Cooperative Communication Network Protocols a Comparative Approach

by

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Certificate

It is certified that the work contained in the thesis titled **Cooperative Communication Network Protocols a Comparative Approach by Nikhil Singh (EE18M093)**, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Synopsis

Networks which uses the Cooperative Diversity have been extensively studied. Such networks form an array of antennas virtually. Neighbouring nodes assist the source node in sending the data to the destination in the cooperative diversity networks. This type of communication can be used to increase the coverage range of wireless networks. In this report we first study two Cooperative communication strategies, namely Amplify and Forward (AF) protocol and Decode and Forward (DF) protocol. For these two protocols we study outage probability. The performance of these conventional approaches in terms of outage probability are discussed by varying the power distribution factor and by varying rate. Also, the effect of varying link distances on probability of outage in conventional AF protocol has been studied.

Later in the report an Amplify and Forward protocol in which relay has three nodes equipped with the buffer has been considered. This scheme is known as incremental relaying technique. This cooperative communication is designed in such a way that it uses the diversity of packets rather than diversity of links. That is the packets that experience worse channel in (S-R) link experiences better channel in (R-D) link & vice versa. In the incremental relaying Maximum Ratio Combining (MRC) technique has been used at the receiver or destination node (D). This incremental relaying technique improves the performance of the system in terms of reduction in the Outage Probability.

Finally, Conventional Decode and Forward (DF) protocol is considered. For conventional DF expression of the Outage has been derived and the probability of Outage has been compared with Conventional AF scheme. Also, optimal power distribution factor β is used for analysing Outage probability and capacities of the links. The results are simulated using MATLAB version 2019B. For all the above analyses Rayleigh fading channel has been considered with channel noise is AWGN. The Binary PSK with NRZ coding is used as a transmission scheme in all the above analyses.

I have also carried out the study of Buffer Aided DF method and Relay Selection algorithms such as Best Relay Selection (BRS) algorithm and MAX-MAX Relay selection algorithm jointly with **Hemant Kumar Singh (EE18M085)**. This part is presented in thesis report with title **"Wireless Cooperative Communication Network Protocols"**.

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I can not forget to thank the library staff for supporting us throughout the course. I would also like to acknowledge my parents, siblings, with their constant support and blessings only it became possible. Lastly, I am grateful to some of my friends who cheered me up during tough times especially Hemant Singh, Rahul Dev Shrivastava, Vishal Bhadauria, Sudhir Yadav, Nikhil Narayan, Aditya Choudhary, Arun Pundir, Sunny Choudhary and all other friends for motivating me throughout my two years of amazing Journey.

Contents

List of Figures

List of Tables

Abbreviations

AF	**A**mplify **F**orward
DF	**D**ecode **F**orward
S-R	**S**ource **R**elay Link
R-D	**R**elay **D**estination Link
S-D	**S**ource **D**estination
SNR	**S**ignal **t**o **N**oise ratio
AWGN	**A**dditive **W**hite **G**aussian **N**oise
HD	**H**alf **D**uplex
FIFO	**F**irst **I**n **F**irst **O**ut
MIMO	**M**ultiple **I**nput **M**ultiple **O**utput
MRC	**M**aximum **R**atio **C**ombining
BRS	**B**est **R**elay **S**election
MMRS	**M**ax **M**ax **R**elay **S**election

To my Family. . .

Chapter 1

Protocols for the Cooperative Communications

1.1 Brief Overview of Wireless Communications

As we move towards the new era, the dependencies over the wireless technologies are increasing day by day. In order to meet the everlasting demand of data traffic several methods have been proposed in order to shape the future of wireless technologies. Wireless network based communication allows user to manage their activities virtually from anywhere across the world. Smart and intelligent systems are mostly driven by wireless network. These intelligent systems involves mobile phones, self driving electrical vehicles. Incorporating wireless technologies with the smart grid systems allows various devices which are connected to this smart system to exchange the information using the wireless channel or link. These dependencies over the wireless networks are doubling within a time frame of every 2.5 years [1]. Because of which the network capacity tends to increase by million folds since the beginning of 1960's.

During past few decades as we move towards the technological advancement in the wireless networks, wireless communication comes out to be the primary or most fundamental way of communication. The most fundamental applications of the communication using the wireless links involve the Global Positioning System (GPS) tracking for satellite, Wifi enabled cell phones etc. But to use these various wireless enabled services comes at a cost of degradation of the signal. The various factor which leads to the degradation of the of the signal are multi-path propagation, scattering due to obstacles comes in the path of the signal. This degradation is best explained by the diagram shown below.

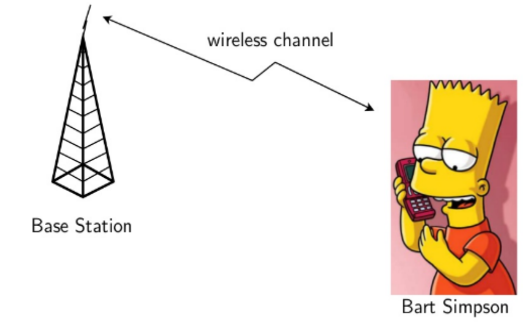

FIGURE 1.1: Communication over simple wireless network

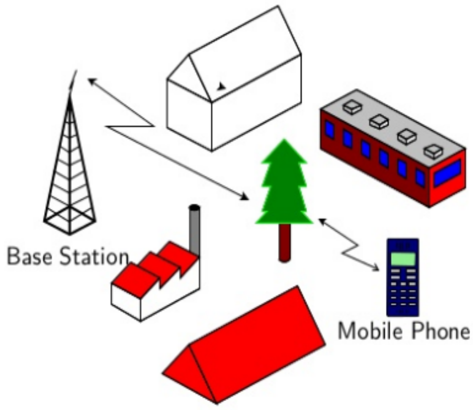

FIGURE 1.2: Obstacles leading to degradation of the signals

So for maintaining the reliable form of communication and to combat the adverse effects it becomes necessary to devise some new protocols. The work presented in this report mainly focuses on the Cooperative network protocols. Cooperative network strategies increases the coverage range and link capacities of the wireless network. Under water capabilities of the wireless networks are exploited by the author in [2] with the help of the network with wireless sensors. AWGN noise corrupts the links of the wireless network because of which the signal quality is downgraded. Combining Multi-Input-Multi-Output (MIMO) systems with the spatial diversity helps to combat the defects present in the wireless channel as mentioned by the author in [3]. These MIMO systems overcomes the adverse effects of the fading, as these are suitable to use in the scattered environment. But cost involved with the MIMO systems is fairly high. An array of virtually operating antennas are formed by the schemes that involves the use of cooperation. So in order to make the wireless networks cost effective and at the same time to achieve reliable communication, cooperative network finds an important place in the literature.

A path between the source and the destination is created by incorporating the relay between them as shown in (1.3) [4]. This path is independent in nature. Figure (1.3) points out the differences between the traditional way of communication and communication with the help of the relaying technique. Spatial Diversity can be exploited by the use of the these relay based protocols. Integrating the relay node between the source and the destination enhances the network performance. The most fundamental concept of the three node network is explained in [5]. As proceeding in the report it can be observed that cooperative communication not only improves the coverage range but also makes the communication more reliable over the slow Rayleigh faded channel.

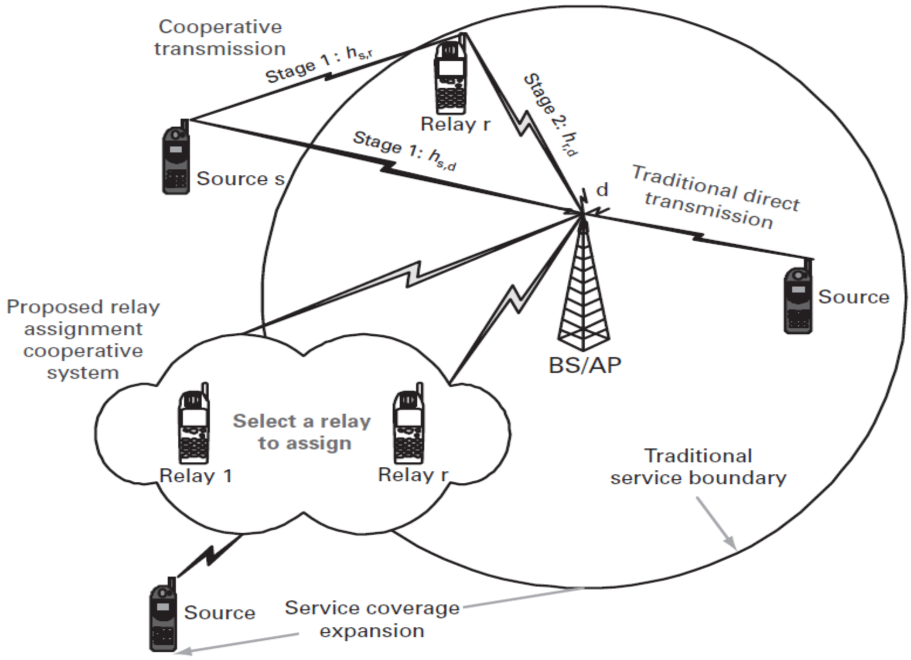

FIGURE 1.3: Direct Vs Cooperative Transmission

1.2 Transmission using the Cooperation

Source node (S) is assisted by the Relay node (R) in the wireless network in order to transmit the information packets towards the Destination node (D). This is the fundamental principle of the networks with cooperation as in [3, 6]. The nodes of this 3 node network operates under half-duplex (HD) mode, which means any of the three nodes can either transmit or receive in a given time slot. Throughput improvement, capacity increment, coverage range expansion and minimization of link outage probability have been observed in the relay integrated cooperative approaches. Literature cited in [7], [8] shows that by incorporating the cooperative schemes diversity gains can by enhanced. Improvement in the routing performance at the Network layer has been cited in articles [9] and [10]. The coverage and throughput performance improvement in the media access layer has been cited in [11] and [12]. This shows cooperative protocols application at various layers.

Relay assisted communication is termed as the cooperative communication. There are two categories of Cooperative communication, first is regenerative relay approach and the second is non-regenerative relay based approach. It incorporates Decode and Forward (DF) and Amplify and Forward (AF) protocols respectively as explained in [4, 13, 14]. As the DF protocol comes under the regenerative category, it has got the ability to decode the received signal from the source and before transmitting towards the destination it encrypts the information. Whereas, non-regenerative relaying includes AF protocol in which the incoming signal from the source is amplified before transmission.

