**Wireless Communication Network Protocols with Cooperation**

by

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# Certificate

It is certified that the work contained in the thesis titled **Wireless Communication Network Protocols with Cooperation by Hemant Kumar Singh (EE18M085)**, 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 have studied Decode and Forward (DF) protocol in a detailed manner.

Later, Decode and Forward (DF) protocol equipped with the buffer is considered which is compared with the Conventional DF method. Two strategies for link selection, Best Relay Selection method and Max-Max Relay Selection (MMRS) are studied. Probability of outage for both these strategies are calculated and comparison has been made. The results are simulated using MATLAB version 2019B. Lastly, the outage probabilities of the conventional way of relaying and the buffer aided way of relaying are compared and conclusions are drawn. 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. Lastly an All Max Link Selection approach coupled with DF method is presented.

I have also carried out the study of conventional Amplify and Forward (AF) method and Optimal power distribution based conventional AF method jointly **Nikhil Singh (EE18M093)**. This part is presented in thesis report with title **"Cooperative Communication Network Protocols a Comparative Approach"**.

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# 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

Our day to day lives is mostly impacted by the wireless medium. Like our mobile phones, self-driving cars, houses are mostly using wireless technology in an era that is more technology-driven. With the help of the phones and the internet, we can be able to connect to anyone in an instant of time. That's the power and capability we are handling in the form of wireless technologies. It has been observed that the dependencies on the wireless technologies have been doubled in every 2.5 years of time [1]. This leads to an increase in capacity by millionfold times since 1960. Here in this project work, our focus is on the cooperative schemes which are capable of increasing the capacity and the coverage. These wireless networks are also known as the point to point networks whose dynamics are handled by the wireless sensors [2] in which the author has discussed the underwater capabilities of wireless sensor networks. Point to Point communication is limited by the fact that they have limited bandwidth. Also, the quality of the signal is downgraded by the noise present in the wireless channel. Channel defects can be overcome by integrating the spatial diversity with the Multi-Input-Multi-Output (MIMO) systems as in [3]. But MIMO systems are expensive. As the nodes of the antennas used in the MIMO systems are dependent on the wireless node because of which the appropriate spacing is required. As we know that the cooperative communication forms an array of virtual antennas. So instead of using so many antenna nodes in the MIMO system, we can exploit the cooperation by the neighboring nodes during the transmission.

An independent path is created with the help of a relay between the user and base station as shown in figure (1.1) [4]. The figure clearly depicts the differences between the direct transmission and the transmission using the cooperation. It also shows the coverage extensions of the network.

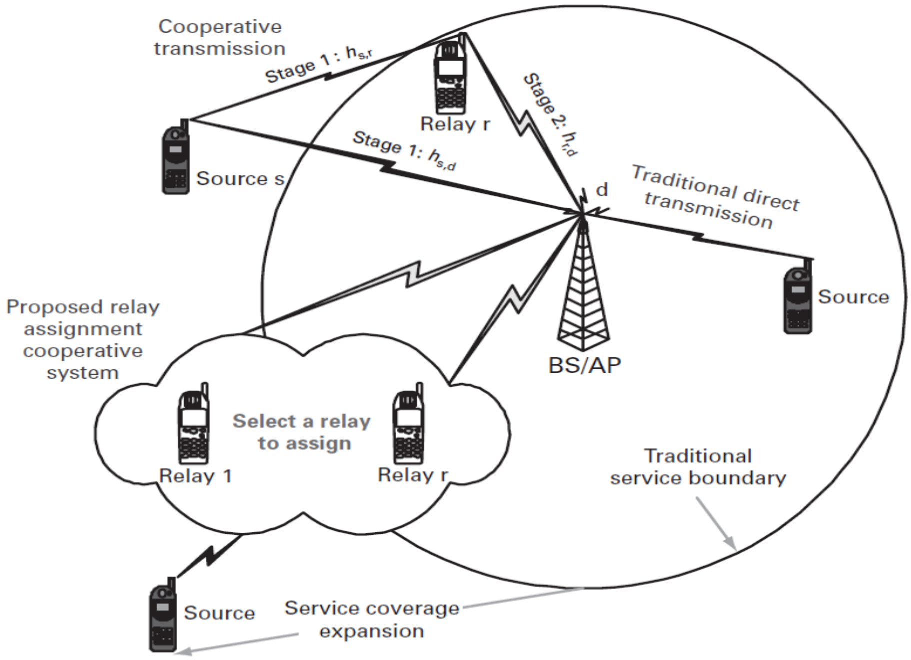


FIGURE 1.1: Communication Network showing difference between the Cooperation and Direct Transmission

## 1.2 Transmission using the Cooperation

In cooperative communication as the name suggests that it takes help or cooperation from the neighbors. The basic principle is that there are a set of nodes that help or assists the Source node (S) to transmit the data towards the Destination node (D) as in [3, 5]. Nodes in the Cooperative Networks usually operate in the half-duplex mode that is at a time it can either transmit it or can receive, means simultaneous transmission and reception is not possible. Relay based cooperative schemes improve the throughput, capacity, minimizes the outage probability, and improves the range of coverage. In the literature shown in [6] shows that improvement in the diversity gain can be achieved by using the cooperative protocols. In [7] and [8] shows the improved routing performance in the network layer by using cooperative schemes. The coverage and throughput performance improvement in the media access layer has been cited in [9] and [10]. This shows cooperative protocols application at various layers.

The cooperative relays are classified into two different types as regenerative relays and non-regenerative relays. Decode and Forward (DF) scheme comes under the regenerative relay category [11]. The DF scheme as the name suggests it has got the capability to decode the signal and re-encrypt it before transmitting towards the destination because of which it comes under the regenerative schemes.

As mentioned in [12], although the coverage and throughput can be increased by incorporating the use of the Cooperative communication schemes. But conventional schemes which are not incorporated with the buffers has limitation as the transmission and reception are done in prefixed schedule of the time. So thereby not been able to make use of the best possible channels thus making bottleneck for the performance. Buffer aided protocols are useful as they provide flexibility in making proper utilisation of the channels. Buffer aided schemes when clubbed with DF provides significant reduction in the outage probability thereby increasing the overall systems performance. Here in this report various buffer aided schemes clubbed with the DF scheme is discussed and compared with the conventional relaying protocols. In the conventional schemes Channel mismatch problem occurs as mentioned in [12]. This problem arises as the quality of the channel might not be reliable. Buffer aided protocols gives freedom to choose the best available links during the process of the transmission and during the process of reception. The diversity gain can be significantly improved in Buffer Aided schemes when compared to the conventional schemes. The links are selected on the basis of the SNR value at that instant. That is if the (S-R) link has high value of SNR than source node must transmit, or else the (R-D) link is selected and relay node will transmit the packet stored in the buffer. Also we have incorporated the Buffer Aided scheme DF protocols in single relay based network and also with two relay network where the link selection mechanism such as Best Relay Selection algorithm (BRS) and Max-Max Relay Selection (MMRS) algorithm have been employed. Although buffer aided schemes offers various profits over the conventional schemes but it has some losses also. The first challenge it offers is the acquisition of the Channel State Information (CSI). As in these buffer based schemes the best link is selected based upon the link SNR values. So in each time slot it is necessary to have the CSI. Also, one more challenge is to monitor the buffer status whether it is empty or full. Other problem that arises due to storing of information in the buffers will introduce the delay in the system. In order to solve these challenges researchers have made considerable amount of the efforts and introduced relay selection algorithms based on the buffer status as discussed in [13] and [14].

Cooperative communications has various pros and cons which is shown next.

### 1.2.1 Advantages and Disadvantages of Canonical Cooperative Communications

Some of the key advantages of using the cooperative networks are [15]

- **Performance Gain.** Because of the path-loss gains and the gains due to multiplexing it is possible to achieve high performance gains in the networks that employs cooperation.
- The coverage and capacity problems are more prominent in the shadowed areas. These disturbances are handled in a good way by the use of the cooperative network thereby giving Quality of Service (QoS) to all the available users. This is known as **Balanced QoS**.
- The main advantage of using the relay based network is that they allow **Infrastructure-less deployment** of the system. During the time of disaster also the relay based network are capable of facilitating the communication even if the cellular system functioning has been collapsed. Maintenance and deployment costs can be significantly lowered if the cellular systems are clubbed with relaying schemes.
- Compared to the cellular network approach the relay based approach are cheaper solution. Also the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) have been significantly optimized if the networks makes use of the relay. It is referred as the **Reduced Cost** approach.

Although Cooperation offers several advantages but it also have some disadvantages to offer which are given as follows.

- Maintaining a single link with relay itself require a considerable effort if the number of the users and the relays grows than maintaining the relay becomes a humongous task. This maintenance will require the use of **Complex Scheduling**. The task of these schedulers is to maintain the data flow and to manage the traffic of the users. Any gain obtained in the Physical Layer can be easily disappeared if the handling of schedulers in not done in a proper way at the MAC layer and Network layers.
- Maintaining the functioning of the full system it necessary to maintain security and synchronization. There by increasing the overheads in comparison to the system which does not involve the use of relays.

- Maintaining proper Cooperation among different users is fairly a complex task. This is known as **Partner Choice.**

- Instead of decreasing the power at the relay node and saving the power during transmission if it is used for increasing the coverage than inter-cell and intra-cell interference are potentially generated by the use of the relay which will degrade the performance of the system. This is referred as **Increased Interference**

- **Overhead Relay Congestion** causes the degradation of the overall throughput the system. Because additional frequency channels needs to be provided.

- By the use of the cooperation the **End to End Latency** is increased. Relay has two operations first is receiving the data and than decoding or amplifying it before it is transmitted towards the destination node. Multimedia web services and voice based communication services are limited by the delay. Increasing latency is based on the increase of relays and interleavers. To combat latency effects novel decoding methods or the relaying methods which are transparent n nature needs to be devised.

