Efficient Power Allocation Schemes for Hybrid Decode-Amplify-Forward Relay Based Wireless Cooperative Network

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Efficient Power Allocation Schemes for Hybrid Decode-Amplify-Forward Relay Based Wireless Cooperative Network

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This is to certify that the work presented in the dissertation entitled Efficient power allocation schemes for hybrid decode-amplify-forward relay based wireless cooperative network submitted by *Kiran Kumar Gurrala*, Roll Number 511EE104, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Electrical Engineering. Neither this dissertation nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

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Declaration of Originality

I, Kiran Kumar Gurralala, Roll Number 511EE104 hereby declare that this dissertation entitled Guidelines for Formatting Dissertation presents my original work carried out as a doctoral student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections “Reference” or “Bibliography”. I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

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Abstract

Cooperative communication in various wireless domains, such as cellular networks, sensor networks and wireless ad hoc networks, has gained significant interest recently. In cooperative network, relays between the source and the destination, form a virtual MIMO that creates spatial diversity at the destination, which overcomes the fading effect of wireless channels. Such relay assisted schemes have potential to increase the channel capacity and network coverage. Most current research on cooperative communication are focused broadly on efficient protocol design and analysis, resource allocation, relay selection and cross layer optimization. The first part of this research aims at introducing hybrid decode-amplify-forward (HDAF) relaying in a distributed Alamouti coded cooperative network. Performance of such adaptive relaying scheme in terms of symbol error rate (SER), outage probability and average channel capacity is derived theoretically and verified through simulation based study. This work is further extended to a generalized multi HDAF relaying cooperative frame work. Various efficient power allocation schemes such as maximized channel capacity based, minimized SER based and total power minimization based are proposed and their superiority in performance over the existing equal power allocation scheme is demonstrated in the simulation results. Due to the broadcast nature of wireless transmission, information privacy in wireless networks becomes a critical issue. In the context of physical layer security, the role of multi HDAF relaying based cooperative model with control jamming and multiple eavesdroppers is explored in the second part of the research. Performance evaluation parameters such as secrecy rate, secrecy outage and intercept probability are derived theoretically. Further the importance of the proposed power allocation schemes in enhancing the secrecy performance of the network in the presence of multiple eavesdroppers is studied in detail through simulation based study and analysis. For all the proposed power allocation schemes in this research, the optimization problems are defined under total power constraint and are solved using Lagrange multiplier method and also evolutionary algorithms such as Differential evolution and Invasive Weed Optimization are employed. Monte Carlo simulation based study is adopted throughout the research. It is concluded that HDAF relaying based wireless cooperative network with optimal power allocation schemes offers improved and reliable performance compared to conventional amplify forward and decode forward relaying schemes. Above research contributions will be applicable for future generation wireless cooperative networks.

***Key words: Cooperative network, hybrid decode-amplify-forward, power allocation, symbol error rate, outage probability, channel capacity, secrecy rate, control jamming*.**

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List of Abbreviations

1. AWGN	Additive white Gaussian noise
2. AF	Amplify-and-forward
3. CSI	Channel state information
4. CR	Conventional relaying
5. CF	Cost function
6. CDF	Cumulative distribution function
7. DF	Decode-and-forward
8. DE	Differential evolution algorithm
9. DEPA	Differential evolution algorithm based power allocation
10. EPA	Equal power allocation
11. HDAF	Hybrid decode-amplify-forward
12. KKT	Karush-kuhn-Tucker
13. LPA	Lagrange multiplier method based power allocation
14. LoS	Line of sight
15. MRC	Maximal ratio combining
16. MGF	Moment generating function
17. MIMO	Multiple input multiple output
18. OSCJ	Optimal selection with control jamming
19. OSJ	Optimal selection with jamming
20. QPSK	Quadrature phase shift keying
21. QoS	Quality of service
22. SNR	Signal-to-noise ratio
23. STBC	Space time block code
24. SER	Symbol error rate
25. TDMA	Time division multiple access

List of symbols

β_i	Amplification factor of the ith relay
$CN(0,\sigma_{ab}^2)$	Complex random variable with variance σ_{ab}^2
C_d	Decoding set (Relays which decode the received signal perfectly)
$E_1(.)$	Exponential integral which is defined as $E_1(x)=\int_x^\infty \frac{\exp(-t)}{t}dt$
λ	Lagrangian Multiplier
N_o	Noise power (assumed as normalized to 1)
N	Number of relay nodes in the cooperative network
α	Path loss exponent
α_i	Power allocation factor of the ith relay
S_{eaves}	Set of eavesdroppers
γ	Signal to noise ratio
R	Target rate
$h_{r_i d}$	The channel link between the ith relay and the destination
$h_{r_i e}$	The channel link between the ith relay and the eavesdropper
h_{s,r_i}	The channel link between the source and i^{th} relay and
d_{ab}	The Euclidean distance between the nodes a and b
g	The individual generation
x	The information signal from the source node
y_{s,r_i}	The information signal received at the i_{th} relay
SNR_{ij}	The instantaneous SNR of the $i \rightarrow j$ link
D	The number of parameters of objective function
NP	The number of population members
Gd	The total number of generations
σ_{ab}^2	The variance of the channel link $a \rightarrow b$
P_T	Total transmit power $(P_T = P_s + P_r + P_j)$
P_j	Transmit power of jammer node
P_r	Transmit power of relay node
P_s	Transmit power of source node
n_{xy}	Zero mean complex Gaussian random variables with variance σ_{xy}^2

Chapter 1

Introduction

Next generation wireless networks using 4G/5G standards are expected to provide a variety of services including voice, data and video. The rapidly growing demand for new multimedia applications needs high data rate wireless devices with enhanced quality and high user capacity. Recently, it has been shown that reliability and achievable data rate of wireless communication systems increase dramatically by employing multiple transmitter and receiver antennas. Specifically, due to the size, cost, or hardware limitations, a wireless device may not be able to support multiple antennas. In order to overcome this problem, a new mode of transmit diversity called cooperative diversity based on user cooperation, has been suggested in recent past by researchers. Such cooperative communication based on relaying nodes has been introduced in Long-term Evolution (LTE) release 10 and presently it is a vibrant area of research in industry and academia. Cooperative communication provides several advantages compared to point to point and point to multiple point transmission with respect to signal quality improvement, efficient power utilization, improved coverage and capacity enhancement. The advantages like diversity gain, virtual antenna gain and channel link quality enhancement lead to the signal quality improvement. Due to more than one link (direct source-to-destination link & links via relays), cooperative diversity systems attain improvement in diversity gain. All the channel links may not have been suffered with same level of fading which leads to the SNR improvement. As the SNR at the receiver increases, the symbol error rate will reduce and at the same time channel capacity will increase. Further with the proper relay selection, cooperative diversity systems have better channel link quality over the direct link. For the same end-to-end SNR level, the transmitted power required for cooperative diversity system is less compared to direct transmission. With all these advantages, cooperative diversity scheme is found suitable in many areas of applications like wireless networks (ad-hoc), wireless sensor networks, vehicular networks etc.

Even though cooperative diversity in wireless network is well investigated, there are several issues which are are to be solved in order to improve the system performance. Optimized resource allocation, relay selection, full duplex operation of relay nodes, implementation complexity of relaying protocols, multi hop relay communication are the

major focus. Moreover a detailed performance analysis of the cooperative wireless network in various fading channel environments is needed for different types of relaying protocols. In addition, physical layer security in wireless networks is another important issue to be addressed. It is due to the fact that the relay node transmissions have to be protected from malicious users (eavesdroppers), which leads to either weakening the relay node or unreliable cooperative transmission. Hence implementation of low complexity algorithms and relaying protocols with proper security mechanisms becomes necessary to derive the advantages of cooperative diversity. Though many researchers have proposed several solutions, the aforementioned limitations of cooperative network in the context of future wireless application still remain an open problem. This research work proposes techniques for efficient power allocation in wireless cooperative network.

1.1 Background theory

The basic of the cooperative communication in wireless network is the relay channel concept which was introduced by the authors Cover and El Gamal based on the information theoretic properties [1]. The authors analyzed the performance of three node network in terms of channel capacity which consists of a source, a cooperative agent called relay and the destination in an additive white Gaussian noise channel. Motivated by this concept, the relays are applied to obtain diversity in fading channels which is called cooperative diversity. The cooperative diversity exhibits the broadcast nature of the wireless network and allows the relay nodes to help the source node by jointly transmitting the information to the destination. The basic cooperation model is represented as Fig 1.1. The total transmission is categorized into two orthogonal phases, either TDMA or FDMA. The phases of cooperative communication are broadcast phase and cooperative phase. In broadcast phase, the source transmits the information to the relay and the destination simultaneously. In cooperative phase, the relay acts as cooperative agent to help the source by forwarding or retransmitting the received signal to the destination. In broadcast phase, the signals received at the relay and the destinations are y_{sr} , y_{sd} respectively which are represented as

$$y_{sr} = \sqrt{P_s} h_{sr} x + n_{sr} \,;\, y_{sd} = \sqrt{P_s} h_{sd} x + n_{sd} \tag{1.1}$$

Here x is the information signal, P_s is the source power, h_{sr}, h_{sd} are channel links

between the source-to-relay and source-to-destination links respectively. The terms n_{sr} and n_{sd} are the Additive White Gaussian Noise (AWGN) introduced in source-to-relay and source-to-destination link respectively.

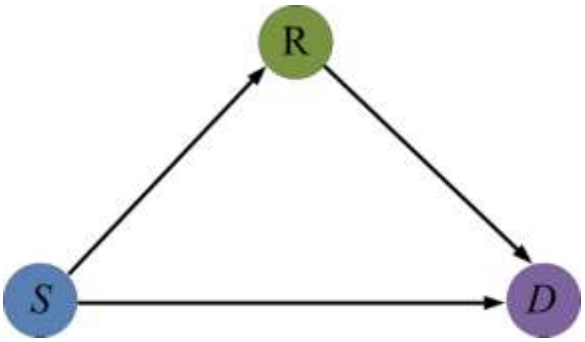


Figure 1.1 Simple relay model

In cooperative phase, the relay processes the received signal and forwards it to the destination. The received signal at the destination y_{rd} is given by

$$y_{rd} = \sqrt{P_r} h_{rd}\, a(y_{sr}) + n_{rd} \tag{1.2}$$

Here the processing function $a(.)$ represents type of the relaying used. P_r is the relay power. h_{rd} is channel coefficients of the relay-to-destination link.

The received signal processing at the relay determines the type of relaying which means that different processing schemes at the relay result in different relaying protocols. These cooperative relaying protocols are basically categorized into fixed relaying and adaptive relaying protocols which are discussed briefly as follows.

1.1.1 Fixed relaying protocols

In fixed relaying, channel resources are shared among the source and relay nodes in a deterministic manner and generally over two phases. In the first “broadcasting” phase, the source broadcasts the information signal to both the destination and relay nodes. In the second “cooperation” phase, the relay re-transmits a processed version of its received signal to the destination. Depending on the type of cooperation protocol, the processing at the relay is determined. The basic types of fixed relaying are as follows

- Fixed amplify and forward relaying (AF) protocol [3]: The fixed AF relay just scales the received signal from source along with the noise added and retransmits it to the destination. The AF protocol as shown in Fig.1.2 has the

advantages like low implementation complexity and provides diversity order of 2. Here, AF protocol suffers from the noise amplification and propagation which can degrade the signal strength. The signal representation is given as

$$y_{rd} = \sqrt{P_r}\, h_{rd}\, \beta\, y_{sr} + n_{rd} \tag{1.3}$$

$$\beta = \frac{\sqrt{P_r}}{\sqrt{P_s |h_{sr}|^2 + N_o}} \tag{1.4}$$

where β is the amplification factor of the AF relay.

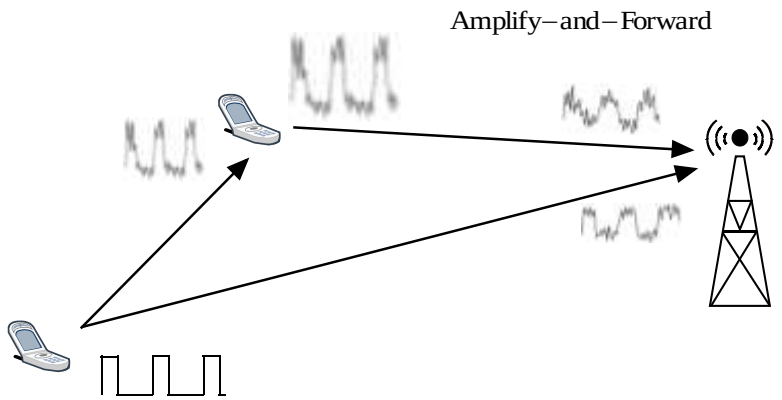


Figure 1.2 Amplify and forward cooperative protocol

- Fixed decode and forward relaying (DF) protocol [3]: The fixed DF relay decodes its received signal, re-encodes it, and then forwards it to the destination as shown in Fig.1.3.

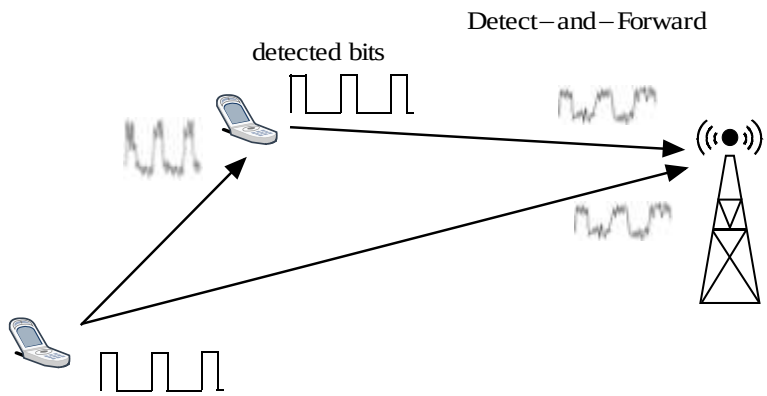


Figure 1.3 Decode and Forward cooperative protocol

If the DF relay unable to decode the received signal perfectly, the error propagation may occur. So in this DF protocol, noise does not propagate but error may propagate. With the assurance of perfect decoding of the received

signal, DF relay protocol achieves a diversity order of two.

The received signal from the DF relay at the destination is represented by

$$y_{rd} = \sqrt{P_r} h_{rd}\ x + n_{rd} \tag{1.5}$$

If the relay decodes the signal perfectly, the relay provided with the power P_r otherwise the relay power is set to zero.

- Coded cooperative communication protocol [3]: Cooperative communication and network coding have been proven to be robust and efficient. This technique as shown in Fig.1.4 allows the simultaneous reception of several signals in same time-slot; hence, spectrum efficiency of the system improves.

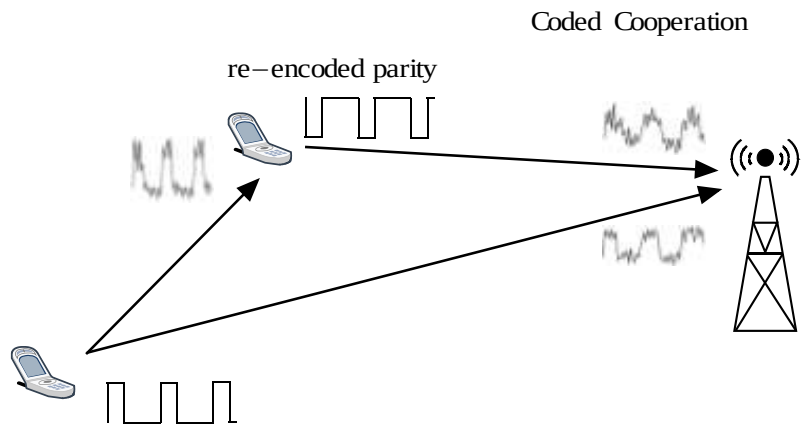


Figure 1.4 Coded cooperation protocol

1.1.2 Adaptive relaying protocols

Even though the fixed relaying schemes have the advantage of easy implementation, they suffer from the limitations like noise/error propagation which reduce the performance of the network significantly. Another limitation is that, the fixed relaying protocols are bandwidth inefficient. It is due to the fact that the channel resources are being shared among the nodes (source and relays) even though the source-to-destination channel link is not necessarily in bad condition which leads to overall rate reduction. The relay forwards the signal to the destination only if it is able to decode the signal correctly.

- Incremental relaying [4]: In this protocol, there is feedback channel from destination to the relay through which the destination can send an acknowledgement to the relay about the perfect reception of the information signal

from source. If the destination is able to receive the source signal perfectly, the relay does not need to transmit. This protocol limits the cooperation according to the source-to-destination link quality.

- Hybrid relaying [4]: The hybrid decode-amplify-forward (HDAF) relay adaptively chooses to operate either AF relaying or DF relaying based on certain condition like SNR threshold, decoding capability etc.

1.1.3 Diversity combining strategies

In a wireless cooperative network, the source broadcasts multiple copies of information signal to number of relays in different paths and these multipath signals are appropriately combined at the destination using the diversity combing strategies. Here, the basic types of diversity combining strategies are discussed briefly.

- Selection Combining (SC): In selection combining, diversity branch with the highest SNR of individual component is chosen at receiver and co-phasing is not required. The block diagram of this scheme is shown below in Fig 1.5.

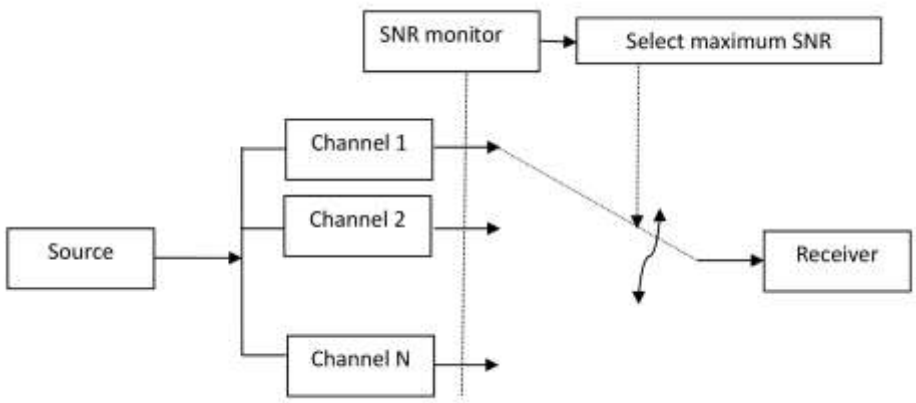


Figure 1.5 Selection combining

- Switch and stay combining (SSC): Switch and stay combining is a simplified form of selection combining. In this scheme, the receiver selects another branch only if SNR of the current branch falls below the required threshold.

- Maximum-ratio combining (MRC): This is an important diversity combining strategy in which all the available paths are combined in a co-phased and weighted manner such that the effective SNR at the receiver is improved. The block diagram of this scheme is shown below in Fig 1.6.

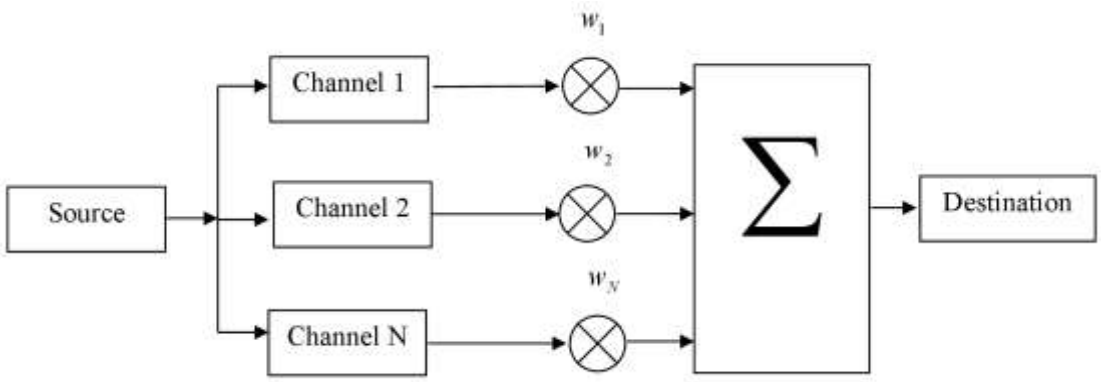


Figure 1.6 Maximal ratio combining

1.2 . Literature review

1.2.1 Cooperative diversity

Cooperative diversity is a new spatial diversity scheme to mitigate the multi path fading by creating a virtual MIMO (multiple input multiple output) system with the cooperation of single antenna relay nodes in between the source and the destination. The basic idea is that single antenna nodes share their antennas to produce virtual MIMO system in a multiuser environment to get spatial diversity [3]. Hence cooperative communication exploits both the spatial and time diversity by using the broadcast nature of wireless medium, is introduced in [4]. A collection of distributed antennas belonging to multiple users, which are dispersed at different locations, in a network is called distributed spatial diversity network. In a distributed cooperative network, transmit diversity is achieved when the selected single antenna relays cooperate the source by forwarding signal to the destination based on relaying protocol. The author in [5], derived the average symbol error rate of the distributed diversity system which overcomes the severe penalty in signal to noise ratio caused by Rayleigh fading. Basic fixed relaying protocols are discussed in [6]. The author in [8] has given the overview of recent development in distributed coding design in cooperative wireless network. In distributed coding based cooperative networks, the whole codeword is constructed in a distributed manner among the cooperative users. Alamouti [7], introduced a powerful space time code which provides full rate and full diversity over complex constellation with symbol wise ML (Maximum Likelihood) decoding. Distributed Alamouti code (extension to Alamouti code), which is applied in distributed cooperative network is introduced [9-10]. In distributed Alamouti code based cooperative network, the selected two relays simultaneously receive a noisy signal from

the source and construct their Alamouti space codes in a distributed manner before forwarding the signals to the destination. The distributed Alamouti code is formed by the single antenna source and the relay. Each terminal transmits each row of Alamouti code. Exact closed form expressions for SER and pair wise error probability of distributed Alamouti scheme with full diversity are derived in [9]. The authors in [11], analyzed the BER performance of the distributed Alamouti code for cooperative network consisting of a source, two relays and a destination node over Rayleigh fading channel with and without direct link condition. Amongst all the cooperative relaying schemes amplify and forward (AF) and decode and forward (DF) are well known relaying strategies. The relay just amplifies the noisy version of received signal from the source and retransmits it to the destination in AF scheme. In the DF scheme, the relay detects the received signal from the source and retransmits the detected signal to the destination [3-4]. The closed form expressions for outage probability and SER of multi relay network with hybrid scheme over independent and non identical Rayleigh flat fading are given in [17]. The SER analysis and power allocation of multi relay network with hybrid DAF scheme are explained in [18]. The authors in [19] proposed a hybrid decode amplify forward incremental cooperative diversity protocol using SNR based relay selection. The HDAF relaying is explained in [20-30].

1.2.2 Power allocation in wireless cooperative network

Power allocation for wireless cooperative network is a promising research area. In addition fixed and adaptive protocols are also introduced for decode and forward relaying as fixed DF relaying and adaptive relaying respectively. SER performance analysis and optimum power allocation for wireless cooperative network with basic relaying schemes are proposed in [31]. Minimized SER based optimum power allocation with the best relay selection for multi relay AF network is proposed in [32]. The authors introduced optimum power allocation schemes based on SER for adaptive relaying schemes in dual hop multi relay cooperative network in [33]. A new cooperative relaying scheme, named, hybrid decode amplify forward (HDAF) which combines the advantages of both the AF and adaptive DF is proposed in [36]. The authors have extended the hybrid relaying scheme to the multiple relays and obtained the performance analysis in [35]. SNR based hybrid relaying which is a combination of fixed AF and DF relaying schemes is proposed for single relay case in [36]. The closed form tight bounds for the outage probability and bit

error rate of the HDAF relaying for multi relay network are derived in [17]. The authors proposed power allocation methods for both minimizing outage probability and minimizing SER based on channel state information and channel statistics in [77]. The closed form expression for SER is derived for single relay cooperative network using moment generating function (MGF) approach for hybrid relaying and based on the SER upper bound optimum power allocation is obtained in [78]. A novel quasi-optimal power allocation scheme to maximize the upper bound of the ergodic capacity of multi AF relay cooperative network is proposed in [79]. Effective capacity maximization based power allocation using particle swarm optimization (PSO) in multi relay cooperative network is proposed in [81].

1.2.3 Cooperative relaying for Physical layer security

The secure communication between the source and the destination in the presence of unauthorized receivers i.e. eavesdroppers is of great importance. The information theoretic secrecy is introduced by Shannon in [85]. Wireless secure communication issue is addressed at the upper layers of the protocol stack using cryptography algorithms like private key management complexity which are complex for implementation in [87]. Recently, implementing information security at the physical layer is the emerging research area. The performance metric for physical layers security is secrecy rate which is defined in terms of the difference of direct link (between source and destination) capacity and the eavesdroppers link capacity. The secrecy rate represents the rate at which the source securely transmits the data to the destination in the presence of eavesdroppers. For the Gaussian channel, the secrecy rate is the difference between the capacities of main and wiretap channels which is a non zero value [86]. To get a non zero secrecy rate that means for perfect secure transmission, the signal-to-noise ratio (SNR) at the unauthorized users tends to degrade when compared to the destination [88]. The secrecy rate in terms of the outage probability at which the eavesdropper unable to decode the information from the source is obtained in [91-92]. The main purpose is to enhance the capacity of main confidential link while the capacity of eavesdropper link decreases. The relays help the source by noise forwarding to confuse the eavesdropper in order to improve the system performance in terms of secrecy rate [93]. The physical layer security is addressed and investigated in wireless cooperative networks [94]. The secure communication for a source and destination pair in the presence of single and multiple eavesdropper with

multiple relays is studied in [95]. The authors in [97] proposed relay selection schemes in cooperative networks such that they can act as relay, cooperative jammer and a new jamming and non jamming switched based scheme. The different types of relay and jammer selection scheme to maximize the secrecy for one way cooperative network in the presence of multiple relays are proposed in [98]. Power allocation for physical security to maximize the secrecy rate in wireless cooperative network is a promising research area. The authors of [102], have proposed power allocation scheme to allocate power to both relay and jammer, where relay is to help the source where as jammer is to create interference at the eavesdropper. To protect the source message being over heard by the eavesdropper, the destination node generates intended jamming noise which is called cooperative jamming. In [103], the three jamming power allocation schemes are proposed in a two-hop relay network to minimize the outage probability of secrecy rate. The condition for positive secrecy rate is derived and power allocation for cooperative jamming via distributed relays is proposed using convex optimization in [104]. The transmission strategy had been investigated with proposed relay selection and power allocation strategies in distributed cooperative network [105]. The cooperative jamming and power allocation schemes in a two-hop untrusted relay network for multiple antenna case are introduced in [106]. The recent work related to issue of power allocation schemes for cooperative jamming are given in [107-108]. In [141], the authors proposed power allocation schemes to optimize both source and relay powers for jamming and AF relaying wiretap channels to maximize secrecy rate a based on both individual and global power constraints. The authors in [142] proposed joint relay and jammer selection and power allocation schemes for physical layer security in two way relay networks using game theoretic approaches. The previous power allocation schemes from the considered literature are dealt with power of cooperative jamming (in which destination unaware of jamming noise) for single eavesdropper case. The impacts of relay and eavesdropper locations on the secrecy rate are not analyzed for power allocation schemes. The power allocation for the collaborative and non collaborative nature of multiple eavesdroppers cases is not analyzed.

1.3 Motivation

Wireless channel transmission suffers from the random fluctuation in received signal at the destination which is known as fading. Mitigation of fading is done by diversity techniques. Possible diversity schemes are frequency diversity, time diversity and spatial diversity. Spatial diversity is obtained by using multiple antennas either for transmission and reception or both. Due to some limitations like size, cost or hardware complexity, a node in a wireless network may not able to prefer multiple antennas either at the transmitter or at the receiver. In cooperative wireless network, the relays (single antenna cooperative users) share their resources effectively to get spatial diversity which is called cooperative diversity forming a virtual MIMO. During the last decade, various conventional relaying schemes are investigated in order to notice their advantages and limitations. New types of adaptive relaying protocols like hybrid decode-amplify-forward (HDAF) relaying are being introduced by researchers to overcome the limitations of conventional relaying schemes, so that the performance is improved. The performance parameter metrics considered mostly are symbol error rate (SER), outage probability and average channel capacity.

Power allocation has significant impacts on system performance of cooperative network. In fact, assisting relays usually have limited radio resources (e.g., bandwidth and power) which are shared by both the relays and the source-destination pair. The channel conditions and location of nodes show the impact on the performance of the wireless cooperative network. Instead of blindly assigning equal power to all the nodes, by assigning proper power to all relay nodes according to the channel link quality and their locations improves the network performance significantly. Therefore, efficient power allocation strategy for wireless relay networks can guarantee good usage of available relays and better overall performance. In multi HDAF relay wireless cooperative network, the conventional water filling method based power allocation already exists in the literature. But there is no explicit method to calculate the optimum power allocation level, hence a simple sub gradient method can be attempted for this. Further to reduce the complexity of sub gradient algorithms, evolutionary approaches are preferable which offer feasible solutions. Performance improvement of wireless cooperative network in terms of SER minimization, QoS improvement and channel capacity maximization are the key challenging issues.

Further confidentiality of data transmission is supposed to be a crucial requirement for upcoming 5G wireless network due to the significant growth in neumerous wireless applications. Traditionally, security in wireless networks has been focused on the upper layers using cryptography methods (like key generation) which becoming more difficult due to the increased number of potential attackers as well as implementation complexity issues. Therefore, researchers have shown growing interest in implementing security at the physical layer. The secrecy is quantified by the secrecy capacity or the maximum rate of reliable information and secrecy outage probability. Recent research shows that cooperative communication not only improves the transmission capacity for wireless networks, but also provides an effective way to improve the secrecy rate. This is achieved by carefully assigning the powers to the relays to maximize the information rate at the intended destination and minimize that at the eavesdroppers, which helps in security issues. Hence, applying adaptive relays and employing proper power allocation strategies to enhance the secrecy performance is a potential field of research.

1.4 Research contributions

This research work aims at proposing efficient power allocation schemes for multi HDAF (hybrid decode-amplify-forward) relay based wireless cooperative network. The performance analysis of an adaptive relay relaying scheme namely HDAF (hybrid decode-amplify-forward) relaying based distributed Alamouti coded cooperative network in terms of symbol error rate, outage probability and channel capacity is carried out analytically and substantiated with simulatin based study. The first part of the research focused on proposing maximized channel capacity based, minimized SER based and QoS (quality of service) based power allocation schemes using convex optimization and evolutionary algorithms like differential evolution (DE) algorithm. The second part of this research introduces secrecy rate maximization based power allocation schemes using both convex optimization and evolutionary approaches in the presence of collaborative and non collaborative multiple eavesdroppers for DF relaying scheme in multi relay network. The third part of the research aimed at utilizing HDAF relaying framework for physical layer security in wireless cooperative network in different scenarios like without jamming, with jamming and with control jamming. Further power allocation schemes are proposed to maximize the secrecy rate of HDAF relay wireless cooperative network in the presence of

eavesdroppers. The proposed maximized secrecy rate based power allocation schemes improve the secrecy performance in terms of secrecy rate.

Details of chapter wise contribution made in this thesis are listed as follows,

- In Chapter 2, SNR based hybrid decode amplify forward (HDAF) relaying scheme is introduced in a distributed Alamouti coded cooperative network. The closed form expressions of the performance metrics like symbol error rate (SER), outage probability and average channel capacity in flat Rayleigh fading channel are derived. Detailed simulation study results are presented which validate the theoretical analysis. Also it is observed that the proposed hybrid relaying technique outperforms the individual AF and DF ones in the distributed Alamouti coded cooperative network. From the study of the impact of relay location on the SER performance, the preferable relay locations for better system performance can be suggested. For low SNR condition, relays located at middle and relays located close to the source are the preferable locations whereas for high SNR condition, relays located close to the source are best.
- In Chapter 3, multi HDAF relay based cooperative network is introduced and efficient power allocation schemes are proposed to minimize SER, maximize the channel capacity and minimize total power to maintain QoS. The closed form expression of the average channel capacity with tight approximation for such network is derived. Lagrange multiplier method and Differential Evolution algorithm based techniques are developed for finding the power allocation factor associated with each relay and optimized relay powers under total power constraint. The robustness of the proposed algorithms is verified for different channel conditions and relay locations. From this detailed study, the proposed approaches outperform the existing equal power allocation scheme.
- In Chapter 4, physical layer security issue like guaranteeing confidentiality against eavesdropping attack in a wireless cooperative network using control jamming is addressed. Efficient power allocation schemes based on Lagrange multiplier method and differential evolution (DE) algorithm are proposed for both relay and jammer power optimization to maximize the secrecy rate in the presence of single and multiple eavesdroppers (both collaborative and non collaborative). The

mathematical expressions for power allocation factor are derived for proposed schemes using Lagrange multiplier method for single and multiple eavesdroppers. Further, the impact of location of the eavesdroppers with respect to source, destination and relay on the secrecy rate is analyzed. From simulation study, it is observed that the proposed schemes perform better than the existing schemes in jamming and non jamming cases.

- In Chapter 5, a system model of multi HDAF relay based wireless cooperative network in the presence of multiple eavesdroppers to analyze physical layer security issue is proposed. The secrecy rate of the proposed cooperative network is derived for three cases, i.e., without jamming, with jamming and with control jamming. The closed form approximation of Ergodic secrecy rate of the system with control jamming is derived analytically. The closed form approximations of secrecy outage and intercept probabilities for HDAF relaying scheme are also derived. The impact of locations of relays and eavesdroppers are analyzed to determine better performance in terms of secrecy rate. Further a trade off between the secrecy rate and intercept probability of HDAF relays suggests that the HDAF relaying outperforms the conventional relaying protocols (AF and DF).
- Further, power allocation schemes are proposed to maximize the secrecy rate of multi HDAF relay based wireless cooperative network with control jamming using both convex optimization (Lagrange multiplier method) and evolutionary approaches (Differential Evolution and Invassive Weed Optimization algorithms). The analytical expressions for optimized relay and jammer powers are derived considering single and multiple eavesdropper cases using Lagrange multiplier method. The proposed power allocation scheme outperforms the equal power allocation scheme. Even though Lagrange multiplier method based power allocation obtains optimal powers with good accuracy but suffers with complexity limitations. To overcome this problem, efficient DE and Invassive Weed Optimization algorithms are applied for finding the suitable power allocation factor to optimize relay and jammer powers which improves the secrecy performance of the cooperative network.

1.5 Thesis outline

The thesis is organized as follows

Chapter 2. This chapter introduces the performance study and analysis of an adaptive relaying scheme namely HDAF (hybrid decode-amplify-forward) relaying in distributed Alamouti coded cooperative network in terms of symbol error rate (SER), outage probability and channel capacity.

Chapter 3. In this chapter we proposed efficient power allocation schemes to improve the performance of the multi relay hybrid decode-amplify-forward (HDAF) wireless cooperative network in terms of symbol error rate (SER) and average channel capacity. The Lagrange multiplier method and differential evolution algorithm are applied to get optimize powers of relay nodes to maximize the channel capacity, minimize SER and to ensure quality of service (QoS) in terms of SER.

Chapter 4. In this chapter, we have developed power allocation schemes for controlled jamming for physical layer security in a DF relay assisted wireless cooperative network in the presence of multiple eavesdroppers. Both convex optimization and evolutionary apaproach are adopted to optimize both relay and jammer powers.

Chapter 5. In this chapter, we present the performance study of SNR threshold based HDAF relaying scheme for physical layer security in wireless cooperative networks. The performance metrics considered here are secrecy rate, secrecy outage and intercept probability. Finally, power allocation schemes are proposed to maximize the secrecy rate. Further to improve the secrecy performance of the system, power allocation algorithms are proposed using Lagrange multiplier method, Differential Evolution algorithm and Invassive Weed Optimization (IWO).

