining the BER with SNR of 10.5dB is obtained. With FRC combining we achieve same BER with SNR of 10dB and using MRC combining, same BER is achieved with SNR of 6.5dB. Thus signal quality is enhanced when user shift from non-cooperative to cooperative model. The virtual MIMO created control fading effects and improve signal quality. The signal combined at the destination show best enhancement with MRC technique. Other combining techniques also show enhancement in BER as compared to non cooperative model of relaying data.

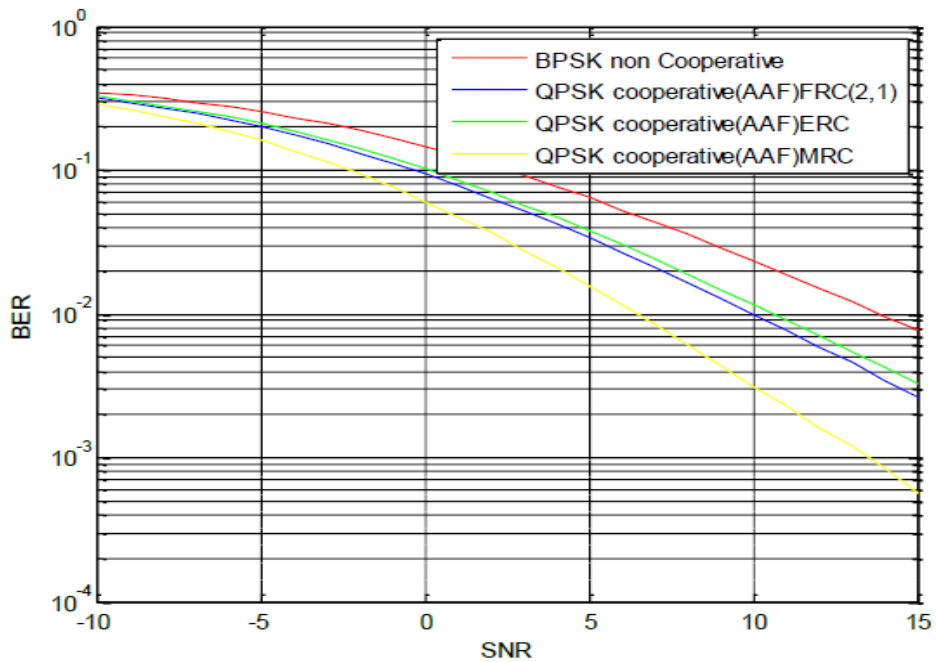


Figure 3.3 Cooperative communication using different combining method.

3.2 APPLICATION OF GAME THEORY FOR RESOURCE ALLOCATION

To make use of cooperative diversity for more than one user, there are two fundamental questions on resource allocation that needs to be answered:

- 1) Which relay nodes to be added in the coalition to get better signal to noise ratio?
- 2) What is the optimal power P_{r_i} ?

However, solving these two problems in a distributed resource allocation only needs local knowledge about channel information. To include relay nodes for relaying the data to the destination, some sort of incentives in the form of dividend need to be given to the relay nodes for helping source nodes. Stackleberg game can be used for this purpose

- Source node/buyer: The buyer in case of cooperative communication can be assumed to be a source node s , which will obviously aim to obtain the most benefits out of the least possible payments. The utility function of source node s can be mathematically expressed as:

$$U_s = aR_{s,r_i,d} - P, \quad (3.5)$$

Where, $R_{s,r_i,d}$ denotes the achievable rate with the relay nodes' help, a denotes the gain per unit of rate at the MRC output, and

$$P = \sum_{r \in \mathcal{L}} p_i P_{r_i}, \quad (3.6)$$

Where, P denotes the total payments paid by source node s to the relay nodes, P_{r_i} denotes how much power node s will buy from node r_i and p_i represents the price per unit of power selling from relay node r_i to source node s .

- Relay node/seller: Each relay node r_i can be assumed to be sellers which will aims to earn the profit as well as payment that covers its forwarding cost. A parameter c_i , is the cost of power for relaying data. Then, on the similar lines as that of source node, the utility of relay node r_i can be expressed as.

$$U_{r_i} = (P_{r_i} p_i - c_i P_{r_i}), \quad (3.7)$$

If a certain relay node r_i demands such a higher amount for relaying data, it will make it less beneficial than the other relay nodes to be asked by the source node s for relaying data. In that case source node s will buy less amount of power from relay node r_i or can even discard it. So overall, there is a trade-off for setting and bargaining the price between relay nodes and the source nodes. If for the best possible price p_i , the resulting utility of relay node r_i is negative, i.e., $U_{r_i} \leq 0$, then node r_i will end the seller-level game since it will not be able to recover the basic cost by remunerative prices it will get by selling power to the source node.

3.2.1 Observation

The system model is consisting of a source, a destination and multiple relay. The model is analyzed for its symbol error rate with one, two, three relays. The position of

destination node d is at coordinate value $(0\text{ m}, 0\text{ m})$, and the position of source node is at coordinate $(100\text{ m}, 0\text{ m})$. Relay node is moving along the x axis in $[-250\text{ m}, 300\text{ m}]$ with y coordinate at 25 m . The propagation loss factor is set to two. The source transmitting power $P_s = 10\text{ mW}$, the noise level is $\sigma^2 = 10^{-8}\text{ W}$, and capacity gap $= 1$, bandwidth $W = 1\text{ MHz}$, the gain of the source node per unit of rate $a = 0.01$, and the cost of relaying data per unit of power $c = 0.2$.

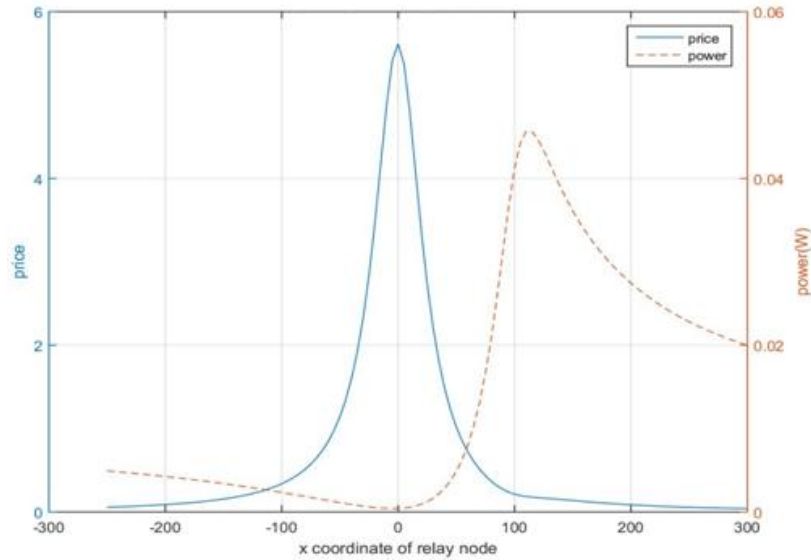


Figure 3.4 Optimal price and power of the relay node.

Figure 3.4 shows that when the moving relay node r is close to source node s at $(100\text{ m}, 0\text{ m})$, the source node will buy less power from the relay node which ultimately will improve the utility U_s of source node as is evident from Equation (13), because lesser the amount of power borrowed from relay node lesser will be the price to be paid to relay node in the game. The optimal power P_r that the source buys from relay node r tends to decrease with price of the power being paid to relay node p , and node r 's utility U_r is concave in p . The main motive of the relay node to be part of the relay node is to increase its utility U_r in best possible manner, so the price p should be carefully selected, because an arbitrarily selected price will ultimately be the reason of rejection of relay node from the cooperative game. The decrease in price of relay node will make it more favourable for the source node. On the other hand, when the moving relay node r comes close to destination node d at $(0\text{ m}, 0\text{ m})$, relay node r tend to ask high price from the source node in order to lend source s 's data, so relay node r tend to ask a very high price from the source node in order to get more profit. When relay node r keeps going away from destination d , source node s stops buying services in the form of power from the relay node.

