KOCAELI UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF COMPUTER ENGINEERING

DOCTORAL DISSERTATION

PERFORMANCE ANALYSIS OF COOPERATIVE RELAYING NETWORKS UNDER GENERALIZED FADING CHANNEL

MUHAMMAD ASSHAD

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In the next generation, wireless network cooperative communication is a promising approach to overcome different challenges such as higher data rate demand, improved reliability, and larger coverage area, etc. in an effective way. This thesis presents the performance analysis on non-regenerative wireless cooperative diversity network under generalized fading channel by using Moment Generating Function (MGF) to determine the lower bound value of the symbol error rate and outage probability. This study would not have been possible without the support of the following names.

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SYMBOLS AND ABBREVIATIONS

Symbols

b_R	: Best Relay
D	: Destination Node
E_s	: Average Energy Per Symbol
$F_{\gamma_{sr_k}}(\gamma)$	: CDF of the received signal SNR of the links $S \rightarrow R_k$
$F_{\gamma_{r_k d}}(\gamma)$	: CDF of the received signal SNR of the links $R_k \rightarrow D$
$F_{\gamma_{b_R}}(\gamma)$	: CDF of the best relay SNR
$f_{\gamma_{b_R}}(\gamma)$	: PDF of the best relay
$G_{l,k}^{m,n}(\cdot)$	: Meijer's G function
G_k	: Amplification gain factor
h_{sr_k}	: Channel gain coefficients for source to relay link
$h_{r_k d}$	: Channel gain coefficients of the relay $R_k$todestinationlink
h_{sd}	: Channel gain coefficients for source to destination link
$\mathbb{L}$	: Laplace transform
$\mathbb{L}^{-1}$	: Inverse Laplace transform
$\mathscr{M}_{\gamma_{b_R}}$	: MGF of best relay
$\mathscr{M}_{\gamma_{tot}}$	: Total MFG at destination
$\mathscr{M}_{\gamma_{sd}}$	: MGF of source to destination
η_{sd}	: Complex additive white Gaussian noise at $S \rightarrow D$
η_{sr_k}	: Complex additive white Gaussian noise at $S \rightarrow R_k$
$\eta_{r_k d}$	: Complex additive white Gaussian noise at $R_k \rightarrow D$
N_0	: Noise variance
$P_{AS}(e)$	: Average symbol error rate
P_{out}	: Outage probability
$\mathfrak{s}$	: Dummy variable
γ	: Instantaneous SNR
γ_k	: Instantaneous SNR of the received signal at thek^{th} relay
$\gamma_{r_k d}$	: Instantaneous SNR of the received signal from $R_k \rightarrow D$
γ_{sd}	: Instantaneous SNR of the received signal from $S \rightarrow D$
γ_{b_R}	: Instantaneous SNR of the best relay
γ_{tot}	: Upper bound of total SNR
γ_{ϑ}	: Threshold value for outage probability
x	: Transmitted signal
$\bar{\gamma}_z$	: Average SNR for each of the direct or relay link
ω_z	: Weibull fading parameter
z	: Link index
Γ	: Gamma

Abbreviations

AF	: Amplify and Forward
AG	: Amplification Gain
ASER	: Average Symbol Error Rate
BER	: Bit Error Rate
BPSK	: Binary Phase Shift Keying
CC	: Code Cooperation
CDF	: Cumulative Density Function
DC	: Direct Channel
DEMOD	: Demodulation
DF	: Decode and Forward
D2D	: Device to Device
dB	: Decibel
EGC	: Equal Gain Combiner
IDC	: Indirect Channel
i.i.d	: independent and identically distributed
ISI	: Inter Symbol Interference
IoT	: Internet of Things
LTE-A	: Long-Term Evolution-Advanced
LOS	: Line of Sight
MGF	: Moment Generating Function
MDH	: Multi Dual-Hop
GHz	: Gigahertz
MIMO	: Multiple Input Multiple Output
ML	: Maximal Likelihood
MM Wave	: Millimetre Wave
MRC	: Maximal Ratio Combiner
M2M	: Machine to Machine
NLOS	: Non Line of Sight
NRS	: No Relay Selection
PSK	: Phase Shift Keying
PDF	: Probability Density Function
QAM	: Quadrature Amplitude Modulation
RN	: Relay Node
RS	: Relay Selection
SC	: Selection Combining
SNR	: Signal to Noise Ratio
UE	: User Equipment
VMIMO	: Virtual Multiple Input Multiple Output
V2V	: Vehicle to Vehicle

GENELLEŞTİRİLMİŞ SÖNÜMLEME KANALI ALTINDA İŞBİRLİKÇİ RÖLE AĞLARININ BAŞARIM ANALİZİ

ÖZET

Kablosuz haberleşme sistemlerinde, yüksek veri hızı, ileri düzeyde güvenilirlik, ve geniş kapsama alanını başarabilmek tüm ağ nesilleri için daima üzerinde çalışılan bir konu olmuştur. İşbirlikçi çeşitleme, gelecek nesil kablosuz ağlarda bu konuların çözümü için önerilen aday çözümler arasındadır. Bir işbirlikçi ağ veya çoklu çift-atlamalı ağ, istenen uçtan-uca başarımı elde edebilmek için gerekli senaryolara göre spesifik röleleme protokolü ile birlikte çeşitli işbirlikçi çeşitleme tekniklerini uygular. Bir işbirlikçi ağda hedef düğüm, gönderilen sinyalin hem kaynak düğümden hemde röle düğümlerden çoklu kopyalarını alır, ve bu sinyalleri alış çeşitlemesi için kullanır.

Literatürde, işbirlikçi çeşitlemenin bir kablosuz kanaldaki sönümleme etkileri ile baş edebildiği gösterimiştir. Bir işbirlikçi ağin başarımını etkileyen farklı bozucu faktörler, bu ağın içinde bulunduğu kanal sönümleme karakteristiklerine bağlıdır. Literatürde iyi bilinen farklı sönümleme kanalları Rayleigh, Rician, Nakagami, Weibull, Lognormal sönümlemeleri olup herbiri spesifik özelliklere ve istatistiksel modele sahiptir. Bu tezde, farklı sönümlemeli kanal koşulları altında işbirlikçi röle ağının başarım analizi üzerinde durulmaktadır. Bu amaçla Rayleigh sönümleme ve Weibull sönümleme koşulları altında hem işbirlikçi ağ hemde çoklu çift-atlamalı ağ için alıcı düğümdeki toplam sinyal-gürültü oranına (SNR) ait moment üretme fonksiyonu (MGF) analitik olarak türetilmiştir. Ağın uçtan uca başarımını analiz etmek için Maksimal Oran Birleştiricisi (MRC), Seçici Birleştirici (SC) gibi alış çeşitleme teknikleri göz önüne alınmaktadır. Bunlara ilave olarak, analitik modelin doğruluğunu teyit etmek için max-min röle seçme tekniği ile birlikte değişen röle sayılarına göre sembol hata oranı ve boğlantı kopma olasılığına ilişkin analitik ve benzetim sonuçları verilmektedir.

Anahtar Kelimeler: Bağlantı Kopma Olasılığı, İşbirlikçi Haberleşme, Moment Üretme Fonksiyonu, Ortalama Sembol Hata Oranı, Yükselt-ve-İlet .

PERFORMANCE ANALYSIS OF COOPERATIVE RELAYING NETWORKS UNDER GENERALIZED FADING CHANNEL

ABSTRACT

In wireless communication systems, achieving a higher data rate, improved reliability, and larger coverage is always an issues to be studied for all generation of networks. A cooperative network or multi dual-hop network employ various cooperative diversity techniques according to the required scenarios with the specific relaying protocol for achieving desired end to end performance. In a cooperative relaying network, the destination nodes receive multiple copies of the transmitted signal from different relay nodes as well as from the source node, and these signal are combined in such a manner that received diversity is obtained.

In literature, cooperative communication techniques have been shown to mitigate the effects of fading in wireless networks. The different degrading factors that affect the performance of cooperative network depend on the channel fading characteristics in which the network operates. The different fading channels well known in the literature are namely Rayleigh, Rician, Nakagami, Weibull, and Lognormal fadings, etc., each of which has specific properties and statistical model. This thesis presents the performance analysis of the cooperative relaying network under various fading channel conditions. For this purpose, moment generating function for total signal-to-noise ratio (SNR) at the destination is analytically derived for both cooperative network and multi dual-hop network under Rayleigh fading and Weibull fading conditions. We consider different received diversity techniques, e.g., maximal ratio combining, selection combining to analyze the end to end performance of the network. Moreover, analytical and simulation results with regard to the outage probability and symbol error rate are given under varying number of relay nodes to verify the accuracy of the analytical model.

Keywords: Outage Probability, Cooperative Communication, Moment Generating Function (MGF), Average Symbol Error Rate, Amplify-and-Forward.

INTRODUCTION

In wireless communication, higher data rate, improved reliability, and larger coverage are always issue to be studied for all generation of wireless networks. Consequently, new methods and techniques are needed to accomplish and to address these issues for the next generation wireless networks. The innovative techniques must be very efficient, reliable and cost-effective in order to achieve the goals of the next generation wireless communication [1]. However, wireless communication faces a lot of challenges such as multipath propagation, fading, and distortion, etc., during transmission of data between transmitter and receiver . The effects of multipath and fading can be overwhelmed by using different diversity techniques. However, these diversity techniques must be capable of generating a good end to end performance.

Transmit diversity is one of the reliable technique to counter down the effects of fading by means of more than one antenna at the transmitter side [2]. Regarding transmit and receive diversity the use of multiple-input and multiple-output (MIMO) is a promising method to combat against fading and to increase the capacity even in multipath prorogation environment. However, different factors like power, cost, and size, as well as weight limitation, make it difficult to abundantly utilize the benefits of MIMO. To overcome those problems another technique so called virtual MIMO recognized as Cooperative Communication which engenders this diversity in a better and cost-effective way [3].

In the next generation wireless network, cooperative communication may be one of the promising approaches for achieving the high data rates as well as efficient utilization of the bandwidth. Cooperative communication uses relay node, to provide coverage in the holes within the Long-Term Evolution-Advanced (LTE-A) cellular networks [4]. Similarly, in mm-wave communication that is considered in 5G the relaying techniques are used to overcome different challenges of link blockage, backhaul connectivity, and path loss etc.,[5]. Moreover, to make this technology more efficient and reliable, further improvements are required to achieve these goals.

The numerous advantages of cooperative communication rely on exploiting diversity gain of multiple relay nodes deployed between source and destination nodes even under degrading fading environments. There are the different back-and-forth between transmitting signals and power in cooperative communication. However, it proposes substantial performance in relationships of enhanced capacity, better-quality transmission reliability, and spatial diversity. Although additional power is essential for each cooperative node to transmit both for itself and also for other nodes. The advantage of diversity gain from cooperative nodes allows to decrease in transmit power and, thereby sustaining the same performance. This technique states a system where cooperative nodes coordinate with each other to utilize their resources to enrich the quality of transmission information [6].

1. OVERVIEW

The basic idea of cooperative communication is demonstrated in Figure 1.1. In the first phase, source (S) broadcast the message signal to the destination (D) as well as to relay node (R). Where each relay node in cooperative network perform significant role for processing of the received signal, by using various relaying protocols. There are different types of relaying protocol in cooperative communication which have different trade-off that depends on the efficiency, reliability, cost, and performance, etc.

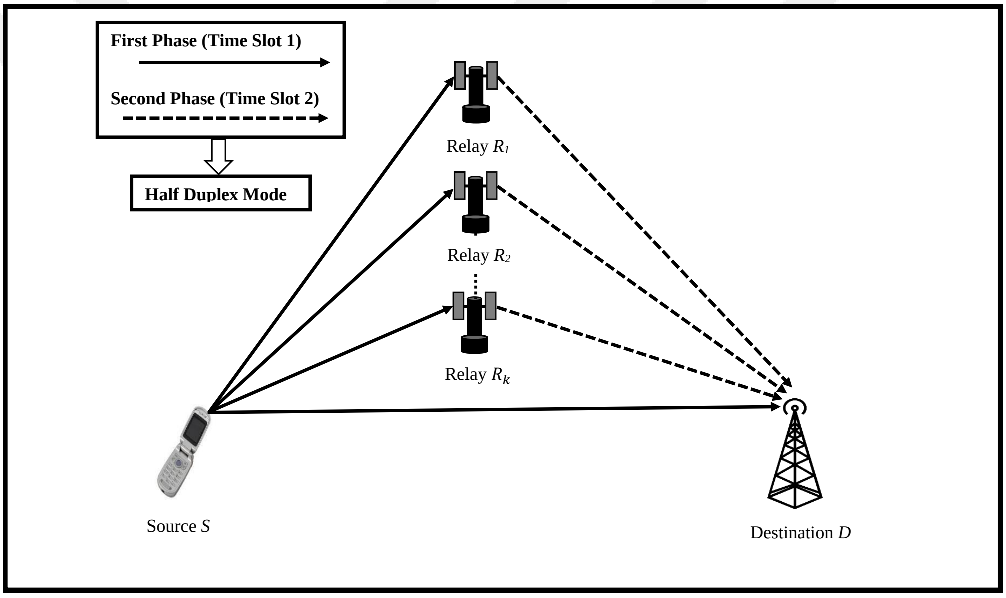

Figure 1.1. Cooperative network model

In cooperative communication two types of transmission mode i.e., half duplex and full duplex are used for the transmission of information. Generally in cooperative network half duplex transmission mode is used between the nodes for the communication due to its cost effectiveness and less signal complexity. The mechanism involved in half-duplex mode is carried out in two time phases as shown in Figure 1.1, in which first phase and second phase are presented by bold line links and doted line links respectively. Moreover, in the second phase of half duplex mode (R) process the received message signal by using different relaying protocols that are according to the system requirements, and its then forwards the processed signal to destination which is attenuated by addition of noise at receiver. However, in full duplex mode, both transmitting and receiving signals can be held at the equivalent time instant in the cooperative relay node [7].

In the final step at the destination side, both signals from the source and relay nodes are combined by using different types of receive diversity techniques such as Maximal Ratio Combiner (MRC), Maximal Likelihood (ML) or Selection Combining (SC), etc., to enhance the performance [8]. However, each receive diversity technique has different trade-off in terms of complexity and performance[9, 10].

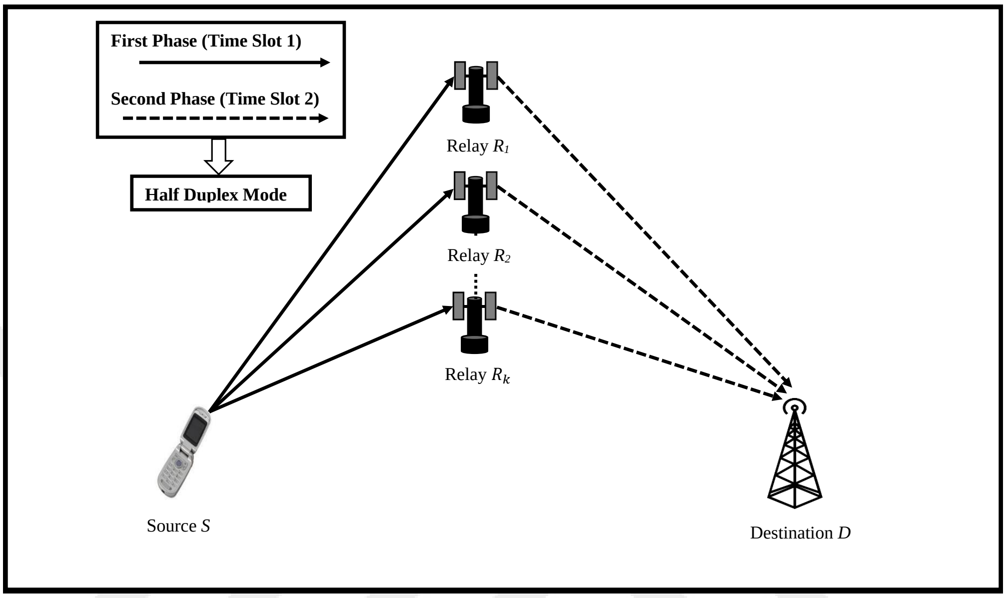

Figure 1.2. Multi Dual-hop network model

In cooperative communication various relay models might be consider for forwarding and processing the required information between source to relay and destination e.g dual-hope relay model, multi-hop relay model etc [11]. In Dual-hop relay model all the process are performed exactly same like multi cooperative relay network, however there is no direct communication between source and destination as shown in Figure 1.2. In this relay model high security measurements are required for reliable communication because of security threads that are highly vulnerable to malicious attack inside the network [12].

Similarly in multi-hop relay model there are more than two relays that are involved between source and destination for transmitting and receiving of information as shown in Figure 1.3. The multi-hop relay network generally consider for providing coverage in the holes and shadowy area of the next generation wireless networks. Moreover, its also plays an important role to enhance the coverage area, thereby increasing link capacity and efficiency of the base station [13].

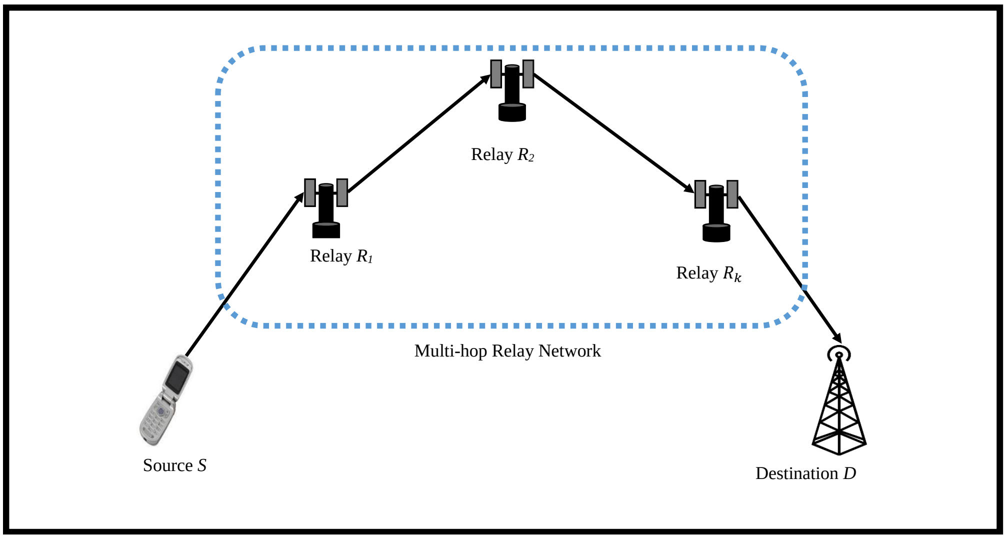

Figure 1.3. Multi-hop network model

In different applications e.g sensor network, ad-hoc network various relay model are used, which depends upon the requirements and specification of the system. However each relay model has different trade off in terms of cost, efficiency, reliability and performance etc [14].

1.1. Literature Review

The rudimentary concepts of cooperative communication are well presented by Cover et al. [15]. The aptitude of more than two nodes network which contains a source and a relay node transmits the duplicates of a signal to the destination independently for achieving better end to end performance. Many ideas regarding cooperative communication were first derived by Nichola et al. [16] for overcoming different challenges in a wireless communication channels which reduce the performance and efficiency of the wireless network.

In cooperative communication the key role for the processing of signal at relay node based on methodology of relaying protocol. In literature, different cooperative relaying protocols have been discussed, of which three are the most generally used at the relay nodes namely, amplify and forward (AF) or non-regenerative protocol, decode and forward (DF) or regenerative protocol and coded cooperation. These relaying protocols have different trade-offs in terms of efficiency, reliability, and performance, etc., which depend upon the scenario and the way that they are utilized [5]. The most commonly used relaying protocol is AF that is recognized as a layer one protocol or booster for forwarding the information from one relay node to other relay nodes or to the destination [17]. The key advantage of AF protocol is the utilization of less complex signal processing resources at the relay node which reduces the computational complexity as well as the reduction in the equipment cost. The DF relaying protocol also referred as a layer two protocol is more reliable and efficient as compared to AF [18]. The performances of these relaying protocols are studied comprehensively in chapter 2.

In a cooperative network, the destination node receives multiple copies of the transmitted signal from different perceiving relay nodes as well as from the source node, and these signals are combined in such a manner that received diversity is generated [19]. In literature, various types of diversity combining techniques are employed to accomplish low bit error rates, enhance signal quality, and reliability, etc., under different fading environments. The maximal ratio combining (MRC), selection combining (SC), equal gain combining (EGC) are generally used to achieve received diversity for maximizing end to end performance [10].

The optimal selection of the relay node has also a great impact on overall performance of the cooperative wireless network in a relationship with efficiency, higher data rate, throughput, efficient energy consumption, bit error rate, and reliability [20]. An appropriate choice of the relay node is based on different channel metrics such as Channel state information (CSI), Bit error rate (BER), and SNR. The minimum capacity of all relaying nodes can be increased by finding the optimal relay nodes between source and destination [21]. The choice of selecting the best relay nodes among many candidate relay nodes is a challenging process. In some cases, the proposed methods are restricted to a single source and a destination pair which are not certainly extended, if there are multiple sources to destination pairs [22].

Initially, it is essential to recognize for a relay node that when and to whom it will communicate for achieving better end to end performance. One of the efficient approaches is a pre-relay selection technique that follows the relay node selection technique before carrying out the actual transmission, i.e. training bits are used to find out the channel condition [23]. In pre-relay selection, the basic point is to update CSI either from source to destination or any relay node. It is probable that a particular selected relay node might not remain optimal because of variation in the channel or some obstacle that makes an indirect channel in deep fade.

The effect of outdated CSI on the performance is explored by Vicario et al., whereby it is revealed that the outdated CSI prompt significant performance degradation [24]. However, if the pre-relay selection is established on the updated CSI, then results will be more efficient [25]. In majority cases, the CSI is not considered during the transmission time [26]. In Proactive-Relay selection technique, the updated CSI must be considered during actual transmission of the data otherwise the optimal relay node may not be the best relay node in the network [27]. Moreover, the anticipated Quality of services (QoS) may not be achieved. The computational complexity increases if the number of relay node turn out to be more in the cooperative network [28]. This degrades the performance of overall system, hence the optimal relay selection is essentially required in the network [29].

S. Hussain et al. proposed two methods for relay selection to optimize the total transmission time with a constant amount of data. The selected relays can be determined by the realization of the channel condition between the source and relay station [30]. On the other hand, YiShi et al came with a different approach based on “linear marking” by giving the name as optimal relay assignment algorithm. The polynomial time base solution can achieve the optimal relay selection, even when the number of relays is less or more in the cooperative network [31]. Ivos et al. proposed smart relay selection schemes to overcome the performance degradation problem when spatial information channel are correlated in MIMO environment [32]. The relay selection method based on eigenvalue properties which also decrease the processing complexity of User Equipment (UE), at receiving end [33]. However, the efficiency and performance are not achieved, especially in case of frequency-flat fading channels.