The article in [15], shows the expansion of coverage range and throughput improvement in the wireless networks that incorporates relay based approaches. But traditional relay based schemes are not integrated with buffers. Transmission and reception in these buffer-less protocols follows the scheduling in the prefixed manner. Because of this prefixed scheduling approach best available links are not exploited which becomes bottleneck. So in order to add more flexibility to these relay based networks buffers are integrated over the relay nodes, thus the best available links are properly exploited. Significant improvement in the reduction of outage probability is observed, if traditional DF and AF protocols are integrated with buffers at the relay node (R). The report shows a comparative study between traditional buffer-less AF and DF protocols with AF and DF protocols coupled with buffer. Traditional schemes suffers from channel impairment as cited in [15]. This problem arises because of low SNR of the channel. The schemes integrated with buffers offers flexibility to choose the best available channel, thus the channel impairment can be tackled. In order to enhance the diversity gain of a wireless network buffer aided protocols are deployed over these networks. The links are chosen based on the instantaneous values SNR. That is if the (S-R) link has a high value of SNR than the source node must transmit, or else the (R-D) link is selected and the relay node will transmit the packet stored in its buffer. Also, buffers are integrated with the traditional AF protocol and a comparative study has been performed by comparing it with buffer-less AF scheme. Cooperative schemes with buffers offers several merits over the traditional schemes without buffer. The first difficulty is the requirement of knowledge of Channel State Information (CSI). Link selection takes place based upon the knowledge of SNR values in a given time slot. As the number of users grows monitoring the buffer status becomes a tedious task in the cooperative network. As the buffer size increases the delay introduced in the network increases, so link selection schemes needs to be properly incorporated with these buffered schemes in order to manage the delay properly. Node cooperation exploits the broadcasting nature of the information from the Source node (S).

Cooperative communications have various pros and cons which are shown next.

1.2.1 Merits and Demerits of Cooperative Communications

- Some of the key merits and demerits of using cooperative networks are cited [16] is summarized below in the form of table.

TABLE 1.1: Key Merits and Demerits

	Advantages	Disadvantages
Supportive Relaying	• Gains due to path-loss. • Maintaining Quality of Service in a balanced manner for users.	• Increased adjacent channel interference • Use of Complex Scheduling algorithms.
Relaying with Cooperation	• Gains due to Diversity. • Maintaining Quality of Service in a balanced manner for users.	• Choosing partner in an optimum manner • Use of Complex Scheduling algorithms.
Relaying with Space Time Coding (STC)	• Gains due to Diversity. • Gains due to Multiplexing. • Availability of the STC. • Maintaining Quality of Service in a balanced manner for users.	• Increment in Overhead relay congestion. • Maintaining the tight synch. • Requires estimation of the channel. • Use of Complex Scheduling algorithms.

1.2.2 Applications of Cooperative Architecture

- **Array of virtual antennas :**

As the traffic load on the network is increasing day by day, so networks with high data rate capabilities are in great demand. These demands can be met with the help of MIMO systems, but these multi antenna technique requires considerable amount of hardware and considerable signal processing even for the tiny nodes as in [17]. But this challenge can be solved with the Cooperative networks, diversity can be achieved and users can share the physical resources to create an array of virtual antennas, thereby reducing these hardware requirements.

- **Ad-Hoc Network :**

These wireless networks are termed as self organising network. Temporary network functionality is formed by the distributed nodes. These networks are wide deployed in the defence applications as well as for the educational purpose.

- **Wireless Sensor Network :**

By using the cooperative protocols the energy consumption can be reduced as it has been observed that energy consumption increases if transmission happens through the weaker links. And also the lifetime of wireless sensors can be increased. So proper integration of cooperative architecture helps in reducing the power supplied to the nodes.

- **Sensing in cognitive radio using cooperation :**

The resources in the cognitive radio system are to be mainly utilised by primary users who have the license, but for allocating these resources secondary users have to vacate these resources. So secondary users needs to sense when primary users wants to use the resources. So sensing using cooperation plays an important role as explained in [17].

1.3 Outline of Thesis

In **Chapter** 1, a brief overview of Wireless Communication and literature review of Conventional Relaying techniques, its advantages and disadvantages are discussed briefly. Also the literature review of how Cooperative communication is useful over the conventional schemes in various network layers is discussed briefly.

Chapter 2, mainly focuses on the modeling aspects of the non-regenerative technique called Amplify and Forward cooperative protocol have been presented. Outage expression has been deeply analyzed for the conventional approach. In the conventional approach, the effect of varying the distance between the (S-R) link as well as (R-D) link on the outage probability has been observed and based on which the conclusions are drawn for the conventional approach for AF protocol.

Also for the conventional approach of AF information rate has been varied and its effect is seen on the outage probability. As we proceed further in the chapter power is optimally distributed among the source node (S) and the relay node (R). For this optimal distribution, analyses have been presented and effect on outage probability is studied. Later in the chapter Incremental Amplify and Forward protocol which is embedded with buffer has been discussed in a detailed manner. The expression for the outage probability has been derived and the delay has been observed. The effect of increasing the buffer size on delay and throughput has been observed. Also, the effect of varying the information rate on the outage probability of Incremental AF relaying has been studied.

In **Chapter** 3, the work mainly focuses on the conventional Decode and Forward (DF) Relaying technique. Here the conventional DF is discussed in a detailed manner. The modeling of the Conventional DF protocol has been studied and its outage probability analyses have been carried out in an extensive fashion. In conventional DF approach the effect of varying the information rate on the outage probability has been observed. Also later in the chapter Conventional DF protocol and Conventional AF protocol is compared in terms of the Outage probability metric. The effect of power distribution between (S-R) link and (R-D) link has been studied. The optimal value of the power distribution factor $\beta_{optimum}$ is obtained graphically. Based upon the analysis of these plots conclusions are drawn.

In **Chapter** 4, Lastly, a short summary has been discussed for the present work, and conclusions are drawn based on it. Also, some future aspects have been discussed which will conclude the report.

Chapter 2

Conventional and Buffer aided Amplify and Forward (AF) Protocol

A discussion has been carried out on two different types of Amplify and Forward protocol. At first the conventional AF scheme is discussed in detail, secondly, AF scheme with incremental relaying equipped with buffer has been discussed.

2.1 Conventional Amplify and Forward Cooperative Protocol

A non-regenerative form of relaying technique known as the Amplify and Forward is discussed in the current chapter. The amplification of the signal received from the source in the analog form is amplified at the relay and then it is forwarded to the destination. This is the basic principle behind the AF scheme. More details are discussed later in this chapter. Here at the relays, it is not required to have the information regarding the modulation technique used or what type of encoding is done at the source.

Complexity of such scheme is fairly low and this scheme is desirable when the Source Relay (S-R) link doesn't meet the desirable SNR to ensure proper decoding at the relay. So to preserve the soft information it is a good idea to amplify the signal. Proceeding further in chapter the probability of outage has been analyzed for the conventional AF scheme .

2.1.1 Amplify and Forward conventional Cooperative Scheme

In this section, the modeling of system in a conventional way is done and derived the expression of the outage probability. Based on which various analyses is carried accordingly. The figure 2.1 shows the basic network which utilizes cooperative communication.

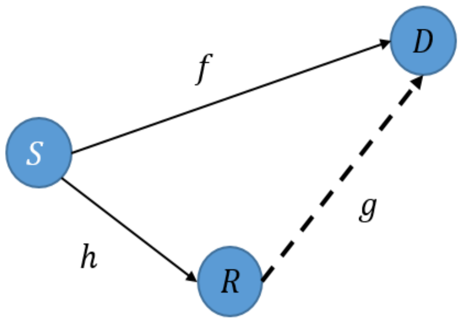

FIGURE 2.1: Wireless Cooperative Diversity Network

Here h, f, g are the channel coefficients between the (S-R), (S-D) and (R-D) links respectively. From the analysis point of view the channels are considered to be Rayleigh faded. Also the relay and destination are corrupted by noise which is AWGN in nature. The noise present at the relay and the destination is denoted as n_{sr},n_{rd} and n_{sd} which are Complex Additive White Gaussian Noise. Where $n_{sr} \sim \mathcal{CN}(0, \sigma_r^2)$, $n_{rd} \sim \mathcal{CN}(0, \sigma_d^2)$ and $n_{sd} \sim \mathcal{CN}(0, \sigma_d^2)$. The system equations can be modelled as

$$y_{sr} = h_{sr}\sqrt{P_s}x_s[m] + n_{sr}[m] \tag{2.1}$$
$$y_{rd} = h_{rd}\sqrt{P_r}x_s[m] + n_{rd}[m] \tag{2.2}$$
$$y_{sd} = h_{sd}\sqrt{P_s}x_s[m] + n_{sd}[m] \tag{2.3}$$

where P_s, P_r are source power and relay power.

In AF scheme, the amplified version of signal received at the relay is transmitted to the destination node. This transmission doesn't depend on the quality of the (S-R) link. The transmission process involves two phases. In phase I of the transmission process the bitstream $x_s = \big[x_s[0], x_s[1], \ldots, x_s[M-1]\big]$ from the source has been transmitted. Wireless medium has broadcasting nature. So when the bits are transmitted both the relay and destination will receive the signal with some noise incorporated in it.

In phase II of the transmission process, the equation 2.2 can be modified as follows, the gain provided at the relay is given by

$$g = \frac{1}{\sqrt{P_s\left|h_{sr}\right|^2 + \sigma_r^2}} \tag{2.4}$$

The transmitted symbol from relay is given by

$$x_{rd}[m] = g y_{rd}[m] \tag{2.5}$$

The overall modified equation is given by

$$y_{rd}^{*} = \sqrt{\frac{P_s P_r}{P_s\left|h_{sr}\right|^2 + \sigma_r^2}} h_{sr} h_{rd} x_s[m] + \sqrt{\frac{P_r}{P_s\left|h_{sr}\right|^2 + \sigma_r^2}} h_{rd}[m]\eta_{rd}[m] + \eta_{sd}[m] \tag{2.6}$$

Now, we begin to show the analysis used in the AF scheme.