- A **Tight Synch needs to be maintained** between the nodes or the relays. In order to maintain this tight synchronization hardware will be required which is a costly affair. Also large overheads will be required to maintain the synchronisation on regular basis.

- More number of channel coefficients needs to be estimated. Because when we use the relays number of wireless channels automatically increases. This is termed as **Estimation**

## 1.3 Outline of Thesis

In **Chapter** 1, a brief overview about Wireless Communication and Conventional Relaying techniques as well as the Buffer Aided Relaying techniques incorporated with Decode and Forward (DF) protocol along with the relay selection schemes are presented.

In **Chapter** 2, the work mainly focuses on Decode and Forward (DF) Relaying technique. Here both the Conventional DF and DF embedded with the buffer both are discussed in a detailed manner. In the beginning of the chapter modelling of the Conventional DF protocol has been studied and its Outage probability analyses has been carried out in an extensive fashion. In the Conventional approach of

Decode and Forward (DF) protocol the effect of varying the information data rate on the Outage Probability has been observed.

Later in the current chapter Single Path Dual Hop DF method equipped with the buffer has been studied and the analysis has been carried out in a detailed manner. The expression of the outage probability is derived and the dynamics of the buffer has been discussed in a detailed fashion. And the results are compared with the Conventional DF method which is also a single path algorithm and various conclusions are drawn. Also the increase of the buffer size on the Outage probability has been discussed. Also the effects has been noticed on the throughput by the variations in the buffer size.

At the end of the chapter Dual Path Dual Hop DF schemes equipped with Buffer has been discussed. Here various relay selection techniques has been employed as these algorithms has two relays. That is these are named as Dual Path schemes. There are two relay selection schemes which are discussed in this chapter. First scheme is Best Relay Selection (BRS) and the Second scheme which has been discussed is Max-Max Relay Selection (MMRS). Both of these schemes are discussed in a detailed manner. The Outage expression of the Decode Forward employing BRS scheme and the Decode and Forward employing MMRS scheme are derived and system modelling has been shown. The conclusions are drawn based on the comparison between the two relay selection schemes. Lastly All max selection method for selecting links has been discussed.

In **Chapter** 3, Lastly a short summary has been presented for the present work and Conclusions are drawn based on it. Also some future aspects has been discussed which will conclude the report.

# Chapter 2

# Conventional and Buffer Aided Decode and Forward Methods

In this chapter, we will be discussing the conventional DF scheme as well as DF scheme equipped with buffer. Here, we will discuss a single relay based approach as well as a multiple relay based approach. In the multiple relay-based buffers aided DF we have studied two methods of relay selection first one is the Best Relay Selection (BRS) method and the second one, is Max-Max Relay Selection (MMRS) approach.

## 2.1 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 (2.1). 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.

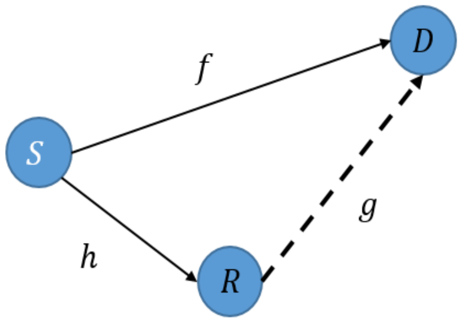


Figure 2.1: Wireless Cooperative Diversity Network

The bit stream $x_s = \left[x_s[0], x_s[1], \ldots, x_s[M-1]\right]$ from the source has been transmitted. The fading coefficients for S-R link is denoted by $h = h_{sr}$ and R-D link is denoted by $g = h_{rd}$. Similarly for S-D link is denoted by $f = h_{sd}$.

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.

$$\begin{aligned} y_{sr} &= h_{sr}\sqrt{P_s}x_s[m] + n_{sr}[m] \\ y_{rd} &= h_{rd}\sqrt{P_r}x_s[m] + n_{rd}[m] \\ y_{sd} &= h_{sd}\sqrt{P_s}x_s[m] + n_{sd}[m] \end{aligned} \tag{2.1}$$

Here $n_{sr}$,$n_{rd}$ and $n_{sd}$ 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 signal to noise ratio of the respective links are given by $\gamma_{sr} = \frac{P_s|h_{sr}|^2}{\sigma_r^2}$, $\gamma_{rd} = \frac{P_r|h_{rd}|^2}{\sigma_d^2}$, $\gamma_{sd} = \frac{P_s|h_{sd}|^2}{\sigma_d^2}$. Where $P_s$ is the power transmitted by source and $P_r$ is the power transmitted by the relay.

For Successfully decoding the code words at the relay node one has to ensure that the rate at which data is transmitted will not be greater than capacity of the s-r link. According to the analysis shown in [16] the outage probability is computed as

$$P_{outage} = P_r(min\{C_{sr}, C_{rd} < 2R\} \tag{2.2}$$

Where $C_{sr}$, and $C_{rd}$ are the capacities of the S-R and R-D links respectively. This can be further simplified as

$$P_{outage} = 1 - P_r(C_{sr} \geq 2R, C_{rd} \geq 2R) \tag{2.3}$$

The relationship between capacities and SNR are given by the following.$C_{sr} = log_2(1+\gamma_{sr})$ and $C_{rd} = log_2(1+\gamma_{rd})$. Considering the scenario in which the channel is 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 $\delta^2_{sr}$, $\delta^2_{rd}$ and $\delta^2_{sd}$.

$h_{sr} \sim \mathcal{CN}(0, \delta^2_{sr})$ and $h_{rd} \sim \mathcal{CN}(0, \delta^2_{rd})$. Also these channel coefficients are independent. As we are considering the Rayleigh Faded channel so $\gamma_{sr}$ and $\gamma_{rd}$ are exponentially distributed Random Variables. The mean of these is given by $\bar{\gamma}_{sr} = \frac{P_s \delta^2_{sr}}{\sigma^2_r}$ and $\bar{\gamma}_{rd} = \frac{P_r \delta^2_{rd}}{\sigma^2_d}$. Using (3) we can calculate outage Probability as

$$P_{outage} = 1 - exp\Big(-\frac{2R-1}{\bar{\gamma}_{sr}}\Big) exp\Big(-\frac{2R-1}{\bar{\gamma}_{rd}}\Big) \tag{2.4}$$

From figure (2.2) the outage probability of the Conventional DF is shown. Also, In the next plot in figure (2.3) we have shown 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.

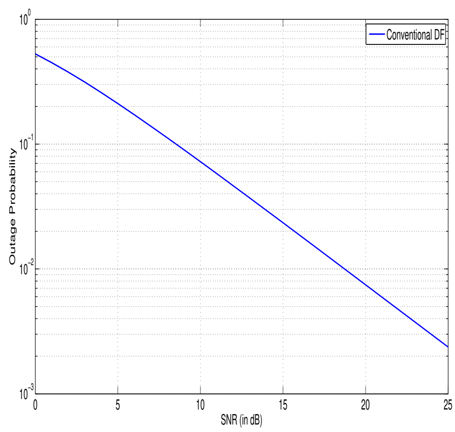


FIGURE 2.2: $\mathcal{P}^{outage}$ of Conventional DF

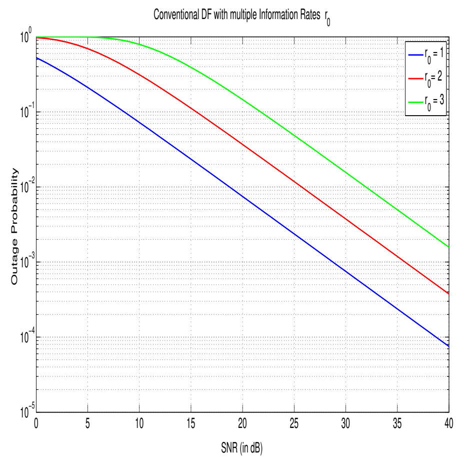


FIGURE 2.3: Outage Probability with multiple R

## 2.2 Single Path Dual Hop DF scheme equipped with Buffer

In this section, we will be discussing a cooperative communication network which is fairly simple and utilises the three-node model in a half-duplex mode and also it uses the Decode and Forward relay technique integrated with the finite length buffer. Here the link selection has been employed. In which the (S-R) or (R-D) link has been selected based on the instantaneous SNR.

### 2.2.1 Modelling of the DF System with Buffer

Here also we have considered a 3 node Cooperative Communication model as discussed in [17]. These three nodes are mainly Source node (S), destination node (D) and Relay node (R). Also, these nodes work in a half-duplex configuration. The information packets are sent by the source reaches the relay which decodes it and stores it in a buffer and later it forwards it towards the destination node. Also, SNR at every instant of the link is denoted by $\gamma_s(n)$ and $\gamma_r(n)$ for the (S-R) and (R-D) links respectively. Instantaneous values of the SNR's changes from one slot to another slot in time. These instantaneous values of the SNR's are i.i.d random process which has expected values of $\omega_s = \mathbb{E}[\gamma_s(n)]$ and $\omega_r = \mathbb{E}[\gamma_n(n)]$. These average values can be further re-written as $\omega_s = \frac{P_{ts}}{\sigma_n^2}\bar{\omega}_s$ and $\omega_r = \frac{P_{ts}}{\sigma_n^2}\bar{\omega}_r$. Where $P_{ts}$ denotes the total transmitted power and $\sigma_n^2$ is the variance of AWGN noise and $\bar{\omega}_s$, $\bar{\omega}_r$ are the variances of the (S-R) and (R-D) links respectively.

In a particular time slot, the values of the instantaneous SNR's $\gamma_s(n)$ and $\gamma_r(n)$ are compared and based upon which the decisions are made whether source node transmits the data or relay node transmits the data. Now we will begin discussing rate transmission algorithm.