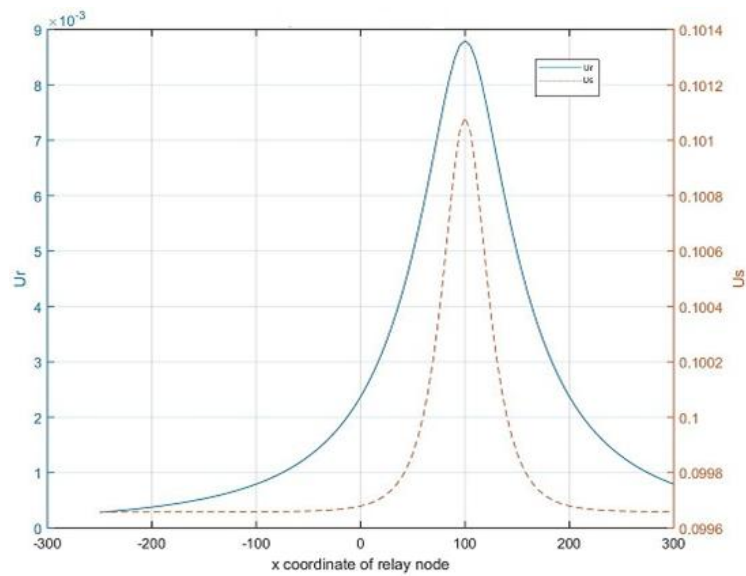


Figure 3.5 Optimal utility of the source and the relay node.

Figure 3.5 shows the optimal utilities of both the relay node r and source node s , that they can obtain using game theory in cooperative communication. The utilities of both the source and the relay node are at maximum when they are at close proximity to each other. Similarly, when the both move away from each other, utilities tend to decrease as source node buys less services from relay node relay node.

CHAPTER 4

COALITION BASED RESOURCE ALLOCATION

4.1 COALITION IN COOPERATIVE COMMUNICATION

In the field of communication using the help of relay nodes, there are times when the source node can't persuade the Quality of Service obligation of the system of communication with only single relay node. So it becomes important to call multiple relay nodes for help. Along with the QoS the number of hops that a signal needs to travel between the arrival and the destination may get reduced, with the help of a number of relay nodes. There are any complexities present in the way of a signal transmission. But the issue of power allocation in case of multi-relay cooperative communication is complex. But the concept of coalitional game theory can be used to deal with the issue of resource utilisation and power allocation constraints. Also the selected relay nodes by the source node are delighted to form a group or different groups simultaneously to work together, because their power to transmit the signal can be reduced significantly. Since wireless radio resources are short of power. So the coalitions of multiple relay nodes can provide better opportunity to deal with this short power problem. The coalition formation process is the joint effort provided by all the relay nodes to help the relay nodes rather than competing with one another and power allocation of relay node is established via a coalition formation strategy based on profit stability. The strategies are valuable to the configuration of global alliance which is stable [21].

4.1.1 Payoff Division within Coalition on the basis of Fairness Criteria

There are various fairness rules in the literature of cooperative communication for dividing the utility $v(S)$ among the members of coalition S that is a sub part of grand coalition. A split or merger operation by Pareto order directly or indirectly depends on the fairness criterion for payoff division.

a. Egalitarian Fair (EF)

It is the simplest method of division of payoff among multiple nodes to divide the extra utility uniformly among users. Mathematically the utility of user j , can be expressed as:

$$\phi_j = \frac{1}{|S|} \left(v(S) - \sum_{i \in S} v(\{i\}) \right) + v(\{j\}), \quad (4.1)$$

where $v(\{j\})$ and $v(\{i\})$ are the non-cooperative payoffs of users i and j . Egalitarian Fairness only represents the extra benefit given to relay nodes and not the whole utility.

b. Proportional Fairness (PF)

The Egalitarian Fairness is no doubt a very simple and strict fairness criterion, however, in practice, the user whose is having its channel in a good condition might not be willing to work together with a user having bad channel conditions, if the dividend is distributed equally amongst them. To take into account the prevailing channel differences, a certain criterion is used called as proportional fairness (PF), in which the extra profit is distributed amongst the participants according to their amount of participation in the process. Thus,

$$\phi_j = w_j \left(v(S) - \sum_{j \in S} \frac{v(\{j\})}{v(\{i\})} \right) + v(\{j\}), \quad (4.2)$$

Where $\sum_{i \in S} w_i = 1$ and $\frac{w_i}{w_j} = \frac{v(\{i\})}{v(\{j\})}$, thus, it is evident that within the coalition for PF, the users having good channel conditions be worthy of more extra payback than the users with bad channel conditions.

c. Shapley value fairness (PF)

Shapley value eradicates the complex strategic interaction way usually followed in game theory. The strategic interaction due to its complexity increase the need of proposing a simple way which was offered by Shapley value which indicates all the alternatives of a player by a number indicating the utility of the player. Shapley proposed a way of representing all the possibility for a player, while playing game, in the form of a value.

A Shapley value ϕ_v assigns to each possible characteristic function v a vector of real numbers, i.e., $\phi_v = (\phi_1, \phi_2, \dots, \phi_M)$, where ϕ_{v_i} represents the worth or value of user i in the game (N, v) .

Basically there are four Shapley axioms that ϕ_v must satisfy:

1. Efficiency Axiom: $\sum_{i \in N} \phi_i = v(N)$
2. Symmetry Axiom: If the two users i and j are s.t. $v(S \cup \{i\}) = v(S \cup \{j\})$ for every coalition S not containing user i and j , then $\phi_{v_i} = \phi_{v_j}$.

3. Dummy Axiom: If user i is s. t. $v(S) = v(S \cup \{i\})$ for every coalition S not containing i , then $\phi_i = 0$.

The characteristic function of Shapley value is given by

$$\phi_i = \sum_{S \in N \setminus \{i\}} \frac{(|S|!)(|N| - |S| - 1)!}{(|N|)} [v(S \cup \{i\}) - v(S)], \quad (4.3)$$

The Shapley Value provides a fair division which takes into consideration the random ordered joining of the players in the coalition. In cooperative communication the nodes in wireless communication are the players which compete with one another. The model has three basic elements: source, relay and destination. The relay is used by the source to retransmit its signal to destination. Resource such as power, spectrum of the player is shared by the sources. The relays compete with one another to help source in retransmitting the signal. The decision making by the sources and the relays is through game theory. The Shapley value is the easiest way of implementing game theory on a model. The player which achieves high value will have highest resource allocated to it.

4.2 SYSTEM MODEL

The system model consists of source and destination network with the multiple relay nodes between them acting as intermediate nodes denoted by $R = \{r_1, r_2, \dots, r_N\}$ to help the source to transmit data to the reception side. The cooperative transmission will employ Amplify and Forward (AF) cooperation protocol, though other cooperation protocols like Decode and Forward (DF) can also be used. As explained in the figure 4.1 itself, the cooperative transmission mode consists of two phases *viz.* Direct and Indirect.

