RELAY SELECTION AND DISTRIBUTED CODE DESIGN FOR COOPERATIVE COMMUNICATION SYSTEMS

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BY

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ABSTRACT

RELAY SELECTION AND DISTRIBUTED CODE DESIGN FOR COOPERATIVE COMMUNICATION SYSTEMS

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Dec. 2015, Page 124

Although multiple-input multiple-output (MIMO) systems increase the transmission speed and the quality of the transmission significantly, small size of the mobile communication equipment prevents the use MIMO systems on these devices. An alternative solution to this problem is the employment of cooperative communication systems via multiple intermediate relay nodes. Once intermediate nodes work cooperatively, they form a virtual MIMO system. The destination receives multiple copies of the information signals from the source and one or more relay nodes, and combines the received signals to make use of the diversity.

Cooperative communication systems can be considered an alternative option for MIMO systems. However, latency issue is one of the main drawbacks of cooperative communication systems when compared to MIMO systems. The destination node should wait for the arrival of all node signals. We propose a relay node selection method which guarantees higher throughput, less latency, a full diversity order, better BER, and higher spectral efficiency.

A multi-relay selection protocol for decentralized wireless networks is also proposed. Using the proposed relay selection protocol, relay nodes within the coverage area of the source and destination can be selected such that the relays are positioned one hop away from the destination. In addition, it is ensured that the best node (best relays with less distance and attenuation from the destination) access the channel first and the proposed relays selection is collision free.

In addıtion, we consider minimizing spectral efficiency loss and BER of cooperative communication systems. We propose a communication protocol which reduces the spectral efficiency loss in cooperative communication systems. Best relay has maximum link quality from source-relay and relay-destination links quality. The destination indicates success or failure by broadcasting a single bit of feedback to the source and best relay node. If the source-destination link quality is sufficiently high compared to source-relay and relay-destination link quality, the feedback indicates success of the direct transmission, and the relay does nothing. Otherwise, the feedback requests send by destination indicates that the best relay node should retransmit what it received from the source. In such a case, relay node does not always retransmit and this increases the spectral efficiency in cooperative communication systems.

We finish this thesis by investigating the optimal power and code rate allocation for cooperative communication systems. The optimal power allocation is done considering the cases such that either the received data at relay includes errors or it does not contain any error. On the other hand, the optimal code rate allocation is done considering the case that received data at relay includes errors. We show that the system performance is better compared to equal power and code rate allocation scenario.

Keywords: Cooperative Communication Systems, Relay Node Selection, Distributed Code Cooperation, Optimal Power Allocation and Optimal Code Rate Allocation.

ÖZ

KOOPERATİF İLETİŞİM SİSTEMLERİ İÇİN RÖLE DÜĞÜMÜ SEÇİMİ VE DAĞINIK KOD TASARIMI

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Dec. 2015, Page 124

Çok girdili çok çıktılı iletişim sistemleri (MIMO) veri gönderme hızını oldukça arttırmaktadır. Ama bu sistemlerin kullanılması için çoklu anten sistemlerine ihtiyaç vardır. Bu da bu sistemlerin küçük boyuttaki kablosuz iletişim cihazlarında kullanılmasını sınırlamaktadır. Bu sorunu çözmek için kooperatif iletişim sistemlerini MIMO sistemleri yerine alternatif olarak kullanabiliriz. Kooperatif sistemlerde yer alan düğüm noktaları birlikte düşünüldüğünde sanal bir MIMO sistemi oluşturulabilir. Alıcı kaynaktan ve röle düğümlerinden gelen sinyalleri harmanlayarak daha iyi sezimleme sonuçları verebilecek birleşik sinyali elde eder.

Kooperatif iletişim sistemleri MIMO sistemleri için bir alternatif olarak düşünülebilir. Ancak, kooperatif sistemler iletişim gecikmesi sorunundan MIMO sistemlere göre daha fazla etkilenmektedirler. Kooperatif sistemlerde varış düğümü bütün diğer düğümlerden gelen sinyallerin ulaşması için beklemelidir. Bu da iletişinde gecikmeye neden olmaktadır. Bu tez çalışmamızda iletişim gecikmelerini azaltmak için yeni bir röle seçme yöntemi öneriyoruz. Önerilen yöntem ile daha yüksek verimlilik, daha iyi bit-hata-oranı ve daha iyi spektrum verimliliği elde etmek mümkündür.

Bu tez çalışmasında ayrıca, merkezi olmayan kablosuz şebekeler için çoklu röle seçimi protokolü önerilmiştir. Önerilen yöntem kullanılarak, kaynak ve varış düğümü kapsama alanına giren düğümlerden varış düğümüne bir sekme uzaklıkta bulunan düğümler seçilmektedir. Önerilen yöntemle en iyi düğümlerin kanalı kullanması garanti edilmiştir. Ayrıca önerilen yöntem çarpışma sorununa sahip değildir.

Ek olarak, kooperatif sistemlerdeki spektral verimlilik kaybını ve bit hata oranını azaltmak için yeni bir iletişim protokolü öneriyoruz. Bunun için en iyi düğüm noktası kaynak-röle ve röle-varış düğümü bağlantılarını göz önüne alarak belirlenmektedir. Eğer kaynak varış düğümü bağlantı kalitesi kaynak-röle veya röle-varış düğümü bağlantı kalitesinden daha iyi ise geri besleme sinyali röleleri devre dışı bırakır. Diğer durumda seçilen en iyi röle iletişime katılır. Bu şekilde en iyi röleyi gerektiğinde kullanarak spektral verimliliği arttırmış oluyoruz.

Son olarak tez çalışmamızda kooperatif iletişim sistemleri için en uygun güç ve oran paylaştırma konusunu inceliyoruz. En iyi güç paylaşımı rölelerin aldığı verinin hata içerip içermediği göz önüne alınarak yapılmaktadır. En iyi kod oranı paylaşımı da rölelerin hatalı veri alma durumları göz önüne alınarak yapılmaktadır. Önerilen yöntemlerle daha iyi performans gösteren kooperatif iletişim sistemleri elde edilmiştir.

Anahtar Kelimeler: Kooperatif iletişim sistemleri, röle düğüm seçimi, dağınık kod işbirlikleri, en iyi güç paylaşımı, en iyi oran paylaşımı.

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TABLE OF CONTENTS

CHAPTERS:

LIST OF FIGURES

FIGURES

LIST OF TABLES

TABLES

LIST OF SYMBOLS AND ACRONYMS

LIST OF ACRONYMS

Acronyms	Explanation
ACK	Acknowledgment
AF	Amplify-and-Forward
APR	Analog Processing Relaying
ARQ	Automatic Repeat Request
ASE	Average Spectral Efficiency
BC	Broadcasting
BER	Bit Error Rate
BTF	Backoff Time Function
BRS	Best Relay Selection
CCM	Cooperatives Communication Mode
CCS	Cooperatives Communication Systems
CDS	Cooperatives Diversity Systems
CSMA/CA	Carrier Sense Multiple Access/ Collision Avoidance
CTS	Clear-to-Send
DCC	Distributed Convolutional Code
DIFS	Distributed Inter-Frame Space
DCF	Distributed Coordination Function
DF	Decode-and-Forward
DO	Diversity Order
DWN	Decentralized Wireless Networks
ER	Errors-in-Relays
EFR	Error-Free Relays
EPA	Equal Power Allocation
ECRA	Equal Code-Rate Allocation
FF	First Frame
JNRS	Joint Next-Hop and Relay Selection
LDCP	Load Distributed Cooperative Protocol
LTE	Long Term Evaluation
MAC	Medium Access Control
MCP	Multihops Cooperative Protocol

MIMO	Multi-Input-Multi-Output
MLSRD	Maximum Links Source-to-Relays and Destination
MISO	Multi-Input-Single-Input
MRC	Maximal Ratio Combining
MRS	Multi-Relays Selection
RCW	Relay-Contention Window
RR	Relay Region
RRM	
RTS	Request-to-Send
PEP	Pairwise Error Probability
PNR	Power-to-Noise Ratio
OCRA	Optimal Code-Rate Allocation
OPA	Optimal Power Allocation
SC	Selection Combining
SER	Symbol Error Rate
SF	Second Frame
SIFS	Short Inter-Frame Space
SIMO	Single-Input-Multi-Output
SNR	Signal –to-Noise Ration
SRS	Single Relay Selection
STBC	Space Time Block Code
3GPP	

LIST OF SYMBOLS

Symbol	Explanation
S	Source Node
D	Destination Node
R_k	Relay(s) Node
L	Number of Relays
y_{SR}	Received Signal at Relay that was Transmitted from Source
y_{RD}	Received Signal at Destination that was Transmitted from Relay
y_{SD}	Received Signal at Destination that was Transmitted from Source
d_{SR}	Distance between Source and Relay
d_{RD}	Distance between Relay and Destination
d_{SD}	Distance between Source and Destination
P_b	Broadcasting Mode Power
P_m	MAC Mode Power
h_{SR}	Channel Coefficients between Source and Relay
h_{SD}	Channel Coefficients between Source and Destination
h_{RD}	Channel Coefficients between Relay and Destination
η_{SR}	Noise Components in Channel between the Source and Relay
η_{SD}	Noise Components in Channel between the Source and Destination
η_{RD}	Noise Components in Channel between the Relay and Destination
x	Modulated Transmitted Signal in Broadcasting Mode
$\widehat{x}$	Modulated Transmitted Signal in MAC Mode
λ	Threshold Value of MLSRD Protocol
P_{DTM}	Total Power of Direct Transmission Mode
γ	Instantaneous SNR
γ_b	SNR in broadcasting Mode
γ_m	SNR in MAC Mode
γ_{DTM}	Total SNR of Direct Transmission Mode
N_o	
R_b	Code-Rate in Broadcasting Mode
R_m	Code-Rate in MAC Mode
R	Transmission Rate
d_b	Hamming Distance in Broadcasting Mode
d_m	Hamming Distance in MAC Mode
γ_{CTM}	Total SNR of Cooperative Transmission Mode

$\overline{\gamma}$	Average SNR
T_k	Backoff Time of k_{th} Relays
$d_{k,D}$	Distance between Best Relays and Destination
d_{Thre}	Distance Threshold
S_{Rec,R_k}	Received Signal at k_{th} Relays from the Destination
S_{Thre}	Received Threshold Signal at k_{th} Relays from the Destination
T_g	Time Gap
T_{Pro}	Propagation Transmission Time
T_{C_p}	Control Packet Transmission Time
D_p	Data Packet
C_p	Control Packet
R	
T_{RTS}, T_{CTS}	RTS and CTS Time Transmission
T_{ds}	Data Transmission Time
T_b	Broadcasting Data Transmission
T_m	MAC Transmission Time
H	Throughput
γ_{Thre}	SNR Threshold
ρ	Node's Degree
ω	Node's Density
$E(h)$	Expected Number of Hops
W_{CTM}	Shannon's Capacity
ρ_{CTM}	Node's Degree of CTM
B_{DTM}	Bandwidth of DTM
B_{CTM}	Bandwidth of CTM
ψ	Direct Transmission Mode Event
ψ_{CTM}	Cooperative Transmission Mode Event
$S-D$	Source to Destination Channel (Link)
$R-D$	Relay to Destination Channel
$S-R$	Source to Relay Channel
$Pr(\psi)$	Probability of Direct Transmission Mode
$Pr(\psi_{CTM})$	Probability of Cooperative Transmission Mode
$p(.)$	Probability Density Function
$Pr(.)$	Cumulative Distribution Function

σ_{SD}	Channel Gain between Source and Destination
σ_{RD}	Channel Gain between Relay and Destination
σ_{SR}	Channel Gain between Source and Relay
$\|h_{i,j}\|^2$	Average
$C(d)$	Sum of Bits Error of Error Event
d_f	Free Hamming Distance of Code
k_c	Number of Information Bits before Encoding
k_{PSK}	PSK Modulation Constant
A_b, A_m	Coding Gain of Broadcasting and MAC Modes
$Pr(out_{i,j})$	Outage Probability between Link i and j
$\|.\|$	Absolute
$\lfloor . \rfloor$	Round Down
$Pr(\phi)$	Probability of Best NH Selection
δ	Exponential Distribution Parameters
Ω	Portion of Time to Transmit Coded Data in Broadcasting Mode
M	Modulation Order

CHAPTER 1
INTRODUCTION

1.1. Motivation and Background to Wireless Communication

In recent years, a large number of wireless applications which require high data rate and high transmission quality have been introduced in order to meet the tremendously increasing demand in wireless communications. Given very limited network resources and a crowded wireless frequency spectrum shared by an increasing number of operators and services, the three fundamental design issues in digital wireless communication systems, namely capacity, coverage area, power allocation, channel fading and interference, have become more intertwined. This problem can be readily faced in any incumbent cellular mobile networks as well as in other recently emerging networks such as wireless ad-hoc networks and wireless sensor networks [1].

Channel fading is major problem of digital wireless communication systems. The wireless channel contains objects and particles which scatter the transmitted signal. These scattered signals follow different paths with different lengths and arrive in the receiver with phase lags and create interference. These scatterers introduce a variety of impairments in the wireless channel such as fading, delay spread and attenuation. This results in severe attenuation of the signal, referred to as deep fade. This instantaneous of the signal-to-noise ratio decrease results in error bursts which significantly degrade the performance. Fading can be classified as long term fading (large scale fading) and short term fading (small scale fading). Long term fading is due to shadowing and the relative distance between the source and destination. It is also referred to as path loss. Short term fading is due to the multipath propagation of the transmitted signal due to reflections from various objects. When the delay differences between the multipath components are small as compared to the symbol interval, these components can add constructively or destructively at the receiver depending upon the carrier frequency and delay differences. Multipath fading can be controlled by techniques like channel coding and diversity.

Channel coding is a technique to correct the transmission errors over a noisy channel. In channel coding redundancy is introduced at the transmitter and utilized at the receiver for error correction. Channel coding is effective in correcting independent random symbols. However when the fading is correlated, channel coding is not an effective technique, in this scenario interleaving is used. In this method, at the transmitter, the coded signals are first interleaved to reduce the effect of correlation. Interleaving is effective in combating the correlated fading at the cost of increased delay and extra hardware.

Alternative ideas of combating multipath fading attracted researchers attention recently, and different approaches were suggested to alleviate the negative effects of multipath fading. An immediate thought to combat multipath fading is to employ redundancy by sending the signal on another channel independent from the original channel, as the chance of two independent channels simultaneously in deep fades is lower than that of one channel in a deep fade. In this way, the additional channel can be regarded as providing more diversity to the radio communication. Diversity has been considered a powerful technique to combat fading and increase reliability. Diversity can be obtained through coding and interleaving, where information is dispersed into different coherence periods, different coherence bandwidth, and sufficiently spaced antennas [2-3]. In another words, there are three basic diversity techniques: (1) time diversity: multiple copies of the same signal are transmitted at different time instants, (2) frequency diversity: the signal is transmitted using several frequency channels, and (3) space diversity: the signal is transmitted over several different propagation paths. Spatial diversity is particularly attractive since it provides diversity gain without using additional time or bandwidth resources [4].

One way to exploit spatial diversity is through the use of multi-antenna or multi-input multi-output (MIMO) technologies, where both of the transmitter and receiver can be installed with more than one antenna. Fig. 1 shows a MIMO example where two antennas are used at the transmitter and receiver. The MIMO technologies include precoding (multi-layer beamforming), diversity coding (space-time coding), and spatial multiplexing. And these technologies either increase throughput (multiplexing gain) or increase reliability (diversity gain) with the same amount of power without using extra scare spectral resources. This performance improvement originates from the increased ability to combat wireless channel variation, i.e. fading, by using multiple transmitting-receiving antenna pairs, where each antenna pair provides a possible statistically independent channel at the same carrier frequency and time. In addition achieving statistical independence requires that the separation distance between antennas employed at transmitter and receiver should be least a few carrier wavelengths. Furthermore, multi-antenna technologies typically require relatively intensive computation, especially in decoding complicated space-time block codes (STBCs).

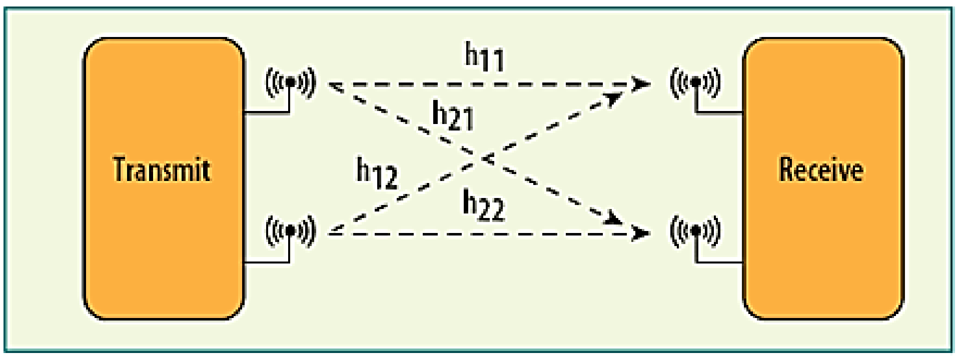


Figure 1: Centralized MIMO system.

Hence, multi-antenna technologies are usually used only at base stations. Owing to the size constraint and limited processing power, small-sized mobile terminal devices seldom use multiple antennas, or usually use no more than two antennas. Another way to exploit spatial diversity is through cooperative communication system systems, or cooperative diversity systems [5-6] which can utilize spatially separated antennas as an array to provide spatial diversity and help in combatting the negative effects of fading. The basic idea of cooperative communication system is to allow single antenna devices to share their antennas in such a way that they form a “virtual antenna array” to gain a similar benefit of MIMO. The key idea in cooperative communication system resides in the broadcast nature of wireless channels. As shown in Fig. 2, when the source transmits to the destination, a relay node within the transmission range can receive the signal and can be a potential auxiliary node that assists in forwarding the signal to the destination.

Cooperative communication systems provide the benefit of energy efficiency, extended coverage, and increased connectivity. The Third Generation Partnership Project's (3GPP) Long Term Evolution-Advanced (LTE-Advanced) has developed a new standard that uses relay nodes in mobile broadband access, resulting in coverage extension [7] in a cost-effective way.

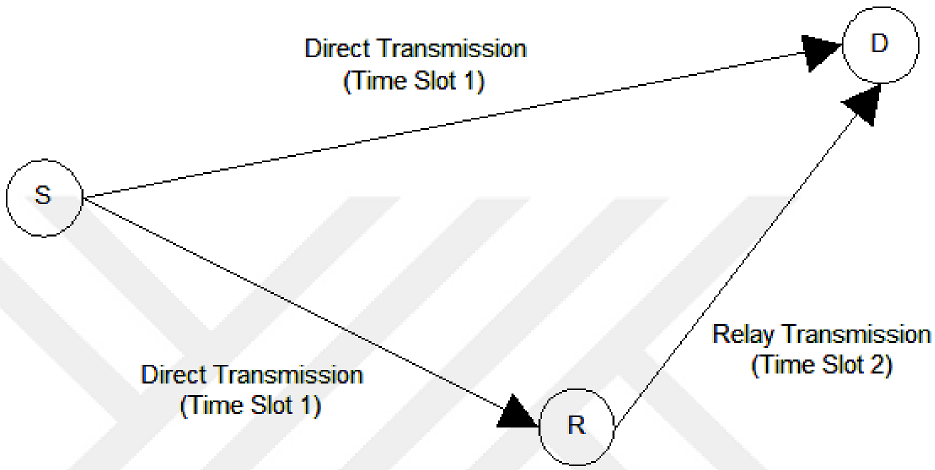


Fig. 2: Cooperative communication system scenario.

Cooperative communication system poses many challenges to communication system designers. To enable cooperative diversity techniques to operate on low-cost small sized devices, the limited processing capability of cooperative relay nodes requires algorithms that do not involve intense computation. Because the antennas are spatially distributed on different mobile devices, many challenges can arise, such as timing, bandwidth efficiency, delay, best relay node selection, and imperfect information recovery at the relay nodes.

Beyond the diversity capability to mitigate the fading effects, relaying transmission can also reduce the propagation attenuation which increases the capacity and/or coverage of the networks. However, to exploit those advantages, various design problems concerning wireless cooperative networks need be addressed. The works presented in this thesis focus on several of these issues, namely the best relay node selection, delay reduction, bandwidth loss reduction, bit error rate reduction and power control/allocation problem.

Although multiple relays can offer higher diversity gains, large number of retransmissions is usually prohibitive due to limited radio resources. To this end, a best relay node selection algorithm is introduced to limit the retransmissions to one or multiple best relays, and then allow the best relay node(s) to participate in cooperation rather than inferior relay nodes.

In cooperative communication systems such as time slots accessing based, the source transmits to the relay node(s) and destination, the relay node(s) re-transmits the received data from the source to destination, and such a scenario requires more transmission time slots which increase the latency in communication systems. For this reason in this thesis work we tried to propose some relay selection approaches which can reduce the latency in cooperative communication.

Bandwidth efficiency loss is another major drawbacks of cooperative communication systems. In subchannel accessing based communication, for the transmission of a single symbol using cooperative systems, two subchannel accessing are required compared to non-cooperative systems. Since relays operate in half-duplex mode and they cannot receive and transmit at the same time. Therefore, two subchannels (or transmission phases) are needed to complete each transmission from the source to the destination. In such a case the bandwidth efficiency is reduced. In this thesis work we also focus on reducing the bandwidth efficiency loss in cooperative communication systems relying on direct transmission. In a conventional wireless networks, power control is one of the main methods to improve the quality of the signal reception, thus increasing the coverage and/or reduce the bit error rate of the overall network. This also represents a potential venue to offer a significant improvement on the quality of transmissions in many situations.

1.2. Organization of the Thesis Work

In this thesis, we develop and analyze a cross-layer basis for utilizing the cooperative communication system paradigm in wireless networks. The ultimate goal of our research is to develop new relay deployment and selection schemes across the network layers that can increase the bandwidth efficiency, reduce the required time for cooperation, maximize the diversity order, maintain a given network to be connected as long as possible, reduces the bit error rate, reduces the outage probability, and mitigate the effect of channel fading. In the following, we present the main contributions of each chapter. The contribution of this thesis can be summarized as follows:

- Chapter 2, We provide background information about cooperative communication systems in Chapter-2.
- Chapter 3, Multi-Relays Selection for Decentralized Cooperative Wireless Networks: In this Chapter, we proposed a multi-relay selection protocol for decentralized wireless networks. The proposed relays selection protocol aim to address three issues: 1) selecting relays within the coverage area of the source and destination to ensure that the relays are positioned one hop away from the destination; 2) ensuring the best node (best relays with less distance and attenuation from the destination) access the channel first; and 3) ensuring that the proposed relays selection is collision free. Our analysis also considers three important characteristics of decentralized wireless networks that are directly affected by cooperation: delay, connectivity and throughput. The focus of this Chapter is to demonstrate that improving connectivity and increasing number of relays reduce the throughput of cooperative decentralized wireless networks; consequently, a trade-off equation has been derived.

- Chapter 4, Relay Selection Deployments: Bandwidth Efficiency, Diversity Order and Outage Probability improvement in Cooperative communication Systems: Cooperative communication systems, which make use of the intermediate relays between the transmitter and the receiver, have been employed as an effective technique to combat the channel fading and to enhance the system performance. Cooperative systems have some drawbacks such as high latency and decreased low spectral efficiency. To alleviate the negative effects of these factors, relay selection criteria is employed in cooperative communication systems to increase overall spectral efficiency and decrease latency. Relay selection in the cooperative systems enables the source to cooperate with the single relay node rather than multiple relay nodes which reduce the overall spectral efficiency. To prestige the benefit of cooperation, an efficient relay selection method is needed. In this Chapter, we propose a novel relay selection method, maximum link source-relay-destination (ML-SRD) method, for wireless communication systems. The design goal of ML-SRD is to improve the spectral efficiency, bit error rate and outage probability of cooperative wireless communication systems.

- Chapter 5, Joint Next Hop/Relay Nodes Selection for Distributive Multi-hop Cooperative Networks: Cooperative networks, which use adjacent nodes to relay the hearing data, are employed as an effective technique to deal with the channel fading to enhance the performance of communication networks. It is critical to select the optimal next-hop node toward destination between source and next-hop (or) destination. Offering next-hop and relay node selection in distributive multi-hop cooperative networks can improve the system performance. In this Chapter, we propose a joint next-hop and relay node selection protocol, namely JNRS, for wireless distributive multi-hop cooperative networks. The goal of JNRS is reduce the spectral efficiency loss and outage probability. Analysis results show that JNRS can enhance the cooperative networks performance under general conditions comparing to cooperative network without JNRS protocol.

- Chapter 6, Enhancing the Performance of Distributed Convolutional Codes through Resource Allocation: Approximate expressions for pairwise error probabilities are derived for the distributed convolutional coded schemes used in cooperative communication systems. The optimal power allocation is used during transmission paying attention to whether the received data at the relay contain error or not. If the received data at the relay is error free, it is re-transmitted to destination, otherwise it is not transmitted. Further, based on the approximate expressions of the pairwise error probabilities, we proposed an optimum code rate allocation approach provided that the distributed convolutional code scheme is used in cooperative communication system. Optimum power and the code rate allocations have been studied considering different source-to-relay and relay-to-destination channels qualities. Finally, we show that with the proposed optimal power and the code rate allocation approach the system performance is better when compared to the systems with equal power (EPA) and equal rate allocation (ECRA) schemes

CHAPTER 2

BACKGROUND ON THE COOPERATIVE COMMUNICATION SYSTEMS

2.1. Multihops Relaying Cooperative communication system

The conventional and simplest form of cooperation is multihops relaying, in which data is delivered to its destination through relay nodes forming a multihops path. The main characteristics of ad hoc networks are self-configuration and autonomous operation without relying on any infrastructure. The promise of ad hoc networks has been that as the term ad hoc proposes their self-organization feature will allow them to adapt to a wide spectrum of applications and network conditions and will reduce the cost for configuration and maintenance. One of the main focuses of research on ad hoc networks has been mobility and dynamic topologies. Besides the uncertainty of link qualities due to wireless fading, nodes can join and leave a network and the topology of the network changes over time. Although the success of ad hoc networks in the commercial domain has been somewhat limited, some new classes of networks emerged, such as community mesh networks and sensor networks that share some of the characteristics of ad hoc networks. Research on wireless sensor networks is mainly driven by the advances in low-power RF and microelectronics, which enabled large scale deployment of small-size and low-cost sensors. In addition to sensing units, Sensors are equipped with transceivers and they can form networks to transmit their measurements. Wireless sensor networks are expected to and a wide range of applications such as security, habitat monitoring, and remote diagnostics and patient care. Typically, a low-cost sensor is constrained to work and last with limited energy resources. This limits the computation and communication capabilities of wireless sensor nodes.

Conventionally, infrastructure based networks follow a single hop cellular architecture, in which users and the base stations communicate directly. The main challenge in today's wireless broadband networks is to support high rate data communication with continuous coverage at a reduced cost. Despite decades of research in wireless communication, and significant advances in signal processing and multi-antenna architectures, these demands are not fully met. The scarcity of wireless spectrum encouraged the allocation of high frequency bands, where power attenuation with distance is more severe. This factor significantly decreases the coverage of a base station. Fast decay of power with distance suggests that both the capacity and the coverage of networks can be improved by increasing the density of base stations. However, this trivial solution sometimes called deploying microcells adds to the already high infrastructure and deployment costs. As a result, we face a situation in which the wireless systems can achieve any two, but not all three, of high capacity, high coverage and low cost [7]. Integrating cooperative communication system to cellular networks and forming hybrid networks emerged as a pragmatic solution to mitigate this problem. Although wireless relays use additional radio resources, they have lower cost compared to base stations since they do not require a high capacity wired connection to the backbone. In the final cost analysis, wireless relays can be a more viable solution than microcells to increase the coverage and to distribute the capacity uniformly with the coverage of a base station. Multihops relaying is already part of the standards currently being developed for wireless broadband systems such as 802.16j and 802.16m, which is an indication of growing consensus on the effectiveness of cooperative communication systems.

2.2. Cooperative Diversity Systems

Cooperative communication system refers to the sharing of resources and the realization of distributed protocols among multiple nodes in a network. It is an active research area with promising developments. Cooperation among peer nodes have been considered in [8-10]. Since the 1990's, proliferation of highly capable mobile devices brought the attention back into peer cooperation and wireless ad hoc networks.

In cooperative diversity within ad hoc networks, nodes can cooperate with each other to provide spatial diversity gain at the destination. In this case, at any given time, any node can be a source, relay, next hop, or destination. The function of the relay node is to assist in the transmission of the source information to the destination node. To ensure diversity gain, these relays are chosen in such a way that their links to the destination are independent from that of the source.

In cooperative communication due to the broadcast nature of wireless medium, most transmissions can be heard by multiple intermediate nodes in the network with no additional transmission power and bandwidth. Deferent nodes have independent channel fading statistics to a given destination node and the destination can listen, store, and then combine signals from different nodes.

One of the first studies that introduced the concept of cooperative diversity is by Sendonaris et al [5]. In this paper, an uplink scenario is considered, in which two users cooperate by relaying data to each other. After showing the potential of cooperation in enlarging the achievable rate region of the two users, the authors demonstrated that cooperation can improve other measures such as outage capacity, error probability and coverage. The first practical cooperative relaying protocols have been proposed by Laneman et al. in [11]. In this seminal paper, the authors identified different classes of cooperative diversity protocols such as fixed protocols, in which the relay node always retransmits, selective protocols, in which the relay node retransmits only when it decodes reliably, and incremental protocols, in which the relay node retransmits only when the direct transmission fails. In a network exploiting cooperative diversity, every node can potentially be considered to be connected to all the other nodes. However, hardware and resource constraints do not allow all the links be used for delivering a given packet and certain connectivity graphs can be more viable than the others. Reference [12] derives the maximum end-to-end diversity orders achievable for any given connectivity graph.

2.2.1. Introductions to Relaying Schemes

Relaying protocols can be classified into two according to the processing at the relay: Analog Processing Relaying (APR) and Digital Processing Relaying (DPR). APR can be implemented in a very primitive way in which the relay node functions as an active reflector, these protocols are also referred as amplify-and-forward (AF) relaying protocols in the literature [11]. In DPR, the relay node regenerates a noise-free version of original signal based on its processing types. If the resource and performance constraints such as relay energy and latency permit, digital relays can also decode and re-encode the received data. These protocols are also referred to as decode-and-forward (DF) relaying protocols in the literature [13].

APR and DPR experience different limitations in practice. In DPR, for example, if the relay is required to first demodulate and detect the received signal, and then modulate and retransmit the regenerated signal. These operations potentially require more processing and causes more latency than simple APR. In its basic form, APR does not require any of these.

However, if implemented blindly, APR can generate constant interference to the rest of the network. Using analog relays as regular network nodes controlled by certain Medium Access Control (MAC) and Radio Resource Management (RRM) protocols requires analog relaying to be implemented digitally. In this case, the relay is required to store analog samples, possibly after quantization.