- Rate Transmission Algorithm

Here the source node and the destination node is assumed to know about the instantaneous values of $\gamma_s(n)$ and $\gamma_r(n)$

1. **Source Transmits :**

The source node transmits the data in the $n^{th}$ time slot with the rate given as

$$C_{sr}[n] = log_2(1 + \gamma_s(n)) \tag{3.11}$$

Normalizing the bits transmitted in a given time with respect to the number of symbols per given time slot. Thereby making the information rate similar to the bits that are normalized in a particular time slot. In this manner, the node R will receive $C_{sr}[n]$ information packets in the form of the bits from the node S and put them into its buffer. The total number of the bits present in the buffer of the node R at the end of the $n^{th}$ time slot is given by equation (3.12)

$$\mathcal{Q}[n] = \mathcal{Q}[n-1] + C_{sr}[n] \tag{3.12}$$

2. **Relay Node Transmits :**

The number of information packets transmitted by the node R is given by the equation (3.13)

$$\mathcal{T}[n] = min\{log_2(1 + \gamma_s(n)), \mathcal{Q}[n-1]\} \tag{3.13}$$

Buffer puts the limit on the number of information packets sent by the node R. Therefore the number of information packets left inside the buffer at the end of the $n^{th}$ time slot is given by equation (3.14)

$$\mathcal{Q}[n] = \mathcal{Q}[n-1] - \mathcal{T}[n] \tag{3.14}$$

If the link that is used in the process of the transmission selected by the destination node (D) than it is possible for the node (D) to predict the Channel State Information of the (R-D) link and also with the help of the feedback it is possible to acquire the Channel State Information of the (S-R). In such case the source node (S) and the relay node (R) do not have the knowledge of the $\gamma_s(n)$ and $\gamma_r(n)$, because of which both these nodes transmits the data at a fixed rate which is denoted by $d_s$ and $d_r$ respectively. Hence if the (S-R) link is selected for the transmission than in the $n^{th}$ time slot than $C_{sr}[n] = d_s$ and $C_{rd}[n] = 0$. On the other hand if the (R-D) link is selected for the transmission than $C_{rd}[n] = min\{d_r, \;\; \mathcal{Q}[n-1]\}$ and $C_{sr}[n] = 0$. The queuing states of the packets inside the buffer at node R will change in accordance with the equations (3.12) and (3.14).

In such cases the outage will occur if the (S-R) link is selected if $log_2(1+C_{sr}[n]) < d_s$ and if (R-D) link is selected than $log_2(1 + C_{rd}[n]) < d_r$. This is happening because we are trying to transmit the bits beyond the capacities of the links.

- Framing of the Problem

Let $b_n \in \{0, 1\}$ is a decision variable in the binary format. $b_n = 1$ if (R-D) link is selected in slot $n$. Also $b_n = 0$ if (S-R) link is selected in the time slot $n$. With the help of $b_n$ the number of bits sent from node S to the node R and from the node R to node D in the $n^{th}$ time slot can be written as

$$C_{sr}[n] = (1 - b_n)log_2(1 + \gamma_s[n]) \tag{3.15}$$

$$C_{rd}[n] = b_n min\{log_2(1 + \gamma_r[n]), \mathcal{Q}[n-1]\} \tag{3.16}$$

To minimize some complexity level the following equation must follow

$$b_n = \begin{cases} 1 & \mathcal{F}(\gamma_r[n]) \geq \mu\gamma_s[n] \\ 0 & otherwise \end{cases} \tag{3.17}$$

Where $\mu$ and $\mathcal{F}(.)$ acts as a threshold for making the decision and function of decision respectively. This function is positive and monotonically increasing smooth function. That is mathematically

$$\mathcal{F}(p + \epsilon) > \mathcal{F}(p) \tag{3.18}$$

As the function is monotonically increasing so its inverse exists and it will be denoted by $\mathcal{F}^{-1}(.)$. For maximizing the throughput we need to optimize the threshold used for making the decisions as explained in [17] and [12].

Now we will begin analysing the outage probability of the Dual hop Buffer Aided DF transmission scheme. For this, we need some base that has been cited in [17].

- **Transmission by fixing the Rate :**

By using the transmission by fixing the rate, for this, we need the decision function such that $\mathcal{F}(p) = p$. The selection of the links is based on the equation given in (3.17). As mentioned in [17] the node R adds the information packets into its buffer irrespective the decoding is successful or not.

1. Optimal Value of $\mu$

The optimal value of the $\mu$ is denoted by the $\mu_{optimum}$. The theorem mentioned in [17] will give the optimal value.

**Theorem 2.1.** *Here the links are assumed to be faded by the Rayleigh distribution. The node S and node R used to send the information data at a rate denoted by* $d_s$ *and* $d_r$*. if the decision threshold function is selected as* $\mathcal{F}(p) = p$ *than the optimal value of the* $\mu_{optimum}$ *is given by*

$$\mu_{optimum} = \frac{\omega_r d_r}{\omega_s d_s} \tag{3.19}$$

*Proof.* It can be shown that the outage probability can be minimized by switching between absorbing and non-absorbing queue. By utilising this fact $\mu_{optimum}$ is given as a solution to the below equation

$$d_s(1 - \mathbb{E}\{b_n\}) - \mathbb{E}\{b_n\}d_r = 0 \tag{3.20}$$

By using equation (3.17) we get

$$\mathbb{E}\{b_n\} = \mathcal{P}_r\{\gamma_r[n] > \mu\gamma_s[n]\} = \frac{\omega_r}{\omega_r + \mu\omega_s} \tag{3.21}$$

Combining equation (3.21) and (3.20) we get

$$\mathbb{E}\{(1 - b_n)(log_2(1 + \gamma_s[n])\} = \mathbb{E}\{b_n(log_2(1 + \gamma_r[n]))\} \tag{3.22}$$

This ends the proof. □

2. Probability of Outage Analysis

As its an analysis based in which the transmission rate is kept fixed. So avoiding the Outages is quite difficult. Therefore it is an important metric for performance analysis. Here an assumption is made that the $\gamma_s[n]$ and $\gamma_r[n]$ are not correlated.

**Theorem 2.2.** *A relaying system equipped with the buffer has been considered in which the rate of the transmission is kept fixed. In order to select the links the decision function $\mathcal{F}(p) = p$ is utilised. That is this function is used for selecting (S-R) or (R-D) link for transmission. Here the outage decreases as the SNR increases. And here the order of diversity is* 2 *with the increase in the value of SNR.*

*Proof.* Event of the outage will happen if the packet that is transmitted by the source in the $n^{th}$ slot of time but the (S-R) link is in the outage. Or on the other hand, if the information packet is transmitted by the node R in some time slot $k > n$ but at the same time, the (R-D) link is in the outage. For making the equations look simple we use the notations $\gamma_s = \gamma_s[n]$, $\gamma_r = \gamma_r[n]$ and $\bar{\gamma_r} = \gamma_r[k]$, $\bar{\gamma_s} = \gamma_s[k]$. Also, these four SNR's are considered to be mutually independent. Thus the probability of the outage expression can be given mathematically based on the statement is

$$\begin{aligned}
\mathcal{P}^{outage} &= \mathcal{P}_r\{log_2(1 + \gamma_s) < d_s|\mu\gamma_s > \gamma_r\} \cup (log_2(1 + \gamma_s) > d_s|\mu\gamma_s > \gamma_r) \\
&\cap \quad (log_2(1 + \bar{\gamma_r}) < min\{d_r, \mathcal{Q}[k - 1]|\bar{\gamma_r} > \mu\bar{\gamma_s}) \\
&= p_1 + p_2 - p_1p_2
\end{aligned} \tag{3.23}$$

where $p_1$, $p_2$, $p_3$ and $p_4$ are given as follows,

$$p_1 = \frac{\mathcal{P}_r(log_2(1+\gamma_s) < d_s \cap \mu\gamma_s > \gamma_r)}{\mathcal{P}_r\{\mu\gamma_s > \gamma_r\}} \tag{3.24}$$

$$p_2 = \frac{\mathcal{P}_r(log_2(1+\bar{\gamma_r}) < min\{d_r, \mathcal{Q}[k-1]\} \cap \bar{\gamma_r} > \mu\bar{\gamma_s}}{\mathcal{P}_r\{\bar{\gamma_r} > \mu\bar{\gamma_s}\}} \tag{3.25}$$

The above can further be written as

$$\mathcal{P}^{outage} = \mathcal{P}_1 + (1-\mathcal{P}_1) \times \frac{\mathcal{P}_r\{\mu\bar{\gamma_s} < \bar{\gamma_r} < 2^{k_1}-1\}}{\mathcal{P}_r\{\bar{\gamma_r} > \mu\bar{\gamma_s}\}} \tag{3.26}$$

where $k_1 = min\{d_r, \mathcal{Q}[k-1]\}$ and $\mathcal{P}_1$ is given by

$$\mathcal{P}_1 = \frac{\mathcal{P}_r\{\frac{\gamma_r}{\mu} < \gamma_s < 2^{d_s}-1\}}{\mathcal{P}_r\{\gamma_s > \frac{\gamma_r}{\mu}\}} \tag{3.27}$$

$$= 1 + \frac{\omega_r}{\mu\omega_s} e^{-\frac{(\omega_r+\mu\omega_s)}{(\omega_s\omega_r}(2^{d_s}-1)} - \frac{(\omega_r+\mu\omega_s)}{(\omega_s\omega_r}) e^{-\frac{(2^{d_s}-1)}{\omega_s}} \tag{3.28}$$