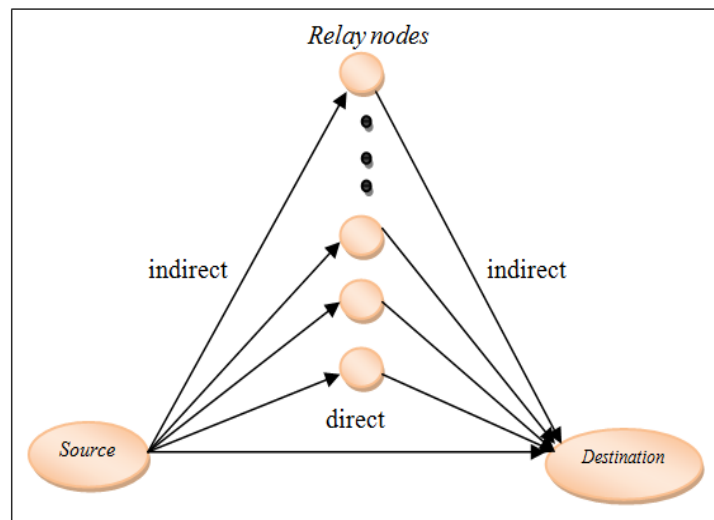


Figure 4.1 System model for the coalitional network

During the initial phase, the source node S broadcasts its information to the relay nodes R and destination node D simultaneously. The corresponding received signals can be expressed as:

$$y_{s,d} = \sqrt{P_S G_{s,d}} x_i + n_{s,d}, [29] \quad (4.4)$$

$$y_{s,r_i} = \sqrt{P_S G_{s,r_i}} x_i + n_{s,r_i}, [29] \quad (4.5)$$

where, $y_{s,d}$ is the received signal at the destination node and y_{s,r_i} is the received signal at the relay nodes. $G_{s,d}$ and G_{s,r_i} are the channel gains, n_{s,r_i} and $n_{s,d}$ are the additive white Gaussian noises (AWGNs) and P_S is the power transmitted by the source node.

When the transmission takes place directly between the sender and the destination node, the resulting signal to noise ratio and data rates can be expressed as:

$$\Gamma_{s,d} = \frac{P_S G_S}{\sigma^2}, \quad (4.6)$$

and

$$R_{s,d} = W \log_2 \left(1 + \frac{\Gamma_{s,d}}{\Gamma} \right), \quad (4.7)$$

where W is the bandwidth of the channel for transmission and Γ is the capacity gap.

During the second phase, the relay node amplifies the amplitude of the received signal and forwards the amplified version of signal from the relay node to destination node acting as an intermediate. The final received signal at the destination terminal can be given as:

$$y_{r_i d} = \sqrt{P_{r_i} G_{r_i d}} x_{r_i d} + n_{r_i d}, \quad (4.8)$$

where

$$x_{r_i d} = \frac{y_{s,r_i}}{|y_{s,r_i}|}, \quad (4.9)$$

Where P_{r_i} and $G_{r_i d}$ are the power received from relay node and the channel gain between relay and destination node. The final signal received at the destination can be given as:

$$y_{r_i d} = \frac{\sqrt{P_{r_i} G_{r_i d}} (\sqrt{P_S G_{s,r_i}} X + n_{s,r_i})}{\sqrt{P_S G_{s,r_i} + \sigma^2}} + n_{r_j, d_i}, \quad (4.10)$$

Using (21), the relayed SNR for the source node can be given as:

$$\Gamma_{s,r_i d} = \frac{P_{r_i} P_S G_{r_i d} G_{s,r_i}}{\sigma^2 (P_{r_i} G_{r_i d} + P_S G_{s,r_i} + \sigma^2)}, \quad (4.11)$$

and the data rate achieved with the help of relay nodes can be given as:

$$R_{s,r_i d} = \frac{W}{2} \log_2 \left(1 + \frac{\Gamma_{s,d} + \Gamma_{s,r_i d}}{\Gamma} \right), \quad (4.12)$$

Consider N set of players from which any coalition $S \subseteq N$ stands for an agreement among the players and $v = 2^N \rightarrow R$ is the characteristic function with $v(\emptyset) = 0$, where \emptyset denotes the empty set.

Def1. A coalition game of N players is defined by $\{N, v\}$, where v is the mapping function which will determine the payoff of the players according to their contribution to the coalition.

Def2. A game $G = \{N, v\}$ is defined as convex is $v\{S \cup T\} + v\{S \cap T\} \geq v(S) + v(T)$ for all $S, T \subseteq N$.

Def3. Core: The core is a set of payoff allocation (x_1, \dots, x_N) satisfying two conditions.

$$\sum_{i \in N} x_i = v(N)$$

$$\sum_{i \in N} x_i > v(S) \quad \forall S \subseteq N$$

Core is analogous to Nash Equilibrium for non cooperative game.

Def4. A game $G = \{N, v\}$ is super additive if $v\{S \cup T\} \geq v(S) + v(T)$ for $\forall S, T \subseteq N$ and $S \cap T = \emptyset$.

Def5. For the coalition $\{N, v\}$, the Shapley value, which is the way to distribute gain among the players, is defined by.

$$\phi_i(v) = \sum_{S \subseteq N \setminus i} \frac{{}^{(S)}(N-S-1)!}{N!} \{v(S \cup \{i\}) - v(S)\}, \quad (4.13)$$

4.3 COALITION FORMATION FOR THE PROPOSED GAME

In case of a single relay node, more power is required by the source node to deliver the data to the destination resulting in lower SNR and high probability of error. So coalition of relay nodes ready to help source nodes can reduce the power consumption to a significant level as each member of the coalition desires to send same data towards the destination node.

Coalition formation: The characteristic function for the proposed game can be defined as.

$$v(s) = -\{aR_{s,r_i d} - c \sum_{i \in s} P_{r_i}\}, \quad (4.14)$$

Where, a is the gain per unit of data rate while $R_{s,r_i d}$ is the data rate achieved at the destination, c is the price per unit of power and P_{r_i} is the power provided by the relay nodes.

The characteristic function is given in Equation (4.14) will determine the cost of sharing of coalition. We desire to achieve minimum value for Equation (4.14), giving characteristic function so as to improve the utility of the source nodes as well as of the relay nodes. From Equation (4.14), it is evident that to achieve the minimum value of the $v(s)$, we need to minimize the second term in the Equation. Since price is fixed by the relay nodes, the onus lies on the power provided by the relay nodes which involves a coalition. So the optimization problem can be formulated as.

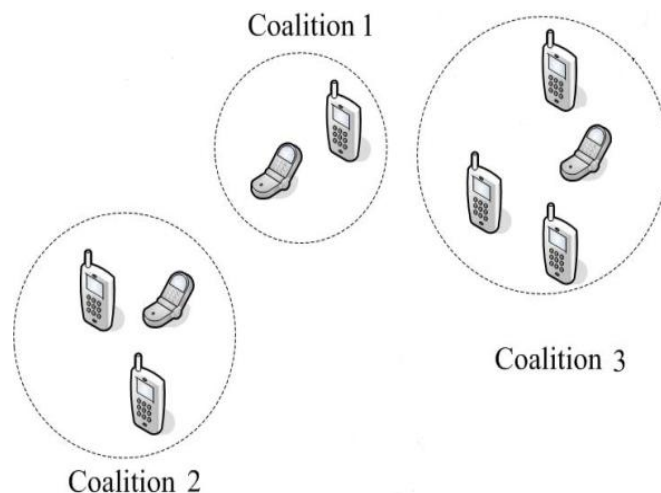


Figure 4.2 Different coalition patterns for three relays.

So the optimization problem can be formulated as:

$$\min P_{r_i}, \quad i = 1, \dots, N$$

$$s. t. \sum_{i=1}^N \Gamma_{s,r_i,d} = \gamma_{tar}$$

where γ_{tar} is the target signal to noise ratio (SNR) required at the destination.

$$\Rightarrow \min \frac{P_s G_{r,d}}{\sigma^2}, \quad i = 1, \dots, N$$

$$s. t. \sum_{i=1}^N \Gamma_{s,r_i,d} = \gamma_{tar}$$

So the power allocation problem can be solved by Lagrange multiplier solution as follows:

$$L(P_{r_i}) = \frac{P_s G_{r,d}}{\sigma^2} - \lambda^2 [\sum_{i=1}^N \Gamma_{s,r_i,d} - \gamma_{tar}], \quad (4.15)$$

The value of power required by the relay node to relay the source data can be given as

$$P_{r_i} = \frac{\Gamma_{s,r_i,d} \sigma^2 (P_s G_{s,r_i} + \sigma^2)}{P_s G_{s,r_i} G_{r_i,d} - \Gamma_{s,r_i,d} \sigma^2 G_{r_i,d}}, \quad (4.16)$$

By substituting the value of power from Equation (4.16) and solving the Equation (4.15) by taking partial derivative w.r.t $\Gamma_{s,r_i,d}$ and λ^2 , we can have:

$$\Gamma_{s,r_i,d} = \frac{\gamma_{tar}}{N}, \quad (4.17)$$

Substituting the value of the signal to noise in Equation (4.17) we can have the required power for the characteristic function.

$$P_{total} = \sum P_{r_i} = \frac{\Gamma_{r,d} \sigma^2 (P_s G_{s,r_i} + \sigma^2)}{P_s G_{s,r_i} G_{r_i,d} - \Gamma_{r,d} \sigma^2 G_{r_i,d}}, \quad (4.18)$$

Substituting Equation (4.18) in Equation (4.14) will give the characteristic function value for unusual characteristic function value for different coalitions. The choice of best coalition can be done by the data rate value. Since the main purpose is to improve the data rate so the coalition giving the higher data rate tends to be the best coalition of relay nodes supporting the source node. The incentive to the relay nodes to join the coalition is the improvement in their payoffs. Payoffs of relay nodes tend to be higher in case of coalition rather in individual case.

