

**“GAME THEORETICAL ANALYSIS OF RESOURCE ALLOCATION IN
COOPERATIVE COMMUNICATION”**

*Thesis submitted towards the partial fulfillment of requirement
for the award of degree of*

Master of Engineering

In

Wireless Communication

Submitted by:

Sunandini Dadwal

Roll No: 801463028

Under the guidance of:

Dr. Sanjay Sharma

Professor and Head, ECED

Dr. Ravi Kumar

(Co-Guide)

Assistant Professor, ECED



ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

(Established under the section 3 of UGC Act, 1956)PATIALA – 147004 (PUNJAB)

DECLARATION

I hereby declare that the work, which is being presented in the dissertation, entitled as “**Game Theoretical Analysis of Resource Allocation in Cooperative Communication**”, submitted by me in partial fulfillment for the award of degree of Master of Engineering in Wireless Communication submitted at Electronics and Communication Engineering Department, Thapar University, Patiala, is an authentic record of my own work carried out under esteemed guidance of **Dr. Sanjay Sharma** (Professor and Head), Electronics and Communication Engineering Department and co-guide **Dr. Ravi Kumar** (Assistant Professor), Electronics and Communication Engineering Department and refers the work of other researchers is duly listed in reference section.

The matter presented in the dissertation has not been submitted in any other university/institute for the award of degree.


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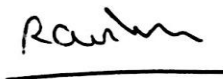

(Sunandini Dadwal)

Roll No. 801463028

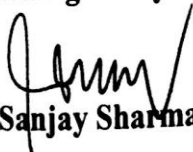
It is certified that the above statement made by the student is correct to the best of my knowledge and belief.


Date: 13/7/16


(Dr. Sanjay Sharma)
Professor and Head
ECED, Thapar University


(Dr. Ravi Kumar)
Assistant Professor
ECED, Thapar University

Countersigned by:


(Dr. Sanjay Sharma)
Professor and Head (ECED)
Thapar University, Patiala


(Dr. S.S. Bhatia)
Dean of Academic Affairs
Thapar University, Patiala

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Sunandini Dadwal

801463028

ABSTRACT

In wireless communication the electromagnetic waves propagate through multiple paths towards the destination which in turn induces variation of strength of the signal received at destination. These rapid fluctuations in signal strength are called fading which can be combat by implementing diversity in space, time, and frequency in wireless communication. Spatial diversity requires multiple antennas, placed at some specified distance from one another, to transmit same signal to the common destination. The multiple antenna deployment for small size, hand held devices is not possible which leads to introduction of cooperative diversity.

Cooperative diversity is a diversity technique in which nodes relay signals for each other. The node uses other nodes to transmit its signal to destination. Without deploying actual multiple antenna the nodes form a virtual multiple input multiple output system which we be used to enjoy the benefits of diversity and combat fading effects. The basic principle of cooperative communication is based on broadcast nature of the wireless communication. Whenever a node transmits, it broadcast its signal in all direction which not only reaches the destination but is also overheard by the nearby nodes which act as a relay for the source.

Cooperative communication helps in combatting fading by reducing the dependency of wireless system on the quality of particular path. It provides transmission reliability and signal strength improvement. It increases the throughput as compared to direct transmission. It increases the link performance, can help in overcoming the shadow effect and thus provide better coverage area.

The main two objective of wireless communication is to find best relay out of all the relay available and proper resource allocation among the nodes. These decisions can be made by using the decision making criteria called game theory. Game theory is a decision making theory which considers nodes as a player which compete with one another to win the game. The game uses utility function as a factor to decide which player wins the game. The player follow strategy to attain maximum or optimal utility value. The game theory can be used to make decision using Shapley value. Shapley value is the easiest, less complex technique to make decision in game theory. The

Shapley formulae is the weighted sum of marginal contribution of each player in a coalition. The value obtained by the player decides the resource allocation in cooperative game model.

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LIST OF ACRONYMS

1. Amplify and forward protocol – AAF
2. Decode and forward protocol – DAF
3. Compress and forward protocol-CAF
4. Signal to noise ration- SNR
5. Multiple input multiple output-MIMO
6. Second generation-2G
7. Third generation-3G
8. Fourth generation-4G
9. Line of sight-LOS
10. Additive white Gaussian noise- AWGN
11. Automatic repeat request-ARQ
12. Equal ratio combining- ERC
13. Fixed ratio combining-FRC
14. Maximal ratio combining-MRC
15. Bit error rate- BER
16. Symbol error rate-SER
17. Signal to noise ratio combining-SNRC

1.1 OVERVIEW

Wireless communication has witnessed an enormous growth in the past few years. The number of subscribers has increased from millions to billions in last few decades. Technology advancement has consequential effects on data requirement per subscriber. This growth has led to the development of successor of global system for mobile communication (2G), in the form of universal mobile telecommunication system (3G) and Long Term Evolution (4G), which provide enhanced data rate. Since more number of devices, with higher data rate are involved in communication in wireless medium the effect of impairments needs to be addressed. Therefore we require ingenious methodologies and techniques to combat effect of environmental impairments on wireless communication. These technologies prevent the communication system from huge losses by ensuring high level system performance.

1.2 FADING

One of the most appalling forms of interference afflicting the wireless communication is multipath propagation of signal. Multipath propagation leads to variation in received signal strength at the receiver. As every multipath propagated signal has different phase and amplitude, they add up constructively and destructively to give the resultant faded signal. There are two types of fading viz. small scale fading and large scale fading.

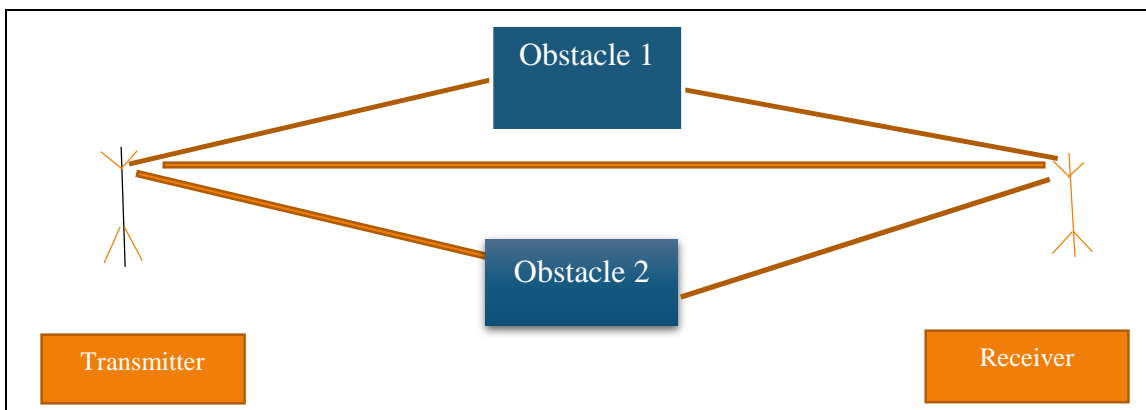


Figure 1.1: Multipath propagation.

a) **Large scale fading:** The attenuation in signal received over a large distance due to multi path propagation is called large scale fading. Signals in wireless communication are affected by both large scale fading and small scale fading. Radio signals are influenced due to motion over the larger area which is called large scale fading. Path loss and shadowing are examples of large scale fading. These fading effects are frequency independent and change gradually over time that is why they are called as large scale fading .Cell planning and routing algorithm are used to combat effects of large scale fading in cellular network and ad-hoc networks respectively.

b) **Small scale fading:** Small scale fading is effect on radio signal over small distance in short duration of time which are frequency dependent and change rapidly. As it cannot be mitigated using cell planning and routing algorithm, it is the main limiting factor of wireless communication. Electromagnetic waves that are radiated from transmitting antenna reaches receiving antenna after striking obstacle in path. Depending on the size of the obstacle and the wavelength of signal, it is scattered, diffracted or reflected. These multipath signals travelling through different channel are superimposed constructively or destructively at the receiver.

Small scale fading manifests its effect in time varying of the channel and time spreading of the signal. Time spreading of the signal is accessed by coherence bandwidth and time varying of the signal is accessed by coherence time parameter. Main cause of small scale fading is motion of the source, motion of the obstacle in the environment, multipath propagation of signal in wireless environment. Small scale fading is further illustrated as Rician fading, if LOS (Line of Sight) exist and Rayleigh fading if it does not exist.

The data rate of received signal is directly related to strength of the signal received. Due to fading strength of signal received can drop due to destructive combining and therefore the data rate is affected. This fading effect has led to intensive research work in developing new wireless technology which can reduce fading effects. Diversity is a technique used to combat fading.

1.3 DIVERSITY

Diversity in wireless communication is technique in which redundant signal is transmitted to the receiver through an uncorrelated channel such that copy of signal travelling through different channel which might have different fading coefficient will be affected in different manner. At the receiver all the signal are combined to have average of all the signals received from different paths that is different channel. The signal travelling through one channel if suffer from deep fade then the signal travelling through other channel will not have such a severe fading effects as the probability that two signal travelling through different channel will be affected by same fading is very less. Thus combined signal at receiver side will never face deep fade.

Some common diversity techniques are:

- a) **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. Coherence time is defined as time in which signal received at destination has same channel impulse response for that time.
- b) **Space diversity:** Space diversity is a phenomenon in which same signals are sent from different antenna placed at a distance in space such the channels through which signal travels are uncorrelated. The optimum distance between the antennas depends on environmental conditions around the antenna. In mobiles multiple antenna are used to exploit spatial diversity should have minimum distance half the wavelength of carrier frequency whereas the base station antenna should have distance more than wavelength of carrier frequency as they are less surrounded by obstacles.
- c) **Frequency diversity:** Frequency diversity is a phenomenon in which same signals are send using different carrier frequency which have difference more than coherence bandwidth. The channel allow the signal to pass through with same gain and phase for a range of frequency which is called as coherence bandwidth.

- d) Polarization diversity:** In this diversity, same signal is transmitted from different antenna with different polarization. The signal with different polarization reacts differently when strike an obstacle. Thus every signal travelling different path will have different fading effects on itself.

In wireless communication fading is combat by deploying multiple antenna at transmitter or the receiver. Limitation on frequency available in wireless communication does not allow frequency diversity to be used in combating fading effects in mobile communication. Moreover the time diversity efficiency depends upon coherence time. Among all the technique spatial diversity is most widely used. For implementing spatial diversity we need more number of antennas located in space which is the limiting factor for small radio devices. Multiple number of antennas are not possible for radio devices such as mobile. The main disadvantage of multiple antenna is the high deployment cost, hardware requirement and device size limitation as these are not impractical for small size, low cost mobile devices.

Thus we come across new form of diversity called cooperative diversity. Cooperative diversity addresses this limitation by using antenna of other devices to create a virtual MIMO. Cooperative diversity is a technique by which a virtual MIMO is created by using antenna of nearby nodes.

1.4 COOPERATIVE DIVERSITY

The network performance can be improved by taking advantage of wireless propagation environment. A new class of spatial diversity called cooperative diversity is a diversity in which mobile terminals interact with one another to transmit data to destination. Cooperative diversity when implemented in wireless communication is called cooperative communication. The main motive behind cooperative communication is to improve outage probability, symbol or bit error rate. Besides these reliability improvement, cooperative diversity also improves transmission rate.

1.4.1 BASIC IDEA

In wireless networks signal is broadcast in all directions such that all the nearby node can overhear the signal transmitted by a source. This property of broadcasting in wireless

network is used in cooperative diversity. The signal sent by the source can be heard by relay which can further forward the signal to destination. Suppose we have a source S, a destination D and a relay R. When signal is transmitted from source it follows two paths: one from S to D directly, another from S to D through R. The relay R overhears the signal from source and retransmits it to D. We can observe that the transmission is carried out in two phases.

The two phases in cooperative diversity are:

- a) **Direct transmission phase:** The phase in which signal is transmitted directly to destination is direct transmission phase. During this transmission relay overhears the signal transmitted by the source. The relay follows certain protocol for the received signal.
- b) **Cooperative transmission phase:** The phase in which signal is overheard by relay in previous time slot is transmitted by relay to destination is cooperative transmission phase.

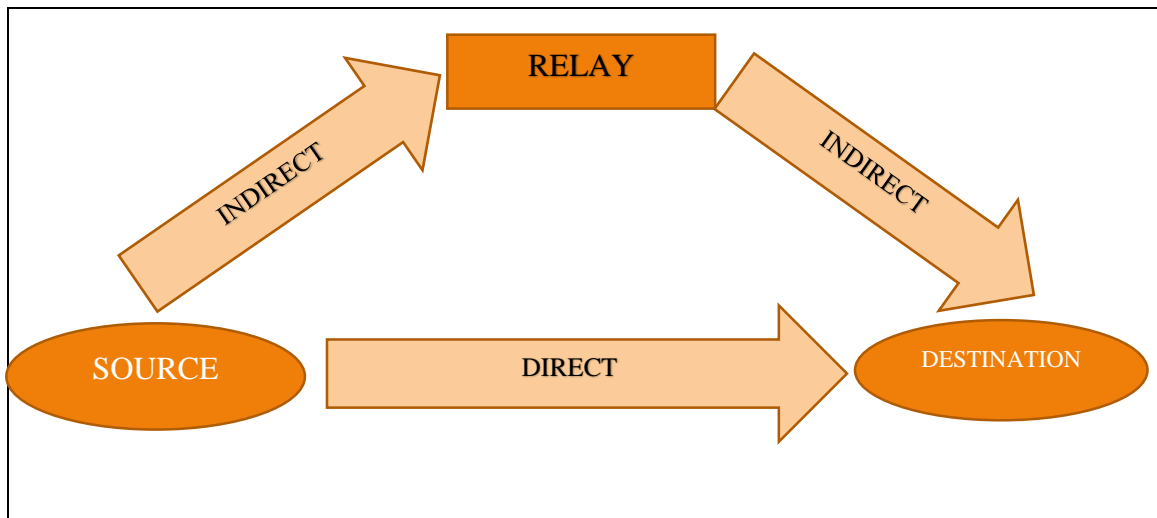


Figure 1.2: Basic model of cooperative communication.

Thus same signal reaches destination by travelling two different uncorrelated independent paths. The signals received are uncorrelated, when combined, the resultant signal will never be in deep fade. As signal travels two paths and is transmitted in two different time slots both spatial and time diversity is exploited in cooperative diversity.

1.4.2 ELEMENTS OF COOPERATIVE DIVERSITY

The basic elements 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 must know about the presence of relay. The signal when reaches relay in first time slot must reach the destination in second time slot. Thus the destination must know about the fact that after receiving signal from source it must wait for signal from relay.

- b) **Relay:** Relay over-hears signal in first time slot and retransmit it to destination after following certain protocol. The protocol followed by the relay depends on system characteristics. The basic protocol followed by relay are amplify and forward mode protocol, decode and forward protocol, compress and forward. In Amplify and forward relay act as a repeater because it only regenerates the signal that is it just amplify the signal and do not demodulate the received signal. As it only amplify the received signal it also amplify the noise, which is its disadvantage. In decode and forward relaying the received signal is first decode and then forwarded to the destination. If the relay is unable to decode no signal is send to destination. The compress and forward relaying compress signal at relay and then forward it to destination.

- c) **Destination:** Destination receives signal from both source and relay. If the signal from source is good enough it can inform relay not to forward the signal and can implement non cooperative mode. The signal received is combined using various combining technique .the techniques are maximal ratio combining, equal gain combining and fixed ratio combining.