SER performance of APR deteriorates at low SNR since relays amplify both the noise and the information bearing parts of the received signal. In the presence of distance dependent attenuation only, DPR performs significantly better than AR [14]. However, if the source to relay link is good (relay can decode the received data that was transmitted by the source correctly), then the performance of DPR is better than APR, otherwise, the performance of APR is better than DPR [11]. In this thesis, the DPR protocol is considered.

2.3. Relay Selection Schemes in Cooperative communication systems

In cooperative diversity systems, retransmissions can decrease the effective rate while increasing the reliability. Hence, it is important to evaluate their performance in terms of diversity-multiplexing trade-off. The half-duplexity constraint requires the use of orthogonal channels for *transmission* and *reception*. For instance, the relay can use different time slots to receive and transmit. In the first time slot the source node transmits and the next relay node receives. In the second time slot, relay node transmits the processed signal to the destination. With this scheme, relaying can be easily integrated to wireless networks using time-division multiple access. As the number of relay nodes increases, the number of time slots allocated for delivering data from the source to the destination increases. In such a case, the spectral efficiency reduces (high multiplexing gain loss). In [11] the outage capacity and diversity-multiplexing trade-off achieved by various schemes are analyzed. When multiple relay nodes are used according to the time division protocol described, the multiplexing loss (bandwidth efficiency loss) becomes very high.

One of the trivial solution is that the relay nodes can operate in full-duplex or half-duplex modes. In full-duplex mode the relay can transmit and receive at the same time on the same frequency band. To implement full-duplex operation, in principle, the relay can cancel its self- interference from the received signal. However, in practice using low cost radios this approach may not be robust. Thus, in the near future relay nodes are expected to operate in half-duplex mode only.

One way of overcoming this loss is through distributed space-time coding [15]. In distributed space-time protocols all the relay nodes that decode the source information transmit different columns of a space-time code matrix simultaneously, i.e., the protocol takes place in two time slots instead of $L+1$ (L is number of relay nodes that had participated in cooperation). These schemes can potentially achieve a better diversity-multiplexing trade-off than repetition based schemes. In [16], the authors propose a distributed space time coding scheme that does not require decoding at relay nodes. Relay nodes implement distributed linear dispersion codes, which requires only linear operations at each relay. A similar scheme for the specific case of two relay nodes implementing Alamouti coding is studied in [17].

More sophisticated protocols that reduce the multiplexing loss by allowing dynamic time slots were proposed to improve diversity-multiplexing trade-off [18-20]. Although cooperative diversity system is a technique that can induce spatial diversity in the absence of multiple antennas, its benefits can be combined with those of multiple antennas.

Another method to reduce the multiplexing loss is relay node selection. Instead of retransmitting the data from all the relay nodes, only a small number of relay nodes can be selected based on their channel quality to the source and the destination. Such schemes are proposed in [21-23].

Incremental redundancy scheme is a good method to reduce the multiplexing loss for APR and DPR cooperative diversity was considered in [11], where the authors proposed a protocol which reduces the spectral efficiency loss in wireless cooperative networks. The destination indicates success or failure by broadcasting a single bit of feedback to the source and relay. If the source-destination signal-to-noise ratio is sufficiently high, the feedback indicates success of the direct transmission, and the relay does nothing. If the source-destination signal-to-noise ratio is not sufficiently high for successful direct transmission, the feedback requests that the relay should retransmit what it received from the source.

Joint techniques can be considered to reduce the multiplexing loss, for instance the incremental redundancy and relay selection protocols can be used together. Instead of retransmission from multiple relays, a single selected relay when the destination sends negative acknowledgment, which indicates the failure of direct transmission, can be used. Such protocols are proposed in [24].

2.4. Channel and Signal-to-Noise Ratio Formulation

In this section, the DPR is analyzed from the channel and signal-to-noise ratio perspective. Two classes of DPR are considered here, first decode-and-forward (DF) and second is distributed code scheme (DCS). In what follow, we indicate the source, kth relay node, and destination nodes by S, R_k and *D*, respectively, as well as, we indicate the direct transmission mode (i.e., non-cooperative mode) and cooperative communication system mode by DTM and CTM, respectively.

2.4.1. Decode-and-Forward Protocol

The decode-and-forward protocol is implemented in two modes and can be described in [24]. In the broadcasting mode (BC), the source broadcasts its information, which is received by both the relay and destination. The received signals at the destination and the relay can be written as

$$y_{SR_k} = \sqrt{P_b}\,(d_{SR_k})^{-\lambda}\,h_{SR_k}\,x + \eta_{SR_k} \tag{2.1}$$

$$y_{SD} = \sqrt{P_b}\,(d_{SD})^{-\lambda}\,h_{SD}\,x + \eta_{SD} \tag{2.2}$$

where P_b is the source transmitted power in BC mode, *x* is the transmitted information symbol with unit energy, and η_{SR_k} with η_{SD} are additive noise terms. Also, h_{SD} and h_{SR_k} are the source-destination and source-relay channel coefficients, respectively, d_{SD} and d_{SR_k} are the distances between S and R_k to destination, respectively; λ is the path-loss exponent that vary from 2 to 6 [25]. If the relay decodes the received symbol correctly, it forwards the decoded symbol to the destination in the MAC mode, otherwise it remains idle. The received symbol at the destination from the relay is written as

$$y_{R_kD} = \sqrt{P_{mc}}\,(d_{R_kD})^{-\lambda}\,h_{R_kD}\,\hat{x}_k + \eta_{R_kD} \tag{2.3}$$

where P_{mc} is the relay transmitted power in the MAC mode and the total power transmitted , i.e., DTM is $P_{DTM} = P_b + P_{mc}$; $d_{R_k D}$ and $\hat{x}$ are the distance and modulated signal transmitted from the R_k to the *D*, respectively. $h_{R_k D}$ are the relay to destination channel coefficients. The destination applies maximal-ratio combining (MRC) [27] on the received signals from the source and the relays.

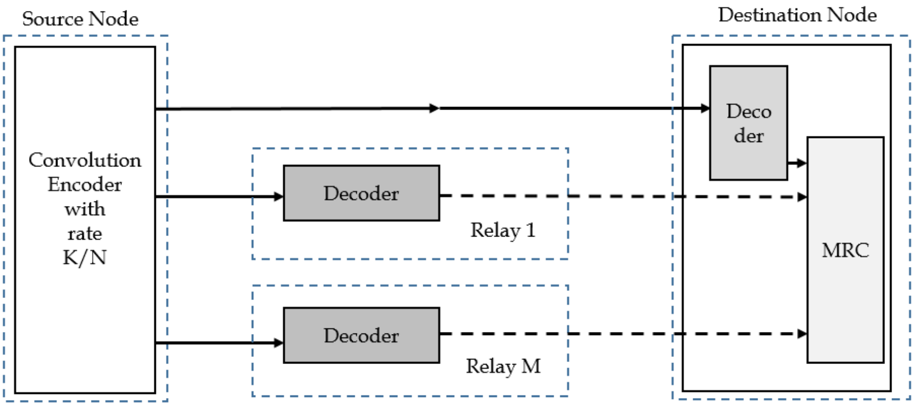


Figure 3: Decode-and- forward diagram.

The instantaneous signal-to-noise ratio (SNR) denoted by γ for DTM is given as:

$$\gamma_{DTM} = \frac{P_{DTM}}{N_o}(d_{SD})^{-\lambda} h_{SD} \tag{2.4}$$

However, when the cooperation is employed, the instantaneous SNR of BC mode at *D* is given as:

$$\gamma_b = \frac{P_b}{N_o}(d_{SD})^{-\lambda} h_{SD} \tag{2.5}$$

In the sequel, the instantaneous SNR of MAC mode at *D* is given as [24]:

$$\gamma_{mc} = \sum_{k=1}^{L} \frac{P_{mc}}{N_o}(d_{R_k D})^{\lambda} \tag{2.6}$$

Therefore, the total received γ of the at *D* uses MRC, it is given as [24]:

$$\gamma_{CTM} = \frac{P_b}{N_o}(d_{SD})^{-\lambda} + \sum_{k=1}^{L} \frac{P_{mc}}{N_o}(d_{R_k D})^{-\lambda} \tag{2.7}$$

2.4.2. Distributed Coded Cooperation

In the earlier decode-and-forward protocols, source distributed the code book, and [26] the source data is encoded in two partitions. In the first time slot, the source transmits the first partition. Then, the relay decodes the data based on the first partition. If its decoding is reliable, it obtains the second partition and transmits it to destination in the second time slot.

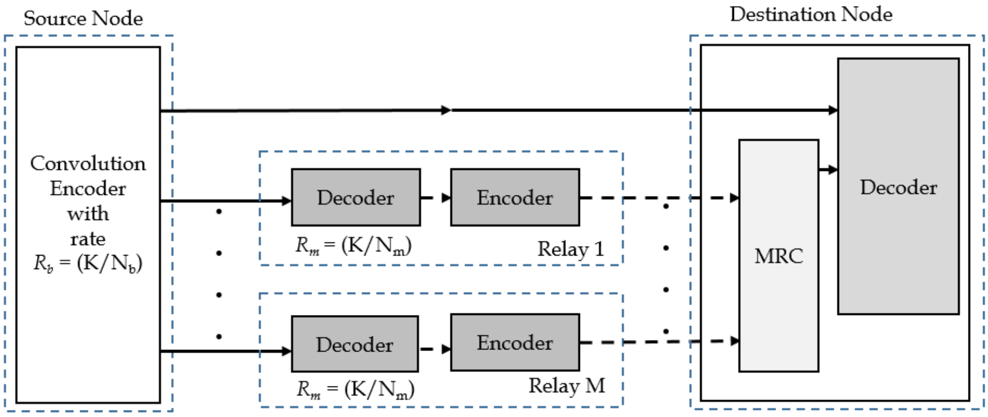


Figure 4:. Distributed convolutional code diagram.

The destination decodes the data based on both the first partition received from the source and the second partition received from the relay, thereby obtains additional coding gain in addition to the diversity gain. In this thesis, we consider distributed convolutional code protocol (DCC) as an approach of DPR. DCC work in two modes: broadcasting (BC) mode followed by medium access control (MAC) mode. Where, in the BC mode, the *S* broadcast the first frame (FF) with half redundant bits N_b to the R_k and *D*. Therefore, the received signals at the R_k and at the *D* are given as:

$$y_{SR_k} = \sqrt{R_b\, P_b}\, (d_{SR_k})^{-\lambda}\, h_{SR_k}\, x + \eta_{SR_k} \tag{2.8}$$

$$y_{SD} = \sqrt{R_b\, P_b}\, (d_{SD})^{-\lambda}\, h_{SD}\, x + \eta_{SD} \tag{2.9}$$

where R_b and P_b are the coding rate and power transmitted in the BC mode, respectively, d_{SD} and d_{SR_k} are the distances between S and R_k to destination,; λ is the pathloss exponent that vary between 2 to 6 [17], $x$and η_{SR_k} with η_{SD} are the modulated signal and the complex white noise with zero mean and unit variance from the S to the R_k and from the *S* to the *D*, respectively. In the MAC mode, if the R_k decode the received FF correctly (the FF that was transmitted by the S in BC mode), then it is re-encoded the FF with half redundant bits named as N_{mc} and it is retransmitted the encoded SF to the *D*, (i.e., $N_{DTM} = N_b + N_{mc}$, N_{DTM} is the total redundant bits of DTM). Where, in the MAC mode the received signals at the *D* is given as:

$$y_{R_k D} = \sqrt{R_{mc}\, P_{mc}}\, (d_{R_k D})^{-\lambda}\, h_{R_k D}\, \hat{x}_k + \eta_{R_k D} \tag{2.10}$$

where R_{mc} and P_{mc} are the coding rate and power transmitted in the MAC mode, respectively, where the total power transmitted or the DTM power is $P_{DTM} = P_b + P_{mc}$ and $d_{R_k D}$ and $\hat{x}$ are the distance and modulated signal transmitted from the R_k to the *D*, respectively.

Therefore the instantaneous signal-to-noise ratio for DTM is given as:

$$\gamma_{DTM} = R_{DTM}\, d_{DTM} \frac{P_{DTM}}{N_o} (d_{SD})^{-\lambda} \tag{2.11}$$

in which R_{DTM} and d_{DTM} are coding rate and the Hamming distance between received and transmitted signal of the DTM, respectively. Where Hamming distance is measure the code capability of correction, i.e. if the d is high, the capability of correction is high at destination, otherwise is low. In our analysis, we interested in coding gain which is given by multiplying the Hamming distance by code rate, i.e., $R_{DTM}\ d_{DTM}$. However, when the cooperation employed, the instantaneous SNR of BC mode at *D* is given as:

$$\gamma_b = R_b\, d_b \frac{P_b}{N_o} (d_{SD})^{-\lambda} \tag{2.12}$$

where R_b and d_b are coding rate and the Hamming distance between received and transmitted signal of the BC mode, respectively. In the sequel, the instantaneous γ of MAC mode at *D* is given as:

$$\gamma_{mc} = \sum_{k=1}^{L} R_{mc}\, d_{mc} \frac{P_{mc}}{N_o} (d_{R_k D})^{\lambda} \tag{2.13}$$

Where R_{mc} and d_{mc} are code rate and the Hamming distance between received and transmitted signal of the MAC mode, respectively, where, $d_{DTM} = d_b + d_{mc}$ and $R_{DTM} = (R_b^{-1} + R_{mc}^{-1})^{-1}$. Therefore, the total received SNR at *D* is given as:

$$\gamma_{CTM} = R_b\, d_b \frac{P_b}{N_o} (d_{SD})^{-\lambda} + \sum_{k=1}^{L} R_{mc}\, d_{mc} \frac{P_{mc}}{N_o} (d_{R_k D})^{-\lambda} \tag{2.14}$$

CHAPTER 3

MULTI-RELAYS SELECTION FOR DECENTRALIZED COOPERATIVE WIRELESS NETWORKS

3.1 Motivation and Background

Despite the advantages of multiple antennas, it is not practical to use multiple antennas for a mobile set because of the size and cost of handsets used in decentralized wireless networks (ad hoc) or cellular networks. A solution to this problem is to employ cooperative communication (CC) systems where the source sets multiple antennas virtually, e.g., the source broadcasts the data to the neighbour nodes (relays) and to the destination, then the relays retransmits the received data to the destination, and the destination combines all the received data from the source and relays.

Two categories of cooperation have been considered in the literature: multi-hop cooperation protocol (MCP) [27] and load distributed cooperation protocol (LDCP), [28-30]. In MCP, the source identifies nodes near to itself and near to the destination, and these nodes are denoted as relays. When the source locates such relays, it transmits the data to the relay, and the relay retransmits the data to the destination. The use of relay in MCP is to avoid the signal attenuation associated with direct transmission, i.e., source destination transmission. In coded distribution protocol, the source divides the redundant bits into two parts instead of transmitting the full redundant bits to the destination; the first part is transmitted by the source to the destination and relays, and the second part is transmitted by the relays to the destination. The key difference between MCP and LDCP is that in MCP, the destination receives the data transmitted by the source through the nodes along a single path merely; on the other hand, in LDCP the destination receives the data from the source and relays. In fact, the LDCP is associated with a longer delay than MCP, consequently, decreased throughput;

however, LDCP associated with high diversity gain compared to MCP. In this paper, we have considered distributed code protocol as an example of LDCP.

The advantages of LDCP are improved detection, better connectivity, and reduced bit error rate, while its disadvantages include delay, synchronisation difficulties and rate reduction. LDCP enhances connectivity by improving the received signal-to-noise ratio through combining the received data from the source and multiple relays using maximal ratio combing (MRC). This can increase the coverage area of the source and size of the prohibited area (more nodes share single time slots); on the other side, the delay increases because of the forwarded data to the relays. Therefore, the throughput is sacrificed because of the delay and connectivity enhancement.

Cooperative communication in decentralized wireless networks (DWN) or infrastructure-less networks require re-design in their protocols, or plan new protocols to use cooperative communication efficiently. One of the efficient protocols that can improve the LDCP is the relay selection protocol, if LDCP is employed and nodes are selected randomly, the communication systems show better performance compared to systems that not use LDCP. Hence, optimal relays selection becomes a critical issue for the performance of cooperative communication systems. Some of the recent works on optimal relay selection have been done in [30-31], and [24], and the effect of delays in cooperative communication systems have been studied in [33-34]. In the DWN, the LDCP has a negative effect on throughput because of delays and connectivity enhancement. Delay and throughput trade-off is in [35], and the trade-off between throughput and connectivity is considered in [36]. Most of the previous works on LDCP based on the backoff time function used to select the best relay did not address several issues [34-37]. These issues are: 1) although the delay is reduced to enhance the throughput, they neglected the connectivity criteria. 2) The protocols usually employ single relay selection. 3) The protocols consider the relays always within the source and destination coverage area. 4) The protocols employ the network coding to enhance the throughput which burden the destination to separate received frames.

To address the above missing issues such as the best relays selection, delay, connectivity and throughput all together, we propose a new cooperative medium access (CMAC) protocol to be used in cooperative communication systems. The contributions of this work are summarised as follows: 1) We propose a backoff time function (BTF), in such the best relays have smaller backoff time and bad relays have a larger backoff time. 2) A CMAC protocol is suggested that reduces the delay and prevents extra negotiation via RTS/CTS packets and it is collision free. 3) Our proposed protocol can be used multi-relay selection. 4) We analysed the connectivity when LDCP is employed in terms of the linking probability and node's degree. 5) The throughput when LDCP is employed is analysed. We also demonstrated that throughput decreases as the delay increases which results in better connectivity and consequently a trade-off exists.

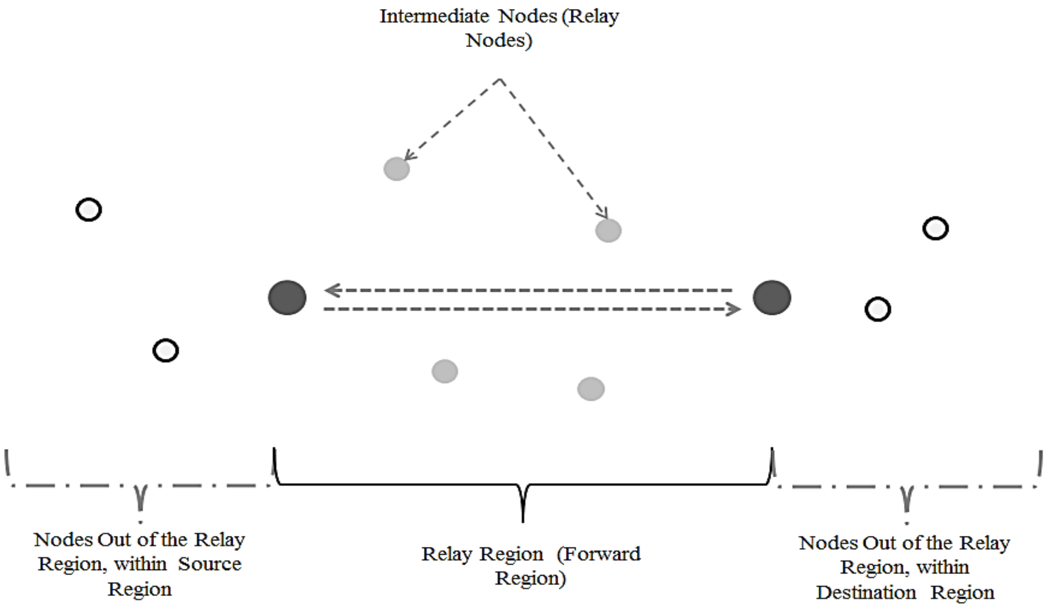


Figure 5: A scenario of communication and relay nodes location

3.2. Proposed Cooperative MAC Protocol

The function of a cooperative MAC protocol is to choice the best relays with good channel qualities. However, classical methods do not consider source to relay channel qualities. Since, if the relays decode the received frame correctly they can participate in the cooperation, otherwise they keep silent. In this section, we propose a new CMAC protocol involving IEEE802.11 distributed coordination function (DCF) with CSMA/CA - RTS/CTS [38-39]. In this Chapter, we address several potential problems associated with cooperation to obtain improved performance:

1. Relay node location or relay region (RR) selection, see Fig. 5. It is important to select relays that can do direct transmission to the destination rather than choosing relays that are two hops away from the destination. Simply, we select only relays that fall within the relay region of both the source and destination.

Selecting relays one hop from the destination can prevent extra delays caused by multiple hops (two or more), i.e., if the time required to transmits data from over single hop relay is T, then the time required to transmit the data over two hop relay is $2T$ [40].

2. Channel access schemes: In DWN, controlling access of relays if of significant importance. Two issues are important to propose a good channel access scheme: (a) The relays must be selected rapidly to prevent delay. (b) The relays with the best channel quality to the destination must access the channel first before relays of inferior quality to ensure superior performance.
3. Collision free: LDCP inherently increases the delay in the DWN; thus, we must re-design the MAC protocol to prevent collisions between relays in order to reduce the delay.

3.2.1. Relay Location Selection

To prevent relays that are two hops away from the destination to participate in the cooperation, we must select the relay region so that only nodes within the RR can participate in the cooperation. In fact, relays are positioned two hops away from destination can increase the delay. The proposed protocol is based on CSMA/CA and RTS/CTS. In this protocol, when the source has frame to transmit to the destination, if the medium is ideal for the DIFS (DCF inter-frame space) time, the source transmits Request-To-Send (RTS) packet to the destination. If the destination is not busy and receives the RTS correctly, it waits for the short inter-frame space (SIFS) time and transmits back the Clear-To-Send packet (CTS) to the source.

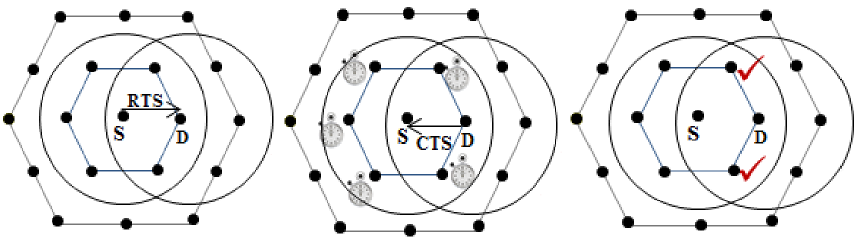


Figure 6: RR selection steps based on the RTS/CTS packets of the proposed protocol.

Then relay region is selected as follows: after destination receives the RTS packet, nodes within the source range set their timer to 2SIFS; during the 2SIFS time, the destination transmit CTS packet. The nodes within the *S* range that hear CTS can participate in cooperation otherwise nodes that do not receive a CTS packet do not participate in the cooperation. As shown in Fig. 6, only nodes within the relay region can receive RTS/CTS packets, identifying them as one hop away from the destination. It is clear that relay is done before the source transmission that we call proactive selection protocol.

3.2.2. Backoff Time Evaluation of the Best Relays

In this subsection, we investigate the best relay selection protocol based on BTF (BTF is time calculated at each relay, and when it expired, relay access the channel and retransmit what received from the source to destination) to ensure that the best relays access the channel first. The BTF is decided as follows. After successful handshaking, in which RTS/CTS packets are received correctly, the source broadcasts the first frame with coding rate R_b to all nodes within the relayed region. Only the relays that decode the received frame correctly re-encodes it with coding rate R_{mc}. After encoding operation contention is initiated. In order to ensure that only the relays with the best channel quality toward to the destination accesses the channel first, we proposed BTF that decreases according to distance and received power quality from the relays to destination. In fact, the reason behind the BTF is to 1) prevent the relays from using the RTS/CTS packets to access the channel, where the RTS/CTS packets cause extra delay and throughput reduction, 2) make a best relays access the channel first and fast. The BTF mathematically is expressed as:

$$T_k = \left(\left\lfloor RCW \left(\frac{d_{k,D}}{d_{Thr}} + \left(1 - \frac{S_{Rec,R_k}}{S_{Thr}} \right)^{-1} \right) \right\rfloor + SIFS \right) \tag{3.1}$$

where T_k is the BTF calculated in each relays inside relay region and $k = 1, 2, ..., L$, L is the number of relays, *RCW* is the relay contention window size, $d_{k,D}$ is the instantaneous normalized distance between k^{th} relay and the destination, d_{Thr} is the normalized threshold distance between the R_k and D, S_{Thre} is the threshold of the received signal power, $S_{rec,R_k} = (d_{k,D})^{-\lambda}$ is the normalized received signal power at

k^{th} relay from the destination which is characterized by large scale fading models [41]. The relays can estimate the received power and distance to destination through the received CTS packet [37].

The backoff time of the relay whose signal level is greater than a threshold and its distance to the destination is shortest one starts decreasing the first. For instance if $RCW = 10 \times (SIFS = 10\ \mu s)$, $d_{Thr} = 1$, $d_{1,D} = 0.25$, $d_{2,D} = 0.9$, $S_{Thr} = 1$ and $S_{Rec,1} = 0.0625, S_{Rec,2} = 0.81$ with $\lambda = 3$, we can calculate $T_1 = 116\ \mu s$ and $T_2 = 469\ \mu s$. Hence, the relay node with T_1 has less backoff time to access the channel compared to the relay with backoff time T_2. In fact, the BTF employs three parameters; the distances from the R_k to D indicated as $d_{k,D}$, received power from the destination at relays indicated as S_{rec,R_k} and relay contention windows indicated as RCW. The $d_{k,D}$ and S_{rec,R_k} depend on the location of the relays from the destination and on the pathloss exponents λ, respectively, however, *RCW* is modifiable. The BTF is proportional directly to the *RCW* size. Then a question arises automatically? What can be the best *RCW* size? The differences between small and large RCW can be outlined as follows:

1. Let *RCW* be equal to $100\ \mu s$ and assume that there are two relays with slight differences in distance to the destination, i.e., $d_{1,D} = 0.2$ and $d_{2,D} = 0.3$; then we can calculate $T_1 = 130\ \mu s$, and $T_2 = 142\ \mu s$; furthermore, $T_{max} = RCW \times 4.6 + (SIFS = 10) = 470\ \mu s$ and $T_{min} = RCW \times 1.2 + 10 = 130\ \mu s$. T_{max} occurs at $d_{max,D} = 0.9$ and T_{min} occurs at $d_{k,D} = 0.2$.
2. Let RCW be equal to $300\ \mu s$, and assume that the relays have equal distances to the destination, then we can calculate $T_1 = 370\ \mu s$ and $T_2 = 406\ \mu s$; and $T_{max} = RCW \times 4.6 = 1390\ \mu s$ and $T_{min} = RCW \times 1.2 = 370\ \mu s$.

Let define the time gap parameter as $\mathrm{T_g} = \mathrm{T_k} - \mathrm{T_{k+1}}$ which is nothing but the difference between two BTFs. It is clear that if $\mathrm{T_g}$ is very small which also means that RCW is small, the collision may occur if two relays have approximately same distances toward to destination (not equal) due to propagation and control packet time. And if the $\mathrm{T_g}$ is large it means that RCW is large, since T_g is proportional to RCW size the collision may not occur even when the two relays have approximately the same distances towards to destination. Where, $\mathrm{T_g}$ is proportional directly to *RCW* size, Hence, the suitable $\mathrm{T_g}$ size leads to the suitable *RCW* size. $\mathrm{T_g}$ is given as:

$$T_g = T_k - T_{k+1} \qquad for\ T_k - T_{k+1} > T_{Pro} + T_{C_P} \tag{3.2}$$

where T_k is the first expired BTF, T_{k+1} is the subsequent expired BTF, T_{Pro} is propagation delay and it is equal to, T_{C_P} which is the time due to the control packet transmission, it is explained in the next section, and it equals to $114\ \mu s$. Therefore, we should set *RCW* to a value such that the time gap given in (3.2) is available, in other words, if two relays with a slight difference in distances from the destination and we use a small *RCW*, relays will have a slight difference in their BTF; in such case collision may occur because of the propagation delay and control packet time, see Fig. 3b and Fig. 3c. However, if *RCW* is set to a large value, in this case the BTF is large, and the far relays can be selected and this makes BTF larger, in such a case unnecessary delays may happen, consequently throughput is reduced. Therefore, choosing appropriate RCW size requires a trade-off between collision occurrence and unnecessary delay.

3.2.3. Relays Contention and Re-Calculation BTF of R_{k+1}

When more than two relays participate in the cooperation, two relays may have the same backoff time, and collision may occur. Collisions cannot be prevented in the DWN, but we can ensure that collisions occur between control packet (C_P) rather than between data packets (D_P). Since retransmission of D_P requires more time than C_P and the control packet is designed with few number of bits. The time difference for the retransmission of data and the control packet is given as:

$$T_{Retransmission} = \begin{cases} Retrans.\ of\ collided\ data \approx DIFS + \dfrac{D_P\ Size}{R} + SIFS \\ Retrans.\ of\ collided\ Control\ Packet \approx \dfrac{C_P\ Size}{R} + SIFS \end{cases} \tag{3.3}$$

We can describe relay contention as follows. After successful handshaking, the source broadcasts the first frame (FF) with half-redundant bits N_b to the destination and relays. Only nodes within the relay region that decode the received FF correctly participate in cooperation and re-encode the second frame (SF) with half redundant bits N_{mc}. Before the relays start retransmitting to the destination, they calculate their BTF given in (3.1) according to the available channel parameters from the R_k to the *D*. Then according to their BTFs relays broadcast their C_P. In this case, two possible situations are considered: 1) No collision occurs among relays control packets. This means that BTF of each relay is different, i.e., $T_1 < T_2 < T_3 < T_4 .... < T_k$; or 2) Collision may occur at least between two relays, this means that BTF of these two relays expires at the same time, i.e., two relays have the same channel parameters toward to destination. The relays wait for SIFS: if the destination does reply with 1 bit digit, it means that either the best relay is already chosen, i.e., it already received the acknowledgement bit or collision did not occurred. Otherwise the collision did occurred. In fact, the collided relays are discarded from the cooperation.

18 bits	16 bits	48 bits	32 bits
BTF Duration	Packet Duration	Receiver Address	CRC

Fig. 7: Control packet (C_P) structure of the proposed protocol.

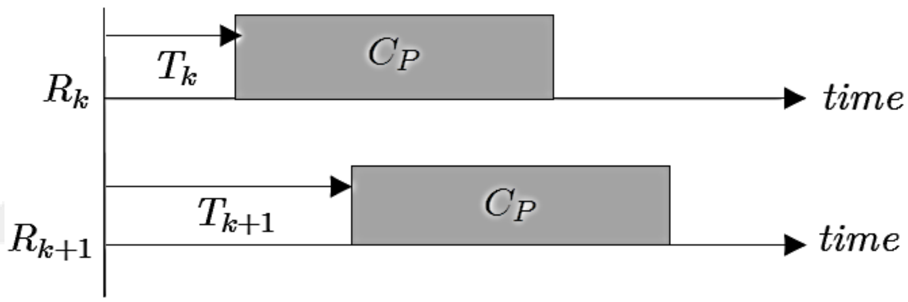


Fig. 8: Collision scenario.