Chapter 6. This chapter outlines the research work carried out in this thesis. Summary of the present work, limitations and focuses on future extention of research are presented.

Chapter 2

Role of Hybrid Decode-Amplify-Forward Relaying in Distributed Alamouti Coded Cooperative Network

In this chapter, we analyzed the performance of SNR based hybrid decode-amplify-forward relaying in a distributed Alamouti coded cooperative network in terms of symbol error rate (SER), outage probability and average channel capacity. We present here the chapter goals.

Objectives of the chapter

- This chapter describes the proposed system model which is a distributed Alamouti coded cooperative network consisting of a source, destination and two single antenna relays operating in hybrid decode amplify forward relaying mode.
- To derive the mathematical expressions for symbol error rate (SER), outage probability and the average channel capacity for HDAF relaying scheme and to compare with the simulation based study results with respect to the conventional relaying schemes.
- To analyze the impact of relay locations in terms of system performance and to suggest preferable location for relay positioning.

Part of the contributions in this chapter are published in

Kiran Kumar Gurrala, Susmita Das**, "Hybrid Decode-Amplify-Forward relaying scheme in Distributed Alamouti coded cooperative network"* ***International Journal of Electronics (Taylor & Francis), *vol. 102, no 5, pp: 725-741, 2014.* ***DOI:*** *10.1080/00207217.2014.938252.*

2.1 Introduction

Wireless channel transmission suffers from random fluctuation in received signal at the destination which is known as fading. Mitigation of fading is done by diversity techniques. Possible diversity schemes are frequency diversity, time diversity and spatial diversity. Spatial diversity is obtained by using multiple antennas either for transmission and reception or both. Due to some limitations like size, cost, or hardware complexity, a wireless user may not able to prefer multiple antennas. Cooperative diversity [1] is a new spatial diversity scheme to mitigate the effect multi path fading effect by creating a virtual MIMO (multiple input multiple output) system with the cooperation of single antenna relay nodes in between the source and the destination. Thus cooperative communication exploits both the spatial and time diversity by using the broadcast nature of wireless medium as introduced in [2]. A collection of distributed antennas belonging to multiple users, which are dispersed at different locations, in a network is called distributed spatial diversity network. In a distributed cooperative network, transmit diversity is achieved when the selected single antenna relays cooperate the source by forwarding signal to the destination based on relaying protocol. The author in [3], derived the average symbol error rate of the distributed diversity system which overcomes the severe penalty in signal to noise ratio caused by Rayleigh fading.

The overview of recent development in distributed coding design in cooperative wireless network is discussed in [4]. In such a system, the whole codeword is constructed in a distributed manner among the cooperative users. Alamouti [7], introduced a powerful space time code which provides full rate and full diversity over complex constellation with symbol wise ML(Maximum Likelihood) decoding. The distributed Alamouti code is an extension to Alamouti code which is applied in distributed cooperative network [5&7]. Here, the selected two relays simultaneously receive a noisy signal form the source and construct their Alamouti space codes in a distributed fashion before forwarding the signals to the destination. Exact closed form expressions for SER and pair wise error probability of distributed Alamouti scheme with full diversity are derived in [6]. The authors in [8], analyzed the BER performance of the distributed Alamouti code for cooperative network consisting of a source, two relays and a destination node over Rayleigh fading channel with and without direct link condition. Amongst all the cooperative relaying schemes amplify and forward (AF) and decode and forward (DF) are well known. The AF relay

just amplifies the noisy version of received signal from source and retransmits it to destination. In the DF scheme, the relay detects the received signal from the source and retransmits the detected signal to the destination [1-2]. The closed form expressions for outage probability and SER of multi relay network with hybrid scheme over independent and non identical Rayleigh flat fading are given in [11]. AF relaying scheme suffers from the noise amplification problem which can degrade the signal quality, particularly at low SNR. DF relaying scheme has the limitation of the error propagation problem which may occur if the relay incorrectly detects/decodes a message and forwards this incorrect information to the destination. To overcome the limitations of the basic conventional relaying schemes, HDAF relaying scheme is introduced. The SER and power allocation of multi relay network with hybrid DAF scheme are explained in [12]. In [13], the author proposed a hybrid decode amplify forward incremental cooperative diversity protocol using SNR based relay selection. The author in [18] derived the expression for ergodic channel capacity of multi relay cooperative diversity system with channel estimation errors. In all these studies, advantages of hybrid relaying have not been studied for the distributed Alamouti coded cooperative network. In this thesis, an attempt has been made through detailed mathematical analysis and simulation based study. The mathematical expressions for various performance parameter metrics such as symbol error rate (SER), outage probability and the average channel capacity for proposed scheme are derived.

The organization of this chapter is as follows Section 2.2 explains the proposed system model. Section 2.3 provides analysis of performance metrics in terms of symbol error rate, outage probability and average channel capacity. The theoretical approximations of these performance metrics are derived. Section 2.4 provides the simulations results and analysis. Finally Section 2.5 gives the summary of this chapter.

2.2 System model of distributed Alamouti coded cooperative network

In this research, a cooperative diversity network as shown in Figure.1 is proposed, which has a source S transmitting to a destination D through 2 cooperating relays. The source with the cooperation of two relays transmits the information to the destination through hybrid decode amplify and forward (HDAF) protocol under our assumption that all the links are mutually independent and are subjected to flat Rayleigh fading condition.

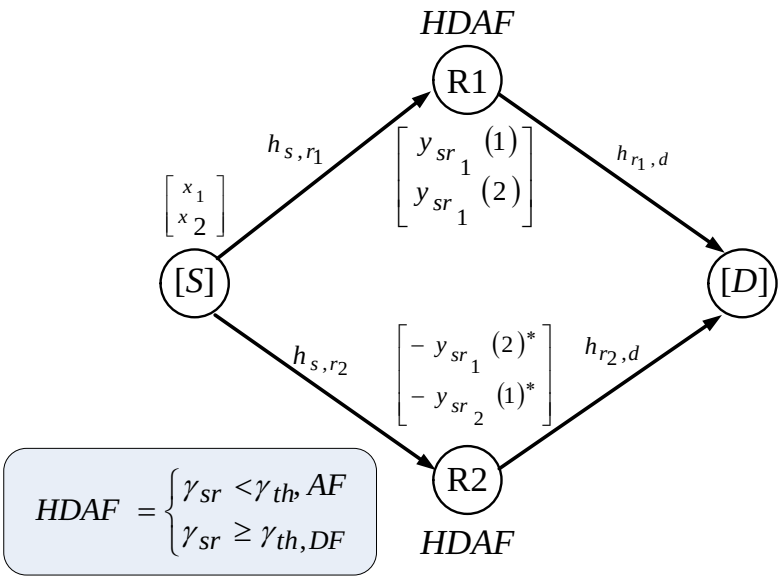


Figure 2.1 System model of distributed Alamouti coded cooperative network

For the proposed system model, detail mathematical analysis follows. Basically there are two phases of operation such as broadcast phase and cooperation phase.

2.2.1 Broadcast phase

The data is broadcasted by the source to the two relays. At first and second time slots, source transmits two information bearing symbols x_1 and x_2 to R1 and R2, respectively.

The received complex base band signal at the ith relay is modelled as

$$y_{sr_i}(j) = \sqrt{P_1} h_{s,r_i} \; x(j) + n_{s,r_i} \qquad for\ i = 1,2\ \&\ j = 1,2 \tag{2.1}$$

$$h_{s,r_i} = l_{s,r_i} \,.\, a_{s,r_i} \tag{2.2}$$

where $y_{sr_i}(j)$ represents the jth symbol received at i^{th} relay.

P_1 is the transmitted power at source node, $h_{s,ri}$ are the channel coefficients of source to relay link of two relays. $a_{s,ri}$: can be modeled as a zero mean, complex Gaussian random variables with variances $\sigma^2_{s,ri}$ for $i=1,2$. The path loss $l_{s,ri}$ is proportional to d^{-4}_{s,r_i} , where d_{s,r_i} is the distance between the source node and i^{th} relay node. $n_{s,ri}$ is additive white Gaussian noise at the destination for the ith relay.

2.2.2 Cooperation phase

The two relays generate a distributed Alamouti code and forward to destination. At the third and fourth time slots, the two relays construct the distributed Alamouti code by transmitting each relay each row of Alamouti code. The Alamouti representation of output signals at the relays is given by

$$\begin{pmatrix} y_{sr_1}(1) & -y_{sr_2}(2)^* \\ y_{sr_1}(2) & y_{sr_2}(1)^* \end{pmatrix} \tag{2.3}$$

where $y_{sr_i}(j)$ represents the jth symbol received at i^{th} relay.

The two relays (each relay transmitting each row of Alamouti code) transmitting distributed Alamouti versions of input signal to the destination using hybrid decode-amplify-forward (HDAF). Here, based on target rate (R), the SNR threshold for hybrid relaying is derived. The threshold SNR [11] is given by

$$\gamma_{th} = 2^{(2R)} - 1 \tag{2.4}$$

where R is target information rate.

If the relay perfectly decodes the symbol it operates in DF mode otherwise it operates in AF mode. The perfect decoding capability of relay depends on channel quality between the source and the relay. If the SNR of source relay link for two relays is less than the threshold, the relays operate in AF mode and if the SNR of source relay link is above the threshold the two relays operate in DF mode. The function of hybrid decode amplify forward (HDAF) is given by

If $\gamma_{s,r_i} < \gamma_{th}$, i.e., the relay operates in AF mode

$$y_{r_i,d}(j) = \beta_i \sqrt{P_2} h_{r_i,d}\ y_{s,r_i}(j) + n_{r_i,d} \quad for\ i = 1,2 \tag{2.5}$$

else $\gamma_{s,r_i} \geq \gamma_{th}$, i.e., the relay operates in DF mode

$$y_{r_i,d}(j) = \sqrt{P_2} h_{r_i,d}\ \hat{y}_{s,r_i}(j) + n_{r_i,d} \quad for\ i = 1,2 \tag{2.6}$$

where $y_{r_i,d}(j)$ is the jth symbol received from the ith relay and β_i is the amplification factor of relay given by

$$\beta_i \leq \sqrt{\frac{P_2}{P_1\left|h_{s,r_i}\right|^2 + N_0}} \tag{2.7}$$

where $h_{r_i,d}$ are the channel coefficients of ith relay for relay to destination node link and is given by

$$h_{r_i,d} = l_{r_i,d} \,.\, a_{r_i,d} \tag{2.8}$$

$a_{r_i,d}$ can be modelled as a zero mean, complex Gaussian random variables with variance $\sigma^2_{ri,d}$ for *i=1,2*. The path loss $l_{r_i,d}$ is proportional to $d^{-4}_{r_i,d}$, where $d_{r_i,d}$ is the distance from the ith relay to destination node. The received signal at the destination are is given by

$$y_1 = P_1\, h_{r_1,d}\; y_{s,r_1}(1) - P_2\, h_{r_2,d}\; y^*_{s,r_2}(2) + n_{r_1,d} \tag{2.9}$$

$$y_2 = P_1\, h_{r_1,d}\; y_{s,r_1}(2) + P_2\, h_{r_2,d}\; y^*_{s,r_2}(1) + n_{r_2,d} \tag{2.10}$$

Finally, the destination node adopts ML (maximum likelihood) detection for the received signals to get symbols x_1 and x_2.

2.3 Analysis of performance metrics

The performance of the proposed system model is analyzed in terms of symbol error rate (SER), outage probability and average channel capacity. The closed form theoretical approximations for these performance metrics are derived as follows.

2.3.1 Theoretical expression for symbol error rate (SER)

In the proposed hybrid relaying, if the source to relay link SNR is greater than the threshold SNR (Eq. (2.4)), i.e., the relay decodes the signal received from the source correctly, the relay will operate in DF mode otherwise operate in AF mode. The instantaneous SNR at the destination for DF and AF scheme are calculated as given below

$$\gamma_{DF} = \sum_{i=1}^{2} \gamma_{r_i,d} \tag{2.11}$$

$$\gamma_{AF} = \sum_{i=1}^{2} \frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i} + \gamma_{r_i,d} + 1} \tag{2.12}$$

where $\gamma_{s,r_i} = \dfrac{P_1 \left| h_{s,r_i} \right|^2}{No}$ $\gamma_{r_i,d} = \dfrac{P_2 \left| h_{r_i,d} \right|^2}{No}$ (2.13)

The author of Ref [18] has derived the SER closed form expression including the source to destination link also. In this work, the direct link between source to destination is excluded and distributed Alamouti is suggested by using two relays. The SER of source relay link depends on the instantaneous SNR for MPSK modulation denoted as Pe given [19] by

$$P_e = \frac{1}{\pi} \int_0^{(M-1)\pi/M} \exp\left(-\frac{g\gamma_{sr}}{\sin^2 \theta} \right) d\theta \tag{2.14}$$

where $g = \sin^2(\pi / M)$ (2.15)

By averaging the conditional SER in (2.14) over the instantaneous SNR of source to relay link, the probability that the relay correctly decodes the signals received from the source is derived as

$$P_c = 1 - \frac{1}{\pi} \int_0^{(M-1)\pi/M} M_{\gamma_{s,r_i}} \left(-\frac{g\gamma_{sr}}{\sin^2 \theta} \right) d\theta \tag{2.16}$$

where $M\gamma_{s,r_i}(s)$ is the MGF of $\gamma_{s,ri}$ which is given by

$$M\gamma_{s,r_i}(s) = E\gamma_{s,r_i} \left\{ \exp\left(-\gamma_{s,r_i} s \right) \right\} \tag{2.17}$$

where $E_x\{.\}$ denotes the expectation operator of variable *x*.

The average SER of hybrid decode amplify forward (DAF) scheme is evaluated as

$$P_{HDAF} = P_c \, P_r(\gamma_{DF}) + (1 - P_c) P_r(\gamma_{AF}) \tag{2.18}$$

where the average SER of two relay DF scheme (in which $\gamma_{r1,d}$ & $\gamma_{r2,d}$ are statistically independent) is given by

$$P_r(\gamma_{DF}) = \frac{1}{\pi} \int_0^{(M-1)\pi/M} M_{\gamma_{DF}} \left(\frac{g}{\sin^2 \theta} \right) d\theta \tag{2.19}$$

$$= \frac{1}{\pi} \int_0^{(M-1)\pi/M} M_{\gamma_{r1,d}} \left(\frac{g}{\sin^2 \theta} \right) \; M_{\gamma_{r2,d}} \left(\frac{g}{\sin^2 \theta} \right) d\theta \tag{2.20}$$

and the average SER of two relay AF scheme [18] is given by

$$P_r(\gamma_{AF}) = \frac{1}{\pi}\int_0^{(M-1)\pi/M} M_{\gamma_{AF}}\left(\frac{g}{\sin^2\theta}\right)d\theta == \frac{1}{\pi}\int_0^{(M-1)\pi/M}\prod_{i=1}^{2} M_{\gamma_{Z_i}}\left(\frac{g}{\sin^2\theta}\right)d\theta \tag{2.21}$$

where $z_i = \dfrac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1}$ *for* $i = 1,2$ (effective SNR of AF relays) (2.22)

and also z_1 and z_2 are statistically independent. Eq (2.18) can be represented as

$$P_{HDAF} = \left(1-\frac{1}{\pi}\int_0^{(M-1)\pi/M}\exp\left(-\frac{g\gamma_{sr}}{\sin^2\theta}\right)d\theta\right)\left(\frac{1}{\pi}\int_0^{(M-1)\pi/M}\prod_{i=1}^{2} M_{\gamma_{ri,d}}\left(\frac{g}{\sin^2\theta}\right)d\theta\right)$$

$$+\left(\frac{1}{\pi}\int_0^{(M-1)\pi/M}\exp\left(-\frac{g\gamma_{sr}}{\sin^2\theta}\right)d\theta\right)\left(\frac{1}{\pi}\int_0^{(M-1)\pi/M}\prod_{i=1}^{2} M_{\gamma_{Z_i}}\left(\frac{g}{\sin^2\theta}\right)d\theta\right) \tag{2.23}$$

The generalised MGF of $\gamma_A (A \in \{sr, rd\})$ is expressed as

$$M_{\gamma_A}(s) = E_{\gamma A}\{\exp(-\gamma_A s)\} = \left(1+\frac{P_i\sigma_A^2 s}{No}\right)^{-1} \quad ,i = 1,2 \tag{2.24}$$

In the high SNR regime, i.e, *Pi/No >>1*, the above MGF given above can be approximated as $M_{\gamma_A}(s) \approx \left(\dfrac{P_i\sigma_A^2 s}{No}\right)^{-1}$ (2.25)

In the higher SNR regime, i.e, $\lambda_1 = N_o P_1\sigma_{sr}^2 \to 0$ and $\lambda_2 = N_o P_2\sigma_{rd}^2 \to 0$.

The MGF of AF cooperative scheme, $M_z(s)$ can be approximated as (approximation from [12]) $M_{z_i} \approx \dfrac{1}{s}(\lambda_1+\lambda_2) = \dfrac{1}{s}\left(\dfrac{N_o}{P_1\sigma_{sr}^2}+\dfrac{N_o}{P_2\sigma_{rd}^2}\right)$ (2.26)

By substituting MGF function approximations (2.27) and (2.26) in (2.24), for HDAF scheme, the asymptotic SER approximation is obtained as

$$SER = \frac{AN_o^2}{P_1P_2\sigma_{r1,d}^2\sigma_{r2,d}^2}+\frac{ABN_o^3}{P_1P_2\sigma_{s,r1}^2\sigma_{s,r2}^2 g^3}\prod_{i=1}^{2}\left(\frac{1}{P_1\sigma_{s,ri}^2}+\frac{1}{P_2\sigma_{ri,d}^2}\right) \tag{2.27}$$

where $A = \dfrac{1}{\pi}\displaystyle\int_0^{(M-1)\pi/M}\sin^4\theta\, d\theta = \dfrac{3(M-1)}{8M}+\dfrac{\sin(2\pi/M)}{4\pi}-\dfrac{\sin(4\pi/M)}{32\pi}$

$$B = \frac{1}{\pi}\int_0^{(M-1)\pi/M}\sin^2\theta\, \mathrm{d}\theta = \frac{\mathrm{M}-1}{2\mathrm{M}}+\frac{\sin(2\pi/M)}{4\pi} \tag{2.28}$$

2.3.2 Theoretical approximation for the outage probability

The outage probability is commonly defined as

$$P_{out} = P(I < R) = P(\gamma < \gamma_{th}) = \int_0^{\gamma_{th}} \Pr(r).dr \tag{2.29}$$

In hybrid relaying, the relay selects the appropriate scheme depending on source to relay link SNR. If the SNR of source to relay link is greater than SNR threshold, the relay operates in DF mode otherwise operates in AF mode. The mutual information between the source and the relay terminal for each relay is given by

$$I_{s,ri} = \frac{1}{2}\log 2(1+\gamma_{s,ri}) \tag{2.30}$$

If this mutual information is greater than target rate the relay operates in DF mode otherwise it operates in AF mode. The mutual information for two relay case of AF scheme is given by

$$I_{AF} = \frac{1}{2}\log(1+\sum_{i=1}^{2}\frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1}) \tag{2.31}$$

The mutual information for two relay case of DF scheme is given by

$$I_{DF} = \frac{1}{2}\log(1+\sum_{i=1}^{2}\gamma_{r_i,d}) \tag{2.32}$$

The mutual information for two relay case of proposed hybrid relaying is given by

$$I_{HDAF} = \begin{cases} I_{AF}, & \gamma_{sri} < \gamma_{th} \\ I_{DF}, & \gamma_{sri} > \gamma_{th} \end{cases} \quad , \textit{for } i = 1,2 \tag{2.33}$$

where $\gamma_{th} = 2^{2R} - 1$ (2.34)

For flat Rayleigh fading channel, the outage probability for hybrid relaying scheme is given by

$$P_{out}^{HDAF} = \Pr[I_{HDAF} < R] \tag{2.35}$$

$$P^{HDAF} = \Pr[I_{HDAF} < R]\Pr[\gamma_{sri} < \gamma_{th}] + \Pr[I_{HDAF} < R]\Pr[\gamma_{sri} \geq \gamma_{th}] \tag{2.36}$$

$$= P_{out}^{AF}.\Pr[\gamma_{sri} < \gamma_{th}] + P_{out}^{DF}.\Pr[\gamma_{sri} \geq \gamma_{th}] \tag{2.37}$$

$$\Pr[\gamma_{sri} < \gamma_{th}] = \Pr\left(\prod_{i=1}^{2}\gamma_{sri} < \gamma_{th}\right) \tag{2.38}$$

$$\approx \prod_{i=1}^{2}\Pr(\gamma_{sri} < \gamma_{th}) = \prod_{i=1}^{2}\exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right) \tag{2.39}$$

$$\approx \prod_{i=1}^{2} \frac{1}{\sigma_{s,ri}^2} \left(\frac{2^{2R}-1}{SNR} \right)^2 \tag{2.40}$$

The outage probability of AF scheme with two relays

$$P_{out}^{AF} = \frac{1}{2} \prod_{i=1}^{2} \left(\frac{1}{\sigma_{s,ri}^2} + \frac{1}{\sigma_{ri,d}^2} \right) \left(\frac{2^{2R}-1}{SNR} \right)^2 \tag{2.41}$$

and the outage probability of DF scheme with two relays

$$P_{out}^{DF} = \frac{1}{2} \prod_{i=1}^{2} \frac{1}{\sigma_{ri,d}^2} \left(\frac{2^{2R}-1}{SNR} \right)^2 \tag{2.42}$$

The exact derivations for outage probabilities of conventional AF and DF scheme are given in the chapter Appendix. By substituting (2.41) and (2.42) in (2.37), the outage probability of HDAF is modified as

$$p_{out}^{HDAF} = \frac{1}{2} \prod_{i=1}^{2} \left(\frac{1}{\sigma_{s,ri}^2} + \frac{1}{\sigma_{ri,d}^2} \right) \left(\frac{2^{2R}-1}{SNR} \right)^2 \prod_{i=1}^{2} \frac{1}{\sigma_{s,ri}^2} \left(\frac{2^{2R}-1}{SNR} \right)^2$$
$$+ \frac{1}{2} \prod_{i=1}^{2} \frac{1}{\sigma_{ri,d}^2} \left(\frac{2^{2R}-1}{SNR} \right)^2 \left(1 - \prod_{i=1}^{2} \frac{1}{\sigma_{s,ri}^2} \left(\frac{2^{2R}-1}{SNR} \right)^2 \right) \tag{2.43}$$

In high SNR regime the first term is neglected, the upper bond is approximated as

$$P_{out}^{Upper} \approx \frac{1}{2} \prod_{i=1}^{2} \frac{1}{\sigma_{ri,d}^2} \left(\frac{2^{2R}-1}{SNR} \right)^2 \tag{2.44}$$

In low SNR cases, the second term is neglected and lower bound is approximated as

$$P_{out}^{Lower} \approx \frac{1}{2} \prod_{i=1}^{2} \frac{1}{\sigma_{s,ri}^2} \left(\frac{1}{\sigma_{s,ri}^2} + \frac{1}{\sigma_{ri,d}^2} \right) \left(\frac{2^{2R}-1}{SNR} \right)^4 \tag{2.45}$$

2.3.3 Theoretical approximation for average channel capacity

The average channel capacity for hybrid relaying is given [38] by

$$C_{HDAF} = \Pr(\gamma_{s,r} < \gamma_{th})\, C_{AF} + \Pr(\gamma_{s,r} \geq \gamma_{th})\, C_{DF} \tag{2.46}$$

where $$\Pr(\gamma_{s,r} < \gamma_{th}) \approx \prod_{i=1}^{2} \exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}} \right) \tag{2.47}$$

$$\Pr(\gamma_{s,r} \geq \gamma_{th}) \approx 1 - \prod_{i=1}^{2} \exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}} \right) \tag{2.48}$$

The average channel capacity of two relay case amplify and forward scheme is expressed as

$$C_{AF} = \frac{W}{2}\int_0^{\infty} \log_2(1+\gamma)\, f_{\gamma_{AF}}(\gamma)\, d\gamma \tag{2.49}$$

The probability distribution function (PDF) $f_{\gamma_{AF}}(\gamma)$ is given by

$$f_{\gamma_{AF}}(\gamma) = \sum_{i=1}^{2} \frac{\beta_i}{\gamma_{AF_i}} \exp\left(-\frac{\gamma}{\gamma_{AF_i}}\right) \tag{2.50}$$

where $\beta_i = \prod_{k=1,k\neq i}^{2}\left(1-\frac{\gamma_k}{\gamma_i}\right)^{-1}$; $\gamma_{AF_i} = \frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1}$ (2.51)

By substituting (2.51), (2.51) in (2.49)

$$C_{AF} = \frac{W}{2}\int_0^{\infty} \log_2(1+\gamma) \sum_{i=1}^{2} \frac{\beta_i}{\gamma_{AF_i}} \exp\left(-\frac{\gamma}{\gamma_{AF_i}}\right) d\gamma \tag{2.52}$$

At last, the channel capacity for two relay amplify and forward scheme is expressed as

$$C_{AF} = \frac{W}{2\ln 2}\sum_{i=1}^{2} \beta_i \exp\left(\gamma_{\mathrm{AF_i}}^{-1}\right)\mathrm{E}_1\left(\gamma_{\mathrm{AF_i}}^{-1}\right) \tag{2.53}$$

where $E_1(.)$ is is the exponential integral defined as $E_1(x) = \int_x^{\infty} \frac{\exp(-t)}{t} dt$ (2.54)

The average channel capacity of two relay case Decode and forward scheme is expressed as $C_{DF} = \frac{W}{2}\int_0^{\infty} \log_2(1+\gamma)\, f_{\gamma_{DF}}(\gamma)\, d\gamma$ (2.55)

The probability distribution function (PDF) $f_{\gamma_{DF}}(\gamma)$ is given by

$$f_{\gamma_{DF}}(\gamma) = \sum_{i=1}^{2} \frac{\beta_i}{\gamma_{DF_i}} \exp\left(-\frac{\gamma}{\gamma_{DF_i}}\right) \tag{2.56}$$

Substituting (2.56) in (2.55) (integration minimization is done in the chapter Appendix), the channel capacity for two relay amplify and forward scheme is expressed as

$$C_{DF} = \frac{W}{2\ln 2}\sum_{i=1}^{2} \beta_i \exp\left(\gamma_{\mathrm{DF_i}}^{-1}\right)\mathrm{E}_1\left(\gamma_{\mathrm{DF_i}}^{-1}\right) \tag{2.57}$$

where $\gamma_{DF_i} = \min\left(\gamma_{s,r_i}, \gamma_{r_i,d}\right)$

Substituting (2.57), (2.53), (2.47) & (2.48) in (2.46), the average channel capacity for HDAF relaying scheme is presented as

$$C_{HDAF} = \left(\prod_{i=1}^{2}\exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right)\right)\frac{W}{2\ln 2}\sum_{i=1}^{2}\beta_i \exp\left(\gamma_{\mathrm{AF_i}}^{-1}\right)\mathrm{E}_1\left(\gamma_{\mathrm{AF_i}}^{-1}\right)$$

$$+\left(1-\prod_{i=1}^{2}\exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right)\right)\frac{W}{2\ln 2}\sum_{i=1}^{2}\beta_i \exp\left(\gamma_{\mathrm{DF_i}}^{-1}\right)\mathrm{E}_1\left(\gamma_{\mathrm{DF_i}}^{-1}\right) \tag{2.58}$$

Finally, the upper bound tight approximation for the above average channel capacity is

$$C_{HDAF} = \frac{W}{2\ln 2}\left\{\left(\prod_{i=1}^{2}\exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right)\right)\sum_{i=1}^{2}\beta_i \, exp\left(\gamma_{AF_i}^{-1}\right)E_1\left(\gamma_{AF_i}^{-1}\right)\right.$$

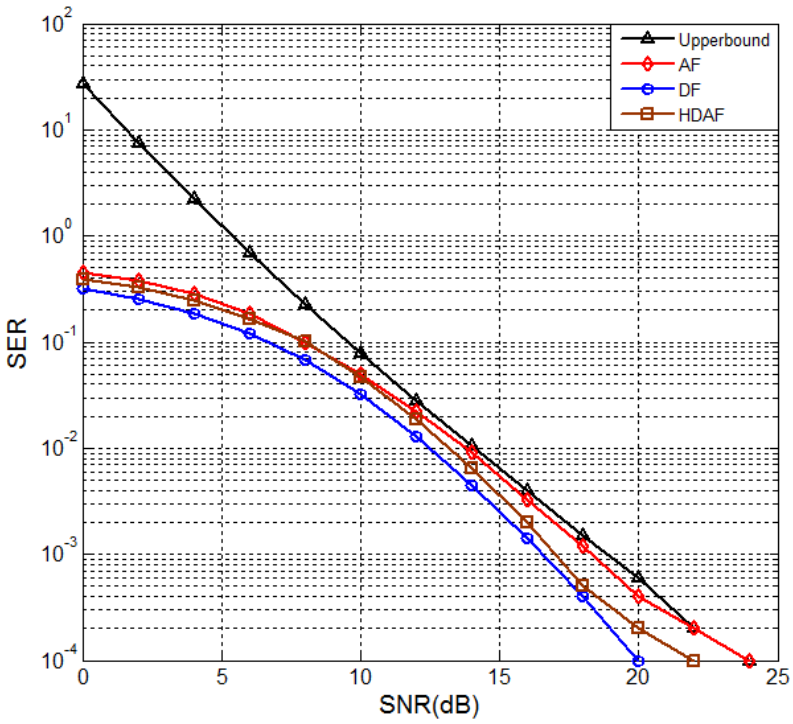
$$\left.+\left(1-\prod_{i=1}^{2}\exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right)\right)\sum_{i=1}^{2}\beta_i \exp\left(\gamma_{\mathrm{DF_i}}^{-1}\right)\mathrm{E}_1\left(\gamma_{\mathrm{DF_i}}^{-1}\right)\right\} \tag{2.59}$$

2.4 Simulation study and analysis

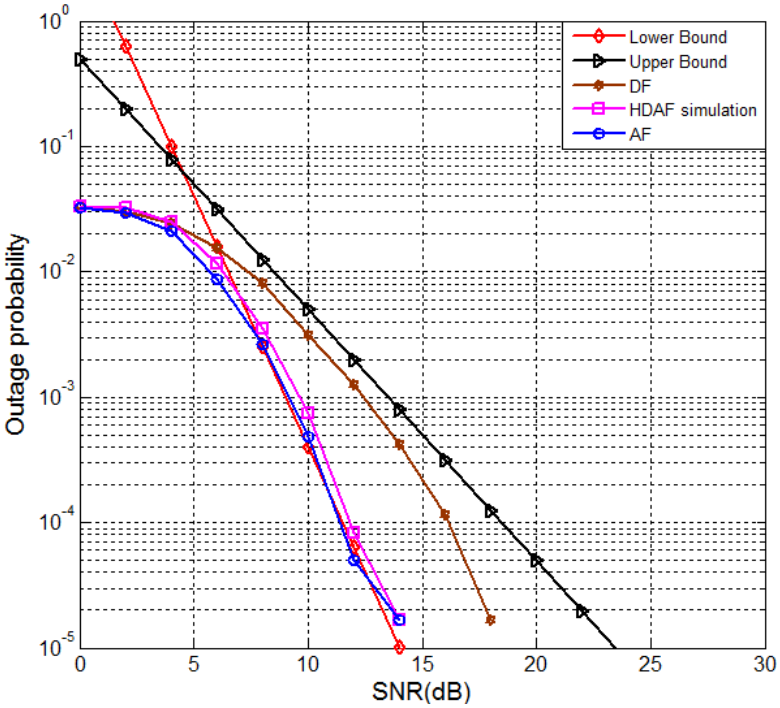
In this work, a distributed Alamouti coded cooperative network which consists of one source, two relays and one destination with hybrid decode amplify forward relaying is simulated and its performance metrics are compared with the theoretical approximations as given in Section 2.3. Here, it is assumed that the users transmit their information through orthogonal channels with the knowledge of CSI (channel state information) at the destination and there is a perfect synchronization between the cooperating nodes. The simulation carried by considering equal power allocation relaying scheme. The SER, the outage probability and the average channel capacity of hybrid DAF scheme for distributed Alamouti coded cooperative network are compared with the result of existing schemes (AF and DF). Matlab environment is chosen for computer simulation and 5×10^5 independent simulations are run for each result. The simulation parameters chosen here are described in Table 2-1.

Table 2-1Simulation parameters

Parameters	Specification
Frame length	256
Number of frames	50
Number of blocks	40
Target rate	0.5 bits/sec
Number of relays	2
Relay network topology	Linear topology
Channel variances	$\sigma^2_{s,r1} = \sigma^2_{s,r2} = 1$, $\sigma^2_{r1,d} = \sigma^2_{r2,d} = 1$
Coding scheme	Distributed Alamouti code
Channel	Flat Rayleigh fading
Modulation	Coherent QPSK



(a)



(b)

Figure 2.2 (a) SER comparison. (b) The outage probability comparison of hybrid scheme with AF, DF and bounds

From the Figure 2.2 (a), it is observed that the suggested hybrid scheme performs better than DF in lower SNR cases and AF in high SNR cases. So combining both the AF & DF, proposed hybrid relaying performs better giving a gain of (about 1.5dB) over AF for SER of 10^{-3}. Further SER of the system lies within the theoretical bounds. The simulation result for the outage probability of the system is compared with the theoretical bounds in Figure 2.2 (b). The outage probability of HDAF is near to DF scheme in low SNR cases and nearer to AF in high SNR scheme. In Figure 2.3(a), the average channel capacity of the proposed system is presented and compared with the theoretical tight approximations of schemes AF, DF and hybrid DAF. It is observed that Alamouti coded distributed network with DF relays only obtain the higher channel capacity compared to the AF where as the proposed hybrid relaying provides nearly same channel capacity obtained with AF relays for low values of SNR. As the SNR increases the channel capacity due to hybrid relaying also increases and for high values of SNR, it becomes the capacity which is very close to capacity with DF relays. The simulation results for channel capacity of hybrid relaying completely agree with the theoretical approximation. The average channel capacity of hybrid relaying for the proposed system over the normalized distance between source and relay is simulated for different SNR values and presented in Figure 2.3 (b).