1.5 BUILDING BLOCKS OF COOPERATIVE COMMUNICATION

Basic building block of the cooperative diversity are assigned to different layer of communication stack. In figure 1.3, organization of blocks in respective block are shown. We will address these blocks in following two section

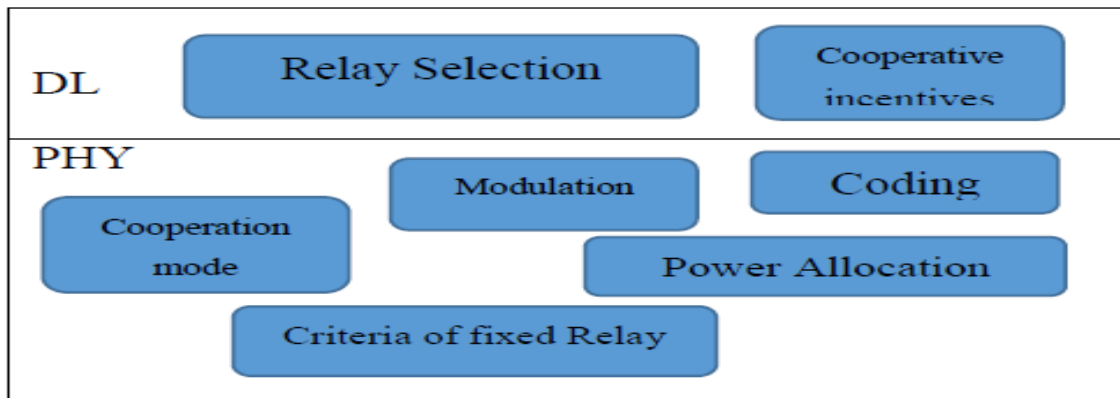


Figure 1.3: Building blocks of cooperative communication.

1.5.1 PHYSICAL LAYER FEATURE

In this section we introduce physical layer aspects of cooperative communication. We will discuss about characteristics of nodes, position of nodes, multiple relays, power allocation, coding at relays etc.

- a) **Characteristics of nodes:** Nodes in cooperative diversity, as discussed earlier, are source, destination, and relay. Source node should know that the data transmitted by it will be relayed by relay node. Relay node can use three different mode i.e. amplify and forward (AAF), decode and forward (DAF), compress and forward (CAF). AAF relay work as a repeater. It regenerate the signal and retransmit it without decoding it. If the SNR for source to relay is very low, no useful data can be transmitted to destination. In this case cooperation mode is a wastage of energy. DAF relay forward the data after decoding. If the data is not decoded properly no transmission is done. This feature make AAF more efficient than DAF as it is better to have some increase in amount of information than to have none. CAF relay transmit compressed data to the destination. Destination combine the data received from source and relay. Depending on received signal from source destination can inform source if cooperation is needed.

- b) **Relay node position:** Position of relay node determines the performance of cooperative communication. In a pure AWGN channel, relay at any position between S and D outperform the non-cooperative transmission. The optimum position of relay is near to

destination but in case of multi hop routing, optimum position is equally distanced from source and destination.

c) Multi relay network: In multi relay network, transmission energy and time need to be equalized. Suppose we have m relay for retransmission, then power need to be divided between source and relay and the rate of transmission in cooperative communication should be $[m + 1]$ times that of non-cooperative communication for fair comparison. For each relay transmission different channel is needed. Therefore, $[m + 1]$ orthogonal channel are required. Distributed beam forming is used to overcome this limitation. Phase and frequency need to be adjusted, such that the signal superimpose at the receiver and for this we need instantaneous channel state information. Also, distributed space time code can be used to encode data at the relay, so that simultaneous data transmission is possible. Network coding is also a method to increase spectral efficiency.

d) Power allocation: Power in multi relay cooperative environment is divided among the nodes. If we have m number of relay and total power is P , then power of source will be p_1 and power of relay will be $p_2 \dots p_{m+1}$. Such that

$$p_1 + p_2 + p_3 \dots \dots \dots p_{m+1} \leq P$$

e) Modulation: Hierarchical modulation uses two modulations simultaneously. Single transmission have two data stream with two modulation type. Applying this modulation to cooperative diversity means to have less robust and more robust signal. Less robust with faster modulation is used for data transmission. More robust is used for signaling and controlling. Relay uses both these signal whereas destination uses only more robust signal.

1.5.2 NETWORK LAYER FEATURE

In previous section we considered the physical layer requirements. Now we will consider the more realistic aspects such as relay selection, data flow and resource management. Relay selection is an important aspect of cooperative communication. Relay which is far

from source and destination is not useful for the network. Selecting the best relay out of m number of nodes is more efficient since in the case of failure of the best relay other node will not be beneficial anyway. Selecting one relay rather than all will provide same diversity gain as gain achieved by using all the relay. Moreover dividing power and data rate become easy when one relay is used.

Selection of the relay should be frequent enough to support cooperative communication. In static network relay selection is performed at the start up time only. In dynamic network the channel is time varying and the relay is selected more frequently i.e. at start up time and in between transmission so as to support cooperative communication.

Relay selection is carried out before direct transmission or after it. Relay selection done before direct transmission is called proactive relay selection. In this, transmission is always carried out in cooperation mode. Mostly carried out in dense network with heavy load. Reactive relay selection is selection of relay after direct transmission. Relay selection is done if direct transmission is unsuccessful. Energy consumption is more in reactive relay selection as every relay has to overhear the data transmitted by source. Outage probability minimization is the aim of best relay selection. Criteria for relay selection can depend on distance, average SNR, residual energy level, overall transmission time, spatial reusability of wireless channel.

Relay selection can be distributed or centralized. In centralized, an authority should have knowledge about the network nodes beforehand and it selects the best relay for cooperation. IEEE802.16j is the example of such relay selection. Distributed relay selection is carried out by source or the destination. Relay itself inform destination about its channel condition.

1.6 COOPERATIVE COMMUNICATION SYSTEM MODEL

The cooperative communication system model consists of source, relay and destination. The channel between source and relay, destination and relay is considered to be additive white Gaussian noise. To achieve diversity the signal reaches destination from source directly and from relay indirectly. The signal reaches destination via two independent orthogonal channel. The orthogonal signal can be achieved by time division multiplexing technique [1].

The channel is considered to have additive white Gaussian noise, path loss and Rayleigh fading. Consider thermal noise to be $Z_{s,d}[n]$ and path loss is calculated using path loss exponent that is $d_{s,d} \propto 1/R^n$, where n is the path loss exponent and fading coefficient $\sigma_{s,d}^2$ which is white Gaussian random variable. Suppose we have a symbol $S_s[n]$ which we have transmitted and at destination $Y_d[n]$ is received, where $Y_d[n]$ can be written as

$$Y_d[n] = d_{s,d} \cdot a_{s,d}[n] \cdot S_s[n] + Z_{s,d}[n] \quad (1)$$

If overall attenuation can be written as $h_{s,d}$ then equation (1) can be written as

$$Y_d[n] = h_{s,d} \cdot S_s[n] + Z_{s,d}[n] \quad (2)$$

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

$$Y_r[n] = h_{s,r} \cdot S_s[n] + Z_{s,r}[n] \quad (3)$$

Equation (2) and (3) represents the first phase where $d_{s,d}$ is the path loss factor, $a_{s,d}[n]$ is the fading coefficient and $h_{s,r}$, $h_{s,d}$ is the overall attenuation factor. The signal received at relay is retransmitted to destination.

,The data is transmitted directly from source to destination or via two antenna [2]. The probability of error in of single link transmission can be given by [2].

$$P_b = \frac{1}{2} \left(1 + \left(\sqrt{\gamma_b / (1 + \gamma_b)} \right) \right) \quad (4)$$

Where $\gamma_b = \frac{\varepsilon}{\sigma^2} E(a^2)$ is the average signal to noise ratio and $E(a^2) = a^2$

The probability of error in two sender link transmission can be given by [2].

$$P_b = \frac{1}{4} (1 - \mu)^2 \cdot (2 + \mu) \quad (5)$$

Where $\mu = \left(\sqrt{\gamma_b / (1 + \gamma_b)} \right)$

1.7 DIVERSITY PROTOCOL

The cooperative communication relay which either follows amplify and forward or decode and forward protocol. The signal received is processed according to these two protocol.

Wireless network can have a variety of less complex cooperative diversity protocols such as i fixed relaying, selection relaying, and incremental relaying. Each protocol process signal at relay. In fixed relaying, we have relays that amplify received signals which is amplify and forward protocol when relay decode, re-encode, and retransmit the signal the protocol [1] is called decode and forward protocol . Selection relaying decides its behavior to cooperate or not based on SNR between source relay and destination [1]. Incremental relaying allow cooperation only when required thus improving spectrum efficiency [1].

1.7.1 FIXED RELAYING

This type of relaying involves amplify and forward protocol and decode and forward protocol

- a) **Amplify and forward protocol:** The received signal at the relay is amplified under power constraints. The received signal $Y_r[n]$ is amplified which contain noise as well original signal part. Thus while amplifying the signal the noise is also amplified which is a disadvantage. This protocol is used when computing time for the relay is less as decode and forward will take high time. The received signal at destination can be written as $S_r[n]$

From equation (3) the power of the signal received at relay is given by

$$E[|Y_r|^2] = E[|h_{s,r}|^2] \cdot E[|S_s|^2] + E[|Z_{s,r}|^2] \quad (6)$$

As the energy of the signal $S_s(n)$ is ε , power of noise is $2\sigma_{s,r}^2$ and s is source and r denotes relay. Thus power of received signal is written as

$$E[|Y_r|^2] = |h_{s,r}|^2 \cdot \varepsilon + 2\sigma_{s,r}^2 \quad (7)$$

The received signal Y_r by relay is amplified at the relay such that transmitted power of the signal transmitted signal from relay is same as the power of signal transmitted by source. The amplification factor is given by

$$\beta = \sqrt{\left(\frac{\varepsilon}{(|h_{s,r}|^2 \cdot \varepsilon + 2\sigma_{s,r}^2)}\right)} \quad (8)$$

The signal received at destination from the relay can be written as

$$Y_{r,d}[n] = h_{r,d} \cdot S_r[n] + Z_{r,d}[n] \quad (9)$$

Where $S_r[n] = \beta(h_{s,r} \cdot S_s[n] + Z_{s,r}[n])$ is the amplified signal transmitted by relay.

The SNR of AAF can be calculated as follow

$$Y_{r,d}[n] = h_{r,d} \cdot \beta(h_{s,r} \cdot S_s[n] + Z_{s,r}[n]) + Z_{r,d}[n] \quad (10)$$

Squaring both side of the equation (8) we get

$$|Y_{r,d}[n]|^2 = |h_{r,d}|^2 \cdot \beta^2(h_{s,r} \cdot S_s[n] + Z_{s,r}[n])^2 + (Z_{r,d}[n])^2 + 2 \cdot (h_{r,d} \cdot \beta(h_{s,r} \cdot S_s[n] + Z_{s,r}[n]) \cdot Z_{r,d}[n]) \quad (11)$$

Taking mean both side we get,

$$E[|Y_{r,d}[n]|^2] = E[|h_{r,d}|^2] \cdot \beta^2 \cdot E[(h_{s,r} \cdot S_s[n] + Z_{s,r}[n])^2] + E[(Z_{r,d}[n])^2] + 2 \cdot E(h_{r,d} \cdot \beta(h_{s,r} \cdot S_s[n] + Z_{s,r}[n]) \cdot Z_{r,d}[n]) \quad (12)$$

As $E(h_{r,d} \cdot \beta(h_{s,r} \cdot S_s[n] + Z_{s,r}[n]) \cdot Z_{r,d}[n])$ is zero because we have zero mean white Gaussian noise therefore equation (10) can be written as

$$E[|Y_{r,d}[n]|^2] = E[|h_{r,d}|^2] \cdot \beta^2 \left(E[|h_{s,r}|^2] \cdot \varepsilon + E[Z_{s,r}[n]^2] \right) + E[(Z_{r,d}[n])^2] \quad (13)$$

$$E[|Y_{r,d}[n]|^2] = [|h_{r,d}|^2] \cdot \beta^2 \left((|h_{s,r}|^2) \cdot \varepsilon + 2\sigma_{s,r}^2 \right) + 2\sigma_{r,d}^2 \quad (14)$$

From equation (14) by separating signal and noise part the signal to noise ratio can be written as

$$\frac{S}{N} = \frac{|h_{r,d}(n)|^2 \cdot \beta^2 (|h_{s,r}(n)|^2) \varepsilon}{\beta^2 (2\sigma_{s,r}^2) + 2\sigma_{r,d}^2} \quad (15)$$

- b) Decode and forward protocol:** Decode and forward method is mostly used as we usually use digital modulation in wireless communication which gives enough computing power to implement decode and forward protocol. The signal received is decoded and then transmitted again to destination after re-encoding the signal [2]. The signal can be decoded completely if relay has enough computing power or it

can decode the signal symbol by symbol. The decoding option can be chosen according to complexity of the system.

1.7.2 SELECTION RELAYING

Fixed relaying protocol is bounded by transmission between source and the relay. The fading coefficients of the channel can be measured by the receivers at high accuracy such that they can decide whether cooperation is required or not. This decision making by the model is called selection relaying [1]. If the SNR between relay and destination is below pre decided threshold, the system works in non-cooperative mode that is only the signal from source to destination is enough for correct reception at destination [1]. If the measured signal to noise ratio is above threshold the system works cooperatively that the signal is transmitted by relay and the destination process both source signal and relay signal. In both the cases the signal received at destination is having probability of error least [1].

1.7.3 INCREMENTAL RELAYING

Incremental relaying is used in model where we have limited feedback such as single bit transmission 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 no correct reception [1]. In this relaying the signal is transmitted to destination in first phase. The signal received if is of good quality the destination sends acknowledgment to relay and source. The relay then does not retransmit the signal. This save spectrum thus incremental relaying spectral efficient. If the signal quality is below threshold the signal is send by relay as well [1]. The destination then combines both signal from source and relay. Thus signal is saved from deep fade.

1.8 DIVERSITY COMBINING TECHNIQUE

When the signal reaches the destination the destination combine signal that reaches at different time instants. Various combining technique are available .We have discussed fixed combining technique, equal combining technique and maximal combining technique.

1.8.1 EQUAL RATIO COMBINING (ERC)

When no feedback about the condition of the channel is available then equal ratio combining technique is used. In this type of combining, all the signal is added at the

destination [2]. Though this is the easiest way of combining but the results are inferior to other combining technique. We have analysed this technique and found that BER is improved using this combining technique in cooperative model.

If $Y_{r,d}[n]$ is the signal received by destination from relay [2] and $Y_{s,d}[n]$ is the signal received from source then at destination the combined signal can be written as

$$Y_d[n] = \sum_{i=1}^n Y_{i,d}[n] + Y_{s,d}[n] \quad (16)$$

Where n denotes the number of relay in the cooperative model.

1.8.2 FIXED RATIO COMBINING (FRC)

Equal ratio combining technique does not depend on channel quality, thus a combining technique which include channel quality as an important factor is required. Fixed ratio combining technique combine signal using weighing factor which represents the average channel condition [2]. This factor does not change during the whole communication as it does not depend on temporal change in channel condition.

Now, the received signal in fixed ratio combining technique can be written as

$$Y_d[n] = \sum_{i=1}^n W_{i,d} \cdot Y_{i,d}[n] + W_{s,d} Y_{s,d}[n] \quad (17)$$

Where $W_{i,d}$ is the weight factor which represents the average channel condition between relay and the destination [2]. The factor $W_{s,d}$ is the weight factor which represents channel condition between source and the destination.

1.8.3 SIGNAL TO NOISE RATIO COMBINING (SNRC)

A better way to weigh the signal from relays and source is using signal to noise ratio as a weighing factor [2]. The signal to noise ratio will be high for better channels and low for bad channels. Thus signal from low quality channel can be multiplied by low factor and ultimately is of little use when combined [2]. The signal to noise ratio can be known by sending extra bit sequence in the information signal. This can be an overhead but ultimately improves signal received at destination. The signal combined at the destination can be written as

$$Y_d[n] = \sum_{i=1}^n SNR_{i,d} \cdot Y_{i,d}[n] + SNR_{s,d} Y_{s,d}[n] \quad (18)$$

Where, $SNR_{i,d}$ indicates signal to noise ratio estimated between relay to destination and $SNR_{s,d}$ is the signal to noise ratio estimated between source and destination.