Case 1: When direct (S-D) link is ignored:

In this case, the signal given in equation 2.6 is used at the destination for proper detection and the analysis has been taken from [18] and [13].

$$\gamma_{srd} = \frac{\gamma_{sr}\gamma_{rd}}{\gamma_{sr} + \gamma_{rd} + 1} \tag{2.7}$$

Here the $\gamma_{sr} = \frac{P_s|h_{sr}|^2}{\sigma_r^2}$, $\gamma_{rd} = \frac{P_r|h_{sr}|^2}{\sigma_d^2}$ and $\gamma_{sd} = \frac{P_s|h_{sd}|^2}{\sigma_d^2}$ are the instantaneous SNR's of the (S-R), (R-D) and (S-D) links respectively. By utilizing these SNR's we can find the maximum capacity of (S-R-D) link in a conventional AF scheme which is given as

$$C_{AF_{con}} = \frac{1}{2} log(1 + \gamma_{srd}) \tag{2.8}$$

The link will go in an outage if the capacity is less than the information rate R (in bits/sec/Hz). The probability of outage is given as $\mathcal{P}_{outage}$. As explained in detail in [18], the expression of the outage is given as

$$\mathcal{P}_{outage} = P(\gamma_{AF} < 2^{2R} - 1) \tag{2.9}$$

where $\gamma_{AF} \approx \frac{\gamma_{sr}\gamma_{rd}}{\gamma_{sr}+\gamma_{rd}}$ this is an approximation at high SNR. As explained in [18] and [13] the expression of the outage is given as

$$\mathcal{P}_{outage} = 1 - \mathfrak{a}\kappa_1(\mathfrak{a}) exp\big(- \frac{2^{2R} - 1}{\bar{\gamma}_{sr}} - \frac{2^{2R} - 1}{\bar{\gamma}_{rd}}\big) \tag{2.10}$$

where $\mathfrak{a} = \frac{2(2^{2R}-1)}{\sqrt{\bar{\gamma}_{sr}\bar{\gamma}_{rd}}}$ and $\kappa_1(.)$ is a Bessel function with first-order dynamics. Utilizing the higher-order approximation of Bessel Function that is $\kappa(x) = \frac{1}{x}$ then at higher values of SNR the equation (2.10) can be approximately written as

$$\mathcal{P}_{outage} = 1 - exp\big(-\frac{2R-1}{\bar{\gamma}_{sr}}\big)exp\big(-\frac{2R-1}{\bar{\gamma}_{rd}}\big) \tag{2.11}$$

Here we have assumed channel to be Rayleigh faded. In which the channel coefficients h_{sr}, h_{rd}, h_{sd} are considered to be Gaussian Circularly Symmetric Random Variable with zero mean and variances as δ_{sr}^2, δ_{rd}^2 and δ_{sd}^2.

$h_{sr} \sim \mathcal{CN}(0, \delta_{sr}^2)$ and $h_{rd} \sim \mathcal{CN}(0, \delta_{rd}^2)$. Also, these channel coefficients are iid. The mean of the instantaneous SNR's is given by $\bar{\gamma}_{sr} = \frac{P_s\delta_{sr}^2}{\sigma_r^2}$ and $\bar{\gamma}_{rd} = \frac{P_r\delta_{rd}^2}{\sigma_d^2}$.

By using the above analysis the conventional AF scheme is analyzed and the results are shown. Here we have varied the distances between the links and their effects are observed on the outage probability. Variances of the channel are considered to vary in accordance with the distance. That is $\delta_{sr}^2 = d^{-\alpha}$, $\delta_{rd}^2 = d^{-\alpha}$ and $\delta_{sd}^2 = d^{-\alpha}$.

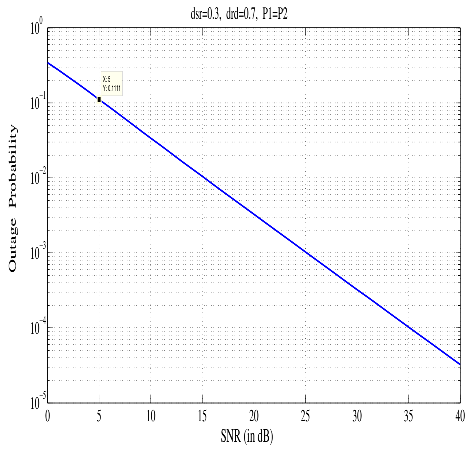

FIGURE 2.2: Configuration 1.

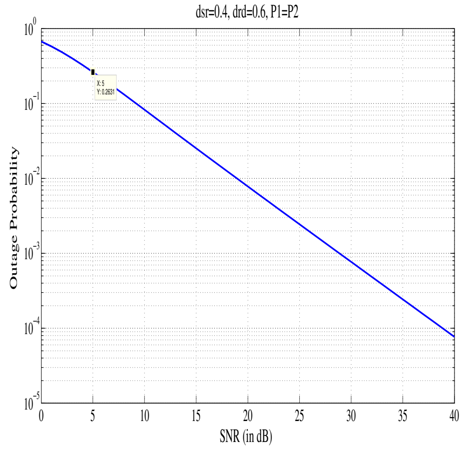

FIGURE 2.3: Configuration 2.

We can observe from the plots as the distance between the (S-R) link keeps on increasing the outage probability keeps on increasing. So in AF protocol link distances play a vital role in the analysis of the outage probability. From figure (2.2), (2.3), (2.4) and (2.5) the outage probability at 5 dB point is 0.1111, 0.2631, 0.7002 and 0.8684 respectively. As you can see from the data that outage probability increases as the (S-R) link distance increases.

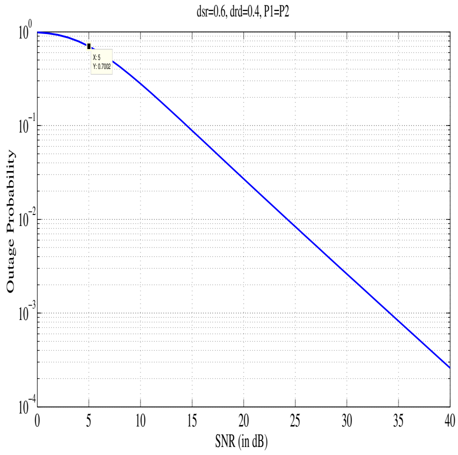

FIGURE 2.4: Configuration 3.

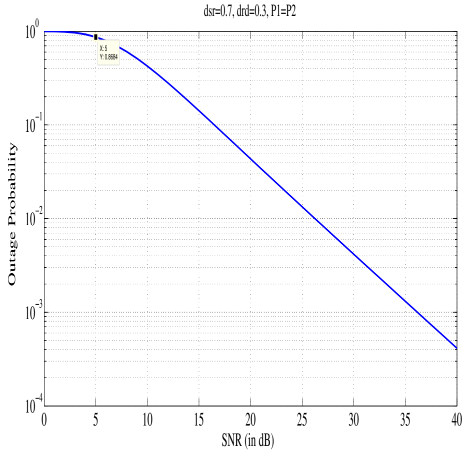

FIGURE 2.5: Configuration 4.

While plotting the above graphs we have set $P_s = 2\beta P$ and $P_r = 2(1-\beta)P$ where P is the total power.

The next plot shows the effect of the information rate R on the outage probability.

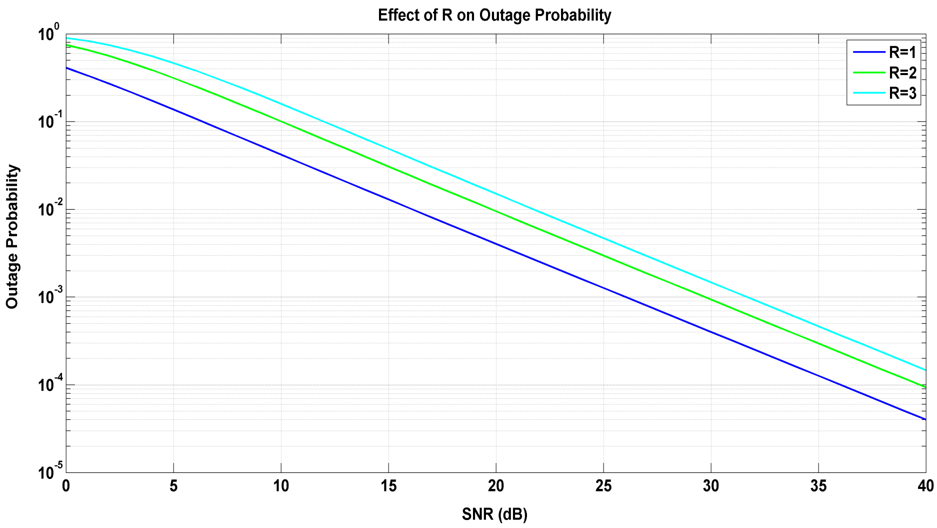

FIGURE 2.6: Effect of R on Outage Probability

As from figure (2.6) it can be seen that as we try to increase the information rate beyond the capacity of the channel than the probability of outage increases.

In the next plot, we have used the optimal power allocation and then compared it with the non-optimal conventional AF scheme. The optimal power distribution uses the following equation as explained in [14].

$$\begin{aligned} \max_{P_s} \quad & f_0(P_s) \\ \text{subject to} \quad & 0 \leq P_s \leq 2P \end{aligned} \tag{2.12}$$

where, $f_0(P_s) = \frac{c1}{c2}$ and $c_1 = P_s(2P - P_s)\frac{|h_{sr}|^2|h_{rd}|^2}{\sigma_r^2\sigma_d^2}$ and $c_2 = 1 + \frac{|h_{rd}|^2(2P-P_s)}{\sigma_d^2} +$ $+P_s\frac{|h_{sr}|^2}{\sigma_r^2}$. After solving the optimization problem in (2.12), the solutions obtained are given by

$$\begin{aligned} P_s &= \frac{2Pa_1}{a_1 + a_2} \\ P_r &= \frac{2Pa_2}{a_1 + a_2} \end{aligned} \tag{2.13}$$

where $a_1 = \sqrt{1 + \frac{2P|h_{rd}|^2}{\sigma_d^2}}$ and $a_2 = \sqrt{1 + \frac{2P|h_{sr}|^2}{\sigma_r^2}}$.

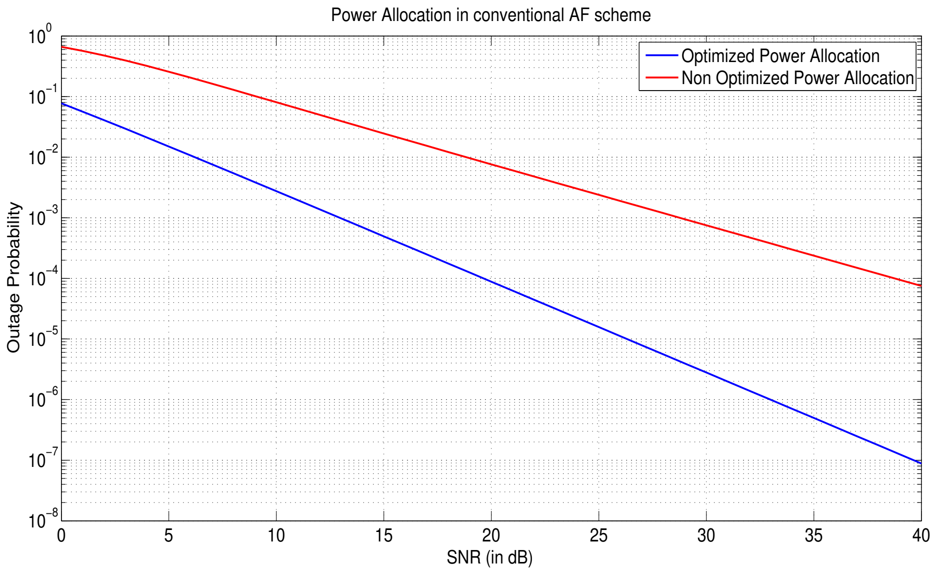

FIGURE 2.7: Comparison in Conventional AF with Optimal Power Allocation AF

In the next figure, the Optimal Conventional AF is analyzed by varying the information rates. And it again shows that as the information rate increases the outage probability keeps increasing.