In multiple relay environment, Salama et al. [34] proposed the best relay selection technique based on highest SNR over independent non-identical Rayleigh fading channel. Moreover, the co-channel interference was eliminated by using orthogonal channels in relationships with time slots, codes, and carriers. A. Qabas et al.[35] accomplished better average symbol error rate by using a moment generating function through which the optimal relay was selected. Mohammad et al. [36] proposed a reliable relay selection scheme based on calculating the Euclidean distance (ED) among received signals and all active and non-active channels coefficient. N. Bahreh et al.[37] suggested a novel scheme for optimal relay selection process in a different manner by using contract theory. The selection criteria based on minimizing the link cost in term of throughput and QoS metric [38].

In aeronautical communication the variations in wireless channel are high and the channel is continuously changing with time [39]. The relay selection must be updated in order to achieve the best performance. Blestasa et al. [40] considered two CSI related cases, firstly the channel condition during relay selection and secondly, during the data transmission. The choice of best relay method is based on opportunistic relay selection strategy which is directly related to the end to end performance of the network [41]. In order to overcome the problem of less performance a new technique namely repeated relay selection is proposed that is based on updated CSI. It is shown that throughput of updated CSI is much better as compared to outdated CSI [42].

In Zhou et al. [43] survey increase in throughput with better performance of wireless ad hoc network are achieved by selecting the best relay in the network based on updated CSI. In Liu et al. [44] they proposed a relay selection that countered down the effect of eavesdropping in a cognitive radio network with is analyzed by using channel power gain. Li et al. [45] proposed a relay selection in the cellular network to overcome the problem of end user degrading performance and power issue at cell edge which is based on efficient energy mechanism. In Device to Device (D2D) communication, the extension in the coverage area and increase in the throughput at the cell edges are achived by the best relay selection technique [46]. Miao et al. [47] proposed a relay selection technique by utilizing AF and DF relaying protocol with a full-duplex mode. In Luo et al. [48], focussed to efficiently utilize the energy in a wireless sensor network by selecting best relay node based on routing algorithm. Zhang et al. [49] proposed the best relay selection based on updated CSI and higher SNR for 5G wireless network.

In a cooperative network, security constraints and measurement must be taken into account for a reliable and efficient end to end communication [50]. In a distributed cooperative network environment the process of selecting best relay and during the transmission of data is highly vulnerable to malicious attacks which generate a lot of security threads [51]. In some scenarios, the eavesdropping link node may have a good channel quality for attracting in the selection process of the relay node and aims to acquire the information during the communication process [52]. Therefore, different techniques must be used to overcome the different security loops in the network. Consequently, some promising methods are proposed in [53] to enhance physical layer security against the effects of eavesdropping.

The higher secrecy capacity could be achieved by artificial noise during the transmission of data to confuse the fake elements in the network [54]. Long et al. [55] studies that the secrecy capacity is increased by combining the optimal relay selection method with artificial noise. Xiao et al. [56] proposed the best relay that based on full and statistical eavesdropping CSI to derive closed-form secrecy outage probability (SOP).

The mutual sharing of information between all the authentic nodes in the cooperative network is very obligatory to update their current status by theoretical derivation [57].

Kuhestanie et al. [58] proposed that joint information sharing can be attained by power management and eavesdropper for the secure optimum relay. Yan et al. [59] proposed secure best relay selection based on instantaneous CSI which counters down the effects of eavesdropping as well as interference. The optimal secure relay was an approach to multi-destination in terms of securing the information and decreasing the effect of eavesdropping [60].Y. Zou et al. [61] proposed that the relay selection scheme secures both the primary and secondary user in the cognitive radio network to improve the performance and reliability of the network.

In different wireless networks such as cognitive radio network, heterogeneous network, and homogeneous network the selection of best relay can increase the overall performance of the wireless communication [62, 63]. In cognitive radio network the cooperative spectrum sensing and transmission of data, aim to sense the idle band to facilitate secondary users through optimum relay selection technique [64]. In a heterogeneous cooperative network, there are numerous UEs that increase the complexity of the entire system [65]. The UEs has less power and low computational capabilities, hence optimal cooperative relay node is highly required to utilize less power and reduce the complexity of the network [66]. However, it is unrealistic to scan all the UEs for the selection of best relay node in the cooperative network [67].

Yinshan et al. [68] consider both heterogeneous and homogeneous cooperative networks, where the optimum relay node is being nominated on the basis of QoS with lower power consumption and high SNR threshold based structure. Zhang et al. [69] suggested optimal relay selection technique for 5G to decrease the complexity that established on the received power of relay nodes with the average link information of source eavesdropper. N. Nguyen et al. [70] proposed two relays jointly selected for an optimal relay to insured the security issues as well as better performance in 5G.

Swain et al. [71] analyzed the performance of optimal relay selection technique based on the harmonic mean of total SNR in a wireless network. Kawabat et al. [72] proposed best relay selection constructed on residual energy mechanism for IoT for less and better energy utilization. R. Ma et al. [73] discussed an efficient technique of optimal relay selection is utilized that based on cross-layer approach to overcome different challenges in D2D communication to upgrade the capacity of traffic offloading.

Sami et al. in [74] demonstrate a survey and taxonomy on medium access control for cooperative communication. This study classifies MAC protocols into two major categories such as contention base and non-contention protocols depending on the mechanism of obtaining channel access. Moreover, this study narrates the current state of the art of MAC protocols for cooperative communication. A review of relay selection with cooperative cache for vehicular networking is demonstrated in [75]. This study classifies current caching discovery techniques with relay selection and their benefits in VANETs. Existing security solutions fall into two categories namely trust and cryptography.

Trust is a complement to cryptography on some models where the latter fails to neutralize all potential attacks and secure the cooperative communication in the network. In [76] a survey on existing trust models for cooperative vehicular networks with optimal relay selection is presented. The authors show existing trust cooperative models and how they are implemented in vehicular networks.

The quest for energy efficiency in cooperative spectrum sensing is surveyed in [77]. The authors in [77] classify potential solutions to the problem of cooperative spectrum sensing with respect to energy efficiency. Silva et al. in [78] provide a review of cooperative strategies for challenged networks and applications. They consider factors such as network delay, bandwidth limitations, noises, disconnections, interference, storage capacity and power.

A tutorial survey on different power and bandwidth allocation techniques for cooperative communications is demonstrated in [79]. The authors compare these techniques and demonstrate their suitability in resource constrained networks such as wireless sensor networks. Gomez et al. present a review of cooperative diversity considering the theoretical framework and the existing medium access control strategies [80]. Protocols that take into consideration existence of cooperative communication at the physical layer are known as cooperative routing protocols. Mansourkiai et al. present a review of existing cooperative routing protocols. This survey explores a taxonomy of cooperative routing protocols and the weakness of each protocol [81].

A survey on cooperative single carrier FDMA is presented in [82] wherein the main concept of both user cooperation and cooperative single-carrier FDMA is discussed. This survey considers factors such as network topologies, resource allocation, signal processing, and transmission mode applicable in cooperative communication. Discussions from [82] demonstrate that relaying in LTE Advanced optimally exploit the resources and it is a promising solution for uplink data transmission.

In fading channel environments, the average symbol error rate (ASER) of the received signal can be analyzed via an effective approach that uses moment generating function MGF of the received signal SNR [83]. Salama et al. [84] studied the performance of multi node cooperative network to explore the best relay by using MGF under Rayleigh fading channel. Qabas et al. [85] analyzed the optimal relay selection procedure by considering MGF function and DF relaying protocol on relay node for maximizing end to end performance under Weibull fading channel. In [86] , the authors evaluated the performance of cooperative relay network by considering MGF function assisting with Meijer G function under Weibull fading channel.

Xinjie et al. [87] analyzed the outage probability Pout, performance by considering two way communication relaying under Weibull fading channel. Nuri et al. [88] derived MGF by considering hyper-geometric function for evaluating the ASER in Weibull fading environment under different modulations techniques. Optimal relay selection was analyzed by using space shift keying to achieve full diversity order [89] . Shao et al. [90] demonstrated that diversity gain by optimal relay selection method over Nakagami fading channel can be achieved. The performance was analyzed by considering selective fading and allowing nodes to be static or moving for exploring the best relay in the network [91] .

In [92], the authors analyzed the performance of DF relay and showed the reduction in the wastage of resources by using best relay selection method over Rayleigh fading channel. In [93] , the probability density function (PDF) and cumulative density function (CDF) are used to derive closed form expression for analyzing the Pout performance over Rician and Nakagami fading channels by optimal relay selection technique.In [94] , closed form expression of outage probability has been derived when both wireless information and power transfer is considered simultaneously over relay network with AF and DF relaying schemes. In [95], closed form analytical expression of secrecy outage probability is derived for inter vehicular relay network with kth best relay selection under Rayleigh fading channel.

1.2. Thesis Contribution

Cooperative diversity is one of the most promising technique in next-generation wireless networks for accomplishing high data rate even in the degrading fading environment. A cooperative network or multi dual-hop network employ various cooperative diversity techniques according to the required scenarios with the specific relaying protocol for achieving desired end to end performance. In a cooperative relaying network, the destination nodes receive multiple copies of the transmitted signal from different relay nodes as well as from the source node, and these signal are combined in such a manner that received diversity is obtained.

It might be possible that direct link between source and destination come across deep fading situation, or considering the worst case when there is no direct communication or sharing of information between sources and destination. As a result, the overall performance of the network will be significantly degraded.

The performance of a relay network considering different fading conditions with different effects (number of relays, the existence of a link between source and destination, etc) still needs to be investigated using an analytical model of end-to-end SNR. In this thesis, we assert that moment generating function based analysis will be helpful for evaluating system performance under generalized fading model.

1.3. Thesis Outline

Section 1 presents a brief introduction to cooperative communication and in the next generation wireless network how this method play a vital role for achieving better performance. The different optimal relay selection techniques and methods by considering various scenarios are discussed in detail in the literature review. The thesis contribution and thesis outline are also given in Section 1.

Section 2 describes the various fading channels with their statistical model and their effects over the performance in wireless network. The different types of relaying protocols in cooperative diversity having a different trade-off between complexity and performance are discussed in detail. Moreover, the applications and benefits of cooperative communication in a next-generation wireless network are also given.

Section 3, presents the system model with max-min relay selection technique for both cooperative diversity networks. The closed-form expression of MGF for instantaneous SNR at the destination is derived under various fading channel conditions on source to destination link and source to relay and relay to destination links.

In Section 4, the outage probability and average symbol rate expressions are derived that based on Moment Generating Function with M- QAM modulation technique. The different received diversity techniques, e.g., Maximal Ratio Combiner, Selection combiner, etc., using MGF, are also considered for analyzing the end to end performance of the cooperative network.

The analytical and simulation results are compared with a varying number of relay nodes to verify the accuracy of the described system model and analyzed the end to end performance of the cooperative diversity network is discussed in Section 5. Section 6 presents the overall conclusion and give direction for future work with different challenges that is faced by cooperative diversity network. In last appendices give the detail explanation of mathematical derivations considered in this study.

2. FADING CHANNEL AND COOPERATIVE RELAYING PROTOCOLS

2.1. Fading In Wireless Channel

The broadcast phenomena for transmitting the required information in wireless communication channel from source to destination come across different challenges, as a result the overall performance of the system is degraded [96]. This degrading factors namely referred as fading which arises due to various factors e.g., multi-path propagation, reflection, diffraction, path loss, etc. The effects of multi-path might be constructive or destructive which depends upon the phase of the received signal at the destination.

In wireless communication, the effects of fading is divided into two further branches, i.e., large scale fading and small scale fading [97]. In large scale fading the transmitted signal is degraded due to path loss or shadowing, whereas in small scale the fading occur because of delay spread and Doppler spread, however, in both cases the overall performance is affected. Moreover, on the other hand, the goal of achieving high data rate without mitigating the effects of fading in wireless channel seems to be difficult especially in the next generation of wireless networks. As a result, some methods and techniques are necessarily needed to combat against fading and to achieve better performance. However, these techniques must be very efficient and cost effective for utilizing them in real scenarios.

The fading can be mitigated by a very effective approach of cooperative diversity relaying technique in terms of reliability, efficiency and better performance. However, it is also necessary to know about the different challenges that come across in wireless fading channel and how to eliminate them in such a manner that better end to end performance can be achieved [45].

2.2. Statistical Model For Fading Channels

The different fading channels scenarios are generally categories in order to know that how the transmitted signal is degraded before reaching the destination. Moreover, how the various degrading factors either might be mitigate or eliminate for achieving better performance in fading channel. The statistical model for various fading channels are divided according to the different scenarios e.g., indoor, outdoor, urban, rural environment etc [98]. In literature, different fading channels that are discussed namely Rayleigh fading, Rician fading, Nakagami fading, Weibull fading, and Lognormal fading, etc., each of which has specific properties and statistical model. In the below section, the various fading channels having a majority of proprieties and fading characteristics, that any wireless channel might face are as follow:

2.2.1. Rayleigh fading channel

In a dense urban environment, there are less chances that transmitter and receiver have a direct line of sight (LOS) communication because of a various obstacle in the environment. The receiver received multiple copies of the same signal but with different delays and shift in the phase due to the effects of the multi-path which is caused by scattering during transmission of information. The Figure 2.1, shows that the power delay profile of the channel with multi-path received signals power which is decreasing exponentially with different delay time instant during the communication. This process is random in nature, and if there is no line of sight communication (NLOS) between the sender and the receiver, then it follows Rayleigh distribution [99].

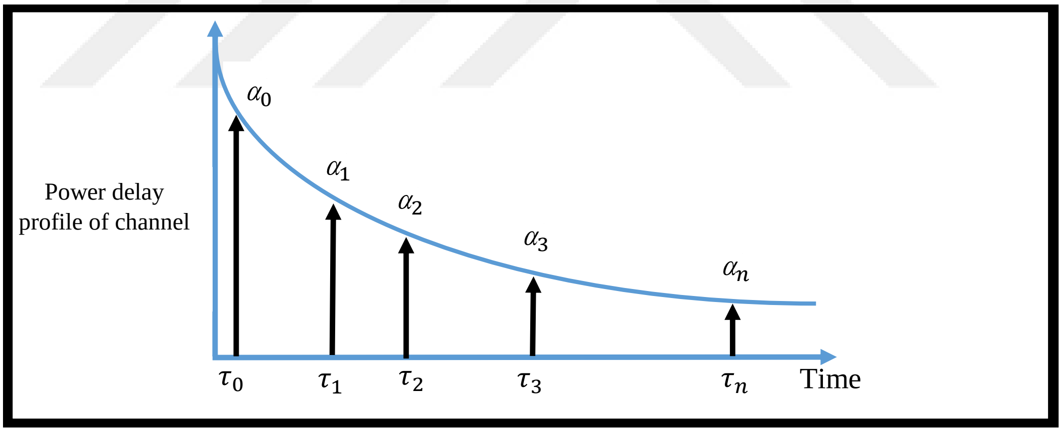

Figure 2.1. Multi path received signals with different delay and exponential power profile

In other words, when the power of the channel coefficient is distributed as an exponential random variable, the amplitude is distributed as a Rayleigh probability density function. Rayleigh is one of the most popular and common fading channels in wireless communication, and its phenomena theoretically based on the central base limit theorem. The received signal by various delay and gain due to multi path effects can be shown as

$$y(t) = \sum_{i=0}^{n} \alpha_i(t) x(t - \tau_i(t)) \tag{2.1}$$

where in (2.1) $\alpha_i(t)$ and $\tau_i(t)$ are the gain and delay of path(i). In terms of channel $h(\tau,t)$ the receive signal can be express as,

$$y(t)=\int_{-\infty}^{\infty} h(\tau,t)x(t-\tau)d\tau \tag{2.2}$$

The impulse response for the fading multi-path channel can be shown as

$$h(\tau,t)=\sum_{i=0}^{n}\alpha_i(t)\delta(\tau-\tau_i(t)) \tag{2.3}$$

The (2.2) and (2.3) are used for multi-path phenomenon whereas, by assuming that there is no multi-path and only one direct path exist between source and destination then channel can be written as,

$$h(t)=\tau_0\delta\left(t-\tau_o\right)=\tau_0\delta(t) \tag{2.4}$$

The (2.4) is considered for single tap and then the received signal can be shown as

$$y(t)=\tau_0.x\left(t\right)+n\left(t\right) \tag{2.5}$$

where in (2.5) $\tau_0=h(t)$ and n(t) is the noise added at the receiver end.

2.2.2. Rician fading channel

The fading channel in which there is a direct line of sight communication between transmitter and the receiver is usually referred as Rician fading channel [100]. There are also multiples copies of same signal that are received at the receiver end with different delay of time instant due to multi path effects of the environment. However, the dominate signal because of (LOS) makes a better choice for decision at the receiver end. The main difference between Rayleigh fading and Rician fading is LOS and NLOS communication between transmitter and the receiver.

2.2.3. Weibull fading channel

Generally, each fading channel in the wireless communication is limited to some specific scenarios e.g. Rayleigh fading or Rican fading usually consider for an urban, suburban or rural area. The impact of limitation and restriction over specific fading channel model eventually reduce the fading severity, as a result, desired performance cannot be achieved. On the other hand a more precise and less complex fading channel is introduced namely as Weibull fading channel which is quite suitable for both indoor and outdoor communication [101]. It can generate more accurate results and better performance even in different fading scenarios.

The Weibull distribution model has the ability to represent a broad range of weak and strong fading circumstances where other fading channel models are insufficient to measure them precisely. The value of Weibull fading channel parameter ω ranges from 0 to ∞. In case if the value of $\omega = 1$, then it shows the exponential distribution, however, in case if $\omega = 2$, it follows a Rayleigh distribution [102]. Moreover, if the value of ω is getting higher it will show more favorable environment for the wireless channel for sharing of information between transmitter and receiver which leads toward better performance as compared to a lesser value of Weibull fading parameter.

2.3. Cooperative Relaying Protocol

In cooperative communication, the relaying protocols at the relay node perform a significant role in processing the signal and forward the required information to a destination in such a manner that it generates efficient outcomes [5]. However, there are some set of rules and procedures for forwarding the required information to the destination. The different types of relaying protocol in cooperative communication have a different trade-off that depends on the efficiency, reliability, cost, and performance, etc. The basic cooperative relaying protocols will be discussed in detail in the following section.

2.3.1. Amplify and forward

One of the main and simplest relaying protocol is the amplify-and-forward (AF) in cooperative diversity network. The AF relaying protocol can also be recognized as a booster for forwarding the information, or layer one relaying protocol [103]. AF has been divided into two processing phases, in the first phase, the process of amplification is done at the relay node, and in the second phase, the amplified version of information is forward to the destination.

The receiver at destination accumulates all the information sent by the source as well as relay nodes, for the final decision on the transmitted signals as shown in Figure 2.2. The major drawback of AF relaying protocol is that noise is also amplified in the cooperative network that originates different complications between S and D channel in term of inter-symbol interference (ISI) [104]. One of the reasons behind the ISI is the amplified version of the noise signal received at D by different multipath which causes different delays [105].

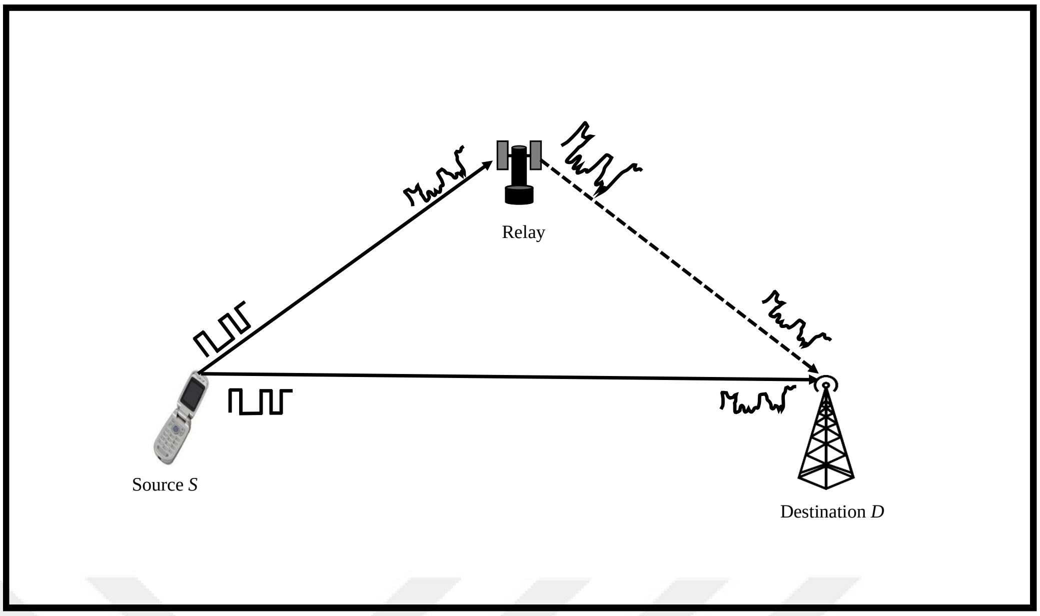

Figure 2.2. Amplify and forward method

The AF protocol has low computational complexity because it involves less signal processing at relay node. As a result, the low computational attribute of AF reduces the net cost of the relay node [106]. Furthermore, the duration of delay for forwarding the information to D is lesser. In fast communication application scenario, the AF is the best solution. Moreover, AF relaying protocol is considered as less energy consumption and efficient which ensure long battery life especially in terms of wireless sensor networks [107].

2.3.2. Decode and forward

Decode and Forward (DF) cooperative relaying protocol is also referred as regenerative protocol which is more complex and progressive when compared to AF [103]. Moreover, in other words, it is also recognized as layer two relay technology that was introduced by A.Sedonari et al. [108] as illustrated in Figure in 2.3.The performance of DF relaying protocol can be accomplished by employing parallel coding and permitting relay nodes to a make change in channel coding according to the requirement of the network [109].

The DF relaying protocol can be divided into two different steps. In the initial step, the received signal on relay node is demodulated that followed by the procedure of encoding. The noise that combined with the received signal is removed in this step as a result, the amplification of noise is not carried out by the relay node [110]. The amplification mitigating in noise comes up with several advantages. It reduces the chance of ISI that leads to less probability of interference in the cooperative communication network [104]. In the second step, modulation is accomplished on the required information signal and the process of encoding is done for transmitting the signal to the destination. Consequently, these stages ensure communication to be reliable and more efficient. However, the main shortcoming of this approach comes up as a processing delay, because relay node requires additional time for processing the received signal [111].