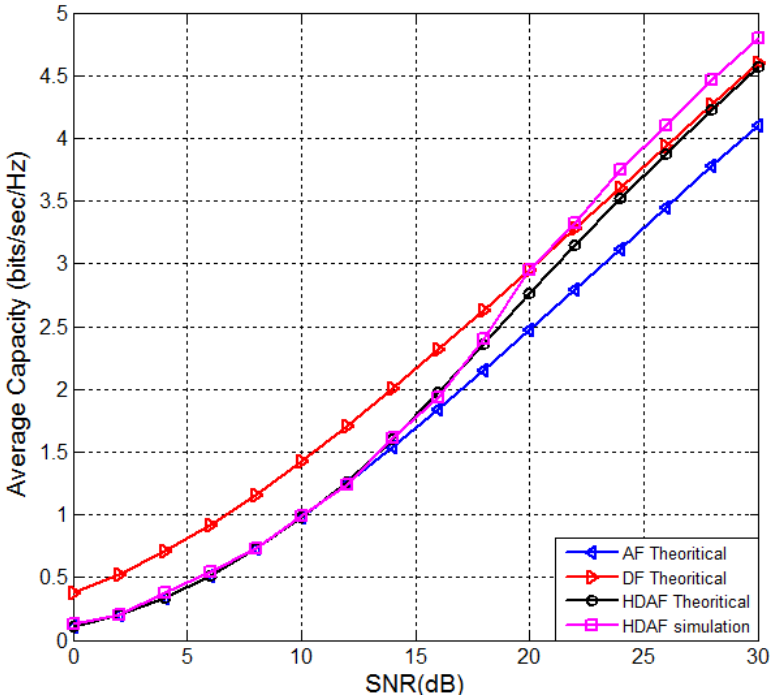


Figure 2.3 (a) The average channel capacity comparison of HDAF relaying scheme with AF, DF and bounds

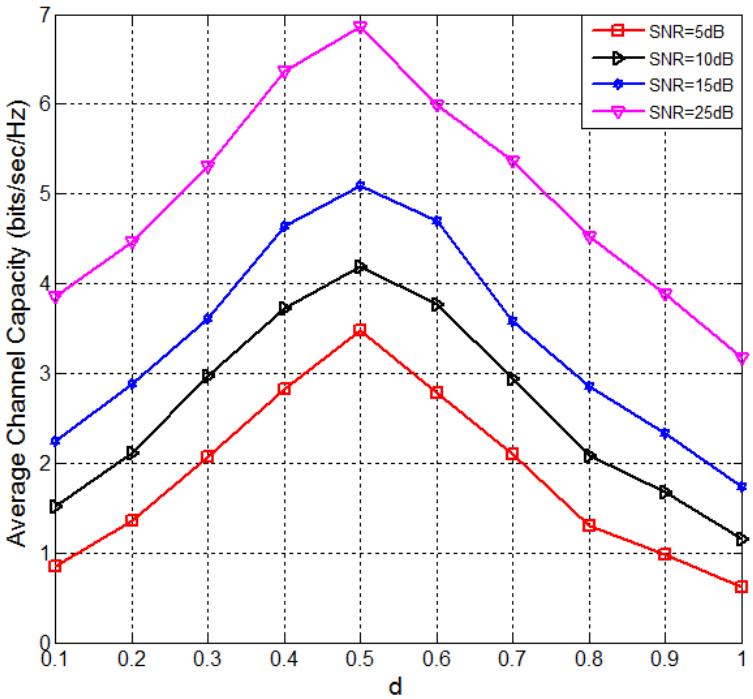


Figure 2.3 (b) The average capacity comparison for different SNRs

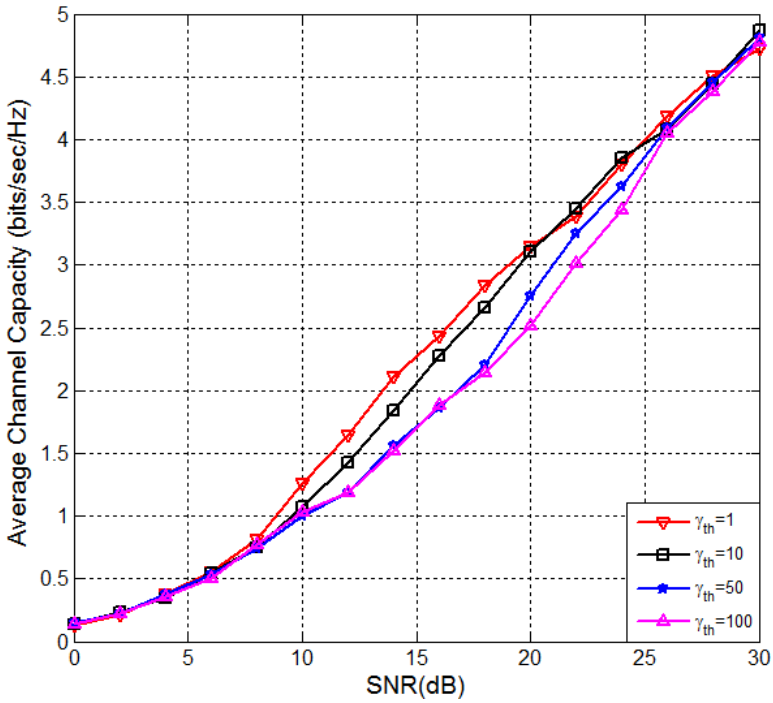


Figure 2.3 (c) The average channel capacity comparison for different thresholds

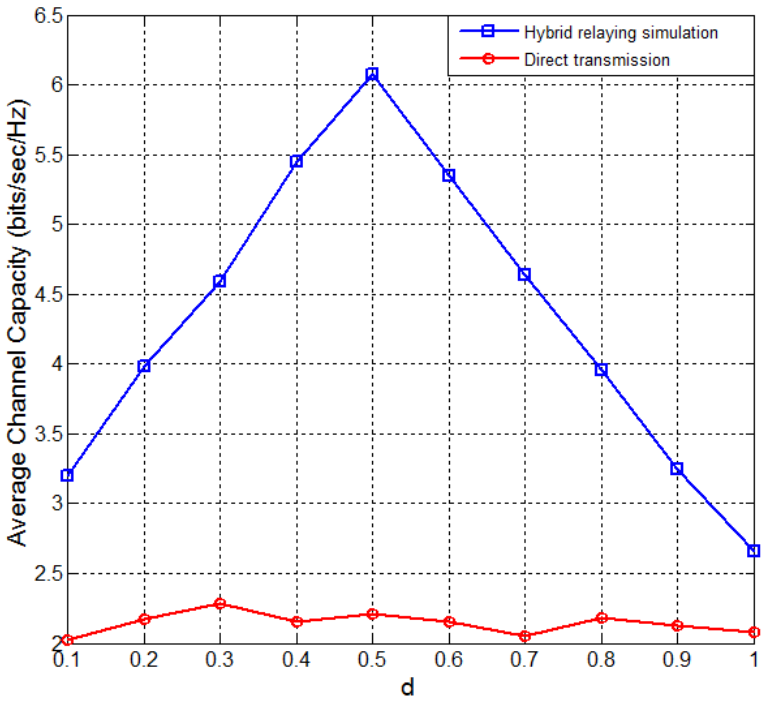


Figure 2.3 (d) The average channel capacity comparison of HDAF relaying scheme with direct transmission for distributed Alamouti cooperative network

The average channel capacity of hybrid relaying for the proposed system over the normalized distance between source and relay is simulated for different SNR values and presented in Figure 2.3(c). The distance between the source and destination is normalized as one. As the SNR increases, the channel capacity also increases and it attains maximum

value at middle distance between the source and the destination. From Figure 2.3(c), the relays operate in DF mode for low values of threshold and with increase in the threshold value the relays tend to behave as AF. Hence, for the low values of threshold, the hybrid DAF scheme provides channel capacity nearly same as DF relays and for high values of threshold, provides nearly same as AF scheme. For low values of SNR, the hybrid relaying is same as both conventional schemes (AF and DF). From Figure 2.3(d), the hybrid DAF relaying provides high channel capacity compared to direct transmission. For the cases, where the relays are close-to-source and close-to-destination, the channel capacities of hybrid relaying are slightly differ. The maximum channel capacity is achieved at the middle for hybrid relaying.

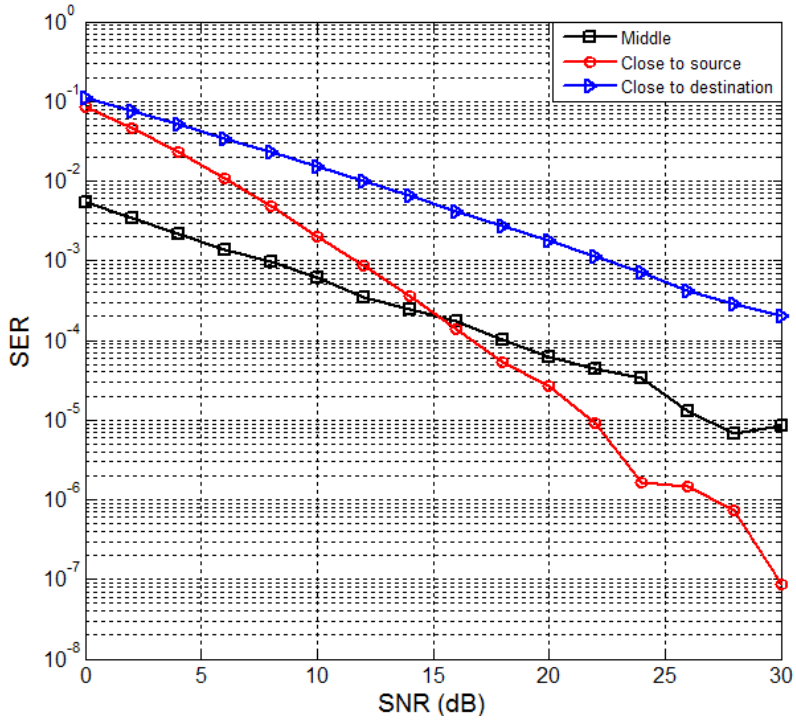


Figure 2.4 SER performance for different relay locations of two relays

Hence, the impact of relay location for the system is analyzed. For this, the simulation of the system carried out in three relay locations (close to source, close to destination and at the middle) following a linear topology.

Table 2-2 The considered three scenarios

Scenario	$d_{s,r}$	$d_{r,d}$
Middle	0.2	0.8
Close to source	0.8	0.2
Close to destination	0.5	0.5

Here the distance between the source and the destination is considered as 1, i.e., $d_{s,r_i} + d_{r_i,d} = 1$. It is assumed that the two relay locations are identical. The relay locations considered are considering a worst case scenario and the path loss coefficient is chosen as 4. Figure 2.4 describes the impact of relay location on the performance in terms of SER. When the relays at the middle, they will operate in AF mode for low SNR values and in DF mode for high SNR values as on the basis of SNR threshold, the operation mode has been selected in the proposed HDAF scheme.

2.5 Summary

In this chapter, an effective cooperative relaying scheme is proposed for distributed alamouti coded cooperative network and its performance metrics such as SER, the outage and the channel capacity are compared with conventional relaying schemes under flat Rayleigh channel fading condition. The theoretical expressions for SER outage probability and the channel capacity for the proposed scheme are derived and it is found also that the Monte Carlo simulation results agree with those closely. The SER performance of HDAF is close to that of AF at low SNR case and close to DF at high SNR cases. The outage probability of hybrid relaying is in between DF and AF (i.e. better than DF but not same as AF). The channel capacity is almost same as the capacity due to AF relays for small values of SNR and it increases as the SNR value increases and finally it becomes very close to the capacity due to DF relays. The effect of relay location on SER performance and channel capacity are studied in detail. The hybrid decode and amplify forward relaying scheme with the advantages of both performs better than AF & DF as the advantages of both AF & DF protocols are combined in this scheme. Further considering a more generalized scenario where more number of HDAF relays should be introduced in to the wireless cooperative network. Power allocation to those relays becomes a major issue. Hence development of efficient power allocation algorithms under total power constraint needs to be attempted.

2.6 Appendix

Fact 1: The CDF of the random variable $X = \dfrac{X_1 X_2}{X_1 + X_2 + \sigma}$

Let X_1 and X_2 be two independent exponential random variables with the PDFs $f_{X_i}(x_i) = \lambda_i e^{-\lambda_i x_i}$, $x_i \geq 0, i \in \{1,2\}$, and the parameters $\lambda_1, \lambda_2 > 0$,and let $\sigma > 0$ be a real constant. Then the CDF of the random variable $X = \dfrac{X_1 X_2}{X_1 + X_2 + \sigma}$ is given by

$$F_X(x) = 1 - 2e^{-(\lambda_1+\lambda 2)x} \sqrt{\lambda_1 \lambda_2 x(x+\sigma)} \times K_1(2\sqrt{\lambda_1 \lambda_2 x(x+\sigma)}) \tag{2.60}$$

Derivation of (42):

The outage probability of two distributed Alamouti coded AF relays is

$$P_{out}^{AF} = \Pr(\sum_{i=1}^{2} \frac{\gamma_{s,r_i} \gamma_{r_i,d}}{\gamma_{s,r_i} + \gamma_{r_i,d} + 1} < \gamma_{th}) \tag{2.61}$$

$$P_{out}^{AF} = \Pr(\sum_{i=1}^{2} z_i < \gamma_{th}) \tag{2.63}$$

$$\text{where } z_i = \frac{\gamma_{s,r_i} \gamma_{r_i,d}}{\gamma_{s,r_i} + \gamma_{r_i,d} + 1} \;\&\; \gamma_{th} = 2^{2R} - 1 \tag{2.64}$$

Using theorem 1, the CDF of z_i for $i = 1,2$ is given by

$$P_{z_i}(\gamma_{th}) = \Pr(z_i < \gamma_{th}) \tag{2.65}$$

$$= 1 - 2\gamma_{th} \sqrt{\lambda_{s,r_i} \lambda_{r_i,d}} e - \gamma_{th}(\lambda_{s,r_i} + \lambda_{r_i,d}) \times K_1(2\gamma_{th} \sqrt{\lambda_{s,r_i} \lambda_{r_i,d}}) \tag{2.66}$$

For smaller values of x, the function $K_1(.)$ can be approximated as $K_1(x) \approx \dfrac{1}{x}$.

$$P_{z_i}(\gamma_{th}) = \Pr(z_i < \gamma_{th}) \approx 1 - e^{-\gamma_{th}(\lambda_{s,r_i} + \lambda_{r_i,d})} \tag{2.67}$$

Assuming $\lambda_i = \lambda_{s,r_i} + \lambda_{r_i,d}$ .where $\lambda_{s,r_i} = \dfrac{N_o}{P_1 \sigma_{s,r_i}^2} = \dfrac{1}{SNR\sigma_{s,r_i}^2}$ & $\lambda_{r_i,d} = \dfrac{N_o}{P_2 \sigma_{r_i,d}^2} = \dfrac{1}{SNR\sigma_{r_i,d}^2}$

(2.67)

Defining the random variable $Z = \sum_{i=1}^{2} z_i$, the CDF of Z, assuming the λ_i are to be distinct, can be written as

$$\Pr(Z < \gamma_{th}) = \sum_{i=1}^{2} \left(\prod_{m=1, m \neq i}^{2} \frac{\lambda_m}{\lambda_m - \lambda_i} \right) (1 - e^{-\lambda_i \gamma_{th}}) \tag{2.68}$$

$$P_{out}^{AF} = \Pr(Z < \gamma_{th}) = \frac{1}{2}\prod_{i=1}^{2} \lambda_i \gamma_{th}{}^2 \tag{2.69}$$

By substituting values of $\lambda_i \& \gamma_{th}$ in the above equation, the outage probability is obtained as

$$P_{out}^{AF} = \frac{1}{2}\prod_{\mathrm{i}=1}^{2}\left(\frac{1}{\sigma_{s,ri}^2} + \frac{1}{\sigma_{ri,d}^2}\right)\left(\frac{2^{2\mathrm{R}}-1}{SNR}\right)^2 \quad for\ i = 1,2 \tag{2.70}$$

Derivation for (43):

Fact 2: Let $w = u + v$, where u and v are independent exponential random variables with parameters $\lambda_{r_1,d}$ and $\lambda_{r_2,d}$,respectively. Then the CDF of w

$$P_w(w) = \begin{cases} 1 - \left[\left(\dfrac{\lambda_{r_2,d}}{\lambda_{r_2,d} - \lambda_{r_1,d}}\right)e^{-\lambda_{r_1,d}w} + \left(\dfrac{\lambda_{r_1,d}}{\lambda_{r_1,d} - \lambda_{r_2,d}}\right)e^{-\lambda_{r_2,d}w}\right], & \lambda_{r_1,d} \neq \lambda_{r_2,d} \\ 1 - (1 + \lambda w)e^{-\lambda w} & , \lambda_{r_1,d} = \lambda_{r_2,d} = \lambda \end{cases} \tag{2.71}$$

Based on transmit diversity bound in [2], the maximum mutual information of two relay DF scheme in distributed Alamouti coded cooperative network is

$$I_{DF} = \log\left(1 + \frac{SNR}{2}\left[\left|h_{r_1,d}\right|^2 + \left|h_{r_2,d}\right|^2\right]\right) \tag{2.72}$$

Hence, the outage probability is obtained as

$$P_{out}^{DF} = \Pr(I_{DF} < R) = \Pr\left(\frac{SNR}{2}\left[\left|h_{r_1,d}\right|^2 + \left|h_{r_2,d}\right|^2\right] < \gamma_{th}\right) \tag{2.73}$$

Using the Fact1, the outage probability of two relay DF scheme is written as

$$P_{out}^{DF} = \Pr(I_{DF} < R) \approx \frac{2}{\sigma_{r_1,d}^2 \sigma_{r_2,d}^2}\left(\frac{\gamma_{th}}{SNR}\right)^2 \tag{2.74}$$

$$P_{out}^{DF} \approx \frac{2}{\sigma_{r_1,d}^2 \sigma_{r_2,d}^2}\left(\frac{2^{2\mathrm{R}}-1}{SNR}\right)^2 \tag{2.75}$$

Derivation for (60):

$$\mathrm{I}_1 = \frac{1}{\gamma_i}\int_0^\infty \log_2(1+\gamma)\ e^{-\frac{\gamma}{\gamma_i}}\ d\gamma \tag{2.76}$$

Now by using integration by parts and let $u = \log(1+\gamma)$ and $dv = \frac{1}{\gamma_i}e^{-\frac{\gamma}{\gamma_i}}d\gamma$

$$\int u\ dv = \mathrm{uv} - \int \mathrm{v\,du} \tag{2.76}$$

$$I_1 = \left|uv\right|_0^\infty - \int_0^\infty v \ du \tag{2.77}$$

$$I_1 = \left|\log(1+\gamma)e^{-\frac{\gamma}{\gamma_i}}\right|_0^\infty - \int_0^\infty \frac{e^{-\frac{\gamma}{\gamma_i}}}{(1+\gamma)} \ d\gamma \tag{2.78}$$

$$I_1 = e^{\left(\frac{1}{\gamma_i}\right)} E_1\left(\frac{1}{\gamma_i}\right) \tag{2.79}$$

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Chapter 3

Development of Power Allocation Schemes to Improve Performance of Multi HDAF Relay Based Cooperative Network

In the previous chapter, the performance analysis of hybrid relaying protocol is studied only for limited number of HDAF relays of wireless cooperative network in flat Rayleigh fading channel. This study is extended to multiple HDAF relay based cooperative network in this chapter. For such network, we can further improve the performance using power allocation schemes which need to be addressed.

Objectives of the chapter

- To describe the system model consisting of multi HDAF (hybrid decode amplify forward) relays in a cooperative network and to obtain the closed form approximation for average channel capacity with tight approximation.
- To propose power allocation schemes on the basis of decoding capability of the relay. The power allocation schemes to be proposed are
  - Maximized channel capacity based power allocation using Differential evolution (DE) algorithm.
  - Minimized SER based power allocation based on lower bound of SER using both Lagrange multiplier method and Differential evolution (DE) algorithm.
  - Total power minimization scheme to improve the quality of service using Lagrange multiplier method based on a given target SER.
- To analyze the impact of relay location and channel variances on the average channel capacity performance.

Part of the contributions in this chapter are published in

Kiran Kumar Gurrala, Susmita Das**, "Maximized Channel Capacity Based Power Allocation Technique for Multi Relay Hybrid Decode-Amplify-Forward Cooperative Network"* ***Wireless Personal Communication (Springer), *vol.87, no.3, pp: 663-678, 2016.* ***DOI*** *10.1007/s11277-015-2622-9.*

3.1 Introduction

Power allocation for wireless cooperative network is a promising research area. The authors have extended the hybrid relaying scheme to the multiple relays and studied the performance analysis in [8]. SNR based hybrid relaying, which is a combination of fixed AF and DF relaying schemes, is proposed for single relay case in [9]. The closed form tight bounds for the outage probability and bit error rate of the HDAF relaying for multi relay network are derived in [10]. SER performance analysis and optimum power allocation for wireless cooperative networks with basic relaying schemes are proposed in [4]. The optimum power allocation based on minimized SER with best relay selection for multi relay AF network is proposed to prolong the network life time in [5]. The authors have introduced optimum power allocation schemes based on SER for adaptive relaying schemes in dual hop multi relay cooperative network in [6]. The authors proposed two power allocation methods for minimizing outage probability and minimizing SER based on channel state information and channel statistics in [11]. The closed form expression for SER is derived for single relay cooperative network using MGF (moment generating function) approach for hybrid relaying and based on the SER upper bound optimum power allocation is obtained in [12]. A novel quasi-optimal power allocation scheme for maximizing the upper bound of the ergodic capacity of multi AF relay cooperative network is proposed in [13]. The authors have introduced two power allocation schemes that are rate adaption with fixed transmit power and joint rate and power adaption algorithms [14]. Effective capacity maximization based power allocation using PSO (particle swarm optimization) in multi relay cooperative network is proposed in [15].

This research work attempts proposing a system model and detail theoretical analysis for a multi HDAF relay based cooperative network. The closed form approximation for average channel capacity with tight approximation is derived. Efficient schemes for relay power allocation with fixed source power are proposed on the basis of decoding capability of the relay. The proposed schemes are based on the maximization of channel capacity using Differential Evolution algorithm and minimized SER based power allocation using both Lagrange multiplier and Differential Evolution algorithm. Further to improve the Quality of Service, a total power minimization scheme is proposed. A study regarding the impact of relay location and channel variances on the average channel capacity is carray

out. Monte Carlo simulations method is used for the validation of the proposed power allocation schemes.

The organization of this chapter is as follows Section 3.2 presents the system model. Section 3.3 provides analysis of performance metrics in average channel capacity for a multi HDAF relay based wireless cooperative network. Section 3.4 introduces proposed power allocation schemes to minimize SER, maximize average channel capacity and total power minimization. Section 3.5 discusses the simulations results and analysis. Finally Section 3.6 presents the summary of this chapter.

3.2 System model

A multi relay cooperative network is considered which consists of one source, N number of half duplex mode HDAF (Hybrid Decode-Amplify-Forward) relays and one destination as shown in Fig 3.1. All the links are mutually independent and subject to flat Rayleigh fading. Here it is assumed that the users transmit their information through orthogonal channels through TDMA with knowledge of CSI (channel state information) at the destination and there is perfect synchronization between the cooperating nodes. The two phases of operation of the multi relay HDAF network are given as follows.

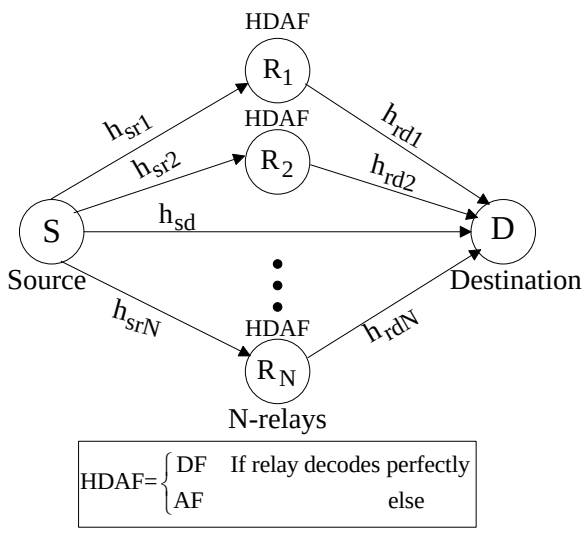


Figure 3.1 Multi relay HDAF (Hybrid Decode-Amplify-Forward) cooperative network model

3.2.1 Broadcast phase

The data is broadcasted by the source to destination as well as N number of relays. The received signal at the destination and the ith relay are given by

$$y_{s,d} = \sqrt{P_S}\, h_{s,d}\, x + n_{s,d} \tag{3.1}$$

$$y_{s,r_i} = \sqrt{P_S}\, h_{s,r_i}\, x + n_{s,r_i} \quad for \;\; i = 1,2,...N \tag{3.2}$$

where $x, y_{s,d}$ and y_{s,r_i} are the transmitted information signal from source, signals received at the destination and i^{th} relay node respectively. P_S is the transmitted source power, h_{s,r_i} and $h_{s,d}$ are the channel coefficients of source to relay links and source to destination link respectively which include the effects of path loss ,shadowing and flat fading between the transmitter and the receiver. The channel coefficients $h_{s,d} \sim CN(0, \sigma^2_{s,d})$ and $h_{s,r_i} \sim CN(0, \sigma^2_{s,r_i})$ are modelled as zero mean complex Gaussian random variables with variances $\sigma^2_{s,d}$ and σ^2_{s,r_i} $for \;\; i = 1,2,..., N$ respectively. The noise terms $n_{s,d}$ and n_{s,r_i} are modelled as zero mean complex Gaussian random variables with variance N_o.

3.2.2 Cooperation phase

In this phase, each relay adaptively chooses between AF and DF relaying schemes based on decoding capability of the relay. If the relay decodes the received information signal correctly the relay operates in DF mode otherwise it operates in AF mode.

If the relay operates in DF mode, the signal received at the destination $y_{r_i,d}$ from the ith relay is given by

$$y_{r_i,d} = \sqrt{P_i}\, h_{r_i,d}\, \hat{y}_{s,r_i} + n_{r_i,d} \quad for \;\; i = 1,2,.., N \tag{3.3}$$

If the relay operates in AF mode, the signal received at the destination $y_{r_i,d}$ from the ith relay is given by

$$y_{r_i,d} = \beta_i \sqrt{P_i}\, h_{r_i,d}\; y_{s,r_i} + n_{r_i,d} \quad for \; i = 1,2,..., N \tag{3.4}$$

where P_i is the power of ith relay node $P_i = \alpha_i \times (P - P_s)$. P is the total power required for message transmission $P = P_s + \sum_{i=1}^{N} P_i$; α_i is the power allocation factor of ith relay node, $\hat{y}_{s,r_i}$ is the estimation of the transmitted signal by the ith relay. β_i is the amplification factor of ith relay given by

$$\beta_i \leq \sqrt{\frac{P_i}{P_S \left| h_{s,r_i} \right|^2 + N_o}} \tag{3.5}$$

$h_{r_i,d}$ *for* $i = 1,2,...,N$ are the channel coefficients of relay to destination links and are modeled as $h_{r_i,d} \sim CN(0, \sigma^2_{r_i,d})$ are modelled as zero mean complex Gaussian random variables with variances $\sigma^2_{r_i,d}$ *for* $i = 1,2,...,N$. The noise terms $n_{r_i,d}$ are modelled as zero mean complex Gaussian random variables with variance N_o.

The destination combines the signals received from source and N number of relays using maximal ratio combining (MRC). To determine the impact of relay location on the performance of the multi relay HDAF cooperative network, the path loss is considered as

$$\sigma^2_{x,y} \propto d^{-\alpha}_{x,y} \tag{3.6}$$

where $d_{x,y}$ is the distance between nodes $x \in \{s, r_i\}$ and $y \in \{r_i, d\}$. In this work, the path loss exponent α is considered as $\alpha = 4$ (for lossy channel environment).

3.3 Performance metrics analysis

The performance metrics considered are average channel capacity and symbol error rate to propose power allocation schemes to improve the network performance. In this section, the closed form of ergodic channel capacity is derived for considered multi HDAF relay based cooperative network. Then, upper bounds to evaluate the average channel capacity when the HDAF relays operate in both AF and DF relaying modes are determined.

3.3.1 Average channel capacity of multi relay HDAF cooperative network

In this hybrid relaying, if the relay decodes the received signal from source perfectly $(\gamma_{s,r} \geq \gamma_c)$ then the relay operates in DF mode otherwise it operates in AF mode $(\gamma_{s,r} < \gamma_c)$. Here SNR at which the relay decodes the received signal perfectly is γ_c.

The average channel capacity for HDAF multi relay cooperative network [38] is given by

$$C_{HDAF} = \Pr(\gamma_{s,r} < \gamma_c)\, C_{AF} + \Pr(\gamma_{s,r} \geq \gamma_c)\, C_{DF} \tag{3.7}$$

where $\Pr(\gamma_{s,r} < \gamma_c) \approx \prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right)$; $\Pr(\gamma_{s,r} \geq \gamma_c) \approx 1 - \prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{s,r_i}}\right)$ (3.8)

The average channel capacity of multi relay cooperative network, in Shannon's capacity sense, depends on the instantaneous SNR at the destination [81].

$$C = \frac{W}{N+1}\int_0^{\infty} \log_2(1+\gamma)\ f(\gamma)\, d\gamma \tag{3.9}$$

where γ is the instantaneous SNR at the destination. N is the number of relays in the network. W is the transmitted signal bandwidth and $f(\gamma)$ is the PDF (probability density function) of γ.

The instantaneous SNR at the destination for multi relay amplify and forward (AF) cooperative network is expressed [4] as

$$\gamma_{AF_i} = \frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i} + \gamma_{r_i,d} + 1} \quad for\ i = 1,2,...,N \tag{3.10}$$

The instantaneous SNR at the destination for multi relay decode and forward (DF) cooperative network is expressed [4] as

$$\gamma_{DF_i} = \min\left(\gamma_{s,r_i}, \gamma_{r_i,d}\right) \quad for\ i = 1,2,...,N \tag{3.11}$$

The average channel capacity of multi relay AF cooperative network is expressed [13] as

$$C_{AF} = \frac{W}{N+1}\int_0^{\infty} \log_2(1+\gamma)\ f_{\gamma_{AF}}(\gamma)\, d\gamma \tag{3.12}$$

The probability distribution function (PDF) $f_{\gamma_{AF}}(\gamma)$ is given by

$$f_{\gamma_{AF}}(\gamma) = \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{AF_i}} \exp\left(-\frac{\gamma}{\gamma_{AF_i}}\right)$$

where $\beta_i = \prod_{k=1,k\neq i}^{N} \left(1 - \frac{\gamma_k}{\gamma_i}\right)^{-1}$; $\gamma_{AF_i} = \frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i} + \gamma_{r_i,d} + 1}$ (3.13)

where $\gamma_{s,r_i} = \frac{P_s}{N_o}\left|h_{s,r_i}\right|^2$ and $\gamma_{r_i,d} = \frac{P_i}{N_o}\left|h_{r_i,d}\right|^2$ $for\ i = 1,2,...,N$. By substituting (3.13) in (3.12)

$$C_{AF} = \frac{W}{N+1}\int_0^{\infty} \log_2(1+\gamma) \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{AF_i}} \exp\left(-\frac{\gamma}{\gamma_{AF_i}}\right) d\gamma \tag{3.14}$$

At last, the average channel capacity of multi relay amplify and forward network is expressed as

$$C_{AF} = \frac{W}{(N+1)\ln 2}\sum_{i=1}^{N} \beta_i \; exp\left(\gamma_{AF_i}^{-1}\right) E_1\left(\gamma_{AF_i}^{-1}\right) \tag{3.15}$$

where E1 (.) is is the exponential integral defined as $E_1(x) = \int_x^{\infty} \frac{\exp(-t)}{t} dt$ (3.16)

The average channel capacity of multi relay DF cooperative network is expressed as

$$C_{DF} = \frac{W}{2}\int_0^{\infty} \log_2(1+\gamma)\, f_{\gamma_{DF}}(\gamma)\; d\gamma \tag{3.17}$$

The probability distribution function (PDF) $f_{\gamma_{DF}}(\gamma)$ is given by

$$f_{\gamma_{DF}}(\gamma) = \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{DF_i}} \exp\left(-\frac{\gamma}{\gamma_{DF_i}}\right) \tag{3.18}$$

Substitute (3.18) in (3.17), the average channel capacity for multi relay decode and forward cooperative network is expressed as

$$C_{DF} = \frac{W}{(N+1)\ln 2}\sum_{i=1}^{N} \beta_i \; exp\left(\gamma_{DF_i}^{-1}\right) E_1\left(\gamma_{DF_i}^{-1}\right) \quad \text{where } \gamma_{DF_i} = \min\left(\gamma_{s,r_i}, \gamma_{r_i,d}\right) \tag{3.19}$$

Substitute (3.8), (3.15) & (3.19) in (3.7), finally the tight approximation for average channel capacity is given by

$$C_{HDAF} = \frac{W}{(N+1)\ln 2}\left\{\left(\prod_{i=1}^{N} \exp\left(-\frac{\gamma_c}{\gamma_{s,r_i}}\right)\right)\sum_{i=1}^{N} \beta_i \; exp\left(\gamma_{AF_i}^{-1}\right) E_1\left(\gamma_{AF_i}^{-1}\right)\right.$$

$$\left. + \left(1 - \prod_{i=1}^{N} \exp\left(-\frac{\gamma_c}{\gamma_{s,r_i}}\right)\right)\sum_{i=1}^{N} \beta_i \; exp\left(\gamma_{DF_i}^{-1}\right) E_1\left(\gamma_{DF_i}^{-1}\right)\right\} \tag{3.20}$$

Since, in Eq.(3.12), $\log(\;)$ is a concave function and using Jensen's inequality [66], the Ergodic capacity based on mutual information of multi relay amplify and forward cooperative network can be upper bounded as

$$C_{AF} = E\left(\log_2\left(1+\gamma_{s,d}+\sum_{i=1}^{N}\gamma_{AF_i}\right)\right) \le \log_2\left(1+E\left(\gamma_{s,d}+\sum_{i=1}^{N}\gamma_{AF_i}\right)\right)$$

$$C_{AF} \le \log_2\left\{1+\gamma_{s,d}+\sum_{i=1}^{N}\frac{\gamma_{s,r_i}\gamma_{r_i,d}}{\gamma_{s,r_i}+\gamma_{r_i,d}+1}\right\} = \log_2\left\{1+\frac{P_S}{N_o}\sigma_{s,d}^2+\sum_{i=1}^{N}\frac{\frac{P_S}{N_o}\sigma_{s,r_i}^2\frac{P_i}{N_o}\sigma_{r_i,d}^2}{\frac{P_S}{N_o}\sigma_{s,r_i}^2+\frac{P_i}{N_o}\sigma_{r_i,d}^2+1}\right\} \tag{3.21}$$

In the same way, the ergodic capacity based on mutual information of multi relay decode and forward cooperative network can be upper bounded as

$$C_{DF} \le \log_2\left\{1+\gamma_{s,d}+\sum_{i=1}^{N}\gamma_{r_i,d}\right\} = \log_2\left\{1+\frac{P_S}{N_o}\sigma_{s,d}^2+\sum_{i=1}^{N}\frac{P_i}{N_o}\sigma_{r_i,d}^2\right\} \tag{3.22}$$

3.4 Proposed power allocation schemes for multi HDAF relay based cooperative network

The channel conditions and location of nodes show the impact on the performance of the wireless cooperative network. Instead of blindly assigning equal power to all the nodes, by allocationg proper power to all relay nodes according to the channel link quality and their locations improves the network performance significantly. For example, when any of the source-to-relay or relay-to-destination channel links are not good, the relay nodes with proper power allocation are able to transmit the signal from the source to the destination. Here the power allocation schemes are proposed under total power constraint. Even-though, the optimization problems with individual power constraints lead to proper power allocation but suffer with computational complexity. It is due to the fact that there is need to update only one Lagrange multiplier using sub gradient method under total power constraint where as in the optimization problem under individual power constraint updation of Lagrangee multipliers many times until all of them converge to the optimum power allocation level is is done. Hence, the formulation of optimization problems is simple and attains low computational complexity compared to individual power constraint. In this section, proposed power allocation schemes as explanined in block diagram as shown in Fig.3.2 for channel capacity maximization, SER minimization and total power minimization under total power constraint. Maximized channel capacity based and minimized SER based power allocation schemes are proposed using both Lagrange

multiplier method and Differential Evolution algorithm in Section 3.4.1 and 3.4.2 respectively. At last total power minimization to maintain required quality of service in terms of SER is proposed using Lagrange multiplier method in Section 3.4.3.