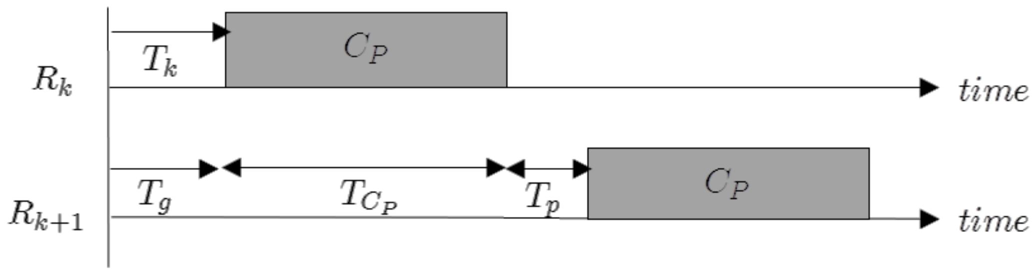


Fig. 9: Collision avoided scenario

Now let describe re-calculation BTF of R_{k+1} as follow: If the collision occurred or not, the R_{k+1} re-calculate their BTF. Where, R_{k+1} decode the received C_P, and it read the BTF duration field (see Fig. 7). Then, the relays reduce their backoff time by subtracting T_k from T_{k+1} (i.e., $T_{k+1} - T_k$). However, we must maintain the gap between the two relays (gap delay is caused by propagation and control packet send by best relay, see Fig. 9) that is given as $T_g = T_P + T_{C_P}$. Finally, the updated BTF at R_{k+1} is given as:

$$T_{k+1_{update}} = T_{k+1} - T_k + T_P + T_{C_P} \tag{3.4}$$

3.3. Cooperative Medium Access Delay

Delay is the time required for a frame to reach the destination after transmission from the source, medium access delay is the time required for successful transmission and reception after including the contention. Cooperative medium access delay is the time required for the successful transmission and reception of the transmitted frame from both source and the relays. In this Chapter, we consider two situations for delay calculation: The delay for the successful transmission of the packets through source-relays-destination path and the delay when collision occurs among control packets (we don't have collided data).

3.3.1. Collision and Collision-Free of the Proposed Protocol

First we consider collision free case. If the source has data to transmit, it senses the channel, if the channel is free, it backoff DIFS, then transmits the RTS to the destination. The destination waits for SIFS then transmit back the CTS packet; after RTS/CTS packets are correctly received, the source broadcasts the FF with half redundant bits. Hence, the total time required to access and broadcast the FF in cooperative transmission mode (CTM) by the source is given as:

$$T_b = DIFS + T_{RTS} + T_{CTS} + 2\ SIFS + T_{d_S} \tag{3.5}$$

where T_{d_S}, T_{RTS} and T_{CTS} are the time required to transmit the FF from the source to the destination, time required to transmit RTS packet from the source to the destination, and time required to transmit CTS packet from the destination to the source, respectively . After receiving the FF at relays, relays start calculating their BTF according (3.1); then, the relay BTF's expired first, it transmits the C_P; then the destination waits for SIFS, and it broadcasts back 1 bit digit as an acknowledgment of received C_P from the first relay correctly. R_1 and R_{k+1} received 1 bit digit. R_1 transmits a SF with half redundant bits to the destination. The time required for a transmission of the SF in the MAC mode is given as:

$$T_{mc,1} = T_1 + T_{C_P} + SIFS + T_{d_{mc,R_1}} \tag{3.6}$$

in which $T_{mc,1}$ is the total time required for R_1 the to access the channel and transmit the SF; T_1 is the first expired BTF given by (3.1); T_{C_P} is the time required for C_P packet to be transmit from the relay to the destination; and $T_{d_{mc,R_1}}$ is the time required to transmit SF from the R_1 to the destination. Where, the next relays have BTF greater than T_1 (i.e., $T_1 < T_2 < T_3 < T_4 \ldots\ldots\ldots\ldots < T_k$). For the next relays, we do not need C_P packet; relays only need to calculate their BTF as well as to the T_g. Therefore, the required time for the next relays is given as:

$$T_{mc,k+1} = (L-1)\,SIFS + \sum_{k=1}^{L}(T_{k+1} - T_1) + \sum_{k=1}^{L} T_{d_{mc,R_{k+1}}} + T_{C_P} + T_P + T_{ACK} \tag{3.7}$$

The second term $(T_1 - T_{k+1})$ is BTF of the next relays; we write it in such form to reduce the delay that will occur when the next relay has a BTF much larger than the first BTF, $T_{d_{mc,R_{k+1}}}$ is time required to transmit SF from R_{k+1} to the destination, and T_{ACK} is time required for the acknowledgment packet of the whole CTM. Therefore, the total time required for the transmission of the data from the source to the destination over DCCP without collision is found by adding (3.5), (3.6) and (3.7) together, and it is given as:

$$T_{tot,nc} = T_b + T_{mc,1} + T_{mc,k+1} \tag{3.8}$$

If the collision take-place, then in the BC mode it is occur between RTS/CTS packets, therefore, the time required for transmission of the FF to the destination is given as:

$$T_{b,c} = DIFS + 2T_{RTS} + 2T_{CTS} + 4SIFS + T_{d_S} \tag{3.9}$$

We assumed maximum two best relays may have collision (two BTF expired together); the collision take place between two C_P packets, therefore, the time required of transmission the SF in the MAC mode is given as:

$$T_{mc,1,c} = 2T_1 + 2T_{C_P} + 2\,SIFS + Td_{mc,R_1} \tag{3.10}$$

Then, the total time required for the transmission of the data from the source to the destination over DCCP under collision assumption is given as:

$$T_{tot,c} = T_{b,c} + T_{mc,1,c} + T_{mc,k+1}$$

(3.11)

The indexes in (3.8) and (3.11) are no collision (nc) and collision (c), respectively.

3.4. Connectivity via Cooperation Scheme

The definition of connectivity is the measure of the possibility of links between neighbouring nodes in their vicinity, in other word, it measures the ability of nodes to be connected under specific conditions. Connectivity is an important issue in DWN because it is may have isolated nodes that could lead to disconnected nodes or clusters. From a γ perspective, two nodes are connected (linked together) if the γ is greater than the threshold value; from the graph theory perspective, connectivity measures the possibility of isolated nodes (node outside their groups) or isolated clusters (isolated groups). In this paper, we consider linking probability.

3.4.1. Linking Probability

Linking probability is the probability of links between two nodes under specific conditions. The linking probability has been defined in detail in [42-43]; where the previous work considered a shadowing channel model; in this paper, the channel model is large scale fading (i.e. distance and pathloss exponent). If the signal-to-noise ratio of the DTM decreases or begins to approach the threshold value, the linking probability decreases or become zero. For a given γ_{DTM} and γ_{Thre} in dB, communication between two nodes is possible when $\gamma_{DTM} \geq \gamma_{Thre}$. In this work, we assume that $\mathrm{P}\left(\gamma_{DTM} \geq \gamma_{Thre}\right) = 1$. However, the definition of the linking probability in the CTM is indicated as the probability that γ_{CTM} of the cooperation is greater than or equal to γ_{DTM}. Therefore, the linking probability of the CTM is given as:

$$P_t\left(\gamma_{CTM} \geq \gamma_{DTM}\right) = P_t\left(\gamma_{CTM}/\gamma_{DTM} \geq 0\right) = \frac{1}{\sqrt{2\pi}\sigma}\int_0^\infty exp\left[-\frac{1}{2\sigma^2}\left(t - \frac{\gamma_{CTM}}{\gamma_{DTM}}\right)^2\right]dt$$

$$P_t\left(\gamma_{CTM} \geq \gamma_{DTM}\right) = \frac{1}{\sqrt{2\pi}\sigma}\int_0^\infty exp\left[-\frac{1}{2\sigma^2}\left(t - \frac{\gamma_{CTM}}{\gamma_{DTM}}\right)^2\right]dt,$$

(3.12)

This yields

$$P_t\left(\gamma_{CTM} \geq \gamma_{DTM}\right) = 0.5\left[1 - erf\left(\frac{\left(\gamma_{CTM} - \gamma_{DTM}\right)}{\sqrt{2}}\right)\right], \tag{3.13}$$

Then, we substitute (2.7) into (3.13), then the linking probability of CTM is given as:

$$P_t\left(\frac{\gamma_{CTM}}{\gamma_{DTM}} \geq 0\right) = 0.5\left[1 - erf\left(0.7071\left(\left(R_b\, d_b \frac{P_b}{N_o}(d_{SD})^{-\lambda}\right)\cdot \times \left(\prod_{k=1}^{L} R_{mc}\, d_{mc} \frac{P_{mc}}{N_o}(d_{R_k D})^{-\lambda}\right) - \gamma_{DTM}\right.\right.\right. \tag{3.14}$$

3.4.2. Number of Neighbor Nodes

The number of neighbour of the nodes are the number of nodes within the coverage area of a node and called the node degree (ρ). If the node does not have nodes within its coverage area, the node is isolated from the network. In this paper, we are interested in calculating the node degree of random nodes distribution over service area which is given as [42]:

$$\rho_{DTM} = \omega \int_0^{2\pi} P\left(\gamma_{DTM} > \gamma_{Thre}\right) d\theta = 2\pi\omega P\left(\gamma_{DTM} > \gamma_{Thre}\right), \tag{3.15}$$

in which ω is the node density within a whole area and $\omega = (n/A)$, where *n* is the number of nodes within the service area and *A* is the service area size (in meters). Then, the node degree due to the CTM is given as:

$$\begin{aligned}\rho_{CTM} &= 2\pi\omega\left(P\left(\gamma_{DTM} > \gamma_{Thre}\right) + P\left(\gamma_{CTM} > \gamma_{DTM}\right)\right)\\ &= 2\pi\omega\left(1 + P\left(\gamma_{CTM} > \gamma_{DTM}\right)\right)\end{aligned} \tag{3.16}$$

in which ρ_{DTM} and ρ_{CTM} are node degree of DTM and CTM, respectively. Therefore, the cooperation increases the coverage area of the source (see Fig. 10) because the cooperation increase the detection capability of destination that it come from combining multiple signals at destination through using MRC ,and this result increasing in node degree of the source.

The question need to be answer, how increasing node degree reduce the throughput, the answer come from the MAC protocol contention based opinion, where, the coverage area share single time slot and the nodes within the coverage area are assume to be circularly access the channel, therefore, the time slot (throughput) divided by number of the nodes within the coverage area, hence increases the node's degree lead to throughput reduction. It is also clear that, if $\gamma_{CTM} = \gamma_{DTM}$, then the $P(\gamma_{CTM} > \gamma_{DTM}) = 0$.

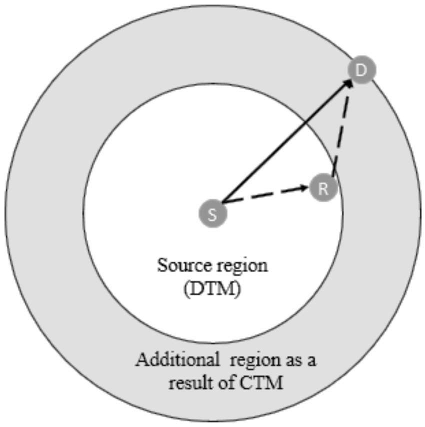


Fig. 10: The additional region as a result of CTM (extra coverage area gained for the source).

3.5. Throughput Analysis

For convenience and to facilitate comprehension, we consider a throughput analysis of the DWN based on an analytical model given in [44]. The throughput (H) is given as:

$$H = \frac{T_{DTM}\; W_{CTM}}{\rho_{CTM}\; T_{t,CTM}\; E(h)} \tag{3.17}$$

in which ρ_{CTM} is the node degree of the CTM; T_{DTM} is the time required to transmit a frame to the destination over DTM which is given in (3.5), $T_{t,CTM} = T_o + T_{CTM}$ is the total time required for transmission frame over CTM ant it is include T_{CTM} and T_o are the time required for transmission over CTM and overhead time, respectively. Where, either the T_{CTM} indicate to $T_{tot,c}$ or to $T_{tot,nc}$, W_{CTM} is the upper bound on reliable data transmission (Shannon capacity), and $E(h)$ is the expected number of hops, in this work, $E(h) = 1$. Note that the variables with index CTM is affected by the cooperation of the DCCP. Where, Shannon capacity of DCCP is given as [26]:

$$W_{CTM} = (2\,B_{DTM})\; log_2\left(R_b\, d_b \frac{P_b}{N_o}(d_{SD})^{-\lambda} + \sum_{k=1}^{L} R_{mc}\, d_{mc} \frac{P_{mc}}{N_o}(d_{R_k D})^{-\lambda}\right) \tag{3.18}$$

in which B_{DTM} is the bandwidth of DTM; generally, the coding scheme reduce the bandwidth efficiency by coding rate ratio $R_{DTM} = (N_{DTM}/k_C)$, in which N_{DTM} is the number of bits out of the encoder, and k_C is the number of inputs bits to the encoder, where $N > k_C$, and R_{DTM} is the coding rate, e.g., if the coding rate is $1/4$, then the bandwidth efficiency reduced by $1/4$; therefore, the bandwidth efficiency of CTM is double compare to DTM because the DCCP divide the redundant bit by 2 over the source and relays which result higher coding rate, $R_{CTM} = 1/2$. The bandwidth efficiency of DCCP is given as $(N/2k_C)B_{CTM} = (N/k_C)B_{DTM}$, as result, $B_{CTM} = 2B_{DTM}$. Finally, we can rewrite (24) as:

$$H = \frac{T_{DTM}\ (2\, B_{DTM})\ log_2\left(R_b\, d_b \frac{P_b}{N_o}(d_{SD})^{-\lambda} + \sum_{k=1}^{L} R_{mc}\, d_{mc} \frac{P_{mc}}{N_o}(d_{R_k D})^{-\lambda}\right)}{T_{t,CTM}\ E(h)(DIFS + T_{RTS} + T_{CTS} + 2\ SIFS + T_{d_S})^{-1}\ (2\pi\omega\,(1 + P\,(\gamma_{CTM} > \gamma_{DTM})))} \tag{3.19}$$

It is clear that, the throughput of the DTM may or may not improve because of the relays always repeating what was transmitted by the source and increasing node's degree of the source, accordingly we can draw theorem of throughput relation to delay and connectivity.

Theorem: For the proposed relays selection protocol with $L \geq 1$ and the DCCP employed for random nodes distribution over service area, the achievable throughput is given as:

$$H = O\left(\frac{\gamma(L)}{T(L)\rho_{CTM}(L)}\right) \tag{3.20}$$

Theorem is provide the throughput for CTM, it is proved that the throughput of the cooperation proportional inversely to the delay and node's degree. In which, $\gamma(L)$, $T(L)$ and $\rho_{CTM}(L)$ are the signal to noise ratio, total time to transmit data from the source to destination over DTM and node degree, respectively. Where, $O(.)$ is the big O notation.

3.6. Performance and Results

In this section, we evaluate the performance of the proposed CMAC protocol via an analytical model. The evaluation is divided into three parts; the first part considers the proposed CMAC protocol from a delay perspective; the second part considers connectivity when the DCCP is employed; and finally, the third part considers throughput performance as a function of increasing delay and connectivity. Evaluation parameters and setting given in table 1.

Fig. 11: illustrate the BTF variation with distance from the relays to the destination and different RCW size. In fact, as distance from the relays to destination increases, the BTF increase as well, that is lead to deferral the relays far away from the destination and accelerate the nearest relay to the destination to access the channel. Furthermore, we can see the BTF is less delay compared to the conventional CSMA/CA with RTS/CTS packets. Therefore, if $d_{k,D} = 0.5$, BTF uses RTS/CTS packets is $2000\,\mu s$, and *RCWs* are $300, 500$ and $750\,\mu s$, accordingly, the BTF of different *RCWs* are $500, 800,$ and $1125\,\mu s$, respectively; hence the achieved delays reduction by the our proposed protocol compared to BTF used RTS/CTS packets are 300%, 150% and 77.7%. It is clear, the delay reduction is less for larger RCW and high for smaller RCW.

Fig. 12: illustrate the SF transmission from the relays to destination using the proposed BTF, in other word, it show MAC mode transmission time. It is clear that the transmission of the SF over proposed BTF with and without collision for $L = 1$ has less delay compared to the conventional CSMA/CA with RTS/CTS packets. Furthermore, if the two relays participate in the cooperation, then we have too much delay compared to single relay participating in cooperation. In fact, at $d_{k,D} = 0.5$, the times required to transmit SF using our proposed protocol are $2.5\,ms$ and $2.7\,ms$ for $L = 1$ and $L = 1$ with collision, respectively, and the time required to transmit SF using RTS/CTS packets is $3\,ms$, as result, the achieved delays reduction using our proposed protocol are 16.66% and 11%. We conclude that, the time required to transmit SF using our proposed protocol compared to conventional RTS/CTS packets is less even when occurred.

Fig. 13: illustrate the total time required for transmission of the FF and SF over BTF using $L = 1$ and $L = 2$. Where, if the number of relays increase the delay increases as well.

Fig. 14: illustrate the incremental ratio comparison to power-to-noise ratio (P/N_o). The incremental ratio is the ratio between node's degrees of CTM to the node degree of the DTM. As shown, based on the results, the connectivity increased using different number of relays, consequently, the incremental ratio increases as well. Increasing

number of relays can increase the connectivity since signal to noise ratio increased at destination which can improve the detection capability and connectively.

Fig. 15: illustrate a comparison of the throughput of the proposed relay selection protocol, traditional CSMA/CA with RTS/CTS packets and number of relays. The important issues are apparent in figure 8:

1. If the number of the relays increase, the throughput reduces.
2. The proposed relay selection protocol can achieve better throughput compared to traditional CSMA/CA with RTS/CTS packets.
3. Increasing number of relay can reduce the throughput compared to single relay.
4. The throughput of the DTM is better at high P/N_o compared to CTM.

In fact, at $P/N_o = 15$ dB the throughput of DTM is larger compared to our proposed protocol because the delay and node degree increased. On other hand, the throughput is larger of our proposed protocol for P/N_o less than $15\,\mathrm{dB}$ compared to DTM. In addition, the throughput of CTM reduced by ratio $1/(\rho_{CTM} = 12) = 0.08$ while DTM throughput reduced by ratio $1/(\rho_{DTM} = 8) = 0.125$. The achieved throughput of our proposed protocol is 78%, for $L = 1$, $P/N_o = 15\,\mathrm{dB}$ and collision free case compared to conventional RTS/CTS packets.

Table 1: Evaluation Parameters and Settings

SIFS, DIFS, T_{CTS}, T_{ACK}, T_{RTS}	10, 50, 304, 304, 352 (μs)
RCW	300, 500, 750 (μs)
R, Transmission Rate	1 Mbps
T_o (overhead time) for IEEEb [14], T_{Pro} (propagation time)	364, 5μs
D_P Size	2000 bits
T_{C_P}	114 μs
B_{DTM}, Bandwidth	1 MHz
(P/N_o)	0 to 25 dB
d_{SD}, $d_{R_k,D}$	1, 0.2 to 0.9
λ, Path loss exponent	3
L_{min}, L_{max}	1, 3
R_{DTM}, d_{DTM} [21]	1/4, 13
R_b, d_b, R_{mc}, d_{mc}	1/2, 7, 1/2, 6
n, Number of Nodes	21
A, Service area	10000 m^2

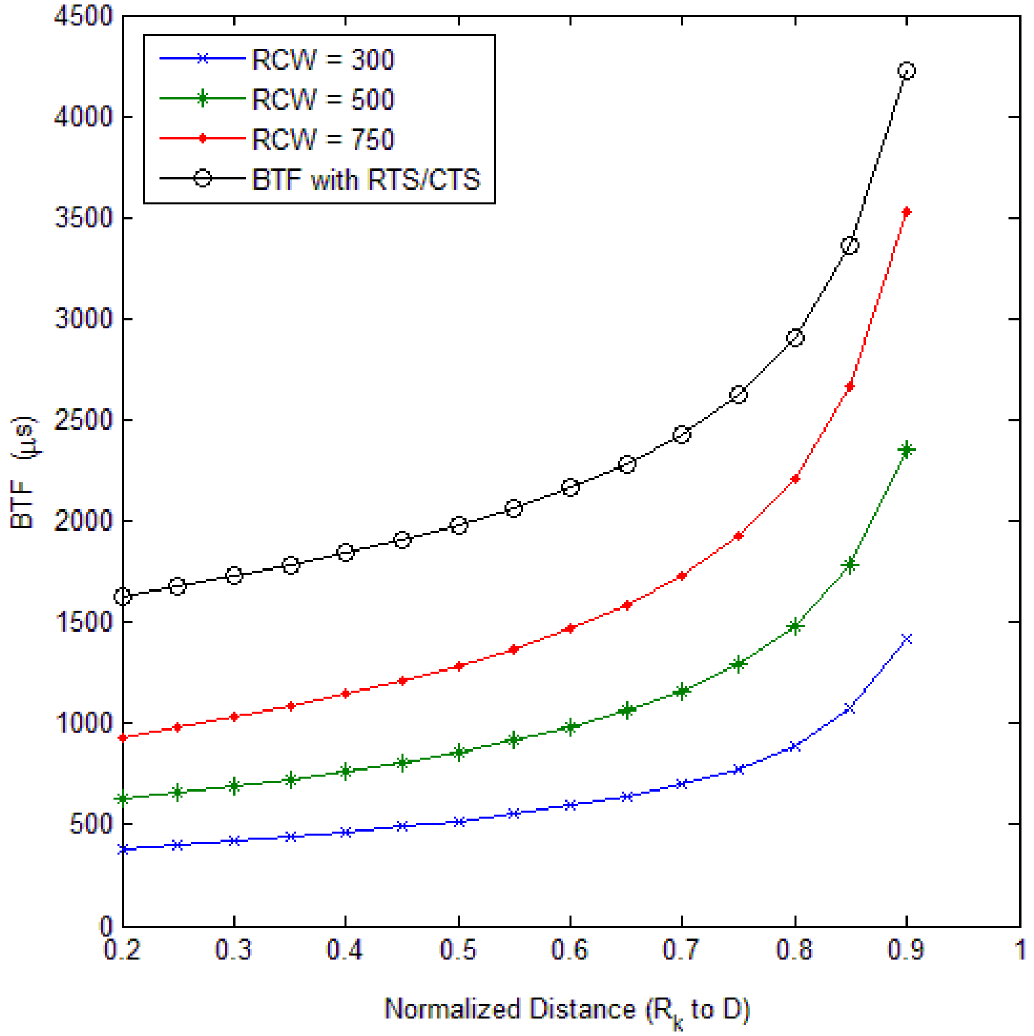
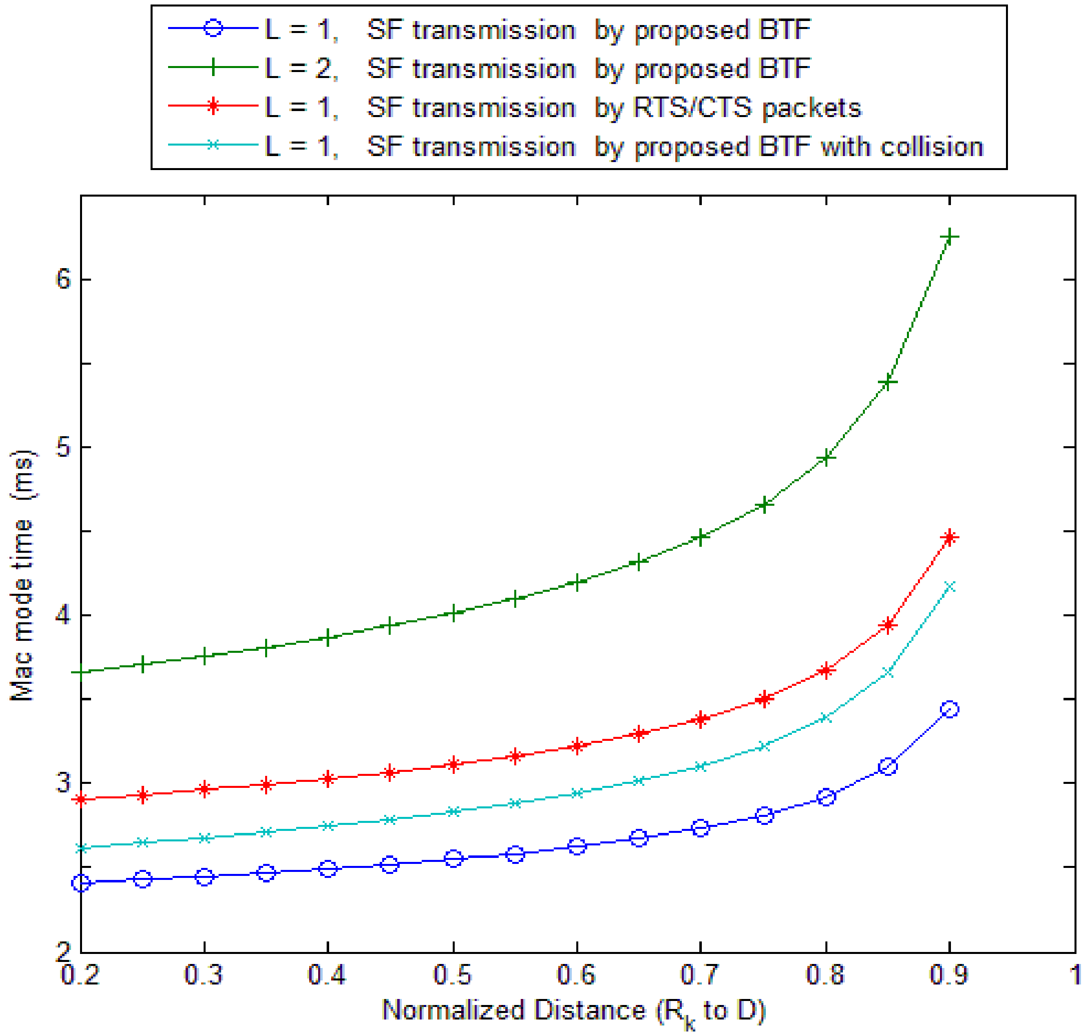


Fig. 11: Comparison of the BTF and distance from the relays to destination for L =1 relay, RCW = 300, 500, 750 μs with traditional CSMA/CA with RTS/CTS packets.



(a)

Fig. 12. Comparison of required time to transmit SF using proposed protocol.

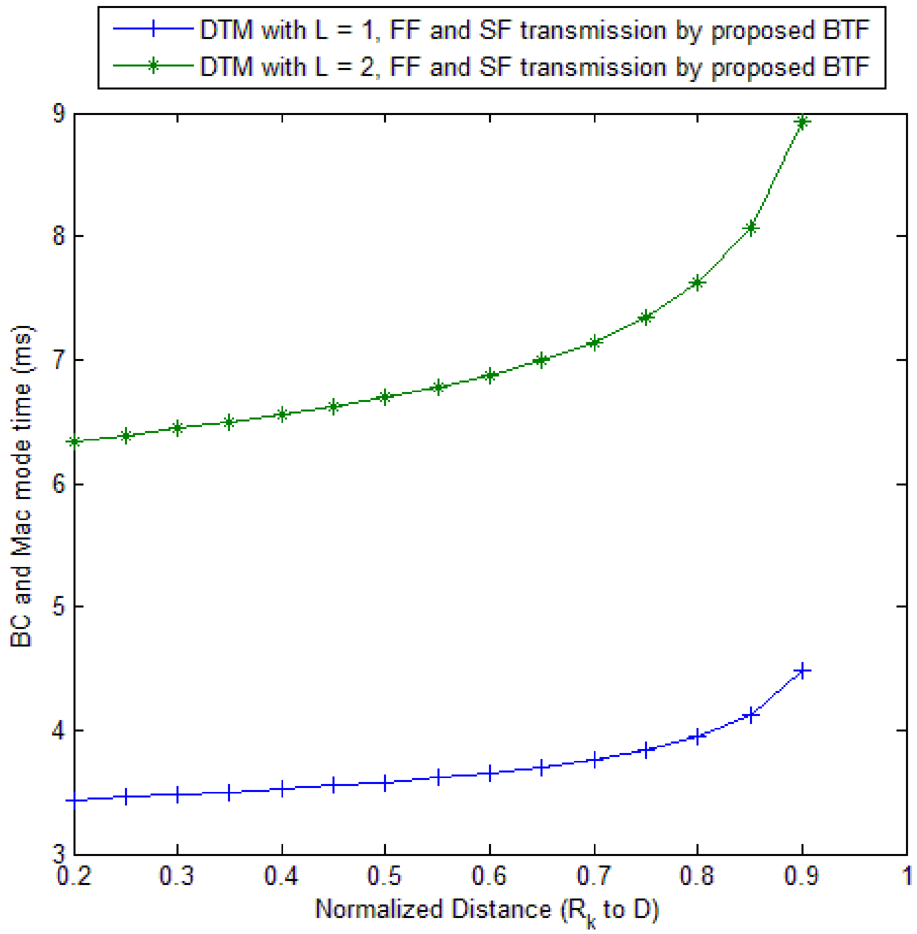


Fig. 13: Comparison of required time to transmit SF using proposed protocol and transmission over traditional CSMA/CS with RTS/CTS packets, comparison of required time to transmit FF and SF; for L =1,2 relays, RCW = 300 μs and λ = 3.

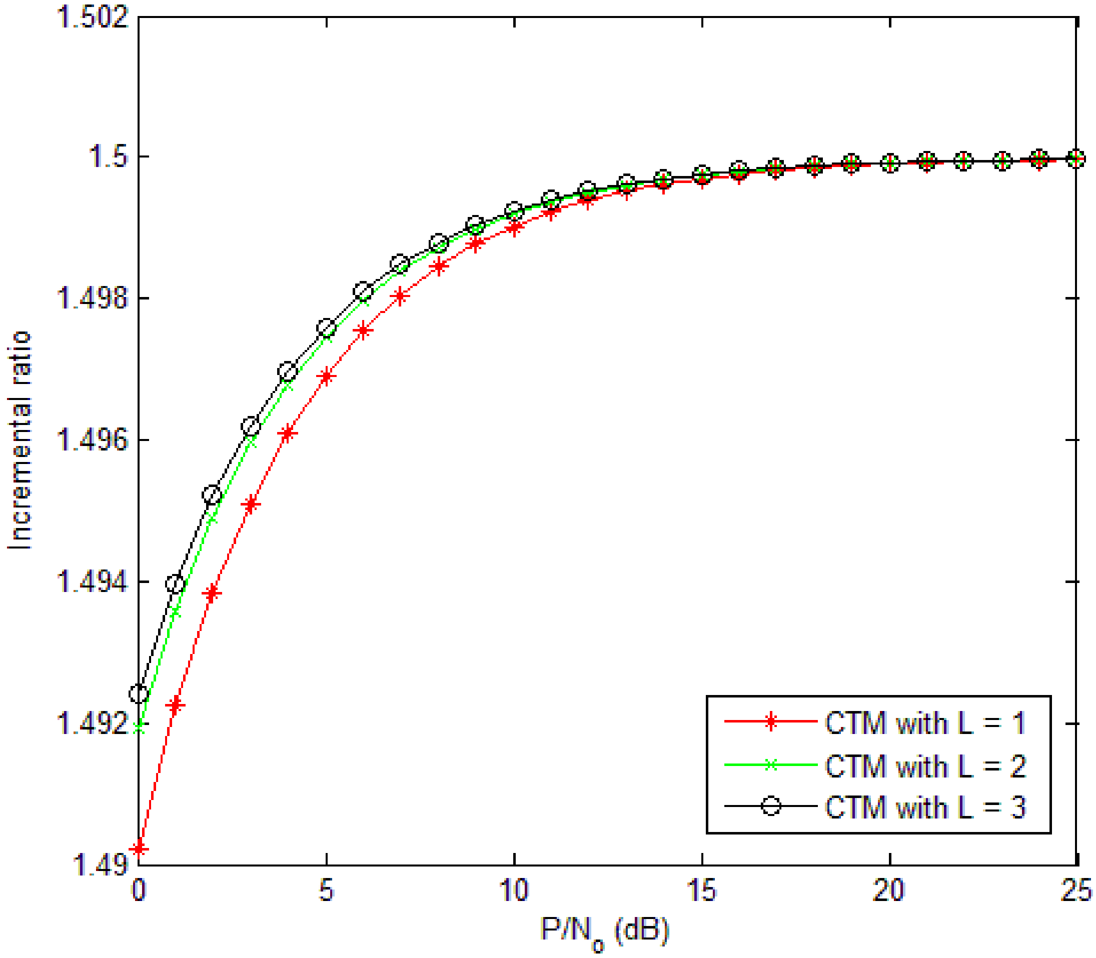


Fig. 14. Comparison of the incremental ratio with P/N_o for L =1, 2, 3 relays, λ =3, $R_{DTM} = 1/4$ and $d_{DTM} = 13$.