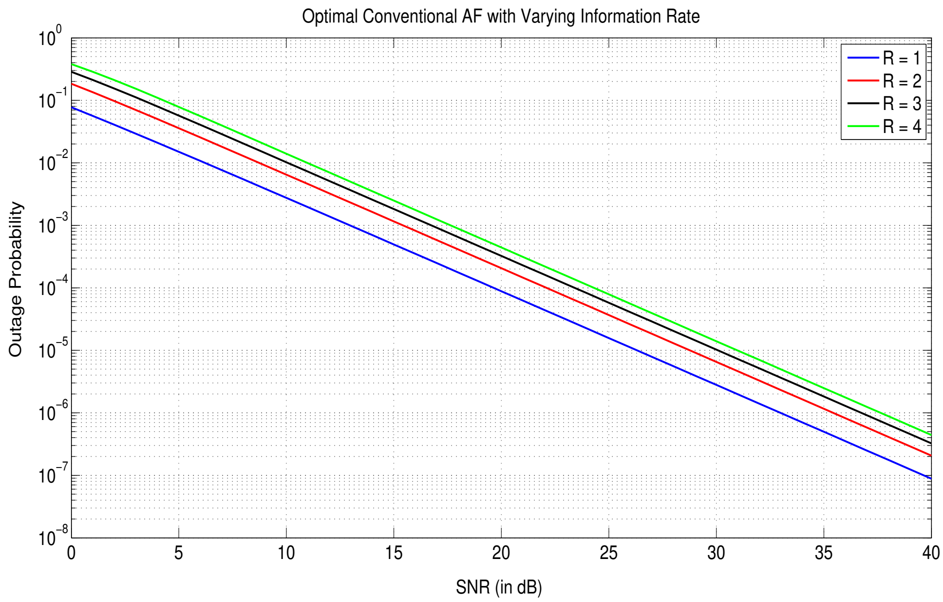

FIGURE 2.8: Outage Probability in Optimal Conventional AF for various rates

The next graph in figure (2.9) describes the throughput variation with information rate in Optimal Conventional AF and also the Conventional AF has been compared with its best case $R = 1$ (since the outage probability is low in that case) and we found that even with $R = 4$ in Optimal Conventional AF, the throughput is better than Conventional AF with $R = 1$.

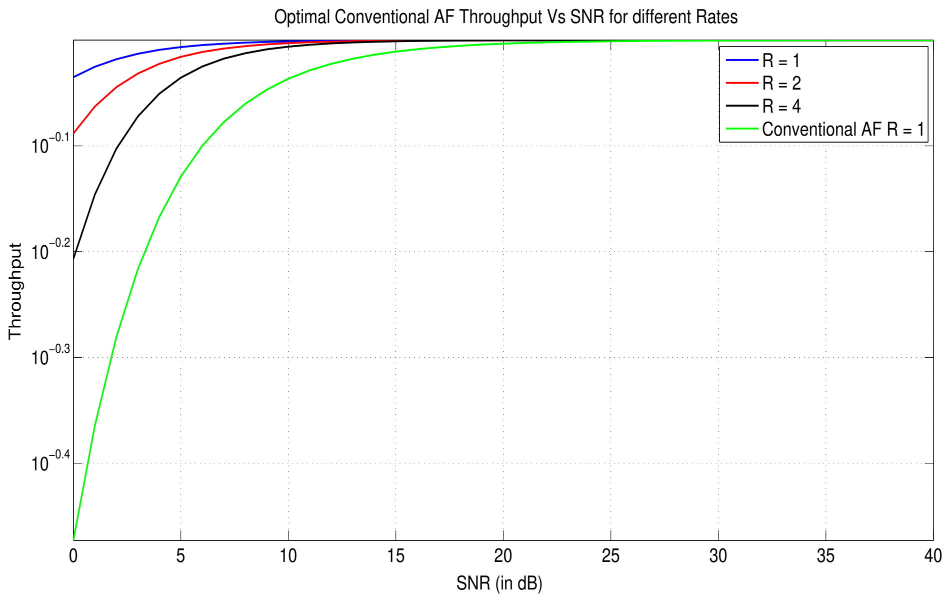

FIGURE 2.9: Throughput Variations with information Rate

2.2 Incremental Amplify and Forward (AF) with Buffer

Here in this section Incremental AF scheme equipped with the buffer has been discussed. This scheme consists of 3 nodes that are Source (S), Relay (R), and Destination (D). The relay is equipped with a buffer of finite size. In this scheme, the diversity is considered in terms of the packets. This cooperative scheme works in such a manner that the packets which go through worst channel condition in the (S-R) link will have reliable channel conditions in (R-D) link. Here in this scheme, the packet is broadcasted by the source, will eventually hear by both the relay node and the destination node. If the transmission through the (S-D) link fails then the source needs the help of the relay node. At the destination node in order to combine the signal coming via relay node and the source node Maximum Ratio Combining Technique (MRC) is used.

Here discussion on the incremental AF technique which is equipped with the buffer for storing the data packets sent from the source is carried out. In this technique selection of the link depends on the instantaneous SNR's of the link. As shown in [19] and [20] when (S-R) link is reliable than the relay receives the data packet and store it in the buffer and when the (R-D) link is active than relay sends the data packet towards the destination node. The basic incremental AF scheme equipped with the buffer is explained by the figure as cited in [20].

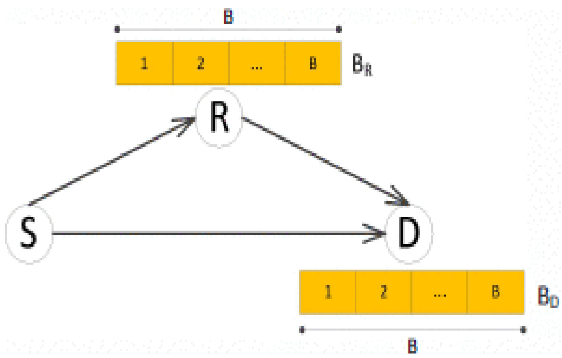

FIGURE 2.10: Basic buffer equipped AF scheme

The figure shows three nodes in which (R) and (D) nodes are equipped with the buffers of finite length $\mathcal{B}$. Generally, the schemes which incorporate the use of the buffers are fairly complex. As the introduction of the buffers will cause a delay in the system. The scheme presented here operates in two phases. Also, direct(S-D) link hasn't been ignored in this scheme. In phase I of the transmission the source broadcasts the information packets. These packets are heard by both the

Source (S) and Destination (D) nodes. On successful reception at the destination, the node then sends a positive feedback signal to the relay, after that the relay drops the packet from its buffer and indicates that packet reception is successful. But if destination doesn't receive the packet successfully than it sends negative feedback to the relay node (R) and stores the packet along with its Channel State Information in the buffer $\mathcal{B}$. In response to the negative feedback, the node R also stores a copy of the same packet along with its Channel State Information in its buffer B_r. Until the buffer is fully filled the process continues.

In phase II of the transmission process Relay node will transmit and the Destination node will receive. The destination picks the packet from the buffer of the relay if the equation (2.14) is satisfied as given in [20].

$$\gamma^d > \gamma^{sd} + \gamma^{srd} \tag{2.14}$$

where γ^{srd} is the instantaneous SNR on the dual-hop path from source to the destination node and its value is calculated as $\gamma^{srd} = \frac{\gamma^{sr}\gamma^{rd}}{1+\gamma^{sr}+\gamma^{rd}}$. The reliable selection of the packet is based on the $\gamma^{th} = 2^{2R} - 1$. Here Maximum Ratio Combining Technique has been employed as given in [20].

2.2.1 System Modelling

Mathematically the transmission process is described according to the following equations

$$y^{sd}[m] = \sqrt{P_{ts}} b_s h_{sd}[m] + \eta_{sd}[m] \tag{2.15}$$
$$y^{sr}[m] = \sqrt{P_{ts}} b_s h_{sr}[m] + \eta_{sr}[m] \tag{2.16}$$
$$y^{rd}[m] = \sqrt{P_{tr}} b_r h_{rd}[m] + \eta_{rd}[m] \tag{2.17}$$

where $b_r = \mathfrak{g} y^{sr}[m]$ and $\mathfrak{g}$ is given by (2.4). And the other symbols used in the above set of equations have there usual meaning. After applying the MRC technique at the destination node (D) the received signal equation becomes as in equation (2.18)

$$y^d[m] = y^{sd}[m] + y^{srd}[m] \tag{2.18}$$

Now proceeding further into the chapter to analyze the expression of the outage probability with the help of Probability Density Function (PDF) and the Cumulative Density Function (CDF). As in the given scheme, Amplify and Forward protocol is used, so only the destination is capable of decoding the packets. The signal reaching the destination is detectable if its SNR value is greater than the threshold SNR (γ^{th}). Therefore, instantaneous SNR at the destination is given by the expression in equation (2.19)

$$\gamma^{d} = \gamma^{sd} + \gamma^{srd} \tag{2.19}$$

As we have taken the channels to be suffered by Rayleigh Fading the PDF of any general link (p-q) is given to be exponential.

$$f_{pq}^{\gamma}(\gamma) = \frac{1}{\bar{\gamma}_{pq}} e^{-\dfrac{\gamma}{\bar{\gamma}_{pq}}} \tag{2.20}$$

$$F_{pq}^{\gamma}(\gamma) = 1 - f_{pq}^{\gamma} \tag{2.21}$$

The CDF of the dual-hop link is given by

$$\begin{aligned} F_{srd}^{\gamma}(\gamma^{th}) &= \mathcal{P}(\gamma^{srd} \leq \gamma^{th}) \\ &= 1 - \int_{\gamma^{th}}^{\infty} f_{rd}^{\gamma}(\gamma)\big[1 - F_{sr}^{\gamma}\big(\frac{\gamma^{th}(\gamma+1)}{\gamma - \gamma^{th}}\big)\big]\, d\gamma \end{aligned} \tag{2.22}$$

Using the instantaneous SNR of (R-D) link that is γ^{rd} the relay node chooses among the $\mathcal{B}$ packets that are stored in the relay buffer such that $\gamma^{d} \geq \gamma^{th}$. Therefore, F_{sr}^{γ} can be expressed as

$$F_{sr}^{\gamma}(\gamma) = (1 - e^{-\frac{\gamma}{\bar{\gamma}_{sr}}})^{\mathcal{B}} \tag{2.23}$$