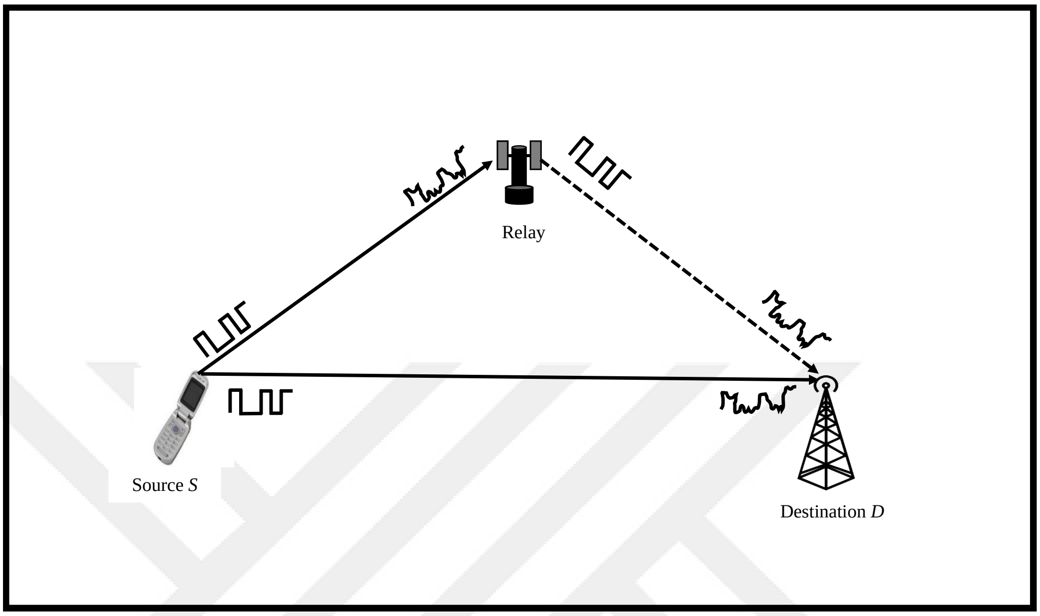

Figure 2.3. Decode and forward method

In cooperative DF relaying protocol, the processing delay can further be distributed into two parts. In the first part, the received signal at relay node follows the entire procedure of demodulation, decoding, subsequently modulation, and encoding [112]. Furthermore, if there is an error in the received signal, it is improved by error correcting code. However, there is a trade-off between delay, accuracy, and reliability. In some applications, the processing delay is not considered to be so important. However, the reliability of the information is more essential required [113].

In the second part, it is not necessary to track all the process of DF relaying protocol as mentioned above to manage delay time. There are certain reasons including the less computational capability of the relay node, and moreover, some application cannot endure more delay. Hence the required signal is impartially decoded and re-encoded symbol by symbol. In both scenarios, there are different trade-off depending on the requirements of the communication system [114].

2.3.3. Coded cooperation

Coded cooperation relaying protocol is more efficient and reliable as compared to AF and DF relaying protocols. It is also referred to as layer three relay technology [103]. Coded cooperation basically incorporates cooperation into channel coding [115]. In coded cooperation, the process is performed by dividing individually user's code word into different parts, for transmitting it through two different independent fading routes [116] as shown in Figure. 2.4. The elementary principle of coded cooperation is that individual relay node tries to transmit incremental redundancy to other relay nodes in the network [103].

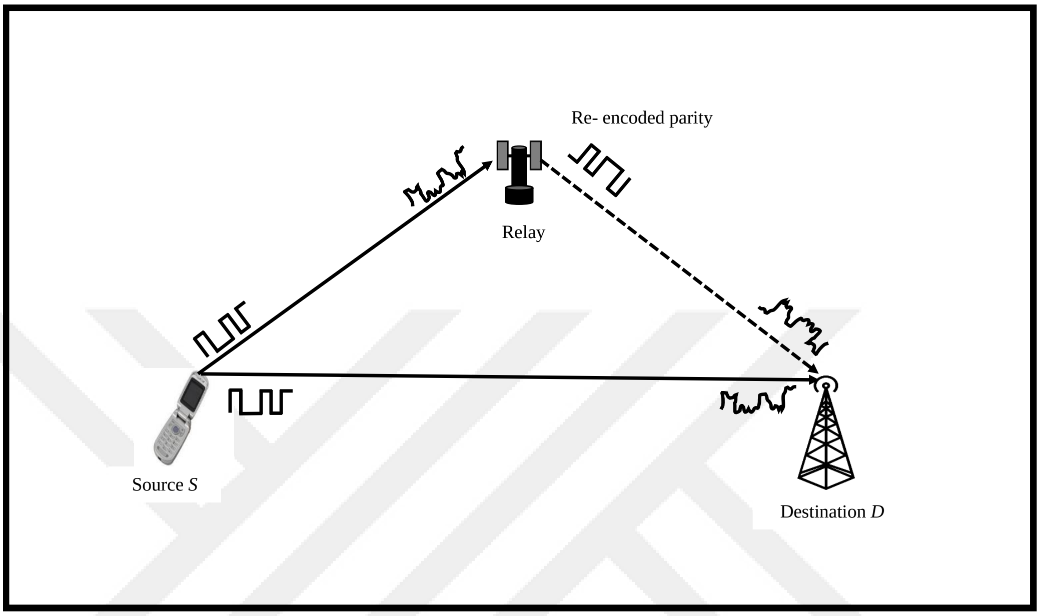

Figure 2.4. Coded cooperation with re-encoded parity method

In cooperative communication, the coded cooperative mode divides the information into different parts by means of segmentation [116]. Furthermore, each segmentation is considered as one block which is integrated by cycle redundancy check [117]. Correspondingly, the duration of data transmission is also alienated into two-time slots for each bit of segment, known as the frame [118]. In some cases when the cooperative mode is not required on the cooperative relay nodes in a network, the code cooperation regress to a non-cooperative mode.

The efficiency of coded cooperation is better because processes are repeatedly performed with the help of code design during transmission time [119]. Moreover, no feedback is required between the relay station and ultimate destination. The process of coded cooperation is illustrated in Figure 2.4, where relay station generates re-encode parity bits for transmitting it to the destination. The major drawback of coded cooperation is the increase in the processing time for performing all these operations, as a result, the delay time factor will increases [120]. However, accuracy and reliability of communication system are much better in this approach. Moreover, coded cooperation reduces interference in the cooperative network [121].

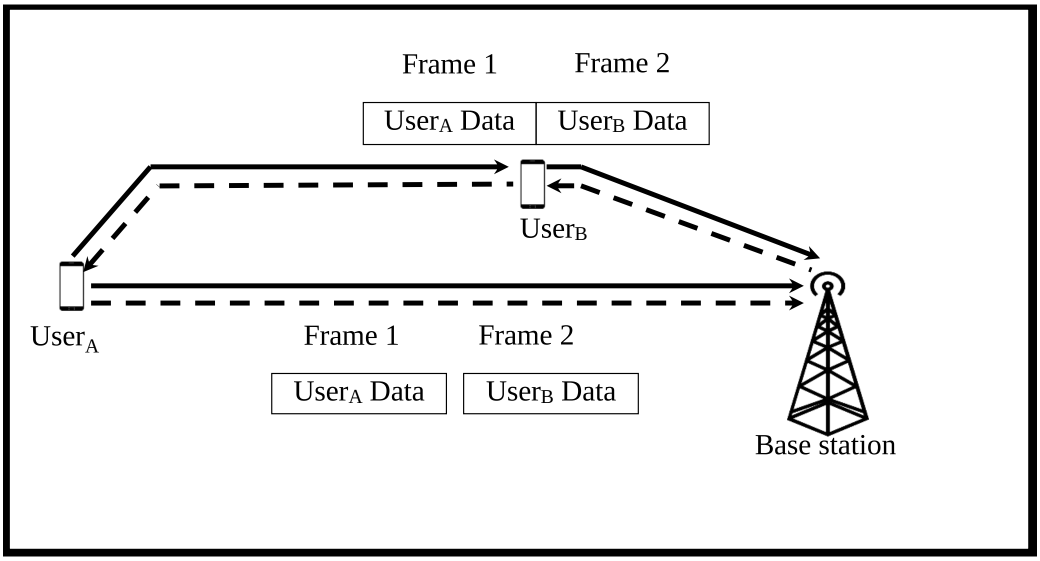

Figure 2.5. Coded cooperation method

Figure 2.5, illustrates the coded cooperation method for two users User_A and User_B. In this method, each user data is given a precise time slot of one frame for the interval of transmitting a specific number of bits. In the first slot, the User_A transmit its data bit1, and in the second time slot, the User_B data is sent, i.e., bit2. In case if the cooperative mode is not required during transmission of data, then User_A transmit its own data in the second time frame, as a matter of fact, in both cases, spectrum efficiency increases [122]. Moreover, in coded cooperative relaying protocol, the reliability of the communication system increases with better utilization of the given spectrum [123].

2.4. Overview Of Cooperative Communication Over Fading Channel

The performance of wireless communication is degraded due to the effects of the fading environment. However different methods and techniques specially cooperative communication can mitigate the effects of fading [96]. The ideal situation in a wireless channel is to be considered when there is no fading between transmitter and receiver. However, even when there is no fading in a channel the addition of noise at the receiver end cannot be ignored which is added due to the involvement of hardware effects, and in this case, the channel is known to be an AWGN channel. The various method and technique in next-generation wireless that approaches toward better performance usually desired to reach near the performance of the AWGN channel [45].

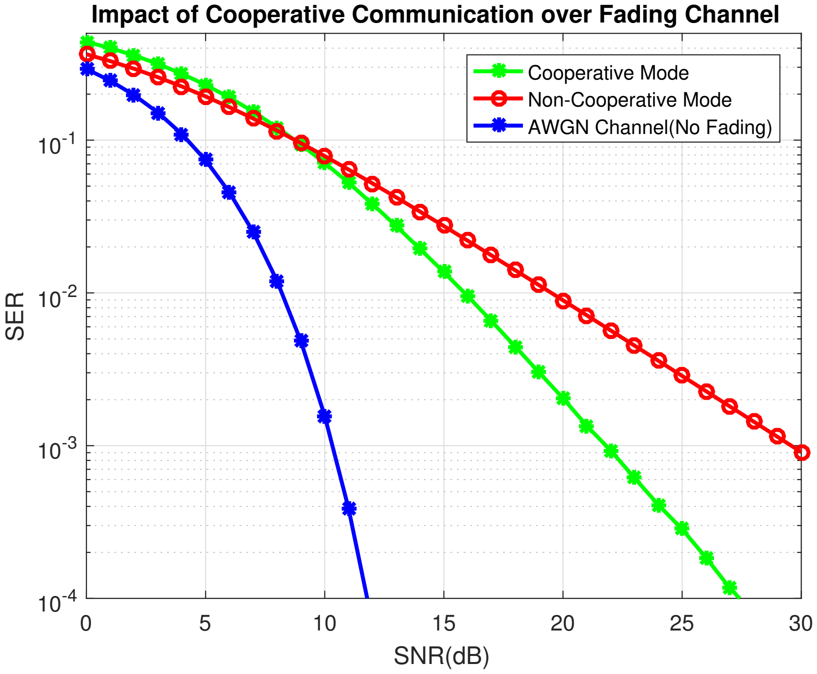

Figure 2.6. Impact of cooperative communication over fading channel

In Figure 2.6 the performance of wireless communication over Rayleigh fading channel with three different scenarios is presented. In non-cooperative mode, the performance is getting better when the SNR approaches higher value. However, In the case of cooperative communication, the performance is getting much better than the non-cooperative mode. This reflects that even in fading channel the cooperative communication can achieve a better end to end performance. On the other hand, when no fading is considered in the wireless channel, and only AWGN is considered, this performance is considered to be an ideal case in wireless communication

2.5. Applications and Benefits of Cooperative Relaying

Cooperative communication plays a vital role in different scenarios of the wireless communication network by increasing the performance and the reliability of the wireless system. It has numerous advantages through which the demand for high data rates in next generation of a wireless network might be fulfilled.

2.5.1. Better spectral efficiency

In the next generation wireless networks, high spectral efficiency requirement is challenging task [124]. Cooperative communication provides better performance in terms of spectral efficiency by using the same spectrum in an efficient way. The relay nodes transmit not only their own data but also their partner relay nodes data, which upgrade the overall system performance. The use of cooperative communication and network coding can also increase the effective bandwidth allocation [125].

2.5.2. Greater spatial diversity

Wireless channel faces different fading environment during transmission of data, through which the efficiency and performance of the communication system decreases. Consequently, it might be possible that direct transmission between the source and destination may be degraded due to many factors and moreover, they might face unbearable error rate that prompts re transmission [126]. In cooperative communication, the higher spatial diversity can be accomplished by forming a virtual antenna array from multiple single-antenna nodes [108]. Thus, cooperative communication has the potential to overcome many challenges and address the effects of fading and generate efficient results as compared to non-cooperative mode.

2.5.3. Enhancement in coverage area

Cooperative communication plays an important role to enhance the coverage area, thereby increasing link capacity and efficiency of the base station. The IEEE 802.16j standard stipulates two types of relay modes namely transparent relay mode and non-transparent relay mode [127]. In IEEE 802.16j, two types of operation for processing information on relay node are defined in detail. The first operation describes that how framing information is transmitted and in the second operation it considers the scheduling algorithm that can be centralized or distributed [128]. Cooperative transparent and non-transparent relay modes both lead to a better performance and give a solid edge to the system [129].The cooperative transparent relay mode assures to fill the gap of a shadow area in the surrounding of the base station, while on the other hand, the information of framing to the Base Station (BS) is not forward by the relay node [130]. Moreover, cooperative transparent relay mode has low computational complexity because the transmission of control message is not done by a relay station, while it operates in centralized scheduling environment [131]. In non-transparent relay mode, the relay nodes are positioned at the border of surrounding area, where there is low data traffic. The relay nodes generate their own information related to framing and forward them to the (BS) [132]. Hence, it covers a large area, however, the generation of framing causes high interference among other relay nodes [127]. This relay mode operates in both centralized and distributed environment, but complexity is much higher than transparent relay mode [133]. Table 2 shows the comparison between the transparent relay and non-transparent relay modes.

2.5.4. Cost reduction

In Cooperative communication the relaying technique helps to reduce the costly installation procedures and equipment's in the network. As a result, the net budget of network decreases as compared to the traditional communication system. Moreover, cooperative communication provides an alternative and effective approach in a wireless network that have high gain in the performance of MIMO [134]. In cooperative communication two types of transmission mode i.e., half duplex and full duplex are used for the transmission of information. In half-duplex mode the information is carried out in two-phase while in another scenario, both transmitting and receiving signals can be held at the equivalent time instant in the cooperative relay node. Additionally, similar frequencies can be recognized as full duplex relaying [135]. However, the implementation of the full-duplex relaying mode is not cost-effective approach [136]. Nevertheless, the cooperative relay node that functions in a half-duplex manner can be an effective approach in term of cost [137] i.e., at relay node the transmission and reception of the signals are detached in term of time or frequency which is also identified as cheap relay[138]. In some cases, the passive relay node is used to cover the NLOS communication in mm-wave, which makes a reduction in the cost of the network.

2.5.5. Energy efficiency

Cooperative communication leads to spatial diversity there by, increasing network capacity and throughput while minimizing energy consumption [139]. Zhang et al. present cooperative relaying technique for sensor network considering energy efficiency [140]. In case if the distance between clusters is larger, cooperative communication can effectively decrease the consumption of total energy [141]. Similarly, in cooperative communication, the energy efficiency can be provided upgraded through optimal energy distribution among all the relaying nodes in minimizing the link outage probability [127]. In the Internet of Things (IoT) the sensors nodes have less computational capabilities hence efficient energy mechanism is required [142].

3. RELAY SELECTION IN COOPERATIVE DIVERSITY NETWORK OVER FADING CHANNELS

In cooperative diversity, there are various wireless network model used for accomplishing high data rate even in the degrading fading environment. However, various cooperative methods and techniques must have to utilize specifically according to the required scenarios for achieving high performance and generating better results. In cooperative diversity, two models are generally used namely as cooperative network and multi-relay dual-hop network. The basic difference between these two networks is that in the cooperative network, the source node can transmit the required information to all the connected relay nodes inside the network as well as to the destination node. However, in multi dual-hop, the destination node is not directly reachable or accessible only to the source node due to the various technical reason for sharing of the information.

In this section these two cases of cooperative diversity are considered, i.e., Cooperative Network and Multi dual-hop network over various fading channel with best relay selection technique in order to analyze the end to end performance of the described system models.

3.1. System Model

Fig. 3.1 presents the cooperative network with multiple relays deployed between source and destination. The system model consists of a source node S and a destination node D, which are communicating with K number of relay nodes R_k (k = 1, 2, 3,...,K) in the cooperative network. We assume that all the nodes are installed with one transmit and one receive antenna, and the destination node has complete channel state information. The message signal *x* from the S is conveyed to the D in two consecutive time slots.

$$Y_{sd} = \sqrt{E_s} h_{sd} x + \eta_{sd} \tag{3.1}$$

In the first time slot, the transmitted signal *x* is received by D and Relay R_k, as Y_{sd} and Y_{sr_k}, respectively, which can be expressed as in (3.1)

$$Y_{sr_k} = \sqrt{E_s} h_{sr_k} x + \eta_{sr_k} \tag{3.2}$$

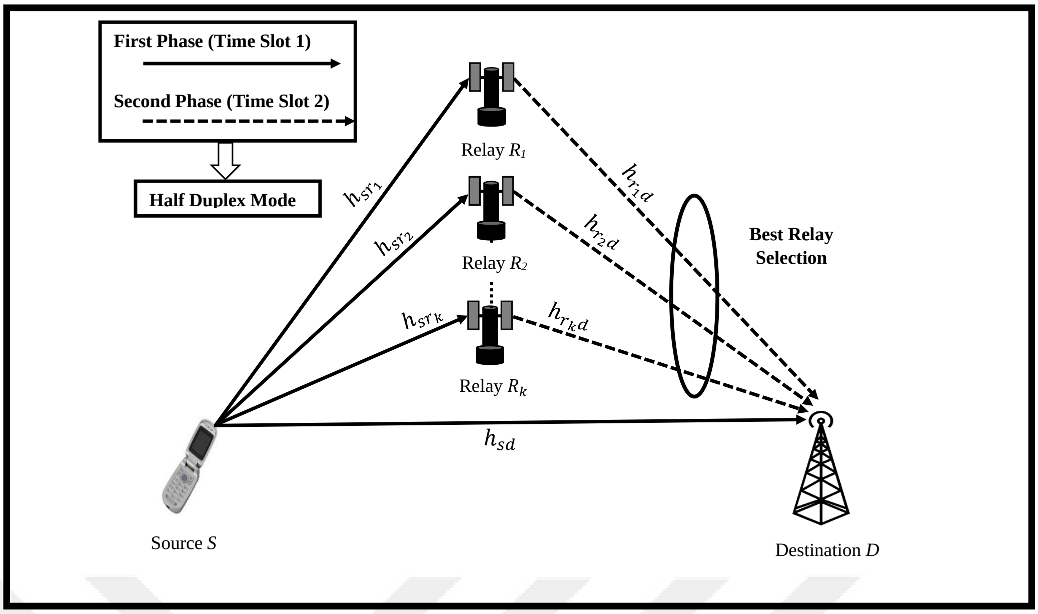

Figure 3.1. Cooperative multi relay diversity network

where in (3.1) and (3.2), E_s denotes the average energy per symbol in the message signal, η_{sd} and η_{sr_k} are the complex additive white Gaussian noise with the distribution $\mathcal{CN}(0, N_0)$, where N_0 is the noise variance, h_{sd} and h_{sr_k} are the channel gain coefficients for source to destination link and source to relay link, respectively. The process of amplification is conceded out at the received signal by the relay node, which is attenuated by the noise in the first phase and then forwarded to D. Then, the received signal at the destination via the relay node can be written as,

$$Y_{r_kd} = G_k\sqrt{E_s}h_{r_kd}Y_{sr_k} + \eta_{r_kd} \tag{3.3}$$

where in (3.3) the h_{r_kd} is the channel gain coefficients of the relay R_k to destination link, η_{r_kd} is the complex AWGN with variance N_0, and in (3.4) G_k is the amplification gain factor at relay R_k, which is given by,

$$G_k = \sqrt{\frac{Es}{Es|h_{sr_k}|^2 + N_0}} \tag{3.4}$$

3.2. Max-Min Relay Selection

In the network model, we consider that there are K number of relay nodes and the best relay selection scheme is consider as,

$$b_R = \arg\max_{k\in\mathfrak{R}}\{\gamma_k\} \tag{3.5}$$

where in (3.5) the $\mathfrak{R} = 1,2,3...K$ is the set of relays, γ_k is the instantaneous SNR of the received signal at the kth relay. The max-min relay selection that performs the function in such a manner that the minimum SNR among the connected relay node links in the cooperative network is maximized. Hence the relay selection in (3.6) with max-min method is given as,

$$b_R = \arg\max_{k\in\mathfrak{R}}\{\min(\gamma_{sr_k}, \gamma_{r_k d})\} \tag{3.6}$$

The upper bound of total SNR γ_{tot} at the destination node is given by,

$$\gamma_{tot} \leq \gamma_{sd} + \max_{k\in\mathfrak{R}}\{\min(\gamma_{sr_k}, \gamma_{r_k d})\} \tag{3.7}$$

where in (3.7), γ_{sd}, γ_{sr_k} and $\gamma_{r_k d}$ are the SNR of the received signals from S $\rightarrow$ D, S $\rightarrow$ R_k and R_k $\rightarrow$ D links, respectively.