The signal to noise ratio in case of amplify and forward can be calculated as shown above by the formula

$$\frac{S}{N} = \frac{[|h_{r,d}(n)|^2] \cdot \beta^2 ([|h_{s,r}(n)|^2]) \varepsilon}{\beta^2 (2\sigma_{s,r}^2) + 2\sigma_{r,d}^2} \quad (19)$$

1.8.4 MAXIMAL RATIO COMBINING (MRC)

Maximal ratio combining is the best combining technique. The signal combined using this technique gives the best results [2]. The incoming signal from relay and source are multiplied by conjugate of the channel gain. The channel state information is assumed to be known at destination completely.

The combined signal can be written as

$$Y_d[n] = \sum_{i=1}^n h_{i,d}^* \cdot Y_{i,d}[n] + h_{s,d}^* \cdot Y_{s,d}[n] \quad (20)$$

Here $Y_d[n]$ is the signal at destination after applying combining technique. $Y_{i,d}[n]$ is the signal transmitted by relay in second phase and $Y_{s,d}[n]$ is the signal transmitted by relay in first phase.

Where, $h_{i,d}^*$ is the conjugate of channel gain between relays and destination. The factor $h_{s,d}^*$ is the conjugate of channel gain between source and destination [2]. Maximal ratio combining technique shows best results when used with decode and forward technique integrated with error correcting code.

1.9 RELAY SELECTION

Cooperative communication is a mean by which performance of wireless communication has improved. Most of the researchers believe that by using cooperative communication they can create an energy efficient communication model as the source needs lesser power to transmit data. As we know in cooperative communication two phase transmission of data is done. Both the phase has same signal but orthogonal to one another. This orthogonality is achieved by sending signal in two different time instance. As two different

time instance are required, for one complete transmission, twice the time cycle and thrice the transmission cycle are required as compared to ordinary transmission.

Suppose we have N number of relays, a single source and a destination. In this cooperative model the time cycles required are given by $(N + 1)$. the transmission cycle will be $(N + 2)$. Increasing transmission cycle can lead to spectrum and time inefficient cooperative model. Thus model is channel inefficient as the transmission cycles increases with number of relays. Thus to have a efficient model we select best or optimal relay out of N number of relays. Selecting all the relay may suppress the benefits of using cooperative model. This selection can depend on various factor such as signal to noise ratio, distance factor etc. Relay selection is an important part of all the cooperative model as it makes the communication more spectral efficient and achieves full diversity gain [3]. In [4] , it has been shown that a full diversity gain is achieved by using single best relay in DAF cooperative model as is achieved in ordinary cooperative model using all the relays [5].

The main challenge in relay selection model is the dynamic nature of the wireless model. The channel is dynamic as its gain changes as position of wireless nodes changes. Thus selecting optimal or the best relay becomes difficult. Thus adaptive relay selection scheme is used in dynamic wireless networks. Generally in cooperative model implementing adaptive relay selection the relay is selected in two phases. And transmission in cooperative communication model is carried out in two phases [3].

The two phases of relay selection are

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

1.9.1 RELAY CANDIDATE SELECTION

In this phase the potential relays are selected as relaying candidate which may be used in cooperative model as best relay depending on various criteria. There are two different types of relay selection scheme

- a) **Pre-assigned selection scheme:** In this scheme the relays are selected prior to transmission connection. The relaying candidates are selected while constructing multi hop mesh structure [3]. Before transmission the route discovery and

establishment is implemented. During this, the relays are selected as candidates. This is the easiest and the simplest form of relay candidate selection scheme [6]. This scheme does not work in dynamic environment since as dynamic channel varies, position of relay changes which leads to change in topology. This makes relay selection process inefficient for wireless communication which is dynamic in nature. The pre-assigned selection scheme can be an overhead as the relay information is gathered before transmission. Thus though being simplest of all schemes it is less preferred for selecting relays as candidate.

- b) Adaptive selection scheme:** Adaptive selection scheme are best suited for wireless network communication due to its dynamic nature. The overhead is reduced by integrating it in multiple access control protocol or in the network layer [7]. The integration of selection scheme in multiple access protocol is done by integrating it with request to send signal send by source or with clear to send signal send by destination [8]. This way relay comes to know that it lies in between source and destination and will be a part of the cooperative model [4]. When a relay receives multiple request to send messages from the source it start competing with the other relays to get selected in cooperation.

In [9] the selection of relays is done by sharing messages between sources and relays. These relays are mostly the one common to source and destination. Ad hoc on demand distance vector routing protocol has been introduced in [9] according to which relay consider itself to be a part of cooperative model once it receives a route request from source and route repeat request from destination. Due to less overhead as compared to pre-assigned selection scheme and more compatibility with wireless system, this selection scheme is more preferred.

1.9.2 RELAY ASSIGNMENT

Once the relays are selected as candidate for the cooperative model the relay assignment phase is implemented. The best or the optimal relay is selected based on various criteria which are discussed below.

- a) **Pre-defined or Random relay assignment:** This is the simplest of all criteria. The relays are selected before transmission [10]. The relay to be a part of cooperative model are pre-assigned. This is the easiest way of assignment of relay but it performs inefficiently in wireless networks due to its dynamic nature.
- b) **Distance based relay assignment:** The best or the optimal relay is selected by using distance between relay to source and destination as an assignment criteria. In [6] the relay is selected on the basis of its distance from destination. The one which is closer to destination is selected as best relay out of number of relaying candidates. In [11] the back off timer algorithm is used for relay assignment. Whenever source wants to find out the best relay out of relaying candidates its sets off a back off timer. The relay near to source will expires its back off timer sooner than the other relays and thus will be selected as an optimal relay. The selected relay will now send a request to send signal to source so that it can send the signal to relays. It also informs the other relaying candidate to stop competing. Though this is an easier way of assignment but distance cannot be considered as an important criteria because the relay which is closer to destination or source may have inferior signal to noise value or can have worst fading effects. Thus more appropriate criteria is required for best relay assignment.
- c) **Signal to Noise Ratio Based Relay Assignment:** Since for successful transmission both paths from source to relay and relay to destination must have good link quality. Thus having signal to noise ratio as the criteria for relay assignment is intelligent choice. The relay having highest signal to noise ratio must be selected as the best relay. In [9] the source maintains the list of relay candidates near to itself and destination. The metric γ_R is used for selecting the best relay out of relaying candidates [3].

$$\gamma_R = \min(SNR(s, r_i), SNR(r_i, d)) \quad (21)$$

$SNR(s, r_i)$, is the signal to noise ratio between source and N is number of relaying candidates and $SNR(r_i, d)$ is the signal to noise ratio between relaying candidates

and destination. The source selects the best relay by selecting two relays having highest SNR out minimum signal to noise ratio possible for relaying candidates. The relays keep updating its signal to noise ratio at the source so that it can make correct choice. In [4] the request to send and clear to send signal are used to estimate channel gain of path between relay to source and destination to relay. The channel gain h_{s,r_i} is estimated through request to send signal. The channel gain $h_{r_i,d}$ is estimated through clear to send signal from destination. These channel gain are used according to two policies. According to first policy the minimum of two relay is rejected and other is used in cooperation model. According to second policy the harmonic mean of two signal to noise ratio is calculated to find out the best relay. The harmonic mean is used as assignment criteria as follows

In [5] the cooperative model requires partial channel state information at the source and the relay. The main motive is to achieve high bandwidth efficiency and achieving diversity order similar to conventional cooperative system. The relays do not forward the signal if source to destination channel gain is high [5]. The source picks only one relay which is best among all. The best relay is the one which has the maximum instantaneous harmonic mean function among the N relay [5]. The harmonic mean function depends on source-relay and relay destination instantaneous channel gains. The source decides to cooperate or not by comparing to threshold, which is called cooperation threshold, the ratio of source –destination channel gain and harmonic mean [5]. The conventional cooperative communication consists of source s, destination d and a relay r and has two phases. First phase, source transmit to relay and destination and the received symbols can be modelled as $y_{s,d}$ and $y_{s,r}$ [5], where

$$y_{s,d} = \sqrt{p_1} h_{s,d} x + \eta_{s,d} \quad (22)$$

$$y_{s,r} = \sqrt{p_1} h_{s,r} x + \eta_{s,r} \quad (23)$$

Where p_1 is the source power, x is is the information symbol, $\eta_{s,d}$ and $\eta_{s,r}$ are noise components, and $h_{s,d}$ and $h_{s,r}$ are the channel gains [5]. Second phase, relay will retransmit the signal if it decode the received signal correctly. The relay to destination received symbol is written as follows where p_2

is the relay power, $h_{r,d}$ is the channel gain, x is the received symbol, $\eta_{r,d}$ is the channel coefficient.

$$y_{r,d} = \sqrt{p_2} h_{r,d} x + \eta_{r,d} \quad (24)$$

The received signal is combined using MRC and is written as [5]

$$y = \frac{\sqrt{p_1} h_{s,d}^*}{N_0} y_{s,d} + \frac{\sqrt{p_2} h_{r,d}^*}{N_0} y_{r,d} \quad (25)$$

The channel gain are modelled as zero mean complex Gaussian random variable having variance $\delta_{s,d}^2, \delta_{s,r}^2, \delta_{r,d}^2$. The symbol error rate for MPSK signal [5] is given by an upper bound written as

$$\Pr(e) \leq \frac{N_0^2}{b^2} \cdot \frac{A^2 P_2 \delta_{r,d}^2 + B p_1 \delta_{s,r}^2}{p_1^2 p_2 \delta_{s,d}^2 \delta_{s,r}^2 \delta_{r,d}^2} \quad (26)$$

Where $b = (\sin(\pi/M))^2$

$$A = (M - 1/2M) + \left(\frac{\sin(2\pi/M)}{4\pi} \right)$$

$$B = (3(M - 1)/8M) + \left(\frac{\sin(2\pi/M)}{4\pi} \right) + \left(\frac{\sin(4\pi/M)}{32\pi} \right)$$

Simplified form can be written as[5]

$$\Pr(e) \leq \frac{N_0^2}{b^2 \delta_{s,d}^2 P p_1} \left(\frac{A^2}{r \delta_{s,r}^2} + \frac{B}{(1-r)\delta_{r,d}^2} \right) \quad (27)$$

Where $r = \frac{p_1}{P}$ is power ratio [5]. The simplified form can be divided into two parts.

First term is independent of relay and the second term depends on relay, power ratio, and type of modulation and is given by [5]

$$m = \left(\frac{A^2}{r \delta_{s,r}^2} + \frac{B}{(1-r)\delta_{r,d}^2} \right) \quad (28)$$

Inverting m give standard harmonic mean function as

$$\begin{aligned} m' &= \frac{2q_1 q_2}{m} = \frac{2 q_1 q_2 \delta_{s,r}^2 \delta_{r,d}^2}{q_1 \delta_{r,d}^2 + q_2 \delta_{s,r}^2} \\ &= \mu_H (q_1 \delta_{r,d}^2, q_2 \delta_{s,r}^2) \end{aligned} \quad (29)$$

Where $q_1 = \frac{A^2}{r}$ and $q_2 = \frac{B}{(1-r)}$

In order to minimize the SER we need to maximize m [5]. Replacing the instantaneous channel gain by average channel gain we get [5]

$$\beta_m = \mu_H (q_1 \beta_{r,d}, q_2 \beta_{s,r}) \quad (30)$$

Where $\beta_{r,d} = |h_{r,d}|^2$ and $\beta_{s,r} = |h_{s,r}|^2$

Thus instantaneous value of β_m can be used to find ability of relay to cooperate or not.

d) Game Theory Based Relay Assignment: Game theory is a paradigm which provide us the tools by which we can model an interaction between decision makers. These decision makers are the players in the game which has a mutual impact on one another. The wireless network is consist of nodes that compete with one another for resources such as time slots, spectrum etc. they all have to make choices that will beneficial for themselves. The researchers have utilized the decision making criteria to select an optimal relay out of relaying candidates selected in phase 1. The relaying candidates are considered as the players which compete with each other for getting selected as a best relay. The player or the relaying candidates compete with one another in distributed manner. The relay selection will depend on the payoff it achieve while competing with other relays. The payoff is difference between benefit a relay achieve on acting as best relay and cost of the same. The relays in order to achieve high payoff act rationally and follow certain predefined strategies. They act selfishly and try to achieve high payoff even if their strategy have adverse impact on other relay's payoff.

In [12] proposed a buyer seller game in which both the relay and source nodes work to mutually earn maximum payoff. They proposed a two level Stackelberg game. In which relays compete to be an optimal. In game theory it is assumed that the players know about other player's strategies in present and the strategies followed by it in previous time slot.

1.10 INTRODUCTION TO GAME THEORY

Game theory provide us with the analytical tools that help us in analysing the interaction among the decision makers. It help us in understanding the way the decision makers interact with one another. It is a bag of tools which help us in predicting the results when two decision makers with same interest interacts [13]. It is a collection of tools not a single technique that help us in predicting results when decision makers interacts with one another for their common interests. It has three components

- A set of players
- A set of actions
- A set of preferences

A set of players are the decision makers that will interact with one another in the designed system model. The players in wireless communication networks are the nodes present in the networks. The actions are the set of strategies that the players can adopt. In wireless communication these action can be modulation type, coding rate, bandwidth, power etc. The actions or the strategies that the players adopt decides the outcomes [13]. The set of preferences are the all possible outcomes if a player follow different strategy. The preferences are represented by the utility function which assigns a number to every outcomes. The higher the number the more the strategy followed is preferred.in wireless communication we can go for strategies which provide us with higher signal to noise ratio, low power consumption, low symbol or bit error rate [13]. We need to model these utility function in an appropriate way as this is the most challenging part of the game theory.

1.10.1 GAME THEORY IN WIRELESS COMMUNICATION

Most of the literature of the wireless communication revolves around the ad hoc network. It is a multi-hop network which is self-configuring and have no central authority. Thus all the aspects of ad hoc network are distributed in nature and are power and energy constrained [13]. The present and the evolving wireless communication model have many features in common with ad hoc network. As game theory is a study of interaction among autonomous agents, this theory can be used to analyse the evolving wireless networks. Wireless network have nodes that make decisions related to power, energy, packet forward etc. which are constrained by rules and different protocols and algorithms. In making such

decisions the node may try to optimize the whole network or work selfishly and work for its own profits [13]. The nodes can also work to act maliciously for the networks and ruining the overall performance of the networks. The second and the third are appropriate for implementation of game theory. The first case which is the rarest case as the nodes may not have conflicting interest but aligned interest can also be analysed using game theory.

Before applying game theory to the model one must be sure that the problem is more than the simple optimization problem. If the model having multiple player can be considered as a game [13]. Sometime artificial players need to be added in order to consider a model as a game. Before applying game theory to model one must ensure its cooperative or non-cooperative nature.

1.10.2 TYPES OF GAMES

Game theory was first introduced by mathematicians and economists. It was used as a tool to study economic and political competitions. The fundamental motive of game theory was to use the decision makers in a model as players of the game which is the logic of games. In which players compete against each other using strategy, tactics, and effort to events in real life.