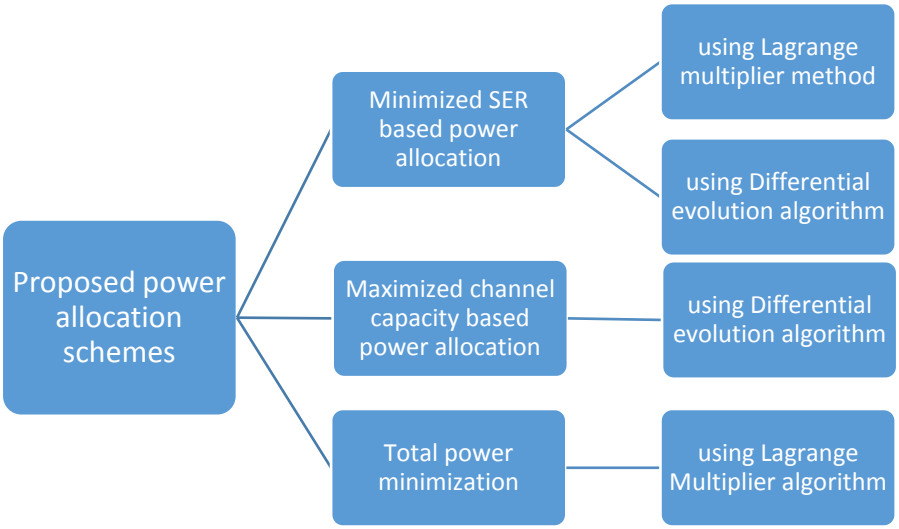


Figure 3.2 Proposed power allocation schemes

3.4.1 Maximized channel capacity based power allocation using Differential Evolution algorithm

The proposed optimization problem is defined on basis of the decoding capability of the relay. Depending on the operation mode of HDAF relay either in AF or DF, the optimization problem is defined based on the upper bound of average channel capacity under total power constraint. Further, the relay powers are optimized using the optimized power allocation factor α. The performance of the proposed technique is validated for different channel variances and for different relay locations. The relation between transmit power at the source and the relay nodes in terms of power allocator are represented as $P_i = \alpha_i (P - P_s) \quad for \;\; i = 1,2,...,N$ where $\sum_{i=1}^{N} \alpha_i = 1$. Hence , the optimization problem for maximization of channel capacity using Differential Evolution (DE) algorithm is defined as follows.

Optimization problem:

If the relay decodes perfectly, then the optimization problem is defined as

$$\text{Maximize } C_{DF} = \log_2\left\{1+\frac{P_S}{N_o}\sigma^2_{s,d}+\sum_{i=1}^{N}\frac{\alpha_i(P-Ps)}{N_o}\sigma^2_{r_i,d}\right\}$$

$$\text{subject to } \sum_{i=1}^{N}\alpha_i = 1,\ \ 0<\alpha_i<1,\ \ for\ i=1,2,...,N$$

else the optimization problem is defined as

$$\text{Maximize } C_{AF} = \log_2\left\{1+\frac{P_S}{N_o}\sigma^2_{s,d}+\sum_{i=1}^{N}\frac{\frac{P_S}{N_o}\sigma^2_{s,r_i}\ \frac{\alpha_i(P-Ps)}{N_o}\sigma^2_{r_i,d}}{\frac{P_S}{N_o}\sigma^2_{s,r_i}+\frac{\alpha_i(P-Ps)}{N_o}\sigma^2_{r_i,d}}\right\}$$

$$\text{subject to } \sum_{i=1}^{N}\alpha_i = 1,\ 0<\alpha_i<1,\ \ for\ i=1,2,...,N \tag{3.27}$$

If the relay decodes perfectly Cost function: $f_{CHDAF} = \arg\min\left(-C_{DF}\right)$

Else Cost function: $f_{CHDAF} = \arg\min\left(-C_{AF}\right)$ (3.28)

The optimization problem can be solved using constraint optimization techniques like linear programming (using Lagrangian multipliers) but unfortunately there is no explicit method to calculate the value of Lagrange multiplier λ, for this we have to use iterative methods or numerical search methods. It may be computational burden to calculate the value of λ using iterative methods as the number of relays increases. To decrease this computational burden, soft computing techniques can be preffered and for this, Differential evolution algorithm is chosen here. Differential Evolution algorithm is an efficient and powerful stochastic search optimization technique like with the advantages like finding the true global minimum regardless of the initial parameter values, fast convergence, and using few control parameters. Differential Evolution is like genetic algorithm using the similar operators; crossover, mutation and selection. The differential evolution has a computational flexibility compared to genetic algorithm because it defines individual variables in a decimal format. The proposed DE based power allocation scheme follows the flowchart shown in Fig 3.3 and the detailed Differential evolution algorithm is given in Fig.3.4.

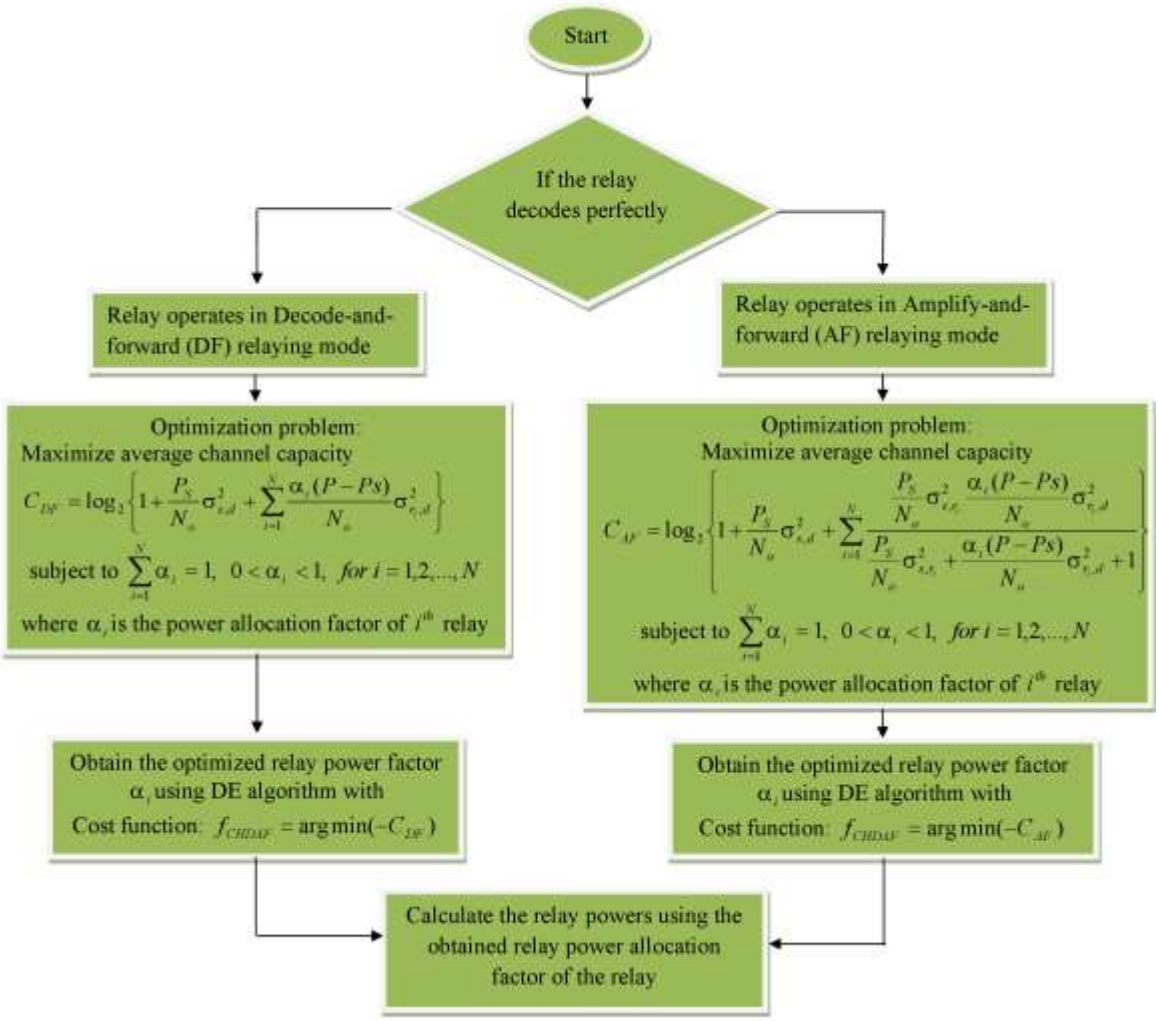


Figure 3.3 Flowchart for proposed DE based power allocation

The parameters in the flowchart shown in Fig. 3.4 are defined as follows. Gd is the total number of generations; g is the individual generation; NP is the number of population members; D is the number of parameters of objective function; α_i is the power allocation of factor of each relay.

Initialization: The nth individual of the population in the gth generation is expressed as

$$\alpha^{g,i} = [\alpha_1^{g,i}, \alpha_2^{g,i}, \ldots\ldots, \alpha_D^{g,i}]^T, i = 1,2,\ldots., NP, g = 1,2,\ldots, G_d \tag{3.29}$$

Fitness evolution:

$E1 = f_{CHDAF}^{g,n}\left(u^{g,n}\right)$ is the fitness (cost function value) of the nth individual in the gth generation of $u^{g,n}$ which is given as follows

If the relay operates in DF mode:

$$E1 = f_{CHDAF}^{g,n}\left(u^{g,n}\right) = -C_{DF}(u^{g,n}) \tag{3.30}$$

If the relay operates in AF mode:

$$E1 = f_{CHDAF}^{g,n}\left(u^{g,n}\right) = -C_{AF}\left(u^{g,n}\right) \tag{3.31}$$

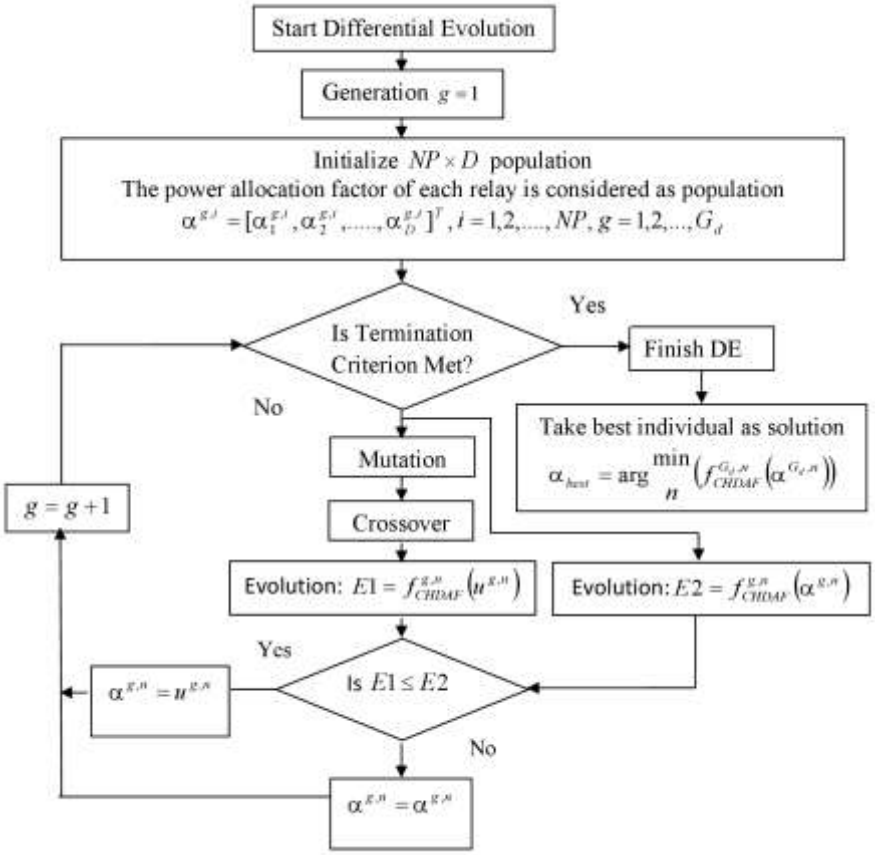


Figure 3.4 Differential evolution algorithm for proposed power allocation

$E2 = f_{CHDAF}^{g,n}\left(\alpha^{g,n}\right)$ is the cost function value of the nth individual in the gth generation of $\alpha^{g,n}$ which is given as follows

If the relay operates in DF mode:

$$E2 = f_{CHDAF}^{g,n}\left(\alpha^{g,n}\right) = -C_{DF}\left(\alpha^{g,n}\right) \tag{3.32}$$

If the relay operates in AF mode:

$$E2 = f_{CHDAF}^{g,n}\left(\alpha^{g,n}\right) = -C_{AF}\left(\alpha^{g,n}\right) \tag{3.33}$$

where $\alpha^{g,n}$ is the target vector, $u^{g,n}$ is the trail vector obtained after mutation and cross over operations

Optimal solution: The optimal solution after meeting the termination criteria, the best individual having the minimum cost function value is considered as the optimal power allocation factor α. The optimal solution for power allocation factor is estimated as

$$\alpha_{best} = \arg\min_n \left(f_{CHDAF}^{G_d,n}\left(\alpha^{G_d,n}\right)\right),\ n = 1,2,\ldots,NP \tag{3.34}$$

$f_{CHDAF}^{G_d,n}\left(\alpha^{G_d,n}\right)$ represents the optimal solution after meeting the termination criteria which is the best individual having the minimum fitness value.

3.4.2 Minimized SER based power allocation scheme

3.4.2.1 Using Lagrange multiplier method

The method of Lagrange multipliers is a mathematical optimization for finding the local maxima and minima of a function subject to equality constraints. In [13], the authors achieved the optimized relay powers with minimization of SER lower bound as optimization problem and total relay power as constraint. But the obtained relay powers depend on the value of λ and have to undergo water filling process for individual power constraints. We simplify the optimization problem by introducing a power allocation factor α for each relay so that there is no need of water filling process again. The derivation for lower bound of SER for multi HDAF relay cooperative network in flat Rayleigh fading channel is considered from [13].The calculation of λ (which was not clearly mentioned in [13]) is obtained here using sub gradient method. Now the optimization problem becomes as Minimize $SER_{HDAF} = \prod_{i=1}^{N}\left(\frac{0.5}{P_S\sigma_{s,r_i}^2} + \frac{1}{(\alpha_i(P-P_S))\sigma_{r_i,d}^2}\right)$

with respect to $\sum_{i=1}^{N}\alpha_i = 1, 0 < \alpha_i < 1 \; for \; i = 1,2,..,N$ (3.35)

The objective function in (3.31) is a monotonically decreasing function. We can use $\log\left(SER_{HDAF}\right)$as the objective function. Now the objective function can be rewritten as

$$\sum_{i=1}^{N}\log\left(\frac{0.5}{P_S\sigma_{s,r_i}^2} + \frac{1}{(\alpha_i(P-P_S))\sigma_{r_i,d}^2}\right) \text{ with respect to } \sum_{i=1}^{N}\alpha_i = 1 \quad (3.36)$$

The Lagrangian function J is defined as

$$J = \sum_{i=1}^{N}\log\left(\frac{0.5}{P_S\sigma_{s,r_i}^2} + \frac{1}{(\alpha_i(P-P_S))\sigma_{r_i,d}^2}\right) + \frac{1}{\lambda}\left(\sum_{i=1}^{N}\alpha_i = 1\right) \quad (3.37)$$

where $\frac{1}{\lambda}$ is the Lagrange multiplier. Then by taking the derivative of with respect to α_i and make equal to zero

$$\frac{1}{\left(\frac{0.5}{P_S\sigma_{s,r_i}^2}+\frac{1}{(\alpha_i(P-P_S))\sigma_{r_i,d}^2}\right)}\left(\frac{1}{(P-P_S)\sigma_{r_i,d}^2}\right)\left(-\frac{1}{\alpha_i^2}\right)+\frac{1}{\lambda}=0 \tag{3.38}$$

$$\Rightarrow\left(0.5(P-P_S)\sigma_{r_i,d}^2\right)\alpha_i^2+\left(P_S\sigma_{s,r_i}^2\right)\alpha_i-\left(\lambda P_S\sigma_{s,r_i}^2\right)=0 \tag{3.39}$$

Finally from the roots of the above equation, the power allocation factor α_i is given by

$$\alpha_i=\left(\frac{P_S}{(P-P_S)}\right)\left(\frac{\sigma_{s,r_i}^2}{\sigma_{r_i,d}^2}\right)\left[-1+\sqrt{1+2\lambda\left(\frac{(P-P_S)}{P_S}\right)\left(\frac{\sigma_{r_i,d}^2}{\sigma_{s,r_i}^2}\right)}\right]\quad for\ \ i=1,2,....,N \tag{3.40}$$

Table 3-1 Steps to find Lagrange multiplier

Proposed algorithm for choosing λ using sub gradient method
1. **Inputs**: $P, P_S, \sigma_{s,r_i}^2, \sigma_{r_i,d}^2$
2. **Output**: λ, α_i
3. Algorithm
4. Initialize $k=1,\ \lambda(1)=0.1,\ f(1)=-1$
5. While (abs(f)>0.001)
6. Calculate
$\alpha_i=\left(\frac{P_S}{(P-P_S)}\right)\left(\frac{\sigma_{s,r_i}^2}{\sigma_{r_i,d}^2}\right)\left[-1+\sqrt{1+2\lambda(k)\left(\frac{(P-P_S)}{P_S}\right)\left(\frac{\sigma_{r_i,d}^2}{\sigma_{s,r_i}^2}\right)}\right]$
$for\ i=1,2,...,N$
7. $f(k)=sum(\alpha_i)-1$
8. $\lambda(k+1)=\lambda(k)-(1/k)\ f(k)$
9. $k=k+1$
10. end

From the derived power allocation factor it is observed that it depends on channel variances that means the channel conditions and relay location are deciding factors of relay power allocation. The power allocation factor depends on value of water filling level which is Lagrange multiplier λ. We have to choose proper value of λ to satisfy the total power constraint and it can be found here using an iterative method given in table 3.1.

3.4.2.2 Using Differential Evolution (DE) algorithm

The optimization problem is defined for Differential Evolution algorithm as follows

Cost function: $$f_{SER_{HDAF}}=\prod_{i=1}^{N}\left(\frac{0.5}{P_S\sigma_{s,r_i}^2}+\frac{1}{(\alpha_i(P-P_S))\sigma_{r_i,d}^2}\right) \tag{3.41}$$

Population: The power allocation factor of each relay is considered as population

$\alpha^{g,i} = [\alpha_1^{g,i}, \alpha_2^{g,i}, ..., \alpha_D^{g,i}]^T, i = 1,2,....,NP, g = 1,2,...,G_d$

where NP is the number of population, g is the generation index, G_d maximum generation, D is the number of variables in the cost function which is equal to number of relays (N), CR is the cross over rate $CR \in (0,1]$, F is the mutation factor $F \in (0,1]$.

3.4.3 QoS (quality of service) based power allocation schemes

For high data rate applications, wireless cooperative networks need more power consumption to maintain the required quality of service. But the nodes (source and relays) are provided with limited transmit power so there is a need to find the power efficient algorithms to maintain the quality of service. Here we proposed power allocation schemes to minimize the total power such that to maintain the required quality of service in terms of SER (symbol error rate).

3.4.3.1 Optimized relay power to maintain QOS

Here the total relay power minimization is obtained using Lagrange multiplier method to achieve the target SER at the destination. The derivation for lower bound of SER for multi HDAF relay cooperative network in flat Rayleigh fading channel is considered from [76].

Problem definition:

$$\text{Minimize } \sum_{i=1}^{N} P_i \quad \text{such that } \frac{C_1}{P_S \sigma_{s,d}^2} \prod_{i=1}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_i}^2} + \frac{1}{P_i \sigma_{r_i,d}^2} \right) \le SER_{target} \tag{3.42}$$

where $C_1 = \dfrac{\binom{2N+1}{N}}{2^{2N+2}}$, N is the number of relay nodes.

The Lagrangian function J is defined as

$$J = \sum_{i=1}^{N} P_i + \lambda \left(\frac{C_1}{P_S \sigma_{s,d}^2} \prod_{i=1}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_i}^2} + \frac{1}{P_i \sigma_{r_i,d}^2} \right) - SER_{target} \right) \tag{3.43}$$

Let $\partial J / \partial P_i = 0 \Rightarrow 1 + \lambda \left(\frac{C_1}{P_S \sigma_{s,d}^2} \prod_{\substack{j=1 \\ j \neq i}}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_j}^2} + \frac{1}{P_j \sigma_{r_j,d}^2} \right) \right) \left(- \frac{1}{P_i^2 \sigma_{r_i,d}^2} \right) = 0$ (3.44)

$$\Rightarrow P_i^2 = \lambda \frac{C_1}{P_S \sigma_{s,d}^2 \sigma_{r_i,d}^2} \prod_{\substack{j=1 \\ j \neq i}}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_j}^2} + \frac{1}{P_j \sigma_{r_j,d}^2} \right) \quad (3.45)$$

The value of Lagrange multiplier λ in Eq. (3.41) is obtained using sub gradient algorithm.

3.4.3.2 Optimized source and relay powers to maintain QoS (quality of service)

In this case, both source and relay powers have to be optimized such that the total power to be minimized in order to maintain the required quality of service (target SER). The total minimization is obtained using Lagrange multiplier method.

Minimize $P_S + \sum_{i=1}^{N} P_i$ such that $\frac{C_1}{P_S \sigma_{s,d}^2} \prod_{i=1}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_i}^2} + \frac{1}{P_i \sigma_{r_i,d}^2} \right) \leq SER_{target}$ (3.46)

The Lagrange function is defined as

$$J = P_S + \sum_{i=1}^{N} P_i + \lambda \left(\frac{C_1}{P_S \sigma_{s,d}^2} \prod_{i=1}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_i}^2} + \frac{1}{P_i \sigma_{r_i,d}^2} \right) - SER_{target} \right) \quad (3.47)$$

Let $\partial J / \partial P_S = 0$

$$\Rightarrow P_S^2 = \lambda \left\{ \frac{C_1}{\sigma_{s,d}^2} \prod_{i=1}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_i}^2} + \frac{1}{P_i \sigma_{r_i,d}^2} \right) + \frac{C_1}{P_S \sigma_{s,d}^2} \sum_{i=1}^{N} \prod_{\substack{j=1, \\ j \neq i}}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_j}^2} + \frac{1}{P_i \sigma_{r_j,d}^2} \right) \left(\frac{1}{\sigma_{s,r_j}^2} \right) \right\} \quad (3.48)$$

Using the constraint $\frac{C_1}{P_S \sigma_{s,d}^2} \prod_{i=1}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_i}^2} + \frac{1}{P_i \sigma_{r_i,d}^2} \right) = SER_{target}$ the above equation can be written as

$$\Rightarrow P_S^2 = \lambda \left\{ \frac{SER_{target}}{P_S} + \frac{C_1}{P_S \sigma_{s,d}^2} \sum_{i=1}^{N} \prod_{\substack{j=1, \\ j \neq i}}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_j}^2} + \frac{1}{P_i \sigma_{r_j,d}^2} \right) \left(\frac{1}{\sigma_{s,r_j}^2} \right) \right\} \quad (3.49)$$

Let $\partial J / \partial P_i = 0$, $1 + \lambda \frac{C_1}{P_S \sigma_{s,d}^2} \prod_{\substack{j=1, \\ j \neq i}}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_j}^2} + \frac{1}{P_j \sigma_{r_j,d}^2} \right) \left(- \frac{1}{P_i^2 \sigma_{r_i,d}^2} \right) = 0$

$$P_i^2 = \lambda \frac{C_1}{P_S \sigma_{s,d}^2 \sigma_{r_i,d}^2} \prod_{\substack{j=1, \\ j \neq i}}^{N} \left(\frac{0.5}{P_S \sigma_{s,r_j}^2} + \frac{1}{P_j \sigma_{r_j,d}^2} \right) \quad (3.50)$$

Table 3-2 Steps to find Lagrange multiplier for optimal relay and source powers

Algorithm for choosing λ using sub gradient method

1. **Inputs**: $P, P_S, C_1, N, P_i, \sigma^2_{s,r_i}, \sigma^2_{r_i,d}$ $for\ i = 1,2,...,N$
2. **Output**: λ, P_S, P_i $for\ i = 1,2,...N$
3. Algorithm
4. Initialize $k = 1, \lambda(1) = 0.1,\ f(1) = 5.84, g(1) = -3.6,\ P_S = 0.1$

   $P_i = 0.1\ for\ \ i = 1,2,...N$
5. While (abs($g > 0.01$) && abs($f > 0.001$)
6. Calculate

$$P_S = sqrt\left(\lambda\left\{\frac{SER_{target}}{P_S} + \frac{C_1}{P_S\sigma^2_{s,d}}\sum_{i=1}^{N}\prod_{\substack{j=1,\\ j\neq i}}^{N}\left(\frac{0.5}{P_S\sigma^2_{s,r_j}} + \frac{1}{P_i\sigma^2_{r_j,d}}\right)\left(\frac{1}{\sigma^2_{s,r_j}}\right)\right\}\right)$$

$$P_i = sqrt\left(\lambda(k)\frac{C_1}{P_S\sigma^2_{s,d}\sigma^2_{r_i,d}}\prod_{\substack{j=1\\ j\neq i}}^{N}\left(\frac{0.5}{P_S\sigma^2_{s,r_j}} + \frac{1}{P_j\sigma^2_{r_j,d}}\right)\right)$$

$for\ i = 1,2,...,N$

7. Substitute P_i in the following

$$f(k) = \frac{C_1}{P_S\sigma^2_{s,d}}\prod_{i=1}^{N}\left(\frac{0.5}{P_S\sigma^2_{s,r_i}} + \frac{1}{P_i\sigma^2_{r_i,d}}\right) - SER_{target}$$

$$g(k) = (sum(P_i) + P_S) - P$$

8. $\lambda(k+1) = \lambda(k) - (1/k)\ f(k)$
9. $k = k+1$
10. end

3.5 Simulation results and analysis

In this work, the performance of proposed power allocation schemes is verified by Monte Carlo simulation and compared with the equal power allocation scheme. Matlab is used for computer simulation and 10000 independent simulations are run for each result. The Monte Carlo simulation is repeated for 100 times to get a fair result. The simulation parameters are given in Table 3-3. In the simulation model as shown in Fig.1, the normalized distance between source and destination is chosen as one $(d_{sd} = 1)$. For the equal power allocation, the power constraints are given by $P_s = P_r = P/(N+1)$. In the same way, the power constraints considered for the validation of proposed power allocation schemes are $P_s = 1; P = N$.

Table 3-3 Simulation parameters

Parameters	Specification
Total no of bits	10^4
Number of relays(N)	2,3 & 4
Relay network topology	Linear topology
Diversity combining strategy	Maximal ratio combining
Channel	Flat Rayleigh fading
Modulation	Coherent QPSK
DE parameters	DE step size (F)=0.8 Crossover probability(CR)=0.5 D=N(number of parameters of objective function) NP(number of population members)=50*D Iterations=200

3.5.1 Results of maximized channel capacity based power allocation using DE algorithm

For case of two relays at middle of distance between source and destination, the average channel capacity of the proposed scheme is compared with the equal power allocation and theoretical approximation which is carried out in Section 3.4.1. and shown in Fig.3.5.

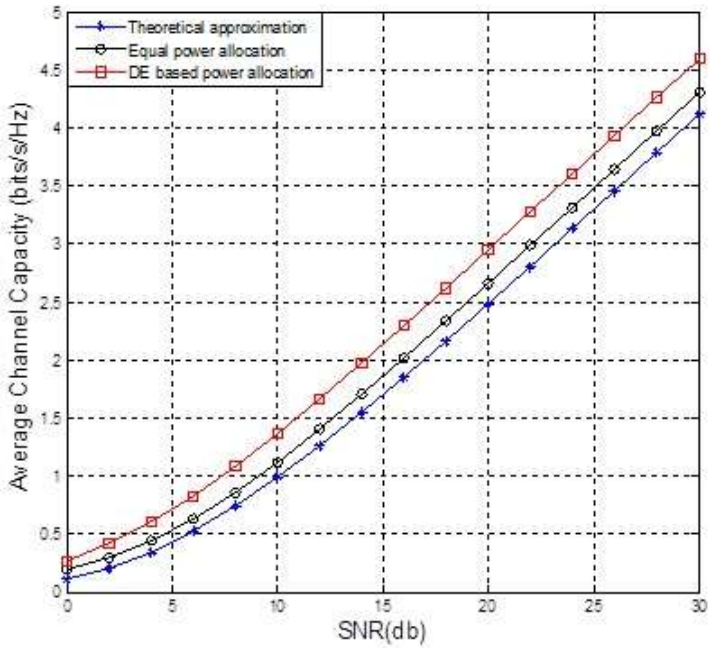


Figure 3.5 Average channel capacity comparison

It is observed that the proposed DE based power allocation provides channel capacity with a gain of 1.1538 over equal power allocation to achieve a channel capacity of 3bits/s/Hz.

The multi relay decode and forward (DF) cooperative network achieves more ergodic channel capacity when compared to multi relay amplify and forward (AF) cooperative network due to the fact that DF relays have high effective SNR at the dsestination compared to AF relays regardless of fading. Hence, the theoretical approximation for lower bound of average channel capacity of HDAF realys becomes equivalent to that of AF relays.

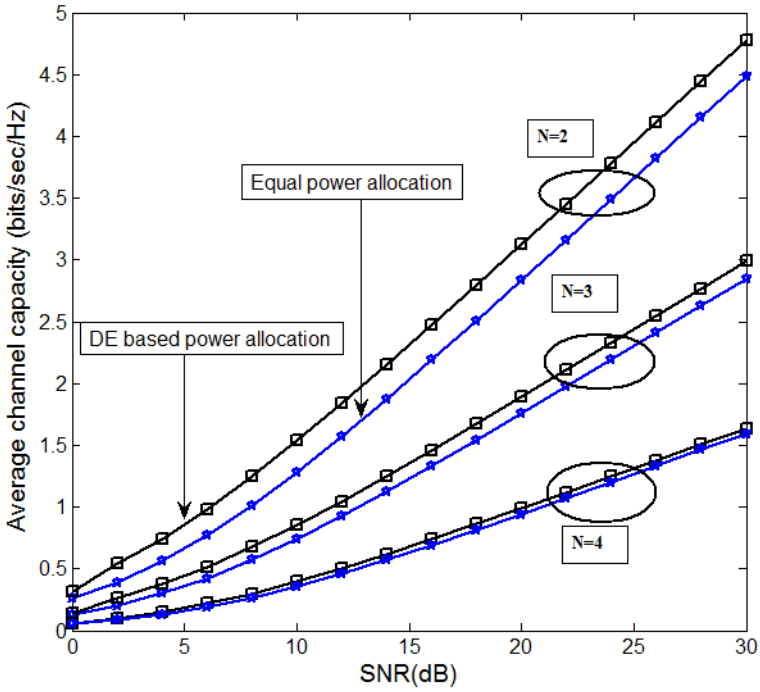


Figure 3.6 Average channel capacity (bits/sec/Hz) versus SNR

Fig 3.6 illustrates the comparison of average channel capacity of the proposed relaying system with equal power allocation and DE based power allocation varying the number of relays. It is observed that as the number of relays increases, the average channel capacity decreases due to the fact that the time division channel allocation in shorter time slots are assigned for transmitting terminals. Fig.3.6 demonstrated that DE based power allocation achieves better channel capacity compared to equal power allocation scheme which is independent of the number of relays. For example at N=3, DE based power allocation achieves channel capacity of 2.5 bits/s/Hz where as the equal power allocation achieves 2.35 bits/s/Hz at a SNR value of 25dB. The average channel capacity versus number of relays for different channel variances considering both the source to relay and relay to destination links is analyzed in Fig 3.7. The proposed power allocation scheme for two relay case attains a capacity gain of 1.1076 dB and 1.1421 dB over the equal power allocation for the channel variances $\sigma_{s,r}^2 = 10, \sigma_{r,d}^2 = 1$ and $\sigma_{s,r}^2 = 10, \sigma_{r,d}^2 = 10$ respectively.

Thus it is observed that the proposed DE based power allocation attains a maximum channel capacity when both source to relay and relay to destination links are good (i.e the channel variances are high).

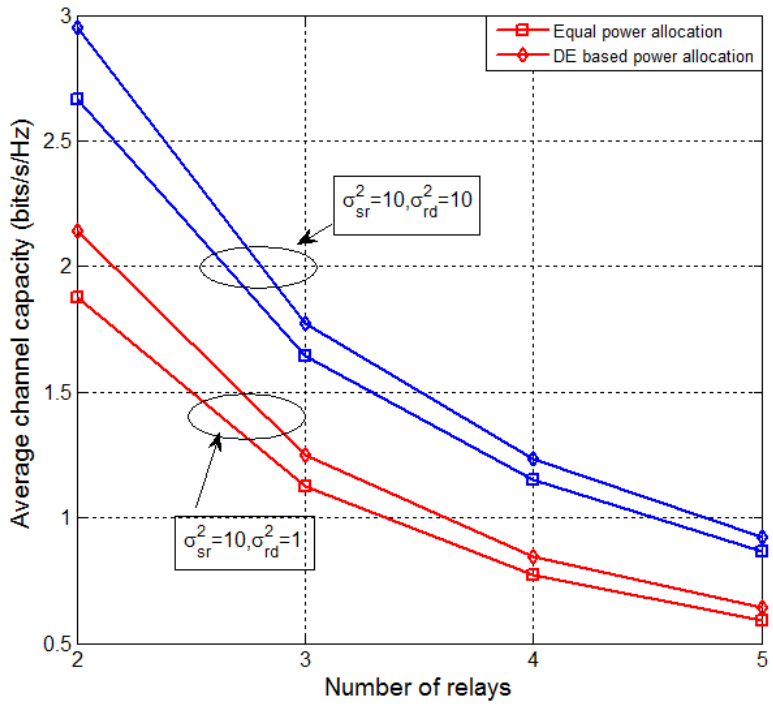


Figure 3.7 Average channel capacity (bits/sec/Hz) versus number of relays

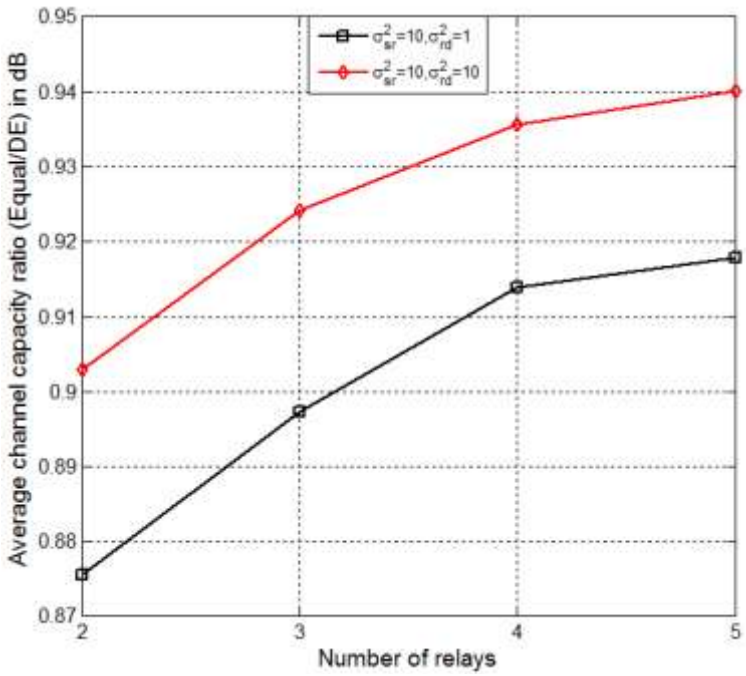


Figure 3.8 Average channel capacity (bits/sec/Hz) versus number of relays

Fig 3.8 demonstrates the average channel capacity ratio (channel capacity due to equal power allocation/channel capacity due to DE based power allocation) versus number of

relays. It is observed that as the number of relays increases, the average channel capacity ratio increases monotonically and attains a maximum channel capacity ratio where location of relays are at the middle corresponding to $\sigma_{s,r}^2 = 10$ and $\sigma_{r,d}^2 = 10$ which indicates a better channel condition. Further the efficacy of proposed DE based power allocation algorithm is evaluated by convergence analysis in Fig.3.9. It is observed that in both cases (AF and DF), the proposed method converges faster and attains the maximum cost value in DF mode compared to AF mode. For example, a high the fitness value of 1.85 at 40th iteration in DF mode is observed where it is 1.3 in AF mode. Here, the fitness stands for the cost function which is channel capacity for the iteration as mentioned in eq (3.27).