3.3. Relay Selection In Cooperative Network Over Rayleigh Fading Channel

We consider that fading channel for all links in the cooperative network given in Fig. 1 follows Rayleigh distribution. In a dense urban environment when a large number of multi path received signals are considered at the destination, the channel fading follows Rayleigh distribution and this phenomenon is theoretically based on central limit theorem [143]. In order to have better Rayleigh distribution number of multi path are required

$$f_{\gamma_z}(\gamma) = \frac{1}{\bar{\gamma}_z}\exp\left(-\left(\frac{\gamma}{\bar{\gamma}_z}\right)\right) \tag{3.8}$$

The SNR of the received signal has following PDF and CDF are given in [144] as

$$F_{\gamma_z}(\gamma) = 1 - \exp\left(-\left(\frac{\gamma}{\bar{\gamma}_z}\right)\right) \tag{3.9}$$

where in (3.8) and (3.9), $z \in \{sd, sr_k, r_k d\}$ are the link index. The MGF of instantaneous SNR γ can be obtained by Laplace transform formula as,

$$\mathscr{M}_\gamma(\mathfrak{s}) = E\{\exp(-\mathfrak{s}\gamma)\} = \int_0^\infty \exp(-\mathfrak{s}\gamma) f_\gamma(\gamma) d\gamma \tag{3.10}$$

where in (3.10), $E\{\cdot\}$ denotes the statistical expectation and $\mathfrak{s}$ is the dummy variable. Hence the MGF of the instantaneous SNR received via S $\rightarrow$ D link is,

$$\mathscr{M}_{\gamma_{sd}}(\mathfrak{s}) = \frac{1}{(1 + \bar{\gamma}_{sd}\mathfrak{s})} \tag{3.11}$$

The MGF of S → $\mathrm{R_k}$ → D link can be derived via its PDF. To obtain PDF we first need to find CDF of both links, i.e., S → $\mathrm{R_k}$ and $\mathrm{R_k}$ → D, links. Suppose that $\gamma_{\mathrm{sr_k}}$ and $\gamma_{\mathrm{r_kd}}$ are i.i.d, then CDF of $\gamma_{\mathrm{k}}=\min\left(\gamma_{\mathrm{sr_k}},\gamma_{\mathrm{r_kd}}\right)$ can be written as [145]

$$\mathrm{F}_{\gamma_\mathrm{k}}(\gamma)=1-[1-\mathrm{F}_{\gamma_{\mathrm{sr_k}}}(\gamma)][1-\mathrm{F}_{\gamma_{\mathrm{r_kd}}}(\gamma)] \tag{3.12}$$

where in (3.12), $\mathrm{F}_{\gamma_{\mathrm{sr_k}}}(\gamma)$, and $\mathrm{F}_{\gamma_{\mathrm{r_kd}}}(\gamma)$ are the CDF of the received signal SNR of the links S → $\mathrm{R_k}$ and $\mathrm{R_k}$ → D, respectively. Considering that the channel gain coefficients of the relay link are i.i.d, and by using equation (3.9) with the proper index, equation (3.12) can be shown to be equal to,

$$\mathrm{F}_{\gamma_\mathrm{k}}(\gamma)=1-\exp\left(-\left(\frac{\gamma}{\overline{\gamma}_{\mathrm{u_k}}}\right)\right) \tag{3.13}$$

where in (3.13) the $\overline{\gamma}_{\mathrm{u_k}}$ is given as,

$$\overline{\gamma}_{\mathrm{u_k}}=\frac{\overline{\gamma}_{\mathrm{sr_k}}\overline{\gamma}_{\mathrm{r_kd}}}{\overline{\gamma}_{\mathrm{sr_k}}+\overline{\gamma}_{\mathrm{r_kd}}} \tag{3.14}$$

Using equation (3.13) the PDF of both direct and relay links can be obtained by taking the derivative of the CDF with respect to γ, which can be shown as,

$$\mathrm{f}_{\gamma_\mathrm{k}}(\gamma)=\frac{1}{\overline{\gamma}_{\mathrm{u_k}}}\exp\left(-\left(\frac{\gamma}{\overline{\gamma}_{\mathrm{u_k}}}\right)\right) \tag{3.15}$$

Hence, the CDF of the best relay SNR $\gamma_{\mathrm{b_R}}$ can be written as [144]

$$\mathrm{F}_{\gamma_{\mathrm{b_R}}}(\gamma)=\left[\mathrm{F}_{\gamma_\mathrm{k}}(\gamma)\right]^{\mathrm{K}} \tag{3.16}$$

where K is the total number of the relays. The PDF of the best relay can be calculated by taking the derivative of CDF,

$$\mathrm{f}_{\gamma_{\mathrm{b_R}}}(\gamma)=\mathrm{K}\mathrm{f}_{\gamma_\mathrm{k}}(\gamma)\left[\mathrm{F}_{\gamma_\mathrm{k}}(\gamma)\right]^{\mathrm{K}-1} \tag{3.17}$$

By substituting equation (3.15) into equation (3.17), it can be rewritten as

$$\mathrm{f}_{\gamma_{\mathrm{b_R}}}(\gamma)=\frac{\mathrm{K}}{\overline{\gamma}_{\mathrm{u_k}}}\exp\left(-\left(\frac{\gamma}{\overline{\gamma}_{\mathrm{u_k}}}\right)\right)\left[1-\exp\left(-\left(\frac{\gamma}{\overline{\gamma}_{\mathrm{u_k}}}\right)\right)\right]^{\mathrm{K}-1} \tag{3.18}$$

Thus, by inserting equation (3.18) into equation (3.10) and using binomial expansion, the MGF of SNR of the best relay in $S \rightarrow R_k \rightarrow D$ link is obtained as,

$$\mathscr{M}_{\gamma_{b_R}}(\mathfrak{s}) = \sum_{k=1}^{K} \binom{K}{k} \frac{k(-1)^{k-1}}{(k+\bar{\gamma}_{u_k}\mathfrak{s})} \tag{3.19}$$

Regarding the MGF $\mathscr{M}_{\gamma_{tot}}$ of total end to end SNR γ_{tot}, with the assumption that SNRs obtained at the links $S \rightarrow D$, $S \rightarrow R_k \rightarrow D$ are i.i.d. $\mathscr{M}_{\gamma_{tot}}$ can be written as,

$$\mathscr{M}_{\gamma_{tot}}(\mathfrak{s}) = \mathscr{M}_{\gamma_{sd}}(\mathfrak{s}) \times \mathscr{M}_{\gamma_{b_R}}(\mathfrak{s}) \tag{3.20}$$

Hence, by replacing equation (3.11) and equation (3.19) into equation (3.20), the MGF of total SNR at the destination node under Rayleigh fading for all links is given by,

$$\mathscr{M}_{\gamma_{tot}}(\mathfrak{s}) = \frac{1}{(1+\bar{\gamma}_{sd}\mathfrak{s})} \sum_{k=1}^{K} \binom{K}{k} \frac{k(-1)^{k-1}}{(k+\bar{\gamma}_{u_k}\mathfrak{s})} \tag{3.21}$$

3.4. NRS In Cooperative Network Over Rayleigh Fading Channel

In cooperative network when no best relay selection is consider among multi-node than by using equation (3.15) the MGF for $S \rightarrow R_k$ and $R_k \rightarrow D$, links can be written as,

$$\mathscr{M}_{\gamma_k}(\mathfrak{s}) = \frac{1}{(1+\bar{\gamma}_{u_k}\mathfrak{s})} \tag{3.22}$$

In the cooperative network both $S \rightarrow D$ and $S \rightarrow R_k \rightarrow D$, links are required for calculating total end to end SNR γ_{tot}. Assuming all the links as i.i.d with no relay selection method, the total MGF $\mathscr{M}_{\gamma_{tot}}$, can be obtained as,

$$\mathscr{M}_{\gamma_{tot}}(\mathfrak{s}) = \mathscr{M}_{\gamma_{sd}}(\mathfrak{s}) \prod_{k=1}^{K} \mathscr{M}_{\gamma_k}(\mathfrak{s}) \tag{3.23}$$

Thus, by inserting equation (3.11) and equation (3.22) into equation(3.23) the $\mathscr{M}_{\gamma_{tot}}$ for no relay selection method can be rewritten as,

$$\mathscr{M}_{\gamma_{tot}}(\mathfrak{s}) = \frac{1}{(1+\bar{\gamma}_{sd}\mathfrak{s})} \prod_{k=1}^{K} \frac{1}{(1+\bar{\gamma}_{u_k}\mathfrak{s})} \tag{3.24}$$

3.5. Multi Dual-Hop Network Over Rayleigh Fading Channel

In case of multi dual-hop network all the process involved in cooperative network are same, however the destination node is not directly reachable only to source node as shown in Figure.3.2.

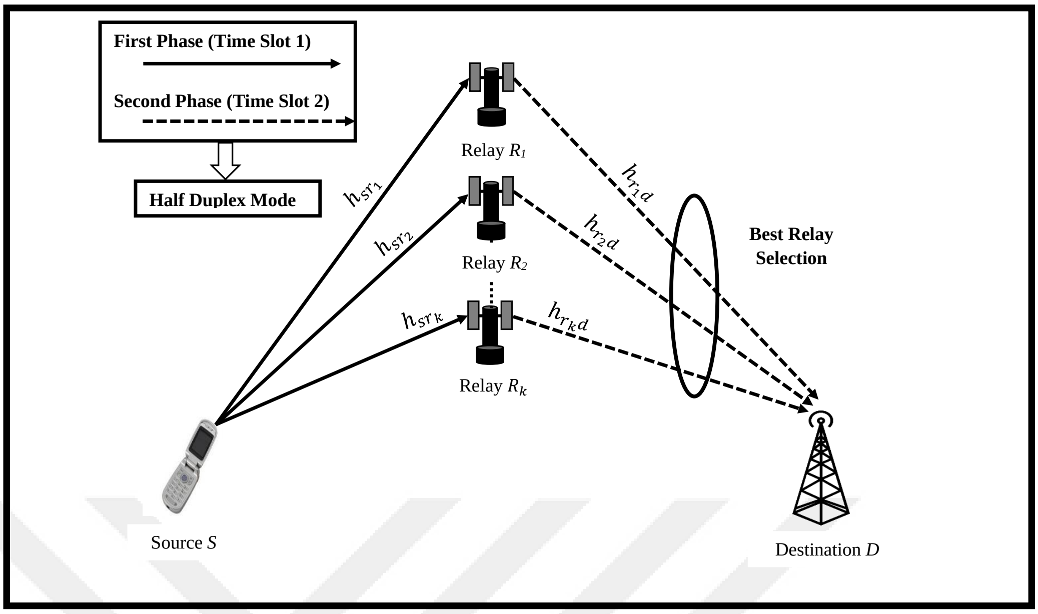

Figure 3.2. Multi dual-hop network

Therefore in multi dual-hop, only MGF of $S \rightarrow \mathrm{R_k}$ and $\mathrm{R_k} \rightarrow \mathrm{D}$, links is required, which is already obtained as shown in equation (3.19) for best relay selection case and equation (3.15) for no relay selection case.

3.6. Relay Selection In Cooperative Network Over Weibull Fading Channel

In this case, we consider that fading channel follows a Weibull distribution model for the direct and all relay links in cooperative network as shwon in Figure. 3.1. The SNR of the received signal has the following PDF [144]

$$\mathrm{f}_{\gamma_\mathrm{z}}(\gamma) = \left(\frac{\beta_\mathrm{z}}{\overline{\gamma}_\mathrm{z}}\right)^{\omega_\mathrm{z}} \omega_\mathrm{z} \gamma^{\omega_\mathrm{z}-1} \exp\left(-\left(\frac{\beta_\mathrm{z}\gamma}{\overline{\gamma}_\mathrm{z}}\right)^{\omega_\mathrm{z}}\right) \tag{3.25}$$

where the SNR of the received signal has the following CDF given as,

$$\mathrm{F}_{\gamma_\mathrm{z}}(\gamma) = 1 - \exp\left(-\left(\frac{\beta_\mathrm{z}\gamma}{\overline{\gamma}_\mathrm{z}}\right)^{\omega_\mathrm{z}}\right) \tag{3.26}$$

where ω_z is the Weibull fading parameter, $\beta_\mathrm{z} = \Gamma(1+2/\omega_\mathrm{z})$, $\overline{\gamma}_\mathrm{z}$ is the average SNR for each of the direct or relay link, and link index is denoted by $\mathrm{z} \in \{\mathrm{sd}, \mathrm{sr_k}, \mathrm{r_k d}\}$. The Weibull distribution model has the ability to represent a broad range of weak and strong fading circumstances where other fading channel models are insufficient to measure them precisely [146]. The value of Weibull fading channel parameter ω ranges from 0 to ∞. In case if the value of $\omega = 1$, then it shows the exponential distribution, however, in case if

$\omega = 2$, it follows a Rayleigh distribution [147]. The PDF of direct link between S → D link can be written as,

$$\mathrm{f}_{\gamma_{\mathrm{sd}}}(\gamma) = \left(\frac{\beta_{\mathrm{sd}}}{\overline{\gamma}_{\mathrm{sd}}}\right)^{\omega_{\mathrm{sd}}} \omega_{\mathrm{sd}} \gamma^{\omega_{\mathrm{sd}}-1} \exp\left(-\left(\frac{\beta_{\mathrm{sd}}\gamma}{\overline{\gamma}_{\mathrm{sd}}}\right)^{\omega_{\mathrm{sd}}}\right) \tag{3.27}$$

The MGF of received signal SNR via S → D is calculated by substituting equation(3.27) into equation(3.10), and by using Meijer's G function $\mathrm{G}_{\mathrm{l,k}}^{\mathrm{m,n}}(\cdot)$ [148], it is expressed as

$$\begin{aligned} \mathscr{M}_{\gamma_{\mathrm{sd}}}(\mathfrak{s}) \quad &= \left(\frac{\beta_{\mathrm{sd}}}{\overline{\gamma}_{\mathrm{sd}}}\right)^{\omega_{\mathrm{sd}}} (2\pi)^{\frac{1-\omega_{\mathrm{sd}}}{2}} (\omega_{\mathrm{sd}})^{\omega_{\mathrm{sd}}+\frac{1}{2}} (\mathfrak{s})^{-\omega_{\mathrm{sd}}} \\ \times \mathrm{G}_{1,\omega_{\mathrm{sd}}}^{\omega_{\mathrm{sd}},1} & \left(\frac{(\mathrm{s})^{\omega_{\mathrm{sd}}}}{(\omega_{\mathrm{sd}})^{\omega_{\mathrm{sd}}} \left(\frac{\beta_{\mathrm{sd}}}{\overline{\gamma}_{\mathrm{sd}}}\right)^{\omega_{\mathrm{sd}}}} \middle| \begin{matrix} 1 \\ 1, 1+\frac{1}{\omega_{\mathrm{sd}}}, \ldots, 1+\frac{(\omega_{\mathrm{sd}}-1)}{\omega_{\mathrm{sd}}} \end{matrix} \right) \end{aligned} \tag{3.28}$$

To derive CDF of the received signal SNR over S → $\mathrm{R_k}$ and $\mathrm{R_k}$ → D links, by substituting equation (3.26) into equation (3.12) with the proper index, we obtain,

$$\mathrm{F}_{\gamma_{\mathrm{k}}}(\gamma) = 1 - \exp\left(-\left(\frac{\beta_{\mathrm{sr_k}}\gamma}{\overline{\gamma}_{\mathrm{sr_k}}}\right)^{\omega_{\mathrm{sr_k}}}\right) \exp\left(-\left(\frac{\beta_{\mathrm{r_kd}}\gamma}{\overline{\gamma}_{\mathrm{r_kd}}}\right)^{\omega_{\mathrm{r_kd}}}\right) \tag{3.29}$$

Then, PDF of γ_{k} can be shown to be equal to

$$\begin{aligned} \mathrm{f}_{\gamma_{\mathrm{k}}}(\gamma) = \exp(- \quad & \left(\frac{\beta_{\mathrm{sr_k}}\gamma}{\overline{\gamma}_{\mathrm{sr_k}}}\right)^{\omega_{\mathrm{sr_k}}} \exp\left(-\left(\frac{\beta_{\mathrm{r_kd}}\gamma}{\overline{\gamma}_{\mathrm{r_kd}}}\right)^{\omega_{\mathrm{r_kd}}}\right) \times \\ \left[\left(\frac{\beta_{\mathrm{sr_k}}\gamma}{\overline{\gamma}_{\mathrm{sr_k}}}\right)^{\omega_{\mathrm{sr_k}}} \right. & \left. (\omega_{\mathrm{sr_k}})(\gamma)^{\omega_{\mathrm{sr_k}}-1} + \left(\frac{\beta_{\mathrm{r_kd}}\gamma}{\overline{\gamma}_{\mathrm{r_kd}}}\right)^{\omega_{\mathrm{r_kd}}} (\omega_{\mathrm{r_kd}})(\gamma)^{\omega_{\mathrm{r_kd}}-1}\right] \end{aligned} \tag{3.30}$$

Replacing equation (3.29) and equation (3.30) into equation (3.17), $\mathrm{f}_{\gamma_{\mathrm{b_R}}}(\gamma)$ of the SNR under Weibull fading channel, with relay selection scheme can be written as,

$$\begin{aligned} \mathrm{f}_{\gamma_{\mathrm{b_R}}} \quad (\gamma) = & \left[\left(\frac{\beta_{\mathrm{sr_k}}}{\overline{\gamma}_{\mathrm{sr_k}}}\right)^{\omega_{\mathrm{sr_k}}} (\omega_{\mathrm{sr_k}})(\gamma)^{\omega_{\mathrm{sr_k}}-1} + \left(\frac{\beta_{\mathrm{r_kd}}}{\overline{\gamma}_{\mathrm{r_kd}}}\right)^{\omega_{\mathrm{r_kd}}} (\omega_{\mathrm{r_kd}})(\gamma)^{\omega_{\mathrm{r_kd}}-1}\right] \\ \sum_{\mathrm{k}=1}^{\mathrm{K}} \quad & \binom{\mathrm{K}}{\mathrm{k}} \mathrm{k}(-1)^{\mathrm{k}-1} \exp\left(-\mathrm{k}\left(\left(\frac{\beta_{\mathrm{sr_k}}\gamma}{\overline{\gamma}_{\mathrm{sr_k}}}\right)^{\omega_{\mathrm{sr_k}}} + \left(\frac{\beta_{\mathrm{r_kd}}\gamma}{\overline{\gamma}_{\mathrm{r_kd}}}\right)^{\omega_{\mathrm{r_kd}}}\right)\right) \end{aligned} \tag{3.31}$$

Now, by assuming that all the relay links in the network in Figure. 3.1 have identical Weibull fading parameters, i.e., ω_{sd}= $\omega_{\mathrm{sr_k}}$ = $\omega_{\mathrm{r_kd}}$=ω_{k}, β_{sd}=$\beta_{\mathrm{sr_k}}$=$\beta_{\mathrm{r_kd}}$= β_{k} and by setting

$\overline{\gamma}_{\mathrm{sd}}$=$\overline{\gamma}_{\mathrm{sr_k}}$=$\overline{\gamma}_{\mathrm{r_kd}}$= $\overline{\gamma}_{\mathrm{k}}$ then equation(3.31) can be simplified to,

$$\mathrm{f}_{\gamma_{\mathrm{b_R}}}(\gamma) = 2\omega_{\mathrm{k}}\left(\frac{\beta_{\mathrm{k}}}{\overline{\gamma}_{\mathrm{k}}}\right)^{\omega_{\mathrm{k}}}\gamma^{\omega_{\mathrm{k}}-1}\sum_{\mathrm{k}=1}^{\mathrm{K}}\binom{\mathrm{K}}{\mathrm{k}}\mathrm{k}(-1)^{\mathrm{k}-1}\exp\left(-2\mathrm{k}\left(\frac{\beta_{\mathrm{k}}\gamma}{\overline{\gamma}_{\mathrm{k}}}\right)^{\omega_{\mathrm{k}}}\right) \tag{3.32}$$

By substituting equation (3.32) into equation (3.10), the MGF $\mathscr{M}_{\gamma_{\mathrm{b_R}}}$ of the received signal SNR over the link $S \rightarrow \mathrm{R_k} \rightarrow \mathrm{D}$ with the best relay selection can be expressed,

$$\begin{aligned}\mathscr{M}_{\gamma_{\mathrm{b_R}}}(\mathfrak{s}) \; &= 2\omega_{\mathrm{k}}\left(\frac{\beta_{\mathrm{k}}}{\overline{\gamma}_{\mathrm{k}}}\right)^{\omega_{\mathrm{k}}}\sum_{\mathrm{k}=1}^{\mathrm{K}}\binom{\mathrm{K}}{\mathrm{k}}\mathrm{k}(-1)^{\mathrm{k}-1}(2\pi)^{\frac{1-\omega_{\mathrm{k}}}{2}}(\omega_{\mathrm{k}})^{\omega_{\mathrm{k}}+\frac{1}{2}}(\mathfrak{s})^{-\omega_{\mathrm{k}}} \\ &\times \mathrm{G}^{\omega_{\mathrm{k}},1}_{1,\omega_{\mathrm{k}}}\left(\frac{(\mathfrak{s})^{\omega_{\mathrm{k}}}}{2\mathrm{m}(\omega_{\mathrm{k}})^{\omega_{\mathrm{k}}}\left(\frac{\beta_{\mathrm{k}}}{\overline{\gamma}_{\mathrm{k}}}\right)^{\omega_{\mathrm{k}}}}\middle|\begin{matrix}1\\1,1+\frac{1}{\omega_{\mathrm{k}}},\ldots,1+\frac{(\omega_{\mathrm{k}}-1)}{\omega_{\mathrm{k}}}\end{matrix}\right)\end{aligned} \tag{3.33}$$

Thus, under the Weibull fading channel conditions for all the links in relay network, total MGF $\mathscr{M}_{\gamma_{\mathrm{tot}}}$ of the overall received signal SNR is obtained by substituting equation (3.28) and equation (3.33) into equation (3.20) as,

$$\begin{aligned}\mathscr{M}_{\gamma_{\mathrm{tot}}}(\mathfrak{s}) = &\left[\left(\frac{\beta_{\mathrm{sd}}}{\overline{\gamma}_{\mathrm{sd}}}\right)^{\omega_{\mathrm{sd}}}(2\pi)^{\frac{1-\omega_{\mathrm{sd}}}{2}}(\omega_{\mathrm{sd}})^{\omega_{\mathrm{sd}}+\frac{1}{2}}(\mathfrak{s})^{-\omega_{\mathrm{sd}}}\right] \\ &\times \mathrm{G}^{\omega_{\mathrm{sd}},1}_{1,\omega_{\mathrm{sd}}}\left(\frac{(\mathfrak{s})^{\omega_{\mathrm{sd}}}}{(\omega_{\mathrm{sd}})^{\omega_{\mathrm{sd}}}\left(\frac{\beta_{\mathrm{sd}}}{\overline{\gamma}_{\mathrm{sd}}}\right)^{\omega_{\mathrm{sd}}}}\middle|\begin{matrix}1\\1,1+\frac{1}{\omega_{\mathrm{sd}}},\ldots,1+\frac{(\omega_{\mathrm{sd}}-1)}{\omega_{\mathrm{sd}}}\end{matrix}\right) \\ &\times\left[2\omega_{\mathrm{k}}\left(\frac{\beta_{\mathrm{k}}}{\overline{\gamma}_{\mathrm{k}}}\right)^{\omega_{\mathrm{k}}}\sum_{\mathrm{k}=1}^{\mathrm{K}}\binom{\mathrm{K}}{\mathrm{k}}\mathrm{k}(-1)^{\mathrm{k}-1}(2\pi)^{\frac{1-\omega_{\mathrm{k}}}{2}}(\omega_{\mathrm{k}})^{\omega_{\mathrm{k}}+\frac{1}{2}}(\mathfrak{s})^{-\omega_{\mathrm{k}}}\right] \\ &\times \mathrm{G}^{\omega_{\mathrm{k}},1}_{1,\omega_{\mathrm{k}}}\left(\frac{(\mathfrak{s})^{\omega_{\mathrm{k}}}}{2\mathrm{m}(\omega_{\mathrm{k}})^{\omega_{\mathrm{k}}}\left(\frac{\beta_{\mathrm{k}}}{\overline{\gamma}_{\mathrm{k}}}\right)^{\omega_{\mathrm{k}}}}\middle|\begin{matrix}1\\1,1+\frac{1}{\omega_{\mathrm{k}}},\ldots,1+\frac{(\omega_{\mathrm{k}}-1)}{\omega_{\mathrm{k}}}\end{matrix}\right)\end{aligned} \tag{3.34}$$

3.7. Multi Dual-Hop Network Over Weibull Fading Channel

In multi dual-hop network there is no direct link between $S \rightarrow \mathrm{D}$ as shown in Figure 3.2. The MGF of $S \rightarrow \mathrm{R_k}$ and $\mathrm{R_k} \rightarrow \mathrm{D}$ with best relay selection can be shown as

$$\begin{aligned}\mathscr{M}_{\gamma_{b_R}}(\mathfrak{s}) &= 2\omega_k \left(\frac{\beta_k}{\bar{\gamma}_k}\right)^{\omega_k} \sum_{k=1}^{K} \binom{K}{k} k(-1)^{k-1} (2\pi)^{\frac{1-\omega_k}{2}} (\omega_k)^{\omega_k+\frac{1}{2}} (\mathfrak{s})^{-\omega_k} \\ \times G^{\omega_k,1}_{1,\omega_k} & \left(\frac{(\mathfrak{s})^{\omega_k}}{2m(\omega_k)^{\omega_k}\left(\frac{\beta_k}{\bar{\gamma}_k}\right)^{\omega_k}} \middle| \begin{matrix} 1 \\ 1, 1+\frac{1}{\omega_k}, \ldots, 1+\frac{(\omega_k-1)}{\omega_k} \end{matrix} \right)\end{aligned} \tag{3.35}$$

3.8. Relay Selection Over Mixed Fading Channels

In the previous scenarios, we assumed that in a cooperative network or multi dual-hop network all the links experience either Rayleigh or Weibull fading. In this section we consider a mixed fading channel (MFC) case for analyzing the end to end performance of cooperative network in a very special and diverse manner. Here, we assume that while $\mathrm{S} \rightarrow \mathrm{D}$ link undergoes Rayleigh fading, and $S \rightarrow \mathrm{R_k} \rightarrow \mathrm{D}$ links undergo Weibull fading as shown in Figure 3.3.