Different games can be formed based on type of model under consideration and number of players involved in the model. The division of games into different types help in applying proper game model to a particular wireless communication system model. Figure shows the tree for the types games Types of games are

- Cooperative and non-cooperative games
- Normal and extensive form of games
- Simultaneous move and sequential move game
- Constant sum ,zero sum and non-zero sum games
- Symmetric and non-symmetric games

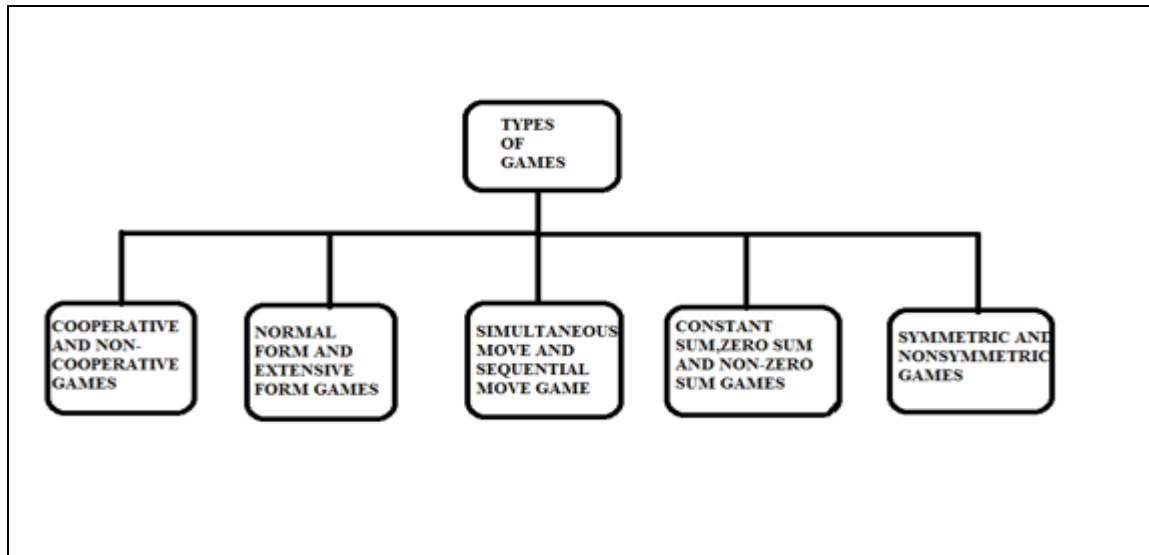


Figure 1.4: Types of game in Game theory [14].

- a) **Cooperative and non-cooperative game:** The cooperative games are the one in which the players negotiate with each other and are convinced to adopt a particular strategy. The negotiation is carried out among the players in order to have mutual benefits. For example in prisoner dilemma both the players interacts with one another in order to have mutual benefits and remain silent [14]. The non-cooperative game are the one in which the players work selfishly and without interaction decides for its own profit.

- b) **Normal form and extensive form of game:** The game in which the matrix form is used to describe a game. The matrix form is basically representing the payoff and the strategy in tabular form. This tabular form basically represent the outcomes of the particular player by following a strategy [14]. Extensive form of game are the one in which tree is used to define the outcome of the player by following a certain strategy.

- c) **Simultaneous move games and sequential move games:** simultaneous games are the one in which players adopt strategy simultaneously without the knowledge of the strategy followed by other players. The sequential move games are the one where players decide its strategy according to the other player's strategy [14]. 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.

- d) **Constant sum, zero sum and non-zero sum games:** Constant games are the games in which the sum of outcome of all the players remain constant even if we get different outcome every time. Zero sum game are the one in which sum of all the player is zero and the do not affect the resources [14]. The loss of one resources is equal to other players profit in zero sum games. For the non-zero sum games the sum is non zero. The non-zero game can be made zero game by adding a dummy player to the model.

- e) **Symmetric and asymmetric games:** In symmetric games all the players adopt same strategy. This type of games are usually short term as in long term games the choice of strategies available increases and thus players decides to go for different strategy. The decision in asymmetric are players independent. In asymmetric games the players adopt different strategy and always look for its own benefits [14]. Players and the strategy affect the decision making in asymmetric games.

1.10.3 UTILITY FUNCTION

Utility function is defined as a function which allocates a number to all the possible outcomes of the player in a game. The incentive of the player is represented by utility function as higher the number allocated by it to an outcome more preferable is that outcome. Let S is the set of strategy from where the players wants to select the strategy and X be the set from where the decision makers wants to select the outcomes [13]. Let Q be the relation on X and let x and y be the elements of the Q , then x is as least preferable as y if $x \geq y$ [13]. the relation of Q on X is basically designed according to the preferences of the model.

In wireless communication the basic preference for the nodes are spectrum, power control, rate, bandwidth etc. Usually the utility function in wireless communication includes these factors. The utility function is not unique.

1.10.4 NASH EQUILIBRIUM

Nash equilibrium is an equilibrium in which the outcome of the player is optimal and no player deviate from its present adopted strategy considering the strategy adopted by other players. Here the players assume that its fellow players will not change its strategy and thus does not deviate from its present strategy as it may receive no incremental benefits by deviating. A game can have many Nash equilibrium [15]. This term was first coined by John Nash and this is being used widely in behavioural ecology and economics.

In game theory if the player has only one time slot to adopt a strategy then that game is called a static game. These static games can be defined in strategic forms as $G = \{S, U, P\}$. The S represents the set of strategy available to players [15]. P represents the all players in the game. U represents the utility function or the payoff achieved by player on following the strategy.

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 way is to depend on iterative strict dominance solution [15]. Strictly dominant strategy can be defined as follows

$$U_i(s'_i, s_{-i}) < U_i(s_i, s_{-i}) \quad \forall s_{-i} \in S_{-i} \quad (31)$$

Where s'_i , the pure strategy of the opponent player, is said to be strictly dominated by s_i strategy if the above equation is satisfied. Where S_{-i} is the pure strategy space of the opponent player. The lack of trust among the players make this method not suitable for all types of players [15]. Another way of solving the game is through iterative elimination of weak dominance strategy. A strategy is said to be weakly dominated by other strategy if it satisfy following inequality.

$$U_i(s'_i, s_{-i}) \leq U_i(s_i, s_{-i}) \quad \forall s_{-i} \in S_{-i} \quad (32)$$

The iterative strict dominant solution gives us the Nash equilibrium. And can be defined as by following equation [15].

$$U_i(s_i^*, s_{-i}^*) > U_i(s_i, s_{-i}^*) \quad \forall s_{-i} \in S_{-i} \quad (33)$$

s_i^* is the strategy where we attain the Nash equilibrium. The player attain the maximum utility function at this strategy and decides not to deviate from this strategy [15]. A game can have more than one Nash equilibrium if the game has more than two players with multiple element choices. so if the players select other choice than the previous choice the Nash equilibrium will be different.

1.11 RESOURCE ALLOCATION USING GAME THEORY

The basic principle of cooperative communication is to exploit the spatial diversity nature of nodes and allow them to relay for each other. While relaying for each other they share each other's resources and this comes with some cost too. Cooperative communication works efficiently when we know whether to cooperate or not and how the resources of a relay are to be shared among the fellow nodes. In [16] bandwidth sharing among the relay nodes is analysed by modelling a buyer seller system. Where the source who act as a buyer wish to buy bandwidth from relay which is acting as a seller. The source compete with one another for the bandwidth of relay. The bandwidth allocation is analysed using game theory. Most of the researchers have worked on centralised model. Here the model is considered to be distributed in nature and game theory concept is used to analyse the resource allocation.

1.11.1 SYSTEM MODEL

The cooperative communication model is consist of sources, a relay and destination. The sources and the relay have pre-assigned bandwidth. The system model is illustrated in the following figure. The trans receiver pair is considered as user. Let there be N number of users and the set can be written as $U = \{u_1, u_2, \dots \dots \dots u_N\}$ and the bandwidth assigned to each user be w Hz for transmission [16]. The user wishes to share the bandwidth w Hz assigned to relay for its own transmission. The amplify and forward protocol is used by relay and FDMA provides orthogonality between the transmission of source and the relay [16] while considering energy to be a constant quantity.

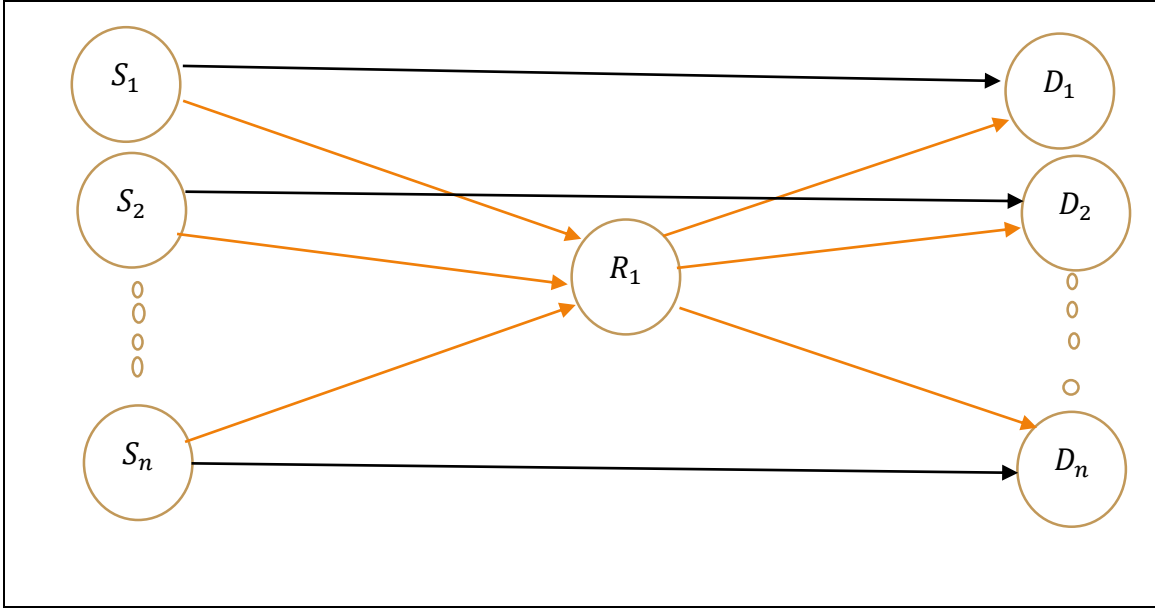


Figure 1.5: Model for resource allocation in cooperative communication.

If the relay decides to share w_i Hz of the bandwidth with user i then source will transmit w_i of the data through relay and the rest of the data $(w - w_i)$ will be transmitted by the source through direct transmission. The transmission by the relay cost it in the form of resource expenditure. This cost is redeemed by selling the bandwidth to the source. The cost function defines the cost which will be paid by source to the relay. The cost function used as in [16] is given by

$$C(w) = a + b \sum_{i=1}^N w_i \quad (34)$$

Where w_i is the bandwidth allocated and $W = \{w_1, w_2, \dots, w_N\}$ is the set of strategies accepted by the relays. The relay will choose bandwidth from set W so that it can achieve maximum utility value. The utility function is designed such that it is directly proportional to throughput and inversely proportional to energy invested. Thus the utility function for this system can be defined as [16]

$$U = T/P \quad (35)$$

Where T is the throughput and can be written as $f(\gamma) \cdot \frac{R}{Q}$, where R is the number of bits transmitted in Q number of bits of a frame [16].

Thus equation (35) can be written as

$$U = (W \cdot f(\gamma) \cdot \frac{R}{Q}) / P \quad (36)$$

This utility defines the benefit gained by the source only. The relay pays some cost for transmission and thus the net utility as in [16] is given by

$$U = (T_{s_i, d_i}(p_i, w - w_i) + T_{s_i, d_i}(p_i, w_i)) / p_i - C \cdot w_i \quad (37)$$

The factor $f(\gamma)$ is the function designed to calculate the probability of correct reception and in this case as in [16] can be given by

$$f(\gamma) = (1 - 2 \cdot BER(\gamma))^Q \quad (38)$$

As the factor $f(\gamma)$ is dependent upon signal to noise ratio of channel between source to relay, relay to destination and source to destination. The signal to noise ratio written as γ_{s_i, d_i} is SNR between source to destination, the signal to noise ratio written as γ_{r, d_i} is the SNR between relay and destination. The net SNR between source, relay and destination in case of amplify and forward protocol [16] can be written as

$$\gamma_{s_i, d_i}^{AF} = \gamma_{s_i, d_i} + \frac{\gamma_{s_i, r} \cdot \gamma_{r, d_i}}{1 + \gamma_{s_i, r} \cdot \gamma_{r, d_i}} \quad (39)$$

Equation (37) can be written as

$$U = \frac{R \cdot W}{Q \cdot p_i} \cdot f(\gamma_{s_i, d_i}) + \frac{R \cdot w_i}{Q \cdot p_i} \cdot \Delta f(\gamma_{s_i, d_i}) - w_i \cdot (a + b \cdot (\sum_{i=1}^N w_i)^T) \quad (40)$$

$$\text{Where } \Delta f(\gamma_{s_i, d_i}) = f(\gamma_{s_i, d_i}^{AF}) - f(\gamma_{s_i, d_i})$$

The utility function of system U is to be maximised for every bandwidth allocation to a user. The bandwidth shared by relay are the strategies available in strategy set W. The value of w_i will be chosen such that the utility of the function has maximum value.

The update function for the bandwidth allocation as in [16] value is given by

$$w_i(t + 1) = w_i(t) + \theta_i \cdot w_i(t) \cdot (\partial u_i(W) / \partial w_i(t)) \quad (41)$$

Where θ_i is the speed adjustment factor [16], $w_i(t)$, $w_i(t + 1)$ is the bandwidth assigned at time t and (t+1) respectively [16]. The value $\partial u_i(W) / \partial w_i(t)$ is calculated by differentiating $u_i(W)$ with respect to $w_i(t)$ and is given by

$$\frac{\partial u_i}{\partial w_i} = \frac{R}{Q \cdot p_i} \cdot \Delta f(\gamma_{s_i, d_i}) - (a + b \cdot (\sum_{i=1}^N w_i)^\tau + w_i \cdot b \cdot \tau (\sum_{i=1}^N w_i)^{\tau-1}) \quad (42)$$

The best strategy of the user where the maximum utility is achieved as in [16] is given by

$$w_i^* = \arg \max U_i(w_i, W_{-1}^*) \quad (43)$$

Where W_{-1}^* is the set of best strategy [16] followed by the other players except user i and is given by

$$W_{-1}^* = \{w_1^*, \dots \dots w_{i-1}^*, w_{i+1}^* \dots \dots w_N^*\} \quad (44)$$

We have used the update function given above in equation (44) to find all the values that can be considered by the relay to offer to source. The update function depend on the differentiated value which rely on $f(\gamma)$ which is channel SNR dependent function. Thus each source have different channel gain which finally give us different bandwidth value at every distance for a source. Thus two source as per our system model both will have different values for bandwidth to be sold to source by the relay. The values available to the source are the strategy available to source it can choose to have maximum value utility function as given in equation (43). We know that the maximum of utility function occur at the point where relay is near to source as at that point cost of relaying will be minimum and utility function will have maximum value.

1.11.2 INTRODUCTION TO SHAPLEY VALUE

Lloyd Shapley in 1953 introduced a new way of evaluating a value for playing a game. He developed a function which gives a value called Shapley value and is of great interest in the field of cooperative game theory. Shapley value eradicates the complex strategic interaction way usually followed in game theory [17]. The strategic interaction due to its complexity increased the need of simple way which was offered by Shapley value which is one step further from Von Neumann and Morgenstern reductionist program which indicates all the alternatives of a player by a number indicating the utility [17].

Shapley proposed for representing all the possibility for a player, while playing game, in the form of a value.