Algorithm to find best coalition:

- Choose the relay nodes.
- Form different coalition of different relay nodes.
- Calculate the characteristic function $v(S)$ for each coalition.
- Find the best coalition which will minimize $v(S)$.

4.4 NUMERICAL RESULTS AND OBSERVATION

The system consists of a source node, three relay nodes forming a coalition and a destination node. This section give some numerical results of power consumption, utility of source nodes and Shapley values related to the proposed methodology.

a. Source node

For the convenience of calculations, we assume that the destination node fixed at [0, 25] with the distance between source and destination ranging from 0 to 1000 with and the relay nodes occupy different places within [0, 1000] with y coordinate fixed at 25.

The propagation loss factor is two. The transmit power $P_s = 0.05W$, the noise level is $\sigma^2 = 10^{-4} W$, and the capacity gap = 1, $W = 1$ MHz, the gain per unit of rate $a = 0.01$, and the cost to buy a unit of power $c = 0.5$

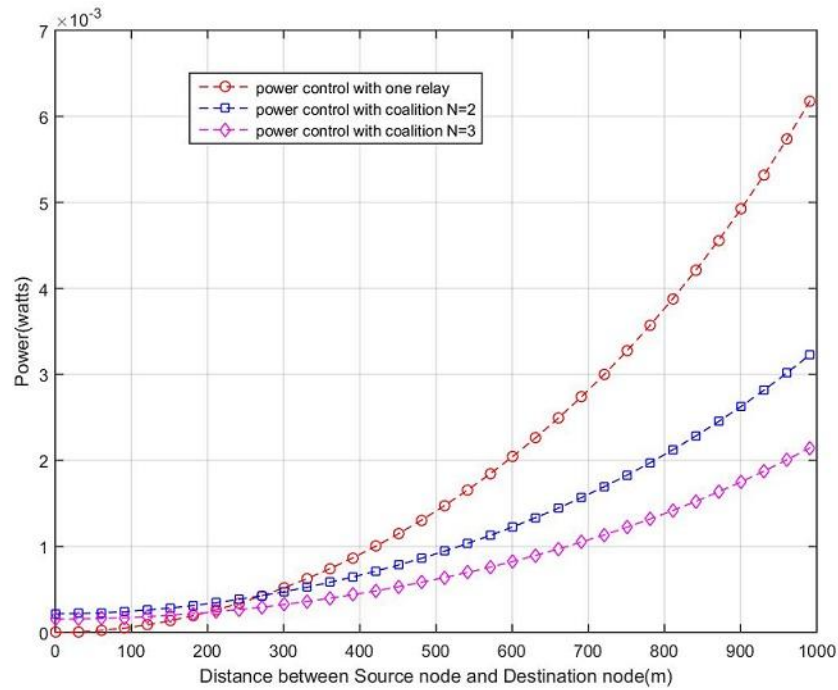


Figure 4.3 Power with the coalition of relay nodes

Figure 4.3 presents the effect of distance between source node and destination node on the power required. As the source node moves away from the destination node the power required increases. The figure also presents the effect of coalition of relay nodes. When only one relay node was present to help the source node it required more power. But as more number of relay nodes join the coalition the amount of power required decreases.

Next, the effect of coalition on the utility of source node is shown. The coalition helps in the improvement of utility of source node as more number of relay nodes is present to help the source node.

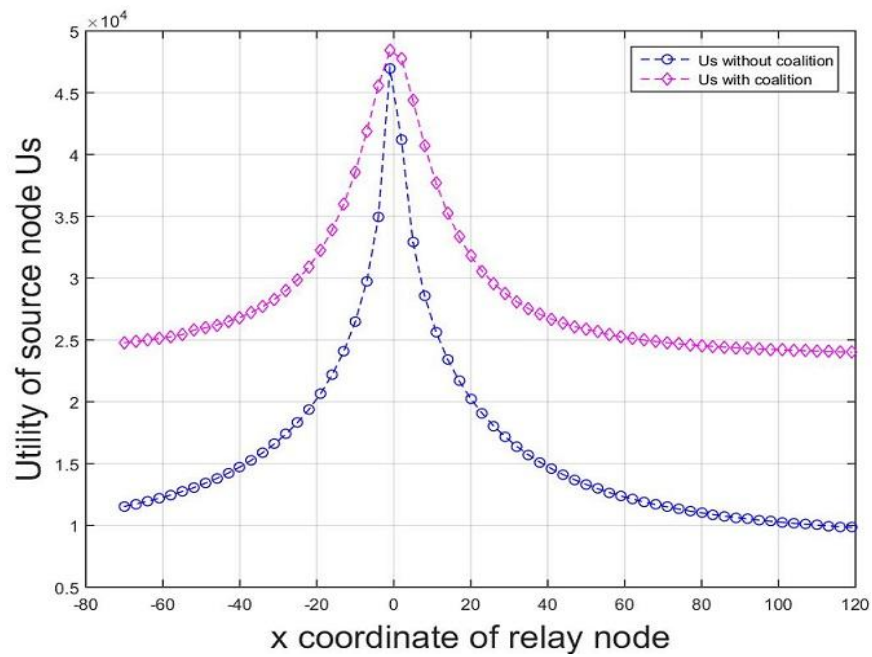


Figure 4.4 Utility of source node.

Figure 4.4 shows the effect of adding more number of relays in the coalition. It is evident that coalition of intermediate nodes help in the improvement of utility of the source nodes. Similarly figure4.5 shows the average power consumption as the number of relay nodes increase to more than one. It shows that when more number of relays join the coalition the average power required transmitting the information decreases.

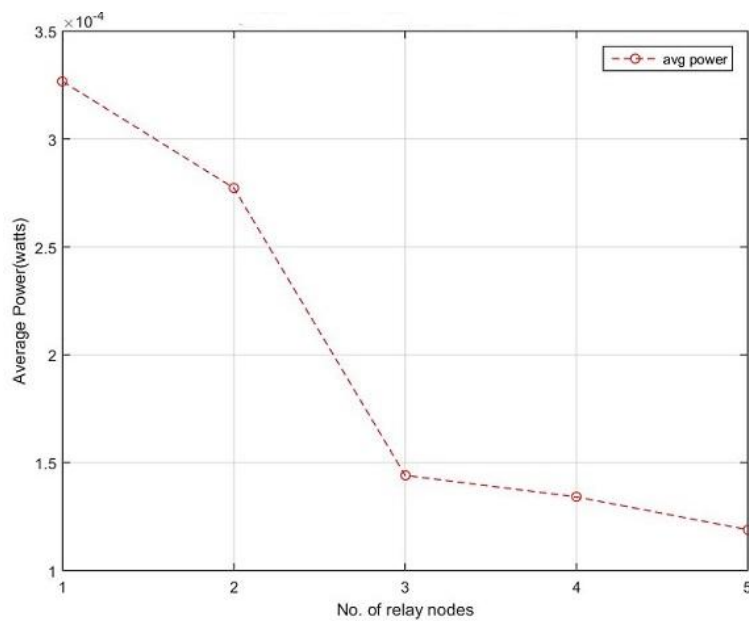


Figure 4.5 Average power.