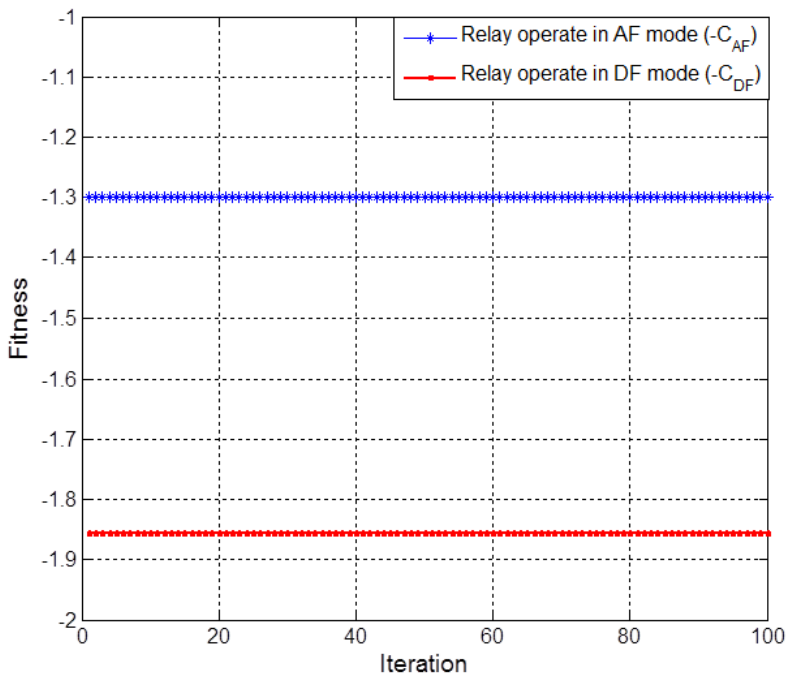


Figure 3.9 Convergence analysis of DE based power allocation (SNR=10dB, 4 relay case)

In order to evaluate the effect of relay location on the channel capacity, comparison of the average channel capacity analysis of proposed DE based power allocation is observed for different relay locations in the chosen linear network topology which is shown in Fig. 3.10. The proposed power allocation achieves highest average channel capacity of 4 bits/s/Hz when the relays are at the middle, when relays close to destination it gets reduced to 3.5 bits/s/Hz and further to 3.2 bits/s/Hz when relays are close to source at SNR value of 20 dB. So from all these results, the best position of relay location is decided on the basis of performance metrics.

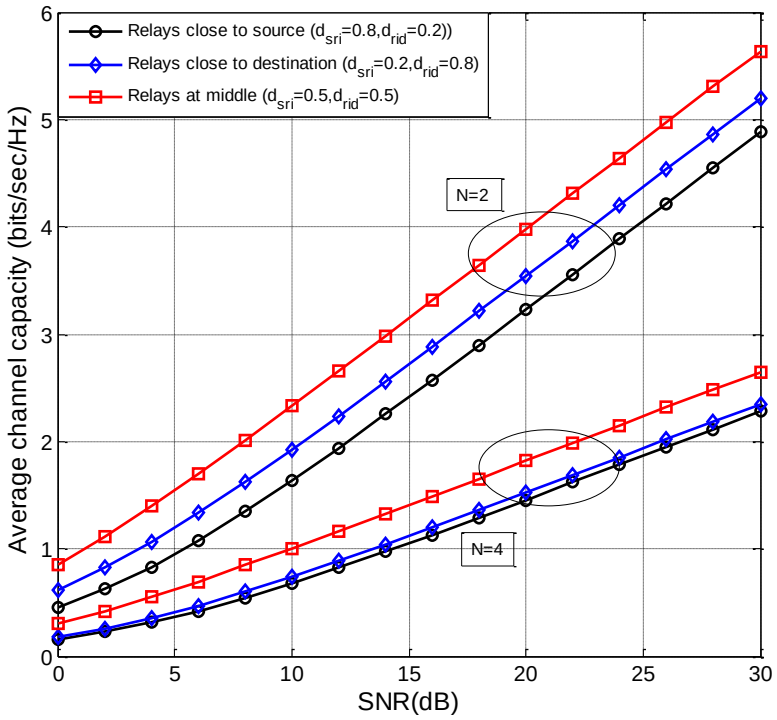


Figure 3.10 Impact of relay location for the proposed power allocation scheme

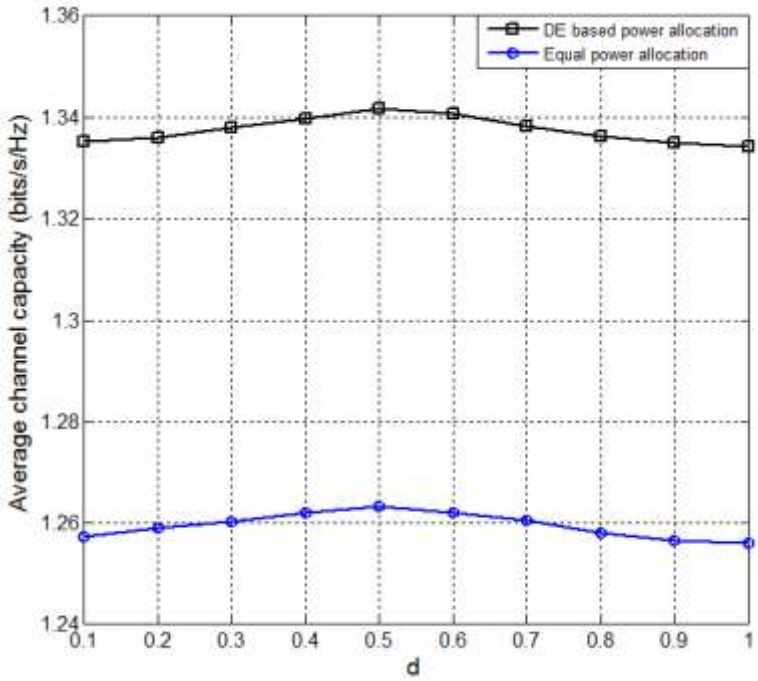


Figure 3.11 Average channel capacity versus relay location (SNR=20dB, for 2 relays case)

Further it is found in Fig 3.11 that even though both equal and proposed power allocation schemes achieve more channel capacity at middle in between source and destination, DE based power allocation attains channel capacity with a gain of 1.0635 compared to equal power allocation scheme. For example at middle DE based power allocation attains a channel capacity of 1.34 bit/s/Hz, where as equal power allocation scheme attains 1.26

bits/s/Hz. For a comparative analysis, the optimized powers obtained using differential evolution (DE) algorithm based power allocation are given in Table no.3-4 for different channel variances and for different relay locations, the results are given in Table 3-5.

Table 3-4 Optimized relay powers under different channel variances

Channel variances	Power allocation method	Source transmit power P_s	Transmit power P_i for each relay		
			2 relays	3 relays	4 relays
For any channel variances	Equal power allocation	For 2 relays 0.667 For 3 relays 0.75 For 4 relays 0.8	0.6667	0.75	0.8
Both source-to-relay and relay-to-destination links have the same variance $\sigma_{s,r}^2 = 10, \sigma_{r,d}^2 = 10$	DE based power allocation	1	0.4998	0.6659	0.7498
Source-to-relay channel link are good than relay-to-destination links $\sigma_{s,r}^2 = 10, \sigma_{r,d}^2 = 1$	DE based power allocation	1	0.4999	0.6666	0.7499
Relay-to-destination links are good compared to source-to-relay links $\sigma_{s,r}^2 = 1, \sigma_{r,d}^2 = 10$	DE based power allocation	1	0.4934	0.6647	0.7150

Table 3-5 Optimized relay powers under different relay locations

Relay location	Power allocation method	Source transmit power (P_s)	Transmit power (P_i) for each relay		
			2 relays	3 relays	4 relays
At any location	Equal power allocation	For 2 relays 0.667 For 3 relays 0.75 For 4 relays 0.8	0.6667	0.75	0.8
Middle ($d_{s,r_i} = 0.5, d_{r_i,d} = 0.5$)	DE based power allocation	1	0.4996	0.6665	0.7498
Close to source $d_{s,r_i} = 0.2, d_{r_i,d} = 0.8$	DE based power allocation	1	0.5	0.6667	0.75
Close to destination $d_{s,r_i} = 0.8, d_{r_i,d} = 0.2$	DE based power allocation	1	0.4323	0.6621	0.7177

Here, it is assumed that all relays are location wise identical, i.e, either at middle or at close-to-source and or close-to-destination in the network topology. From the Table 3-4 and 3-5, it is observed that the more transmit power is allocated to the relay nodes when they are located close to the source and minimum power is allocation when the relay nodes are located close to the destination.

3.5.2 Results of proposed Minimized SER based power allocation scheme

In this analysis, as the location of relay plays an important role, we have considered here three cases, at first relay location close to source, second relays close to destination and the last relays at random location. The relay powers for these three cases are optimized using both Lagrange and DE based power allocations and compared with the equal power allocation scheme. The theoretical approximation is obtained using the SER analysis as discussed in Section 3.1 of the Chapter 2.

3.5.2.1 Relays close to source

Comparison of proposed minimized SER based power allocation schemes with equal power allocation schemes is shown in Figure 3.12. Both the proposed schemes achieve a performance gain of nearly 0.5dB over equal power allocation scheme and optimized relay powers are given in Table 3-6. The reason behind this performance improvement is that when the relays are located close to the source (i.e. the source-to-relay link is good compared to relay destination link) means the relays assigned equal power and easily able to decode the received signal correctly. The DE based power allocation provides nearly the same SER performance as Lagrange multiplier method based power allocation.

Table 3-6 Optimized relay powers when the relays located close to the source

Power allocation method	Source transmit power (P_s)	Transmit power (P_r) for each relay			
		2 relays	3 relays	4 relays	5 relays
EPA	For 2 relays 0.667 For 3 relays 0.75 For 4 relays 0.8 For 5 relays 0.8333	0.6667	0.75	0.8	0.8333
LPA	1	0.5005	0.666	0.7506	0.7996
DEPA	1	0.4935	0.6623	0.7487	0.7784

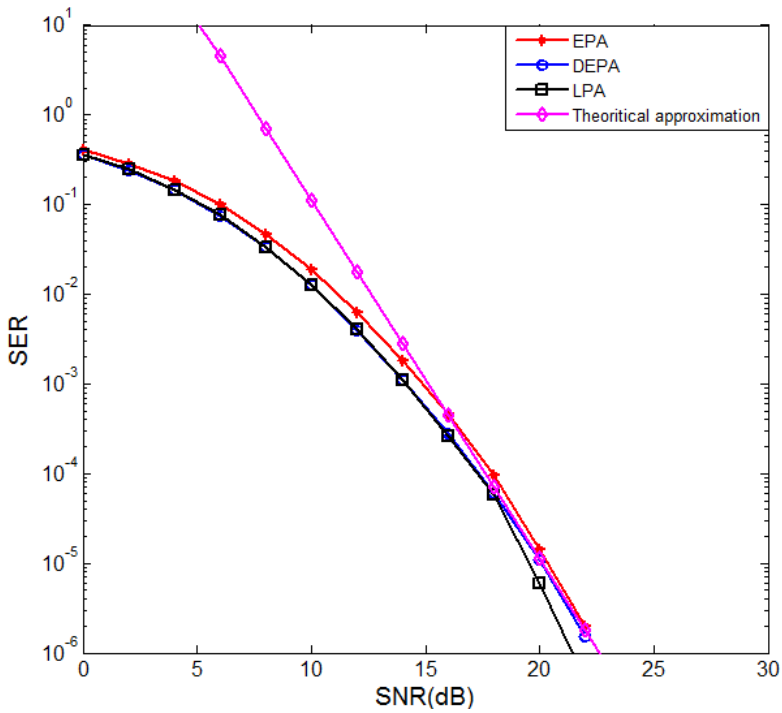


Figure 3.12 SER Comparison of equal and proposed power allocation schemes when the relays close to source

3.5.2.2 Relays close to destination

From the Figure 3.13, it is observed that both proposed schemes provide nearly same SER performance and provides a SER gain of nearly 1.9 dB over equal power allocation. The optimized relay powers are given in Table 3-7. In this case, the HDAF relays operate in AF mode because of strong relay to destination link. The proposed power allocation schemes for the relays close to destination case provide better SER performance than the relays close to the source case.

Table 3-7 Optimized relay powers when the relays located close to destination

Power allocation method	Source transmit power (P_s) in dB	Transmit power (P_r) in dB for each relay			
		2 relays	3 relays	4 relays	5 relays
EPA	For 2 relays 0.667 For 3 relays 0.75 For 4 relays 0.8 For 5 relays 0.8333	0.6667	0.75	0.8	0.8333
LPA	1	0.4978	0.665	0.7494	0.7985
DEPA	1	0.4949	0.6666	0.7492	0.7998

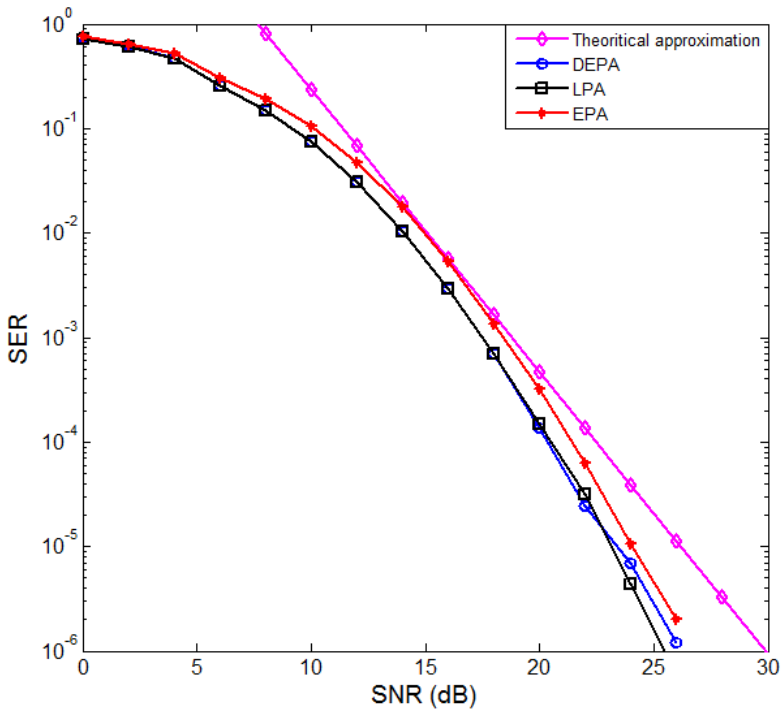


Figure 3.13 SER Comparison of equal and proposed power allocation schemes when the relays close to destination

3.5.2.3 Relays located at different locations

In this case, four HDAF relays considered are placed at different locations, i.e., first relay close to source, second relay at middle, third relay close to destination and fourth relay also close to destination in a linear topology of cooperative framework. In this case, it is confirmed that the proposed power allocation schemes give SER performance gain of nearly 1.5dB over the equal power allocation as shown in Figure 3.14. The system with DE based power allocation scheme has nearly close SER response as Lagrange based power allocation in such type of scenario. From the Table 3-8, it is observed that the relay located close to the source assigned more power compared to relay located close the destination case.

Table 3-8 Optimized relay powers when the relays located at different locations

Power allocation method	Source power (P_s) in dB	Transmit power (P_r) in dB for each relay			
		1st relay	2nd relay	3rd relay	4th relay
EPA	0.8	0.8	0.8	0.8	0.8
LPA	1	1.0143	0.7608	0.3637	0.3637
DEPA	1	0.7481	0.7242	0.6582	0.6582

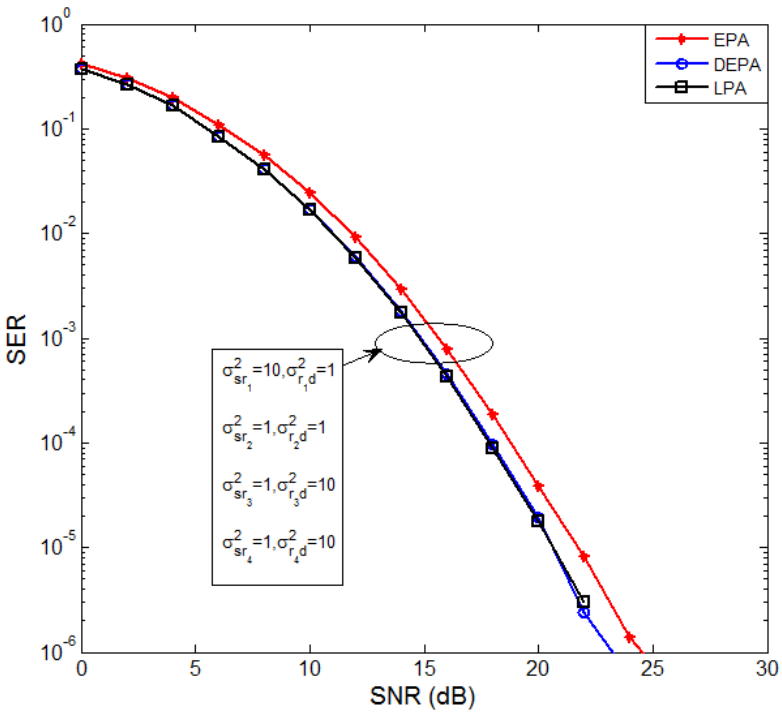


Figure 3.14 SER Comparison of equal and proposed power allocation schemes when the relays located at different locations

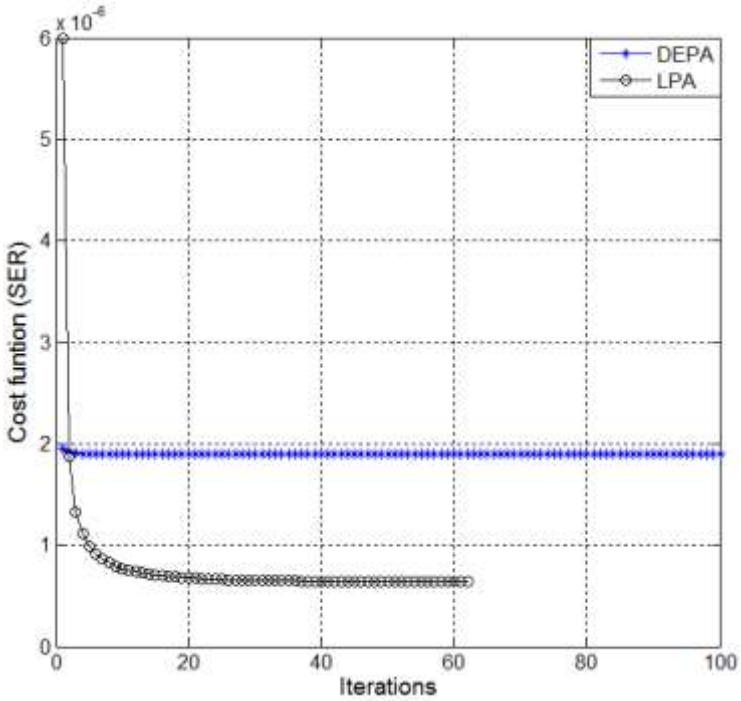


Figure 3.15. Convergence analysis of proposed minimized SER based power allocation when relays close to source

The convergence analysis for two proposed power allocation schemes when the relays are close to source is shown in Figure 3.15. It is observed that the DEPA converges faster than LPA as it is seen that the number of iterations taken for sub gradient method are more

compared to the Differential evolution algorithm due to high computational complexity. The computational complexity of the proposed minimized SER based power allocation algorithms is determined in terms of additions and multiplications and is shown in Table.3-9.

Here N represents number of relays in the network,

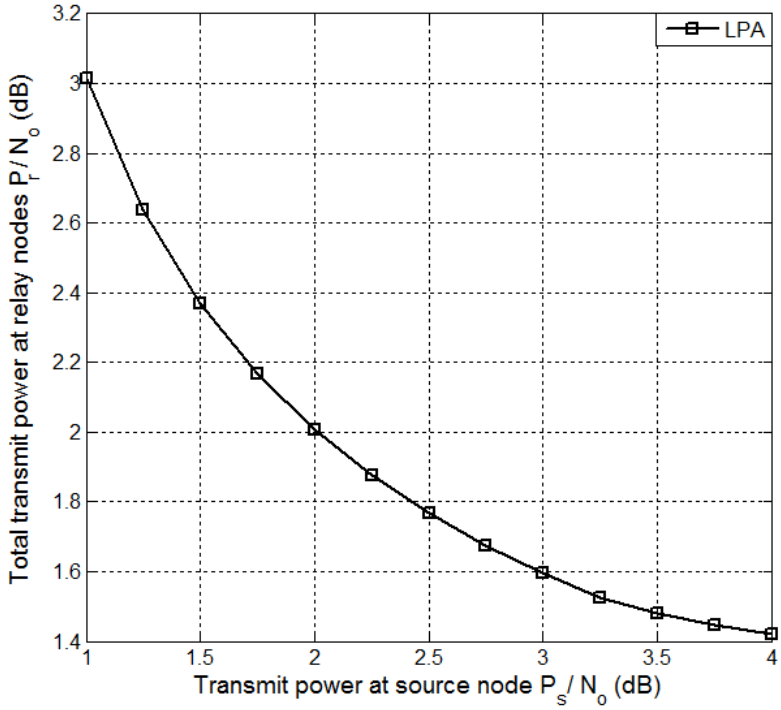
where NP represents number of populations.

Even though, LPA offers low computational burden, it has the severe limitations. The Lagrange multiplier method not only needs an objective function and constraint but also their derivatives. Obtaining the derivative of objective function may become a serious overhead. It is much worse if the objective function needs any approximation to find the derivative. The gradient method used to find the value of Lagrange multiplier λ needs one or more starting points where good selections of starting points will be another important factor affecting the solution. Sometimes the poor selection may lead to poor performance of the algorithm.

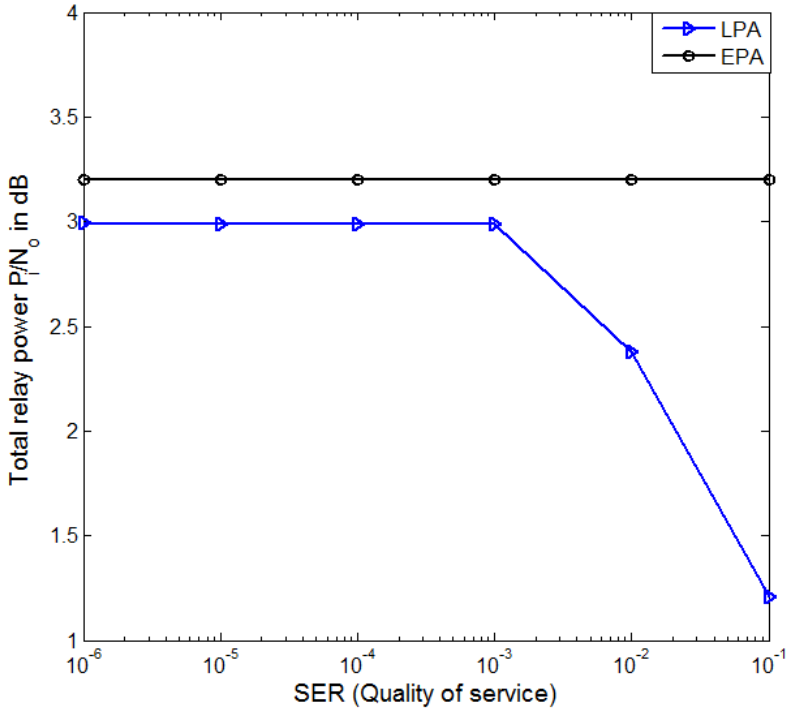
Hence, by considering these factors, Differential evolution algorithm seems to be a better alternative which has been applied to determine the optimal relay powers in the multi relay HDAF cooperative network.

3.5.3 Results of proposed schemes for relay and source power optimization

The proposed total relay power minimization scheme is validated for a four relay HDAF cooperative network as shown in Figure 3.16 (a). It is observed that with increase in source power (P_s), the total relay transmitted power decreases to maintain the QOS in terms of target SER level of 10^{-4}. Irrespective of target SER, equal power allocation assigned same power to the source and the relays according to the total number of relays in the network where as the proposed schemes proportionally allocate the optimized powers to the source as well as to the relay nodes in order to the meet the target SER as shown in Figure 3.16 (b) & (c) respectively.


LPA
Total transmit power at relay nodes P_r / N_o (dB)
Transmit power at source node P_s / N_o (dB)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1
1.5
2
2.5
3
3.5
4

(a)


LPA
EPA
Total relay power P_i/N_o in dB
SER (Quality of service)
4
3.5
3
2.5
2
1.5
1
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}

(b)

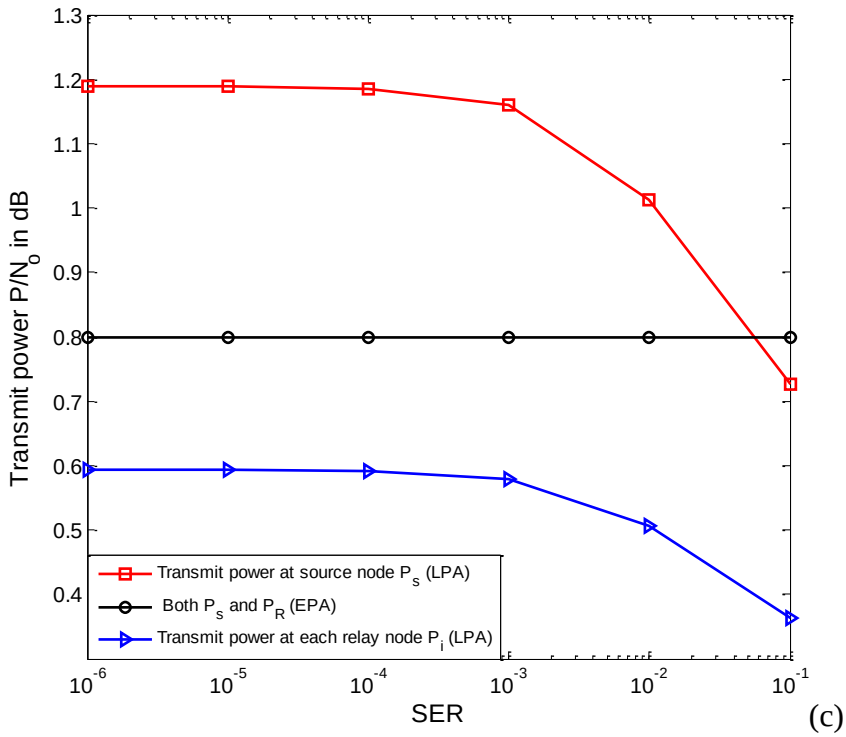


Figure 3.16 (a) Source power versus total relay power for QoS of SER=10^{-4} (b) Minimum relay power allocation: total relay power versus Quality of service. (c) Minimum total (both source and relay individually) power allocation: transmit power versus Quality of service

3.6 Summary

In this chapter, three power allocation schemes are proposed to maximize average channel capacity, to minimize SER and to optimize the total power minimization to maintain QoS. Firstly, maximized channel capcity based power allocation is proposed using Differential Evolution algorithm. The closed form expression for average channel capacity with the tight approximation is derived. Further, the relay powers are optimized using the optimized power allocation factor. From the simulation analysis, it is observed that the proposed DE based power allocation scheme performs better than the existing equal power allocation scheme as the relay powers are adopted acoording to the channel condition and relay location. Secondly, minimized SER based power allocation is proposed using both Lagrange multiplier method and Differential Evolution algorithm. Using the lower bound of SER, the relay powers are optimized to minimize the SER using both Lagrange multiplier method and Differential Evolution algorithm based on power allocation factor. The SER performance of proposed power allocation schemes are compared with the equal power allocation. It is observed that both proposed power allocation schemes perform

better than equal power allocation. When the relays are close to destination, proposed power allocation schemes offer better performance as the distance from source is increasing the fading effects becomes prominent and the proposed schemes are able to mitigate it in comparison to equal power allocation. The SER performance due to DE based power allocation closely follows the Lagrange multiplier method based power allocation. Here the findings reveal that both the schemes perform better than equal power allocation and attain nearly same SER performance, but differ in computational complexity. At last, the source and relay powers are optimized to maintain QoS using Lagrange multiplier method which outperforms the existing equal power allocation. Due to the broadcast nature of transmitting source node, the relay nodes in cooperative network are subjected to security issue at the physical layer. Hence it becomes necessary to enhance the secrecy performance by introducing new type of relaying schemes and also propose proper power allocation schemes reducing the impact of eavesdropper on data transmission.

Chapter 4

Development of Power Allocation Schemes for DF Relay Based Cooperative Security at the Physical Layer via Control Jamming

Confidentiality of data is a fundamental and crucial requirement for any wireless network due to significant growth in wireless applications in contemporary times. The purpose of physical layer security is to prevent eavesdroppers from intercepting the data transmitted between the source and intended destination. In the previous chapters the proposed power allocation schemes not considered the effect of eavesdroppers. So in this chapter we proposed efficient power allocation schemes for controlled jamming in a wireless cooperative network to maximize the secrecy rate. We present here the chapter goals.

Objectives of this chapter

- To solve relay power allocation issue in multiple DF relay based cooperative network to maximize the secrecy rate for control jamming under total relay power constraint by using convex optimization and evolutionary approaches in the presence of single and multiple eavesdroppers (collaborative & non collaborative).
- To propose power allocation to both relay and jammer for control jamming in multiple collaborative and non collaborative eavesdroppers cases.
- Further the impact of locations of relay and eavesdropper on the performance of the system with performance metric as secrecy rate is analyzed.
- The performance of the proposed power allocation schemes are compared with the existing power allocation and equal power allocation schemes in without jamming, jamming and control jamming cases.
- Finally the efficacy of the proposed power allocation schemes is to be discussed.

This part of research is included in the paper published in proceedings of 12th IEEE Malaysia International Conference on Communications (IEEE MICC 2015), Kuching, Malasiya, 23-25 Nov 2015, entitled as "Maximized Secrecy Rate Based Power Allocation for Wireless Cooperative Network with Control Jamming".

4.1 Introduction

The resource allocation for physical layer security in wireless cooperative networks to maximize the secrecy rate in the presence of malicious nodes which are called eavesdroppers is of great importance. The information theoretic secrecy is introduced by Shannon in [85]. Wireless secure communication issue is addressed at the upper layers of the protocol stack using cryptography algorithms like private key management complexity which are complex for implementation in [86]. Recently, implementing information security at the physical layer is the emerging research area. The performance metric for physical layers security is secrecy rate which is defined as the difference of direct link (between source and destination) capacity and the eavesdroppers link capacity. The secrecy rate represents the rate at which the source securely transmits the data to the destination in the presence of eavesdroppers. In order to a get non zero secrecy rate which means a perfect secure transmission, the signal-to-noise ratio (SNR) at the unauthorized users has to degrade compared to that at the destination [87]. For the Gaussian channel, the secrecy rate is the difference between the capacities of main and wiretap channels which is a non zero value [85]. The secrecy rate in terms of outage probability for which the eavesdropper is unable to decode the information from the source is obtained in [90-91]. The main purpose is to enhance the capacity of main confidential link while the capacity of eavesdropper link is to be decreased. The relays help the source by noise forwarding to confuse the eavesdropper in order to improve the system performance in terms of secrecy rate [92]. The physical layer security issue is addressed and investigated in wireless cooperative networks [93]. The secure communication for one source and destination pair in the presence of single and multiple eavesdroppers with multiple relays is studied in [94]. The authors in [96] proposed relay selection schemes in cooperative networks such that they can act as relay, cooperative jammer and a new jamming and non jamming switched based hybrid scheme. The different types of relay and jammer selection scheme to maximize the secrecy for one way cooperative network in the presence of multiple relays are proposed in [97]. Power allocation for physical security to maximize the secrecy rate in wireless cooperative network is a promising research area. The authors of [101] proposed power allocation scheme to allocate power to both relay and jammer, here relay is to help the source where as jammer is to create interference at the eavesdropper. To protect the source message being over heard by the eavesdropper, the

destination node generates intended jamming noise which is called destination assisted jamming scheme. In [102], the three jamming power allocation schemes are proposed in two-hop relay network to minimize the outage probability of secrecy rate. The condition for positive secrecy rate is derived and power allocation for cooperative jamming via distributed relays is proposed using convex optimization in [103]. The transmission strategy had been investigated with proposed relay selection and power allocation strategies in distributed cooperative network [104]. The cooperative jamming and power allocation schemes in two-hop untrusted relay network for multiple antenna case are introduced in [105]. The recent work related to issue of power allocation schemes for cooperative jamming are given in [106 & 107, 141& 142]. The existing power allocation schemes from the considered literature are dealt with power of cooperative jamming (in which destination unaware of jamming noise) for single eavesdropper case. The impacts of relay and eavesdropper locations on the secrecy rate are not studied for power allocation schemes. The power allocation for the collaborative and non collaborative nature of multiple eavesdroppers cases is not been introduced. To the best of our knowledge, we proposed efficient power allocation schemes to overcome all these above limitations. This proposed research work focuses on the power allocation strategies of control jamming for a wireless cooperative network in the presence of single and multiple eavesdroppers in order to maximize the secrecy rate. Initially, relay power allocation issue to maximize the secrecy rate of control jamming based on total relay power constraint is solved by using convex optimization and evolutionary approaches in the presence of both single and multiple eavesdroppers. Later, power allocation to both relay and jammer for control jamming in multiple collaborative and non collaborative eavesdroppers scenarios are proposed. Further the impact of locations of relay and eavesdropper on the performance of the system with performance metric as secrecy rate is analyzed. The performance of the proposed power allocation schemes are compared with the conventional equal power allocation schemes to prove the efficacy of those.

The organization of this chapter is as follows. Section 4.2 presents the system model. Section 4.3 introduces the problem formulation and the proposed power allocation schemes to maximize secrecy rate. Section 4.4 provides the simulations results and analysis. Finally Section 4.5 discusses the summary of this chapter.

4.2 System model

A cooperative wireless network model consists of a single source destination pair, in which source (*S*) sends its data to the destination node (*D*) with the help of half duplex mode multi- Decode and Forward (DF) relays nodes ($R_1, R_2, \ldots, R_N$) is considered in the presence of single and multi- eavesdropper nodes (E) [97]. The channel conditions are subjected to flat Rayleigh fading which are assumed to be mutually independent and orthogonal. It is also considered that given network is employed with TDMA protocol where source transmits its information during the first time slot and relays transmit information during the second time slot. The communication process is performed in two phases named broadcasting phase and cooperative phase as shown in Fig. 4.1.