Suppose if we have a set of n players say N where it can be written as $N = \{1, \dots \dots n\}$ then each player will have its own value for playing a game in its own n position. Thus

there will be n vector having n value. Shapley considered a game v and set U of players. Let the players actually involved be N out of set U such that $v(S) = v(S \cap N)$ where $S \in N$ [17]. A player is a null player and do not affect the value of $v(S)$ if it is not a part of set N . The value assigned to a game v is through a function $\phi_i(v)$ for every player i in N [17]. The function $\phi_i(v)$ follows three axioms. The symmetry axiom states that the value of the player does not depend on name. It depends only on characteristics function reaction to player when it is a part of a coalition [17]. The second axiom called the carrier axiom states that the sum of $\phi_i(v)$ for all the player will be equal to $v(N)$ [17]. This can be called as efficiency axiom and can be written as [17]

$$\sum_{i \in N} \phi_i(v) = v(N) \quad (45)$$

For dummy players, $\phi_i(v) = 0$. This is called dummy player axiom. The third axiom states that for any game v and w , the value of $(\phi_i(v) + \phi_i(w)) = \phi_i(v + w)$ for a player i where the game $(v + w)$ is $[v + w](S) = v(S) + w(S)$ [17]. The unique function ϕ exists that follow all the axioms was proposed by Shapley and is written as [17]

$$\phi_i(v) = \sum_{S \in N} \frac{(S-i)!(n-S)!}{n!} \cdot [v(S) - v(S - i)] \quad (46)$$

The term $[v(S) - v(S - i)]$ is the marginal contribution of each player in coalition S . The formulae represents the weighted sum of marginal contribution [17]. This is the Shapley value formulae where $\phi_i(v)$ can be called as expected marginal contribution of player.

1.12 DESIGN CHALLENGES

- To design a cooperative model having source, relay and destination, where the relay follows cooperative protocols and destination combine signals using combining techniques.
- To design a cooperative model where sources uses relay's bandwidth to transmit its own signal. As bandwidth is a limited resource, efficient allocation among the sources makes cooperative model more efficient.
- To design a cooperative model having multiple sources and relays in which power of the relays, an important resource, must be efficiently allocated among the sources. The challenge is to define the factor which determines the power allocation among

the sources. The factor may depend on distance of the sources from the relays, the SNR of the paths, and the cost paid by relay in relaying signal for the sources.

1.13 OBJECTIVES OF THESIS

- Cooperative model having source, relay and destination, is to be analysed on the basis of bit error rate for different SNR values. BER variation with relay using cooperative protocol (AAF) and destination using different combining techniques is to be analysed to observe the benefits of cooperative model.
- Bandwidth being a limited resource of wireless communication a cooperative model is to be designed where sources uses relay's bandwidth to transmit its own signal. Efficient allocation among the sources makes cooperative model more efficient. The allocation among the sources is to be decided using game theory in which sources and relays are treated as players which compete to have maximum allocation.
- A multi-source, multi-relay cooperative model is to be designed in which sources share relay's power to transmit its own signal. As sharing among the sources is involved, a game theoretical analysis using shapley value can be used to make decision on allocation. A utility function is to be designed which defines the amount of power allocation to sources.

1.14 ORGANISATION OF THESIS

In chapter 2, the research paper are discussed which helps in building a general understanding about the cooperative communication model and basics of game theory. It gives a brief knowledge about the work done by the researchers till date and scope of improvements. In chapter 3, we have discussed a simple cooperative model which have source, relay and destination as an elements. The simulation results are shown which shows the BER improvement on using different combining techniques in cooperative model.in chapter 4, bandwidth allocation among sources is analysed using game theory. Simulation results shows the utility function value of the sources on bandwidth allocation to them by relays. In chapter 5, power allocation in cooperative model is analysed using Shapley value which help in building a simple algorithm for allocation of power of relays to sources.

Simulation results are discussed and observed to analyse the power allocation in multi-source and multi relay networks.

2.1 LITERATURE ON COOPERATIVE COMMUNICATION

- Todd E. Hunter *et al.* [18] in 2002 investigated cooperative communication using coded cooperation. Each code word is partitioned into two subsets that are transmitted from user and relay antenna respectively. Coded cooperation achieve high gain and maintain same rate, bandwidth, and transmit power.
- Fambirai Takawira *et al.* [19] in 2002 proposed cooperative diversity concept applied to land mobile satellite system. The two phase cooperation model uses best relay based on received signal strength. Relay cooperates only if source to destination channel quality is not sufficient to guarantee successful communication. The performance of land mobile satellite system is determined in the form of outage probability and channel capacity.
- J.N. Laneman *et al.* [1] in 2004 developed a protocol that allow single antenna devices to exploit spatial diversity. 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.
- J.S. Thompson *et al.* [2] in 2005 analyzed a simple cooperative model consisting of source, relay and a destination. The model analyzed with relay using different protocol on signal received with different combining method at the destination. The impact of relay position with respect to destination and source is analyzed as well.
- Eric G. Larson *et al.* [20] in 2005 proposed symbol superposition protocol to send data from relay. Relay transmits a superposition of its own information with data received from source in previous time slot. The node fully exploits its time slot thus increases bandwidth efficiency.

- M. Felegyhazi *et al.* [15] in 2006 explains how the nodes in wireless communication can be used by their neighbours to exploit the spatial diversity. They explained the basic concept of non-cooperative game theory.
- Aggelos Bletsos *et al.* [4] in 2006 proposed a distributed method to find best path between source and destination among M relay. A method of distributed timer is used in which timer of relay which has best channel gain will time out early and will transmit data. Other relays will still be in listening mode and will wait for their timer to time out. .When they hear transmission from other relay they back off.
- Zhihang Yi *et al.* [21] in 2008 analyzed the diversity order of decode and forward protocol with relay selection. They combined MRC with relay selection which gave full diversity order but large number of pilot signals is required. Then they combined relay selection with link adaptive regeneration which require lesser pilot signal and give better diversity order.
- Ahmed S. Ibrahim *et al.* [5] in 2008 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 show a significant increase in bandwidth efficiency.
- Min Suk Kang *et al.* [22] in 2008 applied cooperative and selection relaying scheme in downlink system in multiuser diversity. In this, one base station, one nomadic relay, and N number of mobile station is used. Relay is half duplex. They considered four different downlink relaying scheme: direct selection, relay, and cooperate and analyzed ergodic and outage capacity for each scheme.
- Salama S. Ikki, *et al.* [24] in 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 resources required.

- Mustafa Al-Harbawi *et al.* [25] in 2010 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.
- Yawjeng A. Chau *et al.* [26] in 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.
- Nikolaj Marchenko *et al.* [27] in 2011 investigated the effect of relay selection overhead on the cooperative communication. The impact is measured on jitter, throughput, and time delay. It has been investigated that relay selection in some cases can result worse than single relay cooperation due to overhead.
- Eun-Ki Kim *et al.* [28] in 2012 proposed space time cooperative diversity relaying scheme which used partner selection scheme. The scheme proposed usage of cooperative group which is consists of M+N terminals, where M is the managing relay and N is the assisting relay. Managing relay manages the channel state information of the neighboring relay. Out of these terminal only terminals having high SNR is selected and is encoded.

2.2 LITERATURE ON COOPERATIVE COMMUNICATION USING GAME THEORY

- Mark Felegyhazi *et al.* [15] in 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 analysis on main factors of game theory.

- Yingda Chen *et al.* in [34] 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.
- Zhu Han *et al.* [12] in 2009 proposed a game theoretical model in distributed framework to achieve optimal relay selection and power allocation in cooperative communication model. Compared to centralized framework we do not require channel state information. A buyer seller game is designed where source act as buyers and relays act as seller. The sources buy power from relays. The Stacklberg game analysis allow source to choose best relay and help in optimal power allocation from relay such that both relay and source achieves high utility function.
- G. Zhang *et al.* [16] in 2009 considered the resource allocation process in cooperative communication using game theory as a decision making tool. The source and relay are modeled as players. The source buys bandwidth from relay for transmission through relay and pay relay for the same. The price and the bandwidth allocation is done so as to have maximum utility function value or maximum payoff.
- Dan Wu *et al.* [29] in 2014 proposed an auction based relay power allocation scheme over multi user relay network which provide energy efficiency. They have presented three goals which is to efficiently use the relay resources, to insure competitive fairness among competing users and to guarantee distributed implementation with relaxation of restrictions on complete private knowledge and accurate assessments of convergence.

Based upon the literature survey presented above it is evident that there is a huge scope of incorporation of non-conventional optimization paradigm (like game theory) for efficient power allocation and pricing. In general this work seeks to implement a cooperative communication model consisting of multiple sources in AWGN, Rayleigh fading environment. In particular power allocation will be optimized using a novel game theoretic model as defined in chapter 5.

3.1 COOPERATIVE DIVERSITY AND COMBINING TECHNIQUE ANALYSIS

Cooperative diversity is a method of exploiting broadcast nature of wireless communication in helping neighboring nodes to transmit each other signal. A virtual MIMO system is created which implements spatial diversity so as to combat fading effects on the signal. The bit error rate is improved when nodes work cooperative and the performance seems to improve further with different combining method. Further we will examine as the number of relay increases the bit error rate seems to improve.

3.1.1 SYSTEM MODEL

We have considered a source, a destination and a relay model for the cooperative communication. The channel is considered to have path loss, additive white Gaussian noise and Rayleigh fading. The path loss exponent is 2 such that $(d_{s,d} \propto \frac{1}{R^2})$. 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, two phase require two time slots to transmits 2 binary data. For fair analysis we have considered BPSK in non-cooperative model so that 2 bits are transmitted in 2 time slot as in cooperative QPSK model [29].

As described earlier in first phase, source broadcast its signal which is overheard by relay and received by destination [30]. The received signal at destination is given by

$$y_{s,d}[n] = d_{s,d} \cdot a_{s,d} \cdot x_s[n] + z_{s,d}[n] \quad (47)$$

$$y_{s,d}[n] = h_{s,d} \cdot x_s[n] + z_{s,d}[n] \quad (48)$$

Where $x_s[n]$ transmitted signal is the $d_{s,d}$ is the pathloss factor and $a_{s,d}$ is the zero mean Gaussian random variable having variance $\sigma_{s,d}^2$. The factor $z_{s,d}[n]$ is the thermal noise and $h_{s,d}$ is the overall attenuation and is given by $d_{s,d} \cdot a_{s,d}$ [30].The received signal at relay is given by

$$y_{r,d}[n] = h_{s,r} \cdot x_s[n] + z_{s,r}[n] \quad (49)$$

Where $x_s[n]$ transmitted signal. The factor $z_{s,r}[n]$ is the thermal noise and $h_{s,r}$ is the overall attenuation and is given by $d_{s,r} \cdot a_{s,r}$. The power of the signal at relay is given by [30]

$$E[|Y_r|^2] = E[|h_{s,r}|^2] \cdot E[|x_s|^2] + E[|Z_{s,r}|^2] \quad (50)$$

As the energy of the signal $x_s(n)$ is ε , power of noise is $2\sigma_{s,r}^2$ and s is source and r denotes relay. Thus power of received signal is written as [30]

$$E[|Y_r|^2] = |h_{s,r}|^2 \cdot \varepsilon + 2\sigma_{s,r}^2 \quad (51)$$

During first phase the relay either amplify or decode the signal received and then retransmit it in second phase. This is called amplify and forward protocol and decode and forward protocol respectively. In case of decode and forward the data is re-encoded before retransmission. We have considered that the relay uses amplify and forward protocol.

In second phase, the relay transmits the amplified or the re-encoded signal received in first phase. In the simulation, we have used amplify and forward protocol at the relay. The signal is amplified by multiplying it with factor β such that power at which signal is transmitted by the relay is of same power as that of signal transmitted by source in first phase [30].

$$\beta = \sqrt{\left(\frac{\varepsilon}{(|h_{s,r}|^2 \cdot \varepsilon + 2\sigma_{s,r}^2)}\right)} \quad (52)$$

The received signal from source and the relay at the destination is observed using maximal ratio combining, fixed ratio combining and equal ratio combining method. The bit error rate results to be different for all the combining techniques. Maximal ratio combining method has the best results.

The signal received at destination from the relay can be written as [30]

$$Y_{r,d}[n] = h_{r,d}[n] \cdot S_r[n] + Z_{r,d}[n] \quad (53)$$

Where $S_r[n] = \beta(h_{s,r} \cdot S_s[n] + Z_{s,r}[n])$ is the amplified signal transmitted by relay. The signal received at destination is using equal ratio combining technique

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n] \quad (54)$$

For maximal ratio combining technique the signal is [30]

$$Y_d[n] = h_{r,d}^*[n] \cdot Y_{i,d}[n] + h_{s,d}^*[n] \cdot Y_{s,d}[n] \quad (55)$$

For fixed ratio combining technique the signal is [30]

$$y_d[n] = y_{s,d}[n] + 2 \cdot y_{r,d}[n] \quad (56)$$

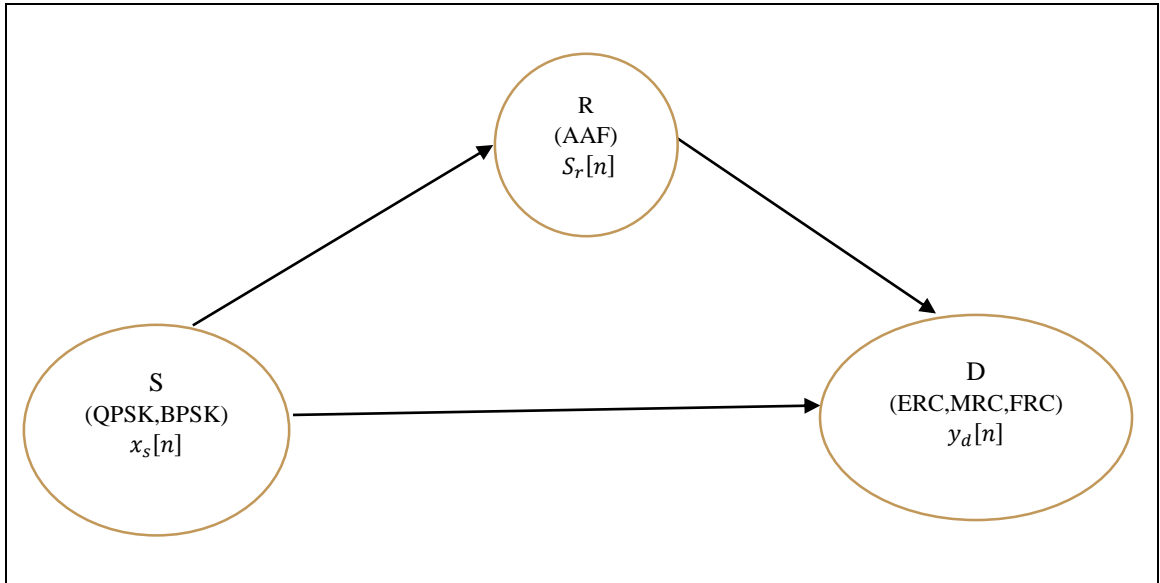


Figure 3.1: System model for cooperative communication.