b. Relay nodes in coalition

The Shapley value taking into consideration the order of joining of different relay nodes in the coalition provides a fair division to all the members of a coalition. Suppose there

are three relay nodes $\{1\}$, $\{2\}$, $\{3\}$. The possible coalitions that the nodes can make are $\{(1,2), 3\}$, $\{(1,3), 2\}$, $\{(2,3), 1\}$ and $\{1,2,3\}$ and the Shapley value is calculated by finding the marginal contribution of each source in sharing the bandwidth of the relay and is calculated by:

$$\phi_i(v) = \sum_{S \subseteq N \setminus i} \frac{(S)(N - S - 1)!}{N!} \{v(S \cup \{i\}) - v(S)\}, \quad (4.19)$$

Putting the value of characteristics function calculated for three relay nodes, we can calculate the Shapley value which will give each player their respective payoffs. The marginal contribution of each relay node can be calculated as:

- Marginal contribution of relay node 1

i	Order R_i	Marginal contribution $[M(R_i)]$
1	1,2,3	$v(\{1\}) - v(\emptyset)$
2	1,3,2	$v(\{1\}) - v(\emptyset)$
3	2,1,3	$v(\{1,2\}) - v(\{2\})$
4	2,3,1	$v(\{1,2,3\}) - v(\{2,3\})$
5	3,1,2	$v(\{1,3\}) - v(\{3\})$
6	3,2,1	$v(\{1,2,3\}) - v(\{2,3\})$

Table 4.1 Marginal contribution of source 1.

The Shapley value of source 1 can be written as

$$\phi_1(v) = \frac{\sum_{i=1}^6 M(R_i)}{6}$$

- Marginal contribution of relay node 2 can be written as

I	Order R_i	Marginal contribution [$M(R_i)$]
1	1,2,3	$v(\{1,2\}) - v(\{1\})$
2	1,3,2	$v(\{1,2,3\}) - v(\{1,3\})$
3	2,1,3	$v(\{2\}) - v(\{\emptyset\})$
4	2,3,1	$v(\{2\}) - v(\{\emptyset\})$
5	3,1,2	$v(\{1,2,3\}) - v(\{1,3\})$
6	3,2,1	$v(\{2,3\}) - v(\{3\})$

Table 4.2 Marginal contribution of source 2.

The Shapley value of relay node 2 can be described as

$$\phi_2(v) = \frac{\sum_{i=1}^6 M(R_i)}{6}$$

- Marginal contribution of relay node 3 can be written as

i	Order R_i	Marginal contribution [$M(R_i)$]
1	1,2,3	$v(\{1,2,3\}) - v(\{1,2\})$
2	1,3,2	$v(\{1,3\}) - v(\{1\})$
3	2,1,3	$v(\{1,2,3\}) - v(\{1,2\})$
4	2,3,1	$v(\{2,3\}) - v(\{2\})$
5	3,1,2	$v(\{3\}) - v(\{\emptyset\})$
6	3,2,1	$v(\{3\}) - v(\{\emptyset\})$

Table 4.3: Marginal contribution of source 3.

The Shapley value of relay node 3 can given as

$$\phi_3(v) = \frac{\sum_{i=1}^6 M(R_i)}{6}$$

Table 4.4 shows that the relay nodes when act individually ended up gaining lower payoff, while joining a coalition improve their payoff to a significant extent. Thus the payoffs act as incentives to the relay nodes to be there in the coalition. As it is evident from the table, when the coalition contains all the three nodes the

get higher pay off when compared to their individual cases. When only one relay node {1} or {2} or {3} act alone they get lower payoffs $(-11.6, -8.84, -3.85) \times 10^6$ respectively. But working in coalition helps them to fetch better payoffs.

COALITIONS	$\phi_1 \times 10^6$	$\phi_2 \times 10^6$	$\phi_3 \times 10^6$
{1} {2} {3}	-11.6	-8.84	-3.85
{1,2} {3}	-6.61	-4.29	-3.85
{1,3} {2}	-9.08	-8.84	-1.77
{2,3} {1}	-11.6	-7.69	-2.71
{1,2,3}	-5.41	-4.60	-1.59

Table 4.4 Payoff of relay nodes for different coalitions.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

This thesis evaluates the coalition of relay nodes in a cooperative diversity model in order to improve the power efficiency and to do efficient resource allocation of radio services. The improvement in the performance has been obtained by forming the different coalitions of intermediate nodes in order to help the sender in communication system employing cooperation and game theory. In case of wireless systems, the broadcast nature of medium permits the use of cooperative diversity wireless communication to achieve a high signal to noise ratio (SNR) at the output. In order to achieve the reduction in power required to transmit a message signal to the final reception point, the source node can use antenna of neighbouring relay nodes to transmit its data. Thus it enables the system to act like a MIMO system called virtual MIMO system. Without actual deploy of multiple antenna, the user can enjoy the benefits of diversity through cooperative communication. The following conclusion can be drawn from respective chapters of the thesis.

In chapter 3, the cooperative communication is discussed and the different combining techniques are studied in order to achieve maximum signal to noise. It was observed from the graph that by using the cooperative model the bit error rate of the signal was improved. The bit error rate of the signal and the SNR also depends on combining technique used at the destination; it was observed that (MRC) has come out to be the best combining technique. Thus signal received at destination has improved SNR and better bit error rate (BER) on using cooperative diversity. Also allocation of radio resources in cooperative model through game theory was analyzed.

Game theory provides an easy way for making a decision where all the source and relay nodes acting as a player, compete with one another for limited radio resources, for example power, bandwidth etc. It has been shown that the Stackleberg game helps to improve the utility of source as well as relay nodes. The follower follows the leader strategy to ask for the prices for relaying of power to deliver the data at the destination.

Chapter 4, proves the reduction in power when the relay nodes relay the data forming different coalitions. The concept of Shapley value theorem is used to distribute the pay offs to the relay nodes in an efficient and fair manner. The characteristic function was designed for power allocation to the sources which depends on target SNR value of the channel. When the source node is unable to achieve trustworthy throughput with the help of only a relay node,

some relay nodes get incentive to work in coalition which eventually lead to the reduction in transmission power of relay nodes taking participation in coalition. From the graphs, it has been observed that the proposed algorithm has practical importance, specially, for the networks whose radio resources are power constrained.

It can thus be concluded that the cooperative communication not only reduce fading but also enhances the throughput as compared to direct transmission by proper resource allocation. Furthermore Shapley value based resource allocation has proved to be fair and efficient division of payoffs. Cooperative communication employing game theory implemented this way has proved to enhance transmission reliability by improving the signal strength at the receiver. Thus the increase in link performance, better coverage area has made cooperative communication an interesting area for further research. The on-going research shows importance of cooperative diversity in future wireless communication standards. The future work mainly focuses on protocol design which is compatible with 3G, 4G, 5G systems which supports high data rate and need to be analyzed both in network simulation and theoretically.