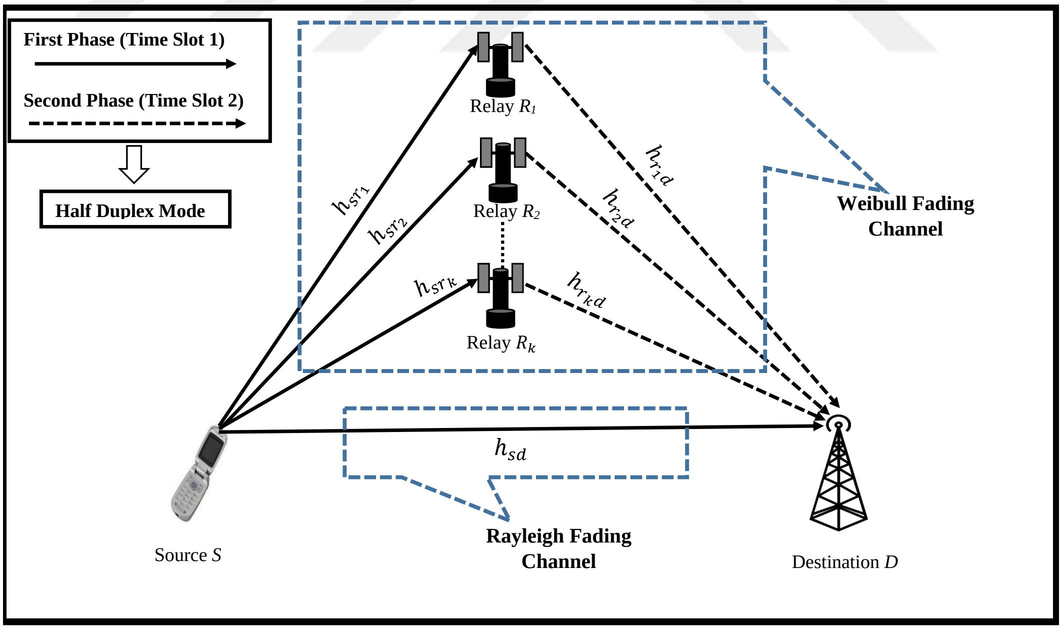

Figure 3.3. Cooperative network with mixed fading channel

By setting $\omega_{sd} = \beta_{sd} = 2$, and using equation (3.28), the MGF of the instantaneous SNR of the received signal via $\mathrm{S} \rightarrow \mathrm{D}$ link is given by,

$$\mathscr{M}_{\gamma_{sd}}(\mathfrak{s}, 2) = \left[\left(\frac{2}{\bar{\gamma}_{sd}}\right)^2 (2\pi)^{\frac{-1}{2}} (2^{\frac{3}{2}}) \mathfrak{s}^{-2} \right] \times G^{2,1}_{1,2} \left(\frac{\mathfrak{s}^2}{4} \middle| \begin{matrix} 1 \\ 1, 1+\frac{1}{2} \end{matrix} \right) \tag{3.36}$$

Using Wittaker function $W_{\iota,\nu}(\upsilon)$ the $G_{1,2}^{2,1}(\cdot)$ can be rewritten as [149],

$$G_{1,2}^{2,1}\left(\upsilon \middle| \begin{matrix} j_1 \\ p_1 . p_2 \end{matrix}\right) = \left[\Gamma(p_1 - j_1 + 1)\Gamma(p_1 - j_1 + 1)\upsilon^{\frac{(p_1 - p2 - 1)}{2}} e^{\frac{z}{2}}\right] \tag{3.37}$$

Substituting equation (3.37) into equation (3.36) and using [149, (3.382, 8.354)] the MGF of the SNR for $\omega = 2$ as a Rayleigh distribution can be further simplified to,

$$\mathscr{M}_{\gamma}(\mathfrak{s}, 2) = \left[1 - \sqrt{\rho\pi}\mathfrak{s}e^{(\rho\mathfrak{s}^2/4)}\mathbb{Q}\left(\sqrt{\frac{\rho}{2\mathfrak{s}}}\right)\right] \tag{3.38}$$

where in the (3.38) that follow Rayleigh distribution can be more simplified as

$$\mathbb{Q}(x) = \int_x^{\infty}\left(\frac{1}{\sqrt{2\pi}}\right)e^{\frac{-t^2}{2}}dt, \tag{3.39}$$

and ρ is the positive scale parameter. For the S → R_k and R_k → D links, we assume Weibull fading channel with $\omega_k = 4$. The overall MGF $\mathscr{M}_{\gamma_{tot}}$ of the instantaneous SNR of received signal, at the destination is given by

$$\mathscr{M}_{\gamma_{tot}}(\mathfrak{s}) = \mathscr{M}_{\gamma_{sd}}(\mathfrak{s}, 2) \times \mathscr{M}_{\gamma_{b_R}}(\mathfrak{s}) \tag{3.40}$$

By substituting equation (3.33) and equation (3.36) into equation (3.40), we obtain,

$$\begin{aligned}\mathscr{M}_{\gamma_{tot}}(\mathfrak{s}, 2) = {} & \left[\left(\frac{2}{\overline{\gamma}_{sd}}\right)^2 (2\pi)^{\frac{-1}{2}}(2^{\frac{3}{2}})\mathfrak{s}^{-2}\right] \times G_{1,2}^{2,1}\left(\frac{\mathfrak{s}^2}{4} \middle| \begin{matrix} 1 \\ 1, 1+\frac{1}{2} \end{matrix}\right) \\ \times {} & \left[2\omega_k\left(\frac{\beta_k}{\overline{\gamma}_k}\right)^{\omega_k}\sum_{k=1}^{K}\binom{K}{k}k(-1)^{k-1}(2\pi)^{\frac{1-\omega_k}{2}}(\omega_k)^{\omega_k+\frac{1}{2}}(\mathfrak{s})^{-\omega_k}\right] \\ \times {} & G_{1,\omega_k}^{\omega_k,1}\left(\frac{(\mathfrak{s})^{\omega_k}}{2m(\omega_k)^{\omega_k}\left(\frac{\beta_k}{\overline{\gamma}_k}\right)^{\omega_k}} \middle| \begin{matrix} 1 \\ 1, 1+\frac{1}{\omega_k}, \ldots, 1+\frac{(\omega_k-1)}{\omega_k} \end{matrix}\right)\end{aligned} \tag{3.41}$$

4. PERFORMANCE ANALYSIS OF COOPERATIVE DIVERSITY NETWORK

4.1. Outage Probability

In fading channel environments, outage probability $\mathrm{P_{out}}$ is one of the important metrics to measure end to end communication performance. We evaluate the outage probability of the cooperative relay network in Fig. 1, by taking the inverse Laplace transform [144] of the MGF. However, in our case, we can derive it by using Euler's summation method [149] which is more accurate and easy to derived in mathematical form

$$\mathrm{P_{out}} = \mathbb{L}^{-1}\left(\mathscr{M}_{\gamma_{\mathrm{tot}}}(\mathfrak{s})/\mathfrak{s}\right)\Big|\gamma_{\vartheta} \tag{4.1}$$

where $\mathbb{L}^{-1}$ is inverse Laplace transform and γ_{ϑ} is the threshold value. For all fading scenarios considered in the previous section the outage probability $\mathrm{P_{out}}$ can be calculated by using Euler's summation method given as,

$$\mathrm{P_{out}} \;=\; \mathrm{P}_{\gamma_{\mathrm{tot}}}(\gamma_{\vartheta},\mathrm{C},\mathrm{U},\mathrm{Q}) = \frac{2^{-\mathrm{Q}}e^{\mathrm{C}/2}}{\gamma_{\vartheta}}\sum_{\mathrm{q}=0}^{\mathrm{Q}}\binom{\mathrm{Q}}{\mathrm{q}} \quad \sum_{\mathrm{u}=0}^{\mathrm{U+q}}\frac{(-1)^{\mathrm{u}}}{\varphi_{\mathrm{u}}}\mathscr{R}\left\{\frac{\mathscr{M}_{\gamma_{\mathrm{tot}}}\left(-\frac{\mathrm{C}+2\pi \mathrm{ju}}{2\gamma_{\vartheta}}\right)}{\frac{\mathrm{C}+2\pi \mathrm{ju}}{2\gamma_{\vartheta}}}\right\} \tag{4.2}$$

where in Euler's summation method as shown in (4.2) φ_{u} can be shown as

$$\varphi_{\mathrm{u}} = \left\{\begin{array}{ll} 2, & u = 0 \\ 1, & u = 1, 2, \ldots U \end{array}\right\},$$

C = 10 ln $\simeq$ 23.02, U = 21, Q = 15 and $\mathscr{R}\,\{\cdot\}$ represents real part respectively, as given in [149]. Moreover whole error term $\mathrm{E(C,U,Q)}$ is almost confined by

$$|\mathrm{E(C,U,Q)}| \simeq \frac{e^{-\mathrm{C}}}{1-e^{-\mathrm{C}}} + \left|\frac{2^{-\mathrm{Q}}e^{\mathrm{C}/2}}{\gamma_{\vartheta}}\sum_{\mathrm{q}=0}^{\mathrm{Q}}(-1)^{\mathrm{U+1+q}}\binom{\mathrm{Q}}{\mathrm{q}}\mathscr{R}\left\{\frac{\mathscr{M}_{\gamma_{\mathrm{tot}}}\left(-\frac{\mathrm{C}+2\pi \mathrm{j(U+q+1)}}{2\gamma_{\vartheta}}\right)}{\frac{\mathrm{C}+2\pi \mathrm{j(U+q+1)}}{2\gamma_{\vartheta}}}\right\}\right| \tag{4.3}$$

For each of aforementioned fading scenario, we can obtain end to end $\mathrm{P_{out}}$ by substituting separately the derived MGF expression into equation (4.2), for all cases.

4.2. Cooperative Communication And Receive Diversity Techniques

The effects of fading can be mitigated by utilizing various diversity techniques in the wireless channel for having a better end to end performance. In the wireless communication, the receiver end requires more efficient and complex signaling handling technique in order to differentiate the effects of noise due to distortion, reflection and multi-path propagation and for decreasing the number of errors arises in the fading channel. In case of cooperative communication receive diversity techniques are specially required for generating cooperative diversity even with a single antenna at the receiver end.

In a cooperative network, the destination received multiple copies of the transmitted signal from different perceiving relay nodes as well as from source that is combined in such a manner that received diversity is generated. It might be possible that some channel links in the network faced deep feed hence, as a result, the communication might not be effective and reliable. However, the other links may not experience this situation and by using received diversity approach better performance can be achieved.

In literature, numerous types of combining diversity techniques are used to accomplished less bit error rate, enhanced signal quality, and reliability, etc., over different fading environments. The maximal ration combing (MRC), selection combining (SC), equal gain combiner (EGC), etc. are generally used to achieve received diversity for maximizing end to end performance.

In MRC all the transmitted signals from relay nodes as well from source node are weighted in such a way that the average SNR of each link is sum together that maximize the output SNR. The EGC processed the received signals differently as compared to MRC by equally weighted them initially and then adding them together. In SC, on the other hand, the selection criteria based on the link channel having the highest SNR. This selection leads to different compensations in term of less complexity at the receiver end and utilizing a limited amount of resources to achieve full order of diversity gain.

4.3. Average Symbol Error Rate

In the previous section, we discussed that in selection combining the receive diversity is generated by selecting the link channel having the highest SNR value for the further process which overall reduces the complexity at the receiver end. When M-ary QAM modulation is used, the average symbol error rate $P_{AS}(e)$ at the received signal by considering selection combining technique can be shown as [144]

$$\begin{aligned}P_{AS}(e) \;&= \left(\frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\pi/2}\mathscr{M}_{\gamma_{tot}}\left(\frac{\Psi}{\sin^2\theta}\right)d\theta\right)\\ &-\left(\frac{4}{\pi}\quad\left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\pi/4}\mathscr{M}_{\gamma_{tot}}\left(\frac{\Psi}{\sin^2\theta}\right)d\theta\right)\end{aligned} \tag{4.4}$$

where $\Psi = 3/[2(M-1)]$, and M is size of constellation alphabet. The derived MGF expressions $\mathscr{M}_{\gamma_{tot}}(\mathfrak{s})$ for all various fading scenarios with two cooperative diversity models, can be substituted into equation (4.4) to obtain $P_{AS}(e)$ for each case. On the other hand, the MRC can achieve better performance as compared to selection combining. The basic technique behind is that the signal from the source and relay nodes at the receiver end is weighted in such a way that the average SNR of each link is sum together that maximize the output SNR value for better performance. In case of M-ary QAM modulation the average symbol error rate $P_{AS}(e)$ at the received signal by considering MRC technique can be shown as

$$\begin{aligned}P_{AS}(e) \;&= \left(\frac{4}{\pi}\left(1-\frac{1}{\sqrt{M}}\right)\int_0^{\pi/2}\left[\mathscr{M}_{\gamma_{tot}}\left(\frac{\Psi}{\sin^2\theta}\right)\right]^K d\theta\right)\\ &-\left(\frac{4}{\pi}\quad\left(1-\frac{1}{\sqrt{M}}\right)^2\int_0^{\pi/4}\left[\mathscr{M}_{\gamma_{tot}}\left(\frac{\Psi}{\sin^2\theta}\right)\right]^K d\theta\right)\end{aligned} \tag{4.5}$$

where $\Psi = 3/[2(M-1)]$, M is size of constellation alphabet and K is the number of relay nodes in the network. The closed-form expression for M-ary QAM can be obtained by inserting (3.21) into (4.4), which can be shown as,

$$\begin{aligned}P_{AS}(e) = 4 \quad &\sum_{k=1}^{K}\binom{K}{k}\frac{(-1)^{k-1}}{(1-2k)}\times\left\{\left(1-\frac{1}{\sqrt{M}}\right)\left[I_1\left(\frac{0.75\bar{\gamma}_k}{k(M-1)}\right)-2kI_1\left(\frac{1.5\bar{\gamma}_k}{(M-1)}\right)\right]-\right.\\ &\left.\left(1-\frac{1}{\sqrt{M}}\right)^2 \qquad \left[I_2\left(\frac{0.75\bar{\gamma}_k}{k(M-1)}\right)-2kI_2\left(\frac{1.5\bar{\gamma}_k}{(M-1)}\right)\right]\right\}\end{aligned} \tag{4.6}$$

where in (4.6) I_1 (.) from (4.7) and I_2 (.), from (4.8) are given in [144](5A.9, 5A.13)

$$I_1 = \frac{1}{\pi}\int_0^{\pi/2}\left(\frac{\sin^2\theta}{\sin^2\theta + c}\right)d\theta = \frac{1}{2}\left(1-\sqrt{\frac{c}{c+1}}\right) \tag{4.7}$$

$$I_2 = \frac{1}{\pi}\int_0^{\pi/4}\left(\frac{\sin^2\theta}{\sin^2\theta + c}\right)d\theta = \frac{1}{4}\left\{1-\sqrt{\frac{c}{1+c}}\left[\frac{4}{\pi}\tan^{-1}\left(1-\sqrt{\frac{1+c}{c}}\right)\right]\right\} \tag{4.8}$$

5. NUMERICAL AND SIMULATION RESULTS

The analytical and simulation results for P_{out} and $P_{AS}(e)$ with max-min relay selection method in two cooperative diversity network model i.e., cooperative network and multi dual hop network for aforementioned various fading scenarios are presented in this section. We assume that all the links in Figures 3.1, 3.2 and 3.3 are i.i.d, and for all cases, $E(|h_{sd}|^2) = E(|h_{sr_k}|^2) = E(|h_{r_k d}|^2)$, and have same E_s/N_0 values. The value of Weibull fading parameter ω= 2 and 4 consider respectively, for various cases except in Rayleigh fading channel case, and the number of relays nodes is $K = (1,2,3,4)$. The PDF and MGF expressions derived separately for each case are substituted into equation (4.2) and (4.6), to obtain analytical results for P_{out} vs E_s/N_0 by considering threshold value γ_{ϑ} =10 dB, and $P_{AS}(e)$ vs E_s/N_0 for each case respectively.

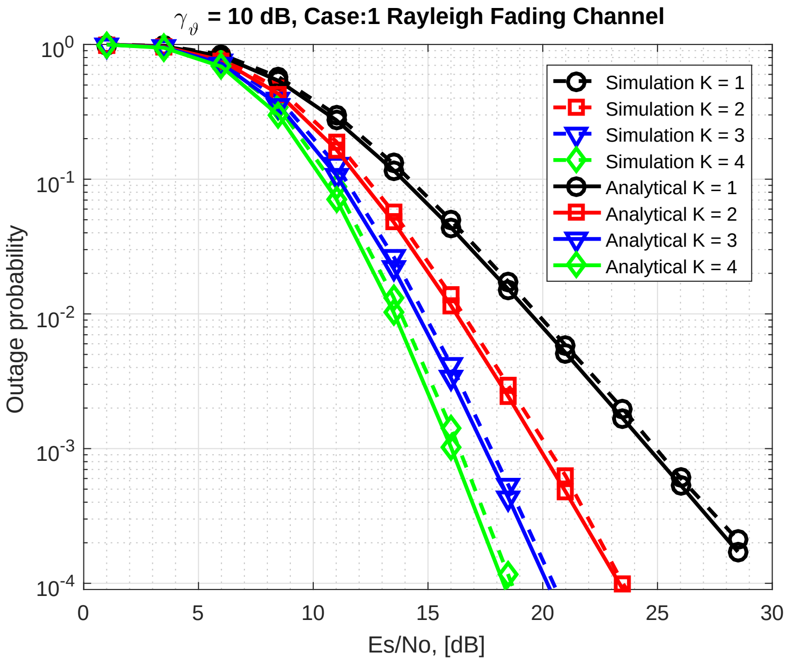

Figure 5.1. P_{out} vs E_s/N_0 over Rayleigh fading channel in the cooperative network

In obtaining the simulation results, transmitted symbols x at the source node are assumed to have 16-QAM and 16-PSK modulations. We run one thousand iterations of Monte Carlo simulation. For each run, total number of 10^7 symbols are generated. The channel coefficients for each transmitted symbol are generated using appropriate distribution for each case considered in Chapter 3.

Table 5.1. The comparative difference of analytical and simulated result for P_{out} in the cooperative network over Rayleigh fading channel

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.3994	0.3681	7.97%
	2	0.2829	0.2518	10.99%
	3	0.2111	0.1823	13.64%
	4	0.1610	0.1351	16.08%
12	1	0.2195	0.1979	9.84%
	2	0.1202	0.1047	12.89%
	3	0.0708	0.5876	17.06%
	4	0.0437	0.0348	20.30%
15	1	0.0736	0.0652	11.32%
	2	0.0652	0.0208	15.46%
	3	0.0035	0.0072	20.14%
	4	0.0091	0.0002	24.66%

The amplification gain of transmitted signal from relay node to destination is obtained by equation (3.4) and criteria used for selecting the best relay based on max-min method is obtained from (3.6). In the next step, the destination node combined both signals from S→ D obtained by (3.1) and from S → R_k → D by (3.3) using MRC technique. We obtain total SNR in the simulation using the upper bound approximation in equation (3.7). The P_{out} over Rayleigh fading channel is presented in Figure 5.1, which shows that

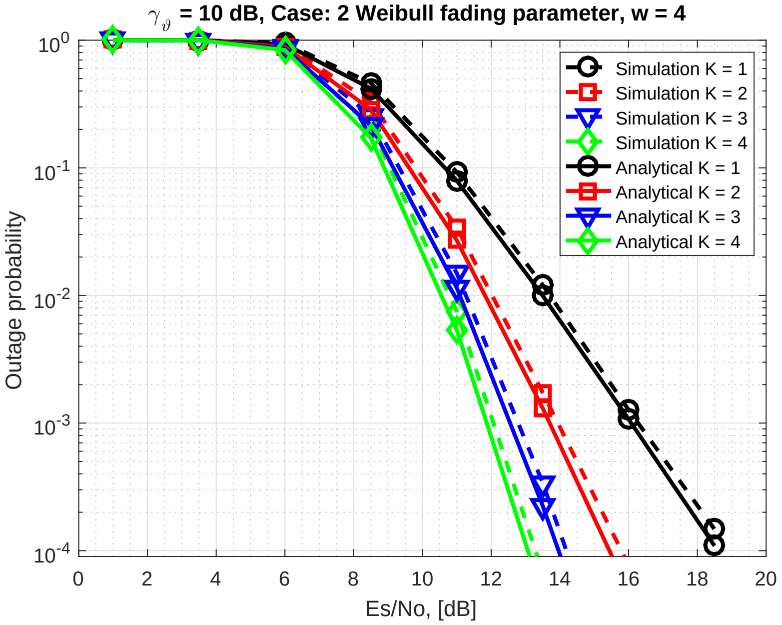

Figure 5.2. P_{out} vs E_s/N_0 over Weibull fading channel in cooperative network

analytical and simulation results agree well with each other at various values of E_s/N_0 with γ_{ϑ} =10 dB. It can be observed that increase in the number of cooperative relay nodes causes smaller P_{out} values. For K=1, E_s/N_0 = 18.5 dB, the exact P_{out} is 1.524×10^{-2}, but for the same E_s/N_0, P_{out} for K= 4, is 8.098×10^{-5}.