As $\mathcal{Q}[k-1]$ is not known. So exact value of the outage can not be obtained. Using the inequalities as given in [17] as equation (3.29) and (3.30)

$$\mathcal{P}_1 < 1 \tag{3.29}$$

$$\mathcal{P}_r\{\mu\bar{\gamma_s} < \bar{\gamma_r} < 2^{k_1}-1\} \leq \mathcal{P}_r\{\mu\bar{\gamma_s} < \bar{\gamma_r} < 2^{d_r}-1\} \tag{3.30}$$

By using the above inequalities the maximum bound over the outage probability is defined as

$$\mathcal{P}^{outage} \leq \mathcal{P}_1 + \mathcal{P}_2 - \mathcal{P}_1\mathcal{P}_2 \tag{3.31}$$

where $\mathcal{P}_2$ is given by

$$\mathcal{P}_2 = \frac{\mathcal{P}_r\{\bar{\gamma_s}\mu < \bar{\gamma_r} < 2^{d_r}-1\}}{\mathcal{P}_r\{\bar{\gamma_r} > \bar{\gamma_s}\mu\}} \tag{3.32}$$

$$= 1 + \frac{\omega_s\mu}{\omega_r} e^{-\frac{(\omega_s\mu+\omega_r)}{(\mu\omega_s\omega_r}(2^{d_r}-1)} - \frac{(\omega_r+\mu\omega_s)}{(\omega_r}) e^{-\frac{(2^{d_r}-1)}{\omega_r}}$$

This completes the proof. □

Maximum bound on the outage probability given in the equation (3.31) is based on choosing a suitable value of the $\mu$. As explained in [17] the buffer will be receives packet if $\mu \geq \mu_{optimum}$. This way we can make sure that the upper bound is tighten.

Now we will begin discussing the various results obtained for buffer aided cooperative communication DF protocol. As mentioned previously we have considered channels to be Rayleigh faded. To analyse the expressions parameters are chosen as $d_s = d_r = r_0 = 2\ bits/sec/Hz$. And the outage probability is varied with the increase of the SNR. Also, the buffer size has been varied and the effect has been observed on the outage probability. It shows that as the buffer size increases the outage probability decreases which is the same effect as observed in the Incremental AF scheme equipped with the buffer. For the DF buffer aided scheme the decision threshold function $\mathcal{F}(p) = p$ is taken.

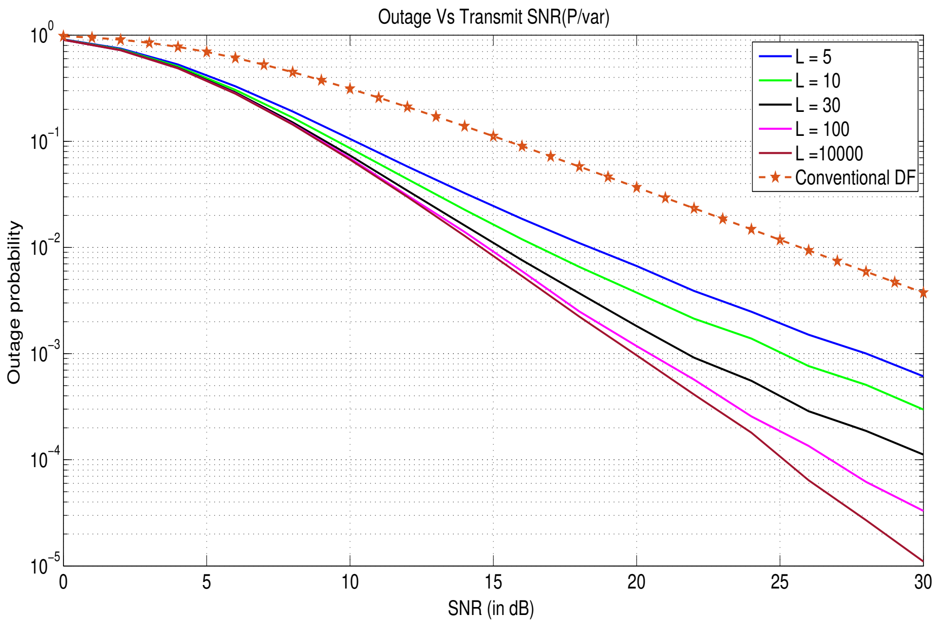


FIGURE 2.4: Outage Probability for various buffer size and Comparison with Conventional DF

The plot in figure (2.4) shows that as the buffer size keeps on increasing the outage probability keeps on decreasing. Also, this has been compared with the Conventional dual-hop DF relaying scheme. And Buffer Aided dual-hop DF relaying scheme shows much better results compared to the conventional DF scheme. This comparison has been done for $r_0 = 2\ bits/sec/Hz$.

In the next figure shown in figure (2.5), in that plot, the Buffer aided DF scheme for $r_0 = 2\ bits/sec/Hz$ is compared against the conventional dual-hop DF scheme without buffer for $r_0 = 1$ $bits/sec/Hz$ and from the plot we observed that for small values of SNR say approximately 10 dB conventional DF performed in a somewhat better manner. But as the buffer size increases and SNR is increased beyond $10-12$ dB point it can be observed that dual-hop DF equipped with buffer has performed in a much better way in terms of decrements of outage probability.

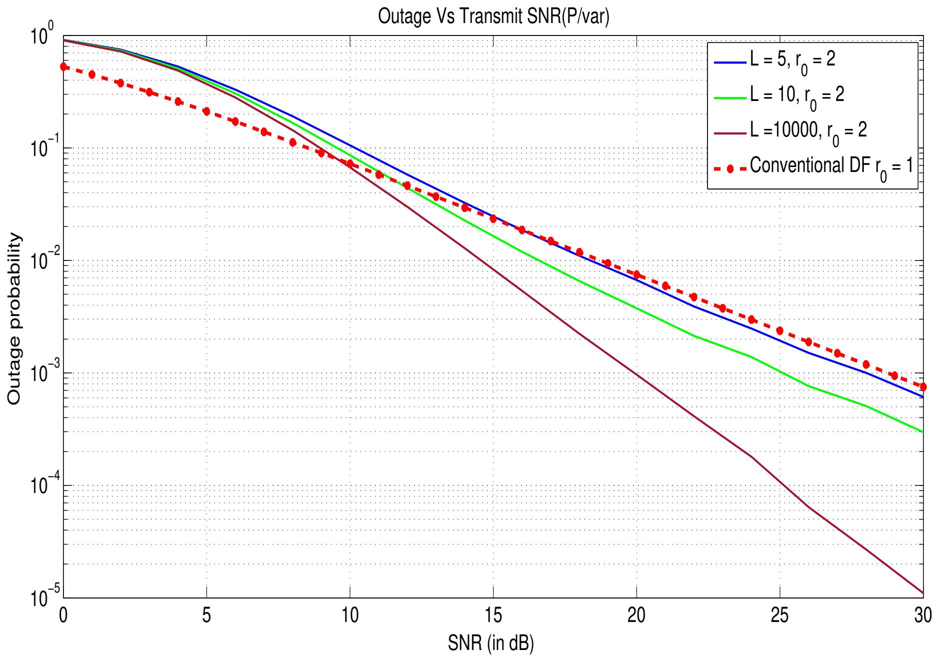


FIGURE 2.5: Outage Probability for various buffer size & $r_0 = 2$ $(bits/sec/Hz)$ and Comparison with Conventional DF with $r_0 = 1$ $(bits/sec/Hz)$

In the next plot in figure (2.6) information rate $r_0$ has been varied from 1 to 3 $bits/sec/Hz$ and we have observed that for dual-hop DF scheme equipped with a buffer, if we try to increase the information rate beyond the capacity of the links than the possibility of the link outage increases which can be clearly observed from the graph. Also the throughput and the outage probability are closely related. If more number of bits transmitted by the Source node S reaches the Destination node D via Relay node R than the throughput of the system will be more. And if the throughput is more than the corresponding Outage probability will be less. That is why the figure shown in (2.6) and (2.7) are in one to one correspondence with each other.

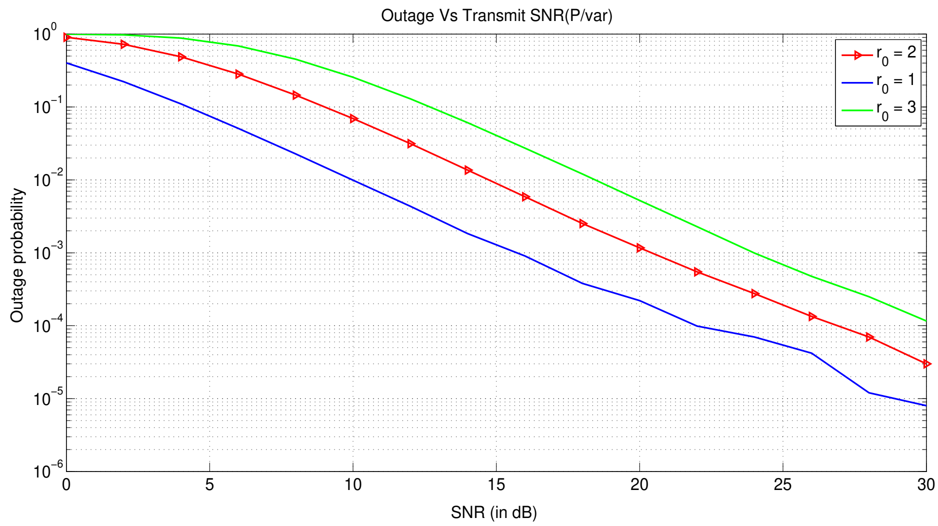


FIGURE 2.6: Outage Probability Vs SNR for various values of $r_0$

Next figure shows the Throughput Vs SNR for various buffer size. As we can see that as outage probability decreases so the throughput value increases. As SNR increases the Throughput goes towards unity.