REFERENCES

- [1] Proakis JG (2001). *Digital Communications*, 4th edition. McGraw-Hill.
- [2] Rappaport TS (1996). *Wireless Communications: Principles and Practice*. Upper Saddle River, NJ: Prentice-Hall.
- [3] Sklar B (1997). Rayleigh Fading Channels in Mobile Digital Communication Systems I.Characterization, *IEEE Commun. Mag.*, 35(7), 90–100.
- [4] Hunter TE and Nosratinia A (2002). Cooperation diversity through coding, in *IEEE International Symposium on Information Theory - Proceedings*, 220.
- [5] Laneman JN, Tse DNC and Wornell GW (2004). Cooperative diversity in wireless networks: Efficient protocols and outage behaviour, *IEEE Transactions on Information Theory*, 50(12), 3062-3080.
- [6] Ikki SS and Aissa S (2012). Performance analysis of two-way amplify-and-forward relaying in the presence of co-channel interferences, *IEEE Trans. Commun.*, 60(4), 933-939.
- [7] Sendonaris A, Erkip E and Aazhang B (2003). User cooperation diversity. Part I. System description, *Communications, IEEE Transactions on*, 51(11), 1927-1938.
- [8] Mahmood A (2010). Cooperative diversity in wireless networks, *Journal of Engineering xScience and Technology Review*, 3(1), 184-187.
- [9] Bletsas A, Shin H and Win WZ (2007). Cooperative communications with outageoptimal opportunistic relaying, *Wireless Communications, IEEE Transactions on*, 6(9), 3450-3460.
- [10] Liang X *et al.* (2013). Cooperative communications with relay selection for wireless networks: design issues and applications, *Wireless Communications and Mobile Computing*, 13(8), 745-759.
- [11] Bletsas A *et al.* (2006). A simple cooperative diversity method based on network path selection,” *Selected Areas in Communications, IEEE Journal on*, 24(3) 659-672.
- [12] Bletsas A, Shin H and Win MZ (2007). Cooperative communications with outage optimal opportunistic relaying, *Wireless Communications, IEEE Transactions on*, 6(9), 3450-3460, 2007

- [13] Lin Y, Song JH and Wong VWS (2009). Cooperative protocols design for wireless ad-hoc networks with multi-hop routing, *Mobile Networks and Applications*, 14(2),143-153.
- [14] Hunter TE and Nosratinia A (2004). Distributed protocols for user cooperation in multi-user wireless networks, *Global Telecommunications Conference, GLOBECOM '04. IEEE* [Dallas, USA: 2004], pp. 378.
- [15] Jakllari G *et al.* (2007). A cross-layer framework for exploiting virtual MISO links in mobile ad hoc networks, *Mobile Computing, IEEE Transactions on*, 6(6), 579-594.
- [16] Wang B, Han Z and Liu KJ (2009). Distributed relay selection and power control for multiuser cooperative communication networks using stackelberg game, *Mobile Computing, IEEE Transactions on*, 8(7), 975-990.
- [17] Shah A, *et al.* (2012). An Overview of Game Theory and its Applications in Communication Networks, *international journal of multidisciplinary sciences and engineering*, 3(4).
- [18] MacKenzie AB and DaSilva LA (2011). Game Theory for Wireless Engineers, Morgan & Claypool, 2006, 86-90.
- [19] Wu D and Cai Y (2010). Power Allocation in Cooperative Communication System Based on Coalitional Game, *International Conference on Wireless Communications Networking and Mobile Computing (WiCOM)*, [6th: Chengdu: 2010], 1-5.
- [20] Roth, A. E. (1988). *The Shapley value: essays in honor of Lloyd S. Shapley*. Cambridge University Press.
- [21] Kang MS, Jung BC and Sung DK (2008). Effect of cooperative and selection relaying schemes on multiuser diversity in downlink cellular systems with relays, *Communications and Networks, Journal of*, 10(2), 175-185.
- [22] Xitirnin Deng and AHaimovich AM (2005). Power allocation for cooperative relaying in wireless networks, in *IEEE Communications Letters*, 9(11), 994-996.
- [23] Laneman JN, Tse DNC and Wornell GW (2004). Cooperative diversity in wireless networks: Efficient protocols and outage behavior, *IEEE Transactions on Information Theory*, 50(12), 3062-3080.

- [24] Ibrahim AS, *et al.* (2005). Cooperative communications with relay-selection: when to cooperate and whom to cooperate with?, *Wireless Communications, IEEE Transactions on*, 7(7), 2814-2827.
- [25] Niyato D and Hossain E (2008). Market-Equilibrium, Competitive, and Cooperative Pricing for Spectrum Sharing in Cognitive Radio Networks: Analysis and Comparison, in *IEEE Transactions on Wireless Communications*, 7(11), 4273-4283.
- [26] Ikki SS and Ahmed MH (2008). On the performance of cooperative-diversity networks with the Nth best-relay selection scheme, *Communications, IEEE Transactions on*, 58(11), 3062-3069.
- [27] Tan CK, Sim ML and Chuah TC (2010). Fair power control for wireless ad hoc networks using game theory with pricing scheme, in *IET Communications*, 4(3), 322-333.
- [28] Chau YA and MHarbawi MA (2011). Simple switch-based relay selection for amplify-and-forward cooperative diversity on rayleigh fading channels, in *2011 IEEE International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)* [15th: Toronto, Canada: 2011]
- [29] Wang B, Han Z and Liu KJ (2012). Distributed relay selection and power control for multiuser cooperative communication networks using stackelberg game, *Mobile Computing, IEEE Transactions on*, 8(7), 975-990.
- [30] Mathur S, Sankar L and Mandayam NB (2008). Coalitions in Cooperative Wireless Networks," in *IEEE Journal on Selected Areas in Communications*, 26(7), 1104-1115.
- [31] Gharehshiran ON and Krishnamurthy V (2009). Dynamic coalition formation for efficient sleep time allocation in wireless sensor networks using cooperative game theory, *International Conference on Information Fusion* [12th: Seattle, WA: 2009].
- [32] Zolezzi JM and Rudnick H (2002). Transmission cost allocation by cooperative games and coalition formation, in *IEEE Transactions on Power Systems*, 17(4), 1008-1015.
- [33] Khayatian H, Saadat R and Mirjalily G (2010). Distributed power allocation based on coalitional and noncooperative games for wireless networks, *International Symposium on Telecommunications* [5th: Tehran, Iran : 2010].
- [34] Wu D and Cai Y (2011). A Cooperative Communication Scheme Based on Dynamic Coalition Formation Game in Clustered Wireless Sensor Networks, *2011 IEEE Global Telecommunications Conference - GLOBECOM 2011* [Houston, TX, USA: 2011].

- [35] Dongming Su *et al.* (2010). A relay selection scheme in cooperative communication based on the coalitional game, *International Conference on Computer and Automation Engineering (ICCAE)* [2nd: Singapore: 2010].
- [36] Bahbahani MS, Baidas MW and Alsusa E (2015). A Distributed Political Coalition Formation Framework for Multi-Relay Selection in Cooperative Wireless Networks, *IEEE Transactions on Wireless Communications*, 14(12), 6869-6882.
- [37] Mokdad F *et al.* (2015). Determination of an optimal feature selection method based on maximum Shapley value, *International Conference on Intelligent Systems Design and Applications (ISDA)* [15th: Marrakech, morocco: 2015].

ORIGINALITY REPORT

%20
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INTERNET SOURCES

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PUBLICATIONS

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STUDENT PAPERS

PRIMARY SOURCES

1 www2.egr.uh.edu **%4**
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2 www.ijmse.org **%2**
Internet Source

3 Dan Wu. "Power Allocation in Cooperative Communication System Based on Coalitional Game", 2010 International Conference on Computational Intelligence and Software Engineering, 09/2010 **%1**
Publication

4 Beibei Wang. "Distributed Relay Selection and Power Control for Multiuser Cooperative Communication Networks Using Stackelberg Game", IEEE Transactions on Mobile Computing, 2009 **%1**
Publication

5 pdfs.semanticscholar.org **%1**
Internet Source

6 vega.c.oka-pu.ac.jp **%1**
Internet Source

7 www.cspl.umd.edu

8 resume.walid-saad.com
Internet Source

9 Submitted to Taylor's Education Group
Student Paper

10 Ren, Zhi, Shuang Peng, Hong Jiang Lei, and Ji Bi Li. "Game Theory-Based Routing Algorithms for Wireless Multi-Hop Networks", *Advanced Materials Research*, 2013.
Publication

11 Zolezzi, Juan M. Rudnick, Hugh. "Transmission cost allocation by cooperative games and coalition formation.(Abstract)", *IEEE Transactions on Power Systems*, Nov 2002 Issue
Publication

12 Yang, Dejun, Xi Fang, and Guoliang Xue. "Game theory in cooperative communications", *IEEE Wireless Communications*, 2012.
Publication

13 terpconnect.umd.edu
Internet Source

14 winlab.rutgers.edu
Internet Source

15 Bahbahani, Mohammed, Mohammed Baidas,

and Emad Alsusa. "A Distributed Political Coalition Formation Framework for Multi-Relay Selection in Cooperative Wireless Networks", IEEE Transactions on Wireless Communications, 2015.