Table 5.2. The comparative difference of analytical and simulated result for P_{out} in cooperative network over Weibull Fading Channel

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.1899	0.1656	12.07%
	2	0.0950	0.0778	18.03%
	3	0.5518	0.0778	18.03%
	4	0.0352	0.0263	25.14%
12	1	0.0435	0.0365	18.87%
	2	0.0107	0.0136	20.66%
	3	0.0003	0.0025	26.16%
	4	0.0012	0.0008	31.17%
15	1	0.003	0.0026	17.07%
	2	0.0002	0.0001	17.97%
	3	2.3×10^{-5}	1.6×10^{-5}	28.04%
	4	3.0×10^{-6}	1.7×10^{-6}	42.01%

Similarly to achieve same performance at P_{out} 10^{-3}, nearly 9 dB gain is observed when the number of relay nodes increases from K= 1 to K= 4. This reflects a strong effect of the cooperative diversity achieved via relay nodes in the Rayleigh fading channel.In order to assess the closeness of analytical and simulation results, we evaluate comparative difference of both results as $\frac{\text{Simulated–Analytical}}{\text{Simulated}} \times 100$ as shown in Table 5.1. Figure. 5.2, shows P_{out} versus E_s/N_0 results when $\omega = 4$ in Weibull fading channel. It can be observed that for E_s/N_0 = 11 dB, P_{out}, for K= 1 and K= 4, are 7.938×10^{-2} and 5.352×10^{-3}, respectively.

Moreover approximately 4 dB gain is observed at P_{out} of 10^{-3}, with increasing the number of relay nodes from K= 1 to K= 4. We also see that considerable improvement in the performance can be achieved in the Weibull fading channel with $\omega = 4$ as compared with the Rayleigh fading channel, when the same number of relay nodes are deployed in both fading cases. By closely examining both Figure 5.1 and Figure 5.2, to achieve same outage probability (i.e., $P_{out} = 10^{-2}$) for the same number of relays we need less E_s/N_0 in Weibull fading case. For instance, $P_{out}= 10^{-2}$ is achieved with K = 3 relays at nearly E_s/N_0 value of 15 dB in Rayleigh fading channel, whereas this value is around 11 dB in Weibull fading channel. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.2 is given in Table 5.2. Figure 5.3

Table 5.3. The comparative difference of analytical and simulated result for P_{out} in cooperative network over mixed fading channel

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.3050	0.2806	8.12%
	2	0.1990	0.1746	12.26%
	3	0.1405	0.1189	15.37%
	4	0.1031	0.0840	18.50%
12	1	0.1143	0.1018	10.93%
	2	0.0411	0.0348	16.61%
	3	0.0176	0.0137	22.05%
	4	0.0078	0.0056	28.67%
15	1	0.0184	0.0161	12.66%
	2	0.0020	0.0016	17.97%
	3	0.0003	0.0002	27.03%
	4	4.0×10^{-5}	2.6×10^{-5}	32.85%

presents the P_{out} versus E_s/N_0 results when S → D link undergoes Rayleigh fading and relay link, i.e., $S \rightarrow R_k$ and $R_k \rightarrow D$ undergo Weibull fading with $\omega = 4$. It is observed that better performance can be achieved as compared to Case 1 (i.e., all the links are Rayleigh fading). However, when compared to the Case 2, performance is slightly smaller even with the same number of relay nodes in the network.

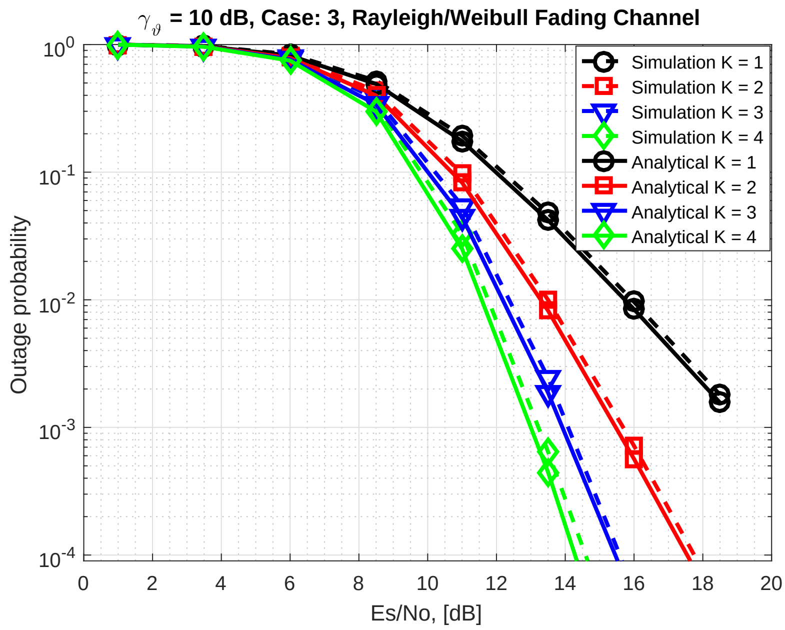

Figure 5.3. P_{out} vs E_s/N_0 over mixed fading channel (Case 3)

In order to assess the closeness of analytical and simulation results, we evaluate comparative difference of both results as $\frac{\text{Simulated–Analytical}}{\text{Simulated}} \times 100$. For K= 1 and E_s/N_0 = 11 dB, in Figure 5.3, the simulated and analytical values are 1.937×10^{-1} and

$1.75 \times 10^{-1}.1.75 \times 10^{-1}$, respectively. The comparative difference of simulated and analytical values is 9.6%. However, this value increase to 13.5% when E_s/N_0 =18.5 dB.

Table 5.4. The comparative difference of analytical and simulated results for P_{out} for three fading scenarios in cooperative network.

E_s/N_0 dB	K	Rayleigh case 1%	Weibull case 2%	Mix fading case 3%
10	1	7.97	12.79	8.12
	2	10.99	18.03	12.26
	3	13.64	21.02	15.37
	4	16.08	25.14	18.50
12	1	9.84	18.87	10.93
	2	12.89	20.66	16.61
	3	17.06	26.16	22.05
	4	20.30	31.17	28.67
15	1	11.32	17.07	12.66
	2	15.46	17.88	17.97
	3	20.41	28.04	27.03
	4	24.66	42.01	32,85

The comparative difference gets larger as E_s/N_0 values increase as shown in Table 5.3.In Table 5.4, the comparative difference of simulated and analytical values of P_{out} for E_s/N_0= 10, 12, 15 dB are summarized. Among the fading scenarios considered, the comparative difference is the smallest in Case 1, i.e., under Rayleigh fading channel case. The comparative difference gets larger as E_s/N_0 values increase as shown in Table 5.3.

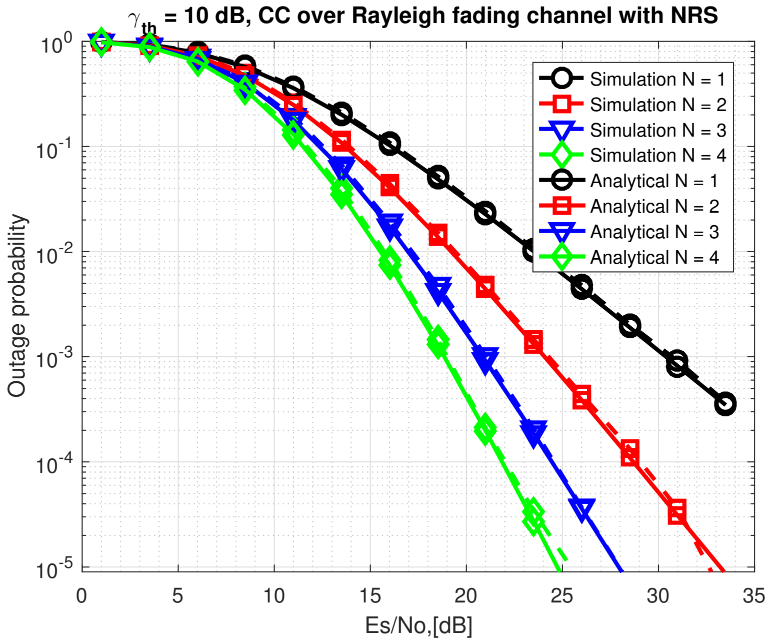

Figure 5.4. P_{out} vs E_s/N_0 over Rayleigh fading channel with no relay selection method

In Table 5.4, the comparative difference of simulated and analytical values of P_{out} for E_s/N_0= 10, 12, 15 dB are summarized. It can be seen that under two conditions, i.e., for the small number of relay nodes and low value of E_s/N_0 the comparative difference is small.

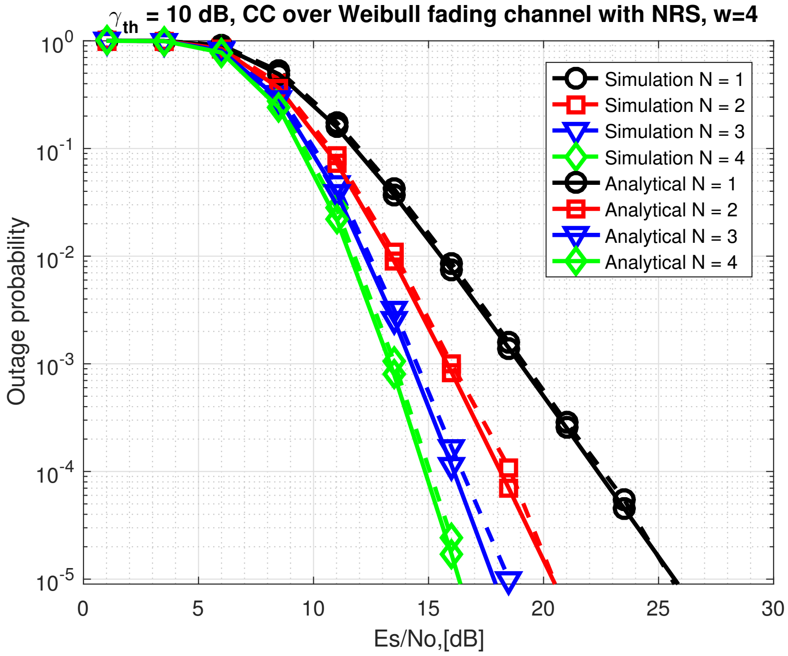

Figure 5.5. P_{out} vs E_s/N_0 in multi dual hop network over Rayleigh Fading Channel

This verifies the effectiveness of the derived model in equation (3.21) for obtaining analytical expression of P_{out} in equation (4.2) especially under Rayleigh fading channel.

Table 5.5. The comparative difference of analytical and simulated result for P_{out} in cooperative network with NRS over Rayleigh fading

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.3739	0.3593	7.30%
	2	0.2637	0.2488	9.86%
	3	0.1917	0.1776	12.43%
	4	0.1428	0.1299	15.63%
12	1	0.1091	0.1028	8.34%
	2	0.0443	0.0408	12.73%
	3	0.0191	0.0172	16.74%
	4	0.0084	0.0074	19.17%
15	1	0.0242	0.0223	9.73%
	2	0.0048	0.0043	14.83%
	3	0.0010	0.0009	19.76%
	4	0.0002	0.0001	22.97%

Table 5.6. The comparative difference of analytical and simulated result for P_{out} in cooperative network with NRS over Weibull fading

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
8.5	1	0.5240	0.4890	6.67%
	2	0.4011	0.3641	9.22%
	3	0.3254	0.2886	11.12%
	4	0.2735	0.2381	12.94%
13.5	1	0.0422	0.0371	12.08%
	2	0.0108	0.0090	21.87%
	3	0.0032	0.0025	24.78%
	4	0.0010	0.0007	29.64%
16	1	0.0085	0.0074	15.08%
	2	0.0010	0.00083	16.78%
	3	1.6×10^{-4}	1.1×10^{-4}	25.03%
	4	2.4×10^{-5}	1.7×10^{-5}	38.53%

The P_{out} over Rayleigh fading channel with no relay selection (NRS) is presented in Figure 5.4, which shows that analytical and simulation results agree well with each other at various values of E_s/N_0 with γ_ϑ =10.

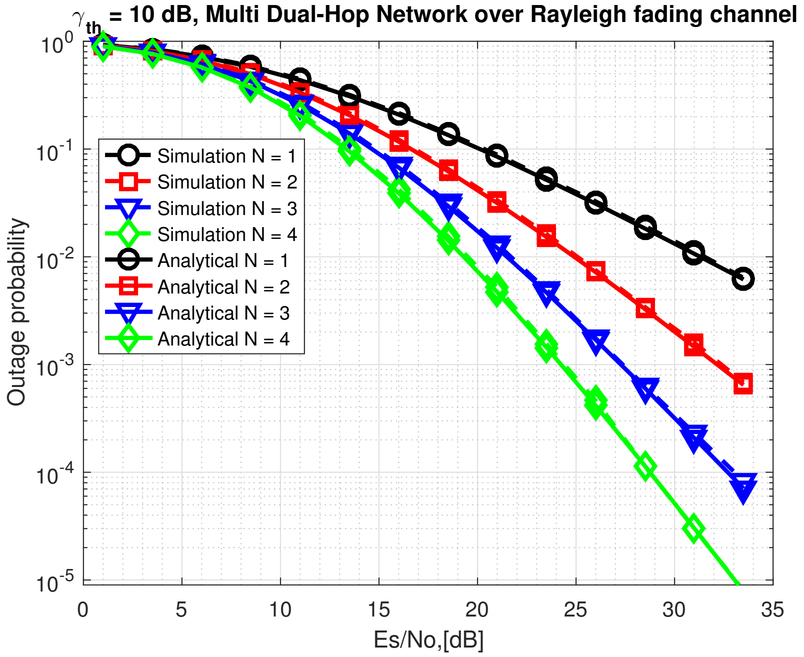

Figure 5.6. P_{out} vs E_s/N_0 in multi dual hop network over Weibull Fading Channel

It can be observed that increase in the number of cooperative relay nodes causes smaller P_{out} values. However, by closely examining both figures 5.1 and 5.4, the relay selection significantly effect the performance. This reflects a strong effect of relay selection in the cooperative diversity network over Rayleigh fading channel. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.4 is given in Table 5.5. Figure. 5.5, shows P_{out} versus E_s/N_0 results when $\omega = 4$ in Weibull fading channel with no relay selection (NRS). It can be observed that for $E_s/N_0 = 11$ dB, P_{out}, for K= 1 and K= 4, are 7.938×10^{-2} and 5.352×10^{-3}, respectively.

Table 5.7. The comparative difference of analytical and simulated result for P_{out} in multi dual hop network over Rayleigh fading channel

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.4464	0.4358	2.37%
	2	0.3458	0.3342	3.35%
	3	0.2712	0.2591	4.46%
	4	0.2151	0.2033	5.48%
12	1	0.3180	0.3093	3.58%
	2	0.2153	0.2059	4.36%
	3	0.1407	0.1394	5.17%
	4	0.1022	0.0951	6.85%
15	1	0.0886	0.0848	9.01%
	2	0.0335	0.0314	13.58%
	3	0.0131	0.0120	18.23%
	4	0.0051	0.0046	22.03%

Moreover approximately 4 dB gain is observed at P_{out} of 10^{-3}, with increasing the number of relay nodes from K= 1 to K= 4.

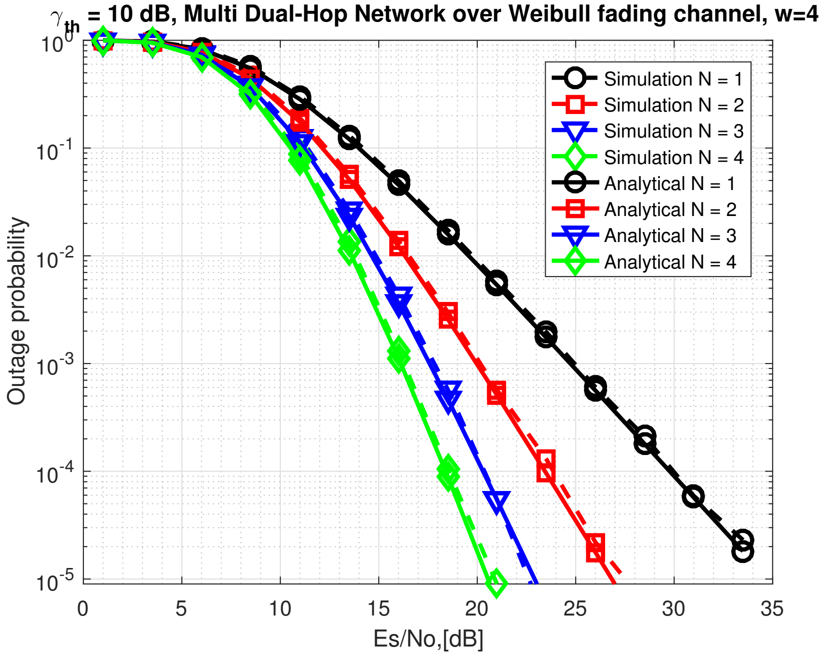

Figure 5.7. ASER vs E_s/N_0 over Rayleigh Fading Channel in cooperative network

We also see that considerable improvement in the performance can be achieved in the Weibull fading channel with $\omega = 4$ as compared with the Rayleigh fading channel, when the same number of relay nodes are deployed in both fading cases.

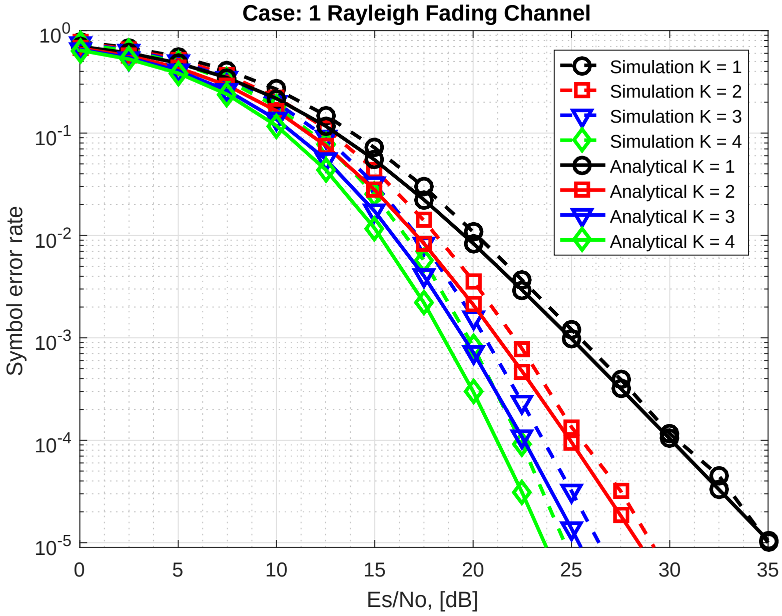

Figure 5.8. ASER vs E_s/N_0 over Weibull Fading Channel in cooperative network

However, by comparing relay selection technique with no relay selection, the performance is much lesser in case of NRS. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.5 is given in Table 5.6.

Table 5.8. The comparative difference of analytical and simulated result for P_{out} in multi dual hop network over Weibull fading channel

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
8.5	1	0.5722	0.2366	4.10%
	2	0.4681	0.4413	5.70%
	3	0.3946	0.3665	7.12%
	4	0.3399	0.3117	8.29%
11	1	0.3007	0.2832	5.81%
	2	0.1897	0.1741	8.22%
	3	0.1266	0.1131	10.66%
	4	0.0874	0.0765	12.39%
15	1	0.0173	0.0159	8.03%
	2	0.0030	0.0025	13.66%
	3	0.0005	0.0004	18.22%
	4	1.06×10^{-4}	9.0×10^{-5}	20.03%

The P_{out} in multi dual hop network over Rayleigh fading channel is presented in Figure

5.6, which shows that analytical and simulation results agree well with each other at various values of E_s/N_0 with γ_ϑ =10.

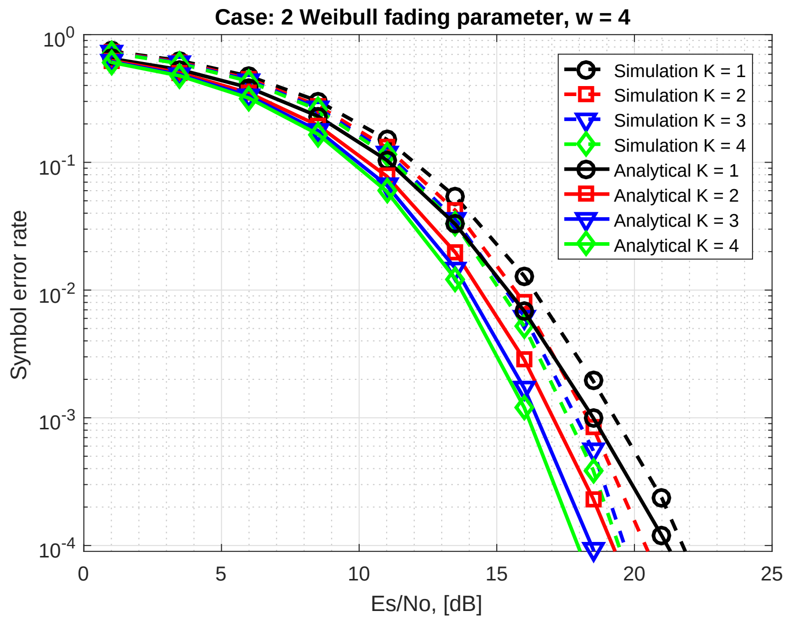

Figure 5.9. ASER vs E_s/N_0 over mixed Fading Channel in cooperative network

It can be observed that if there is no direct communication between source and destination even then the better end to end performance can be achieved by increase in the number of relay nodes in the network.

Table 5.9. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in cooperative network over Rayleigh fading

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.7773	0.7000	9.89%
	2	0.7626	0.6731	11.73%
	3	0.7532	0.6556	12.95%
	4	0.7456	0.6432	13.73%
12	1	0.5566	0.4822	16.53%
	2	0.5235	0.0434	17.98%
	3	0.5034	0.4052	19.50%
	4	0.4875	0.3848	21.06%
15	1	0.0716	0.0545	23.80%
	2	0.0438	0.0277	36.68%
	3	0.0317	0.0171	45.87%
	4	0.0250	0.0116	53.27%

By closely examining both figures 5.1 and 5.6 with cooperative network and multi dual hop network respectively, the cooperative network show better performance. However, in worst scenarios even when there is no communication between source and destination the multi dual hop is best example for a reliable communication in fading. Figure. 5.7, shows P_{out} versus E_S/N_0 results when $\omega = 4$ in Weibull fading channel in multi dual hop diversity network.

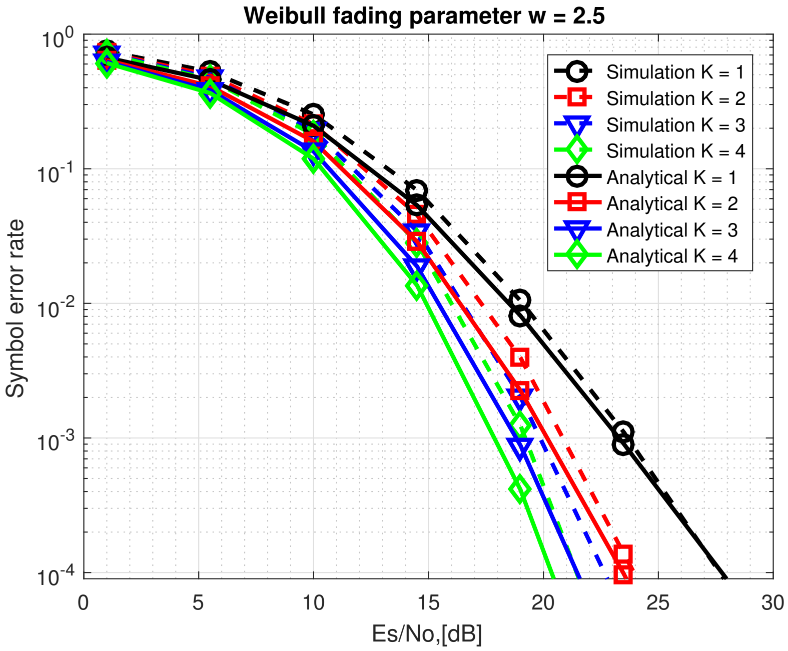

Figure 5.10. ASER vs E_S/N_0 over Weibull Fading Channel in cooperative network

It can be observed that for $E_S/N_0 = 15$ dB, P_{out}, for K= 1 and K= 4, are 5.788×10^{-3} and 4.562×10^{-4}, respectively. Moreover approximately 12 dB gain is observed at P_{out} of 10^{-4}, with increasing the number of relay nodes from K= 1 to K= 4.