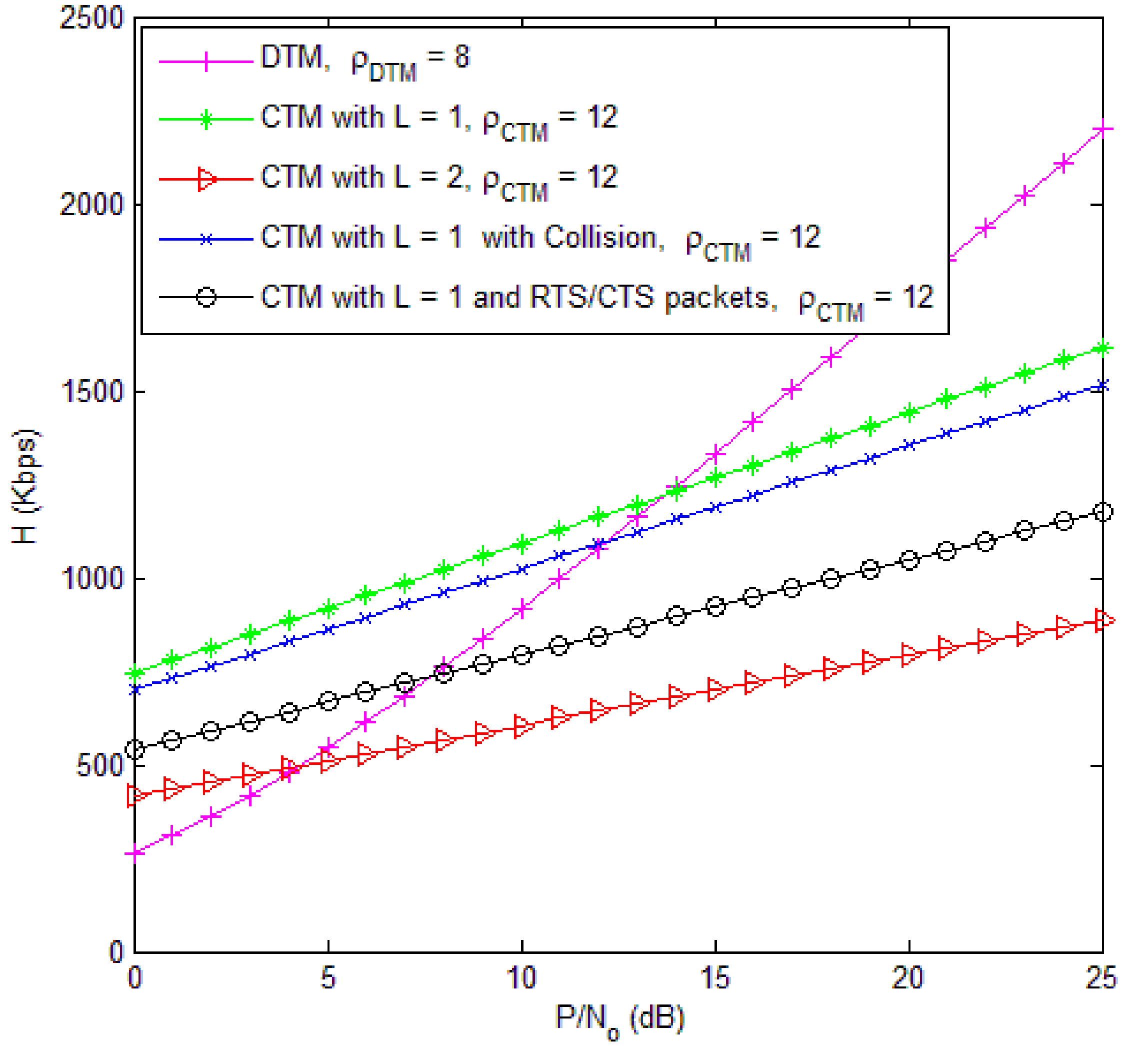


Fig. 15. Comparison of the throughput of the DTM and CTM for the L = 1, 2 relays, $\rho_{\text{DTM}} = 8, \rho_{\text{CTM}} = 12$, RCW = 300 μs, $d_{k,D} = 0.5$ and λ= 3.

CHAPTER 4

RELAY SELECTION DEPLOYMENTS: BANDWIDTH EFFICIENCY, DIVERSITY ORDER AND OUTAGE PROBABILITY IMPROVEMENT IN COOPERATIVE COMMUNICATION SYSTEM SYSTEMS

4.1. Motivation and Background

Cooperative networks (CNs), which exploit a number of intermediate nodes (see Fig. 5) for the relaying of data to the destination, show better performance in terms of bit error rate, connectivity, and robustness. The improved performance of the cooperative networks motivated researchers to focus on the problems appearing in those systems and designing more efficient cooperative systems. The fact behind the improved performance of cooperative networks lies on the achieved diversity gain which is obtained at the destination by combining different signals coming from different relays and source.

In order to achieve the diversity gain through a cooperation, the data are broadcasted by the source to the relays and destination (exploiting the broadcast nature of the wireless medium in CNs).The data received by the relays are treated in two different approaches. In the first approach the received data at the nodes are processed and re-transmitted. In the second approach the received data are directly retransmitted without any more processing. The treatment of the data at the relays may include estimation, demodulation, decoding, re-encoding, etc.

For some communication systems it may be more feasible to get the data from relays only [27], [31] and [46] since there may not be a line of sight between source and destination or the distance between source and destination can be large which results in very low-powered of the directly received signals at the destination. On the other hand, for some cases it may be advantageous to combine the signals received from relays and source directly [47], [28],[29] and [30]. Although cooperative networks have some fundamental benefits compared to non-cooperative systems, by the use of relays during communication can be increased the diversity gain, on other hand relaying the data and the signal processing at the relays produce some negative drawbacks such as reduced spectral efficiency (spatial multiplexing gain) [48], increased delay during communication and increased hardware complexity.

Since retransmission of the data from the relays to the destination reduces the spectral efficiency, researchers focused on developing some techniques to alleviate the spectral efficiency loss. The use of space time codes in a distributed manner in cooperatives systems is studied in [15-16]. Since use of space times codes require the utilization of multiple antennas, it is not practical for small devices. Relays perform full duplex communication, i.e., relays can receive and transmit simultaneously [49] Dynamic allocation of the time slots is studied in [20], some best relay selection protocols are proposed in [22] and [50], relay selection is a simple and efficient way to achieve spectral efficiency as well as diversity gain.

The best relay selection (BRS) can be divided into two categories: the reactive BRS [34] and [51-52], and proactive BRS [53-55]. In reactive BRS protocols relay selection operation is performed after source broadcasting whereas in proactive BRS protocols the selection process is completed before source broadcasting. The disadvantage of proactive BRS protocols is a low spectral efficiency, since re-transmission is performed by relay nodes even if the direct transmission between source and destination is sufficient. Hence, it is critical to design an efficient and reactive BRS protocol to achieve better spectral efficiency.

Incremental redundancy protocol for AF and DF cooperative diversity was considered in [11], where the author proposed protocol which reduces the spectral efficiency loss in wireless cooperative networks. The destination indicates success or failure by broadcasting a single bit of feedback to the source and relay. If the source-destination signal-to-noise ratio is sufficiently high, the feedback indicates success of the direct transmission, and the relay does nothing. If the source-destination signal-to-noise ratio is not sufficiently high for successful direct transmission, the feedback requests that the relay to retransmit what it received from the source.

Relay selection for DF cooperative diversity was considered in [24], the author proposed relay selection based on the maximum harmonic mean of the links between source-relay ($S-R$) and relay-destination ($R-D$). Harmonic mean mathematically can be define as $(2\sigma_{sr}\sigma_{rd}/\sigma_{sr}+\sigma_{rd})$, which σ_{sr}, σ_{rd} are variance of $S-R$ and $R-D$

links, respectively .In addition to relay selection, the author considered incremental redundancy protocol which reduce the spectral efficiency loss. The proposed protocol in [24] has the following drawbacks: 1) the harmonic mean combine the smooth of $S-R$ and $R-D$ links, which it balances the strength of two links, and it is overlooked the weak link by strength link. In other word, the harmonic mean make the randomization due to fading of $S-R$ and $R-D$ links become less noticeable because it is combine the random variable of $S-R$ and $R-D$ links in single random variable 2) The position of the relays considering source and destination points is not paid attention. This may cause the selection of some relays outside the range of either the source or the destination nodes and this may result in performance loss.

We propose a reactive relay selection protocol that choses a maximum links quality (ML) from the source (S) to relay (R) then to destination (D), namely (MLSRD), which address the above problems. The contributions of this paper are summarized as follows:

1. We propose a MLSRD selection protocol that chooses the maximum $S-R$ and $R-D$ links which increases the system performance of cooperative network in terms of spectral efficiency, and bit-error-rate performance. Where the selection protocol that bases on choosing maximum $S-R$ and $R-D$ links independently or separately make randomization due to fading of $S-R$ and $R-D$ links much noticeable, which can increase the system performance. However, The relaying decision based on the criteria of maximum $S-R$ and $R-D$, where if maximum $S-R$ and $R-D$ links less than $S-R$ link, the relay participate in communication, otherwise the relay keep silent.
2. The received data at the relays are decoded and re-encoded partially before re-transmission. The decoding and re-encoding partially is an approach of distributed cooperative code [22], in which the code distributed between the source and relays. We analyzed distributed cooperative code side by side to the relay selection which wasn't studied in the literature to the best of authors' knowledge.
3. We reveal the proposed protocol can improve spectral efficiency (SE), the probability of error ($\Pr(\mathrm{e})$) which is bit error probability, outage probability ($\Pr(\mathrm{Out})$) of cooperative networks compared to the previous works [24], [26] and to the classical cooperation mode.

In this chapter, the direct transmission mode is a non-cooperative transmission and it is indicated as (DTM), the classical cooperation mode is a cooperation without any process at relay and it is indicated as (CCM), the distributed convolutional code is a cooperation mode with process at relay (decode and re-encode at relay before retransmission) and it is indicated as (DCC), the classical cooperation mode with uses the proposed relay selection protocol is indicated as MLSRD-CCM, and the distributed convolutional code with uses the proposed relay selection protocol is indicated as MLSRD-DCC.

4.2. The Proposed Relay Selection Protocol

In this section, the MLSRD is described in detail. The DCC under consideration may be summarized as follows, the source broadcasts the data to the relays and destination with redundant bits N_b , the relays decode the received data correctly, and re-encoded with half redundant bits N_m, otherwise the relay keeps silent. In the MAC mode, the relays retransmit encoded data to the destination. Moreover, if more than one relay decodes the received data correctly, it retransmits the data to the destination. The destination combines all received signals that received from the source (BC mode signals) and the relays (MAC mode signals) via maximal ratio combining (MRC). All the relays that can participate in cooperation are assumed to be inside the forward region as shown in Fig. 1, in other word, the nodes between the source and the destination.

Technically, if the l relays participate in cooperation, then $L+1$ time slots or sub-channels required to transmit single symbol of the data from the source to the destination. Therefore, the spectral efficiency of the CCM is $(1/L+1)$, i.e., if the spectral efficiency of DTM is denoted as $\mathrm{SE_{DTM}}$, then the spectral efficiency of CCM is $\mathrm{SE_{CCM}} = (\mathrm{SE_{DTM}}/(\mathrm{L}+1))$.

The proposed MLSRD protocol is reassemble to the ARQ protocol, if the destination transmits a negative ACK to the source indicating the failure reception, the source retransmit the lost data; our case, if the direct transmission fails to deliver the data to the destination correctly, the relay retransmit what it received from the source to the destination, and destination combines the received data using MRC. The MLSRD protocol in this paper can be summarized as follow; 1) the destination admit a direct transmission data’s, if the link quality of $S-D$ greater than the links quality of $S-R$

and $R-D$, 2) the best relay do retransmission if the link quality of $S-D$less than the links quality of the $S-R$ and $R-D$. Where, the basic idea behind a selection protocol is selecting a best single relay among multiple relays to cooperate with the source to obtain superior performance.

The criteria (or event) which indicates the sufficiency of the directly received data at the destination is given as

$$\psi = I_{sd} > \lambda \; I_{max}. \tag{4.1}$$

Let $h_{i,j}$ be a common channel coefficient representing the channel between any given two nodes. $h_{i,j}$ is modeled as zero-mean complex Gaussian random variables with variance $\sigma_{i,j}$. Thus, the channel gain $|h_{i,j}|$ is modeled a Rayleigh random variable. Furthermore, the channel gain squared $|h_{i,j}|^2$ is modeled as an exponential random variable with parameter $(\sigma_{i,j}^2/d_{i,j}^{\beta})$, which the d_{sd}^{β} distance between i and j nodes, β is the attenuation factor; λ is threshold value. In what follows, $I=(|h_{sr}|^2,|h_{rd}|^2)$, which $|h_{sr}|^2$ and $|h_{rd}|^2$ are exponential random variable with parameter $(\sigma_{sr}^2/d_{sr}^{\beta})$ and $(\sigma_{rd}^2/d_{rd}^{\beta})$ respectively.

The $I_{max} = max\,\{I_1, I_2, ..., I_k\}$, $I_k = max\,((\sigma_{sr_k}^2/d_{sr_k}^{\beta}),(\sigma_{r_kd}^2/d_{r_kd}^{\beta}))$, In which $k = 1, 2, ..., L$ is the number of the relays. Based on the event given in (4.1), the proposed MLSRD protocol can be described as follows; after the source broadcasting the data to the destination and relays. In the MAC mode, the destination checks the criteria given in (4.1), and if the criteria $I_{sd} > \lambda\; I_{max}$ is satisfied the destination resolves the transmitted data and transmits positive ACK, otherwise the destination transmits negative ACK. In the latter case the best relay node re-transmits its decoded re-encoded data. The destination is assumed has knowledge of the links quality of the $S-R$ and $R-D$ of all relays that fall within the relay region.

4.2.1. Spectral Efficiency of the Proposed Relay Selection

In this section, the average spectral efficiency of the MLSRD-CCM protocol has been derived. Which shown that the spectral efficiency improved via the proposed relay selection compared to CCM. As follow, the average spectral efficiency is given as [24]

$$SE = Pr(\psi) + 0.5\; Pr(\psi_{CCM}). \tag{4.2}$$

In which ψ and ψ_{CCM} are the event of DTM and CCM, respectively, $Pr(\psi)$ is the probability of DTM, $0.5\,Pr(\psi_{CCM})$ is the probability of CCM, the 0.5 due to half duplex mode. The direct transmission occurs if the criteria in (4.1) is satisfied. The probability of direct transmission is given as

$$Pr(\psi) := Pr(I_{sd} > \lambda\, I_{max} \mid I_{sd}),$$

(4.3)

$Pr(.)$ is the conditional cumulative distribution function CDF. The unconditional cumulative distribution function is given as

$$Pr(I_{sd} > \lambda\, I_{max}) = \int_0^{\infty} Pr_{I_{max}}(I_{sd}/\lambda)\; p_{I_{sd}}(I_{sd}) dI_{sd}. \quad for\ I_{max} \geq 0$$

(4.4)

in which $p(.)$ is the probability density function. In MLSRD protocol, the best relays selection bases on the maximum links of the $S-R$ and $R-D$ which are represented as exponential random variables. Hence, the cumulative distribution functions and the probability density function of the maximum two independent exponential random variables are given as [24]

$$Pr_{I_{max}}(I) = 1 - exp\left(-(\gamma_1+\gamma_2)I\right),$$

(4.5)

$$p_{I_{max}}(I) = \frac{\partial Pr_{I_{max}}(I)}{\partial I} = (\gamma_1+\gamma_2) exp\left(-(\gamma_1+\gamma_2)I\right).$$

(4.6)

in which $\gamma_1 = (d_{sr}^{\beta}/\sigma_{sr}^2)$ for $|\ h_{sr}\ |^2$ and $\gamma_2 = (d_{rd}^{\beta}/\sigma_{rd}^2)$ for $|\ h_{rd}\ |^2$ are exponential random variables parameters .Substitute (4.5) in (4.4), we rewrite (4.4) as

$$Pr\left(\frac{I_{sd}}{\lambda} >\ I_{max}\right) = 1 - \int_0^{\infty}\ exp\left(-\frac{I_{sd}}{\lambda}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)\ (\frac{d_{sd}^{\beta}}{\sigma_{sd}^2})\, exp\left(-I_{sd}\ \frac{d_{sd}^{\beta}}{\sigma_{sd}^2}\right) dI_{sd},$$

$$Pr\left(\frac{I_{sd}}{\lambda} >\ I_{max}\right) = 1 - (\frac{d_{sd}^{\beta}}{\sigma_{sd}^2})\left(\frac{d_{sd}^{\beta}}{\sigma_{sd}^2} + \frac{1}{\lambda}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)^{-1}.$$

(4.7)

If more than single relay within relay region can participate in cooperation, i.e., $L \geq 2$, therefore, we can rewrite (4.5) as

$$Pr\left(\frac{I_{sd}}{\lambda} >\ I_k\right) = Pr\left(I_{sd} > \lambda I_1, ..., I_{sd} > \lambda I_L\right)$$

$$= \prod_{k=1}^{L} Pr\left(\tfrac{I_{sd}}{\lambda} >\ I_k\right) = \left(1 - exp\left(-(\gamma_1+\gamma_2)I\right)\right)^L$$

(4.8)

in which $(1-x)^L = 1 + \sum_{m=1}^{L} \binom{L}{m} (-1)^m \, x^L$, hence we rewrite (4.8) as

$$Pr\left(\frac{I_{sd}}{\lambda} > \, I_{max}\right) = \sum_{m=0}^{L} \binom{L}{m} (-1)^m \int_0^{\infty} \, exp\left(-\frac{mI_{sd}}{\lambda}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right) \, (\frac{d_{sd}^{\beta}}{\sigma_{sd}^2}) \times exp\left(-I_{sd} \, \frac{d_{sd}^{\beta}}{\sigma_{sd}^2}\right) dI_{sd}, \tag{4.9}$$

$$Pr\left(\frac{I_{sd}}{\lambda} > \, I_{max}\right) = 1 + \sum_{m=1}^{L} \binom{L}{m} (-1)^m (\frac{d_{sd}^{\beta}}{\sigma_{sd}^2}) \left(\frac{d_{sd}^{\beta}}{\sigma_{sd}^2} + \, \frac{m}{\lambda} \, \left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)^{-1}. \tag{4.10}$$

for $L=1$, the spectral efficiency of MLSRD-CCM is given as

$$SE_{L=1} = Pr(\psi) + 0.5 \, (1 - Pr(\psi)) = 0.5(1 + \, Pr(\psi)) \tag{4.11}$$

$$SE_{L=1} = 0.5 \left(2 - (\frac{d_{sd}^{\beta}}{\sigma_{sd}^2}) \left(\frac{d_{sd}^{\beta}}{\sigma_{sd}^2} + \, \frac{1}{\lambda} \, \left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)^{-1}\right) \tag{4.12}$$

Which is the spectral efficiency expression of MLSRD-CCM. However, if MLSRD-DCC is used, the spectral efficiency is doubled, i.e., $\mathrm{SE_{DCC}} = 2\mathrm{SE_{CCM}}$. Because the code rate is distributed over the source and relay, therefore, the spectral efficiency increased [26], [41]. According to (4.12) the spectral efficiency is low if the probability of the cooperation high, and vice versa. The probability of cooperation depends on three parameters; number of relays, $S-R$ and $R-D$ channel coefficients (the $S-D$ link is assumed to be fixed during the communication) and threshold value. The effects of parameters on cooperative systems are explained as follows. If the number of relay nodes increases the probability of cooperation increases as well. And as the number of relay nodes goes to infinity the probability of cooperation goes to "1". Since as the number of relay nodes increase, the probability that there exist a relay node satisfying criteria (4.1) increases. The second parameter is the link variations from the source to the relay and from the relay to the destination. Considering the link quality we can consider the following scenarios:

Case(1) if the $|h_{sr}|^2 >> |h_{sd}|^2$ and $|h_{rd}|^2 >> |h_{sd}|^2$, then the probability of cooperation is high.

Case(2) if the $|h_{sr}|^2 = |h_{sd}|^2$ and $|h_{rd}|^2 = |h_{sd}|^2$, then the probability of cooperation goes to zero.

Case(3) if the $|h_{sr}|^2 >> |h_{sd}|^2$ and $|h_{rd}|^2 = |h_{sd}|^2$, or $|h_{rd}|^2 >> |h_{sd}|^2$ and $|h_{sr}|^2 = |h_{sd}|^2$, then the probability of cooperation are greater than Case (2) and less than Case (1). The last parameter is the threshold value λ which is a critical value and should be determined properly for the good performance of the cooperative communication system system. The initial value threshold parameter can be chosen as $\lambda \approx I_{sd}/I_{max}$ where $I_{max} = max(I_{sr}, I_{rd})$ If the initial value is used for the threshold then the probability of cooperation depends on the channel coefficients $|h_{sr}|^2$ and $|h_{rd}|^2$ And if the threshold value satisfy $\lambda << I_{sd}/I_{max}$ then the probability of cooperation reduces even when $|h_{sr}|^2 >> |h_{sd}|^2$ and $|h_{rd}|^2 >> |h_{sd}|^2$. Furthermore if the threshold value is selected such that $\lambda >> I_{sd}/I_{max}$, the probability of cooperation increases. For the suitability, We assumed λ as function of both links $S - R$ and $R - D$, which we define it as the square root of half harmonic mean of both links and it is given as: $\lambda(\sigma_{sr}^2, \sigma_{rd}^2) = \sqrt{(\sigma_{sr}^2 \sigma_{rd}^2)/(\sigma_{sr}^2 + \sigma_{rd}^2)}$.

4.2.2. Achievable Diversity Order

In this section, it is shown the MLSRD-DCC protocol has diversity order is 2, in which single relay has been chosen within relay region. The derivation of the achievable diversity order is in the sense of pairwise error probability (PEP) since the cooperative networks work on DCC. The relationship between bit error rate (BER) and pairwise error probability (PEP) is given as [26] and [41]

$$Pr(e) \leq \frac{C(d)\ d_f\ P(d)}{k_c\, log_2 M} \tag{4.13}$$

in which M, k_c, d_f, $c(d)$ and $P(d)$ are modulation order, number of information bits before encoding, free hamming distance of the code, sum of bits error of error events and pairwise error probability of coded system, respectively. The parameters of M, k_c, d_f, $c(d)$ are contributing nothing in our analysis, therefore we assume $P(d) \geq Pr(e)$. General definition of the error probability between two nodes given as [56]

$$Pr(e) = Q(\sqrt{k_{psk} A_b P_b\, |h_{i,j}|^2}) \leq \frac{1}{\pi} \int_0^{\frac{(M-1)\pi}{M}} exp\left(-\frac{k_{psk} A_b P_b\, |h_{i,j}|^2}{sin^2(\theta)}\right) d\theta \tag{4.14}$$

In which the k_{psk} is $(sin(\pi/M))/N_o$. The expression of error probability of a DCC consists of two parts; 1) the source broadcasts the data to the destination and relays, but relay does not forward to destination the data that received from the source since the destination send positive ACK to relay, 2) the destination receives the data from source and relays since it send negative ACK to relay. Therefore, considering these cases, the error probability of DCC is given as [26]

$$Pr(e)_{DCC} = \underbrace{Q(\sqrt{k_{psk}\ A_b P_b\ \ |h_{sd}|^2}) \times \prod_{k=1}^{L} Q(\sqrt{k_{psk}\ A_b P_b\ \ |h_{sr_k}|^2})}_{\text{DTM,Term}_{(1)}}$$
$$\underbrace{+\ Q(\sqrt{k_{psk}\ A_b P_b\ \ |h_{sd}|^2 + k_{psk}\ A_m P_m\ \ |h_{r_k d}|^2}) \times \prod_{k=1}^{L}(1 - Q(\sqrt{k_{psk}\ A_b P_b\ \ |h_{sr_k}|^2})}_{\text{DCC,Term}_{(2)}} \tag{4.15}$$

in which, $(1 - Q(\sqrt{k_{psk}\ A_b P_b\ \ |h_{sr_k}|^2})$ is error-free of $S - R$ link. The probability of error of DCC can be upper bounded by removing the negative term and setting $L = 1$, we rewrite (4.15) as [26]

$$Pr(e)_{DCC} = \underbrace{\frac{1}{\pi^2}\int_0^{\frac{(M-1)\pi}{M}} exp\left(-\frac{k_{psk}\ A_b P_b\ \ |h_{sd}|^2}{sin^2\theta}\right)\int_0^{\frac{(M-1)\pi}{M}} exp\left(-\frac{k_{psk}\ A_b P_b\ \ |h_{sr}|^2}{sin^2\theta}\right) d\theta\, d\theta}_{\text{DTM,Term}_{(1)}}$$
$$\underbrace{+\ \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} exp\left(-\left(\frac{k_{psk}\ A_b P_b\ \ |h_{sd}|^2}{sin^2\theta} + \frac{k_{psk}\ A_m P_m\ \ |h_{rd}|^2}{sin^2\theta}\right)\right) d\theta}_{\text{DCC,Term}_{(2)}} \tag{4.16}$$

The error probability of MLSRD-DCC protocol is given as

$$\begin{aligned} Pr(e) &= Pr(e \cap \psi) \cup Pr(e \cap \psi_{DCC}) \\ &= \Pr(e|\ \psi)_{\text{Term(1)}}\ Pr(\psi) + Pr(e \mid \psi_{DCC})_{\text{Term(2)}}\ Pr(\psi_{DCC}) \end{aligned} \tag{4.17}$$

<u>The first term of (4.17)</u> is given as

$$Pr(e \mid \psi)_{\text{Term(1)}}\ Pr(\psi) = \int_0^{\infty} Pr(e \mid \psi)\ \ Pr(\psi \mid I_{sd}/\lambda)\ p_{I_{sd}}(I_{sd})\, dI_{sd}\, dI_{sr} \tag{4.18}$$

The $Pr(e \mid \psi)$ is given in (4.16) as DTM-Term(1), $Pr(\psi \mid I_{sd}/\lambda) = (1 - exp\,(-(\gamma_1 + \gamma_2) I_{sd}/\lambda))$ and $p_{I_{sd}}(I_{sd}) = (1/\sigma_{sd}) exp(-I_{sd}/\sigma_{sd})$, we rewrite (4.18) as

$$Pr(e \mid \psi)_{\text{Term(1)}}\ Pr(\psi) =$$
$$\frac{1}{\sigma_{sd}^2\,\pi^2}\int_0^{\infty}\int_0^{\frac{(M-1)\pi}{M}}\int_0^{\frac{(M-1)\pi}{M}} exp\left(-\frac{2\,k_{psk}\ A_b P_b\ I_{sd}}{sin^2\theta}\right) exp\left(\frac{-I_{sd}\, d_{sd}^{\beta}}{\sigma_{sd}^2}\right)$$

$$\times\, exp\left(-k_{psk}\ A_b P_b\ I_{sr}\right)\left(1-exp\left(-\frac{I_{sd}}{\lambda}(\gamma_1+\gamma_2)\right)\right)\ d\theta\ d\theta\, dI_{sd}\, dI_{sr} \quad (4.19)$$

Then (4.19) can be upper bounded by setting $\sin^2\theta = 1$, and $\int_0^{\frac{(M-1)\pi}{M}}\int_0^{\frac{(M-1)\pi}{M}} d\theta d\theta = \left(\frac{(M-1)}{M}\right)^2$[58], [59], then we rewrite (4.19) as

$$Pr(e \mid \psi)_{\text{Term(1)}}\ Pr(\psi) \leq$$

$$\frac{\bar{m}}{\sigma_{sd}^2}\int_0^{\infty} exp\left(-\, k_{psk}\ A_b P_b\ I_{sd}\ -\ \frac{I_{sd}\, d_{sd}^{\beta}}{\sigma_{sd}^2}\right) exp\left(-\, k_{psk}\ A_b P_b\ I_{sr}\right)$$

$$\times\left(1-exp\left(-\frac{I_{sd}}{\lambda}(\gamma_1+\gamma_2)\right)\right) dI_{sd}\, dI_{sr} \quad (4.20)$$

Solving the integration of (4.20) with respect to I_{sd}, I_{sr} and substitute γ_1 and γ_2; further, SDL is assumed to be fixed during the cooperation, as follow we set $\sigma_{sd}^2 = 1$ and $d_{sd}^{\beta} = 1$. We rewrite (4.20) as

$$Pr(e \mid \psi)\ Pr(\psi))_{\text{Term(1)}} \leq$$

$$\frac{\bar{m}}{(\,k_{psk}\ A_b P_b + 1)}\left(k_{psk}\ A_b P_b\ \frac{\sigma_{sr}^2}{d_{sr}^{\beta}}\right)^{-1} - \bar{m}\left(1+\ k_{psk}\ A_b P_b + \frac{1}{\lambda}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2}+\frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)^{-1}$$

(4.21)

in which $\bar{m}$ is $(\mathrm{M}/(\mathrm{M}-1))^2$.