Using the above equation (2.23) and substituting in the (2.22) we obtain,

$$\begin{aligned} F_{srd}^{\gamma}(\gamma^{th}) &= 1 - \int_{0}^{\infty} \frac{e^{-\frac{\gamma+\gamma^{th}}{\bar{\gamma}_{rd}}}}{\bar{\gamma}_{rd}} \times \left(\sum_{n=1}^{\mathcal{B}} \binom{\mathcal{B}}{n} (-1)^{n} e^{-\frac{\gamma^{th} n(\gamma+\gamma^{th}+1)}{\gamma}} \right) d\gamma \\ &= 1 + \sum_{n=1}^{\mathcal{B}} \binom{\mathcal{B}}{n} (-1)^{n} \frac{e^{-\gamma^{th}\frac{\bar{\gamma}_{sr}+n\bar{\gamma}_{rd}}{\bar{\gamma}_{sr}\bar{\gamma}_{rd}}}}{\bar{\gamma}_{rd}} \int_{0}^{\infty} e^{\left(\frac{\gamma^{th} n(\gamma^{th}+1)}{\gamma\bar{\gamma}_{sr}} - \frac{\gamma}{\bar{\gamma}_{rd}}\right)} d\gamma \end{aligned} \tag{2.24}$$

By using the following identity

$$\int_0^\infty e^{\left(-\frac{c_1}{4p}-c_2p\right)}dp = \sqrt{\frac{c_1}{c_2}}\kappa_1(c_1c_2) \tag{2.25}$$

the equation (2.24) can be reduced to

$$F^{\gamma}_{srd}(\gamma^{th}) = 1 + \sum_{n=1}^{\mathcal{B}} \binom{\mathcal{B}}{n}(-1)^n e^{\frac{a_1}{\bar{\gamma}_{rd}}} 2\sqrt{b_1}\kappa_1(2\sqrt{b_2}) \tag{2.26}$$

where, $a_1 = \frac{e^{-\gamma^{th}\frac{\bar{\gamma}_{sr}+n\bar{\gamma}_{rd}}{\bar{\gamma}_{sr}\bar{\gamma}_{rd}}}}{\bar{\gamma}_{rd}}$, $b_1 = \frac{\gamma^{th}n(\gamma^{th}+1)\bar{\gamma}_{rd}}{\bar{\gamma}_{sr}}$ and $b_2 = \frac{\gamma^{th}n(\gamma^{th}+1)}{\bar{\gamma}_{sr}\bar{\gamma}_{rd}}$ The CDF at the destination node can be given by the equation as cited in [19].

$$\begin{aligned} F^{\gamma^d}(\gamma^{th}) &= \int_0^\infty F^{\gamma}_{srd}(\gamma) f^{\gamma}_{sd}(\gamma^{th}-\gamma)d\gamma \\ &= (1-e^{-\frac{\gamma^{th}}{\bar{\gamma}_{sd}}}) + \sum_{n=1}^{\mathcal{B}} \binom{\mathcal{B}}{n}(-1)^n \frac{\bar{\gamma}_{sr}\bar{\gamma}_{rd}(e^{k_2 - e^{-\frac{\gamma^{th}}{\bar{\gamma}_{sd}}}}}{k_3}) \end{aligned} \tag{2.27}$$

where, $k_2 = -\gamma^{th}\left(\frac{\bar{\gamma}_{sr}+n\bar{\gamma}_{rd}}{\bar{\gamma}_{sr}\bar{\gamma}_{rd}}\right)$ and $k_3 = \bar{\gamma}_{sr}\bar{\gamma}_{rd} - \bar{\gamma}_{sr}\bar{\gamma}_{sd} - \bar{\gamma}_{sd}\bar{\gamma}_{rd}$

The outage probability is nothing but the SNR at the destination node (D) is unable to cross the bare minimum γ^{th}. That is in the mathematical form $\gamma^d < \gamma^{th}$. In phase II of the transmission process and by utilizing the instantaneous SNR of the (R-D) link, a packet is chosen from the buffer $\mathcal{B}_r$ and then sent at the destination node and from the buffer of node R that is $\mathcal{B}_d$ same packet copy is accessed and combined using the MRC technique.

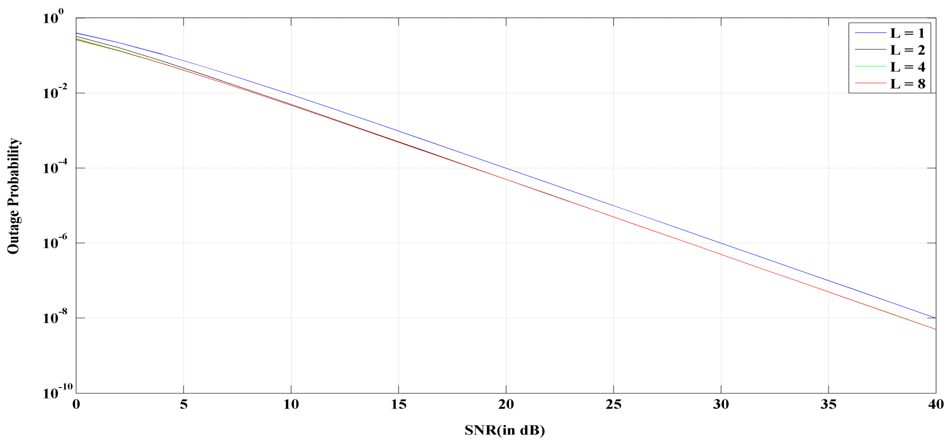

FIGURE 2.11: Incremental Buffer Aided AF scheme

The equation of the outage probability is given by

$$\mathcal{P}^{outage} = \int_0^{\gamma^{th}} f^{\gamma^d}(\gamma) = F^{\gamma^d}(\gamma^{th}) \tag{2.28}$$

By using the expression in equation (2.28) the plot of outage probability can be plotted as in figure (2.11). The zoomed view of the above plot is shown in figure (2.12) to clearly distinguishes between the buffer sizes.

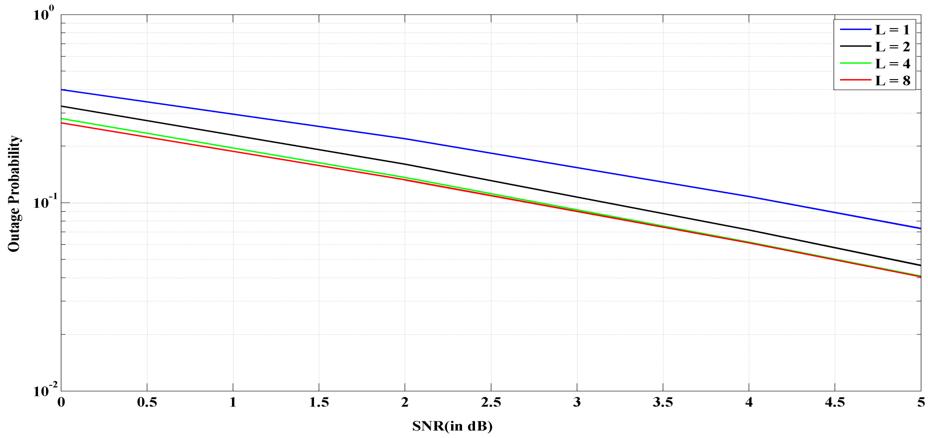

FIGURE 2.12: Zoomed View of Incremental Buffer Aided AF scheme

2.2.1.1 Delay due to Buffers

As the buffers are involved in this scheme so the packets transmitted in the scheme might experience the delay. This is happening because a packet is selected in the scheme only when its SNR meets the condition given in the equation (2.14). As mentioned in the article [20] there are two types of delays involved in this scheme. The first one is the Block Delay t^b and the Second type of delay that is involved in this scheme is the Packet Delay t^p. Time slots are used to capture the delay. It is the time required by the packet to travel over the link. The total delay in phase I and phase II can be expressed as

$$t^b = t^b_{p_1} + t^b_{p_2} \tag{2.29}$$

$$t^p = t^p_{p_1} + t^p_{p_2} \tag{2.30}$$

- **Block Delay**

When all the transmitted packets from the source reach the destination node that is defined as the block delay. If it takes say t_1 time slot to fill the buffer $\mathcal{B}_r$ and same t_1 time to remove the packets from the buffer than total block delay present in the dual-hop link is given by

$$t^b = 2t_1 \tag{2.31}$$

When the packets are directly transmitted using the (S-D) link in this case we define an outage factor as δ which is given as

$$\delta = \begin{cases} 1 & \gamma^{sd} \leq \gamma^{th} \\ 0 & \gamma^{sd} > \gamma^{th} \end{cases} \tag{2.32}$$

Combining the block delay and packet delay to the one equation which is given by

$$t^b = \delta t_1 + 2(1-\delta)t_1 \tag{2.33}$$

If the transmission of the packets over (S-D) link is successful then the $\delta = 1$ and block delay reduces to $t^b = t_1$. Otherwise $\delta = 0$ and the block delay is $t^b = 2t_1$.

- Packet Delay

This delay is calculated for a particular packet. The lowest delay will be considered for the packet which enters the buffer last and leaves it first. However, the highest delay is considered for the packet which enters the buffer first and waits till $\mathcal{B}-1$. (R-D) link is utilized for phase II of the transmission process which requires $\mathcal{B}$ time slots to empty the buffer. So the overall equation dealing the dual-hop transmission and the single-hop transmission of the packet is given by

$$t^b = \delta t_1 + 2(1-\delta)t_1 \tag{2.34}$$

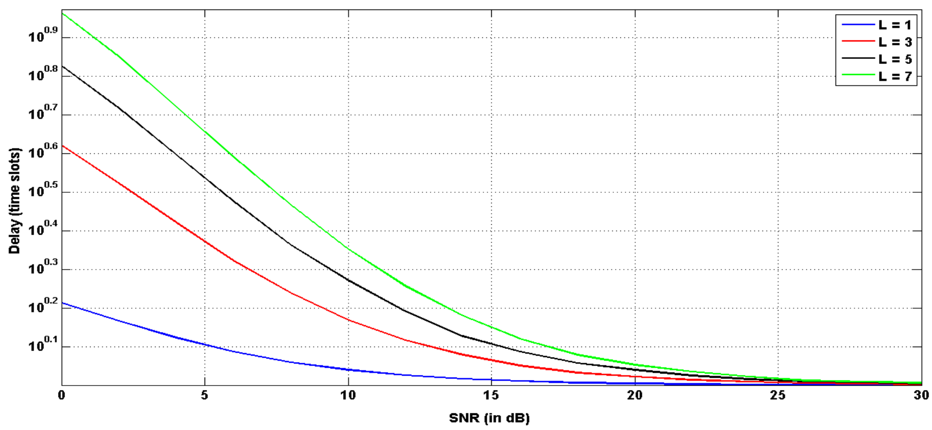

FIGURE 2.13: Delay in Buffer Aided AF scheme

The figure in (2.13) considers two aspects for delay variations which involves increased buffer size as well as increased SNR. From the plot, it can be observed that with the increase in the buffer size the delay keeps on increasing especially for lower values of Signal to Noise Ratio. This happens because as the buffer size increases packet has to wait for more time before it gets transmitted towards the destination node. At higher values of SNR the delay decreases as the (S-D) link has the required SNR value to transmit the packet.
The next plot in figure (2.14) shows the behavior of Outage Probability with the variation of the information rates.