3.1.2 OBSERVATION

Following is the graph between BER and SNR for QPSK signal in cooperative model with different combining method and BPSK signal in non-cooperative model. We can see in non-cooperative communication, for BPSK transmission, we get BER of .977 with SNR of 14dB. In cooperative model, for QPSK transmission with ERC combining we get same BER with SNR of 10.5dB. With FRC combining we achieve same BER with SNR of 10dB and with MRC combining same BER is achieved with SNR of 6.5dB. Thus signal quality is improved when we shift from non-cooperative to cooperative model. The virtual MIMO created combat fading effects and enhance signal quality. The signal combined at the

destination show best improvement with maximal combining technique. Other combining technique also show improvement in BER as compared to non-cooperative model

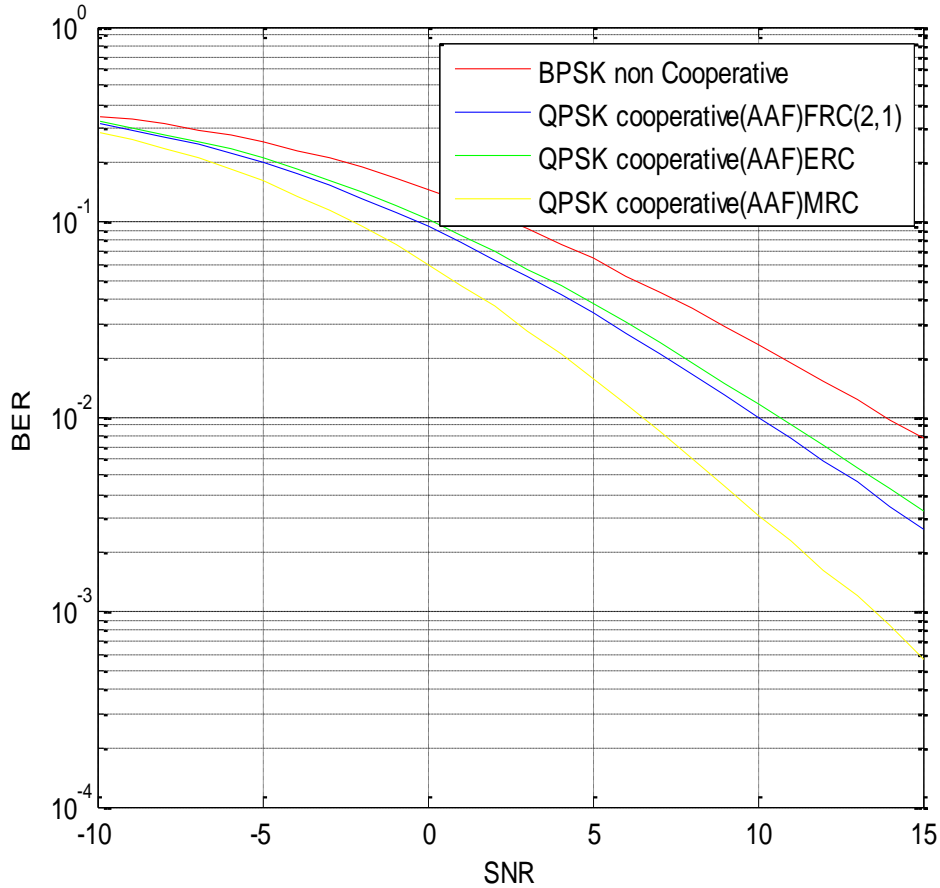


Figure 3.2: Cooperative communication using different combining method.

3.2 COOPERATIVE MODEL USING MULTIPLE RELAYS

Cooperative communication is consist of source, relay and destinations. A relay in a cooperative model creates an extra path for the signal to travel to destination. If the direct path from source to destination is in deep fade then the probability that the relay to destination path will be in deep fade is very low. The two signal when combined at destination will never be in deep fade. In cooperative communication model as the number of relays increases the number of paths increases, thus signal quality is also improved.

3.2.1 SYSTEM MODEL

The system model is consist of a source, a destination and multiple relay. The model is analyzed for its symbol error rate with one, two, three relays. The channel is considered to have path loss, additive white Gaussian noise and Rayleigh fading. The path loss exponent is 2 such that $(d_{s,d} \propto \frac{1}{R^2})$. The signal transmitted in cooperative model is QPSK.

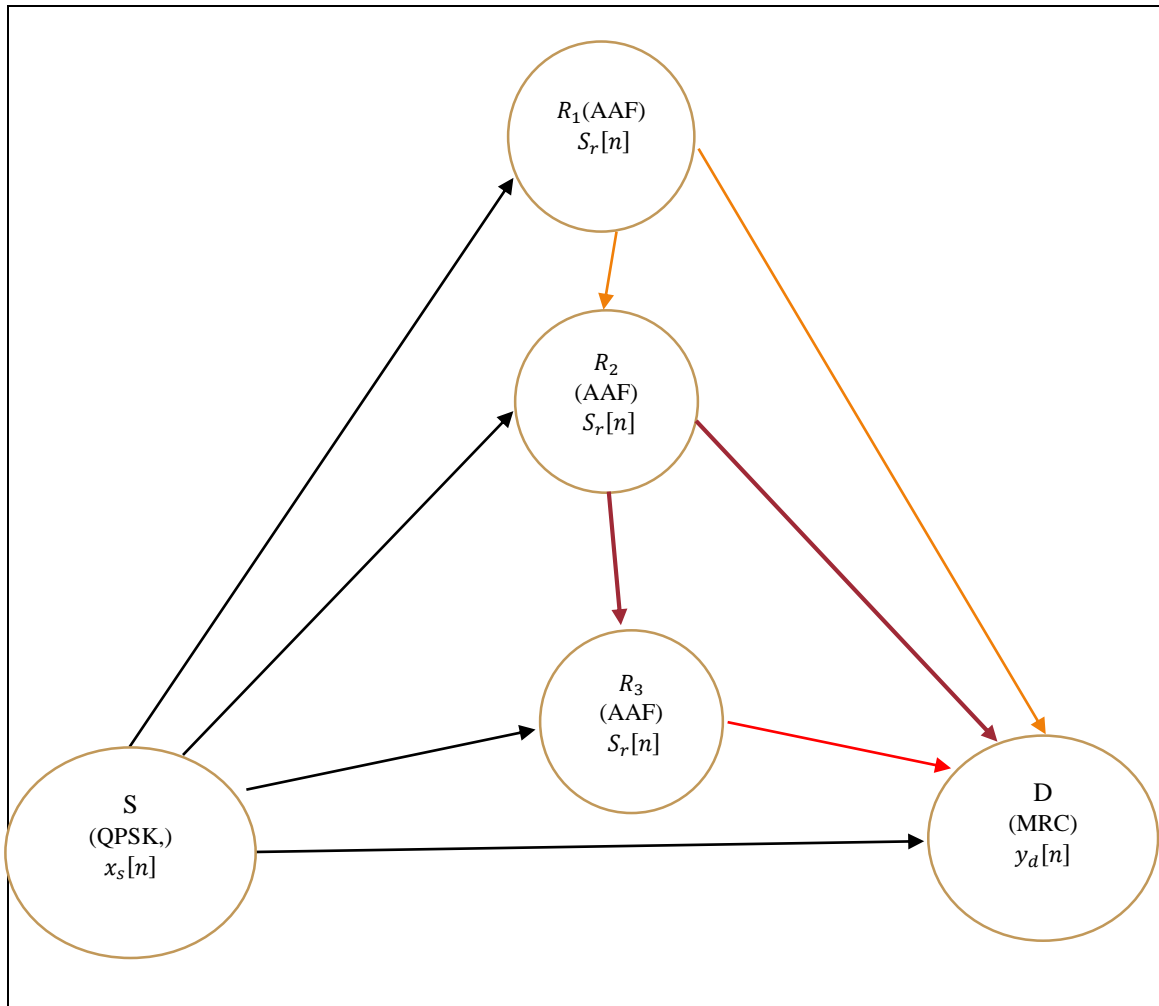


Figure 3.3: System Model for multiple relays.

In single relay model two phase transmission is implemented. Source broadcast to destination and relays in first phase. Relay retransmits to destination in second phase. In two relay model three phase transmission is implemented where source transmits to destination and relays in first phase, relay1 transmits to destination and relay2 in second

phase and relay2 after combining data from source and relay1 retransmits its data to destination in third phase. Similarly in three relay model four phases are implemented for complete transmission. As we can see as the relay increases the number of relays increases which further increases number of time slots required for complete transmission. Thus we cannot increase the number of relays as it will become bandwidth inefficient. The signal received at destination are combined using MRC technique.

3.2.2 OBSERVATION

Following is the graph between SER and SNR for cooperative QPSK with different number of relays. In QPSK cooperative with one relay, we get SER of 1.0023 with SNR of 19dB. Using 2 relay we get same SER with SNR of 16.5dB. In 3 relay cooperative model we get same SER with SNR of 14.5dB. Thus increasing number of relays shows improvement in required SNR for same SER. The gain on moving from 1 to 2 relay is 15.4dB and for 1to 3 relays is 17dB.

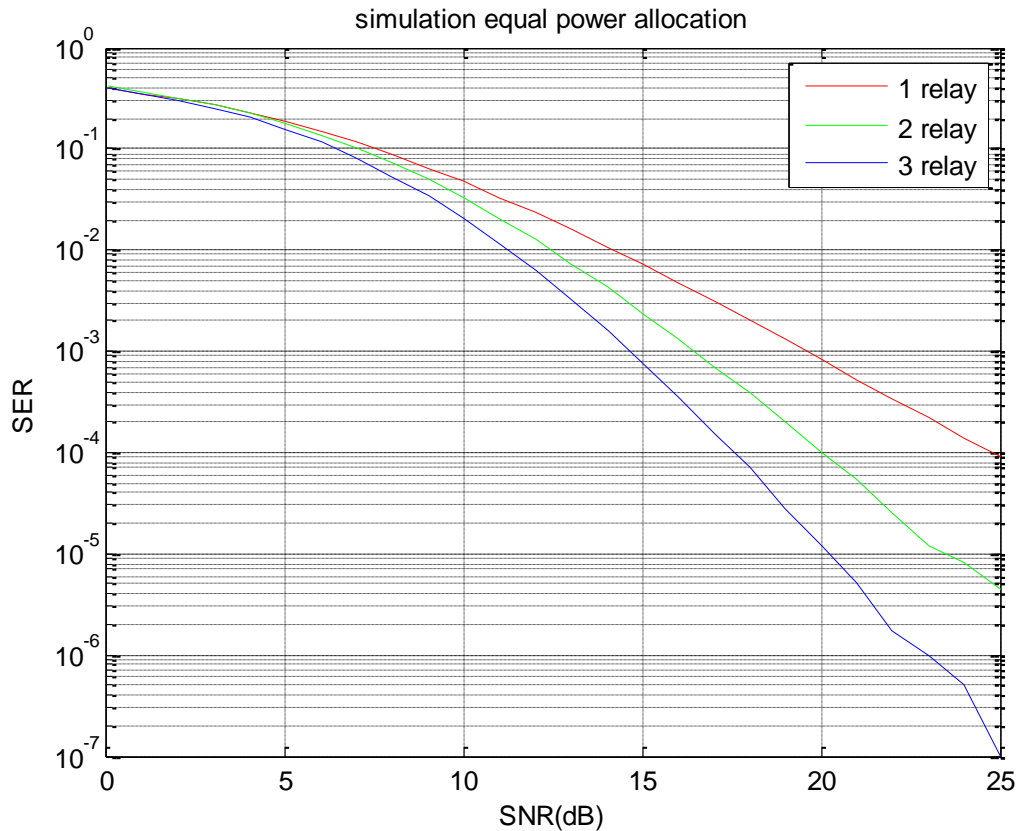


Figure 3.4: SER of cooperative model using different number of relays versus SNR(dB)

RESOURCE ALLOCATION USING GAME THEORY

Game theory is a theory which provide us the tools by which we can model an interaction between decision makers. The players in the game are the decision makers which has a mutual impact on one another. 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.

4.1 SYSTEM MODEL

The cooperative communication model is consist of two sources, a relay and two destination. The sources and the relay have pre-assigned bandwidth w Hz. The system model is shown in the figure 4.1. The system has two user where a user is a source destination pair. Both the sources transmits its some data directly to destination and left over data through relay. The relay shares its bandwidth with both the sources. The bandwidth allocation is a decision made by the relay using game theory. The relay uses amplify and forward protocol for the signal received from the source and the system is based on frequency division multiplexing (FDMA).

A buyer seller game is designed where a relay is the seller wishing to sell its bandwidth to source at some cost decided by cost function. The two source act as a buyer and wishes to buy optimal bandwidth from relay at a price which gives non negative utility function. The optimal bandwidth is a bandwidth which results in maximum value of the utility function.

$$w_i^* = \arg \max U_i(w_i, W_{-1}^*) \quad (57)$$

Where W_{-1}^* is the set of best strategy followed by the other players except user i and is given by

$$W_{-1}^* = \{w_1^*, \dots \dots w_{i-1}^*, w_{i+1}^* \dots \dots w_N^*\} \quad (58)$$

The utility function U_i is given by

$$U_i = (T_{s_i,d_i}(p_i, w - w_i) + T_{s_i,d_i}(p_i, w_i))/p_i - C \cdot w_i \quad (59)$$

Where T_{s_i,d_i} is the throughput which depend on power of transmission and bandwidth. The w_i is the bandwidth allocated to source by the relay and C is the cost function.

The source S1 is located at (0,-50).source S2 is located at (0,50),relay moves from -200 to 200 with constant x axis co-ordinate at 80 , and destination 1 and 2 at (200,-50),(200,50) respectively. The channel is considered to have path loss, additive white Gaussian noise and Rayleigh fading. The path loss exponent is 4 such that $(d_{s,d} \propto \frac{1}{R^4})$. We have defined the set of bandwidth available to source 1 and 2 which is calculated by an update function as given by

$$w_i(t + 1) = w_i(t) + \theta_i \cdot w_i(t) \cdot (\partial u_i(W)/\partial w_i(t)) \quad (60)$$

Where θ_i is the speed adjustment factor. The $w_i(t)$, $w_i(t + 1)$ is the bandwidth assigned at time t and (t+1) respectively [16]. The value $\partial u_i(W)/\partial w_i(t)$ is calculated by differentiating $u_i(W)$ with respect to $w_i(t)$ and is given by

$$\frac{\partial u_i(w)}{\partial w_i(t)} = \frac{R}{Q \cdot p_i} \cdot \Delta f(\gamma_{s_i,d_i}) - (a + b \cdot (\sum_{i=1}^N w_i)^\tau + w_i \cdot b \cdot \tau (\sum_{i=1}^N w_i)^{\tau-1}) \quad (61)$$

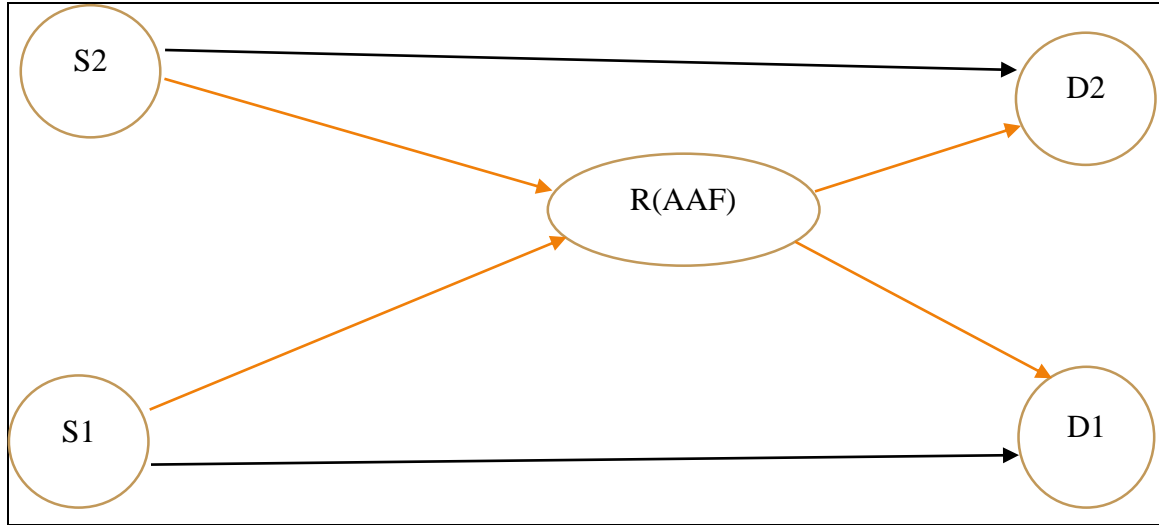


Figure 4.1: System model.