The second term of (4.17) is given as

$$Pr(e \mid \psi_{DCC})_{\text{Term(2)}}\ Pr(\psi_{DCC}) = \int_{\bar{I}} Pr(e \mid \psi_{DCC})\ \ Pr(\psi_{DCC} \mid \bar{I})\ p_{\bar{I}}(\bar{I})\ \ d\bar{I}$$

(4.22)

in which $\bar{I} := [I_{sd}, I_{sr}, I_{rd}]$. $Pr(\psi_{coop} \mid \bar{I})$ is the probability of the MLSRD-DCC protocol and it is given as

$$Pr(\psi_{DCC} \mid I_{sd}, I_{sr}, I_{rd}) = Pr(I_{sd} < \lambda I_{max} \mid \bar{I}) = 1 - exp\left(-\left(\frac{k_{psk} A_b\, P_b}{sin^2\theta}+\frac{d_{sd}^{\beta}}{\sigma_{sd}^2}\right)\lambda I_{max}\right)$$

(4.23)

$Pr(e \mid \psi_{DCC})$ is given in (4.16) as DDC-Term(2), $p_{\bar{I}}(\bar{I}) = p(I_{sd})\ p(I_{sr})\ p(I_{rd})$; we rewrite (4.22) as

$$Pr(e \mid \psi_{DCC}))_{Term(2)} Pr(\psi_{DCC} \leq$$

$$\times\frac{1}{\pi}\int_{\bar{I}}\int_0^{\frac{(M-1)\pi}{M}} exp\left(\frac{-k_{psk}\ A_b P_b\ I_{sd}\ -\ k_{psk}\ A_m P_m\ I_{rd}}{sin^2\theta}\right)$$

$$\times\ \left(1-exp\left(-\left(\frac{k_{psk}\, A_b\, P_b}{sin^2\theta}+\frac{d_{sd}^{\beta}}{\sigma_{sd}}\right)\lambda I_{max}\right)\right)$$

$$\times\ p_{I_{sd}}(I_{sd})\ p_{I_{sr}}(I_{sr})\ p_{I_{rd}}(I_{rd})\ \ d\theta\ dI_{sd}\, dI_{sr}\, dI_{rd} \tag{4.24}$$

Evaluate the integration with respect to I_{sd} and we take into account the upper bound assumption that is made on (4.20), we rewrite (4.24) as

$$Pr(e \mid \psi_{DCC})_{Term(2)} Pr(\psi_{DCC}) \le \ddot{m} \int_{\bar{I}} (k_{psk}\ A_b P_b\ )^{-1} exp\,(-k_{psk}\ A_m P_m\ I_{rd})$$
$$(1 - exp\,(-\,(k_{psk}\, A_b\, P_b + 1)\,\lambda I_{max}))\ \ p_{I_{sr}}(I_{sr})\ p_{I_{rd}}(I_{rd})\, dI_{sr}\, dI_{rd} \tag{4.25}$$

in which $\ddot{m}$ is $\mathrm{M}/(\mathrm{M}-1)$; taking into account worst case state by substituting $I_{sr} = \kappa I_{max}$ and $I_{rd} = \kappa I_{max}$, where $0 < \kappa < 1$,i.e., $Pr(e)_{\kappa=0.1} >$ $Pr(e)_{\kappa=0.2} > .... > Pr(e)_{\kappa=0.9} > Pr(e)_{\kappa=1}$, then we rewrite (4.25) as

$$Pr(e \mid \psi_{DCC})_{\mathrm{Term(2)}} Pr(\psi_{DCC}) \le$$
$$\ddot{m}\,(k_{psk}\ A_b P_b\ +1)^{-1} \int_{I_{max}} exp\,(-k_{psk}\ A_m P_m\ \kappa I_{max})\, p(I_{max})\, dI_{max}$$
$$-\ddot{m}\,(k_{psk}\ A_b P_b\ +1)^{-1} \int_{I_{max}} exp\,(-\,(k_{psk}\ A_m P_m\, \kappa + \lambda k_{psk}\, A_b\, P_b + \lambda)\, I_{max})\ dI_{max} \tag{4.26}$$

Given a moment generating function of I_{max} , $M_{I_{max}}(.)$ [57], we can rewrite (4.26) as

$$Pr(e \mid \psi_{DCC}) Pr(\psi_{DCC})_{Term(2)} \le \ddot{m}\,(k_{psk}\ A_b P_b + 1)^{-1}$$
$$[M_{I_{max}}\,(k_{psk}\ A_m P_m\ \kappa) - M_{I_{max}}\,((k_{psk}\ A_m P_m\ + \lambda k_{psk}\, A_b\, P_b + \lambda))] \tag{4.27}$$

The I_{max} is constitute two random variables are I_{sr} and I_{rd}, and the moment generating function of two independent random variables is given as: $M_{x,y}(s,t) = M_x(s) M_y(t)$, then we rewrite (4.27) as

$$Pr(e \mid \psi_{DCC}) Pr(\psi_{DCC})_{Term(2)} \le \ddot{m}\,(k_{psk}\ A_b P_b\ + 1)^{-1}$$
$$\omega_\sigma \left[\left(\frac{d_{sr}^{\beta}}{\sigma_{sr^2}} + F(P_b) \right)^{-1} \left(\frac{d_{rd}^{\beta}}{\sigma_{rd^2}} + F(P_b) \right)^{-1} - \left(\frac{d_{rd}^{\beta}}{\sigma_{rd^2}} + F(P_b, P_m) \right)^{-1} \left(\frac{d_{sr}^{\beta}}{\sigma_{sr^2}} + F(P_b, P_m) \right)^{-1} \right] \tag{4.28}$$

in which $\omega_\sigma = \left((d_{sr}^{\beta} \sigma_{rd}^2 + d_{sr}^{\beta} \sigma_{rd}^2) / \left(\sigma_{rd}^2 \times \sigma_{rd}^2 \right) \right)$, $F(P_m) = k_{psk}\ A_m P_m\ \kappa$ and $F(P_b, P_m) = (k_{psk}\ A_m P_m\, \kappa + \lambda k_{psk}\, A_b\, P_b + \lambda)$. Finally, total error probability of MLSRD-DCC is obtained by adding the (4.21) and (4.28), it is given as

$$Pr(e) \le \ddot{m}\,(k_{psk}\ A_b P_b + 1)^{-1}$$

$$\times\left(\ddot{m}\left(k_{psk}\ A_bP_b\ \frac{\sigma_{sr}^2}{d_{sr}^{\beta}}\right)^{-1} - \ddot{m}\left(1 + k_{psk}\ A_bP_b + \frac{1}{\lambda}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)^{-1} + \omega_{\sigma}\left[\left(\frac{d_{sr}^{\beta}}{\sigma_{sr^2}} + F(P_b)\right)^{-1}\left(\frac{d_{rd}^{\beta}}{\sigma_{rd^2}} + F(P_b)\right)^{-1} - \left(\frac{d_{rd}^{\beta}}{\sigma_{rd^2}} + F(P_b, P_m)\right)^{-1}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr^2}} + F(P_b, P_m)\right)^{-1}\right]\right) \quad (4.29)$$

The definition of diversity is mean transmitting the symbol over two or more independent paths to the destination; and the definition of diversity gain (diversity order) is said as the power-to-noise ratio exponent of the error probability, i.e., $P(e) = (PNR)^L$ L is independent paths, the diversity order is given as [48]

$$d = -\lim_{(P/N_o)\to\infty} \frac{log(Pr(e))}{log(P/N_o)} \quad (4.30)$$

To obtain the diversity order, we rewrite the probability error as function of signal-to-noise ratio, we can rewrite (4.30) as

$$d \approx -\lim_{P/N_o\to\infty} \frac{log((k_{psk}\ A_bP_b + 1)^{-1})}{log(P/N_o)} - \lim_{(P/N_o)\to\infty} log\left[\ddot{m}\left(k_{psk}\ A_bP_b\ \frac{\sigma_{sr}^2}{d_{sr}^{\beta}}\right)^{-1} - \ddot{m}\left(1 + k_{psk}\ A_bP_b + \frac{1}{\lambda}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr}^2} + \frac{d_{rd}^{\beta}}{\sigma_{rd}^2}\right)\right)^{-1} + \omega_{\sigma}\left[\left(\frac{d_{sr}^{\beta}}{\sigma_{sr^2}} + F(P_b)\right)^{-1}\left(\frac{d_{rd}^{\beta}}{\sigma_{rd^2}} + F(P_b)\right)^{-1} - \left(\frac{d_{rd}^{\beta}}{\sigma_{rd^2}} + F(P_b, P_m)\right)^{-1}\left(\frac{d_{sr}^{\beta}}{\sigma_{sr^2}} + F(P_b, P_m)\right)^{-1}\right]\right] / log(P/N_o) \quad (4.31)$$

It is clear that, the proposed MLSRD-DCC protocol has diversity order 2.

4.2.3. The Outage Probability Behavior

The outage probability $Pr(out)$ is another standard for system performance evaluation; it measures the probability of an event to be less than the threshold value. In this section, we consider the probability of a given transmission rate $C(\frac{A_bP_b}{N_o}) = (1/2)\, log_2(1 + |h_{sd}|^2\ \frac{A_bP_b}{N_o})$ to be less than the threshold value R, it is given as [11]:

$$Pr((\frac{1}{2}\,log_2(1+|h_{sd}|^2\,\frac{A_bP_b}{N_od_{sd}^{\beta}})<R)=Pr(|h_{sd}|^2<(2^{2R}-1)\,\frac{N_od_{sd}^{\beta}}{A_bP_b})$$

$$=1-exp\left(-\frac{2^{2R}-1}{\sigma_{sd}^2}\frac{N_od_{sd}^{\beta}}{A_bP_b}\right) \tag{4.32}$$

The outage probability once the DCC employed is decomposed into two parts; 1) the relay does not decode what was transmitted by the source with a probability of 0.5, and the destination receives the source data only, 2) the relay decode what was transmitted by the source with a probability of 0.5, and the destination receives the data from the source and relay. As follow, the outage probability is given as [37]

$$Pr(out)\leq\;0.5\,Pr(out_{sd})\,Pr(out_{sr})\;+0.5\,Pr(out_{sd})\,Pr(out_{rd}) \tag{4.33}$$

in which, the complement of $Pr(out_{sd})\,,Pr(out_{sr})$ and $Pr(out_{rd})$ of DCC are given as

$$\overline{P(out_{sd})}=exp\left(-\frac{2^{2R}-1}{\sigma_{sd}^2}\frac{N_od_{sd}^{\beta}}{A_bP_b}\right),$$
$$\overline{P(out_{sr})}=exp\left(-\frac{2^{2R}-1}{\sigma_{sr}^2}\frac{N_od_{sr}^{\beta}}{A_bP_b}\right),$$
$$\overline{P(out_{rd})}=exp\left(-\frac{2^{2R}-1}{\sigma_{rd}^2}\frac{N_od_{rd}^{\beta}}{A_mP_m}\right) \tag{4.34}$$

Further, the outage probability once the MLSRD-DCC protocol employed, it is given as

$$Pr(out)\leq 0.5\,P(out_{sd,sr}\mid\psi)P(\psi)\;+0.5\,P(out_{sd,rd}\mid\psi_{DCC})P(\psi_{DCC}) \tag{4.35}$$

in which, $P(out_{sd,sr}\mid\psi)P(\psi)$ is the outage probability of DTM and $P(out_{sd,rd}\mid\psi_{DCC})P(\psi_{DCC})$ is the outage probability of DCC. For simplicity, we have taken a complement of $Pr(out)$, therefore we rewrite (4.35) as

$$\overline{Pr(out)}=\overline{P(out_{sd,sr}\mid\psi)}P(\psi)\;+\;\overline{P(out_{sd,rd}\mid\psi_{DCC})}P(\psi_{DCC}) \tag{4.36}$$

the unconditional $\overline{P(out_{sd,sr}\mid\psi)}P(\psi)$ is given as

$$\overline{P(out_{sd,sr}\mid\psi)}P(\psi)=\int_0^{\infty}\int_0^{\infty}\overline{P(out_{sd})}\;\overline{P(out_{sr})}P(I_{sd}>\lambda I_{max})p(I_{sd})p(I_{sr})dI_{sd}dI_{sr} \tag{4.38}$$

Further, the unconditional $\overline{P(out_{sd,rd} \mid \psi_{DCC})}P(\psi_{DCC})$ is given as

$$\overline{P(out_{sd,rd} \mid \psi_{DCC})}P(\psi_{DCC}) = \int_0^\infty \int_0^\infty \overline{P(out_{sd})}\ \overline{P(out_{rd})} P(I_{sd} < \lambda I_{max}) p(I_{sd}) p(I_{rd}) dI_{sd} dI_{rd} \tag{4.39}$$

The integration with respect to I_{sd} in the above expression is given as

$$\int_0^\infty exp\left(\frac{2^{2R}-1}{\sigma_{sd}^2}\frac{N_o}{A_b P_b}\right)\ p(I_{sd})\ dI_{sd} = exp\left(\frac{2^{2R}-1}{\sigma_{sd}^2}\frac{N_o d_{sd}^\beta}{A_b P_b}\right) \tag{4.40}$$

Hence (4.38) and (4.39) are given as

$$\overline{P(out_{sd,sr} \mid \psi)}P(\psi) = exp\left(\frac{2^{2R}-1}{\sigma_{sd}^2}\frac{N_o d_{sd}^\beta}{A_b P_b}\right) \int_0^\infty \overline{P(out_{sr})} P(I_{sd} > \lambda I_{max}) p(I_{sr}) dI_{sr} \tag{4.41}$$

Further,

$$\overline{P(out_{sd,rd} \mid \psi_{DCC})}P(\psi_{DCC}) = exp\left(\frac{2^{2R}-1}{\sigma_{sd}^2}\frac{N_o d_{sd}^\beta}{A_b P_b}\right) \int_0^\infty \overline{P(out_{rd})} P(I_{sd} < \lambda I_{max}) p(I_{rd}) dI_{rd} \tag{4.42}$$

As follow the $P(\psi)$ and $P(\psi_{DCC}) = 1 - P(\psi)$ are given as

$$P(\psi) = P(I_{max} < \lambda I_{sd}) = 1 - exp\left(-\left(\frac{d_{sr}^\beta}{\sigma_{sr}^2} + \frac{d_{rd}^\beta}{\sigma_{rd}^2}\right)\lambda I_{max}\right) \tag{4.43}$$

$$P(\psi_{DCC}) = P(I_{max} > \lambda I_{sd}) = exp\left(-\left(\frac{d_{sr}^\beta}{\sigma_{sr}^2} + \frac{d_{rd}^\beta}{\sigma_{rd}^2}\right)\lambda I_{max}\right) \tag{4.44}$$

Substituting (4.43) in (4.41), we rewrite (4.41) as

$$\overline{P(out_{sd,sr} \mid \psi)}P(\psi) = exp\left(\left(\frac{d_{sr}^\beta}{\sigma_{sr}^2} + \frac{d_{sd}^\beta}{\sigma_{sd}^2}\right)\frac{(2^{2R}-1)N_o}{A_b P_b}\right) \int_0^\infty \left(1 - exp\left(-\omega_\sigma \lambda I_{max}\right)\right) p(I_{sr}) dI_{sr} \tag{4.45}$$

Further, Substituting (4.44) in (4.42), we rewrite (48) as

$$\overline{P(out_{sd,rd} \mid \psi_{DCC})}P(\psi_{DCC}) =$$

$$exp\left(N_o(2^{2R}-1)\left(\frac{d_{sd}^{\beta}}{\sigma_{sd}^2 A_b P_b}+\frac{d_{rd}^{\beta}}{\sigma_{rd}^2 A_m P_m}\right)\right)\int_0^{\infty} exp\left(-\omega_\sigma \lambda I_{max}\right)p(I_{rd})dI_{rd}$$

(4.46)

Finally, evaluating the integration of (4.45) and (4.46), we rewrite (4.45) and (4.46) respectively as

$$\overline{P(out_{sd,sr}\mid\psi)}P(\psi)\leq\frac{1}{\kappa}\left(1-\left(\frac{\kappa\sigma_{sr}^2}{\omega_\sigma\lambda\sigma_{sr}^2+d_{sr}^{\beta}}\right)\right)exp\left(\left(\frac{d_{sd}^{\beta}}{\sigma_{sd}^2}+\frac{d_{sd}^{\beta}}{\sigma_{sr}^2}\right)\frac{(2^{2R}-1)N_o}{A_b P_b}\right)$$

(4.47)

$$\overline{P(out_{sd,rd}\mid\psi_{DCC})}P(\psi_{DCC})\leq$$
$$\frac{1}{\kappa}\left(\frac{\kappa\sigma_{rd}^2}{\omega_\sigma\lambda\sigma_{rd}^2+d_{rd}^{\beta}}\right)exp\left(N_o(2^{2R}-1)\left(\frac{1}{\sigma_{sd}^2 A_b P_b}+\frac{1}{\sigma_{rd}^2 A_m P_m}\right)\right) \quad (4.48)$$

The outage probability can be obtained by adding (4.47) and (4.48) as

$$Pr(out)=\frac{\left(1-\left(\frac{\kappa\sigma_{sr}^2}{\omega_\sigma\lambda\sigma_{sr}^2+d_{sr}^{\beta}}\right)\right)}{\kappa\left(1-exp\left(\frac{(2^{2R}-1)N_o d_{sr}^{\beta}}{\sigma_{sr}^2 A_b P_b}\right)\right)\left(1-exp\left(\frac{(2^{2R}-1)N_o d_{sd}^{\beta}}{\sigma_{sd}^2 A_b P_b}\right)\right)}$$
$$+\frac{\left(\frac{\kappa\sigma_{rd}^2}{\omega_\sigma\lambda\sigma_{rd}^2+d_{rd}^{\beta}}\right)}{\kappa\left(1-exp\left(\left(\frac{N_o(2^{2R}-1)}{\sigma_{sd}^2 A_b P_b}+\frac{N_o(2^{2R}-1)}{\sigma_{rd}^2 A_m P_m}\right)\right)\right)} \quad (4.49)$$

4.3. Performance and Results

In this section, the performance of the MLSRD protocol that is presented in the previous sections is evaluated by the terms of spectral efficiency, bit error rate and outage probability. The evaluation separated into two main parts 1) the performance of the MLSRD-CCM are given in Fig.16, Fig. 17, and MLSRD-DCC Fig.18, Fig. 19 ,respectively, and 2) the performance of the MLSRD-CCM and MLSRD-DCC compared to the previous work of [21] and [22], which are given in table 3. In what follow, The evaluation parameters of this chapter have been summarized in table 2.

The first main part of the evaluation is separated into three parts; a) the probability of cooperation and the spectral efficiency are evaluated using different links quality, i.e.,

$\sigma_{sr}^2, \sigma_{rd}^2$, and $d_{sr}^{\beta}, d_{rd}^{\beta}$ of $S-R$ and $R-D$, respectively, which given in Fig.16 and Fig. 17 b) The bit error rate of MLSRD-DCC is evaluated for different links quality and the results compared to DCC which given in Fig.18 , c) outage probability correspondingly evaluated for MLSRD-DCC which is given in Fig. 19.

Fig. 16 show the probability of cooperation after the relay selection employed, the important results apparent in the figure is summarized as follows:

1. If the distance isn't accounted in the selection criteria, the results is shown that the cooperation probability increased as links quality increases, i.e., $\sigma_{sr}^2 >> \sigma_{sd}^2$, $\sigma_{rd}^2 >> \sigma_{sd}^2$, on the other hand, the cooperation probability is lower, if one of the link quality is high, i.e., $\sigma_{sr}^2 >> \sigma_{sd}^2$ and $\sigma_{sr}^2 = \sigma_{sd}^2$.
2. If the distance is accounted in cooperation criteria, it is seen that if the relay nodes are placed in the mid distance between the source and the destination, the probability of cooperation is higher compared to the case where distance is not accounted in cooperation criteria.

It is clear that, if both the distances and the links quality are accounted in the selection criteria, the cooperation probability is higher compared to case in which the distances isn't accounted.

Fig. 17 show the spectral efficiency using different links quality and the distances. If the links quality are good, i.e., $\sigma_{sr}^2 >> \sigma_{sd}^2$, $\sigma_{rd}^2 >> \sigma_{sd}^2$, the probability of cooperation is increased which make the destination send request to the relay to repeat what received from the source and it is well known repeating the information by the relay is spectral efficiency loosing. In what follow, if $\sigma_{sr}^2 \to \infty$ and $\sigma_{rd}^2 \to \propto$, the spectral efficiency of MLSRD-CCM equal to CCM spectral efficiency and it is equal to $1/2$.

Fig. (1-a) show the bit error rate results with power-to-noise ratio (P/N_o), where the important results apparent in the figure are summarized as follows:

1. The bit error rate of DTM is reduced after the DCC employed.
2. The bit error rate of is reduced after MLSRD-DCC is employed compared to DTM and CCM.
3. After the MLSRD-DCC is employed with links quality of $\sigma_{sr}^2 >> \sigma_{sd}^2$, $\sigma_{rd}^2 >> \sigma_{sd}^2$, the bit error rate reduced. Further enhancement gained, if the relay is placed in in the mid distance between the source and the destination.

4. If the relay placed near to source or destination, the performance reduces compared to case when the relay placed in in the mid distance between the source and the destination.

Fig. (1-b) show the bit error rate results with power-to-noise ratio (P/N_o), where the important results apparent in the figure is summarized as follows: the bit error rate is reduced after MLSRD-DCC protocol is employed compared to protocol given in [21], where for σ^2_{sr} = 10 and $\sigma^2_{rd} = \sigma^2_{sd}$ = 1, the achieved gain () over [21], further achieved gain, if the relay placed in the mid distance between source and destination, i.e., for σ^2_{sr} = 10, $\sigma^2_{rd} = \sigma^2_{sd}$ = 1 and $dsr = drd = 0.5$, the achieved gain () over [21].

Fig. 19 show the outage probability results with (P/N_o), the same result is appeared in Fig 4, the outage probability of MLSRD-DCC is less than the outage probability of DCC.

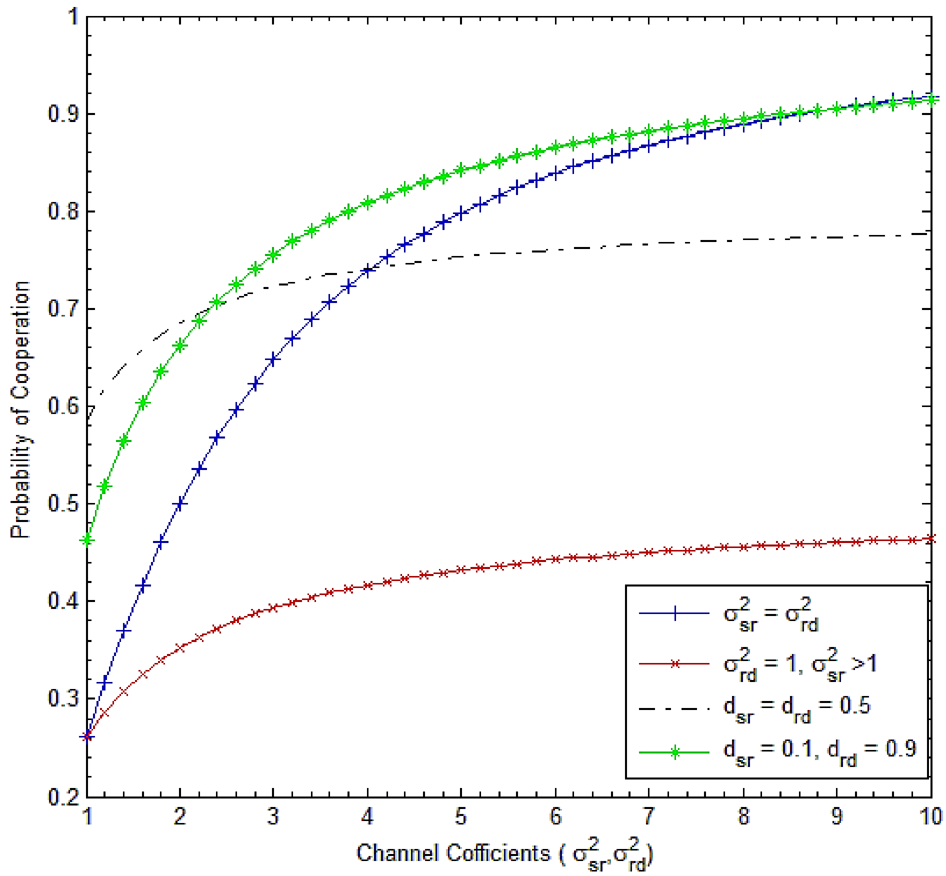


Fig 16: Probability of cooperation of MLSRD protocol per links quality and the distances of the $S-R$ and $R-D$.

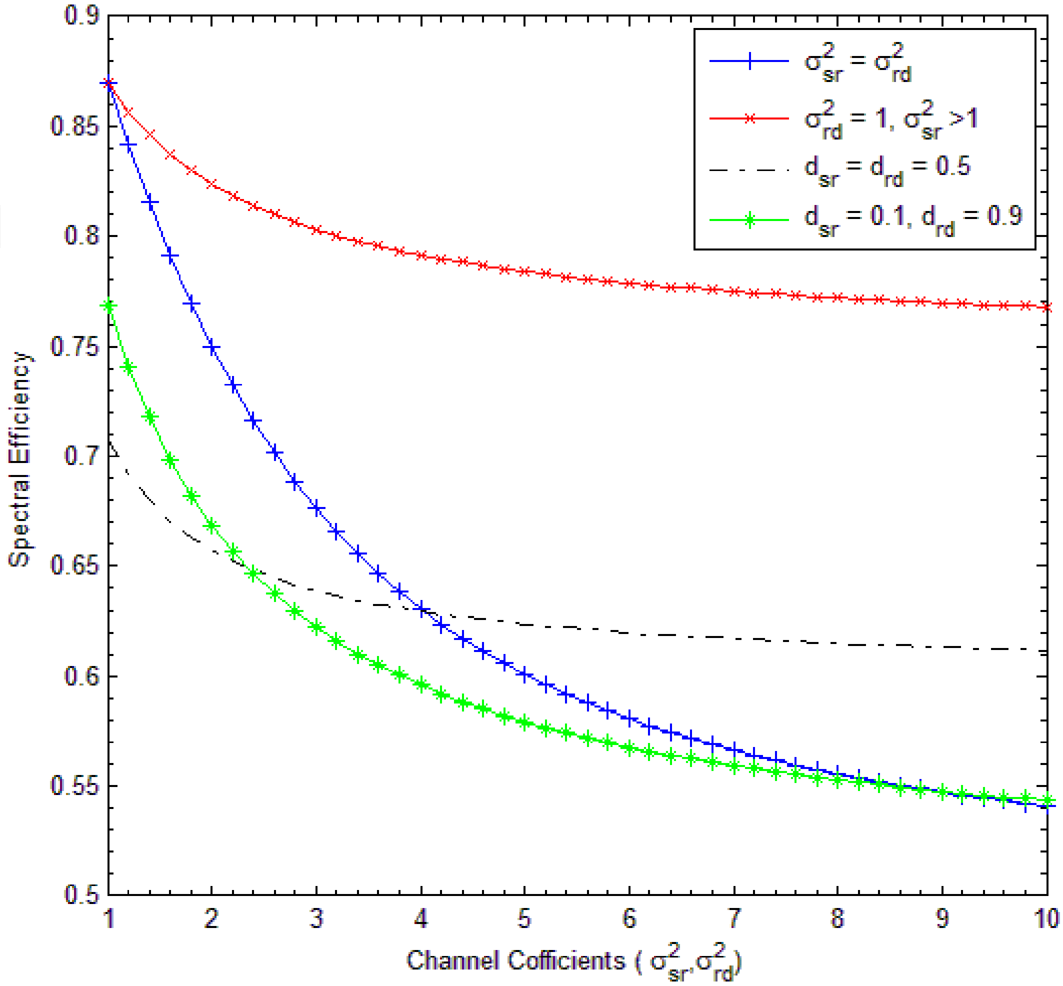
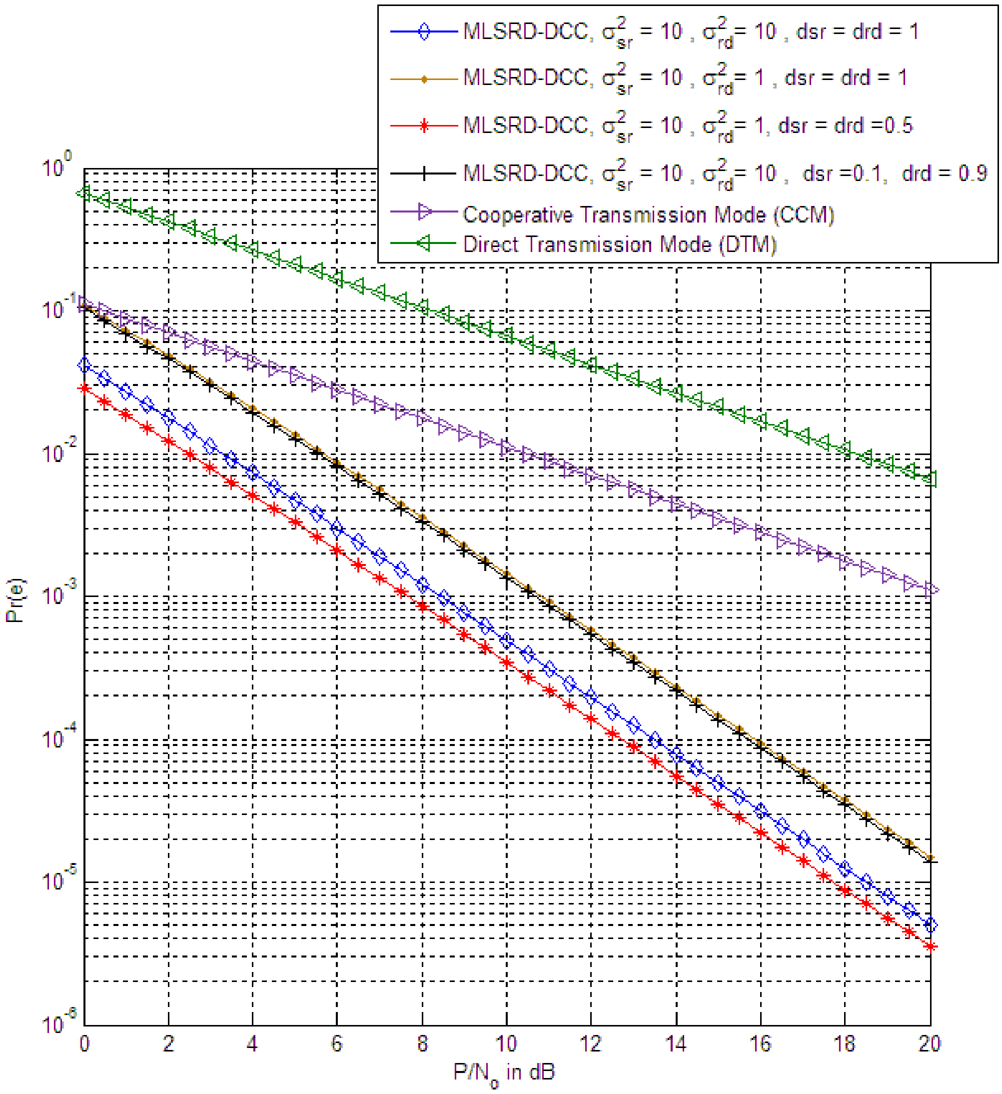
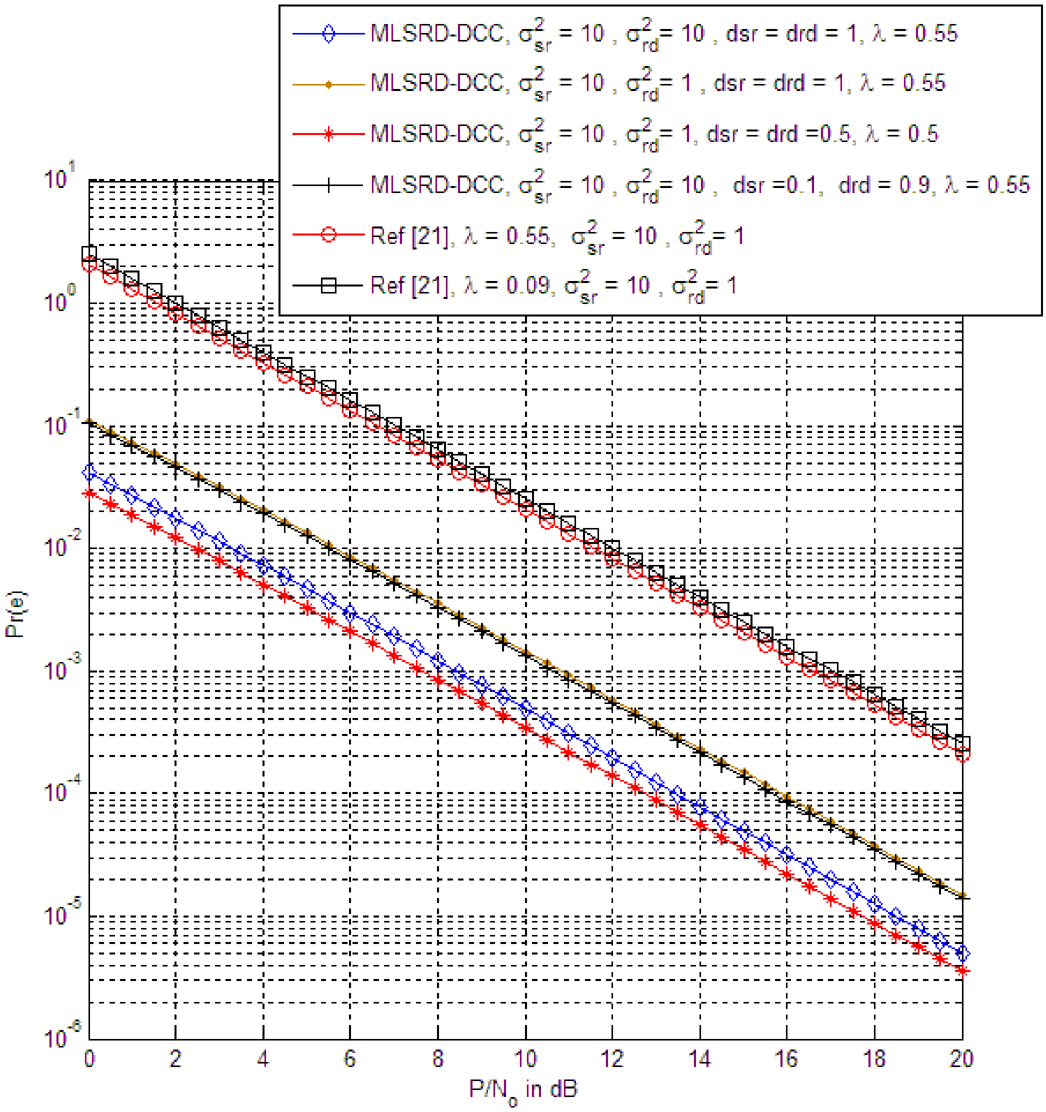


Fig 17: Spectral efficiency of MLSRD protocol per links quality and the distances of the $S-R$ and $R-D$.