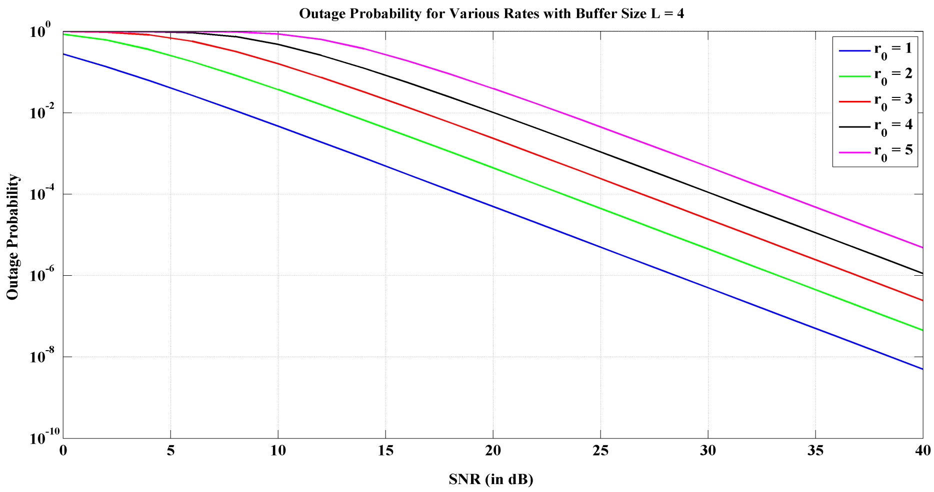

FIGURE 2.14: Outage Probability with varied R in Buffer Aided AF scheme

As from the figure one can observe that as the rate of information tries to exceed the capacity of the channel the probability of link going into outage increases. Here we have kept the buffer size as the constant that is $L = 4$.

- Throughput

Now here we are going to show the relationship between the throughput and delay. As mentioned in [20] it is defined as the information transmitted per unit time is known as the throughput. Mathematically it is expressed as

$$\tau = \frac{r_0}{t^p} \tag{2.35}$$

Utilising equation (2.34) and putting in equation (2.35) we get,

$$\tau = \frac{r_0}{\delta t_1 + 2(1-\delta)t_1} \tag{2.36}$$

From equation (2.36) it can be observed that the τ lies between $\frac{r_0}{2t_1} \leq \tau \leq r_0$. That is when transmission takes place through the dual hop link the throughput is $\tau = \frac{r_0}{2t_1}$ or if the transmission takes place via direct link the throughput will become $\tau = r_0$. The graph between Throughput and SNR is given in figure (2.15).

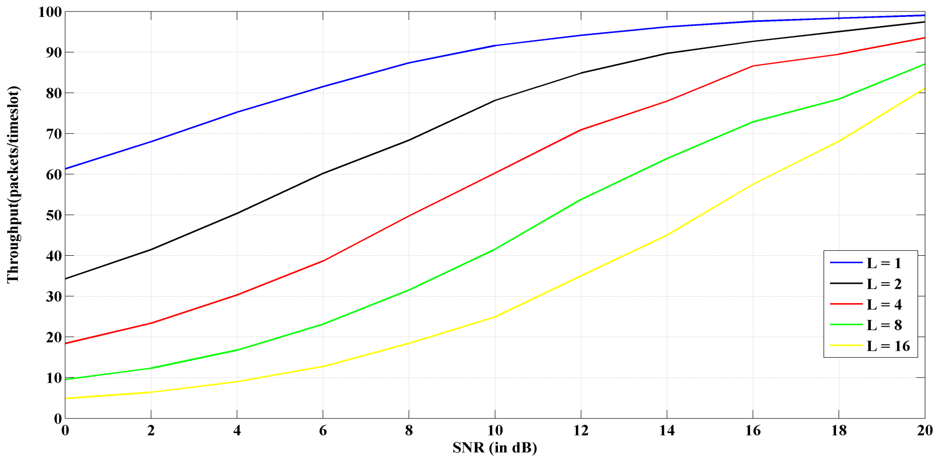

FIGURE 2.15: Throughput Vs SNR for varied Buffer Size in Incremental AF Scheme

The figure in (2.15) shows the variation of the throughput with the increasing value of SNR. Maximum throughput can be observed around 60% which occurs for the buffer $\mathcal{B}_r$ when its length is $L = 1$. As the buffer size keeps increasing the throughput decreases. This is happening because the packets are transmitted in the two phases. As buffer size increases more time is required for the packet to get transmitted which ultimately affects the throughput. As from the plot, one can see that for higher values of SNR the throughput tends to approach towards 100%. This is because the transmission can happen successfully over the (S-D) link. So the main conclusion can be drawn as the buffer size increases for the lower values of the SNR the throughput decreases.

Chapter 3

Conventional Decode and Forward Method

In this chapter, the discussion of the conventional DF scheme is done. Here, discussion on a single relay based approach is carried out. Here the main focus on the effect of power distribution factor on the Outage probability. The optimum value of the power distribution factor is obtained. Impact of optimal value of power distribution factor β is observed on the Capacity of the links.

3.1 Decode and Forward conventional Cooperative Scheme

The main idea behind the decode and forward method is that the message signal sent by the source node (S) is received at the relay and then the relay node (R) is responsible for the decoding of the message signal before it is sent towards the destination node (D). The conventional DF scheme also follows the two user Cooperative Network for communication as shown in figure (3.1). The figure shown below is a three node arrangement. The communication over the below network is done in two phases. Phase I is shown by the solid line and Phase II by dotted line.

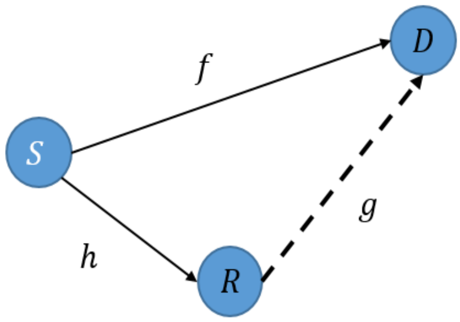

FIGURE 3.1: Wireless Cooperative Diversity Network

where $h = h_{sr}$, $f = h_{sd}$, $g = h_{rd}$ are the channel coefficients between the (S-R), (S-D) and (R-D) links respectively. From the analysis point of view the channels are considered to be Rayleigh faded. Also, the relay and destination are corrupted by noise which is AWGN in nature. The noise present at the relay and the destination is denoted as η^{sr},η^{rd} and η^{sd} which are Complex additive white Gaussian Noise. Where $\eta^{sr} \sim \mathcal{CN}(0, \sigma_r^2)$, $\eta^{rd} \sim \mathcal{CN}(0, \sigma_d^2)$ and $\eta^{sd} \sim \mathcal{CN}(0, \sigma_d^2)$. The system equations can be modelled as in [14]

$$y_{sr} = h_{sr}\sqrt{P_{ts}}b_s[m] + \eta^{sr}[m] \tag{3.1}$$
$$y_{rd} = h_{rd}\sqrt{P_{tr}}b_s[m] + \eta^{rd}[m] \tag{3.2}$$
$$y_{sd} = h_{sd}\sqrt{P_{ts}}b_s[m] + \eta^{sd}[m] \tag{3.3}$$

where P_{ts} denotes the power transmitted by the source node and P_{tr} denotes the power transmitted by the relay node. Here the channel is assumed to be i.i.d. and one can invoke the theorem related to the channel capacity to ensures that the relay will decode the message properly if the information rate doesn't exceed the capacity of the (S-R) link. The link capacity of the (S-R) link is given by

$$C_{sr}(\gamma^{sr}) = log_2(1 + \gamma^{sr}) \tag{3.4}$$

where $\gamma^{sr} = \frac{P_{ts}|h_{sr}|^2}{\sigma_r^2}$. Outage of the link will happen when $2r_0 > C_{sr}(\gamma^{sr})$. Else decoding at the relay is successfully achieved if $2r_0 \leq C_{sr}(\gamma^{sr})$. After the decoding is successful the message is transmitted towards the destination and this is the phase II of the transmission process and its equation is given by(3.2). In these two phases of transmission 2 copies are reached at the destination node (D). One through (S-D) link and the other through (R-D) link. When the source and the destination nodes are at a larger distance than the signal reaching via (S-D) link can be discarded. But if they are similar in the strength then they have to be combined at the destination. Here we have assumed that the direct link is weak for the outage probability analysis.