The source selects the bandwidth which give maximum utility function value. Bandwidth of each node is considered to be 10^6 Hz and the power of transmitted signal to be .1 watts

and noise power is 10^{-13} watts. Where R the number of bits transmitted is considered to be 64 in Q, which is the number of bits of a frame which is considered to be 80.

4.2 OBSERVATION

Following is the graph between utility function value and distance moved by the relay. The model has two source and a relay. As the relay moves from (-200) to (200) on y axis its distance value from two sources changes. In starting as the relay moves it is far from source S1 and S2. Bandwidth allocated to source S1 will be maximum as it is nearer from relay than source S2. As for source S1, the bandwidth allocated is maximum it gets maximum price value and lesser utility function value at (0,-50). The utility function value will be maximum for source S2 as the bandwidth allocated to it is low and the price demanded by the relay is low which results in higher payoff for source S2 at (0,-50). Later we will see as the relay moves closer to source S2 at (0,50) more bandwidth is allocated to source S2 and utility function is minimum for source S2 at that location and maximum for source S1.

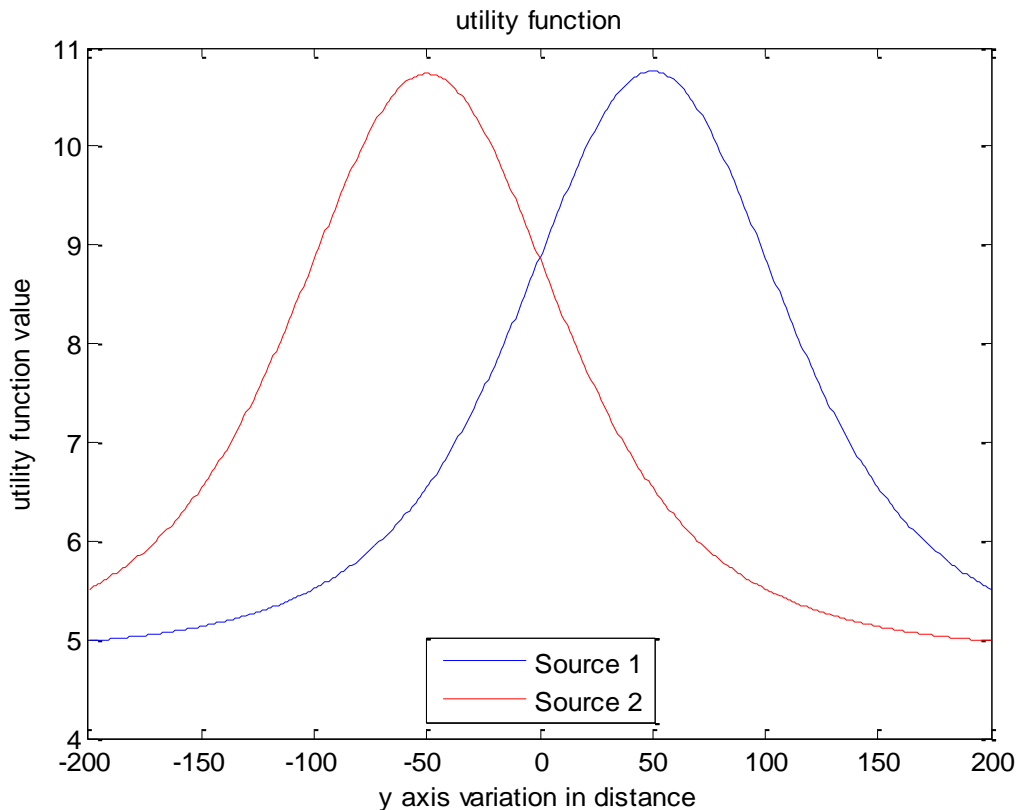


Figure 4.2: Graph showing utility function value for two sources.

RESOURCE ALLOCATION BASED ON SHAPLEY VALUE

5.1 SHAPLEY VALUE

Shapley value is a new way of evaluating a value for playing a game. He developed a function given in equation (62) which gives a value called Shapley value and is of great interest in the field of cooperative game theory [17].

$$\phi_i(v) = \sum_{S \in N} \frac{(S-i)!(n-S)!}{n!} \cdot [v(S) - v(S - i)] \quad (62)$$

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.

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.

5.2 SYSTEM MODEL

The system model is consist of M number of source, N number of relays and M destinations. The relay uses the Amplify and Forward protocol to resend received signal to destinations. The transmission occur in two phases. The signal is broadcasted by the source in first phase, which is received by relay as well as destination. The signal received by relay can be written as $Y_{S_i r_k}$ and the destination receives $Y_{S_i d_i}$ [12]. Here we assume that signal sent by

a source is received to its own destination only. The signal $Y_{S_i r_k}$ and $Y_{S_i d_i}$ can be written [12] as equation (63) and equation (64) respectively.

$$Y_{S_i r_k} = \sqrt{p_{S_i} g_{S_i r_k}} \cdot X_S + \eta_{S_i r_k} \quad (63)$$

$$Y_{S_i d_i} = \sqrt{p_{S_i} g_{S_i d_i}} \cdot X_S + \eta_{S_i d_i} \quad (64)$$

Where $g_{S_i r_k}$, $g_{S_i d_i}$ are the channel gain [12] between source-relay and source –destination respectively. The p_s is the power with which source broadcast signal and X_S is the signal transmitted and $\eta_{S_i r_k}$, $\eta_{S_i d_i}$ are the additive white Gaussian noise [12]. We here assume that the noise power is same for all paths σ^2 . The signal to noise ratio for source to destination is written as [12]

$$\Gamma_{S_i d_i} = \frac{p_{S_i} \cdot g_{S_i d_i}}{\sigma^2} \quad (65)$$

And the rate of direct transmission as [12]

$$R_{S_i d_i} = w \log_2 \left(1 + \frac{\Gamma_{S_i d_i}}{\Gamma} \right) \quad (66)$$

Where w and Γ is the bandwidth allocated to each node and capacity gap respectively [12]. In phase 2 the signal is amplified by the relay and send it to destination. The signal is written as $Y_{r_k d_i}$ as in equation (68), where $X_{r_k d_i}$ is the $Y_{S_i r_k}$ signal amplified by the relay [12] which can be written as

$$X_{r_k d_i} = \frac{Y_{S_i r_k}}{|Y_{S_i r_k}|} \quad (67)$$

$$Y_{r_k d_i} = \sqrt{p_k g_{S_i r_k}} \cdot X_{r_k d_i} + \eta_{r_k d_i} \quad (68)$$

Putting (65) and (66) in equation (68), $Y_{r_k d_i}$ can be written as [12]

$$Y_{r_k d_i} = \frac{\sqrt{p_k g_{S_i d_i}} \left(\sqrt{p_{S_i} g_{S_i r_k}} \cdot X_S + \eta_{S_i r_k} \right)}{\sqrt{p_{S_i} g_{S_i r_k} + \sigma^2}} + \eta_{r_k d_i} \quad (69)$$

From (69) we can see the SNR between the source, relay and destination can be written as [12]

$$\Gamma_{S_i r_k d_i} = \frac{p_{S_i} g_{S_i d_i} p_{r_k} g_{S_i r_k}}{\sigma^2 (p_{S_i} g_{S_i r_k} + p_{r_k} g_{S_i d_i} + \sigma^2)} \quad (70)$$

From (70) we can write the SNR expression for a source and all the relay as

$$\Gamma_{S_i r_1 d_i} = \frac{p_{S_i} g_{r_1 d_i} p_{r_1} g_{S_i r_1}}{\sigma^2 (p_{S_i} g_{S_i r_1} + p_{r_1} g_{S_i d_i} + \sigma^2)} \quad (71)$$

$$\Gamma_{S_i r_2 d_i} = \frac{p_{S_i} g_{r_2 d_i} p_{r_2} g_{S_i r_2}}{\sigma^2 (p_{S_i} g_{S_i r_2} + p_{r_2} g_{r_2 d_i} + \sigma^2)} \quad (72)$$

Finally for n^{th} relay we can write SNR as

$$\Gamma_{S_i r_n d_i} = \frac{p_{S_i} g_{r_n d_i} p_{r_n} g_{S_i r_n}}{\sigma^2 (p_{S_i} g_{S_i r_n} + p_{r_n} g_{r_n d_i} + \sigma^2)} \quad (73)$$

Therefore the SNR among sources, relays and destinations can be written as follows by neglecting higher order terms and considering all channel gain between all sources and relays to be same.

$$\Gamma_{S r d} = \sum_{i=1}^M \frac{p_{S_i}}{\sigma^2} \cdot \left(\sum_{k=1}^N \left(\frac{g_{r_k d_i} p_{r_k} g_{S_i r_k}}{(p_{r_k} g_{r_k d_i} + p_{r_k} g_{r_k d_i} + \sigma^2)} \right) \right) \quad (74)$$

The signal to noise expression can be used to write the rate expression . thus the rate for M sources N relays and destination can be written as in equation(75)

$$R_{S r d} = \frac{w}{2} \log_2 \left(1 + \frac{\sum_{i=1}^M \Gamma_{S_i d_i}}{\Gamma} + \frac{\sum_{i=1}^M \sum_{k=1}^N \Gamma_{S_i r_k d_i}}{\Gamma} \right) \quad (75)$$

Here w is the bandwidth allocated in Hz. This expression is designed to define the utility function of the buyer seller model for evaluating the power allocation among the relays and the sources. The utility function is a function of rate of transmission and cost relay has to pay to retransmit signal.

The source act as a buyer and the relay act as the seller. The utility function for source is defined as

$$U_S = (a \cdot R_{S r d} - C) \quad (76)$$

Where R_{srd} is the rate of transmission, a is the gain per unit rate at maximal ratio combining output. The factor C is the price paid by source to relay for transmitting for the source [12] and can be written as

$$C = p \cdot \sum_{i=1}^M \sum_{k=1}^N P_{s_i r_k} \quad (77)$$

Where p is the price decided by the relay for transmitting source data. Where $P_{s_i r_k}$ is the power allocated to source by the relay. The power allocated will be such that the utility function U_S has the maximum value [12] and can be defined as

$$\max_{P_{s_i r_k}} U_S = (a \cdot R_{srd} - C) \text{ where } P_{s_i r_k} \geq 0, r_k \in M \quad (78)$$

We consider the price decided by the relay to be constant and find the optimal power allocation so that we have maximum utility function. The source nearer to relay will receive maximum power allocation. As the relay moves further from a source the power allocated decreases and the allocation to other source which is nearer than previous source is increased. The allocation of power is carried out by using game theory analysis, where Shapley value decides the allocation. The formulae in equation (79) is used to calculate the marginal contribution of a source in coalition for sharing bandwidth of a relay [17].

$$\phi_i(v) = \sum_{S \in N} \frac{(S-i)!(n-S)!}{n!} \cdot [v(S) - v(S-i)] \quad (79)$$

Here $v(S) = (a \cdot R_{srd} - C)$ where R_{srd} and C is described in equation (77) and equation (61) respectively. Suppose if we have N sources then, to calculate the marginal contribution of a source we can have the following table. The value of marginal contribution of i^{th} player is calculated by subtracting the value of $v(S-i)$ which is the set of player proceeding the i^{th} player from $v(S)$ which is set of i^{th} player and players proceeding i^{th} player. Suppose if we have three players then the marginal contribution of player one can be written as in following table. Similarly the contribution of other two player can be written in same way.

Order R	Marginal contribution
1,2,3	$v(\{1\}) - v(\emptyset)$
1,3,2	$v(\{1\}) - v(\emptyset)$
2,1,3	$v(\{1,2\}) - v(\{2\})$
2,3,1	$v(\{1,2,3\}) - v(\{2,3\})$
3,1,2	$v(\{1,3\}) - v(\{3\})$
3,2,1	$v(\{1,2,3\}) - v(\{2,3\})$

Table 5.1: Marginal contribution calculation for all possible coalition.

Once the marginal contribution of a player for every order is calculated, all the values are added, which is contribution of a player to coalition. The final Shapley value is calculated by using Shapley formulae given in equation (79).

The player having the highest Shapley value will be allocated highest power. The nearer the source is to relay more is the power allocated to it as more Shapley value is achieved. Thus Shapley value is an easiest and analytically less complicated method by which game theory analysis can be done on a cooperative model.

5.2.1 PROBLEM FORMULATION

The system model is consist of 3 sources, a relay and 3 destinations. The relay uses the Amplify and Forward protocol to resend received signal to destinations. The following figure 4.3 shows the model and the positions of different nodes. The three sources are present at (-100,250), (-100,0), (-100,250) coordinates. The relay1 and 2 moves -300 to 300 with constant x axis at 0 and 10 respectively. The destination are at (100,250), (100, 0), (100,-250) coordinates. The path loss factor is considered 2, noise power is 10^{-5} mW, power of transmission is 10 mW, bandwidth is 1 MHz and capacity gap is 1. The price for transmission by the relay is 0.2 .The transmission occur in two phases. The signal is broadcasted by the source in first phase, which is received by relay as well as destination.

The SNR among sources, relays and destinations can be written as follows

$$\Gamma_{s r d} = \sum_{i=1}^M \frac{p_{s_i}}{\sigma^2} \cdot \left(\sum_{k=1}^N \left(\frac{g_{r_k d_i} p_{r_k} g_{s_i r_k}}{(p_{r_k} g_{r_k d_i} + p_{r_k} g_{r_k d_i} + \sigma^2)} \right) \right) \quad (80)$$

The signal to noise expression can be used to write the rate expression. Thus the rate for M sources N relays and destination can be written as in equation (80)

$$R_{s r d} = \frac{w}{2} \log_2 \left(1 + \frac{\sum_{i=1}^M \Gamma_{s_i d_i}}{\Gamma} + \frac{\sum_{i=1}^M \sum_{k=1}^N \Gamma_{s_i r_k d_i}}{\Gamma} \right) \quad (81)$$

The utility function for this model is [12]

$$U_S = (a \cdot R_{s r d} - C) \quad (82)$$

Where $R_{s r d}$ is the rate of transmission given, a is the gain per unit rate at maximal ratio combining output. The factor C is the price paid by source to relay for transmitting for the source and can be written as [12]

$$C = p \cdot \sum_{i=1}^M \sum_{k=1}^N P_{s_i r_k} \quad (83)$$

In first case we consider only single relay which moves from -250 to 250 with constant x axis coordinates at 0. The figure is given below

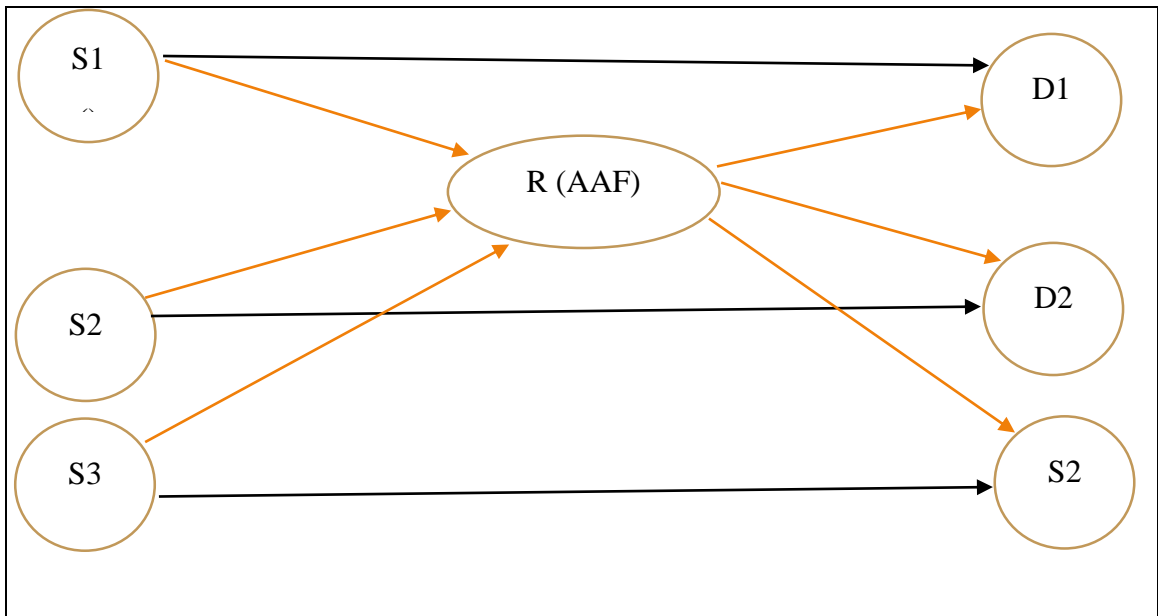


Figure 5.2: Multi source single relay cooperative system model.