(a)

Fig 18: (a) BER performance comparison of the proposed relay selection protocol (MLSRD-DCC), CCM and DTM for BPSK (M =2), L =1, d = 13, $R_B = R_M = 0.5$ [30], $\lambda = 0.5$ and $\beta = 3$.



(b)

Fig 18: (b) BER performance comparison of the proposed relay selection protocol (MLSRD-DCC) and the protocol in [21], for BPSK (M =2), L =1, d = 13, $R_B = R_M$ = 0.5 and β = 3.

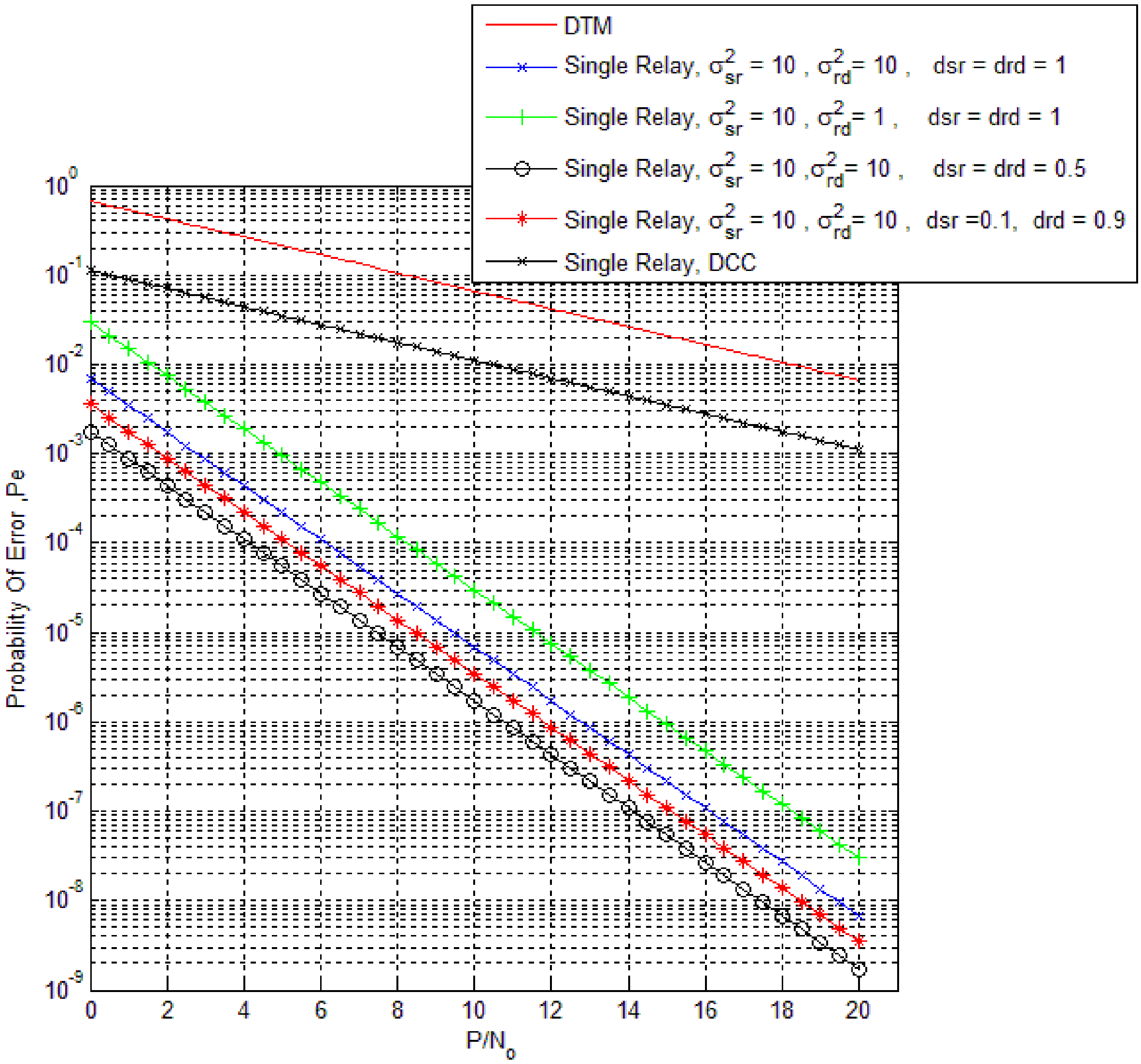


Fig 19: Outage probability performance comparison of the MLSRD protocol and CCM, for L =1, and links quality and the distances of the $S-R$ and $R-D$.

Table 2: evaluation parameters and setting.

$Modulation\ Order,\ M$	8
$Coding\ Rate,\ R$ [30]	$1/4,\ (13, 15, 15, 17)$
$R_b,\ R_m$	$1/2\,(13, 15),\ 1/2\,(15, 17)$
$Pathloss\ Exponents, \beta$	3
$Normalized\ Distnace, d$	$0.1 - 0.9$
$Channel\ Gain, \sigma^2_{i,j}$	$1 - 10$
$P_b/N_o, P_m/N_o = 0.5(P_{b/N_o})$	$0\ to\ 40\, dB$

Table 3: Comparisons of the MLSRD with the previous work given in [24] and [26].

Protocol	$\sigma^2_{sd}/d^{\beta}_{sd}$	$\sigma^2_{sr}/d^{\beta}_{sr}$	$\sigma^2_{rd}/d^{\beta}_{rd}$	λ	SE	ASE over [24]
MLSRD-CCM	1/1	1/1	1/1	0.55	0.8922	3.455%
	1/1	1/1	10/1	0.09	0.9622	28.516%
	1/1	10/1	1/1	0.14	0.9435	0.372%
	1/1	10/0.25	1/0.25	0.55	0.6667	-29.36%
MLSRD-DCC	1/1	1/1	1/1	0.55	1.7844	106.91%
	1/1	1/1	10/1	0.09	1.9244	157.03%
	1/1	10/1	1/1	0.14	1.887	100.7%
	1/1	10/0.25	1/0.25	0.55	1.3334	54.61%
Ref [24]	1/1	1/1	1/1	0.55	0.8624	
	1/1	1/1	10/1	0.09	0.7487	
	1/1	10/1	1/1	0.14	0.940	
Ref [26]	1/1	10/1	10/1	1	0.6	
CCM	1/1	10/0.5	10/0.5	1	0.5	

CHAPTER 5

JOINT NEXT HOP AND RELAY NODES SELECTION FOR DISTRIBUTIVE MULTI-HOP COOPERATIVE NETWORKS

5.1. Motivation and Background

Distributive multi-hop cooperative networks have been considered in various areas as promising networks for ubiquitous communication situations. In such networks, a sequence of multi-hop transmissions is required to transmit data from the source to the destination. As well, the relay nodes which are intermediate nodes between source and destination, and the relay nodes can cooperate in each hop transmission by using cooperative systems, which can provide spatial diversity gains. Diversity systems are well-known to offer an effective method of combating fading in wireless networks. Frequency, spatial and time diversities are the three methods of these diversity systems [25]. Where, it has been revealed that a scheme with multiple transmitter and Single receiver antennas (MISO) enhance the received signal quality through diversity systems [60]. As a different method to use separated antennas at the transmitter, which can reach the similar spatial diversity gain is cooperative systems [5] and [61-62]. In cooperative systems, many nodes in a wireless network work together to form a virtually multiple antennas system. Adapting cooperation, it is potential to utilize the spatial diversity of the conventional MISO systems, however it is not essentially having multiple antennas. The destination or next-hop node receives multiple versions of the data from the source and relay nodes and combines these to get an additional reliable transmitted signal which can offer better performance. In distributive multi-hop cooperative networks, nodes can cooperate with each other to offer spatial diversity gain at the destination or the next-hop node. In such, any node can be a source, a relay, next-hop or a destination. The purpose of next-hop node is to help the source to reach to destination over multiple hop nodes even when the source and destination aren't in the same range. As follow, the purpose of the relay node is to help in the transmission of the source data to the destination node. To guarantee diversity gains, the relay nodes are chosen in such a way that its connection to the destination and (or) next-hop node is independent of the connection to the source. In the context of cooperative systems, there are two main cooperative diversity systems for transmission between a couples of nodes over a multiple relay nodes: decode and forward (DF) [63] and amplify and forward (AF) protocols [11].

Although cooperative systems have some fundamental benefits compared to non-cooperative systems, by the use of relay nodes during communication which can increase the diversity gain, on other hand relaying the data and the signal processing at the relay nodes produce some negative drawbacks such as reduced spectral efficiency (spatial multiplexing gain) [48], increased delay during communication and increased hardware complexity. Since retransmission of the data from the relay nodes to the next hop and (or) destination reduces the spectral efficiency, researchers focused on developing some techniques to alleviate the spectral efficiency loss. The use of space time codes in a distributed manner in cooperatives systems is studied in [16], Relay nodes perform full duplex communication, i.e., relays can receive and transmit simultaneously [49] Dynamic allocation of the time slots is studied in [20], some best relay selection protocols are proposed in [21-22].In the practical, the implementation of distributed space code requires to set up multiple antennas at the mobile set and this not practical for small devices; full duplex cooperation required the relay to cancel its self-interference from the received signal, but this not robust in the low cost radio devices; dynamic allocation required overhead and global information; relay selection is simplistic way and does not require hard upgrading and can achieve a spectral efficiency as well as diversity gain. Incremental redundancy protocol for AF and DF cooperative diversity was considered in [11], where the author proposed protocol which improves the spectral efficiency in wireless cooperative networks. The destination indicates success or failure by broadcasting a single bit of feedback to the source and relay nodes. If the source-destination signal-to-noise ratio is sufficiently high, the feedback indicates success of the direct transmission, and the relay node does nothing. If the source-destination signal-to-noise ratio is not sufficiently high for successful direct transmission, the feedback requests that the relay node AF or DF what it received from the source.

Relay node selection for DF cooperative diversity was considered in [64], where the author presented a relay node selection protocol based on link signal-to-noise ratio in wireless networks. The relay node decide when to retransmit based on signal-to-noise ratio between source-relay and relay-destination. Spectral efficiency loss reduction wasn't studied. Relay node selection for DF cooperative diversity was considered in [24], the author proposed relay node selection based on the harmonic mean of the links between source-relay and relay-destination. In addition to relay node selection, the author consider Incremental redundancy protocol which reduce the spectral efficiency loss.

Most previous work on cooperative networks either 1) makes no try to select next-hop node [11], [24] and [64], 2) selects next-hop node, supposing a cooperating sets have been allocated a prior, 3) make relay node selection but no try on the spectral efficiency loss reduction and no try on next-hop selection . There has been very few works on joint next-hop and relay nodes selection in Distributive multi-hop cooperative networks [64]. We propose a selection protocol that is chosen a maximum links signal-to-noise ratio (γ) from the source to next hop node, source to relay node and relay to next-hop nodes, namely joint next-hop and relay nodes selection (JNRS), which address the above problems of the Distributive multi-hop cooperative networks.

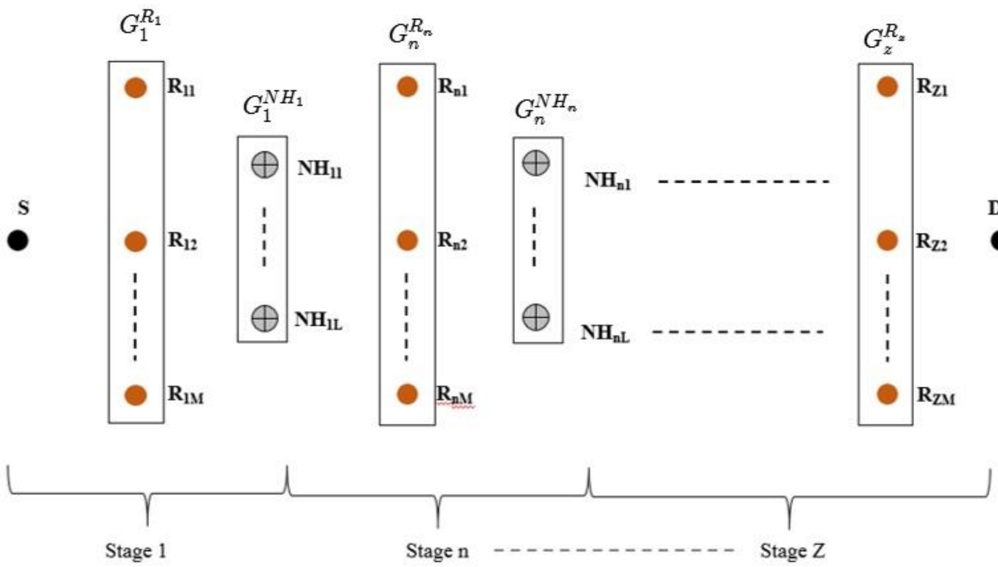


Fig. 20: Distributive multi-hop cooperative networks scenario.

5.2. Multi-hop Cooperative Structure Construction in JNRS

5.2.1. Architecture Overview

In this subsection, the JNRS architecture has been presented in brief which is showing in Fig. 20. Let indicate $G_n^{R_m}$ the m_{th} relay nodes groups, $G_n^{NH_k}$ the k_{th} next-hop nodes groups. Where, the source and destination are separated by n_{th} stages, each stage consists $G_n^{NH_k}$ and $G_n^{R_m}$ groups, while the last stage consists $G_n^{R_m}$ groups. To make the picture clear, we give an example showing in Fig. 21.

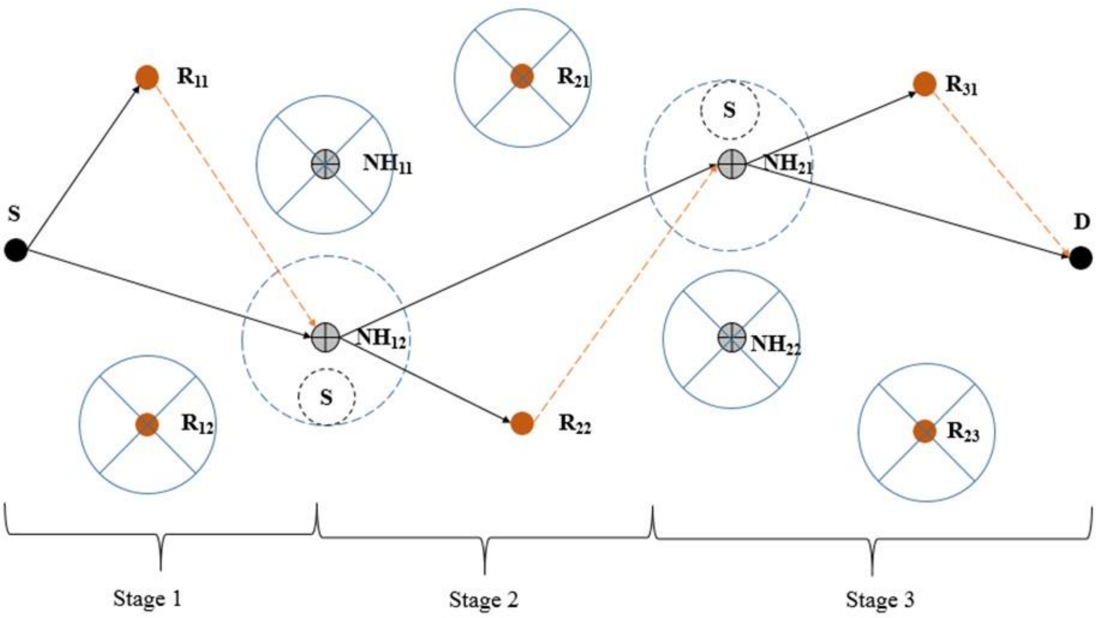


Fig. 21: Distributive multi-hop cooperative networks example, the source and destination are separated by three stages (Z = 3), every stage consist two relay nodes and two next hop nodes. The sold and dashed lines represent the first phase and the second phase, respectively. The dashed circle represent the node action at further stage (n+1), the crossed circle represent nodes which are filter out from the communication.

We consider the DF protocol, which is described as follow; in the first phase (first time slot) the source broadcast the data to receiver and relay nodes. In the second phase (second time slot), the relay nodes retransmit the data that received from source to receiver. Receiver is combined the received data via MRC. However, the DF under the consideration of distributive multi-hop cooperative networks is described as follow; in the first phase and at stage 1, the source broadcast the data to optimal R_1 and optimal NH_2 nodes (optimal relay and next hop nodes selection are given in subsection 5.2.2). In the second phase, the optimal R_1 node retransmit what received from the source to the NH_2 which is combined the received data via MRC. At stage 2 and in the first phase, the NH_2 act as source and re-broadcast the data that received from the stage 1 to optimal R_2 and optimal NH_1 nodes. In the second phase, the optimal R_2 retransmit what received from the NH_2 to the NH_1 which is combine the received data via MRC, and so on. At last stage, which is stage 3, the next-hop node is the destination. In this paper, we consider first stage in our analysis because we assumed the performance is identical in every stage.

5.2.2. Next-Hop and Relay Nodes Selection

In distributive multi-hop cooperative networks, any source may have direct transmission links with some other nodes in its neighborhood and each node can, if needed, action as a next-hop node (sink node) which routing the data to its final destination [65]. As well as, any transmitter may have intermediate nodes between itself and the receiver node which can function as relay nodes in which help the transmitter to forward the data to receiver, see Fig. 20, and 21. In this section, the JNRS has been described in details in which the single next hop and single relay nodes have been jointly selected. Primarily, the next-hop selection is described (in fact, if the source and destination within the same range, next-hop node not exit, see Fig. 21). The NH node selection is resemble to selection combing (SC) protocol in the diversity systems [57]. The SC is described as follow; the receiver received multiple signals from multiple transmitted antennas (L) which installed on the transmitter, where the receiver select largest signal-to-noise ratio (γ) coming from L transmitter antennas and filtered out the small. Where, the proposed NH node selection is described as; the source determine multiple next-hop nodes within its neighborhood or within stage 1 in G_{NH_k} groups; and because each S-NH paths are independent sample of the fading process, the S-NH with the greatest is chosen for communication, such process can be expressed as

$$\mathrm{S-NH_k} = \begin{cases} 1 & \gamma = max_k\{\gamma_k\} \\ 0 & \text{otherwize} \end{cases} \tag{5.1}$$

The NH node has been selected, in the sequel, relay selection is started. The proposed relay selection drawn from ARQ protocol, in which the destination transmits negative ACK signal if the received data from the source are corrupted, which make the source retransmits the corrupted data again. On other hand, if data received correctly by the destination, it is transmit positive ACK signal. The proposed relay selection protocol is described as follow; in the first phase, the source broadcasts the data to optimal NH node which has been selected by the source, and relay nodes (relay nodes within stage 1 in GRm 1 groups). In the second phase, the optimal NH node received the source data, and it is determine the relay node with largest signal-to-noise ratio SR;RNH max and it is expressed as

$$\gamma_{max}^{SR} = max\left\{\gamma^{SR_1}, \gamma^{SR_2}, ..., \gamma^{SR_m}\right\},$$
$$\gamma_{max}^{RNH} = max\left\{\gamma^{RNH_1}, \gamma^{RNH_2}, ..., \gamma^{RNH_k}\right\},$$
$$\gamma_{max}^{SR,RNH} = max\left\{\gamma_{max}^{SR}, \gamma_{max}^{RNH}\right\}. \tag{5.2}$$

$\gamma_{max}^{SR,RNH}$ is represent the maximum signal-to-noise ratio from the S-R node and from R-NH node that is chosen by the optimal NH node. If the $\gamma_{max}^{SR,RNH}$ is determined then the NH node compares it to γ_{SNH}. If $\gamma_{SNH} > \gamma_{max}^{SR,RNH}$, then the next-hop node transmits positive ACK and DTM occurred, on other hand, if $\gamma_{SNH} > \gamma_{max}^{SR,RNH}$, then the NH node transmits negative ACK, and optimal relay nodes that has $\gamma_{max}^{SR,RNH}$, it is retransmit what received from the source to NH node. The NH node is combined the received data from the source and relay nodes using MRC in such DF-JNRS is occurred. Where, it is assumed that every node in the networks has knowledge of links quality to neighborhood.

5.3. Mathematical Analysis of JNRS Protocol

In this section, the mathematical model and analysis of JNRS protocol is provided. The average spectral efficiency, outage probability and diversity order are analyzed after the JNRS protocol employed.

5.3.1. Average Spectral Efficiency Analysis

Technically, if the M relays participate in cooperation, then $M+1$ time slots or sub-channels required to transmit single symbol of the data from the source to the next-hop node or (and) destination. Therefore, the spectral efficiency of the CCM is scaled by $(1/M+1)$, i.e., if the spectral efficiency of DTM is denoted as $\mathrm{SE_{DTM}}$, then the spectral efficiency of CCM is $\mathrm{SE_{CCM}} = (\mathrm{SE_{DTM}}/(\mathrm{M}+1))$.

The CCM under JNRS consideration may be summarized as follows; in the first phase, the source broadcasts the data to the relay nodes and to the optimal next-hop node, if the relays decode the received data correctly, it save the data in their buffer, otherwise the relays keeps silent and drop the data from the buffer's. In second phase, the optimal next-hop node compute$\gamma_{SNH} < \gamma_{max}^{SR,RNH}$, if it is satisfied, the optimal next-hop transmits negative ACK (the ACK message can be represented by single bit, where positive ACK by 1 digit and negative ACK by 0 digit, to avoid extra overhead). The optimal relay node retransmits what received from the source to optimal next-hop node. The optimal next-hop node combines all received signals which are transmitted by the source and optimal relay node via MRC. The JNRS can dramatically improve spectral efficiency over CCM because if the source to optimal next hop node γ is sufficiently high, the relay does nothing which can reduce the spectral efficiency loss. The average spectral efficiency (ASE) is given as [24]

$$ASE = \underbrace{Pr(\psi^{DTM})}_{\mathrm{Term(1)}} \bigcup \underbrace{0.5Pr(\psi^{CCM})}_{\mathrm{Term(2)}}, \tag{5.3}$$

The average spectral efficiency (ASE) after JNRS employed is given as

$$ASE_{JNRS} = \underbrace{Pr(\phi^{SNH} \bigcap \psi^{DTM})}_{\mathrm{Term(1)}} \bigcup \underbrace{0.5Pr(\phi^{SNH} \bigcap \psi^{CCM})}_{\mathrm{Term(2)}}, \tag{5.4}$$

in which ϕ^{SNH} , ψ^{DTM} and ψ^{CCM} are next-hop selection, direct transmission mode and classical cooperation mode events, respectively, which are independent. Where Term(1) and Term(2) of (5.4) are exclusively independents events, therefore we rewrite (5.4) as

$$ASE_{JNRS} = 0.5\ (1\ +\ Pr(\phi^{SNH})\, Pr(\psi^{DTM} \mid \phi^{SNH})). \tag{5.5}$$

in which $Pr(\phi^{SNH})$ is the probability of next-hop selection and $Pr(\psi^{DTM})$ is the probability of direct transmission mode selection, consequently $Pr(\psi^{DF})$ = 1- $Pr(\psi^{DTM})$ is probability of DF mode selection. If γ is assumed to be exponentially distributed, then The complementary probability of optimal NH node selection is given aswhich are given as

$$\overline{Pr(\phi^{SNH})} = \overline{Pr_{\gamma_{max}}(\gamma^{SNH})} =$$

$$Pr(max[\gamma_1, \gamma_2, ..., \gamma_L] \geq \gamma^{SNH}) = \prod_{k=1}^{L} \left(1 - exp\left(-\frac{\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right)\right), \tag{5.6}$$

this yields

$$\overline{Pr_{\gamma_{max}}(\gamma^{SNH})} = \sum_{k=0}^{L} \binom{L}{k} (-1)^k \left(exp - \frac{k\,\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right)\Bigg), \tag{5.7}$$

The probability of optimal NH node selection is given as

$$Pr_{\gamma_{max}}(\gamma^{SNH}) = 1 - \sum_{k=0}^{L} \binom{L}{k} (-1)^k \left(exp\left(-\frac{k\,\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right)\right), \tag{5.8}$$

Furthermore, if more than single relay within $G_1^{R_m}$, the probability of the DTM is given as

$$Pr(\psi^{DTM}) = Pr_{\gamma_{max}^{SR,RNH}}(\gamma^{SNH} > \gamma_{max}^{SR,RNH}) = 1 - exp\left(-\left(\frac{1}{\overline{\gamma^{SR}}} + \frac{1}{\overline{\gamma^{RNH}}}\right)\gamma^{SNH}\right) \tag{5.9}$$

As follow, the average $Pr(\phi^{SNH})\,Pr(\psi^{DTM} \mid \phi^{SNH})$ is given as

$$Pr(\phi^{SNH})\,Pr(\psi^{DTM} \mid \phi^{SNH}) =$$

$$\int_0^\infty Pr_{\gamma_{max}}(\gamma^{SNH}) Pr_{\gamma_{max}^{SR,RNH}}(\gamma^{SNH}) p_{\gamma^{SNH}}(\gamma^{SNH})\; d\gamma^{SNH} \tag{5.10}$$

Substitute (5.8) and (5.9) in (5.10), yields

$$Pr(\phi^{SNH})Pr(\psi^{DTM} \mid \phi^{SNH}) = \int_0^\infty \sum_{m=0}^{M} \binom{M}{m} (-1)^m\, exp\left(-(\frac{1}{\overline{\gamma^{SR}}} + \frac{1}{\overline{\gamma^{RNH}}}\right)\, m\, \gamma^{SNH}\Bigg)$$

$$\frac{1}{\overline{\gamma^{SNH}}} exp\left(-\frac{\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right) d\gamma^{SNH} - \int_0^\infty \sum_{k=0}^{L} \binom{L}{k} (-1)^k \left(exp\left(-\frac{k\,\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right)\right) \underbrace{\sum_{m=0}^{M}}_{m \neq k} \binom{M}{m} (-1)^m$$

$$\times\, exp\left(-\left(\frac{1}{\overline{\gamma^{SR}}} + \frac{1}{\overline{\gamma^{RNH}}}\right) m\,\gamma^{SNH}\right) \frac{1}{\overline{\gamma^{SNH}}} exp\left(-\frac{\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right) d\gamma^{SNH} \tag{5.11}$$

yields,

$$Pr(\phi^{SNH})\,Pr(\psi^{DTM}\mid\phi^{SNH}) = \int_0^\infty \sum_{m=0}^{M}\binom{M}{m}(-1)^m\, exp\left(-\left(\frac{1}{\overline{\gamma^{SNH}}}+\left(\frac{1}{\overline{\gamma^{SR}}}+\frac{1}{\overline{\gamma^{RNH}}}\right)m\right)\right)$$

$$\gamma^{SNH}\frac{1}{\overline{\gamma^{SNH}}}d\gamma^{SNH} - \sum_{k=0}^{L}\binom{L}{k}\frac{(-1)^k}{\overline{\gamma^{SNH}}}\underbrace{\sum_{m=0}^{M}}_{m\neq k}\binom{M}{m}(-1)^m$$

$$\times\int_0^\infty exp\left(-\left(\frac{(k+1)}{\overline{\gamma^{SNH}}}+\left(\frac{1}{\overline{\gamma^{SR}}}+\frac{1}{\overline{\gamma^{RNH}}}\right)m\right)\gamma^{SNH}\right)d\gamma^{SNH} \quad (5.12)$$

Evaluate the integration with respect to γ^{SNH}, we rewrite (5.12) as

$$Pr(\phi^{SNH})\,Pr(\psi^{DTM}\mid\phi^{SNH}) = \frac{1}{\overline{\gamma^{SNH}}}\sum_{m=0}^{M}\binom{M}{m}(-1)^m\left(\frac{1}{\overline{\gamma^{SNH}}}+\left(\frac{1}{\overline{\gamma^{SR}}}+\frac{1}{\overline{\gamma^{RNH}}}\right)m\right)^{-1}$$

$$-\sum_{k=0}^{L}\binom{L}{k}\frac{(-1)^k}{\overline{\gamma^{SNH}}}\underbrace{\sum_{m=0}^{M}}_{m\neq k}\binom{M}{m}(-1)^m\left(\frac{(k+1)}{\overline{\gamma^{SNH}}}+\left(\frac{1}{\overline{\gamma^{SR}}}+\frac{1}{\overline{\gamma^{RNH}}}\right)m\right)^{-1} \quad (5.13)$$

Substituting (5.13) in (5.4), then the average spectral efficiency is given as

$$ASE_{JNRS} = 0.5\ (2+\frac{1}{\overline{\gamma^{SNH}}}\sum_{m=1}^{M}\binom{M}{m}(-1)^m\left(\frac{1}{\overline{\gamma^{SNH}}}+\left(\frac{1}{\overline{\gamma^{SR}}}+\frac{1}{\overline{\gamma^{RNH}}}\right)m\right)^{-1}$$

$$-\sum_{k=0}^{L}\binom{L}{k}\frac{(-1)^k}{\overline{\gamma^{SNH}}}\underbrace{\sum_{m=0}^{M}}_{m\neq k}\binom{M}{m}(-1)^m\left(\frac{(k+1)}{\overline{\gamma^{SNH}}}+\left(\frac{1}{\overline{\gamma^{SR}}}+\frac{1}{\overline{\gamma^{RNH}}}\right)m\right)^{-1})).$$

(5.14)

It is clear that the spectral efficiency of the JNRS protocol is depended on: 1) number of the NH nodes within $G_1^{NH_k}$ groups. Where if the number of NH nodes increased, the probability of choosing optimal NH node increases which reduce the spectral efficiency loss. In addition, the spectral efficiency goes to 1 as L goes to ∞. 2) signal-to-noise ratio of S – NH link. Where if the S – NH is large which increases the probability of DTM, the spectral efficiency increases. In addition, the spectral efficiency goes to 1 as S – NH goes to ∞. 3) number of relay nodes within $G_1^{R_m}$ groups. The spectral efficiency decreases, if the number of relay nodes increases because as number of R increases the probability of CCM increased as well. In addition, the spectral efficiency goes to 0.5 as M goes to ∞. 4) signal-to-noise ratio of S – R and R – NH inks. The spectral efficiency decreases, if the signal-to-noise ratios of S – R and R – NH inks greater than S – NH link. In addition, the spectral efficiency goes to 0.5 as signal-to-noise ratio of S – R and R – NH inks goes to ∞ because the probability of CCM goes to 1. We can conclude that: If the probability of DTM increased, i.e.,

$P(\psi^{DTM})$, the spectral efficiency increases but the spectral efficiency reduces as $P(\psi^{CCM})$ increases.