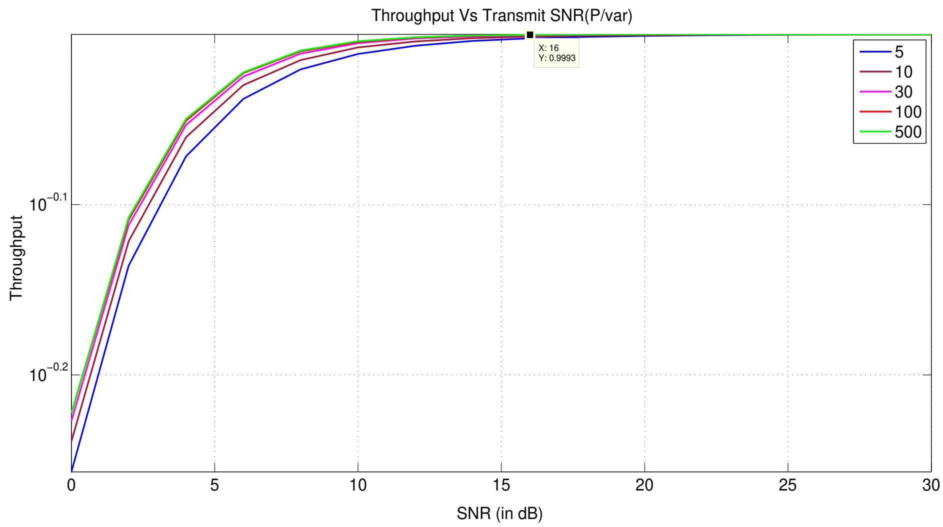


FIGURE 2.7: Throughput Vs SNR for various Buffer Sizes

## 2.3 Dual Path Dual Hop DF Schemes Equipped with Buffer

In this section, we will discuss different link selection schemes employed in two relay cooperative communication networks. The two schemes that are presented here are the first Best Relay Selection (BRS) scheme and the second scheme is Max-Max Relay Selection (MMRS). In order to understand the two relays cooperative network, we need to understand the relay selection mechanism in the single relay network as explained in [12] and [18].

Here we use the Half Duplex transmission mechanism in which nodes can transmit to receive one at a time. That is Half Duplex transmission takes place in two-time intervals. In the $1^{st}$ slot the data transmitted by the source node (S) will be received by the relay node (R). Whereas in the $2^{nd}$ interval the relay forwards the decoded data to the destination node (D). The conventional approach requires scheduling in the prefixed manner which will degrade the performance as mentioned in [18]. A 3 node model relay network with buffer and without buffer has been considered in the figure (2.8). In the odd interval of time the relay receives the information packets and in the even slot of time the relay nodes actively transmit the data packets.

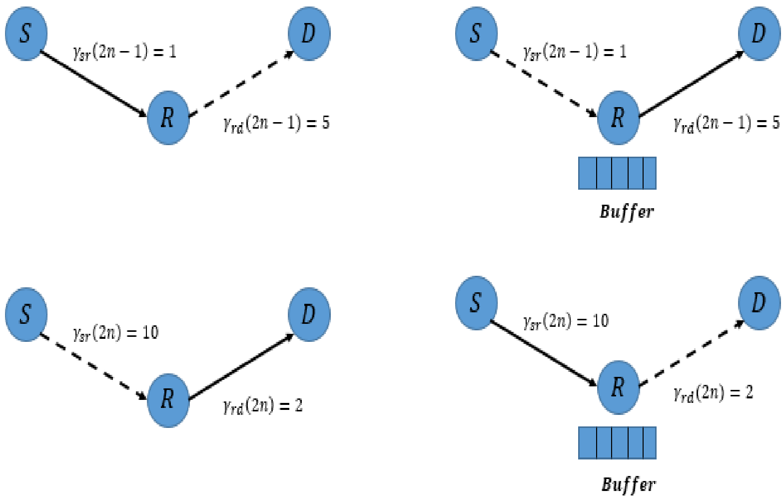


Figure 2.8: Conventional and Buffer Aided Relay selection

The above diagram uses the fixed scheduling because of this fix mechanism of the scheduling the system is not been able to utilise the link with the highest SNR. In left side of the diagram it is shown that in slot $(2n-1)$ the link with $\gamma_{sr}(2n-1) = 1$ is selected for the transmission but in this slot (R-D) link has SNR of $\gamma_{rd}(2n-1) = 5$. Similarly, if we look for the even time slot we can be able to see that (R-D) link with SNR $\gamma_{rd}(2n) = 2$ is selected although the (S-R) link has got good SNR value of $\gamma_{sr}(2n) = 10$ during that slot. So this is the main disadvantage of using the fixed scheduling technique for the transmission. If the link with the higher SNR is selected in each of the time intervals than the performance can be significantly improved. This improvement can be achieved by utilising the buffer at the relay node R. Buffer store packets until the link with the best SNR is activated. Therefore the relays equipped with buffer will exploit the link selection. Although it improves the system's performance, it has some disadvantages as it will introduce some amount of delay because of storing the packets. Because of this buffer equipped schemes are fairly complex when compared to the conventional schemes. As we have understood the link selection process in the dual-hop single relay cooperative network. Now we list the transmission steps over these links as follows as explained in [18].

- Transmission Rate and Relay Selection

The links (S-R) and (R-D) try to reach the data rates equivalent to the capacities of the link so that the probability of outage can be minimised. In order to achieve this CSI, information is required by the links. Here we introduce a protocol that minimizes the outage probability. An unbounded delay has been introduced by this protocol. But practically the protocol has to be limited by the finite delay as mentioned in [12] and [18].

In case when unbounded delay is considered based on the links capacities denoted by $C_{sr}[n]$ and $C_{rd}[n]$. Suitably choose the threshold $\mu_{optimum}$ as presented in section (3.2). By using this decision threshold relay selection takes place in the time slot $n$.

- If source node $S$ transmits and the relay node $R$ receives according to the $C_{sr}[n] > \mu C_{rd}[n]$.
- Otherwise relay node R will be in transmission mode and the destination node D will be in the reception mode.

If delay constraints are deployed than above has to be changed slightly. Here an upper cap has been put on the buffer size and deploy the following below steps.

- If the buffer doesn't have any information packet, that is it is empty than in such case relay node $R$ should be in the reception mode and the source node $S$ will be in the transmission mode.
- If the buffer at the relay node is full than in that case destination node $D$ must operate under the reception mode and the relay node $R$ operates under the transmission mode.

- Else the source node or relay node must be selected according to the decision threshold condition described above without the delay constraints.

If nodes have the information about Channel State Information of the receiving end but not have the information about the Channel State of the transmitting end, then the transmission rate becomes fixed at $r_0$ for both the source and relay nodes. This might lead to outage of the links. In such cases also we can have an unbounded delay as well as finite delay constraints. For unbounded delay constraints following must be followed

- If the destination node D is operating in the reception mode and the relay node R is operating under the transmission mode than we can say that the (S-R) link is in the outage but the (R-D) link is working normally.
- If the relay node R is operating under the reception mode and the source node S is operating under the transmission mode than the (S-R) link is working normally and (R-D) a link is operating in the outage.
- Else relay node transmit for some fraction of time and source node transmit for some fraction of time when the both (S-R) and (R-D) links are not in the outage.

When the buffer size is limited than the above algorithm steps needs to be changed slightly. If the buffer does not contain any packet or it contains only a single packet than the Source node S must transmit and the Relay node R must receive. Or else the link for transmission must be selected based on the above algorithm steps. Now in the next subsection Dual Path Dual Hop Relaying Technique equipped with the buffer has been discussed.

### 2.3.1 Two Relay Cooperative Communication DF Network equipped with Buffer

Here there are two techniques for selecting the relay employed with the Decode and Forward protocol equipped with Buffer. First is the Best Relay Selection (BRS) method and the second one is Max-Max Relay Selection (MMRS) method.

#### 2.3.1.1 System Modelling

Here also a cooperative network with 3 nodes is considered. These three nodes are namely source node ($S$), relay node ($R$) and the destination node ($D$). Also, this network has two relays equipped with the buffer. A diagram in (2.9) will describe the relay selection in case of the two relay network. Here the network with two relays is shown. Figure ($a$) shows the conventional relaying that is without the buffer. While the figure ($b$) shows the relaying equipped with the buffer.

Also, the link SNR values have been depicted in the figure. The link selection algorithm works over these values of the SNR which we will be explaining shortly. Here in these networks, Best Relay Selection method in DF protocol equipped with buffer has been employed and also Max-Max Relay Selection technique has been employed with DF protocol equipped with the buffer. And finally, the comparison has been carried out.

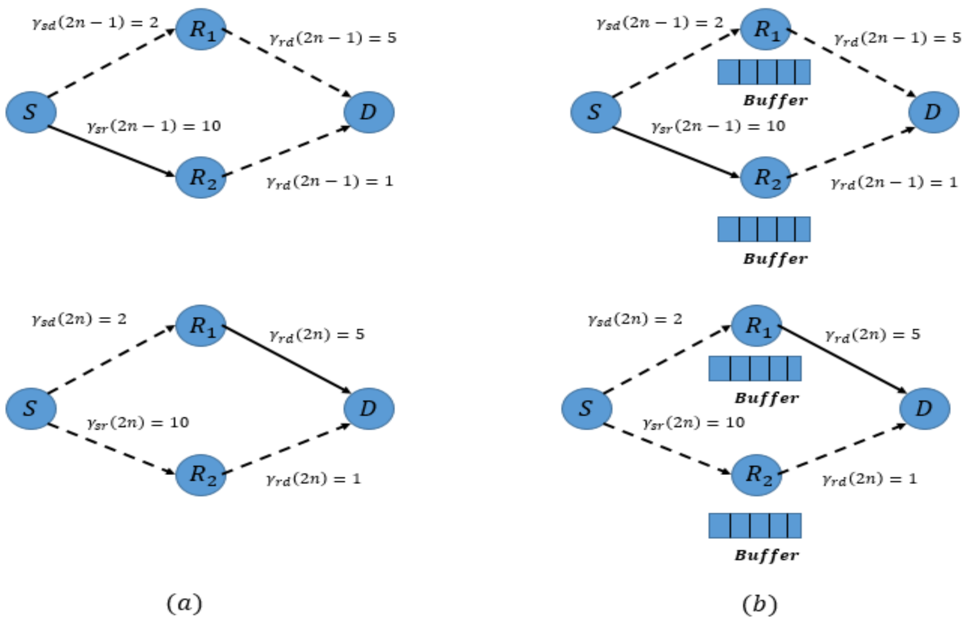


FIGURE 2.9: Relay Selection with BRS and MMRS in conventional and buffer aided cooperative communication network

1. Best Relay Selection (BRS) Method

As more than one relay has been used to improve the performance of the system in terms of minimizing the probability of the outage. Various approaches are proposed to improve the system performance like Beamforming, STC etc but the relay selection method has got more attention due to its simplicity. A detailed BRS algorithm has been discussed in [18].