Table 5.10. The comparative difference of analytical and simulated result for ASER vs E_S/N_0 in cooperative network over Weibull fading

E_S/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.7424	0.6991	12.50%
	2	0.7313	0.6266	14.31%
	3	0.724	0.6149	15.06%
	4	0.7202	0.6067	15.75%
12	1	0.5374	0.4459	17.02%
	2	0.5166	0.4116	20.32%
	3	0.5053	0.3942	21.98%
	4	0.4982	0.3825	23.19%
15	1	0.0237	0.0133	43.75%
	2	0.0167	0.0066	59.74%
	3	0.0133	0.0044	67.06%
	4	0.0112	0.0033	72.08%

We also see that considerable improvement in the performance can be achieved in the Weibull fading channel with $\omega = 4$ as compared with the Rayleigh fading channel, when the same number of relay nodes are deployed in both fading cases. However, by comparing with cooperative network, the performance is much lesser in case of muti dual hop network over Weibull fading channel. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.7 is given in Table 5.8. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.6 is given in Table 5.7. Figure 5.9, shows the ASER performance of the cooperative network when Weibull fading with $\omega = 4$ for all links is considered. For K= 1 and E_s/N_0= 11 dB, the simulated and analytical results of ASER are 1.513×10^{-1} and 1.0412×10^{-1}.

Table 5.11. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in cooperative network over mixed fading channel

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
10	1	0.7385	0.6458	12.55%
	2	0.7272	0.6229	14.34%
	3	0.7221	0.6112	15.38%
	4	0.7166	0.6026	15.90%
12	1	0.5441	0.4501	17.27%
	2	0.5216	0.4144	20.55%
	3	0.5102	0.3966	22.26%
	4	0.5037	0.3849	23.85%
15	1	0.0047	0.0265	44.06%
	2	0.0167	0.0129	60.03%
	3	0.0326	0.0008	67.08%
	4	0.0232	0.0064	71.01%

Similarly for the same number of relay nodes but E_s/N_0= 21 dB, the simulated and analytical values are 2.34×10^{-4} and 1.087×10^{-4}. The comparative difference of analytical and simulated ASER results are 31.13% and 49.27%, for E_s/N_0 value of 11 dB and 21 dB, respectively.

Similarly for K= 4 and E_s/N_0= 5 dB, the comparative difference is 23.19%, and for same number of relay nodes K= 4, and E_s/N_0= 15 dB, the comparative difference is 72.08%, which shows that with more relay nodes in the network especially at high SNR values the difference of approximation is increasing as shown in Table 5.10. Figure 5.10 illustrates the effect of mixed fading channels i.e., S→ D link is Rayleigh fading and relay links $S \rightarrow R_k$ and $R_k \rightarrow D$ are Weibull fading channel with $\omega = 4$. We see that the ASER performance of the relay network under mixed fading scenario is in between Rayleigh fading Case and Weibull fading case presented in Figure 5.8 and Figure 5.9, respectively. The ASER values of simulated and analytical results for K= 1 and E_s/N_0= 11 dB, are 1.888×10^{-1} and 1.292×10^{-1}, respectively.Figure 5.11 shows the ASER performance of the cooperative network when Weibull fading with $\omega = 2.5$ for all links is considered.

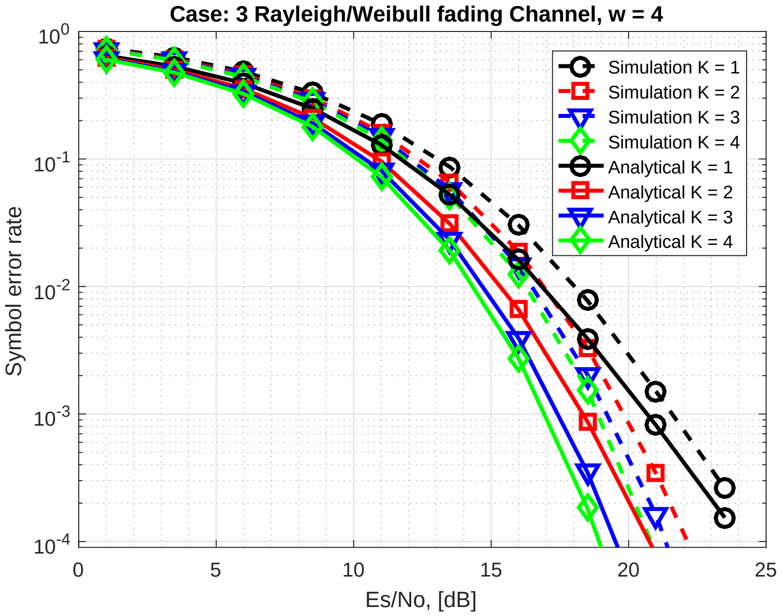

Figure 5.11. ASER vs E_s/N_0 over Rayleigh fading channel with NRS in cooperative network

When closely examining the Figure 5.9 and 5.11, we easily observe that the performance gap between analytical and simulation results increase when the value of ω gets larger in the cooperative network.

Table 5.12. The comparative difference of analytical and simulated results for ASER vs E_s/N_0 for three fading scenarios.

E_s/N_0 dB	K	Rayleigh case 1%	Weibull case 2%	Mix fading case 3%
1	1	9.89	12.53	12.55
	2	11.73	14.31	14.34
	3	12.95	15.06	15.38
	4	13.73	15.75	15.90
5	1	13.36	17.02	17.27
	2	17.03	20.32	20.55
	3	19.50	21.98	22.26
	4	21.06	23.19	23.58
15	1	22.70	43.75	44.06
	2	36.68	59.74	60.03
	3	45.87	67.06	67.08
	4	53.27	72.08	72.01

And for the same number of relay nodes at E_s/N_0= 16 dB, the simulated and analytical values are 3.019×10^{-2} and 1.613×10^{-2} respectively. The comparative difference of the two values are 31.356% and 46.57% for E_s/N_0 = 11dB and 16dB, respectively.

Table 5.13. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in cooperative network over Rayleigh fading

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
8.5	1	0.3748	0.3673	2.31%
	2	0.3225	0.3066	4.78%
	3	0.2930	0.6556	8.39%
	4	0.2684	0.2421	9.79%
12	1	0.1554	0.1526	2.30%
	2	0.5235	0.0325	2.90%
	3	0.5986	0.2360	7.38%
	4	0.0644	0.0560	11.80%
15	1	0.0450	0.0428	4.88%
	2	0.0195	0.0189	5.34%
	3	0.0102	0.0099	6.38%
	4	0.0062	0.0056	9.67%

In Table 5.12, the comparative difference of analytical and simulation results of ASER for E_s/N_0= 1, 5 and 15 dB, are summarized. Similar observations can be made as in outage probability results in Table 5.8. When closely examining all the ASER cases, we easily observe that the performance gap between analytical and simulation results increase when a larger number of relay nodes are deployed in the cooperative network. The comparative difference in Fig.5.9, for K=1 and E_s/N_0 = 15 dB is 43.75%, whereas in case of K=4 at same E_s/N_0 is 72.08%. Similar, observations can be made as in Fig.5.10. Moreover, the larger value of Weibull fading parameter ω also has a greater impact over the performance gap difference between analytical and simulation results. It can be summarized from both Fig.5.9 and Fig.5.10 under two conditions .i.e., for the small number of relay nodes in the cooperative network and smaller value of ω can lead to better accuracy with lesser comparative difference.

The ASER performance of cooperative network in Figure 3.1, under Rayleigh fading channel is given in Figure 5.12, with no relay selection (NRS) method. For K= 1 and E_s/N_0 = 15 dB, the simulated and analytical values of ASER are 5.262×10^{-2} and 6.327×10^{-2}, respectively. For the same number relay nodes, i.e., K= 1 and E_s/N_0 = 30 dB, the simulated and analytical values are 1.16×10^{-3} and 1.033×10^{-4}. It can be seen that symbol error rate decreases with increasing E_s/N_0 values as well as with increasing the number of relay nodes in the network. Moreover, better performance can be seen in

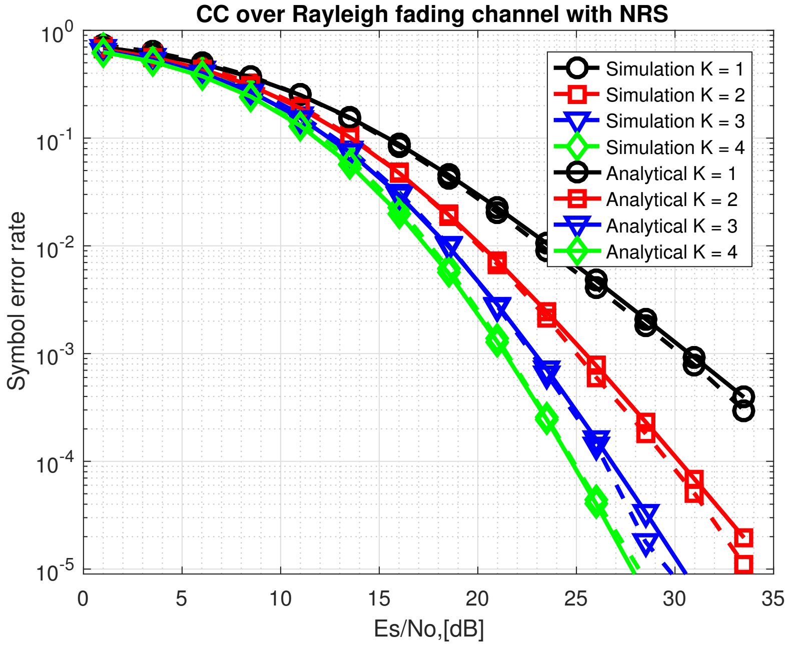

Figure 5.12. ASER vs E_s/N_0 over Weibull fading channel with NRS in cooperative network

relay selection technique as compare to NRS. However, in multi dual hop network the better end to end reliability can be achieved by increasing number of relay nodes in the network, which also show robust against deep fading. We easily observe in Figure 5.12, that the comparative difference between analytical and simulation results of ASER gets larger with increasing number of relay nodes and increasing E_s/N_0 values.

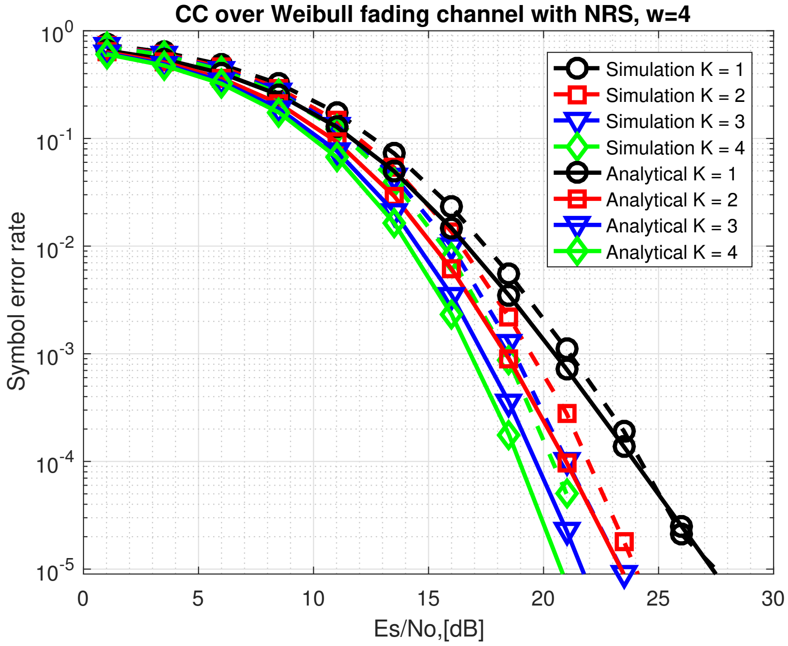

Figure 5.13. ASER vs E_s/N_0 in multi dual hop network over Rayleigh fading channel

In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.12 is given in Table 5.13. Figure 5.13, shows the ASER performance of the cooperative network with no relay selection technique is considered.

Table 5.14. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in cooperative network over Weibull fading with NRS

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
8.5	1	0.3221	0.2540	21.14%
	2	0.2905	0.2107	27.46%
	3	0.2731	0.1881	31.11%
	4	0.2622	0.1739	33.17%
13.5	1	0.0727	0.0496	31.17%
	2	0.0537	0.0292	45.62%
	3	0.0448	0.0209	53.34%
	4	0.0349	0.0164	54.73%
15	1	0.0230	0.0147	36.08%
	2	0.0135	0.0056	44.05%
	3	0.0099	0.0035	64.64%
	4	0.0078	0.0023	70.51%

In addition, the Weibull fading with $\omega = 4$ for all links is considered. For K= 1 and E_s/N_0= 11 dB, the simulated and analytical results of ASER are 1.483×10^{-1} and 1.065×10^{-1}.Similarly for the same number of relay nodes but E_s/N_0= 21 dB, the simulated and analytical values are 2.42×10^{-3} and 1.59×10^{-4}.

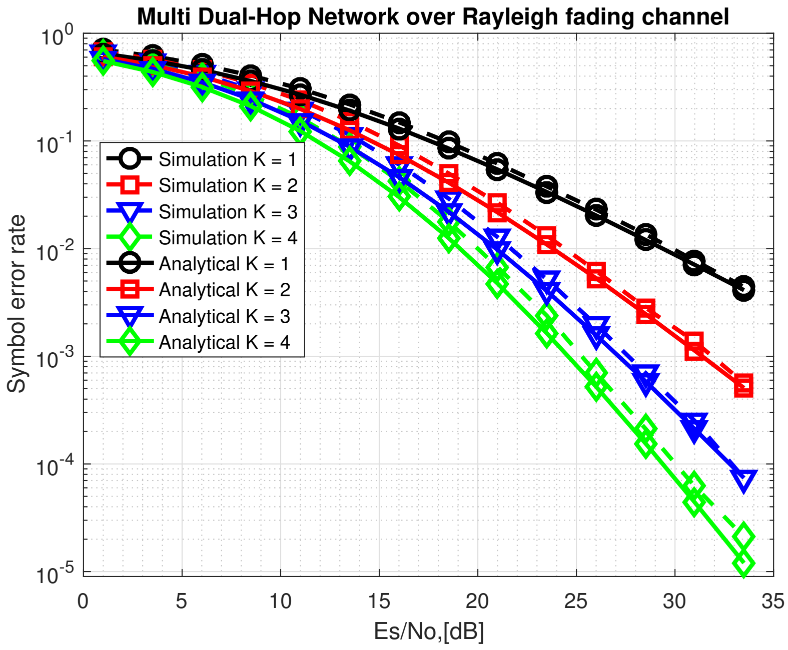

Figure 5.14. ASER vs E_s/N_0 in multi dual hop network over Weibull fading channel

The comparative difference of analytical and simulated ASER results are 29.13% and 47.27%, for E_s/N_0 value of 11 dB and 21 dB, respectively. Similarly for K= 4 and E_s/N_0= 5 dB, the comparative difference is 24.30%, and for same number of relay nodes K= 4, and E_s/N_0= 15 dB, the comparative difference is 69.05%, which shows that with more relay nodes in the network especially at high SNR values the difference of approximation is increasing.

On the other hand when closely examining Figure 5.13 and Figure 5.9 the relay selection has better effect over performance as compared to no relay selection. However, the increasing the number of relay nodes in the network decreased the symbols error rate. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.13 is given in Table 5.14. The ASER performance of multi dual hop relay network in Figure 3.2, under Rayleigh fading channel is given in Figure 5.14. For K= 1 and E_s/N_0 = 15 dB, the simulated and analytical values of ASER are 4.356×10^{-1} and 5.783×10^{-1}, respectively. For the same number relay nodes, i.e., K= 1 and E_s/N_0 = 30 dB, the simulated and analytical values are 1.16×10^{-2} and 1.033×10^{-2}. It can be seen that symbol error rate decreases with increasing E_s/N_0 values as well as with increasing the number of relay nodes in the network.

Table 5.15. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in multi dual hop network over Rayleigh fading

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
11	1	0.3053	0.2691	11.75%
	2	0.2380	0.1982	16.72%
	3	0.1982	0.1536	22.50%
	4	0.1636	0.1236	24.44%
12	1	0.1492	0.1306	12.46%
	2	0.0908	0.0742	18.28%
	3	0.0603	0.0461	23.54%
	4	0.0424	0.0301	29.00%
15	1	0.0616	0.0546	13.83%
	2	0.0265	0.0532	18.11%
	3	0.0127	0.0598	23.62%
	4	0.0067	0.0047	29.85%

Moreover, comparing all the above discussion i.e., the relay selection method, no relay selection, in cooperative network or multi dual hop network, the least performance can be seen in multi dual hop network. This reflects the dominate factor of source to destination communication missing in the network. In order to achieve same performance as compare to cooperative network more relay are needed with more efficient techniques in multi dual hop network. However, in multi dual hop network even when there is no direct communication between source to destination the relay nodes assistant to make communication possible which show more robustness against fading environment.In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.14 is given in Table 5.15.

Figure 5.15, shows the ASER performance of the multi dual hop network over the Weibull fading channel with $\omega = 4$ for all links is considered. For K= 1 and E_s/N_0= 11 dB, the simulated and analytical results of ASER are 1.378×10^{-1} and 1.0754×10^{-1}. Similarly for the same number of relay nodes but E_s/N_0= 21 dB, the simulated and analytical values are 2.36×10^{-3} and 1.43×10^{-3}. The comparative difference of analytical and simulated ASER results are 25.63% and 42.27%, for E_s/N_0 value of 11 dB and 21 dB, respectively. Similarly for K= 4 and E_s/N_0= 5 dB, the comparative difference is 24.30%, and for same number of relay nodes K= 4, and E_s/N_0= 15 dB, the comparative difference is 65.34%, which shows that with more relay nodes in the network especially at high SNR values the difference of approximation is increasing.

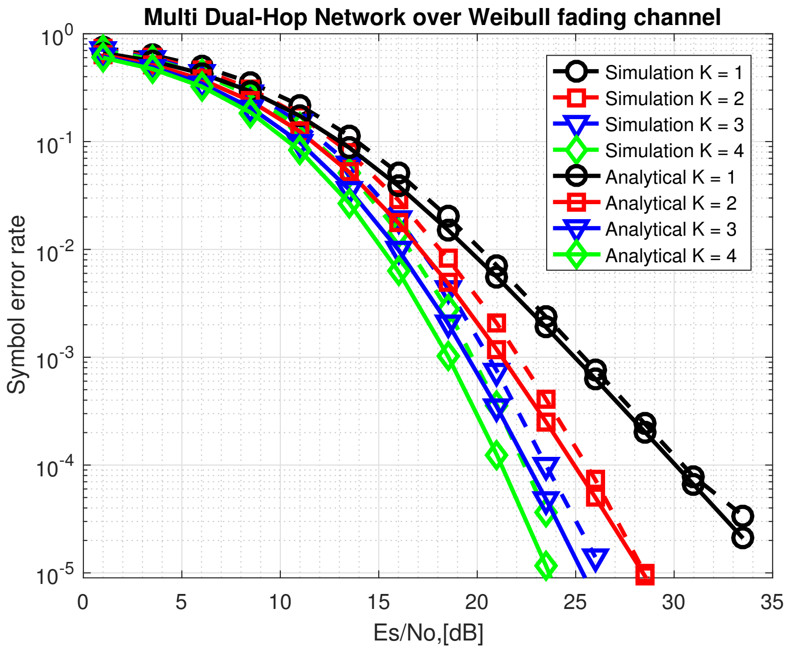

Figure 5.15. ASER vs E_s/N_0 in cooperative network over Rayleigh fading with MRC

On the other hand when comparing all the above discussion i.e., the relay selection method, no relay selection, in cooperative network or multi dual hop network, the least performance can be seen in multi dual hop network. However, by closely examining Figure 5.14 and Figure 5.15 the multi dual hop over Weibull fading channel shows better performance. This reflect that when channel condition are good and though there is no source to destination communication, better performance can be achieved in the network. Similarly in order to achieve same performance as compare to cooperative network more relay are needed with more efficient techniques in multi dual hop network.

Table 5.16. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in multi dual hop network over Weibull fading

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
8.5	1	0.3520	0.2921	16.94%
	2	0.3089	0.2373	23.17%
	3	0.2834	0.2061	27.27%
	4	0.2661	0.1856	30.25%
13.5	1	0.1136	0.0878	22.27%
	2	0.0793	0.0520	34.42%
	3	0.0230	0.0359	38.24%
	4	0.0520	0.0268	48.84%
15	1	0.0201	0.0152	24.43%
	2	0.0082	0.0049	40.02%
	3	0.0043	0.0020	53.48%
	4	0.0027	0.0010	62.96%

In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.15 is given in Table 5.16.