5.3.2. Outage Probability Analysis

The outage probability $\Pr(\text{out})$ is another standard for system performance evaluation; it measures the probability of an event to be less than the threshold value. In this section, we consider the probability of a given signal-to-noise ration (γ) to be less than the threshold value γ_o. If the channel modeled as Raleigh fading channel, then the signal-to-noise ratio (γ) distribution is exponential, therefore the outage probability is given as [37]

$$p(\gamma < \gamma_o) := Pr(\gamma_o) = \int_0^{\gamma_o} \frac{1}{\overline{\gamma}} exp(\frac{\gamma}{\overline{\gamma}}) d\gamma = 1 - exp(\frac{\gamma_o}{\overline{\gamma}}) = \frac{1}{\overline{\gamma}} exp(\frac{\gamma_o}{\overline{\gamma}}) \quad (5.15)$$

in which the $\overline{\gamma}$ is the average signal-to-noise ratio as $E[\gamma] = \beta\gamma$. The outage probability after JNRS employed, it is given as []

$$P_{out}^{JNRS} \leq \underbrace{(P_{out}^{SNH} \bigcap P_{out}^{SR})}_{\text{First phase, Term(1)}} \bigcup \underbrace{((\,, P_{out}^{SNH} \bigcap P_{out}^{RNH})}_{\text{Second phase, Term(2)}} \quad (5.16)$$

The outage probability after JNRS employed, it is given as

$$P_{out}^{JNRS} \leq \underbrace{Pr(\phi^{SNH}) \bigcap P_{out}^{SR,SNH} \bigcap Pr(\psi^{DTM})}_{\text{Term(1)}} \bigcup \underbrace{Pr(\phi^{SNH}) \bigcap P_{out}^{RNH,SNH} \bigcap Pr(\psi^{DF})}_{\text{Term(2)}} \quad (5.17)$$

All the events given in (5.17) are independents; and Term(1) with Term(2) of (5.17) are exclusively independent events, therefore we rewrite (5.17) as

$$P_{out}^{JNRS} \leq P_{out}^{SNH} \left[Pr(\phi^{SNH})\ Pr(\psi^{DTM}) \left(P_{out}^{SR} - P_{out}^{RNH}\right) + Pr(\phi^{SNH})\, P_{out}^{RNH}\right] \quad (5.18)$$

in which the average $Pr(\phi^{SNH})\Pr(\psi^{DTM})$ given in (5.13) and the average of $Pr(\phi^{SNH})$ is given as

$$P(\phi^{SNH}) = 1 - \int_0^{\infty} \sum_{k=0}^{L} \binom{L}{k} (-1)^k exp\left(-\frac{k\,\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right) \frac{1}{\overline{\gamma^{SNH}}} exp\left(-\frac{\gamma^{SNH}}{\overline{\gamma^{SNH}}}\right) d\gamma^{SNH} \quad (5.19)$$

$$P(\phi^{SNH}) = 1 - \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{1}{\overline{\gamma^{SNH}}} \left(\frac{k+1}{\overline{\gamma^{SNH}}} \right)^{-1}$$

(5.20)

in which P_{out}^{SNH}, P_{out}^{SR} and P_{out}^{RNH} are the outage probabilities of the S-NH link, S-R link and R-NH link, respectively. These probability are given as

$$P_{out}^{SNH} = Pr(\gamma^{SNH} > \gamma_o) = 1 - exp(-\frac{\gamma_o}{\overline{\gamma^{SNH}}}) = g\left(\gamma^{SNH}, \gamma_o\right),$$

$$P_{out}^{SR} = Pr(\gamma^{SR} > \gamma_o) = 1 - exp(-\frac{\gamma_o}{\overline{\gamma^{SR}}}) = g\left(\gamma^{SR}, \gamma_o\right) \qquad ,$$

$$P_{out}^{RNH} = Pr(\gamma^{RNH} > \gamma_o) = 1 - exp(-\frac{\gamma_o}{\overline{\gamma^{RNH}}}) = g\left(\gamma^{RNH}, \gamma_o\right).$$

(5.21)

Substituting (5.20) and (21) in (5.18), then the outage probability is obtain as

$$P_{out}^{JNRS} \leq g\left(\gamma^{SNH}, \gamma_o\right) \left[\frac{1}{\overline{\gamma^{SNH}}} \sum_{m=0}^{M} \binom{M}{m} (-1)^m \left(\frac{1}{\overline{\gamma^{SNH}}} + \left(\frac{1}{\overline{\gamma^{SR}}} + \frac{1}{\overline{\gamma^{RNH}}} \right) m \right)^{-1} \right.$$

$$- \sum_{k=0}^{L} \binom{L}{k} \frac{(-1)^k}{\overline{\gamma^{SNH}}} \sum_{\underbrace{m=0}_{m \neq k}}^{M} \binom{M}{m} (-1)^m \left(\frac{(k+1)}{\overline{\gamma^{SNH}}} + \left(\frac{1}{\overline{\gamma^{SR}}} + \frac{1}{\overline{\gamma^{RNH}}} \right) m \right)^{-1}$$

$$\left. \left(g\left(\gamma^{SR}, \gamma_o\right) - g\left(\gamma^{RNH}, \gamma_o\right)\right) + g\left(\gamma^{RNH}, \gamma_o\right) \left(1 - \sum_{k=0}^{L} \binom{L}{k} (-1)^k \frac{1}{\overline{\gamma^{SNH}}} \left(\frac{k+1}{\overline{\gamma^{SNH}}} \right)^{-1} \right) \right]$$

(5.22)

The outage probability is proportional directly to probability of DTM and probability of CCM. Where, it is effected by four parameters which can be summarized as follow: 1) the outage probability reduces as L increases because the probability of choosing optimal S – NH link increases and vice versa. 2) The outage probability reduces as S – NH link increases and vice versa. 3) The outage probability reduces as M increases because the probability of choosing optimal S – R and R – NH links increases and vice versa. 4) The outage probability reduces as S – R and R – NH links increases and vice versa. 5) The outage probability reduces more comparing to 1 – 4, if the S – NH, S – R and R – NH.

5.3.2.1 Diversity Order

A good cooperation systems has to maintain the diversity gain and spectral efficiency. In fact, DF may be provide diversity gain but spectral efficiency may not. Hence, we need protocol that can give both spectral efficiency and diversity gain. One of the simplest existing protocol which can reduce the spectral efficiency loss is resemble to ARQ protocol, but such protocol may not offer diversity gain. Therefore, it is important to design protocol resemble to ARQ protocol which offer diversity gain. Where, the diversity order (DO) is considered in our analysis, because it is can be translated into the diversity gain.

Definition 3.2.1 if the symbol of the information is transmitted from the source and a single relay node (M = 1) to the destination node (or next-hop node). We say DO = 2, if $\gamma \to \infty$.

Proposition 3.2.1. the diversity order of the DF which use JNRS that employee M relay nodes, achieve diversity order of 2 through choosing maximum signal-to-noise ratio from S-NH, S-R and R-NH, respectively.

Proof. The probability density function of outage probability of JNRS protocol is given as

$$p_{out}^{JNRS} \leq p_{out}^{SNH} p(\phi^{SNH}) \left[\, p(\psi^{DTM}) \left(p_{out}^{SR} - p_{out}^{RNH}\right) \; + \; p_{out}^{RNH}\right] \tag{5.23}$$

in which p_{out}^{SNH},p_{out}^{SR} and p_{out}^{RNH} are given as

$$\begin{aligned} p_{out}^{SNH} &:= Pr(\gamma^{SNH} > \gamma_o) = 1 - exp(-\frac{\gamma_o}{\overline{\gamma^{SNH}}}) \sim \frac{\gamma_o}{\overline{\gamma^{SNH}}}, \\ p_{out}^{SR} &:= Pr(\gamma^{SR} > \gamma_o) = 1 - exp(-\frac{\gamma_o}{\overline{\gamma^{SR}}}) \sim \frac{\gamma_o}{\overline{\gamma^{SR}}} \qquad , \\ p_{out}^{RNH} &:= Pr(\gamma^{RNH} > \gamma_o) = 1 - exp(-\frac{\gamma_o}{\overline{\gamma^{RNH}}}) \sim \frac{\gamma_o}{\overline{\gamma^{RNH}}}. \end{aligned} \tag{5.24}$$

The probability density function of $Pr(\phi^{SNH})$ and $Pr(\psi^{DTM})$ for L = 1 and M = 1 are given as

$$p_{\gamma_{max}}(\gamma^{SNH}) := Pr_{\gamma_{max}}(\gamma^{SNH}) = 1 - \sum_{k=0}^{L} \binom{L}{k} (-1)^k \left(exp\left(-\frac{k\, \gamma^{SNH}}{\overline{\gamma^{SNH}}}\right)\right) \sim \frac{\gamma^{SNH}}{\overline{\gamma^{SNH}}},$$

and,

$$p_{\gamma_{max}^{SR,RNH}}(\gamma_k) := Pr_{\gamma_{max}^{SR,RNH}}(\gamma_k) = \sum_{m=0}^{M} \binom{M}{m} (-1)^m \, exp\left(-(\frac{1}{\overline{\gamma^{SR}}} + \frac{1}{\overline{\gamma^{RNH}}}\right) \, m \, \gamma^{SNH}\right)$$

$$\sim \ \gamma^{SNH}\left(\frac{1}{\gamma^{SR}}+\frac{1}{\gamma^{RNH}}\right)$$

(5.25)

Substitute (5.25) and (5.24) in (5.23), we obtain

$$p_{out}^{JNRS} \leq \left(\frac{k\ \gamma_o^2}{\gamma\beta^{SNH}}\right)\left[\left(\left(\frac{1}{\beta^{SR}}+\frac{1}{\beta^{RNH}}\right)m\right)\left(\frac{1}{\gamma\beta^{SR}}-\frac{1}{\gamma\beta^{RNH}}\right)\ +\ \frac{1}{\gamma\beta^{RNH}}\right]$$

(5.26)

in which β^{SNH}, β^{SR} and β^{RNH} are average of the squared of Raleigh random variable from the source to next-hop, source to relay and relay to next-hop nodes, respectively. In what follow, the diversity order of JNRS protocol is given as

$$d^{JNRS} = -\lim_{\gamma\to\infty}\frac{log(p_{out}^{JNRS})}{log(\gamma)}$$

(5.27)

Substitute (5.26) in (5.27), the diversity order is equal to

$$d^{JNRS} = -\lim_{\gamma\to\infty}\frac{log\left(\left(\frac{k\ \gamma_o^2}{\gamma\beta^{SNH}}\right)\left[\left(\left(\frac{1}{\beta^{SR}}+\frac{1}{\beta^{RNH}}\right)m\right)\left(\frac{1}{\gamma\beta^{SR}}-\frac{1}{\gamma\beta^{RNH}}\right)\ +\ \frac{1}{\gamma\beta^{RNH}}\right]\right)}{log(\gamma)}$$

$$=\ 2. \quad (5.28)$$

5.4. Performance and Results

In this section, the performance of the JNRS protocol that presented in the previous sections is evaluated. The evaluation in this paper are gathered spectral efficiency and outage probability using JNRS protocol. In the evaluation, we assume different γ between the source, next-hop and the relay nodes, which is the most general case. However, in the Fig. 22, we assume the γ between S - NH is vary and between S – R and R – NH are fix, while in the Fig. 23, the γ between S - NH is fix and between S – R and R – NH are vary, in the Fig. 24, the γ between S – NH, S – R and R – NH are vary.

Fig. 22. Show the comparison of average spectral efficiency uses JNRS protocol and DF for L = 2, 3 and 4. The important results apparent in the figure are summarized as follow:

1. The average spectral efficiency increases as the number of the next-hop nodes increases.
2. The average spectral efficiency increases as the γ^{SNH} increases.
3. The average spectral efficiency is 0.5 for DF even when γ^{SNH} increases.

Fig. 23. Show the comparison of average spectral efficiency uses JNRS protocol and DF for L = 1, 2 and M =1, 2. The important results apparent in the figure are summarized as follow:

1. The average spectral efficiency reduces as number of relay nodes increases.
2. The average spectral efficiency increases as γ^{SNH} increases.
3. The average spectral efficiency increases as number of the next-hop nodes increases.
4. The average spectral efficiency is \$0.5\$ for DF even when γ^{SNH} increases.

Fig. 24. Show the comparison of outage probability uses JNRS protocol and DF for L = 1, 2 and M =1, 2. The important results apparent in the figure are the outage probability reduces as the number of relay and next-hop nodes increase. The outage probability is higher for DF compared to DF-JNRS.

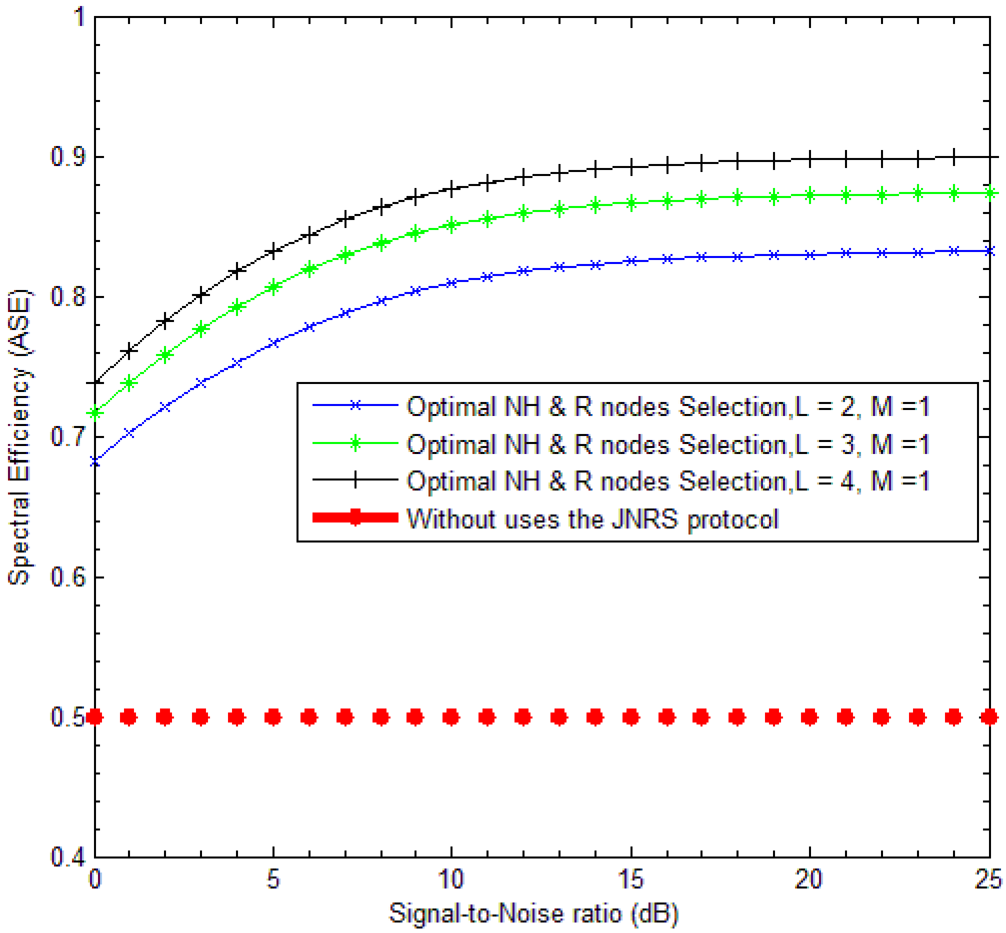


Fig. 22. The average spectral efficiency for L = 1, 2 and M = 1, and different signal-to-noise ratio.

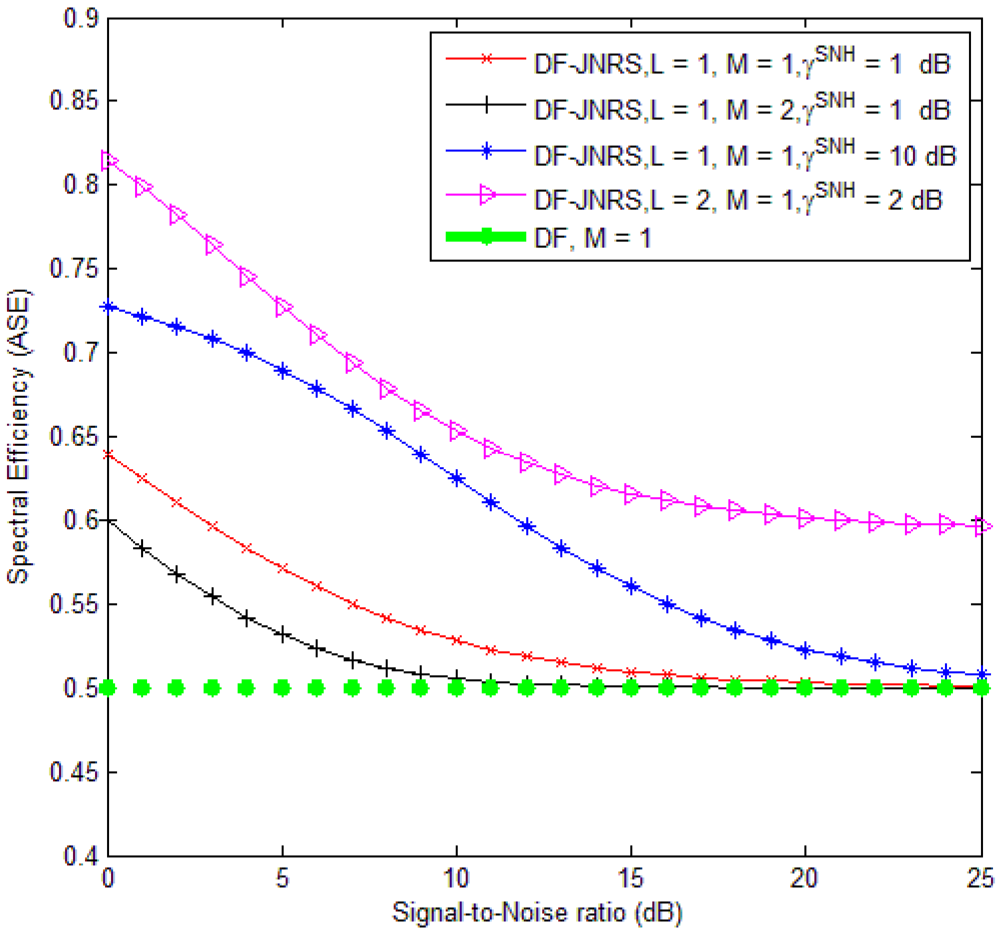


Fig. 23. The average spectral efficiency for L = 1, 2 and M = 1, 2, and different signal-to-noise ratio.

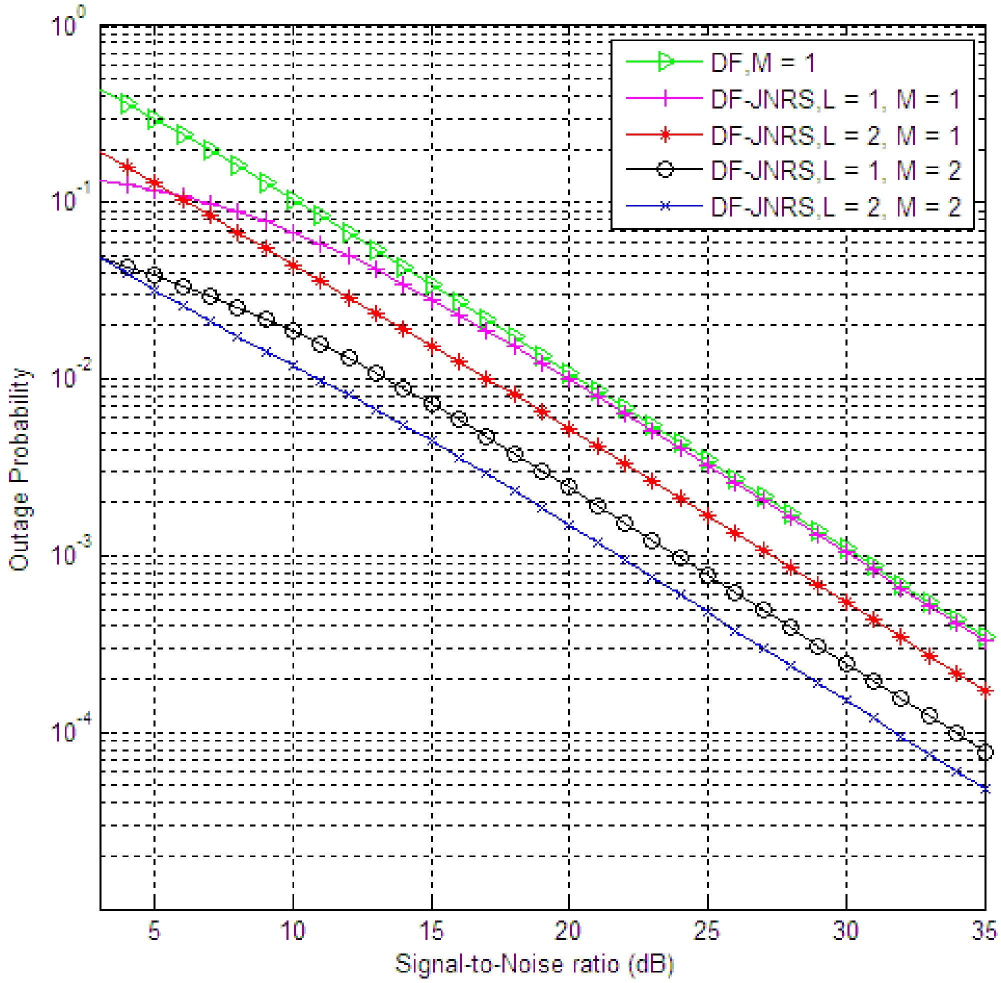


Fig. 24. Outage probability for L = 1, 2 and M = 1, 2, $\beta = 1$ and different signal-to-noise ratio.

CHAPTER 6

PERFORMANCE ENHANCEMENT THROUGH OPTIMAL POWER AND CODE RATE ALLOCATION OF DISTRIBUTED CONVOLUTIONAL CODE FOR THE COOPERATIVE WIRELESS NETWORKS

6.1. Motivation and Background

The communication devices which employ multiple antennas can achieve higher transmission capacity and better performance due to the spatial diversity and the use of the multipath transmission. However, it may not be always feasible to use multiple antennas in some mobile communication devices considering the brought size and cost increment. In order to achieve the spatial diversity without using multiple antennas on mobile devices we can use cooperative communication (CC) approach. In cooperative communication different type of methods such as amplify-and-forward [66-67], un-coded cooperation [68] and distributed coded cooperation (DCC) [26]. In this paper, we consider distributed coded cooperation method where the code rate is distributed among the relays (helpers or neighbors) and the source. Distributed coded cooperation has more cooperation gain when compared to uncoded or amplify-and-forward cooperation methods. We provide pairwise error probability analysis of distributed coded cooperation considering the cases in which the received data at relay includes errors or it does not include errors. We only consider single relay use and derive approximated PEP for single relay case.

In the literature, the optimum power allocation (OPA) studies have been done considering the symbol error rate [14] and outage probability parameters for the cooperative communication systems employing either uncoded or amplify-and-forward transmission techniques [69]. To the best of the authors' knowledge the analysis of distributed coded cooperation employing optimal power allocation has not been done. In this paper, we derived the optimum power allocation criteria for the cooperative communication systems considering the cases in which the received data at relay either includes errors or not. In addition, we derived optimum code rate allocation formulas for the case where the received data at relay include errors. All the results are obtained considering the channel variations from source-to-relay and relay-to-destination.

6.2. Error Free Data at Relay

After source broadcasting to the relay and destination, the relay decodes the received data correctly and re-encodes it before its retransmission to the destination. We assume that the decoded data at the relay has no errors. Generally, the conditional PEP of the direct transmission mode is given as:

$$P(d \mid \gamma_{dt}) = Q\left(\sqrt{2\, k_{psk}\, d_{dt}\, R_{dt}\, \gamma_{dt}}\right) \tag{6.1}$$

where $k_{psk} = (sin^2 \frac{\pi}{M})$ is PSK modulation constant, $R_{dt} = \left(R_b^{-1} + R_m^{-1}\right)^{-1}$is the direct transmission code rate, d_{dt} is the Hamming distance between the received and transmitted signal for the direct transmission mode and γ_{dt} is the instantaneous received signal to noise ratio of the direct transmission mode and it is represented as (P_{dt}/N_o). The conditional pairwise error probability of the distributed coded cooperation [4] is given as:

$$P(d_{dt} \mid \gamma_{SD}, \gamma_{RD}) = Q\left(\sqrt{\frac{2k_{psk}}{N_o}\left(R_b\, d_b\, P_b\, |h_{SD}|^2 + R_m\, d_m\, P_m\left(|h_{SD}|^2 + |h_{RD}|^2\right)\right)}\right) \tag{6.2}$$

where d_b and d_m are the Hamming distances of encoded data in the BC and MAC mode respectively such that $d_{dt} = d_b + d_m$. Using Craig's formula $\frac{1}{\pi}\int_0^{\frac{(M-1)\,\pi}{M}} exp\left(\frac{-x^2}{2\,sin^2\theta}\right) d\theta$ [9] for Q(x) function, we can rewrite (6.2) as:

$$P(d_{dt} \mid \gamma_{SD}, \gamma_{RD}) = \frac{1}{\pi}\int_0^{\frac{(M-1)\,\pi}{M}} exp\left(\frac{2k_{psk}}{N_o}\frac{\left(R_b\, d_b\, P_b\, |h_{SD}|^2 + R_m\, d_m\, P_m\, |h_{SD}|^2\right)}{2sin^2\theta}\right)$$

$$\times exp\left(\frac{2k_{psk}}{N_o}\frac{R_m\, d_m\, P_m\, |h_{RD}|^2}{2sin^2\theta}\right)\, d\theta \tag{6.3}$$

The unconditional PEP in [4] is given as:

$$P(d) = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \left(1 + \frac{k_{psk}}{N_o}\frac{\left(R_b\, d_b\, P_b\, |h_{SD}|^2 + R_m\, d_m\, P_m\, |h_{SD}|^2\right)}{sin^2\theta}\right)^{-1} \times \left(1 + \frac{k_{psk}}{N_o}\frac{R_m\, d_m\, P_m\, |h_{RD}|^2}{sin^2\theta}\right)^{-1} d\theta \quad (6.4)$$

where the integrand takes its maximum value when $sin^2(\theta) = 1$, which results to $\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} (sin^2\theta)^{2L+2}\, d\theta = \frac{M-1}{M}$ [10], [11], and assuming that γ_{SD} and γ_{RD} are large enough, we can obtain the approximated expression for (6.4) as:

$$P(d) \le \left(\frac{M-1}{M}\right)\left(\frac{k_{psk}}{N_o}\right)^{-2} \left(|h_{SD}|^2 (R_b\, d_b\, P_b + R_m\, d_m\, P_m)\right)^{-1} \left(R_m\, d_m\, P_m\, |h_{RD}|^2\right)^{-1} \quad (6.5)$$

We analyze a distributed coded cooperation `cooperative communication system employing a convolutional encoder with rate $1/4$, constraint length 5, and generator polynomial $(25, 27, 33, 35)_{octel}$ [12] (we use a such convolution encoder structure in our analysis in Section 6.4). In the BC mode source encodes the data using the $(25, 27)_{octel}$ sub-generator polynomial. And in MAC mode the source and relay encode the data to be transmitted using the $(33, 35)_{octel}$ sub-generator polynomial. And for such convolution encoder the minimum Hamming distance is $d = 16$, and $d_b = d_m = d_{cc}$, besides $R_b = R_m = R_{cc}$. Therefore, we can rewrite (6.5) as:

$$P(d) \le \left(\frac{M-1}{M}\right)\left(\frac{k_{psk}}{N_o}\right)^{-2} \left(|h_{SD}|^2\; R_{cc}\, d_{cc}\; (P_b + P_m)\right)^{-1} \left(R_{cc}\, d_{cc}\, P_m\, |h_{RD}|^2\right)^{-1} \quad (6.6)$$

6.3. The Case of Erroneous Data at Relay

In this section, we consider the case where the received stream at the relay includes some transmission errors. The PEP includes two terms: the first term is due to the non-cooperation case; that is in BC mode source transmits to the destination and relay and in the MAC mode relay cannot decode the received data correctly, so the destination receives data from source only and relay keeps silent. The second term is due to the cooperative communication case, i.e., relay successfully decodes the data and retransmits, receiver gets signal from both relay and source. Therefore, PEP is given as

$$P(d \mid \gamma_{SD}, \gamma_{RD}) = Q\sqrt{\frac{2k_{psk}}{N_o}\,|h_{SD}|^2\,(R_b\, d_b\, P_b + R_m\, d_m\, P_m)} \times Q\sqrt{\frac{2k_{psk}}{N_o}\, R_b\, d_b\, P_b\, |h_{SR}|^2}$$

$$+Q\sqrt{\frac{2k_{psk}}{N_o}\left(R_b\,d_b\,P_b\,|h_{SD}|^2+\,R_m\,d_m\,P_m\left(|h_{SD}|^2+\,|h_{RD}|^2\right)\right)}$$

(6.7)

and following similar steps as in the approximation of (6.3), we can obtain the approximated expression for (6.7) as :

$$P(d)\le\left(\frac{M-1}{M}\right)^2\left(\frac{k_{psk}}{N_o}\right)^{-2}\left(|h_{SD}|^2\left(R_b\,d_b\,P_b\,+\,R_m\,d_m\,P_m\right)\right)^{-1}\times\left(R_b\,d_b\,P_b\,|h_{SR}|^2\right)^{-1}$$
$$+\left(\frac{M-1}{M}\right)\left(\frac{k_{psk}}{N_o}\right)^{-2}\left(R_m\,d_m\,P_m\,|h_{RD}|^2\right)^{-1}\left(|h_{SD}|^2\left(R_b\,d_b\,P_b\,+\,R_m\,d_m\,P_m\right)\right)^{-1}$$

(6.8)

6.4. Optimum Power Allocation

In the previous section, we derived approximate expression of PEP of the cooperative communication system employing distributed coded cooperation. In this section, we derive the optimum power allocation criteria P_b in the BC and in MAC mode P_m and such that the total constant power is $P_{dt}=P_b+P_m$.