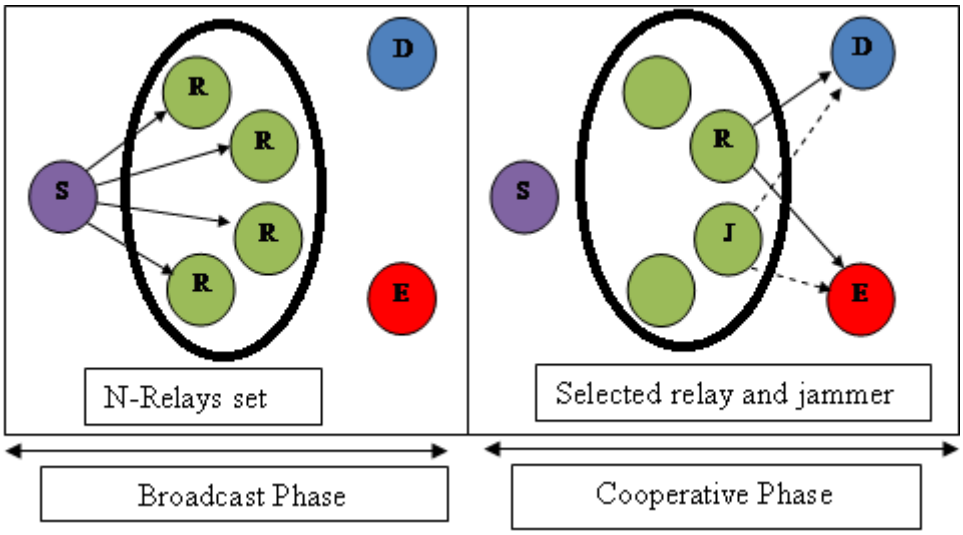


Figure 4.1 System model for DF relay based cooperative network for physical layer security

Broadcast phase: The source transmits data to the destination via N number of relays. Here there are no direct links available between source to destination and source to eavesdroppers. On the other hand, the broadcast phase is secured means eavesdropper cannot has impact on source to relay transmission.

$$y_{sr_i} = \sqrt{P_s} h_{sr_i} x + n_{sr_i} \quad for \;\; i = 1,2,\ldots,N \tag{4.1}$$

where x and y_{sr_i} are the transmitted information signal from source and the signals received at the ith relay node respectively. P_S is the transmit power at the source node, $h_{sr_i} \sim CN(0, \sigma^2_{sr_i})$ are the channel coefficients of source to relay links. The noise terms n_{sr_i} are the zero mean complex Gaussian random variables with variance N_o.

Cooperative phase: Among the relay set, two relays are selected from the relay set based on the secure relay and jammer selection schemes among which one relay can decode the received signal correctly will operate in DF relay mode and another relay can act as jammer. The jammer node generates interference for the relay transmission by noise forwarding. In control jamming, interference caused by jammer is known at the destination but not at the eavesdropper. So the destination can decode the interference provided by the jammer. Hence, the received signals at the destination and eavesdropper for the selected relay and jammer nodes are given by

$$y_{rd} = \sqrt{P_r} h_{rd} \hat{y}_{sr} + n_{rd} \tag{4.2}$$

$$y_e = y_{re} + y_{je} \text{ where } y_{re} = \sqrt{P_r} h_{re} y_{sr} + n_{re}; y_{je} = \sqrt{P_j} h_{je} n_{je} \tag{4.3}$$

P_r is the transmit power of the selected relay node and P_j is the transmit power of the jammer node. $\hat{y}_{sr}$ is the estimation of the transmitted signal by the selected relay. $h_{rd} \sim CN(0, \sigma_{rd}^2)$ is the channel coefficient for the selected relay to destination link. The noise term n_{rd} is zero mean complex Gaussian random variables with variance N_o. The channel variance is given as $\sigma_{xy}^2 \propto d_{xy}^{-l}$ where d_{xy} is the Euclidean distance between nodes $x \in \{s, r, j\}$ and $y \in \{e, r, d\}$. In this chapter, the value of the path loss exponent is assumed as $l = 4$. The relation between transmit powers of the source, the relay and the jammer is assumed as follows $P_s = P_r = L * P_j = P$, where $L = 100$.

Conventional selection techniques without and with jamming:

The relay and jammer node selection is done using selection algorithms in [98] which are briefly given as follows.

Conventional Selection (Without Jamming)

This scheme aims to select a DF relay which can able to decode the received signal correctly and does not involve any jamming process. It selects the best relay based on the maximum instantaneous relay-destination link and source-destination link and is expressed as

$$R^* = \max_{R \in C_d} \left(1 + SNR_{rd}\right) \tag{4.4}$$

Secrecy rate for conventional selection is expressed as

$$C_S^{|C_d|}(R) = \max\left(0, 0.5 * \log_2\left(\frac{1+SNR_{rd}}{1+SNR_{re}}\right)\right) \tag{4.5}$$

Optimal Selection with Jamming (OSJ): While selecting the cooperative relay and jammer, it assumes that relay-eavesdropper links are available and the destination is unaware of the noise generated by the jammer node. The selection of relay and jammer is done based on the following equations

$$R^* = \arg\max_{R \in C_d}\left(\frac{SNR_{rd}}{SNR_{re}}\right) \quad J^* = \arg\max_{J \in S_{relay}}\left(\frac{SNR_{je}}{SNR_{jd}}\right) \tag{4.6}$$

Secrecy rate for OSJ is expressed as

$$C_S^{|C_d|}(R, J) = \max\left(0, 0.5 * \log_2\left(\frac{1+\frac{SNR_{rd}}{1+SNR_{jd}}}{1+\frac{SNR_{re}}{1+SNR_{je}}}\right)\right) \tag{4.7}$$

Optimal Selection with Control Jamming (OSCJ): The relay and jammer nodes are selected in this selection scheme with an assumption that the destination knows about the noise generated by the jamming node where the eavesdropper is unaware of it. Hence only destination can decode the jamming signal but not the eavesdropper. Cooperative relay and jammer nodes are selected based on the following equations

$$R^* = \arg\max_{R \in C_d}\left(\frac{SNR_{rd}}{SNR_{re}}\right); J^* = \arg\max_{J \in S_{relay}}\left(SNR_{je}\right) \tag{4.8}$$

Secrecy rate for OSCJ can be expressed as

$$C_S^{|C_d|}(R, J) = \max\left(0, 0.5 * \log_2\left(\frac{1+SNR_{rd}}{1+\frac{SNR_{re}}{1+SNR_{je}}}\right)\right) \tag{4.9}$$

The instantaneous signal to noise ratio for the channel link $i \rightarrow j$ is given by $SNR_{ij} = P_i / N_o \, \sigma_{i,j}^2$. Here, the noise power is normalized to 1.

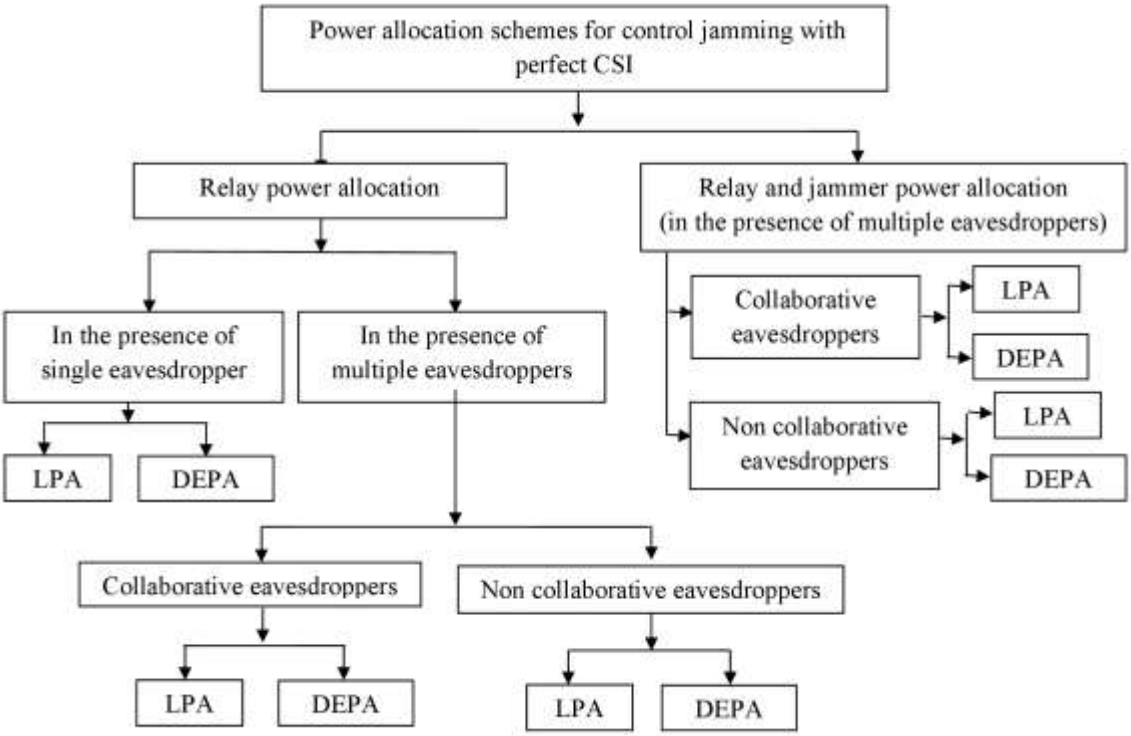


Figure 4.2 Proposed power allocation schemes

4.3 Problem formulation basics

4.3.1 Proposed optimized relay power allocation

4.3.1.1 In the presence of single eavesdropper using convex optimization

The transmit powers of the selected relay and jammer node to be optimized for secrecy rate enhancement of DF relay based wireless cooperative network with control jamming according to the channel knowledge available. For this, the optimization problem is defined in the presence of single eavesdropper as

$$Max\left(log_2(1+SNR_{rd})-\log_2\left(1+\frac{SNR_{re}}{1+SNR_{je}}\right)\right) \text{ such that } P_s+P_r+P_j \le P_T$$

$$\text{where } P_s = P_r = \alpha P_T \ \& \ P_j = \alpha P_T/100 \ ; P_T = 3P \qquad (4.10)$$

Theorem.1: (Maximized secrecy rate based optimal relay power allocation in presence of single eavesdropper) : With the perfect CSI , SNR_{re}, SNR_{rd} and SNR_{je}, the power allocation factor α to maximize the secrecy rate of control jamming using Lagrange multiplier method is given by

$$\alpha = 0 < roots\ ((d_1\lambda_1)\alpha^3 + (d_2\lambda_1 - c_1)\ \alpha^2 + (d_3\lambda_1 - c_2)\alpha + (\lambda_1 - c_3)) < 0.4975 \qquad (4.11)$$

The roots of the polynomial are obtained. The root which is in the limits [0, 0.4975] and gets the maximum secrecy rate is the feasible solution. Theorem 1 is proved in Appendix. The value of λ is obtained using sub gradient method as follows.

Table 4-1 Sub gradient algorithm to find the Lagrange multiplier λ

Algorithm to find λ
1. Initialize $k=1,\ \lambda(1)=0.1,\ f(1)=-P_T$
2. While (abs(f)>0.0001)
3. Calculate roots of the polynomial
$\alpha = 0 < roots\ ((d_1\lambda_1)\alpha^3 + (d_2\lambda_1 - c_1)\ \alpha^2 + (d_3\lambda_1 - c_2)\alpha + (\lambda_1 - c_3)) < 0.4975$
where $d_1 = x_o y_1 y_2$;
$d_2 = x_o(y_1 + y_2) + (y_1 y_2)$;
$d_3 = x_o + y_1 + y_2$;
$c_1 = x_o y_1 y_2$;
$c_2 = 2x_o y_1$;
$c_3 = x_o - y_o$; $y_2 = y_o + y_1$;
$y_o = P_T\sigma_{re}^2$; $y_1 = (P_T/100)\ \sigma_{je}^2$; $x_o = P_T\sigma_{rd}^2$
11. $f(k) = ((2 + (1/L)) \times P_r) - P_T$
12. $\lambda(k+1) = \lambda(k) - (1/k)\ f(k)$
13. $k = k+1$
4. End

4.3.1.2 In the presence of multiple eavesdroppers for convex optimization

Maximizing the secrecy rate of DF relay based cooperative network with control jamming in the multiple eavesdroppers is considered as the optimization problem. Here, multiple eavesdroppers are categorized in to two categories: non collaborative eavesdroppers that try to decode the overheard signal received from the source node individually and, collaborative eavesdroppers for which the eavesdroppers are in cooperation to decode the overheard signal [131].

The optimization problem for collaborative eavesdroppers case is defined as

$$Max\left(log_2(1+SNR_{rd}) - \log_2\left(1+\sum_{m=1}^{M}\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right) \text{ such that } P_s + P_r + P_j \le P_T \qquad (4.12)$$

And the optimization problem for non-collaborative eavesdroppers case is defined as

$$Max\left(\log_2(1+SNR_{rd})-\log_2\left(1+\max_{e_m\in S_{eaves}}\left(\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)\right)\text{such that } P_s+P_r+P_j\le P_T \tag{4.13}$$

Lemma.1: (Maximized secrecy rate based optimal relay power allocation in the case of collaborative eavesdroppers)

Given the channel information SNR_{rd} and $SNR_{re_m} SNR_{je_m}$ $for\ m=1,2,..,M$, the optimal power allocation factor α is obtained by solving optimization problem in Eq. [4.12] using Theorem 1 with the following substitutions.

$$x_o=P_T\sigma_{rd}^2;\ y_o=P_T\left(\sum_{m=1}^{M}\sigma_{re_m}^2\right)\ \&\ y_1=\left(\frac{P_T}{100}\right)\left(\sum_{m=1}^{M}\sigma_{je_m}^2\right) \tag{4.14}$$

Lemma.2: (Maximized secrecy rate based optimal relay power allocation in the case of non collaborative eavesdroppers)

Given the channel information, SNR_{rd} and $SNR_{re_m} SNR_{je_m}$ $for\ m=1,2,..,M$, the optimal power allocation factor α is obtained by solving optimization problem in Eq.[4.13] using Theorem 1 with the following substitutions

$$x_o=P_T\sigma_{rd}^2;\quad y_o=P_T\left(\max_{e_m\in S_{eaves}}\sigma_{re_m}^2\right)\ \&\ y_1=\left(\frac{P_T}{100}\right)\left(\max_{e_m\in S_{eaves}}\sigma_{je_m}^2\right) \tag{4.15}$$

4.3.1.3 In the case of single and multiple eavesdroppers using Differential evolution algorithm

Differential Evolution algorithm is an efficient stochastic search optimization technique like genetic algorithm using the similar operators: crossover, mutation, and selection. It finds the true global minimum irrespective of initial parameters which converges fast with only few control parameters [109]. In optimum power allocation using Lagrange multiplier method, the transmit power at the relay node is optimized with the Lagrange multiplier value λ. Here, subgradient method can be utilized to find the optimum value of Lagrange multiplier which may lead to computational burden. To avoid this computational burden, we use evolutionary approach like differential evolution.

Table 4-2 Problem formulation for relay power allocation using DE algorithm

Problem definition	Cost function
In the presence of single eavesdropper Maximize $C_{\sec_1}^{\lvert C_d \rvert} = \left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\frac{SNR_{re}}{1+SNR_{je}}\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function: $f_{\sec_1} = \arg\min\left(-C_{\sec_1}^{\lvert C_d \rvert}\right)$ Subject to $0 \le \alpha \le 1/(2+1/L)$
In the presence of multiple collaborative eavesdropper Maximize $C_{\sec_2}^{\lvert C_d \rvert} = \left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\sum_{m=1}^{M}\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function $f_{\sec_2} = \arg\min\left(-C_{\sec_3}^{\lvert C_d \rvert}\right)$ Subject to $0 \le \alpha \le 1/(2+1/L)$
In the presence of multiple non collaborative eavesdropper Maximize $C_{\sec_3}^{\lvert C_d \rvert} =$ $\left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\max_{e_m \in S_{eaves}}\left(\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function: $f_{\sec_3} = \arg\min\left(-C_{\sec_3}^{\lvert C_d \rvert}\right)$ Subject to $0 \le \alpha \le 1/(2+1/L)$

where $SNR_{rd} = P_r\sigma_{rd}^2, SNR_{re} = P_r\sigma_{re}^2, SNR_{je} = P_j\sigma_{je}^2; P_r = \alpha P_T; P_j = \alpha P_T / L;$

4.3.2 Proposed optimized relay and jammer power allocation schemes

When the transmit power of the source node is known, with the perfect knowledge of CSI, the relay and jammer power are optimized to enhance the secrecy rate for control jamming case using both Lagrange multiplier method and evolutionary approach (DE algorithm). The optimization problem for the proposed relay and jammer power allocation scheme are defined as follows

4.3.2.1 LPA based relay and jammer power allocation scheme

The optimization problem for collaborative eavesdroppers case is defined as

$$Max\left(log_2\left(1+P_r\sigma_{rd}^2\right) - \log_2\left(1+\sum_{m=1}^{M}\frac{P_r\sigma_{re_m}^2}{1+P_j\sigma_{je_m}^2}\right)\right) \text{ such that } 0<\alpha<1 \tag{4.16}$$

And the optimization problem for non-collaborative eavesdroppers case is defined as

$$Max\left(log_2\left(1+P_r\sigma_{rd}^2\right)-\log_2\left(1+\max_{e_m\in S_{eaves}}\left(\frac{P_r\sigma_{re_m}^2}{1+P_j\sigma_{je_m}^2}\right)\right)\right) \text{ such that } 0<\alpha<1$$

where $P_r=\alpha(P_T-P_s)$; $P_j=(1-\alpha)(P_T-P_s)$ & $P_s=P_T/3$. (4.17)

Theorem.2: (Maximized secrecy rate based optimal relay and jammer power allocation in the case of collaborative eavesdroppers): Given the channel information, SNR_{rd} and $SNR_{re_m} SNR_{je_m}$ *for* $m=1,2,..,M$, the power allocation factor α to maximize the secrecy rate of DF relay based cooperative network with control jamming using Lagrange multiplier method is given by

$$\alpha=0<roots\ ((d_1\lambda_1)\alpha^3+(d_2\lambda_1-c_1)\alpha^2+(d_3\lambda_1-c_2)\alpha+(\lambda_1-c_3))<1 \quad (4.18)$$

Here $x_o=(P_T-P_s)\sigma_{rd}^2$; $y_o=\sum_{m=1}^{M}\left(\frac{\sigma_{re_m}^2}{\sigma_{je_m}^2}\right)$; $y_1=1+\frac{1}{\left((P_t-P_s)\sum_{m=1}^{M}\sigma_{je_m}^2\right)}$

The proof of Theorem.2 is given in Appendix.

Lemma.3: (Maximized secrecy rate based optimal relay and jammer power allocation in the case of non collaborative eavesdroppers) Given the channel information, SNR_{rd} and $SNR_{re_m} SNR_{je_m}$ *for* $m=1,2,..,M$, the optimal power allocation factor α is obtained by solving optimization problem in Eq.[4.13] using Theorem 2 with the following substitutions.

$$x_o=(P_T-P_s)\sigma_{rd}^2;\ y_o=\max_{e_m\in S_{eaves}}\left(\frac{\sigma_{re_m}^2}{\sigma_{je_m}^2}\right);\ y_1=1+\frac{1}{\left((P_t-P_s)\max_{e_m\in S_{eaves}}\left(\sigma_{je_m}^2\right)\right)} \quad (4.19)$$

4.3.2.2 DE algorithm based relay and jammer power allocation scheme

The problem definition and cost function are given as follows to find the power allocation factor α for optimizing both relay and jammer power such that the secrecy rate is enhanced.

Table 4-3 Problem formulation for relay and jammer power allocation using DE algorithm

Problem definition	Cost function
In the presence of multiple collaborative eavesdropper Maximize $C_{\sec_4}^{\lvert C_d \rvert} =$ $\left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\sum_{m=1}^{M}\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function: $f_{\sec_4} = \arg\min\left(-C_{\sec_4}^{\lvert C_d \rvert}\right)$ subject to $0<\alpha<1$
In the presence of multiple non collaborative eavesdropper Maximize $C_{\sec_5}^{\lvert C_d \rvert} =$ $\left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\max_{e_m \in S_{eaves}}\left(\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function: $f_{\sec_5} = \arg\min\left(-C_{\sec_5}^{\lvert C_d \rvert}\right)$ subject to $0<\alpha<1$

Here $SNR_{rd} = P_r\sigma_{rd}^2, SNR_{re} = P_r\sigma_{re}^2, SNR_{je} = P_j\sigma_{je}^2$; $P_r = \alpha(P_T - P_s)$; $P_s = P_T/3$; $P_j = (1-\alpha)(P_T - P_s)$.

The detailed algorithm for the proposed power allocation schemes using Differential evolution algorithm is shown in the following flowchart. The parameters in the flowchart shown in Fig. 4.3 are defined as follows G_d represents the total number of generations; g represents the individual generation; NP and D represent the number of population members and the number of parameters of objective function respectively.

Initialization: For proposed power allocation schemes (for the cases of both single and multiple eavesdroppers)

The nth individual of the population in the gth generation is expressed as

$$\alpha^{g,i} \quad for\ i = 1,2,....,NP,\ g = 1,2,...,G_d \tag{4.20}$$

Cost function evolution: $E1 = f_{\sec}^{g,n}\left(u^{g,n}\right)$ is the cost function value of the nth individual in the gth generation of $u^{g,n}$ which is represented as follows

For relay power allocation for single eavesdropper case:

$$E1 = f_{\sec}^{g,n}\left(u^{g,n}\right) = f_{\sec_1}\left(u^{g,n}\right) = -C_{\sec_1}^{|C_d|}\left(u^{g,n}\right) \tag{4.21}$$

For relay power allocation for multi collaborative eavesdropper case:

$$E1 = f_{\sec}^{g,n}\left(u^{g,n}\right) = f_{\sec_2}\left(u^{g,n}\right) = -C_{\sec_2}^{|C_d|}\left(u^{g,n}\right) \tag{4.22}$$

For relay power allocation for multi non-collaborative eavesdropper case:

$$E1 = f_{\sec}^{g,n}\left(u^{g,n}\right) = f_{\sec_3}\left(u^{g,n}\right) = -C_{\sec_3}^{|C_d|}\left(u^{g,n}\right) \tag{4.23}$$

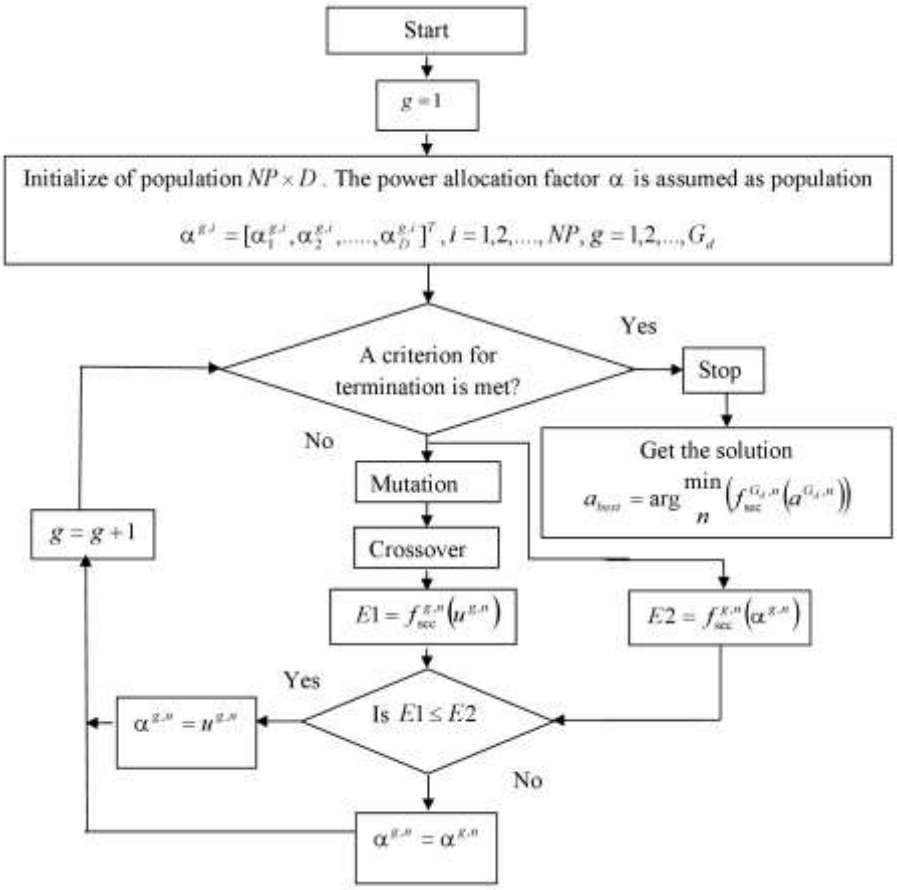


Figure 4.3 Differential Evolution algorithm for proposed power allocation schemes

$E2 = f_{\sec}^{g,n}\left(a^{g,n}\right)$ is the cost function value of the nth individual in the gth generation of $\alpha^{g,n}$ which is represented as follows

For relay power allocation for single eavesdropper case:

$$E2 = f_{\sec}^{g,n}\left(a^{g,n}\right) = f_{\sec_1}\left(\alpha^{g,n}\right) = -C_{\sec_1}^{|C_d|}\left(\alpha^{g,n}\right) \tag{24}$$

For relay power allocation for multi collaborative eavesdropper case:

$$E2 = f_{\sec}^{g,n}\left(a^{g,n}\right) = f_{\sec_2}\left(\alpha^{g,n}\right) = -C_{\sec_2}^{|C_d|}\left(\alpha^{g,n}\right) \tag{25}$$

For relay power allocation for multi non collaborative eavesdropper case:

$$E2 = f_{\sec}^{g,n}\left(a^{g,n}\right) = f_{\sec_3}\left(\alpha^{g,n}\right) = -C_{\sec_3}^{|C_d|}\left(\alpha^{g,n}\right) \tag{26}$$

where $a^{g,n}$ and $u^{g,n}$ are the target and the trail vectors which are obtained after mutation and cross over operations respectively.

Optimal search: The best individual which has the minimum cost function value is considered as the optimal power allocation factor α. The optimal solution for power allocation factor is obtained as

$$\alpha_{best} = \arg \min_{n} \left(f_{\sec}^{G_d,n}\left(a^{G_d,n}\right)\right),\ n = 1,2,...,NP \tag{27}$$

Here $f_{\sec}^{G_d,n}\left(a^{G_d,n}\right)$ is the optimal solution after meeting the termination criteria.

In the above proposed relay and jammer power allocation, the transmit power of source node is fixed but which also effects the secrecy rate. Hence finally, we proposed a power allocation in which both transmit powers of relay and jammer nodes are obtained in terms of power allocation factors $\alpha \,\&\, \beta$ respectively based on total power constraint. The optimization problems defiend in Table 4-3 and 4-4 are solved using the DE algorithm which follows the Figure 4.3.

Table 4-4 Problem formulation for relay and jammer power allocation using DE algorithm

Problem definition	Cost function
In the presence of multiple collaborative eavesdropper Maximize $C_{\sec_6}^{\lvert C_d \rvert} =$ $\left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\sum_{m=1}^{M}\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function: $f_{\sec_6} = \arg\min\left(-C_{\sec_6}^{\lvert C_d \rvert}\right)$ subject to $0 < \alpha < 1$
In the presence of multiple non collaborative eavesdropper Maximize $C_{\sec_7}^{\lvert C_d \rvert} =$ $\left(log_2\left(1+SNR_{rd}\right) - \log_2\left(1+\max_{e_m \in S_{eaves}}\left(\frac{SNR_{re_m}}{1+SNR_{je_m}}\right)\right)\right)$ subject to $P_s + P_r + P_j \le P_T$	Cost function: $f_{\sec_7} = \arg\min\left(-C_{\sec_7}^{\lvert C_d \rvert}\right)$ subject to $0 < \alpha < 1$

where $P_s = \alpha P_T$; $P_r = (1-\alpha)\ \beta P_T$ $P_j = (1-\alpha)(1-\beta) P_T$

4.4 Simulation results and analysis

The proposed power allocation schemes are validated through computer simulations using Matlab. The simulation model for the system as shown in Fig.4.1 is assumed as 2-D square topology where the locations of the source, the destination and the eavesdropper are considered as $S(0,0)$, $D(1,0)$ and $E(0,1)$ respectively and also the area of this network is supposed as a 1×1 square unit. Here it is also assumed that the direct paths i.e., source-to-eavesdropper and source-to-destination links are not available so the effect of eavesdropping rise in cooperative phase only. For the simulation results, the number of relays in the considered secure cooperative network are four $(N=4)$ for which location are mentioned for each case. The performance metric considered here is the secrecy rate. The DE algorithm parameters are given as DE step size (F)=0.8, Crossover probability(CR)=0.5, D=1(number of parameters of objective function) NP(number of population members)=50*D Iterations=200.

4.4.1 Impact of eavesdropper location on the secrecy rate performance

4.4.1.1 Eavesdropper close to source

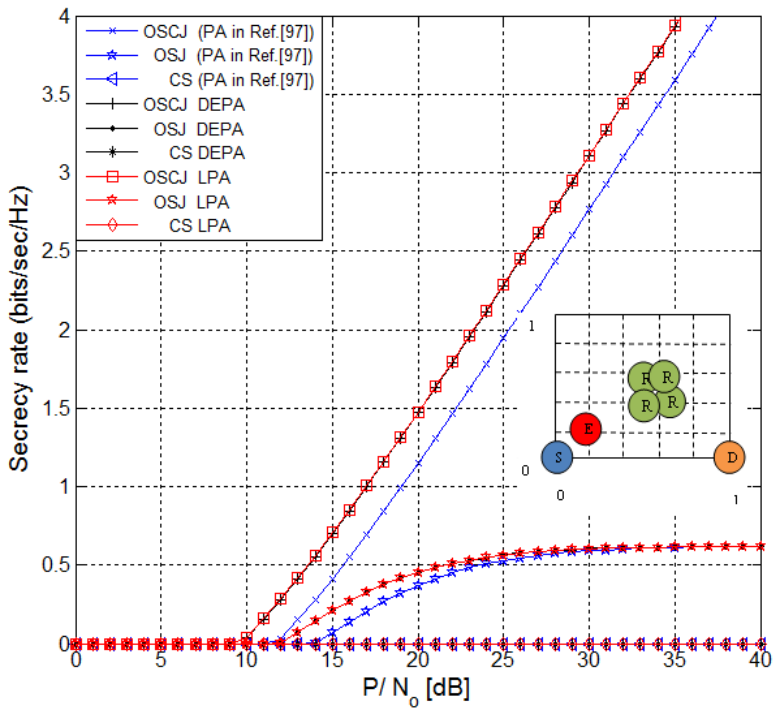


Figure 4.4 Secrecy rate versus total power when eavesdropper close to source

The proposed power allocation schemes obtain a secrecy rate of 1.5bits/sec/Hz where as the conventional equal power allocation achieves a secrecy rate of 1.2 bits/sec/Hz for

OSCJ. On the other hand, the proposed schemes get a secrecy rate value as 0.5 bits/sec/Hz where as the equal power allocation scheme achieves a secrecy rate of 0.3bits/sec/Hz for OSJ. Since the source-to-eavesdropper link is very stronger than the direct link between relay and destination, the non jamming scheme performs very poor and also the OSJ achieves low secrecy rate compared to OSCJ. The optimized power of relay, the control jamming confuses the eavesdropper by creating noise which increases the secrecy rate. From Fig.4.4, it is observed that the proposed schemes achieve more secrecy rate compared equal power allocation.

4.4.1.2 Eavesdropper close to destination

The proposed power allocation schemes achieve a secrecy rate of 3.3 bits/sec/Hz where as the equal power allocation achieves a secrecy rate of 3 bits/sec/Hz for OSCJ. In the case of OSJ, the proposed power allocation schemes achieve a secrecy rate of 2.25 bits/sec/Hz and for the equal power allocation can get a secrecy rate of 2.1 bits/sec/Hz at transmit power 20 dB. In Fig.4.5, the non jamming scheme is in efficient and achieves almost close to zero secrecy rate where as jamming schemes especially control jamming with optimized relay and jammer powers increases the secrecy rate significantly by generating sufficient noise at the eavesdropper.

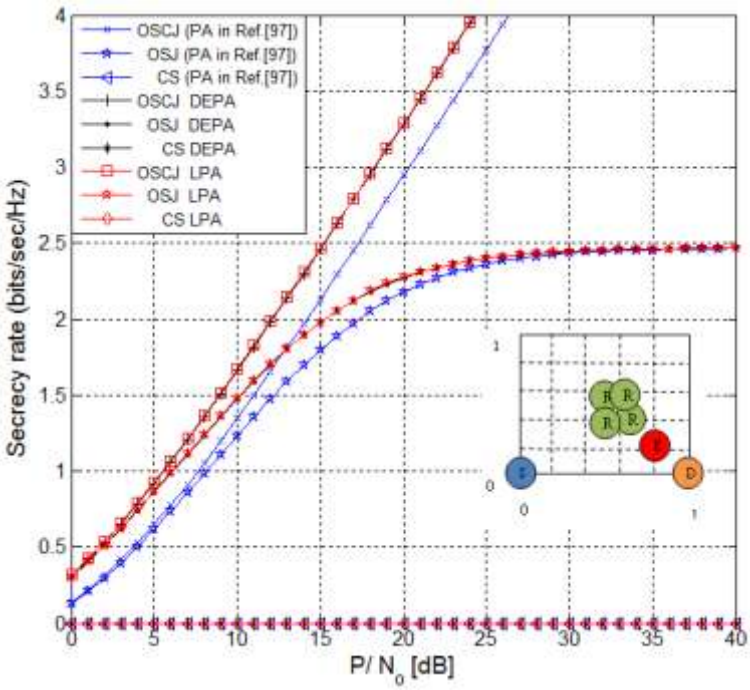


Figure 4.5 Secrecy rate versus total power when eavesdroppers close to destination

4.4.2 The impact of multi eavesdroppers on the secrecy rate analysis

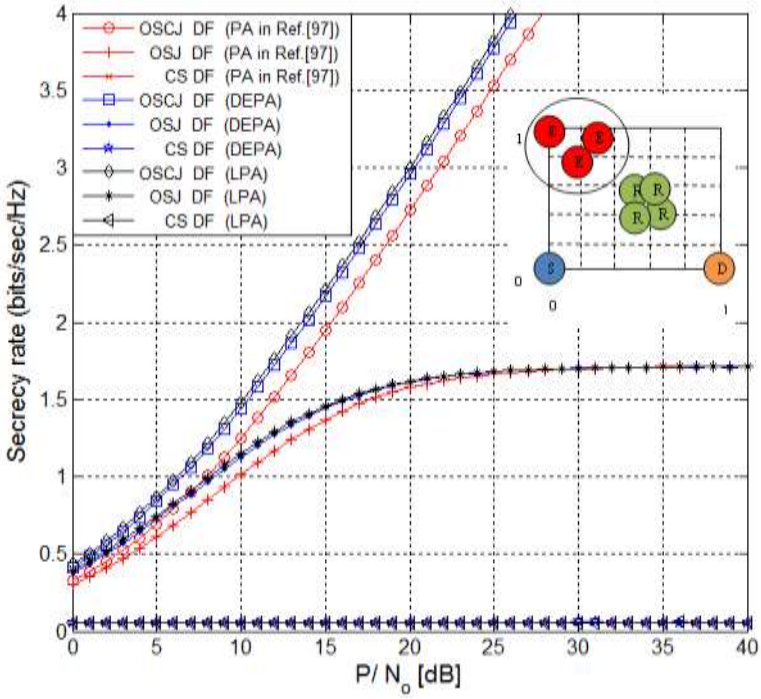


Figure 4.6 Secrecy rate versus transmit power for collaborative eavesdroppers

To validate the efficacy of proposed power allocation schemes in the presence of collaborative and non collaborative eavesdroppers, we consider here 3 eavesdroppers which are located at $(0,1),(0.2,0.8)\,\&\,(0.35,0.65)$. For collaborative eavesdroppers' case, the proposed power allocation schemes achieve a secrecy rate of 3 bits/sec/Hz where as existing power allocation achieves it as 2.75 bits/sec/Hz for OSCJ. In the case of OSJ, the proposed power allocation schemes achieve a secrecy rate of 1.6 bits/sec/Hz and equal power allocation obtains a secrecy rate of 1.55 bits/sec/Hz at a transmit power of 20dB. From Fig.4.6, it is observed that with the optimized powers, the non jamming relay selection scheme achieves a non-zero secrecy rate which is inefficient compared to jamming schemes. Among the jamming schemes, control jamming with optimized powers achieves best performance compared to OSJ and non jamming schemes. In Figure.4.7, the proposed relay power allocation schemes achieve a secrecy rate of 3.4 bits/sec/Hz where as existing power allocation achieves it as 3.1 bits/sec/Hz for OSCJ. In the case of OSJ, the proposed power allocation schemes achieve a secrecy rate of 2 bits/sec/Hz and equal power allocation obtains a secrecy rate of 1.9 bits/sec/Hz at a transmit power of 20dB. From the Fig.4.6 & 4.7, it is determined that the non collaborative eavesdropper attains more secrecy rate compared collaborative eavesdroppers.