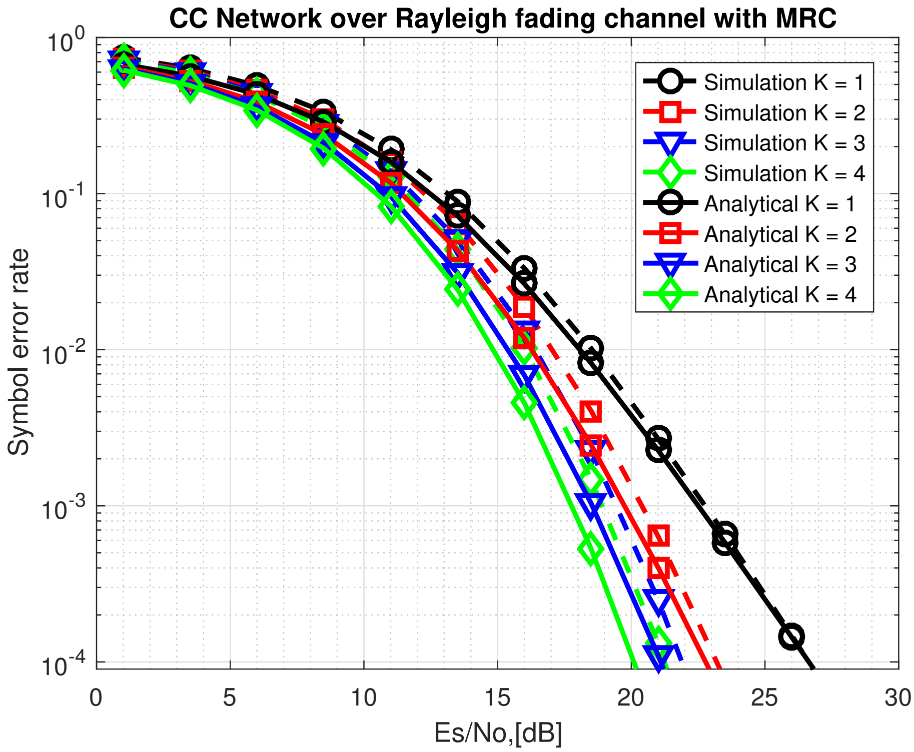

Figure 5.16. ASER vs E_s/N_0 in cooperative network over Rayleigh fading with MRC

The ASER performance of cooperative network in Figure 3.1, under Rayleigh fading channel with MRC diversity technique is given in Figure 5.16. For K= 1 and E_s/N_0 = 15 dB, the simulated and analytical values of ASER are 3.739×10^{-2} and 4.516×10^{-2}, respectively. For the same number relay nodes, i.e., K= 1 and E_s/N_0 = 25 dB, the simulated and analytical values are 1.16×10^{-3} and 1.033×10^{-3}. It can be seen that symbol error rate decreases with increasing E_s/N_0 values as well as with increasing the number of relay nodes in the network. Moreover, comparing all the above discussion i.e., the relay selection method, no relay selection, in cooperative network or multi dual hop network, the better performance can be seen by using MRC diversity technique. This results also shows that cooperative network with efficient diversity technique can enhance the end to end performance. In order to assess the closeness of analytical and simulation results, the comparative difference for Figure 5.16 is given in Table 5.17.

Table 5.17. The comparative difference of analytical and simulated result for ASER vs E_s/N_0 in cooperative network over Rayleigh fading with MRC

E_s/N_0 dB	K	Simulated Value	Analytical Value	Comparative Diff.
8.5	1	0.3353	0.2877	14.19%
	2	0.2985	0.2391	19.89%
	3	0.2877	0.2126	26.16%
	4	0.2646	0.1947	26.41%
12	1	0.1919	0.1598	16.72%
	2	0.1574	0.3566	25.74%
	3	0.1388	0.4830	30.06%
	4	0.1275	0.0831	34.82%
15	1	0.0332	0.0264	20.48%
	2	0.0188	0.0118	37.23%
	3	0.0133	0.0068	48.41%
	4	0.0102	0.0045	55.92%

Summarizing all the above discussion it can be absorbed that the best performance can be seen in a cooperative network by using MRC receive diversity technique at the receiver end and considering the larger value of Weibull fading parameter. However, increasing the number of relay nodes in cooperative network cannot be an effective approach, especially when the channel condition is good.

6. CONCLUSIONS AND FUTURE WORK

6.1. Conclusions

Cooperative diversity is a promising technique which contributes to achieving high data rates in the next generation wireless networks. Cooperative diversity can possibly overcome different challenges faced by wireless channel and enhanced the number of significant factors i.e. spectral efficiency, coverage in the shadow area, utilization energy efficiently etc. for better performance. However, in cooperative diversity the various network models i.e., cooperative network and multi dual hop network have their own benefits and drawback in terms of efficiency and better end to end performance.

In case of cooperative network better performance can be achieved by adding more number of relay nodes in the network whereas, in case of multi dual-hop similar performance cannot be achieved even by considering the same number of relay nodes in the network. The direct channel between S→ D contributes well for decreasing the symbols errors which increases the overall performance of the network. In order to achieve the same performance while considering the same number of relay nodes in multi dual-hop network more efficient techniques and methods are required. However, in both cases, the reliability factor of cooperative diversity in the wireless network can trigger a better end to end reliable performance as compare to the non-cooperative network.

Cooperative diversity is also a reliable technique to counter down the effects of fading in wireless channel. The different degrading factors which effects the performance of wireless channel are necessary to be pointed out and how to overcome them for better performance is also a challenging task. This thesis analyzed the end to end performance of cooperative diversity with both networks models under different fading channel conditions. In order to analyze the overall performance of cooperative diversity network the outage probability $\mathrm{P}_{\mathrm{out}}$ and average symbol error rate $\mathrm{P}_{\mathrm{AS}}(\mathrm{e})$ for different fading channel conditions in which non-regenerative relay nodes employ best relay selection technique was considered. The MGF of SNR of the received signal at the destination node *D* was derived and closed form expressions of $\mathrm{P}_{\mathrm{out}}$ and $\mathrm{P}_{\mathrm{AS}}(\mathrm{e})$ were obtained by using derived MGF under different cases. The comparison is drawn among all the fading cases to analyze the performance of both cooperative network models.

It can be concluded that in Rayleigh fading environment the increasing the number of relay nodes is a better option as compared to Weibull fading channel with larger value of ω due to the notable gain difference between the relay nodes in the network. However, with less number of relay nodes in cooperative diversity network by considering larger Weibull fading parameter value can achieve better end to end performance.

In a cooperative diversity, the destination nodes receives multiple copies of the transmitted signal from different perceiving relay nodes as well as form the source node, and these signal are combined in such a manner that received diversity is generated. This thesis also considered different received diversity techniques e.g. Maximal Ratio Combiner and Selection combiner in the cooperative diversity network. It was shown that by considering MRC technique better performance can be achieved even in multi dual hop network as compared to SC at the receiver end.

For verifying the accuracy of the P_{out} and ASER equations, analytical and simulation results are compared. Analytical results agree well with the simulation results for lower number of relay nodes (i.e., K is small) and under Rayleigh fading channel condition. It can also be concluded that increasing number of relay nodes in the network might not be an effective approach for achieving better performance especially when Weibull fading parameter ω gets larger. However, less number of relay nodes having best relay selection can trigger two benefits in terms of accuracy of analytical model and avoiding unnecessary use of resources. Moreover, in all cases the cooperative network with best relay selection method over Weibull fading channel with MRC technique at receiver end shows best performance as compared to multi dual hop network with NRS.

6.2. Cooperative Relaying For The Next Generation Wireless Network

The next generation of wireless network requires high spectral efficiency and huge bandwidth for increasing the capacity. The current spectrum between 300 MHz to 3GHz is already full because of several key advantages which often referred as “sweet spot”. Therefore new methods and techniques are required to find out the new opportunities to enhance spectral efficiency, extension in the coverage area, fulfilling the demand of huge bandwidth, reliability etc., to meet the standard requirement of 5G. In term of bandwidth requirement, the mm-wave have huge potential to fulfill the demand of next generation of the wireless network. The available mm-wave spectrum between 3GHz to 300GHz is shown in Figure 6.1. However, the realization of this idea is difficult because of several technical challenges to implement and utilize the bandwidth effectively. The basic

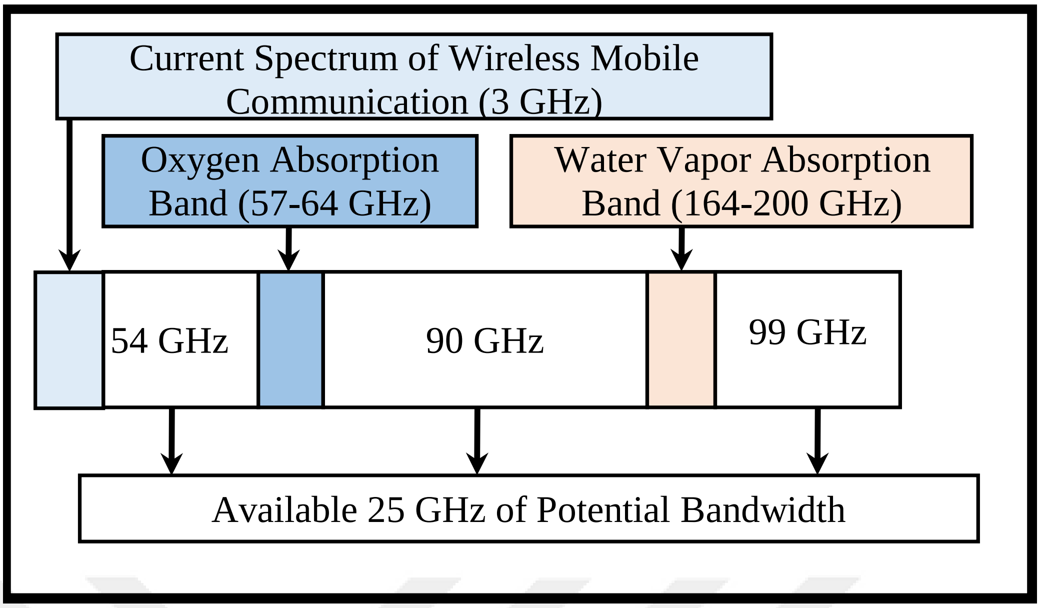

Figure 6.1. Spectrum availability of 3–300 GHz in mm-wave

challenges faced by mm-wave are path loss, propagation loss, link blockage, power consumption, limited coverage area and implementation design issue etc..

In terms of link blockage, three possible solutions are available to overcome this challenge as shown in Figure 6.2. In the first option, the link blockage is tackled by a technique known as “fallback”. In fallback, the process of switching is performed between mm-wave band to micro band until the blockage of the link is not cleared. In second option two types of relay nodes (active and passive) are used to overcome the link blockage. These relay nodes are added in the network and link blockage is eliminated by an alternative path in which no obstacle exists between source and destination. The comparison between fallback and relay node link showed that for high data rate traffic demand the relaying link option is more superior. In passive relay type, no power consummation is utilized and cost of reflecting material is not so much expensive as compared to active relay.

The mechanism of the passive relay is to reflect the incoming signal towards appropriate direction.The coverage in NLOS by using passive relay node in mm-wave band can achieved a gain more than 20dB whereas it can be more by eliminating link blockage and by selecting best path with the best relay selection. The optimal relay deployment in mm-wave increases the coverage area and capacity of the network. The third option for clearing link blockage is installing directional antennas in the network however, this option is not suitable for NLOS of communication. The three possible solutions for link blockage have their own advantages and disadvantages. The mm-wave with relaying

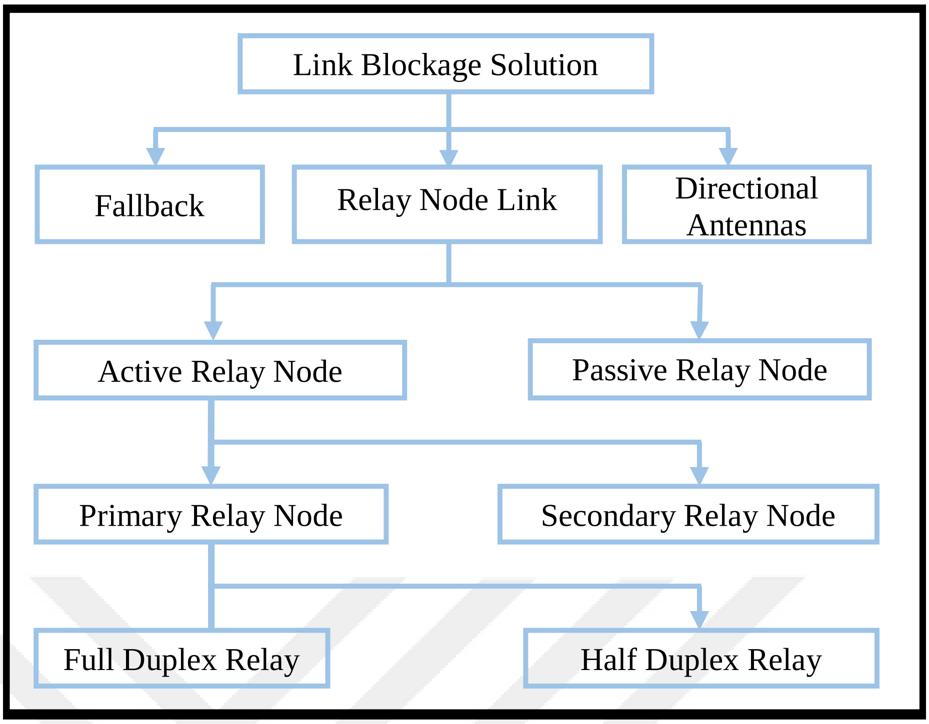

Figure 6.2. Possible solutions to overcome link blockage in mm-wave

technique is the most convenient as compared with other options in next generation wireless network. However, further deep research is required in order to avail huge potential of cooperative communication with mm-wave.

6.3. Backhaul Connectivity With Mm-wave Cooperative Relaying

In outdoor communication, especially in the dense urban area, the mm-wave spectrum band experiences different challenges. However, a lot of opportunities and advantages make mm-wave a promising approach for the next generation of the wireless network. Moreover, the cooperative wireless backhaul connectivity in mm-wave communication is a better choice as compared to wired backhaul connectivity due to the costly installation process.

Figure 6.3 shows that the outdoor 5G wireless network having D2D, vehicle-to-vehicle (V2V), machine to machine (M2M), and backhaul connectivity in the small cell can be used by employing cooperative relays. In 5G cellular network, the backhauling connectivity is also possible with the multi-dual hop network with the aiming to extend the coverage area and increase the end to end performance.

6.4. Elimination Of Link Blockage In Indoor Communication With Mm-wave Cooperative Relaying

In next generation of the wireless networks, the target of 10 Gbits/s for the indoor environment without mm-wave seems difficult to be achieved. However, as compared to conventional micro frequency band the mm-wave have high penetration losses for different obstacles. In indoor communication the penetration losses for the ceiling, walls, door, window etc. vary with the different frequency band of mm-wave. The most appropriate band of 60 GHz consider being suitable for the indoor environment for achieving high data rates. However, the losses still exist that need to be overcome. In recent studies it is demonstrated that the deployment of the relay node in the middle of the ceiling of the room can maximize the performance of end-user. The better connectivity and link blockage problem can be overcome by two types of relay nodes i.e., Primary node and Secondary node in the network. The primary node connected with the wired link of the backbone network and secondary with a wireless link for the purpose of improving reliability, coverage, and capacity. Fig. 6.4 shows a possible solution for indoor communication in mm-wave band. A Home eNodeB (HeNB) is connected to the backbone network via an optical fiber link. Inside the buildings, the rooms are connected with a number of relay nodes (RN) via a wireless link. The UE can be connected by different relay nodes to avoid NLOS and link blockage. Similarly, the

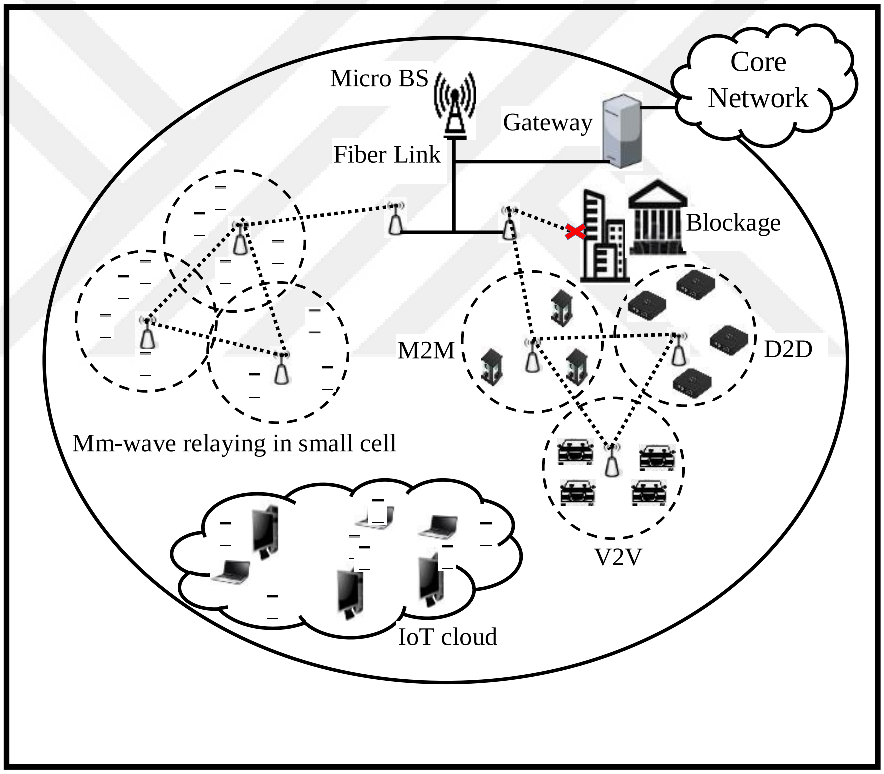

Figure 6.3. Mm-wave relaying communication network

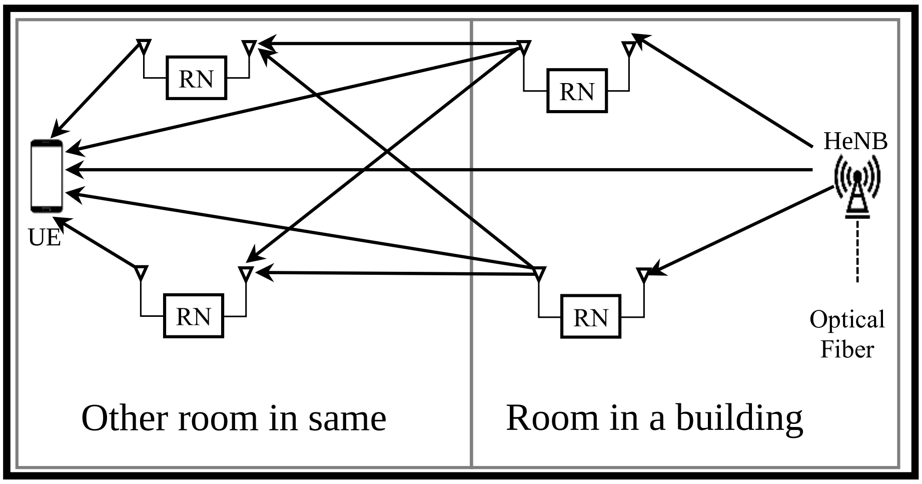

Figure 6.4. Mm-wave relaying for indoor communication

concept of mm-Wave with optimal relaying technique is proposed to overcome different challenges such as shared users distributed antenna system (SUDAS), and Shared UE side distributed antenna component (SUDAC). However, in such case, the fixed relay is considered to be installed at an optimal location that optimal prerequisite location to install.

The mm-wave with relaying technique is the most appropriate approach for both indoor as well for outdoor communication as compared with other options in the next-generation wireless network. However, further deep research is required in order to overcome various obstacles to avail huge potential of cooperative communication with mm-wave.

6.5. Future Challenges

There are certain futures challenges to implement cooperative relaying for better performance. The brief overview of the main future challenges is outlined below.

Interference Management: In cooperative communication, interference management is a challenging task. The cooperative relay node may possibly suffer from co-channel and adjacent channel interference. The use of AF relaying protocol for the purpose of less complexity mechanism at one end can increase the amplification in the noise which introduces interference in a cooperative network. In a distributed cooperative network many relay nodes have incomplete knowledge of overall network and flooding of information boost interference in the network. A proper mechanism is required to tackle the interference management issue for the better performance.

Power Optimization: The increasing number of relay nodes in the cooperative network for efficient communication and a better end to end connectivity utilizes more power. In a network where nodes have limited battery power need to have a power optimization mechanism.

Channel Estimation: In literature, the optimal relay selection generally considers static channel condition. However, in real time scenarios, the channel is time-varying and channel estimation is a challenging task. The channel state information is highly required in the selection of the relay node as well as during the actual transferring of the information between the connecting nodes.

Security Issues: Security is an important challenge for the reliability of cooperative communication. There are a number of security threads in the cooperative network wherein fake node acts as a reliable node by presenting its full availability and better channel condition to attract the other nodes in the network for the purpose of acquiring the information. In future strong secure mechanism is required in the cooperative network for reliable and fulfill the security loops in the network for effective communication.

Optimal Location and Cost Effectiveness: In a cooperative network, the optimal location of the selected relay node has a greater impact on the end to end performance. The different challenges faced by mm-wave can be overwhelmed by relaying nodes, however, increase in a number of relay nodes affect the implementation cost. In future studies, a proper mechanism is needed to sort out the deployment of a relay node in optimal location especially in mm-wave relaying technique for cost effectiveness and better performance.

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APPENDICES

Appendix-A

Cummulative Distribution Function

$$F_{\gamma_k}(\gamma) = 1 - [1 - F_{\gamma_{sr_k}}(\gamma)][1 - F_{\gamma_{r_k d}}(\gamma)] \tag{1}$$

$$F_{\gamma_k}(\gamma) = 1 - 1 + F_{\gamma_{r_k d}}(\gamma) + F_{\gamma_{sr_k}}(\gamma) - F_{\gamma_{sr_k}}(\gamma) F_{\gamma_{r_k d}}(\gamma)] \tag{2}$$

The SNR of the received signal has following CDF

$$F_{\gamma_k}(\gamma) = 1 - \exp\left(-\left(\frac{\gamma}{\overline{\gamma}_k}\right)\right), \tag{3}$$

$$\begin{aligned} F_{\gamma_k}(\gamma) = {} & 1 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) + 1 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right) - \\ & \left(1 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right)\right)\left(1 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right)\right) \end{aligned} \tag{4}$$

$$\begin{aligned} F_{\gamma_k}(\gamma) = {} & 2 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right) \\ & - \Big[1 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right) - \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) + 1 \\ & \quad - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right) \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) \end{aligned} \tag{5}$$

$$\begin{aligned} = {} & 2 - \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right) - 1 + \exp\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) \\ & + \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right) - \exp\left(-\left(\tfrac{\gamma}{\gamma_{sr_k}}\right)\right)\left(-\left(\tfrac{\gamma}{\gamma_{r_k d}}\right)\right) \end{aligned} \tag{6}$$

$$= 1 - \exp - \left(\frac{\gamma}{\gamma_{sr_k}}\right) - \left(\frac{\gamma}{\gamma_{r_k d}}\right) \tag{7}$$

$$= -\left(\frac{\gamma}{\gamma_{sr_k}}\right) - \left(\frac{\gamma}{\gamma_{r_k d}}\right) \tag{8}$$

$$\overline{\gamma}_{u_k} = \frac{\overline{\gamma}_{sr_k}\overline{\gamma}_{r_k d}}{\overline{\gamma}_{sr_k} + \overline{\gamma}_{r_k d}}. \tag{9}$$

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B. Conferences

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Muhammad Asshad was born in 1984 in Abbottabad, Pakistan. He received his BS degree in Computer Science from Hazara University Mansehra and MS degree in Telecommunication and Computer Network from Iqra University Islamabad, Pakistan. Moreover, in the supplement to attained understanding of the communication technologies, he obtained a variety of certifications like CCNA, MCSE etc., which improved his practical skills and developed his concepts more translucent. He served in Ministry of IT Telecom Islamabad for the period of one year in Computer Network Division and in the Department of National IT Policy. He also served in Allama Iqbal Open University Islamabad and Govt. Post Graduate College Abbottabad. He is currently a Ph.D. student at the department of Computer Engineering at Kocaeli University in Turkey. His current research areas include performance analysis, relaying diversity schemes, cooperative network and wireless fading channel.