Case 2: When direct (S-D) link is ignored:

The detection at the destination node is based only on the signal received via the Dual hop link. For the transmission to be successful the following condition mentioned in [14] must be satisfied.

$$2r_0 \leq min\{log_2(1+\gamma^{sr}), log_2(1+\gamma^{rd})\} \tag{3.5}$$

where $\gamma^{sr} = \frac{P_{ts}|h_{sr}|^2}{\sigma_r^2}$ and $\gamma^{rd} = \frac{P_{tr}|h_{rd}|^2}{\sigma_d^2}$. The capacity of the conventional DF scheme is given by

$$C^{DF}(\gamma^{sr}, \gamma^{rd}) = \frac{1}{2} min\{log_2(1+\gamma^{sr}), log_2(1+\gamma^{rd})\} \tag{3.6}$$

The expression of outage probability is given as

$$\begin{aligned} \mathcal{P}_{outage} &= \mathcal{P}_r(min\{C_{sr}(\gamma^{sr}), C_{sr}(\gamma^{rd})\} < 2r_0) \\ &= 1 - \mathcal{P}_r(min\{C_{sr}(\gamma^{sr}), C_{sr}(\gamma^{rd})\} \geq 2r_0) \\ &= 1 - \mathcal{P}_r(min\{C_{sr}(\gamma^{sr}) \geq 2r_0, C_{sr}(\gamma^{rd}) \geq 2r_0\}) \end{aligned} \tag{3.7}$$

where $C_{sr}(\gamma^{sr}) = log_2(1+\gamma^{sr})$ and $C_{rd}(\gamma^{rd}) = log_2(1+\gamma^{rd})$. Also h_{sr} and h_{rd} are assumed to be i.i.d and with Complex AWGN distribution given as $h_{sr} \sim \mathcal{CN}(0, \delta_{sr}^2)$ and $h_{rd} \sim \mathcal{CN}(0, \delta_{rd}^2)$. Also γ^{rd} and γ^{rd} will follow the exponential distribution. The mean value of these exponential distribution can be given as $\bar{\gamma}^{sr} = \frac{P_{ts}\delta_{sr}^2}{\sigma_r^2}$ and $\bar{\gamma}^{rd} = \frac{P_{tr}\delta_{rd}^2}{\sigma_d^2}$. Using equation (3.7) the expression of outage can be further written as

$$\begin{aligned} \mathcal{P}_{outage} &= 1 - \mathcal{P}_r(\gamma^{sr} \geq 2^{2r_0} - 1)\mathcal{P}_r(\gamma^{rd} \geq 2^{2r_0} - 1) \\ &= 1 - \left(e^{-\frac{2^{2r_0}-1}{\bar{\gamma}^{sr}}}\right)\left(e^{-\frac{2^{2r_0}-1}{\bar{\gamma}^{rd}}}\right) \end{aligned} \tag{3.8}$$

By utilising the power constraint $P_{ts} + P_{tr} \leq 2P_t$, thus making $P_{ts} = 2\beta P_t$ and $P_{tr} = 2(1-\beta)P_t$. Where β denotes the power distribution factor. At the higher values of the SNR the expression of the outage probability given in (3.8) can be approximated as

$$\mathcal{P}_{outage} = \frac{2^{2r_0} - 1}{\bar{\gamma}^{sr}} + \frac{2^{2r_0} - 1}{\bar{\gamma}^{rd}} \tag{3.9}$$

If the transmission has taken place directly than the outage probability expression is given by

$$\mathcal{P}_{outage}^{direct} = \mathcal{P}_r(\gamma^{sd} < 2^{r_0} - 1) \qquad (3.10)$$
$$= 1 - \left(e^{-\frac{2^{r_0}-1}{\bar{\gamma}^{sd}}}\right)$$

Now we will show the outage probability plot of the conventional DF scheme.

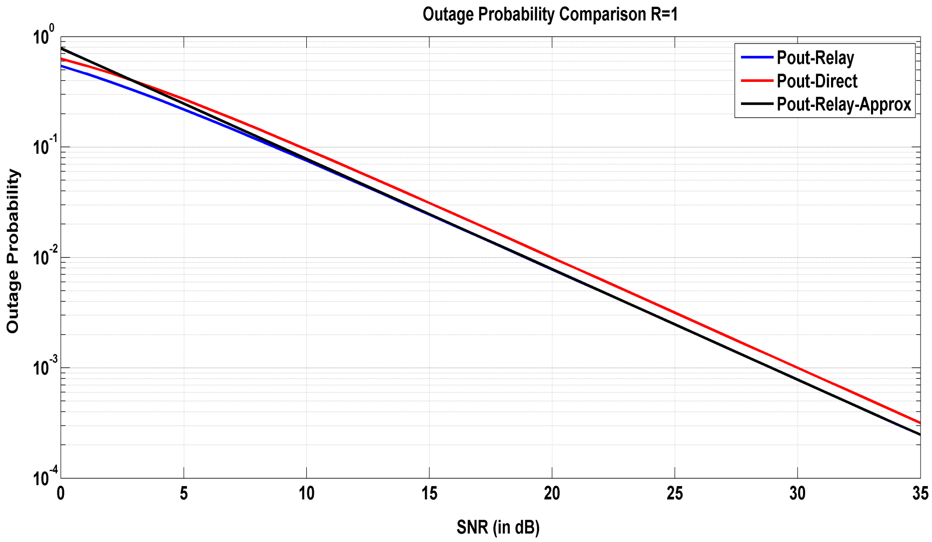

FIGURE 3.2: Outage Probability of Conventional DF scheme

The figure shows the outage probability of the conventional DF based relay scheme which is compared to the direct transmission of the message signal, shown in red colour. Also higher SNR approximation is plotted for the dual-hop DF relay-based scheme which is shown by a black line. It can be observed from the plot that the dual-hop path is more favourable compared to the direct transmission. Here information rate $r_0 = R = 1$ is considered.

The next plot in figure (3.3) will show the variation of the outage probability in Conventional DF relay scheme varied with SNR and keeping power distribution factor β same. From the plot in (3.3) it can be concluded that as the β keeps on increasing the probability of link going into the outage will also keep increasing. This happens because we are trying to give more power to (R-D) link over the link (S-R). In the next figure (3.2), variation of the power distribution factor β keeping the SNR same is shown. The plot shows that $\beta = 0.5$ is the optimum value for any SNR. It can be easily observed that for every value of SNR the outage probability is minimum when $\beta = 0.5$. Also in the figure, the comparison of conventional DF with conventional AF is done and found that conventional DF performs in a better way.

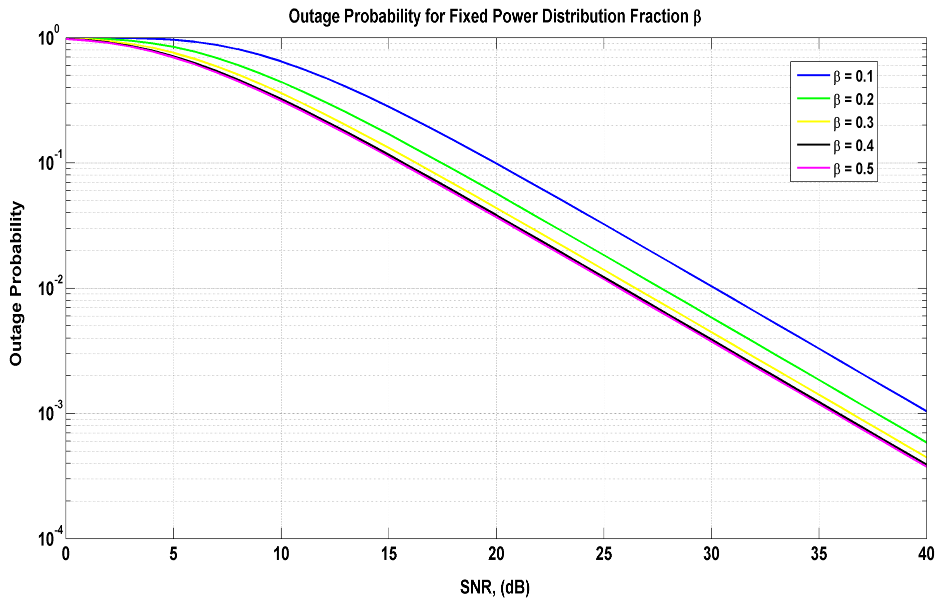

FIGURE 3.3: Outage Probability of Conventional DF scheme for various β

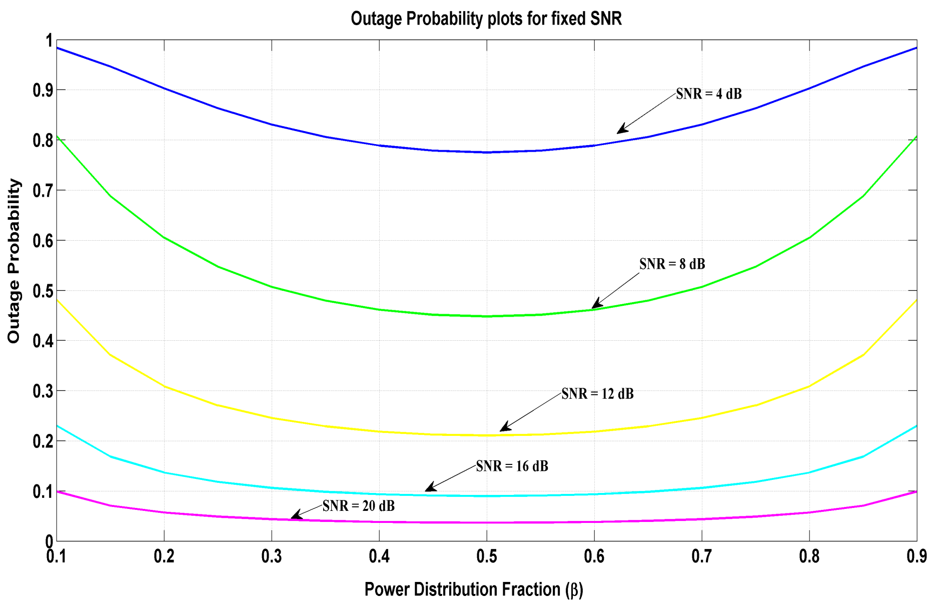

FIGURE 3.4: Outage Probability of Conventional DF scheme for with varied Power Distribution Factor

From figure (3.5) we can see that the conventional DF performed in a better manner. At 5 dB point the value of outage probability for conventional DF is

0.2111 and for Conventional AF 0.2572. Here power distribution factor is kept at $\beta = 0.5$.

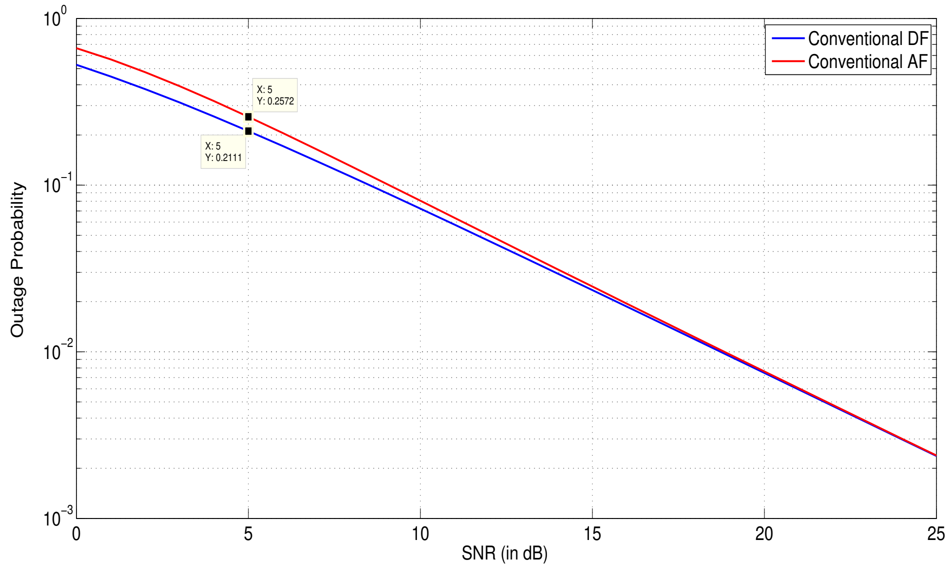

FIGURE 3.5: Comparison of $\mathcal{P}^{outage}$ of Conventional DF and Conventional AF

In the next plot in figure (3.6) shows the variation of the outage probability with the multiple values of the information rates. It can be observed that as we try to increase the information rate beyond the capacity of the channel than the probability of link getting into outage increases.