Here in this approach best channel is selected for the transmission within the available links. Once the (S-R) link with best SNR is selected then the information packet has been sent over it in the first interval of time and the second interval, the relay node passes the packet to the destination node (D). Although BRS method isn't able to gain the full advantage of best links available for the transmission. Because here the assumption is that the source transmits in the odd interval of the time whereas the relay sends the information packets in the even interval of the time. From the figure (a) it can be seen that $min\{\gamma_{sr}(2n-1) = 2, \ \gamma_{rd}(2n) = 5\}$ the (S-R) link is selected although (R-D) link has better SNR for transmission. So this will become a bottleneck in this scheme. Mathematically the BRS scheme can be expressed as if there are $N$ links are present as explained in [18].

$$l \triangleq \underset{\theta \in \{1,2,\ldots,N\}}{\operatorname{argmax}} \{min\{\gamma_{sr_\theta}, \gamma_{rd_\theta}\} \tag{3.33}$$

2. Max-Max Relay Selection (MMRS) Method

The buffers at the relay nodes are used for storing the information packets transmitted by the source node. It will hold that packet for some time before transmitting towards the destination node (D) so that the (R-D) link's SNR becomes good. In this manner, best available (S-R) and (R-D) links are utilised in each time slot. This method of relay selection is best explained in [18]. That is in the odd intervals of time the (S-R) link with best SNR is chosen for receiving the data at Relay node (R). And in the even intervals of time, the best (R-D) links with high SNR values are chosen for sending the data at the destination node (D).

Mathematically, it can be explained with the help of the following equations. The equation (3.34) is used for selecting the link with the best SNR available out of the $N$ available links.

$$l_{sr} \triangleq \underset{\theta \in \{1,2,\ldots,N\}}{\operatorname{argmax}} \{\gamma_{sr_\theta}\} \tag{3.34}$$

Next equation is used for selecting the best available (R-D) link with high SNR.

$$l_{rd} \triangleq \underset{\theta \in \{1,2,\ldots,N\}}{\operatorname{argmax}} \{\gamma_{rd_\theta}\} \tag{3.35}$$

In the first interval of the time, the relay node that will be selected is given by $R_{l_{sr_\theta}}$. This relay node will be receiving the information packets transmitted from the source node and it will store these information packets into its buffer. This stored information will be available into the queue of the buffer until the same relay node $R_{l_{sr_\theta}}$ is selected for transmitting the stored information to the destination node D. In the second interval of the time the relay node is selected based on the equation (3.35) that is $R_{l_{rd_\theta}}$. It will transmit the first available bits stored in the queue. The algorithm we discussed is known as the MMRS algorithm. As mentioned in [18] for the MMRS protocol to work properly we need to ensure that the selected relay with the best SNR value is not full so that at any time it can receive. So to ensure this we assume large buffers for storing the information. Also to ensure that the best relay buffer selected is never empty so ideally, we sent a large number of packets. So buffers of infinite capacity have been used.

- **Analysis of the Probability of Outage of Dual Path Dual Hop DF scheme equipped with buffers employing BRS and MMRS protocols :**

Here we will analyse the outage expressions of the BRS and MMRS scheme. Both these relay selection protocols are employed with Dual Path Dual Hop Buffer equipped DF scheme.

1. Probability of Outage overview for the BRS scheme

The expression of probability is given as

$$\mathcal{P}_{BRS_{DF}}^{outage} = \prod_{\theta=1}^{N} \left(1 - e^{-\frac{\gamma}{\bar{h}_\theta}}\right) \tag{3.36}$$

where, $\bar{h} = \left(\frac{1}{\bar{\gamma}_{sr_\theta}} + \frac{1}{\bar{\gamma}_{rd_\theta}}\right)^{-1}$. The approximation of equation (3.36) at high SNR is given by

$$\mathcal{P}_{BRS_{DF}}^{outage} \approx \frac{\gamma^N}{\prod_{\theta=1}^{N} \bar{h}_\theta} \tag{3.37}$$

If iid assumption holds the above equation can be reduced to

$$\mathcal{P}_{BRS_{DF}}^{outage} \approx \left(\frac{2\gamma}{\bar{\gamma}_{rd_\theta} \quad OR \quad \bar{\gamma}_{sr_\theta}}\right)^N \tag{3.38}$$

2. Probability of Outage overview for the MMRS scheme

If we incorporate MMRS with Dual Hop Buffer Aided DF scheme than we get the following expression for the probability of outage. For this we have to use

$\gamma_{Threshold} \triangleq min\{\gamma_{l_{sr}}, \gamma_{l_{rd}}\}$ where $\gamma_{l_{sr}} = \max_{\theta\in\{1,2,...,N\}}\{\gamma_{sr_\theta}\}$ and $\gamma_{l_{rd}} = \max_{\theta\in\{1,2,...,N\}}\{\gamma_{rd_\theta}\}$ The expression of outage can be written as,

$$\begin{aligned}
\mathcal{P}^{outage}_{MMRS_{DF}} &= \mathcal{P}_r(min\{\gamma_{l_{sr}}, \gamma_{l_{rd}}\} \leq \gamma \\
&= 1 - \mathcal{P}_r(\gamma_{l_{sr}} > \gamma)\mathcal{P}_r(\gamma_{l_{rd}} > \gamma) \\
&= 1 - [1 - \mathcal{P}_r(\gamma_{l_{sr}} \leq \gamma)][1 - \mathcal{P}_r(\gamma_{l_{rd}} \leq \gamma)] \\
&= 1 - \left[1 - \prod_{\theta=1}^{N}\left(1 - e^{-\frac{\gamma}{\gamma_{sr_\theta}}}\right)\right] \times \left[1 - \prod_{\theta=1}^{N}\left(1 - e^{-\frac{\gamma}{\gamma_{rd_\theta}}}\right)\right] \qquad (3.39)
\end{aligned}$$

At high values of the SNR the equation (3.39) can be reduced to

$$\mathcal{P}^{outage}_{MMRS_{DF}} \approx \left(\frac{1}{\prod_{\theta=1}^{N}\bar{\gamma}_{sr_\theta}} + \frac{1}{\prod_{\theta=1}^{N}\bar{\gamma}_{rd_\theta}}\right) \qquad (3.40)$$

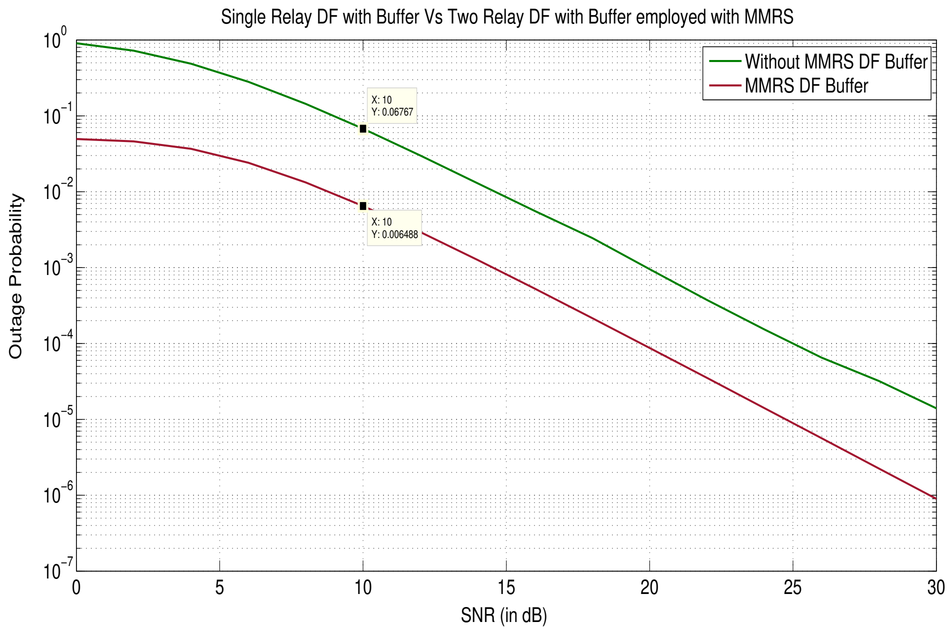


FIGURE 2.10: Relay Selection with BRS and MMRS in conventional and buffer aided cooperative communication network Outage Behaviour

In the plot shown below in figure (2.10) the curve shows the difference between the outage of the BRS and MMRS scheme.