6.4.1. Error Free Data at Relay

In this subsection, we determine the criteria for optimum power allocation for the cooperative communication systems that has error free data at the relay. For the PEP given in (6.5), the optimization function is defined as:

$$F\left(P_b,P_m\right)=\left(k_{psk}\,|h_{SD}|^2\left(R_b\,d_b\,P_b\,+\,R_m\,d_m\,P_m\right)\right)^{-1}\left(R_m\,d_m\,P_m\,k_{psk}\,|h_{RD}|^2\right)^{-1},$$
$$s.t\ P_{dt}=P_b+P_m.$$

(6.9)

Let's define the terms $A=R_m\,d_m\,|h_{RD}|^2$, $B=R_b\,d_b\,|h_{SD}|^2$, $C=R_m\,d_m\,|h_{SD}|^2$, $J=R_b\,d_b\,|h_{SR}|^2$ for simplicity of the mathematical expressions, then (6.9) can be rewritten as:

$$F\left(P_b,P_m\right)=\left(k_{psk}B\,P_b\,+k_{psk}C\,P_m\right)^{-1}\times\ \left(k_{psk}A\,P_m\right)^{-1}$$

(6.10)

Defining $P_m=(P_{dt}P/P+1)$ and $P_b=(P_{dt}/P+1)$ [13], where $P=P_b/P_m$, we rewrite (6.10) as:

$$F\left(P_b,P_m\right)=P_{dt}\,log\left(\frac{P+1}{\overline{B}+P\,\overline{C}}\right)+P_{dt}\,log\left(\frac{P+1}{\overline{A}P+1}\right)$$

(6.11)

Knowing the fact that the logarithmic function is a monotone increasing function, and $\overline{A} = 1 + A$, $\overline{C} = 1 + C$ and $\overline{A} = 1 + A$, taking derivative of (6.11) with respect to P and equating to zero, we can rewrite (6.11) as:

$$\left(\frac{2}{P+1}\right) P_{dt} - \left(\frac{(P+\overline{A})(\overline{C}P+\overline{B})}{(\overline{C}P+\overline{B})(P+\overline{A})}\right) P_{dt} = 0,$$

this yield,

$$\overline{C}P^2 + (2\overline{AC} - \overline{C})P + (2\overline{A}^2 - 2\overline{A}) = 0$$

(6.12)

where we made use of the assumptions; $C - 1 = C, 2AC - 1 = 2AC, A = B$, then solving quadratic equation for P we get

$$P = \frac{\sqrt{\left|4(\overline{A}^2 - 4\overline{A} + 1)\overline{C}^2 + (8\overline{A} - 8\overline{A}^2)\overline{C}\right|} + (2\overline{A} - 1)\overline{C}}{2\overline{C}}$$

(6.13)

where $|x|$ is the absolute of x. Considering on assumption given in (6.6), The OPAs in the BC and MAC modes are given as:

$$P_b = \frac{2g_c h_{RD}}{((2g_c h_{SD} - 1) + 2)g_c h_{RD} + \sqrt{|4(g_c^2 h_{SD}^2 - 4g_c h_{SD} + 1)g_c^2 h_{RD}^2 + (8g_c h_{SD} - g_c^2 h_{SD}^2)g_c h_{RD}|}} P_{dt}$$

(6.14)

$$P_m = \frac{(2g_c h_{SD} + 1)g_c h_{RD} + \sqrt{|4(g_c^2 h_{SD}^2 - 4g_c h_{SD} + 1)g_c^2 h_{RD}^2 + (8g_c h_{SD} - g_c^2 h_{SD}^2)g_c h_{RD}|}}{((2g_c h_{SD} - 1) + 2)g_c h_{RD} + \sqrt{|4(g_c^2 h_{SD}^2 - 4g_c h_{SD} + 1)g_c^2 h_{RD}^2 + (8g_c h_{SD} - g_c^2 h_{SD}^2)g_c h_{RD}|}} P_{dt}$$

(6.15)

where $g_c = R_{cc} d_{cc}$. The above results are valid, if the cooperation channels are available, i.e., $h_{SD} \neq 0$, $h_{SR} \neq 0$ and $h_{RD} \neq 0$. The OPAs are affected from the following issues:

1. Channels qualities of the $R - D$, $S - D$ links have great impact on the optimal power allocation process. Different cases which should be taken into account during the optimal power allocation affects the allocation process significantly. The following scenarios can be given as examples for these channel states. The channel state of the $S - D$ may be constant, and the $R - D$ channel state may vary during cooperative cooperation. Therefore, if the channel quality of the $R - D$ is much better than the channel quality of the $S - D$, i.e., $h_{RD} > h_{SD}$, or, if the channel quality the $R - D$ is approximately equal to the channel quality

the $S-D$, i.e., $h_{RD} \simeq h_{SD}$, then more power is required in the BC mode comparing to the MAC mode. Furthermore, if the channel quality of the $R-D$ is much larger when compared to the channel quality of $S-D$, i.e., $h_{RD} >> h_{SD}$, then P_m approaches to zero and P_b approaches to total power P_{dt} .

2. We observe that less power is required in the MAC mode when compared to the BC mode. Note that, we can divide the power in the MAC mode between source and relay, hence $P_m = P_{S,m} + P_{R,m}$ where $P_{S,m}$ is the power of the signal transmitted from source in the MAC mode and $P_{R,m}$ is the power of the signal transmitted from the relay in the MAC mode. In our study, we consider the same amount of power for source and relay.

6.4.2. Erroneous Data at Relay

In this sub-section, we consider the case in which the data received at the relay includes some bit errors after decoding operation, which means that relay does not make retransmission. The optimization function according to (6.8) considering the erroneous data at the relay is given as:

$$F_{errors}(P_b, P_m) = \frac{1}{B\,P_b + C\,P_m}\left(\frac{1}{\widehat{m}J\,P_b} + \frac{1}{A\,P_m}\right), s.t\ P_{dt} = P_b + P_m \quad (6.16)$$

where $\widehat{m} = M/M-1$. Taking the derivative of (6.16) with respect to P_b and equating to zero we get

$$2\,ABP_bP_m + mJBP_b^2 + ACP_m^2 = 0 \quad (6.17)$$

where substituting $P_b = (P_{dt}P/P+1)$ and $P_m = (P_{dt}/P+1)$ and solving the quadratic equation for P, we get:

$$P = \frac{mBJ}{MBJ + AB + \sqrt{A^2B^2 - mABCJ}} \quad (6.18)$$

Replacing the explicit expressions for A, B, C and J in (6.18), and taking into account the assumption given in (6.6), the OPAs are found as:

$$P_b = \frac{h_{RD} + \sqrt{|h_{RD}^2 - \widehat{m}\,h_{SR}h_{RD}|}}{(\widehat{m}\,h_{SR} + h_{RD}) + \sqrt{|h_{RD}^2 - \widehat{m}\,h_{SR}h_{RD}|}} P_{dt}$$

(6.19)

$$P_m = \frac{\widehat{m}\, h_{SR}}{(\widehat{m}\, h_{SR} + h_{RD}) + \sqrt{|h_{RD}^2 - \widehat{m}\, h_{SR} h_{RD}|}} P_{dt}$$

(6.20)

Considering the derived expressions (6.19) and (6.20) we can draw the following results for OPAs in case of erroneous data at the relay.

1. OPAs depend on channels qualities of $S-R$ and $R-D$ links. The channel quality of the $S-D$ has no effect on OPAs. If the channels quality of the $S-R$ larger than the channel quality of the $R-D$, $i.e.\ h_{SR} > h_{RD}$, then more power is required in the MAC mode than in the BC mode, and if the channel quality of $S-R$ is much larger than the channel quality of $R-D$, i.e., $h_{SR} >> h_{RD}$ then the P_b approaches to zero and P_m approaches to total power. Further, if the channel quality of $S-R$ is less than the channel quality of the $R-D$, $i.e.\ h_{RD} > h_{SR}$, then then more power required in the BC mode than in the MAC mode and if the channel quality of the $S-R$ is much less than the channel quality of the $R-D$, i.e., $h_{SR} << h_{RD}$, then the P_m approaches to zero and P_b approaches to total power P_{dt}, moreover, if the channel quality of $S-R$ equals the channel quality of $R-D$, $i.e.\ h_{SR} = h_{RD}$, then more power required in the MAC mode than in the BC mode, $P_b < P_m$.
2. OPAs depend on the modulation order M(modulation level). If the modulation order is larger than 2, i.e., $M > 2$, then more power is required in MAC than the power required in the BC mode, furthermore if the modulation order is much greater than 2, i.e., $M >> 2$, then the P_b approaches to zero and P_m approaches to total power P_{dt} assuming that all the channels have similar qualities.
3. Finally, the required power of the BC mode is less than the required power of the MAC mode, when all channels have similar qualities.

Note that, if P_b approach to zero and P_m approach to total power P_{dt}, it favorable to use the CC instead of direct transmission, while, if the P_m approach to zero and P_b approach to total power P_{dt} then direct communication more favorable.

6.5. Optimum Code Rate Allocation for Distributed Coded Cooperation

In distributed coded cooperation the total code rate of the encoder are shared between BC and MAC modes i.e., $R_{dt} = (1/R_b + 1/R_m)^{-1}$, where R_{dt} is the total code rate or direct transmission mode code rate, $i.e.\ R_{dt} < R_b$ and $R_{dt} < R_m$, R_b is the code rate at the first phase of the transmission operation, i.e., source broadcasting to the relay and destination and R_m is the code rate at the second phase of the transmission, i.e., transmission of data from the source and relay either on orthogonal channels or on competing time slots. In fact, we assume that the channel quality between $S - D$ does not change during the cooperation, but the channel qualities of $S - R$, and $R - D$ links can change during the cooperation. Then we can ask the question: can we change the rate with respect to channel variations of $S - R$ and the $R - D$ links? The solution of this problem can be achieved by finding the optimal code rate as a function of both channels.

Fortunately, the derivation of the optimal code rate allocation as a function both channels, h_{SR} and h_{RD} can be done in the same way that has been done for optimal power allocation that was given in the Section 6.3. According to PEP given in (6.7), the optimization function (as code rate function) can be written as:

$$F_{errors}\left(\beta_b, \beta_m\right) = \left(\left|h_{SD}\right|^2 \left(\frac{P_b}{\beta_b} + \frac{P_m}{\beta_m}\right)\right)^{-1} \left(\frac{m\beta_b}{P_b \left|h_{SR}\right|^2} + \frac{\beta_m}{P_m \left|h_{RD}\right|^2}\right),$$
$$s.t\ \beta_{dt} = \beta_b + \beta_m$$

(6.21)

For the sake of the simplicity, we delete the term $P_m/\beta m$ from equation (6.21), we can rewrite (6.21) as:

$$F_{errors}\left(\beta_b, \beta_m\right) = \left(\left|h_{SD}\right|^2 \frac{P_b}{\beta_b}\right)^{-1} \left(\frac{m\beta_b}{P_b \left|h_{SR}\right|^2} + \frac{\beta_m}{P_m \left|h_{RD}\right|^2}\right)$$

(6.22)

Calculating the logarithm of (6.22) and substituting $\beta_b = \beta_{dt}/(\beta+1)$ and $\beta_m = \beta_{dt}\beta/(\beta+1)$, and then taking derivative with respect to β and equating to zero we get:

$$-mP_m h_{RD}\beta^2 + (P_b h_{SR} + 2mP_m h_{RD})\beta + P_b h_{SR} = 0$$

(6.23)

where β_b is the portion of time for transmitting encoded bits in the BC mode, β_m is the portion of time for transmitting encoded bits in the MAC mode, β_{dt} is the total time of both modes or direct transmission mode , and $R_{dt} = (\beta_b/R_{dt} + \beta_m/R_{dt})^{-1}$, the optimum code rate allocation (OCRA) is given as:

$$\beta_b = \frac{mP_m h_{SR}}{2mP_m h_{RD} + \sqrt{mP_m h_{RD}(mP_m h_{RD} + P_b h_{SR})}} \tag{6.24}$$

$$\beta_m = \frac{\sqrt{mP_m h_{RD}(mP_m h_{RD} + P_b h_{SR})}}{2mP_m h_{RD} + \sqrt{mP_m h_{RD}(mP_m h_{RD} + P_b h_{SR})}} \tag{6.25}$$

where $m = M - 1/M$. The interpretation of (6.24) and (6.25) is as follows:

1. Optimum rate allocation depends on channel qualities of the $S - R$ and $R - D$ links, the channel quality of the $S - D$ has no effect in optimum rate allocation. If the channel quality of $S - R$ is better than the channel quality of $R - D$, $i.e., h_{SR} > h_{RD}$, this results in larger code rates in BC mode and smaller code rates in MAC mode and if $h_{SR} >> h_{RD}$, then R_m is much less than R_b which means that β_m is much greater than β_b. On the other hand, if the channel quality from $R - D$ is better than the channel quality from the $S - Ri.e.h_{RD} > h_{SR}$, then smaller code rates are available in BC mode relatively higher code rates are available in MAC mode, and if $h_{SR} << h_{RD}$, then R_m approach to 0.5 and R_b approach to 0.5.
2. Modulation order M(modulation level) affect the optimum rate allocation. If modulation order $M > 2$, then the lower code rates are required in the BC and higher code rates are available in MAC mode, and if$M >> 2$, then R_m is much less than R_b meaning that β_m is much greater than β_b, ssuming that the quality of the channels are similar to each other.
3. Signal power transmission also affects the code rate such that if the signal power in BC mode is greater than the signal power in MAC mode, $i.e.\ P_b > P_m$, then lower code rate is require in MAC mode and higher code rate is require in broadcasting mode, in other word, R_m approach to R_c and R_b approach to 1 or β_m approach to β_{dt} and β_b approach to zero. It is clear that, if β_b approach to zero and β_m approach to β_{dt}, we can use cooperative communication instead of direct transmission, on the other hand, if β_m has very small values close to

zero and β_b has a value similar to β_{dt}, then direct communication mode is more favorable.

4. If the channel qualities have the same amount, i.e., $h_{SR} = h_{RD}$, then more code rate is required in MAC mode than BC mode, i.e., $\beta_b < \beta_m$.

6.6. Performance Results

In this section, we numerically calculate the performance of the OPA and OCRA of DISTRIBUTED CODED COOPERATION through the theoretical formulas derived in the previous sections. The numerical calculation results, which are depicted in Table 1, Figs. 25 and 26, are explained as follows.

Considering the lines in Fig. 25 we can draw the following results. Considering the case for which $S-R$ and $S-D$ channels are perfect, i.e., $h_{SR} = h_{SD} = 1,$ and successful decoding occurs at the relay, i.e. error free data at the relay , then optimal power allocation in BC mode $P_b/P_{dt} = 0.375$ shows better performance when compared to the equal power allocation $P_b/P_{dt} = 0.5$. On the other hand, with erroneous data at the relay even though channels are perfect optimal power allocation in BC mode $P_b/P_{dt} = 0.4$ shows slightly better performance than equal power allocation scheme $P_b/P_{dt} = 0.5$. Furthermore, if channels quality aren't equal to each other, for instance $h_{SR} = 1, h_{SD} = 10, ER$, then optimal power allocation in BC mode $P_b/P_{dt} = 0.087$ shows better performance when compared to the equal power allocation $P_b/P_{dt} = 0.5$. The error free relayed data case has better performance when compared to the erroneous data case at the relay even optimal power allocation or equal power allocation is employed.

The results of Fig. 26 can be summarized as follow. For the equal channel quality and erroneous data at the relay case optimal code rate allocation in BC mode $\beta_b/\beta_{dt} = 0.276$ shows better performance when compared to the equal code rate allocation in BC mode $\beta_b/\beta_{dt} = 0.5$. Furthermore, if channels quality aren't equal to each other, for instance $h_{SR} = 1, h_{SD} = 10$ or $h_{SR} = 10, h_{SD} = 1$, and considering the erroneous data at the relay it is seen that

the optimal code rate allocation in BC mode $\beta_b/\beta_{dt} = 0.327$ or $\beta_b/\beta_{dt} = 0.15$, shows better performance than equal code rate allocation.

In addition considering the 10^{-5} value of PEP we see that the optimal code rate allocation has 1 dB better performance compared to equal code rate allocation, and optimal power allocation has 0.75 dB better performance compared to equal power allocation.

Table 4: Optimal power/Code rate allocation for single relay-cooperation

Optimum Allocation	Relayed Data	$h_{SD}=1, h_{SR}[1-10], h_{RD}[1-10]$				
		$h_{SR} > h_{RD}$	$h_{SR} < h_{RD}$	$h_{SR} = h_{RD}$	$h_{RD}=10$	$h_{RD}=1$
Power	Not Include Error, EFR	-	-	-	$P_b=0.212\ P_{dt}$ $P_m=0.788\ P_{dt}$	$P_b=0.16\ P_{dt}$ $P_m=0.84\ P_{dt}$
	Include Error, ER	$P_b=0.087\ P_{dt}$ $P_m=0.913\ P_{dt}$	$P_b=0.9045\ P_{dt}$ $P_m=0.09549\ P_{dt}$	$P_b=0.4\ P_{dt}$ $P_m=0.6\ P_{dt}$	-	-
Code Rate	Include Error, ER	$\beta_b=0.15\ \beta_{dt}$ $\beta_m=0.85\ \beta_{dt}$	$\beta_b=0.327\ \beta_{dt}$ $\beta_m=0.673\ \beta_{dt}$	$\beta_b=0.267\ \beta_{dt}$ $\beta_m=0.732\ \beta_{dt}$	-	-

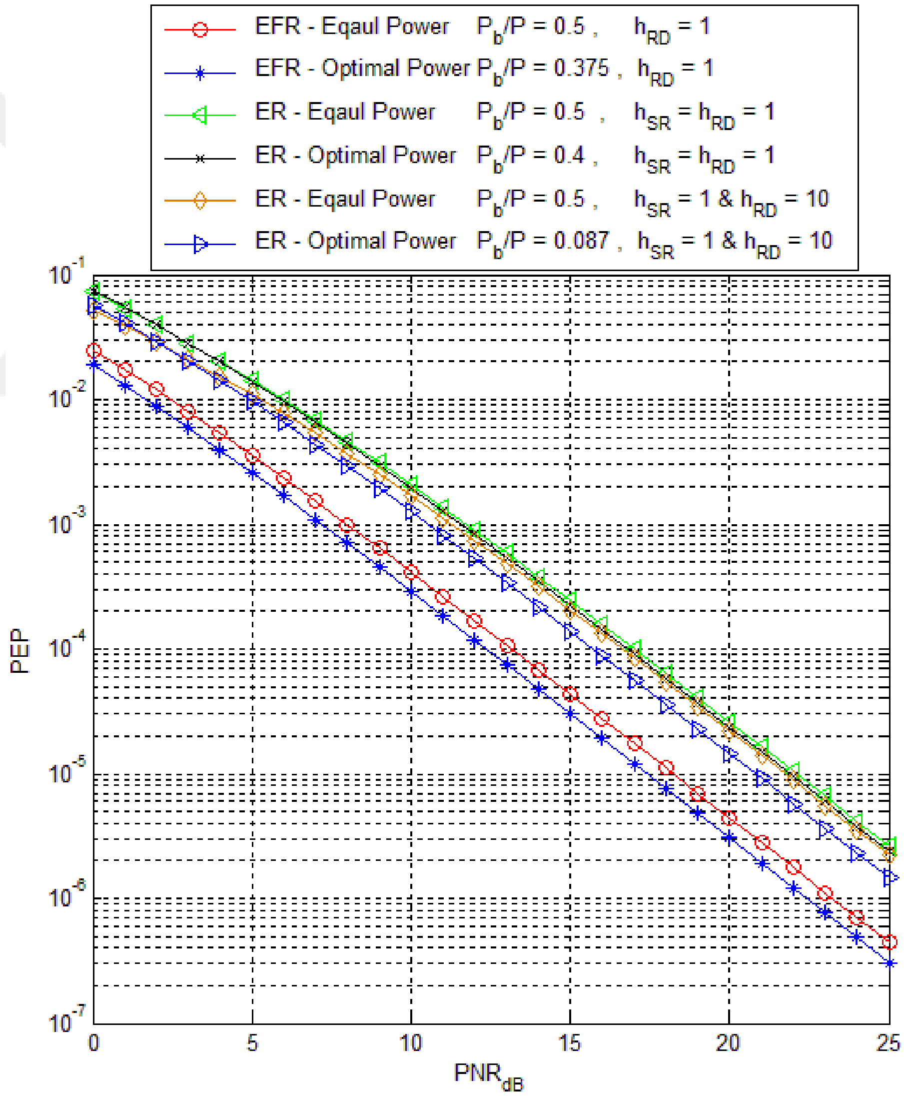


Fig. 25: Comparison of the PEP for MPSK (M =2) modulation for EPA with OPA of both the EFR case and of the ER case.

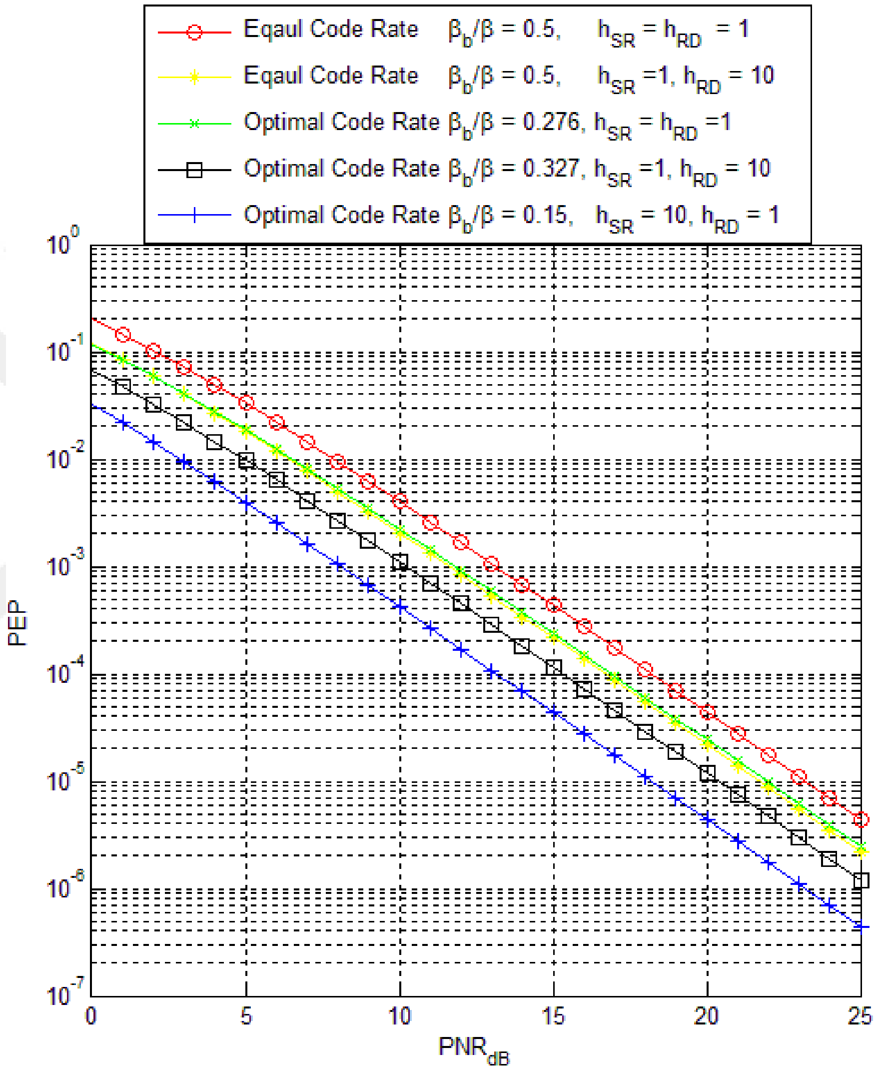


Fig. 26: Comparison of the PEP for MPSK (M =2) modulation for ECRA and OCRA of ER.

CHAPTER 7
CONCLUSIONS AND FUTURE WORKS

In this thesis, we have developed and analyzed a cross-layer agenda for exploiting the cooperative communication systems in wireless networks. In particular, we have designed new relay nodes selection scheme across the data link layer that can increase network throughput, connectivity, and delay reduction, quick relay node selection. On other hand, we have designed new relay nodes selection scheme across the physical layer that can increase spectral efficiency, diversity order, and reduce bit error rate and outage probability. Furthermore, we obtained optimal power allocation and code rate allocation that can reduce bit error rate.

The main conclusions and suggested future work for each part are summarized below:

- In chapter 3, we have proposed a cooperative MAC protocol for decentralized DWN in which the proposed schemes consider the best single or multiple relays selection, delay, and collision avoidance. We also investigated a BTF; when the channel parameters between the relay and destination are bad, a longer time will be associated with the relay and vice versa. We have demonstrated that connectivity in the cooperation is improved which results in an increased node degree. Finally, we have shown that employing cooperation leads to higher delays and decreased the throughput of a DWN.
- Possible future work for this chapter
    - In future work, we can reduce the delay by using a different frequency channel for source and relay nodes through cognitive systems rather than the single frequency channel that used by the source and relay nodes for contention channel accessing based.
    - Reduce transmission power of relay nodes through power control or optimal power allocation to reduce the prohibited area that can improve the throughput of the cooperative communication systems.
- In chapter 4, we have proposed a relay selection protocol for Cooperative communication systems, namely MLSRD. The proposed protocol has been

shown to be effective in providing both spectral efficiency and diversity gain. We have verified the advantage of the relay selection in providing spectral efficiency and diversity gain through analysis and numerical results. We have observed that, if the selection criteria based on the maximum links from *S - R* and *R -D* gives better performance compared to selection criteria based on the maximum harmonic mean. In addition, we have considered the convolutional distribution codes in our analysis which not considered in exiting work.

- Possible future work for this chapter
    - We will investigate the MLSRD for wireless ad hoc network, where the selection is elaborated from relay selection to next hop and relay selection jointly which can offer better performance for wireless ad hoc networks.
    - It is also promising future work to develop a relay node selection for cooperative communication systems based on cognitive channels. In such, we selected relay node that already assigned unlicensed or licensed channel.
    - In the dense wireless network, source can have many intermediate nodes that can be exploit for cooperation. In such, we can propose two best relay nodes selection instead of single relay node selection for contention free channel accessing based.
- In chapter 5, we derived optimal power allocation formulas for cooperative communication systems with single relay and employing distributed convolutional codes. If the received data at the relay includes errors after decoding operation it is not retransmitted otherwise it is retransmitted. We found optimal power allocation in the BC mode and the MAC modes. It is seen that optimal power allocation results is smaller PEP compared to equal power allocation schemes. Next, we derived optimal code rate allocation formulas. It is shown that optimal code rate allocation results in better performance than both the equal code rate allocation and optimal power allocation.
- Possible future work for this chapter
    - It is promising to develop joint optimal power allocation and relay node selection or code rate allocation and relay node selection.

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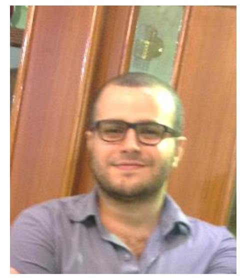
APPENDICES A

CURRICULUM VITAE

PERSONAL INFORMATION



Surname, Name: Ahmed, AlKHAYYAT

Date and Place of Birth: 28 Feb 1985, Iraq

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EDUCATION

Degree	**Institution**	**Year of Graduation**
Ph.D.	Cankaya Univ. Electronics and Communication engineering	2015
M.Sc.	Dehradun Instituted of Technology , IIT Rooke, India	2010
B.Sc.	Al-Kuffa Univ. General Electrical engineering	2007
High School	Najaf for Boys	2003

FOREIN LANGUAGES

Advanced English

PUBLICATIONS

- The Role of Delay and Connectivity in Throughput Reduction of Cooperative Decentralized Wireless Networks, Ahmed Alkhayyat, Orhan Gazi, and Sattar B. Sadkhan
  Mathematical Problems in Engineering
  Volume 2015 (2015), Article ID 294016, 10 pages

- Joint Next-Hop/Relay Selection for Distributive Multihop Cooperative Networks, Ahmed Alkhayyat
  Discrete Dynamics in Nature and Society
  Volume 2015 (2015), Article ID 613168, 10 pages

PROJECTS

Improving Capacity of the Ad hoc networks through using Smart antennas base on Honey Grid Model

HOBBIES
Games, Travel, Books, Fitness