The Shapley value is calculated by finding the marginal contribution of each source in sharing the bandwidth of the relay. The marginal contribution is calculated as described earlier. The marginal contribution of source 1 can be written as

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 5.3: Marginal contribution of source 1.

Where order is the possible combination of the three player and $v(S)$ is the utility function as defined above in equation (82). The shapley value of source 1 can be written as

$$\phi_1(v) = \frac{(\sum_{i=1}^6 M(R_i))}{6} \quad (84)$$

The marginal contribution of source 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 5.4: Marginal contribution of source2.

Where order is the possible combination of the three player and $v(S)$ is the utility function as defined above in equation (82). The shapley value of source 2 can be written as

$$\phi_2(v) = \frac{(\sum_{i=1}^6 M(R_i))}{6} \quad (85)$$

The marginal contribution of source 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 5.5: Marginal contribution of source 3.

Where order is the possible combination of the three player and $v(S)$ is the utility function as defined above in equation (82). The shapley value of source 3 can be written as

$$\phi_3(v) = \frac{(\sum_{i=1}^6 M(R_i))}{6} \quad (86)$$

5.2.2 OBSERVATION

a) Multi source single relay model: In this model , three sources S1,S2,S3 buy power from relay R1 which is moving from -300 to 300 y axis coordinates. As the relay moves from -300 it is closer to S3 than from S2 and S1. Thus the power allocated to S3 is high as it reaches at -250 maximum bandwidth is allocated to S3. As relay moves further it move closer to S2 which increases allocation to S2 and become maximum at 0 coordinate. Similarly at 250 y axis coordinate power allocation to S1 is maximum.

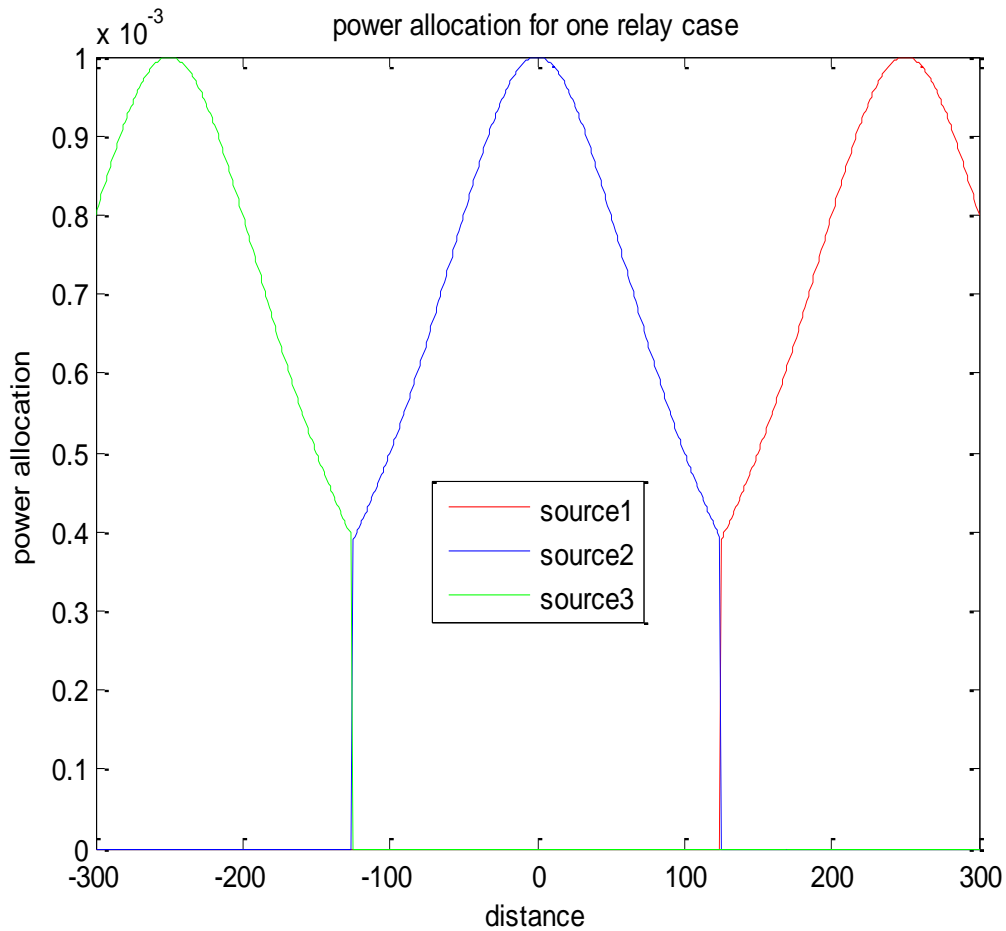


Figure 5.6: Power allocation among sources in cooperative model.

The power allocated is decided by calculating Shapley value for each source. The player having maximum Shapley value will be allocated maximum power. This maximum power is the optimum power that must be allocated so as to achieve equilibrium. Once power allocation to all three sources is complete. The value of utility function for power value is evaluated and is shown in figure (5.7). As the power allocated to source vary with position of relay so does the value of utility function. It is maximum at the position of S1,S2,S3 with values of power allocated to all the three sources

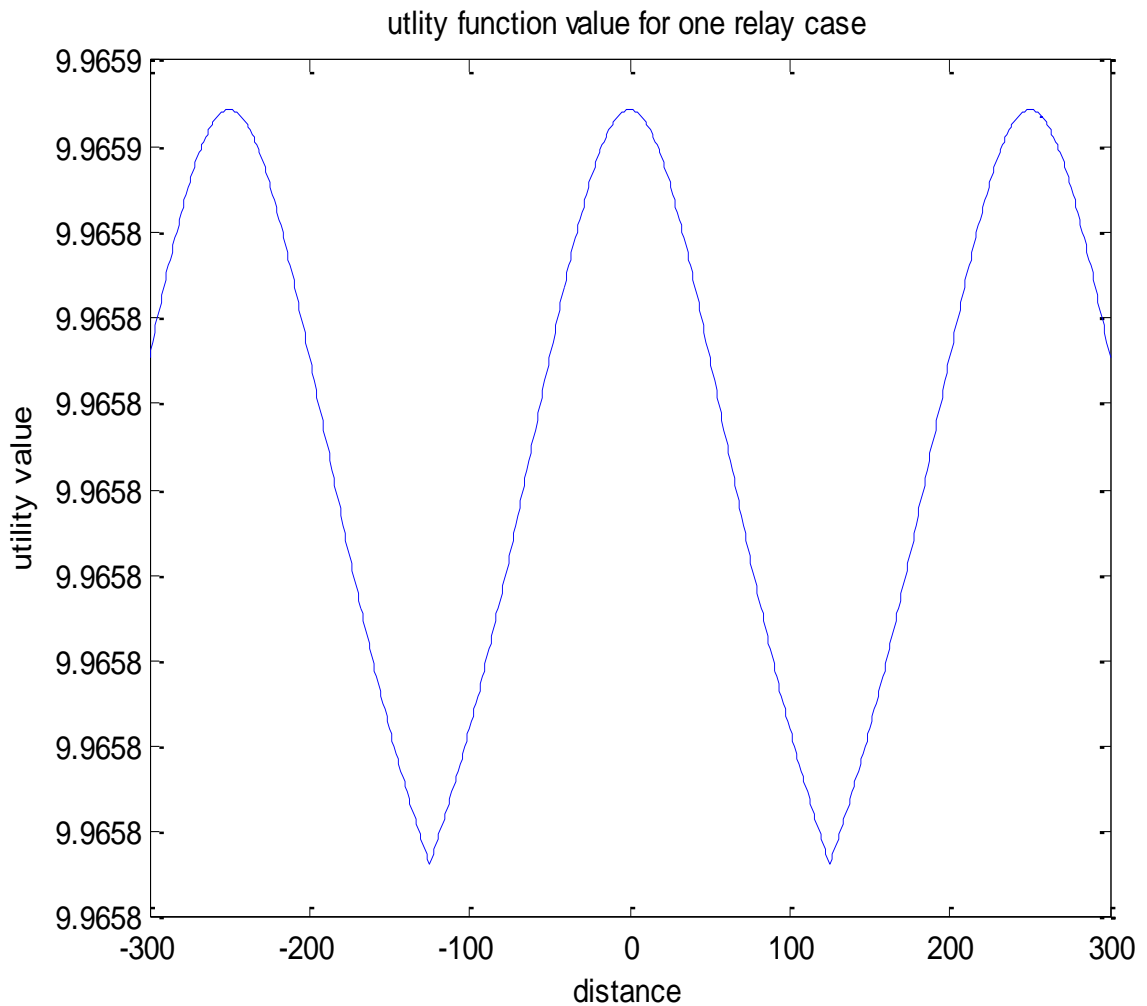


Figure 5.7: Utility function for the sources in cooperative model.

b) Multi source ,two relay case : In this model , three sources S1,S2,S3 buy power from relay R1 and R2 which is moving from -300 to 300 y axis coordinates with 0 and 20 as

x constant coordinate. As the relays moves from -300 it is closer to S3 than from S2 and S1. Thus the power allocated to S3 is high as it reaches at -250 maximum bandwidth is allocated to S3. As relay moves further it move closer to S2 which increases allocation to S2 and become maximum at 0 coordinate. Similarly at 250 y axis coordinate power allocation to S1 is maximum. The relay R1 is nearer to source than R2 thus relay R1 is allocates more power to sources than relay R2.

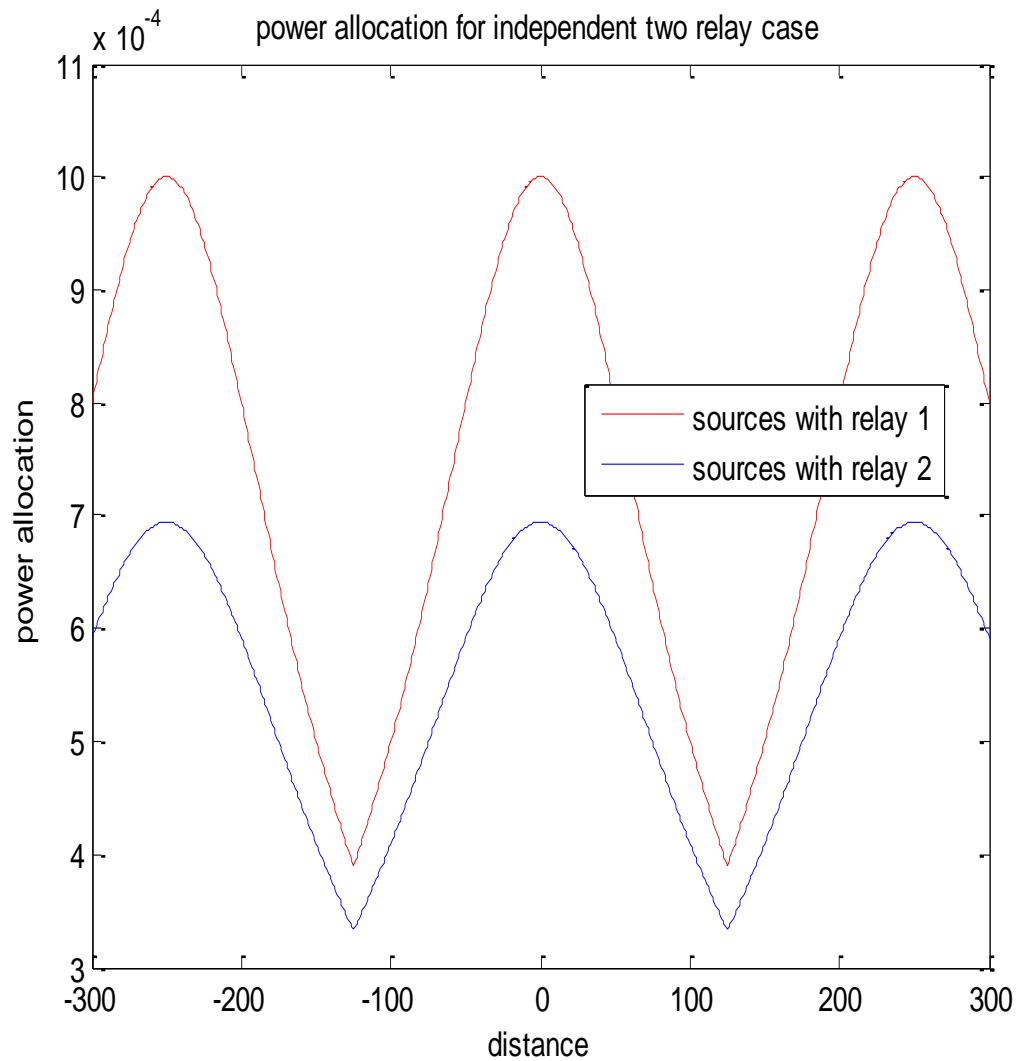


Figure 5.8: Power allocation among sources from two independent relays in cooperative model.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

This thesis evaluates a cooperative diversity model in the backdrop of power efficiency and efficient resource allocation. The improvement in the performance has been obtained by employing a game theoretic optimization technique. Taking into account the fact that the broadcast nature of the wireless medium permits cooperative diversity to be used in wireless communication to combat fading effect hence a node can use antenna of neighboring devices to transmit its data. Thus without deploying actual multiple antenna we can enjoy the benefits of diversity through cooperative communication. The following conclusion can be drawn from respective chapters.

In chapter 3, the bit error rate variation of the signal with SNR of the channel was analyzed. It was observed that by using the cooperative model the bit error rate of the signal was improved. Since the bit error rate also depends on combining type used at the destination, maximal ratio combining has proved to be the best combining technique. Thus signal received at destination has shown benefit of increase in performance on using cooperative diversity. Also the number of relays have effects on bit error rate performance of the model where the bit error rate versus SNR with three relays have shown best results.

In chapter 4, resource allocation in cooperative model through game theory was analyzed. Game theory has provided an easy way for making a decision where all the sources acting as a player, compete with one another for bandwidth pre allocated to relay. It has been shown that the bandwidth allocation to sources depends on their distance from the relay since as the distance increases the bandwidth allocated to a source decreases. As bandwidth is a limited resource and need to be optimized, game theory have proved to be an efficient method.

In chapter 5, power allocation to multiple source was analyzed using Shapley value. The utility function was designed for power allocation to the sources which depends on signal to noise ratio value of the channel which further depends on distance factor. Shapley value considers the marginal contribution of the sources in coalition for sharing power of the relay. It has been observed that the power allocation among the sources increases as relay

moves nearer to the sources. Thus the Shapley value analysis of the power allocation in cooperative model has proved to be an efficient and easy way of resource allocation.

It can thus be concluded that the cooperative communication not only combat fading by reducing the dependency of wireless system on the quality of particular path but also increases the throughput as compared to direct transmission by proper resource allocation. Furthermore Shapley value based resource allocation has proved to be efficient and reliable alternative in place of traditional method based on nonlinear optimization which involves computation of several coupled differentials of relevant parameters. Cooperative communication 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 have 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 systems which supports high data rate and need to be analyzed both in network simulation and theoretically.

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