Publication

<% 1

16

research.ijcaonline.org

Internet Source

<% 1

17

scholarworks.uaeu.ac.ae

Internet Source

<% 1

18

www.mdpi.com

Internet Source

<% 1

19

Mokdad, Fatiha, Djamel Bouchaffra, Nabil Zerrouki, and Azzedine Touazi.

"Determination of an optimal feature selection method based on maximum Shapley value", 2015 15th International Conference on Intelligent Systems Design and Applications (ISDA), 2015.

Publication

<% 1

20

dspace.lboro.ac.uk

Internet Source

<% 1

21

Altubaishi, Essam Saleh, and Xuemin Shen. "Efficient decode-and-forward relaying scheme for wireless communication systems", 2012 25th IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), 2012.

Publication

<% 1

22 Tony Q. S. Quek. "Robust Wireless Relay Networks: Slow Power Allocation With Guaranteed QoS", IEEE Journal of Selected Topics in Signal Processing, 12/2007 <% 1

Publication

23 Dan Wu. "A Cooperative Communication Scheme Based on Dynamic Coalition Formation Game in Clustered Wireless Sensor Networks", 2011 IEEE Global Telecommunications Conference - GLOBECOM 2011, 12/2011 <% 1

Publication

24 ieeexplore.ieee.org <% 1

Internet Source

25 Khayatian, H., R. saadat, and J. Abouei. "Coalition-based Approaches for Joint Power Control and Relay Selection in Cooperative Networks", IEEE Transactions on Vehicular Technology, 2012. <% 1

Publication

26 Submitted to University of Aberdeen <% 1

Student Paper

27 Kovalchuk, Yevgeniya, and Victor Callaghan. "A Self-Organizing System for Online Maintenance of a Living Organism", 2010 Sixth International Conference on Intelligent Environments, 2010. <% 1

Publication

28	hal.univ-nantes.fr Internet Source	<% 1
29	www.vodafone-chair.com Internet Source	<% 1
30	fedetd.mis.nsysu.edu.tw Internet Source	<% 1
31	etrij.etri.re.kr Internet Source	<% 1
32	Ni, Saifeng, Sihai Zhang, Wuyang Zhou, and Bin Xia. "Relay Aided Lifetime Prolongation for User Equipments in Hotspots", 2011 IEEE Vehicular Technology Conference (VTC Fall), 2011. Publication	<% 1
33	www.themistoklis.org Internet Source	<% 1
34	scholar.lib.vt.edu Internet Source	<% 1
35	Saad, Walid, Zhu Han, Merouane Debbah, Are Hjørungnes, and Tamer Basar. "Coalitional game theory for communication networks", IEEE Signal Processing Magazine, 2009. Publication	<% 1
36	www.academypublisher.com Internet Source	<% 1

37	espace.curtin.edu.au Internet Source	<% 1
38	cdn.intechopen.com Internet Source	<% 1
39	Power Indices and Coalition Formation, 2001. Publication	<% 1
40	www.ict-optimix.eu Internet Source	<% 1
41	K. J. Ray Liu. "SPC12-5: Relay Selection in Multi-Node Cooperative Communications: When to Cooperate and Whom to Cooperate with?", IEEE Globecom 2006, 11/2006 Publication	<% 1
42	Zheng, Zijie, Tianyu Wang, Lingyang Song, and Zhu Han. "Efficient resource optimization for heterogeneous smart-building networks", 2014 IEEE International Conference on Communications (ICC), 2014. Publication	<% 1
43	open.library.ubc.ca Internet Source	<% 1
44	www.actapress.com Internet Source	<% 1
45	Submitted to University of Newcastle upon Tyne Student Paper	<% 1

Submitted to University of Bristol

47

Shah, Ibrar Ali(AI-Raweshidy, H). "Channel assignment and routing in cooperative and competitive wireless mesh networks", Brunel University School of Engineering and Design PhD Theses, 2012.

Publication

<% 1

48

archive.org

Internet Source

<% 1

49

Rohit Bhakar. "Cost allocation of DG embedded distribution system by game theoretic models", 2009 IEEE Power & Energy Society General Meeting, 07/2009

Publication

<% 1

50

Youngwook Ko. "Power allocation strategies across N orthogonal channels for single-relay networks at both source and relay", 2010 17th International Conference on Telecommunications, 04/2010

Publication

<% 1

51

documents.mx

Internet Source

<% 1

52

Zhang, Rongqing, Lingyang Song, Zhu Han, and Bingli Jiao. "Relay and Jammer Cooperation as a Coalitional Game", Wireless Networks and Mobile Communications, 2013.

Publication

<% 1

53

prof.mt.tama.hosei.ac.jp

Internet Source

<% 1

54

omg.simon.rochester.edu

Internet Source

<% 1

55

Hossain, . "Game Theoretic Approaches for Resource Management in Multi-Tier Networks", Radio Resource Management in Multi-Tier Cellular Wireless Networks, 2013.

Publication

<% 1

56

Xuemin Sherman Shen. "A game-theoretic approach for relay assignment over distributed wireless networks : A game-theoretic approach for relay assignment", Wireless Communications and Mobile Computing, 12/2011

Publication

<% 1

57

Myung, Jungho, Hoojin Lee, and Joonhyuk Kang. "Performance Analysis of a Dual-Hop Relay With STBC-CIOD over Rayleigh Fading Channels", IEEE Transactions on Vehicular Technology, 2013.

Publication

<% 1

58

Huan Sun. "Power Allocation Algorithm in Amplify-and-Forward Relay Networks", 2008 4th International Conference on Wireless Communications Networking and Mobile Computing, 10/2008

Publication

<% 1

- | | | |
|----|---|------|
| 59 | ietict.org
Internet Source | <% 1 |
| 60 | www.ele.uri.edu
Internet Source | <% 1 |
| 61 | Jindan Yang. "A novel relay selection scheme in multi-antenna cooperative systems", 2010 IEEE International Conference on Software Engineering and Service Sciences, 07/2010
Publication | <% 1 |
| 62 | bujict.bimcs.edu.pk
Internet Source | <% 1 |
| 63 | Avram, Iancu, and Marc Moeneclaey. "Quantize and forward cooperative communication: Joint channel and frequency offset estimation", 2012 IEEE 23rd International Symposium on Personal Indoor and Mobile Radio Communications - (PIMRC), 2012.
Publication | <% 1 |
| 64 | Y.-W. Peter Hong. "Networking and Cross-Layer Issues in Cooperative Networks", Cooperative Communications and Networking, 2010
Publication | <% 1 |
| 65 | asu.pure.elsevier.com
Internet Source | <% 1 |
| 66 | bura.brunel.ac.uk
Internet Source | <% 1 |

67 Rahima, Sayeb, and Nouredine Hamdi. "Generalized beamforming (GBF) for MIMO amplify-and-forward relaying", 2012 8th International Wireless Communications and Mobile Computing Conference (IWCMC), 2012.
Publication <% 1

68 mro.massey.ac.nz
Internet Source <% 1

69 Chin-Liang Wang. "A Geographic-Based Approach to Relay Selection for Wireless Ad Hoc Relay Networks", VTC Spring 2009 - IEEE 69th Vehicular Technology Conference, 04/2009
Publication <% 1

70 waset.org
Internet Source <% 1

71 www.jocm.us
Internet Source <% 1

72 Chao Zhang. "Power-efficient cooperative relaying with node location information in wireless sensor networks", 2008 International Conference on Intelligent Sensors Sensor Networks and Information Processing, 12/2008
Publication <% 1

73 Setareh Maghsudi. "A hybrid centralized-decentralized resource allocation scheme for <% 1

two-hop transmission", 2011 8th International Symposium on Wireless Communication Systems, 11/2011

Publication

74

Hui Hui. "Distributed Power Allocation Schemes for Amplify-and-Forward Networks", 2009 IEEE Wireless Communications and Networking Conference, 04/2009

Publication

<% 1

75

Somchai Jitapunkul. "Adaptive protocol for differentially modulated cooperative communications", TENCON 2007 - 2007 IEEE Region 10 Conference, 10/2007

Publication

<% 1

76

Kim, Kyeong Jin, Theodoros A. Tsiftsis, and H. Vincent Poor. "Power Allocation in Cyclic Prefixed Single-Carrier Relaying Systems", IEEE Transactions on Wireless Communications, 2011.