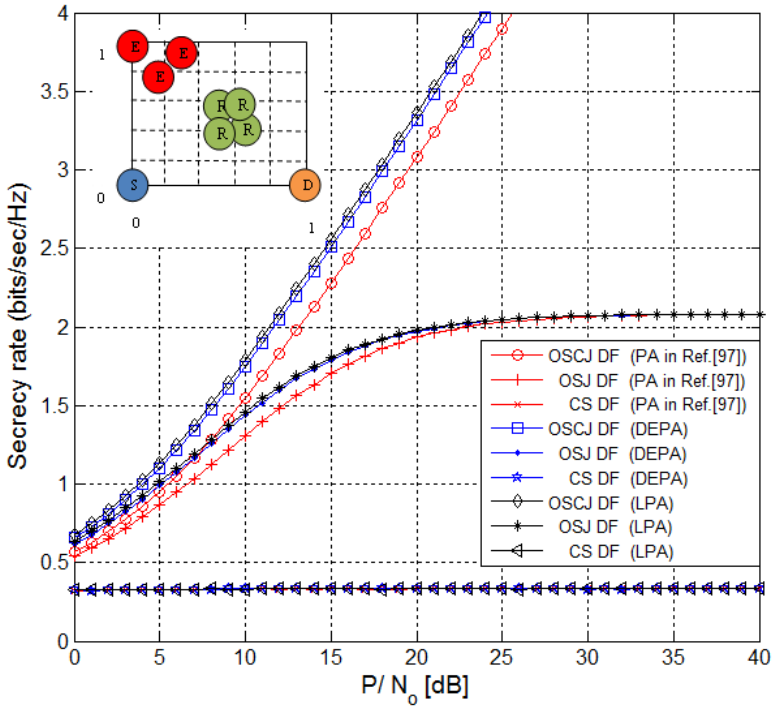
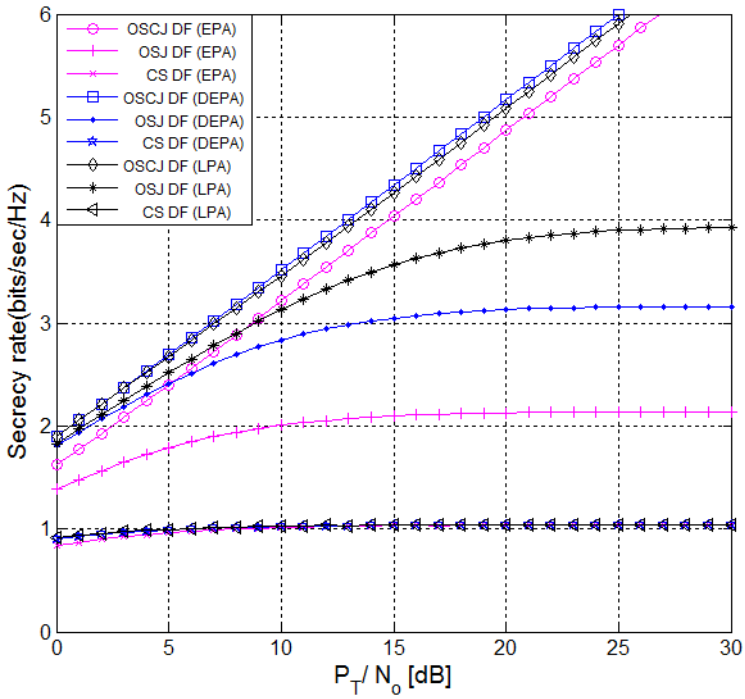


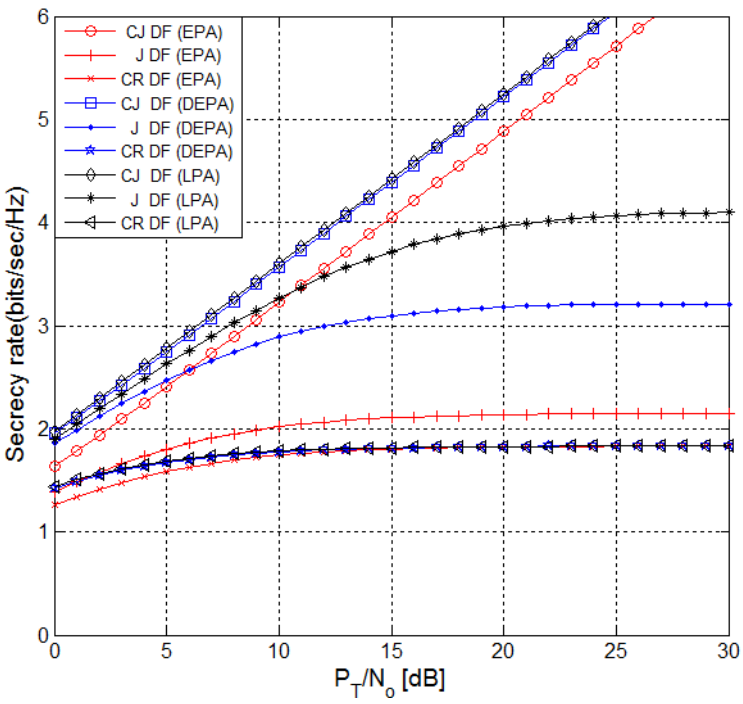
Figure 4.7 Secrecy rate versus transmit power for non collaborative eavesdroppers

4.4.3 Optimized relay and jammer power allocation based secrecy performance

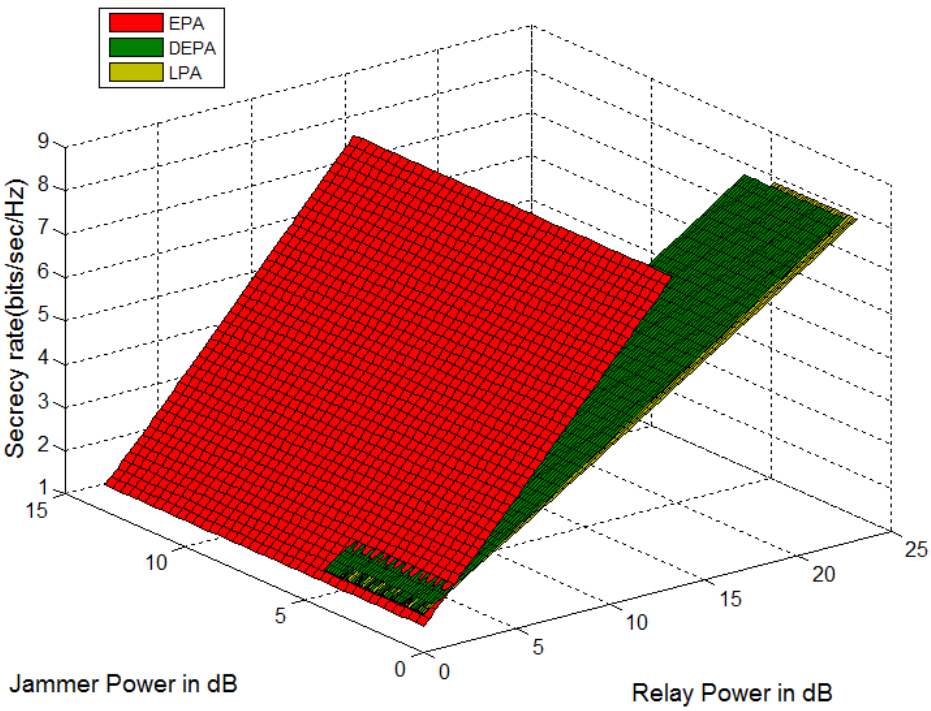
In Figure 4.8, the secrecy rate performance of proposed power allocation schemes is compared with the equal power allocation in the presence of the collaborative and non collaborative eavesdroppers respectively.



(a)



(b)

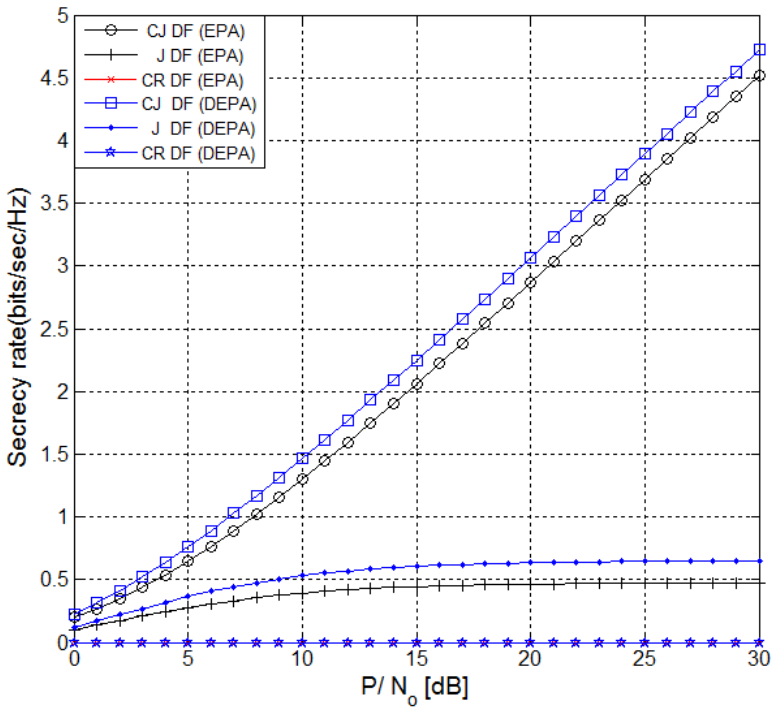


(c)

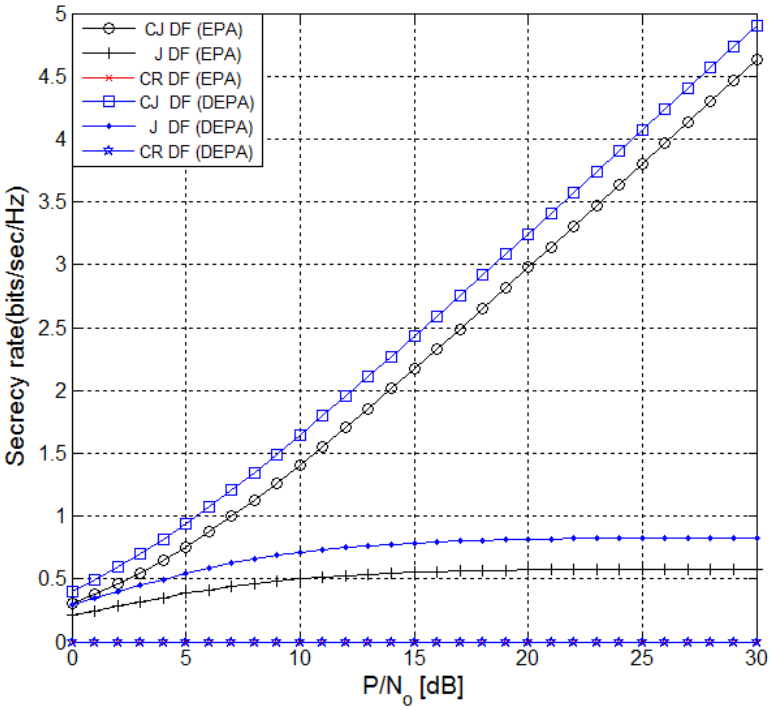
Figure 4.8 Secrecy rate versus total transmit power for (a) Collaborative eavesdroppers (b) Non collaborative eavesdroppers (c) Secrecy rate versus relay power versus Jammer power for OSCJ case

The proposed relay and jammer power allocation schemes are compared with the equal power allocation $(P_s = P_r = P_j = P_T/3)$. Here P_T is the total transmit power. From Fig 4.8 (a), it is observed that the proposed relay power allocation schemes achieve a secrecy rate

of 5.1 bits/sec/Hz (LPA), and 5 bits/sec/Hz (DEPA) where as the existing power allocation achieves it as 4.8 bits/sec/Hz for OSCJ. In the case of OSJ, the proposed power allocation schemes achieve a secrecy rate of 3.8bits/sec/Hz (LPA), 3.1 bits/sec/Hz (DEPA) and the equal power allocation obtains a secrecy rate of 2.1 bits/sec/Hz at a transmit power of 20dB. From Fig 4.8 (b), it is proclaimed that the proposed power allocation schemes achieve a secrecy rate of 5.15 bits/sec/Hz (LPA), and 5.1 bits/sec/Hz (DEPA) where as the existing power allocation achieves it as 4.9 bits/sec/Hz for OSCJ. In the case of OSJ, the proposed power allocation schemes achieve a secrecy rate of 4 bits/sec/Hz (LPA), 3.1 bits/sec/Hz (DEPA) and the equal power allocation obtains a secrecy rate of 2.1 bits/sec/Hz at a transmit power of 20dB. From the comparison over collaborative and non collaborative eavesdropper's cases, it is concluded that non collaborative eavesdroppers case attains more secrecy rate compared to the collaborative eavesdropper's case; especially in non jamming schemes it obtains more secrecy rate. The optimized relay and jammer power versus the secrecy rate of control jamming is when the relay location at middle is shown in Figure 4.8 (c), which confirms that the proposed power allocation schemes allocated less power to the jammer node compared to the equal power allocation but gets more secrecy rate.



(a)



(b)

Figure 4.9 Secrecy rate versus total transmit power for (a) Collaborative eavesdroppers (b) Non collaborative eavesdroppers when the relay is located close to eavesdropper

In Fig 4.9 (a), it is observed that the proposed relay power allocation schemes achieve a secrecy rate of 3 bits/sec/Hz (DEPA) where as the existing power allocation achieves it as 2.8 bits/sec/Hz for OSCJ. In the case of OSJ, the proposed power allocation schemes achieve a secrecy rate of 0.6 bits/sec/Hz (DEPA) and equal power allocation obtains a secrecy rate of 0.5 bits/sec/Hz at a transmit power of 20dB. From Fig 4.9 (b), it is proclaimed that the proposed relay power allocation schemes achieve a secrecy rate of 3.25 bits/sec/Hz (DEPA) where as the existing power allocation achieves it as 3 bits/sec/Hz for OSCJ at a transmit power of 20dB.

The effect of path loss exponent on the secrecy rate of the network is analysed for OSCJ scheme. Here the relays are located at middle in between the eavesdropper and the destination. The locations of the nodes are assumed as $S(0,0), E(0,1) \& D(1,0)$ respectively. From the Fig.4.10, it is observed that as the path loss exponent increases from 2 to 4, the performance is also increases in terms of secrecy rate. The convergence analysis of the proposed power allocations schemes in the presence of single eavesdropper is compared with the equal power allocation scheme and it is shown in Fig.4.11. The DE based power allocation achieves a secrecy rate close to Lagrange multiplier method and also converges fast compared to Lagrange multiplier method.

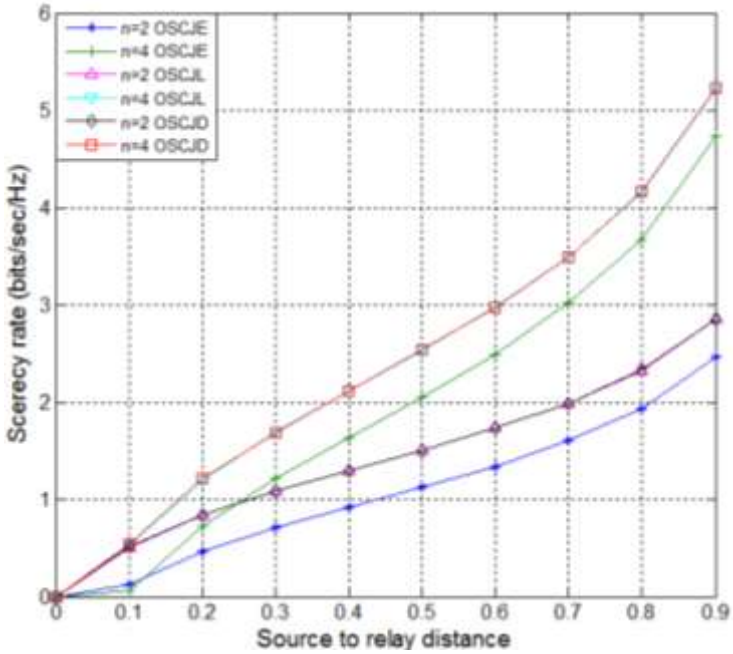


Figure 4.10 Secrecy rate versus source-to-relay distance

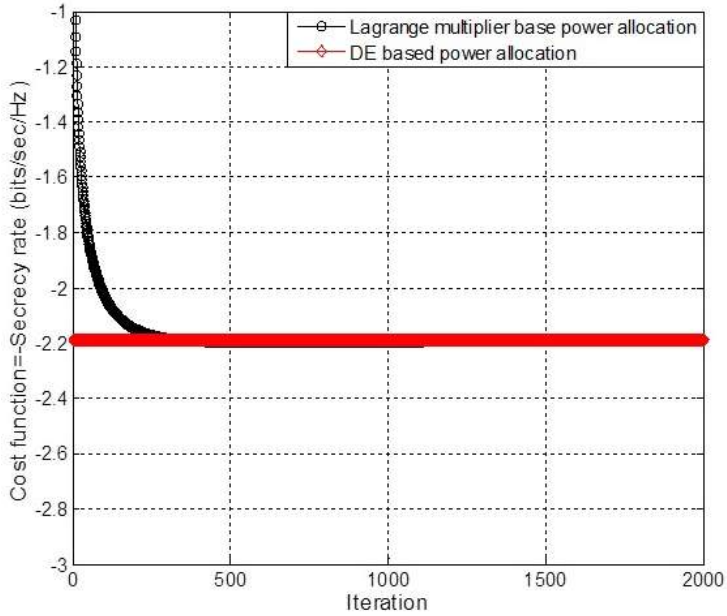


Figure 4.11 Convergence analyses of the proposed schemes

4.4.4 Impact of relay location on the performance of proposed power allocation schemes

Three different cases have been considered to determine the effect of relay location on the secrecy rate of proposed power allocation schemes.

4.4.4.1 When relays located at middle between eavesdropper and destination

The proposed schemes are compared with the existing power allocation schemes Ref. [97] and Ref.[110]. From the Fig.4.12, it is observed that the proposed power allocation schemes outperform the existing power allocation schemes in terms of secrecy rate for control jamming case. The secrecy rate of proposed power allocation schemes outperforms with control jamming than the non jamming relay selection schemes. Both the Lagrange multiplier method and the DE algorithm based power allocation scheme achieve nearly same secrecy rate of 2.75 bits/sec/Hz while the existing power allocation scheme achieves a secrecy rate of 2.5 bits/sec/Hz at transmit power 20dB for the control jamming case. The two proposed schemes achieves nearly same secrecy rate. Hence it is conlcuded that the proposed power allocation schemes outperform than the existing equal power allocation schemes in Ref.[97] & Ref.[110].

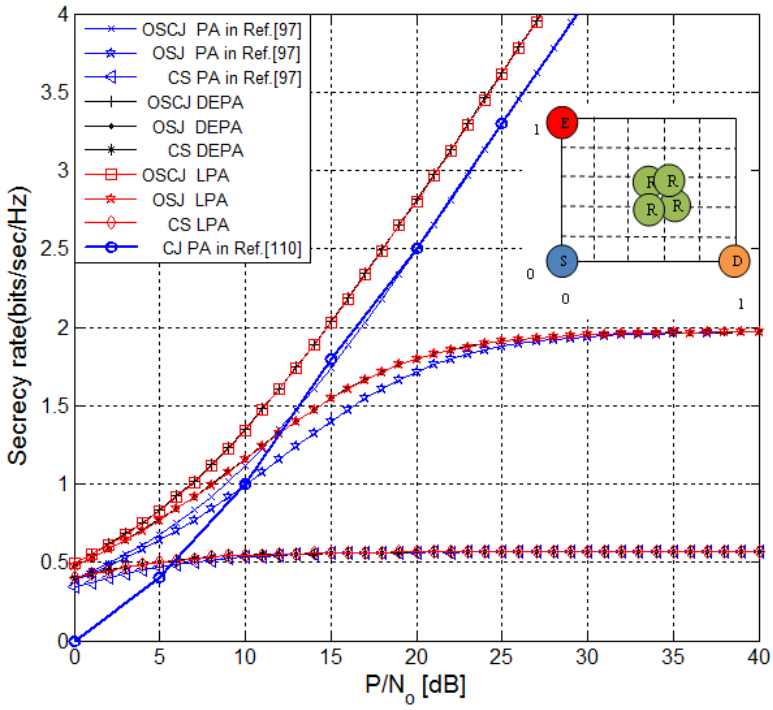


Figure 4.12 Secrecy rate versus total power when relays at middle

4.4.4.2 When the relay close to eavesdropper

From Fig.4.13, the performance of the non jamming schemes is very poor compared to the jamming schemes. Where the OSJ scheme achieves almost nearly same secrecy for low SNRs and for high SNRs OSCJ performs better than OSJ. Both the proposed power allocation schemes achieve nearly the same secrecy rate.

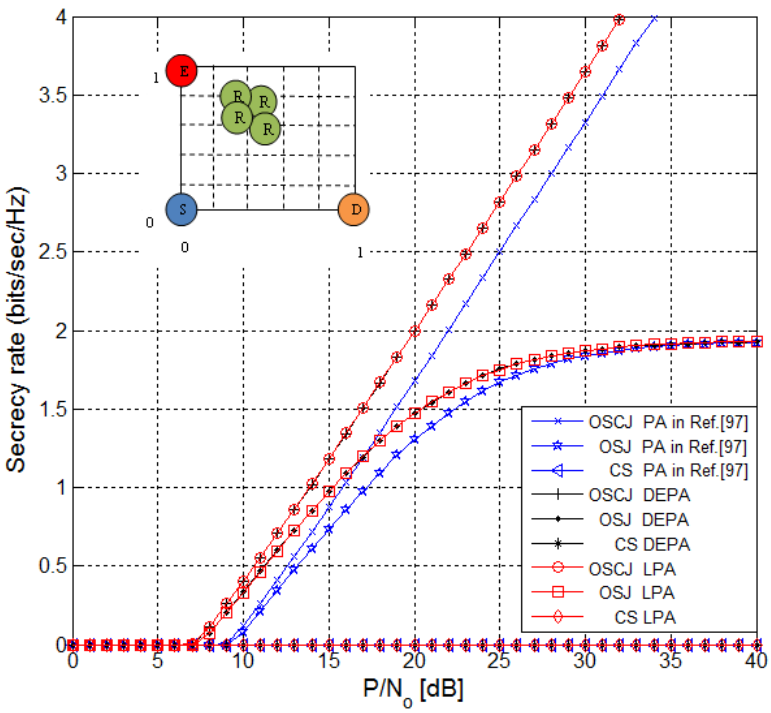


Figure 4.13 Secrecy rate versus total power when relays close to eavesdropper

Proposed power allocation schemes achieve a secrecy rate of 2 bits/sec/Hz where as conventional power allocation can offer a secrecy rate of 1.7 bits/sec/Hz for OSCJ. On the other hand, proposed schemes obtain a secrecy rate of 1.5 bit/sec/Hz for OSJ where as equal power allocation can achieve a secrecy rate of 1.3 bits/sec/Hz at transmit power of 20dB. Here the performance of non jamming scheme is poor. It is observed that with the optimized jamming and relay powers both the proposed schemes perform better than equal power allocation where both achieve almost the same secrecy rate.

4.4.4.3 When the relays close to destination

The proposed power allocation schemes achieve a secrecy rate of 2.8 bits/sec/Hz where as equal power allocation can get a secrecy rate of 2.5 bits/sec/Hz for OSCJ. The proposed schemes achieve a secrecy rate of 1.8 bits/sec/Hz where with equal power allocation a secrecy rate of 1.7 bits/sec/Hz for low SNR values is achieved. For high SNR value, both the equal power allocation and the proposed schemes achieve the sane secrecy rate for OSJ and CS cases. Fig.4.14 demonstates that the secrecy rate is high for non jamming schemes because the relay to destination link is very strong. With the optimized power the jamming schemes introduce interference at the destination which reduces the secrecy rate compared to OSCJ.

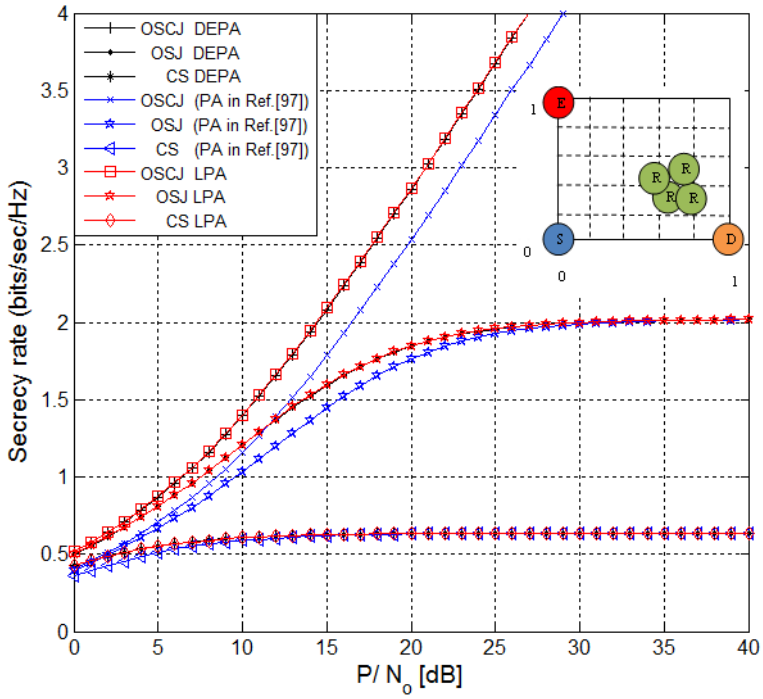


Figure 4.14 Secrecy rate versus total power when relays close to destination

4.5 Summary

In this chapter, various effcient power allocation schemes are proposed by using convex optimization and evolutionary approach for physical layer security of single source destination pair based wireless cooperative network with control jamming. The constrained optimization problems are defined and solved using Lagrange multiplier method and Differential Evolution algorithm in order to optimize the allocation of the relay and jammers powers such that the secrecy rate can be maximized subject to the total power constraint. The performance of proposed power allocation schemes are validated using Monte Carlo simulations and compared with the conventional equal power allocation for both jamming and non jamming relay selection cases. Further, the impact of locations of relays, eavesdropper on the performance of the system is analyzed. Among all relay locations, the performance of the system is poor when the relays close to eavesdropper case. The non jamming schemes demonstrates poor secrecy rate when the eavesdropper is close to source and close to destination. Among all, the control jamming achieves better secrecy rate in collaborative and non collaborative eavesdroppers cases compared to non jamming schemes. The secrecy rate performance enhances with increase in the path loss exponent. From all the observations, it is confirmed that the proposed power allocation schemes outperforms equal power allocation in a conventional DF relay

based cooperative network only. So study of physical layer security for the HDAF relaying based cooperative network with the proposed power allocation schemes need to be attempted.

4.6 Appendix

Proof of Theorem.1:

Maximized secrecy rate based relay power allocation problem in the case of single eavesdropper is solved using Lagrange multiplier method as follows. The optimization problem to find the power allocation factor α is defined as

$$Max\left(log_2\left(1+SNR_{rd}\right)-\log_2\left(1+\frac{SNR_{re}}{1+SNR_{je}}\right)\right) \text{ such that } P_s+P_r+P_j \le P_T$$

$$\text{where } P_s=P_r=\alpha P_T \ \& \ P_j=\alpha P_T/100 \ ; P_T=3P \tag{4.28}$$

The instantaneous signal to noise ratio for the channel link $i \to j$ is given by $SNR_{ij}=P_i\,\sigma_{i,j}^2$.

$$\text{Let us assume } a=x_o\alpha\,; b=\frac{\alpha y_o}{1+\alpha y_1} \text{ here } x_o=P_T\sigma_{rd}^2\,; y_o=P_T\sigma_{re}^2\,; y_1=\frac{P_T}{100}\sigma_{je}^2. \tag{4.29}$$

The Lagrangian function is defined as follows

$$J=\log_2\left(\frac{1+a}{1+b}\right)-\lambda\left(P_s+P_r+P_j-P_T\right) \tag{4.30}$$

By solving the defined Lagrangian function,

$$\partial J/\partial\alpha=0 \Rightarrow \left(\frac{1+b}{1+a}\right)\frac{\partial}{\partial\alpha}\left(\frac{1+a}{1+b}\right)-\lambda_1=0 \text{ where } \lambda_1=2.01\times P_T\times\lambda \tag{4.31}$$

$$\frac{1}{(1+a)}\frac{\partial a}{\partial\alpha}-\frac{1}{(1+b)}\frac{\partial b}{\partial\alpha}=\lambda_1$$

$$\text{where } \frac{\partial a}{\partial\alpha}=x_o\,; \frac{\partial b}{\partial\alpha}=\frac{y_o}{(1+\alpha y_1)^2} \ ; \ \frac{x_o}{(1+a)}-\frac{1}{1+\frac{\alpha y_o}{1+\alpha y_1}}\frac{y_o}{(1+\alpha y_1)^2}=\lambda \tag{4.32}$$

$$(x_o y_1 y_2)\ \alpha^2+(2x_o y_1)\,\alpha+(x_o-y_o)=\lambda_1\,(1+\alpha x_o)\ (1+\alpha y_1)\ (1+\alpha y_2)$$

The polynomial equation in terms of α is obtained as

$$(d_1\lambda_1)\,\alpha^3+(d_2\lambda_1-c_1)\,\alpha^2+(d_3\lambda_1-c_2)\,\alpha+(\lambda_1-c_3)=0 \tag{4.33}$$

The roots of the binomial equation are obtained. The root which is in the limits [0, 0.4975] and gets the maximum secrecy rate is the feasible solution.

$$\alpha = 0 < roots\left((d_1\lambda_1)\,\alpha^3 + (d_2\lambda_1 - c_1)\,\alpha^2 + (d_3\lambda_1 - c_2)\,\alpha + (\lambda_1 - c_3)\right) < 0.4975 \qquad (4.34)$$

Here $d_1 = x_o y_1 y_2$;

$d_2 = x_o(y_1 + y_2) + (y_1 y_2)$;

$d_3 = x_o + y_1 + y_2$;

$c_1 = x_o y_1 y_2$;

$c_2 = 2x_o y_1$;

$c_3 = x_o - y_o$; $y_2 = y_o + y_1$;

$$y_o = P_T\sigma_{re}^2;\ y_1 = (P_T/100)\ \sigma_{je}^2;\ x_o = P_T\sigma_{rd}^2 \qquad (4.35)$$

Proof for Theorem.2:

Maximized secrecy rate based optimal relay and jammer power allocation in the case of collaborative eavesdroppers is solved using Lagrange multiplier method as follows. The optimization problem is defined as

The optimization problem for collaborative eavesdroppers case is defined as

$$Max\left(log_2\left(1 + SNR_{rd}\right) - \log_2\left(1 + \sum_{m=1}^{M}\frac{SNR_{re_m}}{1 + SNR_{je_m}}\right)\right) \text{ such that } P_s + P_r + P_j \le P_T \qquad (4.36)$$

The instantaneous signal to noise ratio for the channel link $i \to j$ is given by $SNR_{ij} = P_i\,\sigma_{i,j}^2$. $SNR_{rd} = P_r\sigma_{rd}^2$, $SNR_{re} = P_r\sigma_{re}^2$ $P_r = \alpha(P_T - P_s)$; $P_s = P_T/3$;

$$P_j = (1-\alpha)(P_T - P_s);\ 0 < \alpha < 1 \qquad (4.37)$$

The Lagrangian function is defined as follows

$$J = \log\left(\frac{1+a}{1+b}\right) - \lambda(P_r + P_j - P_T)$$

Here $a = x_o\alpha$; $b = \dfrac{y_o\alpha}{y_1 - \alpha}$ (4.38)

where $x_o = (P_T - P_s)\,\sigma_{rd}^2\,;\, y_o = \sum_{m=1}^{M}\left(\frac{\sigma_{re_m}^2}{\sigma_{je_m}^2}\right);\, y_1 = 1 + \frac{1}{\left((P_t - P_s)\sum_{m=1}^{M}\sigma_{je_m}^2\right)}$ (4.39)

$$\frac{\partial J}{\partial \alpha} = 0 \Rightarrow \frac{(1+b)}{(1+a)}\frac{\partial}{\partial \alpha}\left(\frac{1+a}{a+b}\right) - \lambda = 0 \tag{4.40}$$

$$\Rightarrow \frac{1}{(1+a)}\frac{\partial a}{\partial \alpha} - \frac{1}{(1+b)}\frac{\partial b}{\partial \alpha} = \lambda$$

$$\frac{\partial a}{\partial \alpha} = x_o\,;\, \frac{\partial b}{\partial \alpha} = \frac{y_o y_1}{(y_1 - \alpha)^2} \tag{4.41}$$

$$\frac{x_o}{(1 + x_o\alpha)} - \frac{y_o y_1}{(y_1 + (y_o - 1)\ \alpha)(y_1 - \alpha)} = \lambda$$

The polynomial equation in terms of α is obtained as

$$(d_1\lambda_1)\ \alpha^3 + (d_2\lambda_1 - e_1)\,\alpha^2 + (d_3\lambda_1 - e_2)\,\alpha + (d_4 - e_3) = 0 \tag{4.42}$$

The roots of the binomial equation are obtained. The root which is in the limits [0, 0.4975] and gets the maximum secrecy rate is the feasible solution.

Here $d_1 = x_o(1 - y_o);$

$$d_2 = (1 - y_o) - (x_o y_1 (2 - y_o));$$

$$d_3 = x_o y_1^2 - y_1(2 - y_o);$$

$$d_4 = y_1^2;\ \ e_1 = x_o(1 - y_o); e_2 = -2x_o y_1; e_3 = \left(x_o y_1^2\right) - \left(y_0 y_1\right). \tag{4.43}$$

Chapter 5

Performance Analysis and Power Allocation Schemes for HDAF Relaying for Physical Layer Security in Wireless Cooperative Network

In the previous chapter, the power allocation schemes are developed for conventional relaying based multi relay cooperative network to maximize the secrecy rate. In this chapter we proposed SNR threshold based HDAF relaying for physical layer security in wireless cooperative networks. The main objectives of this chapter are presented as follows

Objectives of the chapter

- Describe the proposed system model consists of a wireless cooperative network of a single source-to-destination, a jammer and multi HDAF relays in the company of eavesdroppers.
- To analyze the secrecy rate of the proposed system in three cases, without jamming, with jamming and with control jamming. In addition, to derive theoretical approximations for secrecy outage and intercept probability.
- Derive the Ergodic secrecy rate of the system analytically.
- To analyze the impact of locations of relays and eavesdroppers on the secrecy rate are analyzed.
- Define power allocation problems based on secrecy rate of control jamming in wireless cooperative network and to solve the optimization problems with both Lagrange multiplier method and evolutionary approaches.
- To compare the secrecy performance of the proposed power allocation schemes with existing equal power allocation schemes.

Part of the contributions in this chapter are accepted to be published in

Kiran Kumar Gurrala, Susmita Das**, ""Performance Study of Hybrid Decode-Amplify-Forward relaying scheme for physical layer security in wireless cooperative network"* ***(Wiley) International Journal of Communication Systems (accepted). (Manuscript ID: IJCS150676.R2).