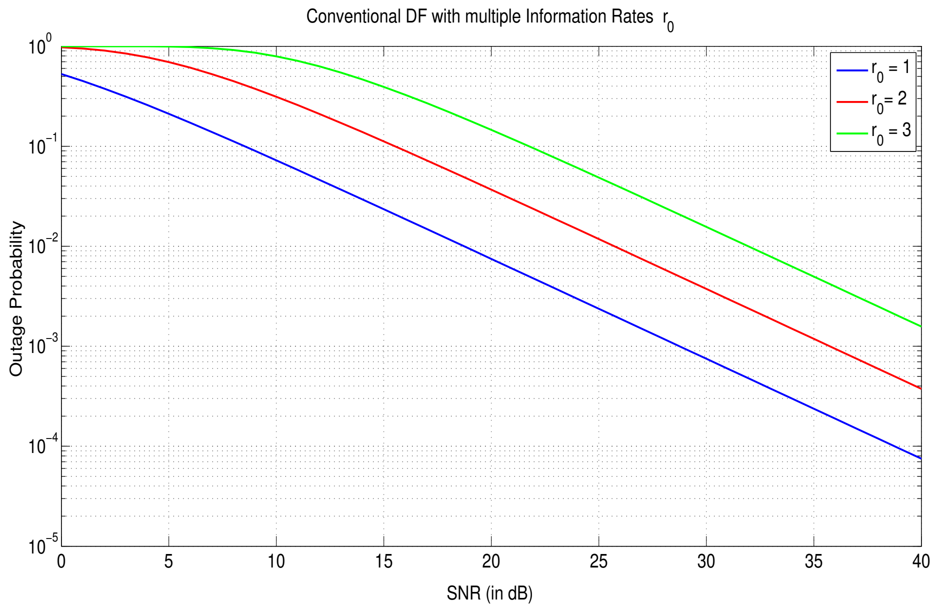

FIGURE 3.6: Outage Probability with multiple R

Next plot in figure (3.7) will show the capacity of DF scheme which is varied against two indexes, that keeping the power distribution factor fixed and varying SNR in increasing manner, it is found that the capacity increases. Also, if lesser power is supplied to the (S-R) link then its capacity decreases. It can be clearly observed that when $\beta = 0.5$ the capacity is more compared to when $\beta = 0.3$ and $\beta = 0.1$.

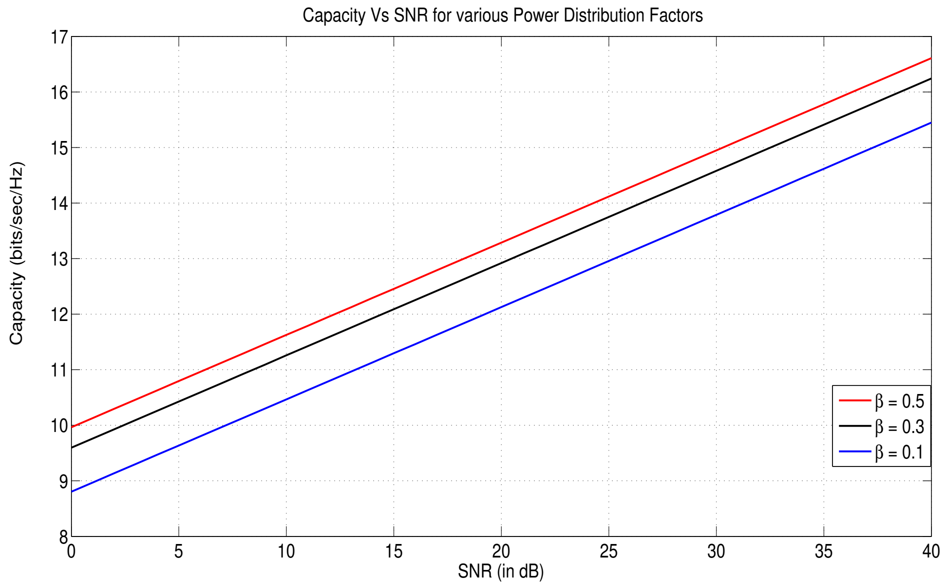

FIGURE 3.7: Capacity Vs SNR for fixed β

Chapter 4

Conclusion and Future Aspects

This chapter will give you a brief idea and a summary of the conclusions which are drawn in this report. In chapter (2) the following things have been discussed in a detailed manner and some conclusions are drawn.

- In section (2.1) Conventional AF Cooperative protocol has been discussed. Its equations are modelled and the expression of outage probability has been derived and analysed.

- The distance between (S-R) link and (R-D) link is varied in figure (2.2), (2.3), (2.4) and (2.5) the outage probability at 5 dB point is 0.1111, 0.2631, 0.7002 and 0.8684 respectively. You can see in those plots that as long as the distance between the (S-R) link is increased the probability of outage is increased. This is happening because the link SNR degrades with $d^{-\alpha}$ where $\alpha = 3$.

- In figure (2.6) the information rate has been varied and that is R is increased from 1 to 3 and it can be observed that as we try to increase the rate of information beyond the capacity of the link the probability of outage starts increasing. As you can observe the upward shift in the curves of figure (2.6).

- In the next plot shown in figure (2.7) the power to the Source node (S) and Relay node (R) are distributed optimally and its effect has been observed on outage probability by comparing it with the Conventional AF without optimal distribution of power. It can be seen a huge decrease in the outage probability if power distributed to the nodes in an optimal fashion which can be observed from the plot in (2.7).

- The figure (2.8) shows the variation in the data rate and the effect is observed on the outage probability for optimally allocated power-based AF. It can be seen that outage probability will start increasing as we try to go beyond the capacities.

- Next figure in (2.9) shows the variation of the throughput with various values of information rates namely $R = 1$, $R = 2$ and $R = 3$ for optimal power allocation. And it can be found that for $R = 1$ throughput is more this is because it has a lesser probability of outage. Also, these graphs are compared with the throughput of the Conventional non optimally power distributed AF and it is found that even at an information rate of $R = 3$ optimal power allocated AF perform in a superior manner when compared to the non-optimally power allocated Conventional AF which can be clearly noticed from (2.9). Also, it is observed that at high values of SNR throughput tends towards 100%. This is happening because when SNR is high the capacities will increase so link outages will decrease and throughput will increase for both Non-Optimal Conventional AF as well as the optimal power allocated Conventional AF.

So these are some conclusions that can be drawn from the **Conventional** approaches of the **Amplify and Forward**.

Now its time to draw some new conclusions from the new **Incremental AF** relay scheme equipped with the buffer. Some of the conclusions that are drawn are given as follows.

- Firstly the system equations have been modelled. Packet selection has been done using (2.14) at the destination. outage probability expression has been derived. And the MRC technique has been employed at the destination node (D).

- The plot in figure (2.11) shows the variation of the outage probability with the increasing of buffer size. It can be seen that as the buffer size increases the outage probability starts shifting down which can be seen from the graph. The graph is plotted for different buffer sizes namely $L = 1$, $L = 2$, $L = 4$ and $L = 8$. For $L = 8$ the outage probability is minimum.

- In the next plot, we have analysed the delay introduced due to the buffer which is also a critical parameter. This takes into account the Block Delay and the Packet Delay. The delay has been analysed for $L = 1$, $L = 2$, $L = 3$ and $L = 7$ in figure (2.13). One can see that as the buffer size increases the delay has been increased for lower values of SNR it can be observed in the figure (2.13) that delay is more for $L = 8$.

- In the next plot, Incremental AF has been analysed by varying the information rate from $r_0 = 1$ to $r_0 = 5$. As this also has a similar conclusion that as we try to increase the data transmission rate beyond the capacity of the link then the link is most likely to go into outage which can be noticed in the graph shown in (2.14).
- Next figure shows the throughput shown in figure (2.15).

Next in **Chapter** (3) we will draw some important conclusions for the Conventional DF methods and DF schemes equipped with buffers.

- Firstly in section (3.1) conventional DF based approach has been discussed in the detail. And the expression of the probability has been derived and system equations are modelled.
- Figure (3.2) shows the outage probability plot for data rate $R = 1$. It shows a comparison with the direct transmission VS transmission using Dual Hop Conventional DF relay based approach. And it is shown that the relay-based approach leads the way in comparison to direct transmission. So cooperation using the neighbouring relay is more useful.
- Figure (3.2) shows the variation of the outage probability with the variation of the power distribution factor. It can be seen that if we supply lesser power to the Source node (S) than the probability of outage will be more which can be seen when $\beta = 0.1$. This is because the SNR of (S-R) link will reduce. So the link will get into outage.
- Next plot will show the outage probability plot for fixed SNR values and power distribution factor β has been varied from $\beta = 0$ to $\beta = 1$. One can notice the symmetry in the graph and one can comment that the optimum value for every value of SNR is $\beta = 0.5$. Also as SNR keeps increasing the curve starts shifting downwards as observed in figure (3.4).
- Using the optimal value of $\beta = 0.5$ we have compared with conventional AF and we found that optimal way of selecting β will significantly affect the outage metric. And conventional DF is better than conventional AF algorithm as at 5 dB point it can be seen in figure (3.5) that $\mathcal{P}_{DF}^{outage} = 0.2111$ and that of conventional AF is $\mathcal{P}_{AF}^{outage} = 0.2572$.

- Next figure shown in (3.6) shows that as the information rate R is increased than the outage probability will keep decreasing. These plots are plotted by taking the optimum power distribution factor $\beta = 0.5$.

- Also the optimum power distribution factor has significant impact over the capacity of the link. As one can see that in the Conventional DF as the value of β increases from $\beta = 0.1$ to $\beta_{opt} = 0.5$ the capacity of the channel increases which can be seen in figure (3.7).

A comparative study has been performed among cooperative communication protocols such as Conventional AF is compared with the Incremental AF which is equipped with the Buffer. Also conventional Decode and Forward algorithm has been studied and compared with the Conventional AF scheme. It is found that Conventional DF is better in terms of the Outage performance. Also Incremental AF is better than Conventional AF. So overall Incremental AF relaying equipped with Buffer has been performed in a superior manner. As we have seen that in conventional approaches the optimal distribution of power to relay and source nodes have significantly reduced the outage probability. The similar thing might happen with the buffer aided schemes if we incorporate the optimal power distribution algorithm.

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