Publication

<% 1

77

www.cnsr.ictas.vt.edu

Internet Source

<% 1

78

Swasdio, Wanakorn, Chaiyod Pirak, Somchai Jitapunkul, and Gerd Ascheid. "Alamouti-coded decode-and-forward protocol with optimum relay selection and power allocation for cooperative communications", EURASIP Journal on Wireless Communications and

<% 1

Networking, 2014.

Publication

79

Edith Elkind. "On the computational complexity of weighted voting games", *Annals of Mathematics and Artificial Intelligence*, 10/20/2009

Publication

<% 1

80

www.slideshare.net

Internet Source

<% 1

81

www.kellogg.northwestern.edu

Internet Source

<% 1

82

spectrum.library.concordia.ca

Internet Source

<% 1

83

Guo, Songtao, Yang Yang, and Yuanyuan Yang. "Wireless energy harvesting and information processing in cooperative wireless sensor networks", 2015 IEEE International Conference on Communications (ICC), 2015.

Publication

<% 1

84

www.isid.ac.in

Internet Source

<% 1

85

Fujimoto, K.. "Axiomatic characterizations of probabilistic and cardinal-probabilistic interaction indices", *Games and Economic Behavior*, 200604

Publication

<% 1

Wang, Jun-Bo, Jin-Yuan Wang, Xiaoyu Song,

86

Zhe Cao, and Ming Chen. "Distributed SNR-Based Power Allocation in Wireless Parallel Amplify-and-Forward Relay Transmissions Using Cournot Game", Wireless Personal Communications, 2013.

Publication

<% 1

87

Yan Lindsay Sun. "Self-Learning Cooperative Transmission - Coping with Unreliability Due to Mobility, Channel Estimation Errors, and Untrustworthy Nodes", IEEE GLOBECOM 2007-2007 IEEE Global Telecommunications Conference, 11/2007

Publication

<% 1

88

web.mit.edu

Internet Source

<% 1

89

Daeho Kang, Seungbeom Jeong, Changhee Joo, Saewoong Bahk. "A Reliable and Scalable Broadcast Protocol for Wireless Multi-Hop Networks Using Subcarrier-Level Tone-Signals", 2016 13th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), 2016

Publication

<% 1

90

eeweb.poly.edu

Internet Source

<% 1

91

Farshad Lahouti. "Cooperative Communication Using Distributed Differential Space-Time Codes", 2006 International

<% 1

Conference on Wireless Communications Networking and Mobile Computing, 09/2006

Publication

92

eprints.whiterose.ac.uk

Internet Source

<% 1

93

doras.dcu.ie

Internet Source

<% 1

94

F. Pantisano. "Cooperative Interference Alignment in Femtocell Networks", 2011 IEEE Global Telecommunications Conference - GLOBECOM 2011, 12/2011

Publication

<% 1

95

www.math.hcmuns.edu.vn

Internet Source

<% 1

96

eprints.mdx.ac.uk

Internet Source

<% 1

97

Kun Xie, , Ling Wang, XueLi Liu, Jigang Wen, and Jiannong Cao. "Cooperative routing with relay assignment in multi-radio multi-hop wireless networks", 2014 IEEE 22nd International Symposium of Quality of Service (IWQoS), 2014.

Publication

<% 1

98

www.utdallas.edu

Internet Source

<% 1

99

Xu, Hongli, Liusheng Huang, Chunming Qiao, Yindong Zhang, and Quan Sun. "Bandwidth-

<% 1

Power Aware Cooperative Multipath Routing for Wireless Multimedia Sensor Networks", IEEE Transactions on Wireless Communications, 2012.

Publication

100

Bansal, A., M. Bhatnagar, A. Hjørungnes, and Z. Han. "Low Complexity Decoding in DF MIMO Relaying System", IEEE Transactions on Vehicular Technology, 2012.

<% 1

Publication

101

Khan, I. U., C. E. Tan, and A. S. Khan. "The Enhanced Amplify-and-Forward Three Time Slots TDMA-Based Protocol Using Inter-Relay Communication Over Rician Fading Channel", International Review on Computers and Software (IRECOS), 2014.

<% 1

Publication

102

Suwen Wu. "A statistic channel information-based relay selection scheme in cooperative networks", 2009 Global Mobile Congress, 10/2009

<% 1

Publication

103

Lim, Sungmook, and Kyunbyoung Ko. "Performance evaluation of HDAF relaying systems for pilot and data symbol burst transmission over quasi-static Rayleigh fading channels : HDAF RELAYING SYSTEMS FOR PILOT AND DATA SYMBOL BURST TRANSMISSION", International

<% 1

-
- 104 www.commsp.ee.ic.ac.uk <% 1
Internet Source
-
- 105 Zhengyang Qu. "A Distributed Relay Selection Algorithm Using Game on Real-Time Testbed", 2011 IEEE Global Telecommunications Conference - GLOBECOM 2011, 12/2011 <% 1
Publication
-
- 106 Daniel Grosu. "Divisible Load Scheduling: An Approach Using Coalitional Games", Sixth International Symposium on Parallel and Distributed Computing (ISPDC 07), 07/2007 <% 1
Publication
-
- 107 Marchenko, Nikolaj, and Christian Bettstetter. "Cooperative Multicast with Low-Cost Radios", 2010 IEEE 72nd Vehicular Technology Conference - Fall, 2010. <% 1
Publication
-
- 108 Bai, Zhiquan, Rongkai Li, Haixia Zhang, and Kyungsup Kwak. "Relay power allocation schemes for multiuser cooperative communication", 2011 IEEE Wireless Communications and Networking Conference, 2011. <% 1
Publication
-
- 109 A. Hjørungnes. "A Distributed Merge and Split Algorithm for Fair Cooperation in Wireless <% 1

Networks", ICC Workshops - 2008 IEEE
International Conference on Communications
Workshops, 05/2008

Publication

- 110 Mahdavi Lenji, Atefe, and Ali Shahzadi. "$\leq\%$ 1
"Power Allocation in Cooperative
Communication System Based on
Stackelberg Game", Wireless Personal
Communications, 2015.

Publication

- 111 Suhas Mathur. "Coalitions in Cooperative
Wireless Networks", IEEE Journal on
Selected Areas in Communications, 09/2008

Publication

- 112 Ahmed Ibrahim. "Cooperative
communications with relay-selection: when to
cooperate and whom to cooperate with?",
IEEE Transactions on Wireless
Communications, 07/2008

Publication

- 113 Balaji, V., and Chittaranjan Hota. "Efficient
cooperative spectrum sensing in Cognitive
Radio using coalitional game model", 2014
International Conference on Contemporary
Computing and Informatics (IC3I), 2014.

Publication

- 114 Hazra, R., and A. Tyagi. "Performance
Analysis of Impulse-Radio Ultra-Wideband
Energy Detector system using cooperative

dual-hop Amplify and Forward strategy :
PERFORMANCE ANALYSIS", International
Journal of Communication Systems, 2015.

Publication

115

An, Ruijian, Yu Gu, and Yusheng Ji. "Relay
assignment over distributed wireless
networks: A game theoretic approach", 2012
IEEE Globecom Workshops, 2012.

Publication

<% 1

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