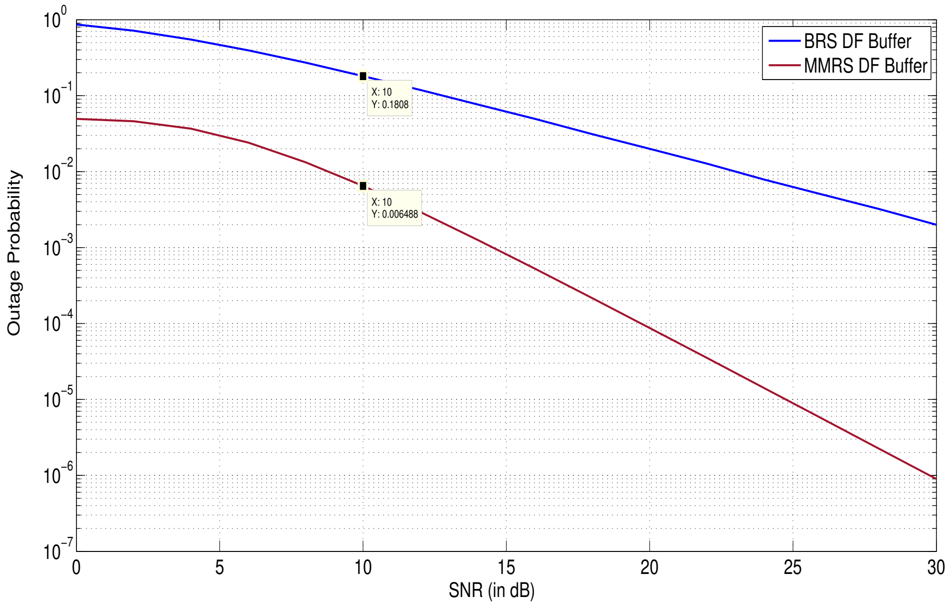


FIGURE 2.11: Buffer equipped DF Vs MMRS based Buffer equipped DF

From the figure it can be clearly seen that at the 10 dB point outage probability for BRS selection algorithm is $\mathcal{P}^{outage}_{BRS_{DF}} = 0.1808$ and for the MMRS is $\mathcal{P}^{outage}_{MMRS_{DF}} = 0.006488$. There has been 96.4% reduction has been observed in the outage probability when Dual Hop Dual Path DF with buffer is employed with MMRS algorithm than compared to Dual Hop Dual Path DF with buffer is employed with BRS algorithm. This is plotted for $R = 2\ bits/sec/Hz$.

Next plot shows the performance comparison between the DF equipped with buffer and the MMRS based DF equipped with buffer. From the plot in figure (2.11), it can be observed that the MMRS algorithm based buffer equipped DF performed in a much better way. From plot it can be seen that at the 10 dB point the value of outage probability in without MMRS based DF is $\mathcal{P}^{outage}_{DF} = 0.06767$ and that of MMRS based DF is $\mathcal{P}^{outage}_{MMRS_{DF}} = 0.006488$. Which shows approximately 90.4% reduction in the Outage Probability.

3. All Max Relay Selection Method

The principle of this method is based on the Max-Max Relay Selection (MMRS) algorithm discussed in (2). This method is fairy new to adapt. Here I tried to simulate the results and have done the analysis based on the Outage probability. Till the previous sections discussed we are underlying the basic concept of the trivial transmission. That is the transmission happens from Source node (S) to

Relay node (D). Than in the next coming slot the transmission happens after re-coding at the Relay node (R) and than transmitting the information towards the Destination node (D). This type of the transmission is called as the Dual Hop Transmission. But this will incorporate more amount of the delay. So in order to save the time we will be moving towards the concept in which during the same time slot that is in a single slot transmission happens from Source node (S) to the Relay node (R) and in the same slot from the Relay node towards the Destination node (D). This wil save more time. The filling of buffer and emptying of buffer takes place in the following manner. This link selection algorithm works in the following manner. Here basically we have two links available from Source node (S) towards the Relay nodes namely as $R_1$ and $R_2$. This is also a dual path algorithm. So corresponding to the $S - R_1$ we have the channel coefficient as $h_{sr_1}$ and with respect to $S - R_2$ we have the coefficient as $h_{sr_2}$. Similarly from the Relay nodes towards the destination node (D) we have two more links with the channel coefficients namely $h_{rd_1}$ and $h_{rd_2}$ between $R - D_1$ and $R - D_2$ respectively.

Here basically we have to select the two links in the single time slot. The selection is done according to the following equation

$$l_{max} \triangleq \underset{\theta \in \{1,2\}}{\operatorname{argmax}} \{\gamma_{sr_1}, \gamma_{sr_2}, \gamma_{rd_1}, \gamma_{rd_2}\} \tag{3.42}$$

TABLE 2.1: Parameters

| Interval | I1 | | I2 | | I3 | | I4 | |
|---|---|---|---|---|---|---|---|---|
| Time Slots | $T_1$ | $T_2$ | $T_1$ | $T_2$ | $T_1$ | $T_2$ | $T_1$ | $T_2$ |
| $\gamma_{sr_1}$, $\gamma_{sr_2}$ | 4, 1 | | 2, 3 | | 1, 4 | | 5, 1 | |
| $\gamma_{rd_1}$, $\gamma_{rd_2}$ | 1, 3 | | 1, 2 | | 3, 2 | | 2, 4 | |
| $l_{sr}$ | $R_1$ | $R_1$ | $R_1$ | $R_1$ | $R_2$ | | $R_1$ | |
| $l_{rd}$ | | | | | | $R_1$ | | $R_2$ |
| Packets from S | $P_1$ | $P_1$ | $P_2$ | $P_2$ | $P_2$ | | $P_1$ | |
| Packets from D | | | | | | $P_1$ | | $P_2$ |
| Buffer $R_1$ | $000P_1$ | $00P_2P_1$ | $00P_2P_1$ | $00P_2P_1$ | $00P_2P_1$ | $000P_2$ | $00P_6P_2$ | $00P_6P_2$ |
| Buffer $R_2$ | 0000 | 0000 | $000P_3$ | $00P_4P_3$ | $0P_5P_4P_3$ | $0P_5P_4P_3$ | $0P_5P_4P_3$ | $00P_5P_4$ |

These are the first 4 slots the next 4 slots are given below in the next table

TABLE 2.2: Packet Transmission

| Interval | I5 | | I6 | | I7 | | I8 | |
|---|---|---|---|---|---|---|---|---|
| Time Slots | $T_1$ | $T_2$ | $T_1$ | $T_2$ | $T_1$ | $T_2$ | $T_1$ | $T_2$ |
| $\gamma_{sr_1}, \gamma_{sr_2}$ | 3, 1 | | 3, 2 | | 4, 1 | | 1, 4 | |
| $\gamma_{rd_1}, \gamma_{rd_2}$ | 4, 2 | | 1, 4 | | 3, 5 | | 3, 2 | |
| $l_{sr}$ | $R_1$ | | $R_1$ | | $R_1$ | | $R_2$ | |
| $l_{rd}$ | | $R_1$ | | $R_2$ | | $R_1$ | | $R_1$ |
| Packets from S | $P_1$ | $P_1$ | $P_2$ | $P_2$ | $P_2$ | | $P_1$ | |
| Packets from D | | | | | | $P_1$ | | $P_2$ |
| Buffer $R_1$ | $000P_1$ | $00P_2P_1$ | $00P_2P_1$ | $00P_2P_1$ | $00P_2P_1$ | $000P_2$ | $00P_6P_2$ | $00P_6P_2$ |
| Buffer $R_2$ | 0000 | 0000 | $000P_3$ | $00P_4P_3$ | $0P_5P_4P_3$ | $0P_5P_4P_3$ | $0P_5P_4P_3$ | $00P_5P_4$ |

Where, $\gamma_{sr_1}$, $\gamma_{sr_2}$, $\gamma_{rd_1}$ and $\gamma_{rd_2}$ in equation (3.42) are the instantaneous SNR's of the links. Based on the values of these SNR's the All Max selection algorithm works. Find the max of the above 4 links than select the opposite of that link. That is suppose $h_{rd_2}$ is selected from (3.42) than in addition to that select $h_{sr_1}$ in the same time slot and take all the possible combination. This happens in the same time slot.

By using the above algorithm outage expression can be formulated. But before that buffer filling and emptying needs to be understood. This can be understand by a table shown below and it is based on the assumption that for proper functioning we need to assume that the buffer needs to be half filled which is shown in the diagram (2.12).

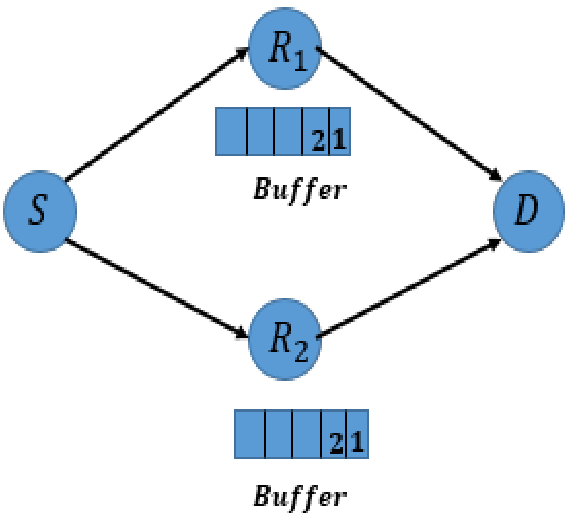


FIGURE 2.12: Working of All Max selection with Half filled buffer

Where, 1 and 2 denote the filled buffer. The expression of the Outage can be written in an analytical fashion which is given by

1. When (S-R) link is selected as $h_{sr_1}$ than for the (R-D) link the link selected will be $h_{rd_2}$. The Outage will be given as

$$\mathcal{P}_1^{outage} = \frac{|h_{sr_1}|^2(n)P_t}{\delta_{sr}^2} < 2^R - 1 \;\; \&\& \;\; \frac{|h_{rd_2}|^2(n)P_t}{\delta_{rd}^2} < 2^R - 1 \tag{3.43}$$

This $\mathcal{P}_1^{outage}$ will iterate through all the time slots when these channels are selected. Similarly we can go for the $\mathcal{P}_2^{outage}$ as

1. When (S-R) link is selected as $h_{sr_2}$ than for the (R-D) link the link selected will be $h_{rd_1}$. The Outage will be given as

$$\mathcal{P}_2^{outage} = \frac{|h_{sr_2}|^2(n)P_t}{\delta_{sr}^2} < 2^R - 1 \;\; \&\& \;\; \frac{|h_{rd_1}|^2(n)P_t}{\delta_{rd}^2} < 2^R - 1 \tag{3.44}$$

The overall expression of the Outage is than given by (3.45)

$$\mathcal{P}^{outage} = \frac{\mathcal{P}_1^{outage} + \mathcal{P}_2^{outage}}{N} \tag{3.45}$$

By analysing the expression of the Outage the following fingure is obtained

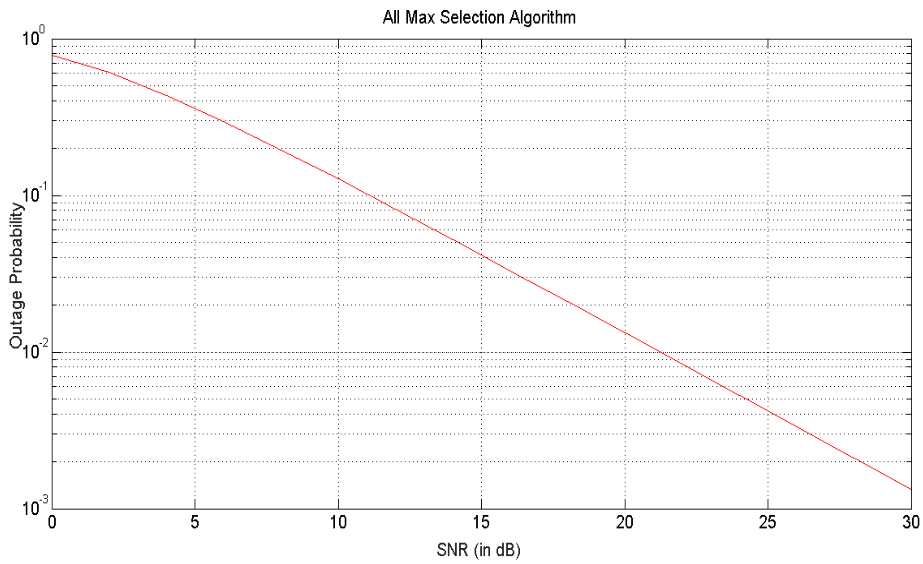


Figure 2.13: Outage Probability of All Max selection Algorithm

The next plot in figure (2.14) will show the variation of the Outage Probability with information rate.

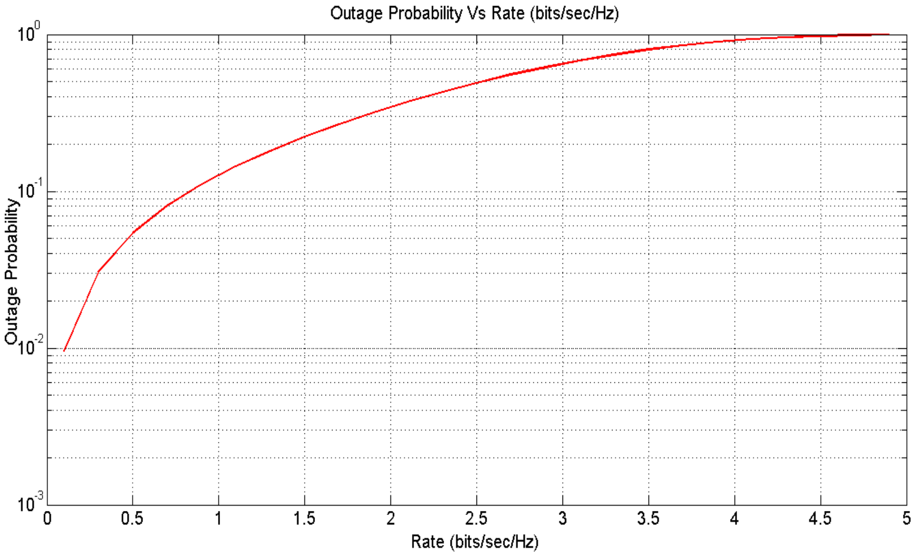


FIGURE 2.14: Outage Probability of All Max selection Algorithm Vs Information Rate

As one can see that as the Rate starts to go beyond the link capacity the Outage will start increasing.

The final plot in figure (2.15) will show that as the SNR increases the throughput will start increasing because the Outage Probability will start falling.

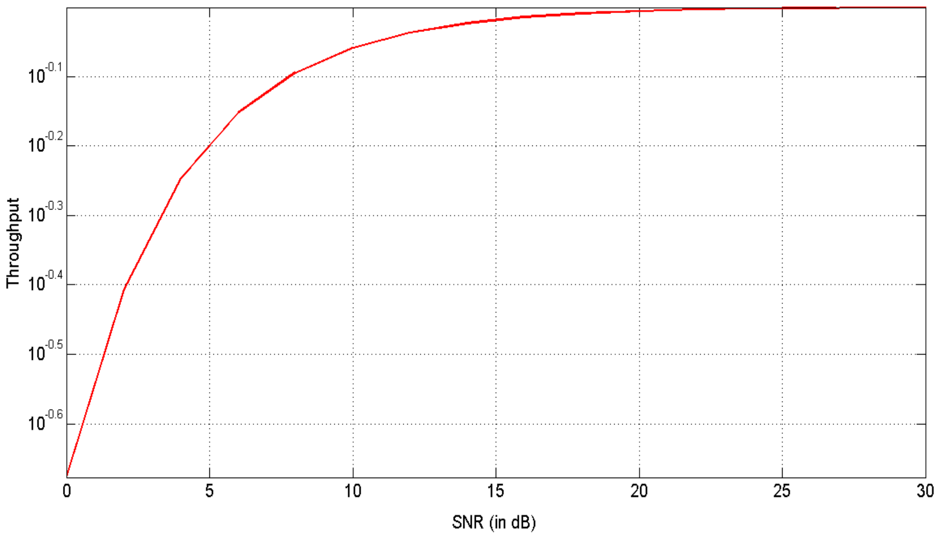


FIGURE 2.15: Throughput of All Max selection Algorithm

# Chapter 3

# Conclusion and Future Aspects

This chapter will give you a brief idea and a short summary about the conclusions which are drawn in this report.

In **Chapter** (2) we will draw some important conclusions for the Conventional DF methods and DF schemes equipped with buffers.

- Firstly in section (2.1) conventional DF based approach have been discussed in the detail. And the expression of the probability has been derived and system equations are modelled.
- Next figure shown in (2.3) shows that as the information rate $R$ is increased than the Outage probability will keep decreasing.

Next we will begun discussing the results obtained in section (2.2). Here the results are obtained for Single path Dual Hop DF protocol equipped with the buffer.

- Initially the system modelling has been presented. Buffer status has been analysed using various mathematical equations. Buffer filling and emptying algorithm has been discussed in more simplified manner. Outage expression has been derived.
- Figure shown in (2.4) shows that plot of Outage Probability for various buffer sizes. It can be noticed that as Buffer size has been increased the probability of link going in to Outage comes down significantly. Also the Buffer Aided Dual Hop DF has been compared with the Conventional DF with optimum power allocation. And it has been found that Conventional DF even with optimum power allocation lags the Buffer Aided scheme.

- In the next figure shown in figure (2.5), in that plot the Buffer aided DF scheme for $r_0 = 2$ $bits/sec/Hz$ is compared against the Conventional dual hop DF scheme without buffer for $r_0 = 1$ $bits/sec/Hz$ and from the plot we observed that for small values of SNR say approximately 10 dB Conventional DF performed in somewhat better manner. But as the buffer size increases and SNR is increased beyond $10 - 12$ dB point it can be observed that dual hop DF equipped with buffer has performed in a much better way in terms of decrements of outage probability.
- Next plot in figure (2.6) shows the variations of the Outage of DF equipped with Buffer with information rate. Also throughput plot with increasing buffer size has been shown in figure (2.7). As buffer size increases the throughput increases as the probability of the Outage decreases.

Next some conclusions are drawn based on the Dual Path Dual Hop Decode Forward scheme integrated with Relay selection algorithms have been discussed.

- Initially the procedure for selection of best possible link has been discussed by two algorithms. First is Best Relay Selection (BRS) and the second one is Max-Max Relay Selection (MMRS) approach. After that the outage expressions for buffer equipped DF combining the BRS and MMRS algorithm are derived in a detailed manner. Lastly based on these equations and buffer status the Probability of Outage analysis has been carried out.
- The plot shown in figure (2.10) shows that relay selection algorithm based on MMRS performed in a better manner. We can see a 10 dB point in the graph which shows that $\mathcal{P}^{outage}_{BRS_{DF}} = 0.1808$ and for the MMRS is $\mathcal{P}^{outage}_{MMRS_{DF}} = 0.006488$. There has been 96.4% reduction has been observed in the outage probability when Dual Hop Dual Path DF with buffer is employed with MMRS algorithm than compared to Dual Hop Dual Path DF with buffer is employed with BRS algorithm. This is plotted for $R = 2$ $bits/sec/Hz$.

Lastly a new algorithm has been studied known as **All Max link selection algorithm**. This is new in the literature so no much conclusions can be drawn as the results are not as promising compared to other Link Selection approaches. Some mathematical foundations are still needed for this approach. As this algorithm has potential to minimize the time slots required.

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