5.1 Introduction

In the previous chapter, the efficient power allocation schems for maximizing secrecy rate in DF relay based cooperative network with controlled jamming are proposed. The secrecy rate analysis of both AF and DF relaying schemes is discussed and compared in [127]. The physical layer security is addressed and investigated in wireless cooperative networks [129]. The secure communication for a single source and destination pair in the presence of single and multiple eaves dropper with multiple relays is studied in [131]. The authors in [123] proposed relay selection schemes in cooperative networks such that they can act as decode and forward relay, cooperative jammer and a new jamming and non jamming switched based hybrid scheme. The different types of relay and jammer selection schemes to maximize the secrecy rate for one way decode and forward relay cooperative network consist of multiple eavesdroppers are proposed in [136]. In the Gaussian wiretap channel, direct transmission and conventional relaying schemes are compared based on secrecy rate and it is observed that the best relaying strategy is determined based on the relay location [86]. The exact mathematical approximation for the secrecy rate and outage probability of AF and DF relaying schemes are derived and analyzed in [114]. In [123] the authors have introduced two basic relaying schemes AF and DF for large scale MIMO system and did asymptotic analysis and comparison is carried out. From these recent works, it is observed that the physical layer security issue is analyzed in cooperative wireless network using conventional relaying schemes such as AF & DF where the relays tend to operate either in full duplex mode or two way communication mode. But these conventional schemes have their own advantages along with some limitations in the context of physicaly layer security. So there is a need of utilizing efficient adaptive relaying techniques to improve the secrecy performance of the wireless cooperative network by considering different channel and SNR conditions. In this chapter, the proposed adaptive relaying such as SNR based HDAF (hybrid decode-amplify-forward) relaying is utilized for physical layer security in wireless cooperative network. As observed, the AF relaying scheme outperform DF relaying in terms of outage, whereas DF outperforms AF in terms of secrecy rate. By incorporating the advantages of AF and DF, SNR based HDAF relaying is proposed in wireless cooperative network. The performance of such cooperative network is analyzed in terms of various performance parameters such as secrecy rate, secrecy outage and intercept- probability to demonstrate the efficacy of

proposed scheme. The closed form approximation of these performance parameters are derived analytically and validated with the simulation study results. The effect of relay and eavesdroppers locations on the secrecy rate is also analyzed. Further to improve the secrecy performance of the system and to optimize the relay and jammer powers are key issues. In this chapter, the optimization problems under total power constraint are defined based on the secrecy rate of the HDAF relay based cooperative network single and multi HDAF relay cases with control jamming. In this work, both convex optimization and evolutionary algorithms (Differential Evolution and Invassive Weed Optimization algorithms) are adopted to optimize relay and jammer powers according to the obtained power allocation factor. The secrecy performance of the proposed schemes is compared with the equal power allocation scheme. From the comparison, it is proved that proposed power allocation schemes outperform the equal power allocation in terms of secrecy rate. Finally, the convergence analysis of proposed power allocation schemes is provided to validate the efficacy.

The organization of this chapter is as follows Section 5.2 explains the proposed system model. Section 5.3 provides the secrecy rate analysis of the proposed system in three cases without jamming, with jamming and with control jamming. The Ergodic secrecy rate also derived analytically. In addition, the secrecy outage probability and intercept probability are also discussed. In Section 5.4, the optimization problems are defined and power allocation schemes are proposed to maximize the secrecy rate. Section 5.4 provides the simulations results and analysis. Finally Section 5.5 presents the conclusion of this chapter.

5.2 Proposed system model

A cooperative wireless network model consists of single source destination pair, in which source (S) sends its data to the destination node (D) via N number of half duplex mode hybrid decode-amplify-forward (HDAF) relays along with a jammer node in the presence of eavesdropper node (E). Here all the channel links are subjected to flat Rayleigh fading channel which are mutually independent and orthogonal. The considered network is employed with TDMA in which the source transmits its information during the first time slot and relays transmit information during the second time slot. Here entire communication is accomplished in two phases named broadcasting phase and cooperation phase as shown in Fig.5.1.

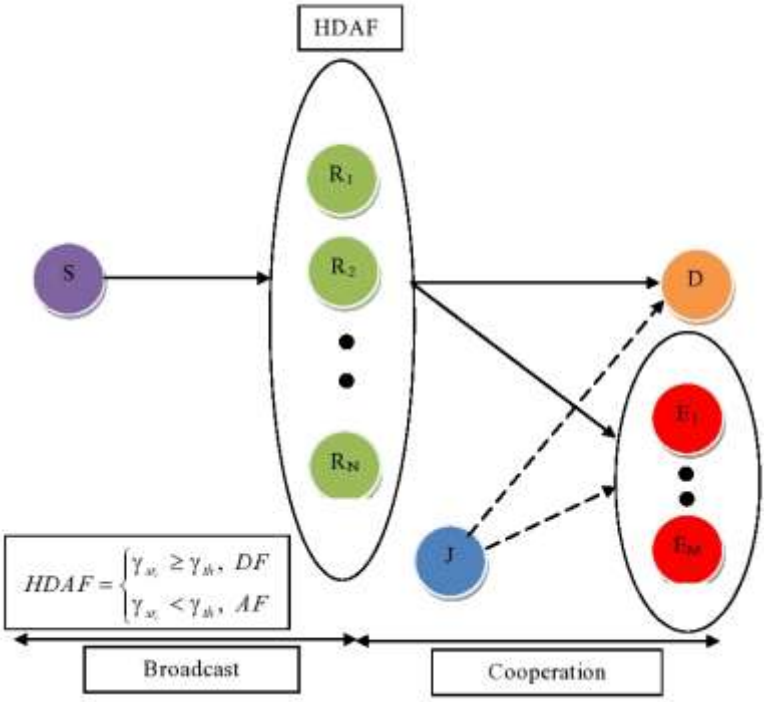


Figure 5.1 System model of multi relay HDAF cooperative network for physical layer security

Broadcast phase: The information from the source is broadcasted to the hybrid decode-amplify-forward (HDAF) relays. Here it is assumed that both the direct links between source-to-destination and source-to-eavesdroppers are unavailable. On the other hand, the broadcast phase is secured means eavesdropper cannot has impact on source to relay transmission.

$$y_{sr_i} = \sqrt{P_s} h_{sr_i} x + n_{sr_i} \quad for \quad i = 1,2,...N \tag{5.1}$$

where x and y_{sr_i} are the message signal broadcasted by the source, signal received at the ith HDAF relay node respectively. P_s is the transmitted source power, $h_{sr_i} \sim CN(0, \sigma_{sr}^2)$ are the channel coefficients of source to i^{th} HDAF relay link. The noise terms n_{sr_i} which are complex Gaussian random variables with zero mean and with a variance N_o.

Cooperative phase: In this phase, HDAF relays forward the received signal from source to destination without jamming and with jamming cases while it is being heard by the multiple eavesdroppers. The jammer node generates interference for the relay transmission by noise forwarding. In control jamming, interference caused by jammer is known at the destination but not at the eavesdropper. So the destination can decode the interference provided by the jammer. Here, the HDAF relays which adaptively switches between AF

and DF relaying schemes based on SNR threshold of the source to relay link. Here based on the target rate (R), the SNR threshold for hybrid relaying is derived. The SNR threshold is given by

$$\gamma_{th} = 2^{(2R)} - 1 \tag{5.2}$$

where R is the target information rate.

The perfect decoding capability of each relay depends on the source-to-relay link quality, and the relay. If the SNR of source to relay link is greater than or equal to SNR threshold, the HDAF relay operates in AF mode otherwise in DF mode.

The function of the each HDAF relay is given by

If $\gamma_{s,r_i} < \gamma_{th}$, i.e., the relay operates in AF mode, the received signal at the destination by the ith HDAF relay

$$y_{r_i d} = \beta h_{r_i d}\ y_{r_i d} + n_{r_i d} \qquad for\ i = 1,2,....,N \tag{5.3}$$

else $\gamma_{s,r_i} \geq \gamma_{th}$, i.e., the relay operates in DF mode, the received signal at the destination by the ith HDAF relay

$$y_{r_i d} = \sqrt{P_r}\, h_{r_i d}\ \hat{y}_{sr_i} + n_{r_i d} \qquad for\ i = 1,2,....,N \tag{5.4}$$

where P_{r_i} is the ith relay power. ; $\hat{y}_{s,r_i}$ is the decoded version of the transmitted signal by the ith relay. β_i is the amplification factor of ith relay given by $\beta_i \leq \sqrt{\dfrac{P_{r_i}}{P_S \left|h_{sr_i}\right|^2 + N_o}}$

Hence, the received signals at the destination and the eavesdroppers from the relays and the jammer are given as follows. The received signal from i^{th} relay at the eavesdroppers is given by

$$y_{e_i} = \sum_{m=1}^{M} \left(y_{r_i e_m} + y_{je_m} \right)\ for\ i = 1,2,...,N \tag{5.5}$$

where $y_{r_i e_m} = \sqrt{P_i}\, h_{r_i e_m} y_{sr_i} + n_{r_i e_m}$; $y_{je_m} = \sqrt{P_j}\, h_{je_m} x_1$;

where P_j is the jammer power. $y_{r_i e_m}$ is the received signal at the mth eavesdropper from i^{th} relay . y_{je_m} is the received signal at the mth eavesdropper from the jammer. $h_{r_i d} \sim CN(0, \sigma^2_{r_i d})$, $h_{r_i e_m} \sim CN(0, \sigma^2_{r_i e_m})$ and $h_{je_m} \sim CN(0, \sigma^2_{je_m})$ are the channel coefficients of ith relay to destination link, i^{th} relay to the mth eavesdropper link, jammer

to the mth eaves dropper links respectively. The noise term n_{re} and n_{je} are zero mean complex Gaussian random variables with variance No. The channel variance is given as $\sigma_{xy}^2 \propto d_{xy}^{-n}$ where d_{xy} is the Euclidean distance between nodes $x \in \{s, r, j\}$ and $y \in \{e, r, d\}$. In this chapter, the value of the path loss exponent is assumed as $n = 2$.

5.3 Performance analysis

The performance metrics considered in this chapter to analyse the proposed system are secrecy rate, secrecy outage and intercept probability. These metrics are obtained analytically as follows.

5.3.1 Secrecy rate

The secrecy rate of proposed system in the case of multiple eavesdroppers for the cases without jamming, with jamming and with control jamming are given as follows.

Table 5-1 Secrecy rate of HDAF relaying

Relay mode	Jamming type	Secrecy rate
In AF mode	Without jamming [A1]	$C_{AF}^{C} = \left(C_D^C(R,J) - C_E^C(R,J)\right)^+$ where $C_D^C(R,J) = 0.5 * log_2\left(1 + \sum_{i=1}^{N} \frac{P_s\lvert h_{sr_i}\rvert^2 P_i \lvert h_{r_i d}\rvert^2}{P_s\lvert h_{sr_i}\rvert^2 + P_i\lvert h_{r_i d}\rvert^2 + 1}\right)$ $C_E^C(R,J) = 0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_s\lvert h_{sr_i}\rvert^2 P_i \lvert h_{r_i e_m}\rvert^2}{P_s\lvert h_{sr_i}\rvert^2 + P_i\lvert h_{r_i e_m}\rvert^2 + 1}\right)$
	With jamming [A2]	$C_{AF}^{J} = \left(C_D^J(R,J) - C_E^J(R,J)\right)^+$ where $C_D^J(R,J) = 0.5 * log_2\left(1 + \sum_{i=1}^{N} \frac{P_s P_i \lvert h_{sr_i}\rvert^2 \lvert h_{r_i d}\rvert^2}{P_s\lvert h_{sr_i}\rvert^2\left(2 + P_j\lvert h_{jd}\rvert^2\right) + P_i\lvert h_{r_i d}\rvert^2 + P_j\lvert h_{jd}\rvert^2 + 2}\right)$ $C_E^J(R,J) = 0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_s P_i \lvert h_{sr_i}\rvert^2 \lvert h_{r_i e_m}\rvert^2}{P_s\lvert h_{sr_i}\rvert^2\left(2 + P_j\lvert h_{je_m}\rvert^2\right) + P_i\lvert h_{r_i e_m}\rvert^2 + P_j\lvert h_{je_m}\rvert^2 + 2}\right)$

	With control jamming [A3]	$C_{AF}^{CJ} = \left(C_D^{CJ}(R,J) - C_E^{CJ}(R,J)\right)^+$ where $C_D^{CJ}(R,J) = 0.5 * log_2\left(1 + \sum_{i=1}^{N} \frac{P_s\left\|h_{sr_i}\right\|^2 P_i\left\|h_{r_i d}\right\|^2}{P_s\left\|h_{sr_i}\right\|^2 + P_i\left\|h_{r_i d}\right\|^2 + 1}\right)$ $C_E^{CJ}(R,J) =$ $0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_s P_i \left\|h_{sr_i}\right\|^2 \left\|h_{r_i e_m}\right\|^2}{P_s\left\|h_{sr_i}\right\|^2\left(2 + P_j\left\|h_{je_m}\right\|^2\right) + P_i\left\|h_{r_i e_m}\right\|^2 + P_j\left\|h_{je_m}\right\|^2 + 2}\right)$

Here $[a]^+ = \max\{0, a\}$;

In DF mode	Without jamming [98]	$C_{DF}^{S}(R,J)^+ =$ $\left(0.5 * log_2\left(1 + \sum_{i=1}^{N} P_i\left\|h_{r_i d}\right\|^2\right) - 0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} P_i\left\|h_{r_i e_m}\right\|^2\right)\right)^+$
	With jamming [98]	$C_{DF}^{J}(R,J) =$ $\left(0.5 * log_2\left(1 + \frac{\sum_{i=1}^{N} P_i\left\|h_{r_i d}\right\|^2}{1 + P_j\left\|h_{jd}\right\|^2}\right) - 0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_i\left\|h_{r_i e_m}\right\|^2}{1 + P_j\left\|h_{je_m}\right\|^2}\right)\right)^+$
	With control jamming [98]	$C_{DF}^{CJ}(R,J) =$ $\left(0.5 * log_2\left(1 + \sum_{i=1}^{N} P_i\left\|h_{r_i d}\right\|^2\right) - 0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_i\left\|h_{r_i e_m}\right\|^2}{1 + P_j\left\|h_{je_m}\right\|^2}\right)\right)^+$

The ergodic secrecy capacity of the HDAF relay with control jamming in considered cooperative network is given [38] by

$$C_{HDAF} = \Pr(\gamma_{s,r} < \gamma_{th})\ C_{AF} + \Pr(\gamma_{s,r} \geq \gamma_{th})\ C_{DF} \tag{5.6}$$

where $\Pr(\gamma_{sr} < \gamma_{th}) \approx \prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{sr_i}}\right); \Pr(\gamma_{sr} \geq \gamma_{th}) \approx 1 - \prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{sr_i}}\right)$ (5.7)

The ergodic secrecy capacity of multi AF relay cooperative network with control jamming is given by

$$C_{AF} = C_{d_{AF}} - C_{e_{AF}} = \left(\frac{W}{2} \int_0^\infty \log_2(1+\gamma)\, f_{\gamma_{d_{AF}}}(\gamma)\, d\gamma \right) - \left(\frac{W}{2} \int_0^\infty \log_2(1+\gamma)\, f_{\gamma_{e_{AF}}}(\gamma)\, d\gamma \right) \tag{5.8}$$

The probability distribution functions (PDF) $f_{\gamma_{d_{AF}}}(\gamma)$ and $f_{\gamma_{e_{AF}}}(\gamma)$ is given by

$$f_{\gamma_{d_{AF}}}(\gamma) = \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{d_{AF_i}}} \exp\left(-\frac{\gamma}{\gamma_{d_{AF_i}}} \right); \quad f_{\gamma_{e_{AF}}}(\gamma) = \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{e_{AF_i}}} \exp\left(-\frac{\gamma}{\gamma_{e_{AF_i}}} \right)$$

where $\beta_i = \prod_{k=1, k\neq i}^{N} \left(1 - \frac{\gamma_k}{\gamma_i} \right)^{-1}$ (5.9)

By substituting (5.8) in (5.9), finally the ergodic secrecy capacity for multi AF relay cooperative netwok is expressed as

$$C_{AF} = \frac{W}{2\ln 2} \sum_{i=1}^{N} \beta_i \left(\exp\left(\gamma_{d_{AF}}{}^{-1}\right) E_1\left(\gamma_{d_{AF}}{}^{-1}\right) - \exp\left(\gamma_{e_{AF}}{}^{-1}\right) E_1\left(\gamma_{e_{AF}}{}^{-1}\right) \right) \tag{5.10}$$

where $E_1(\ )$ is the exponential integral is defined as $E_1(x) = \int_x^\infty \frac{\exp(-t)}{t} dt$ (5.11)

The ergodic secrecy capacity of multi DF relay cooperative network with control jamming is given by

$$C_{DF} = C_{d_{DF}} - C_{e_{DF}} = \left(\frac{W}{2} \int_0^\infty \log_2(1+\gamma)\, f_{\gamma_{d_{DF}}}(\gamma)\, d\gamma \right) - \left(\frac{W}{2} \int_0^\infty \log_2(1+\gamma)\, f_{\gamma_{e_{DF}}}(\gamma)\, d\gamma \right) \tag{5.12}$$

The probability distribution functions (PDF) $f_{\gamma_{d_{DF}}}(\gamma)$ and $f_{\gamma_{e_{DF}}}(\gamma)$ is given by

$$f_{\gamma_{d_{DF}}}(\gamma) = \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{d_{DF_i}}} \exp\left(-\frac{\gamma}{\gamma_{d_{DF_i}}} \right); \quad f_{\gamma_{e_{DF}}}(\gamma) = \sum_{i=1}^{N} \frac{\beta_i}{\gamma_{e_{DF_i}}} \exp\left(-\frac{\gamma}{\gamma_{e_{DF_i}}} \right); \tag{5.13}$$

By substituting (5.12) in (5.13), finally the Ergodic secrecy capacity is expressed as

$$C_{DF} = \frac{W}{2\ln 2} \sum_{i=1}^{N} \beta_i \left(\exp\left(\gamma_{d_{DF}}{}^{-1}\right) E_1\left(\gamma_{d_{DF}}{}^{-1}\right) - \exp\left(\gamma_{e_{DF}}{}^{-1}\right) E_1\left(\gamma_{e_{DF}}{}^{-1}\right) \right) \tag{5.14}$$

Finally, the tight approximation for Ergodic secrecy capacity of multi HDAF cooperative network is given by

$$C_{HDAF} = \frac{W}{2\ln 2} \left\{ \left(\prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{sr_i}} \right) \right) \sum_{i=1}^{N} \beta_i \left(\exp\left(\gamma_{d_{AF}}{}^{-1}\right) E_1\left(\gamma_{d_{AF}}{}^{-1}\right) - \exp\left(\gamma_{e_{AF}}{}^{-1}\right) E_1\left(\gamma_{e_{AF}}{}^{-1}\right) \right) \right.$$
$$\left. + \left(\sum_{i=1}^{N} \left(1 - \exp\left(-\frac{\gamma_{th}}{\gamma_{sr}} \right) \right) \right) \left(\sum_{i=1}^{N} \beta_i \left(\exp\left(\gamma_{d_{DF}}{}^{-1}\right) E_1\left(\gamma_{d_{DF}}{}^{-1}\right) - \exp\left(\gamma_{e_{DF}}{}^{-1}\right) E_1\left(\gamma_{e_{DF}}{}^{-1}\right) \right) \right) \right\}$$

For the control jamming case, the SNR values are given as

$$\gamma_{d_{AF}} = \sum_{i=1}^{N} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i d}\right|^2}{P_s \left|h_{sr_i}\right|^2 + P_i \left|h_{r_i d}\right|^2 + 1} ; \gamma_{d_{DF}} = \sum_{i=1}^{N} P_i \left|h_{r_i d}\right|^2$$

$$\gamma_{e_{AF}} = \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i e_m}\right|^2}{P_s \left|h_{sr_i}\right|^2 (2 + P_j \left|h_{je_m}\right|^2) + P_i \left|h_{r_i e_m}\right|^2 + P_j \left|h_{je_m}\right|^2 + 2} ; \gamma_{e_{DF}} = \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_i \left|h_{r_i e_m}\right|^2}{1 + P_j \left|h_{je_m}\right|^2} \tag{5.16}$$

5.3.2 Secrecy Outage probability

Another performance metric to characterize the system secrecy performance is secrecy outage probability. It is defined as follows

The secrecy outage probability is defined as the probability that the achievable instantaneous secrecy capacity C is less than chosen target rate $R_s > 0$.

$$P_{out} = P\{C < R_s\} \tag{5.17}$$

The secrecy outage probability of a quasi static Rayleigh fading channel is characterized in [5] as follows

$$P[C_s < R] = 1 - \frac{\overline{\gamma_d}}{\overline{\gamma_d} + 2^R \overline{\gamma_e}} \exp\left(-\frac{2^R - 1}{\overline{\gamma_d}}\right) \tag{5.18}$$

Proof: $P[C_s < R] = 1 - P\left[\log_2\left(\frac{1+\Gamma_d}{1+\Gamma_e}\right) > R\right]$

$$= 1 - P\left[\Gamma_d > 2^R(1+\Gamma_e) - 1\right]$$

$$= 1 - \int_0^\infty P(\gamma_e) \left(\int_{2^R(1+\gamma_e)-1}^{\infty} P(\gamma_d)\, d\gamma_d\right) d\gamma_e$$

$$= 1 - \frac{\overline{\gamma_d}}{\overline{\gamma_d} + 2^R \overline{\gamma_e}} \exp\left(-\frac{2^R - 1}{\overline{\gamma_d}}\right) \tag{5.19}$$

Assuming Perfect CSI, the secrecy outage probability of HDAF (hybrid decode-amplify – forward) relaying scheme for physical layer security in multi relay cooperative network with control jamming is given by

$$P_{outHDAF} = P[C_s < R] = 1 - \prod_{i=1}^{N} \frac{\overline{\gamma_{d_i}}}{\overline{\gamma_{d_i}} + 2^R \overline{\gamma_{e_i}}} \exp\left(-\frac{2^R - 1}{\overline{\gamma_{d_i}}}\right) \tag{5.20}$$

Here $\overline{\gamma_d}$ & $\overline{\gamma_e}$ are average SNRs of the main link and eavesdropper's link respectively which are given by

γ_d: when the relay operates in DF mode $\gamma_{d_i} = \gamma_{d_{DF_i}} = P_i \left|h_{r_i d}\right|^2 \quad for\ i = 1,2,...,N$

the relay operates in AF mode $\gamma_{d_i} = \gamma_{d_{AF_i}} = \dfrac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i d}\right|^2}{P_s \left|h_{sr_i}\right|^2 + P_i \left|h_{r_i d}\right|^2 + 1} \quad for\ i = 1,2,...,N$

γ_e: when the relay operates in DF mode $\gamma_{e_i} = \gamma_{e_{DF_i}} = \dfrac{P_i \left|h_{r_i e}\right|^2}{1 + P_j \left|h_{je}\right|^2} \quad for\ i = 1,2,...,N$

when the relay operates in AF mode

$$\gamma_{e_i} = \gamma_{e_{AF_i}} = \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i e_m}\right|^2}{P_s \left|h_{sr_i}\right|^2 (2 + P_j \left|h_{je_m}\right|^2) + P_i \left|h_{r_i e_m}\right|^2 + P_j \left|h_{je_m}\right|^2 + 2} \quad for\ i = 1,2,....,N \tag{5.21}$$

An outage occurs in two cases. Firstly when the information transmission is unreliable (i.e. the destination unable to decode the received data perfectly) or it is not secure transmission due overhearing of eavesdropper.

5.3.3 Intercept probability

The secrecy intercept probability is defined as the probability at which the achievable instantaneous secrecy capacity C_e at the eavesdropper is greater than chosen target rate $R_s > 0$.

$$P_{\text{int}} = P\{C_e > R_s\} \tag{5.22}$$

The intercept occurs when the secrecy capacity becomes negative value which means that the channel capacity at the eavesdropper is greater the channel capacity at the destination. According to [24], the intercept probability of direct transmission is independent of transmit power. This motivates the authors in [24], to employ the cooperative users i.e relays to reduces the intercept probability and to enhance the physical layer security. Hence the intercept probability of multi relay HDAF cooperative network is formulated as follows

$$P_{\text{int}_{HDAF}} = \Pr\{\gamma_{sr} \geq \gamma_{th}\} \text{P}_{\text{int}_{\text{DF}}} + \Pr\{\gamma_{sr} < \gamma_{th}\} \text{P}_{\text{int}_{\text{AF}}} \tag{5.23}$$

where $\Pr[\gamma_{sr} < \gamma_{th}] = \Pr\left(\prod_{i=1}^{N} \gamma_{sr_i} < \gamma_{th}\right) \approx \prod_{i=1}^{N} \Pr\left(\gamma_{sr_i} < \gamma_{th}\right) = \prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{sr_i}}\right)$

$$\Pr[\gamma_{sr} \geq \gamma_{th}] = \Pr\left(\prod_{i=1}^{N} \gamma_{sr_i} > \gamma_{th}\right) \approx 1 - \prod_{i=1}^{N} \Pr\left(\gamma_{sr_i} < \gamma_{th}\right) = 1 - \prod_{i=1}^{N} \exp\left(-\frac{\gamma_{th}}{\gamma_{sr_i}}\right)$$

$$\mathrm{P}_{\mathrm{int}_{\mathrm{DF}}} = \prod_{i=1}^{N} \frac{\sigma_{r_i d}^2 \sigma_{r_i e}^2 + \sigma_{sr_i}^2 \sigma_{r_i e}^2}{\sigma_{r_i d}^2 \sigma_{r_i e}^2 + \sigma_{sr_i}^2 \sigma_{r_i e}^2 + \sigma_{sr_i}^2 \sigma_{r_i d}^2}; \qquad \mathrm{P}_{\mathrm{int}_{\mathrm{AF}}} = \prod_{i=1}^{N} \frac{\sigma_{r_i e}^2}{\sigma_{r_i e}^2 + \sigma_{r_i d}^2} \tag{5.24}$$

5.4 Proposed power allocation schemes

5.4.1 Problem formulation

In this subsection, the secrecy performance of the multi HDAF relay based wireless cooperative network is improved using Differential evolution algorithm. Here the optimization problem is defined based on the secrecy rate of the network with control jamming which is represented in terms of power allocation factor α.

Optimization problem:

If the relay operates in DF mode, then the optimization problem is defined as

$$\text{Maximize} \left(0.5 * \log_2\left(1 + \sum_{i=1}^{N} P_i \left|h_{r_i d}\right|^2\right) - 0.5 * \log_2\left(\sum_{i=1}^{N}\sum_{m-1}^{M} \frac{P_i \left|h_{r_i e}\right|^2}{1 + P_j \left|h_{je}\right|^2}\right)\right)^+$$

subject to $0 < \alpha_i < 1$ *for* $i = 1,2,...,N$; $P_s + \sum_{i=1}^{N} P_i + P_j = P$;

$$P_i = \alpha_i (P - P_s); P_j = (1 - \alpha_i)(P - P_s);\ Ps = P/(N+2); \tag{5.25}$$

else the optimization problem is defined as

$$\text{Maximize} \quad 0.5 * \left(\log_2\left(1 + \sum_{i=1}^{N} \frac{P_s \left|h_{sr_i}\right|^2 P_i \left|h_{r_i d}\right|^2}{P_s \left|h_{sr_i}\right|^2 + P_i \left|h_{r_i d}\right|^2 + 1}\right)\right)$$

$$- \log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i e_m}\right|^2}{P_s \left|h_{sr_i}\right|^2 (2 + P_j \left|h_{je_m}\right|^2) + P_i \left|h_{r_i e_m}\right|^2 + P_j \left|h_{je_m}\right|^2 + 2}\right)$$

subject to $0 < \alpha_i < 1$ *for* $i = 1,2,...,N$; $P_s + \sum_{i=1}^{N} P_i + P_j = P$; $P_i = \alpha_i (P - P_s); P_j = (1 - \alpha_i)(P - P_s);$

$$Ps = P/(N+2); \tag{5.26}$$

If the relay decodes perfectly Cost function: $f_{S_{HDAF}} = \arg\min(-C_{DF}^{CJ})$

Else Cost function: $f_{S_{HDAF}} = \arg\min\left(-C_{AF}^{CJ}\right)$ (5.27)

5.4.2 Lagrange multiplier method based power allocation

Theorem.1: (Maximized secrecy rate based optimal relay power allocation in presence of M number of eavesdroppers) : with the perfect CSI , $h_{sr_i}, h_{r_i d}$, $for\ i = 1,2,..,N$ and $h_{r_i,e_m} h_{je_m}$ $for\ m = 1,2,...M$, the optimal relay power to maximize the secrecy rate of AF multi relay network using control jamming using Lagrange multiplier method is given by

$$\alpha_i = 0 < \alpha_i \left(= roots\ \left((s_1\lambda)\,\alpha_i^4 + (s_2\lambda)\,\alpha_i^3 + (s_3\lambda - d_1)\,\alpha_i^2 + (s_4\lambda - d_2)\,\alpha_i + (s_5 - d_3)\right)\right) < 1 \tag{5.28}$$

Proof: Maximized secrecy rate based relay power allocation problem in the case of multiple eavesdroppers is solved using Lagrange multiplier method as follows. The optimization problem is defined as

$$\text{Maximize}\ \ 0.5 * \left(log_2 \left(1 + \sum_{i=1}^{N} \frac{P_s \left|h_{sr_i}\right|^2 P_i \left|h_{r_i d}\right|^2}{P_s \left|h_{sr_i}\right|^2 + P_i \left|h_{r_i d}\right|^2 + 1} \right) \right)$$

$$- log_2 \left(1 + \sum_{i=1}^{N} \sum_{m=1}^{M} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i e_m}\right|^2}{P_s \left|h_{sr_i}\right|^2 (2 + P_j \left|h_{je_m}\right|^2) + P_i \left|h_{r_i e_m}\right|^2 + P_j \left|h_{je_m}\right|^2 + 2} \right) \tag{5.29}$$

subject to $0 < \alpha_i < 1$ $for\ i = 1,2,...,N$; $P_s + \sum_{i=1}^{N} P_i + P_j = P_t$;

$$P_i = \alpha_i \frac{(P_t - P_s)}{N}; P_j = (1 - \alpha_i)\ (P_t - P_s); P_s = \frac{P_t}{N+1} \tag{5.30}$$

Let us assume $a = \dfrac{\alpha_i x_o}{x_1 + \alpha_i}; b = \dfrac{\alpha_i y_o}{y_1 + \alpha_i}$

where $x_o = P_s \left|h_{sr_i}\right|^2; x_1 = \dfrac{1 + P_s \left|h_{sr_i}\right|^2}{P_t \left|h_{r_i d}\right|^2};\ y_o = \dfrac{q_2}{q_1}; y_1 = \dfrac{q_0}{q_1};$

$$q_0 = 2P_s\left|h_{sr_i}\right|^2 + \left(P_s\frac{(P_t - P_s)}{N}\left(\left|h_{sr_i}\right|^2\sum_{m=1}^{M}\left|h_{je_m}\right|^2\right)\right) + 2 \;;$$

$$q_1 = \left(\frac{(P_t - P_s)}{N}\sum_{m=1}^{M}\left|h_{r_ie_m}\right|^2\right) - \left((P_t - P_s)P_s\left|h_{sr_i}\right|^2\sum_{m=1}^{M}\left|h_{je_m}\right|^2\right);$$

$$q_2 = P_s\frac{(P_t - P_s)}{N}\left|h_{sr_i}\right|^2\sum_{m=1}^{M}\left|h_{r_ie_m}\right|^2 \tag{5.31}$$

The secrecy rate

$$\log_2(1 + xP_r) - \log_2(1 + x_oP_r)$$

Assume $a = xP_r, b = x_oP_r$ (5.31)

The Lagrangian function is defined as follows

$$J = \log\left(\frac{1+a}{1+b}\right) - \lambda(P_r + P_j - P_T) \tag{5.31}$$

$$\frac{\partial J}{\partial\alpha_i} = 0 \Rightarrow \frac{(1+b)}{(1+a)}\frac{\partial}{\partial\alpha_i}\left(\frac{1+a}{a+b}\right) - \left(\frac{(1-N)}{N}\right)\lambda = 0 \tag{5.31}$$

$$\Rightarrow \frac{1}{(1+a)}\frac{\partial a}{\partial\alpha_i} - \frac{1}{(1+b)}\frac{\partial b}{\partial\alpha_i} = \left(\frac{(1-N)}{N}\right)\lambda \tag{5.31}$$

$$\frac{\partial a}{\partial\alpha_i} = \frac{x_ox_1}{(\alpha_i + x_1)^2}\;;\frac{\partial b}{\partial\alpha_i} = \frac{y_oy_1}{(\alpha_i + y_1)^2} \tag{5.31}$$

$$\frac{x_0x_1}{(\alpha_i(1+x_o) + x_1)(\alpha_i + x_1)} - \frac{y_0y_1}{(\alpha_i(1+y_o) + y_1)(\alpha_i + y_1)} = \left(\frac{(1-N)}{N}\right)\lambda\;; \tag{5.31}$$

Assume $\lambda_1 = \left(\frac{(1-N)}{N}\right)\lambda$ (5.31)

The polynomial equation in terms of α_i is given by

$$(s_1\lambda_1)\alpha_i^4 + (s_2\lambda_1)\alpha_i^3 + (s_3\lambda_1 - d_1)\alpha_i^2 + (s_4\lambda_1 - d_2)\alpha_i + (s_5 - d_3) = 0 \tag{5.31}$$

The roots of the above equation, the optimized relay power to maximize the secrecy rate is given by

$$\alpha_i = 0 < roots\;((s_1\lambda_1)\alpha_i^4 + (s_2\lambda_1)\alpha_i^3 + (s_3\lambda_1 - d_1)\alpha_i^2 + (s_4\lambda_1 - d_2)\alpha_i + (s_5 - d_3)) < 1 \tag{5.31}$$

Here $d_1 = (e_1x_ox_1 - e_2y_oy_1)$; $d_2 = (x_ox_1y_1(e_1+1)) - (y_oy_1x_1(e_2+1))$

$d_3 = (x_ox_1y_1^2) - (y_oy_1x_1^2)$; $e_1 = 1 + y_o$; $e_2 = 1 + x_o$; $s_1 = e_1e_2$;

$s_2 = (y_1(e_1+1)e_2) + (x_1(e_2+1)e_1)$;

$$s_3 = (e_2 y_1^2) + (e_1 x_1^2) + (e_1+1)(e_2+1)x_1 y_1$$

$$s_4 = x_1 y_1^2 (e_2+1) + x_1^2 y_1 (e_1+1);\ s_5 = x_1^2 y_1^2 \tag{5.31}$$

Theorem.2: : (Maximized secrecy rate based optimal relay power allocation in presence of M number of eavesdroppers): with the perfect CSI, $h_{sr_i}, h_{r_i d}$ $for\ i = 1,2,..N$ and $h_{r_i e_m}\ h_{je_m}$ $for\ i = 1,2,..N$, the optimal relay power to maximize the secrecy rate of DF multi relay network using control jamming using Lagrange multiplier method is given by

$$\alpha_i = 0 < \alpha_i \left(= roots\left(\left(d_1\lambda_1\right)\alpha_i^3 + \left(d_2\lambda_1 - e_1\right)\alpha_i^2 + \left(d_3\lambda_1 - e_2\right)\alpha_i + \left(d_4 - e_3\right)\right)\right) < 1 \tag{5.32}$$

Proof:

Maximized secrecy rate based relay power allocation problem in the case of multiple eavesdroppers is solved using Lagrange multiplier method as follows. The optimization problem is defined as

$$\text{Maximize}\ \left(0.5 * log_2\left(1 + \sum_{i=1}^{N} P_i \left|h_{r_i d}\right|^2\right) - 0.5 * log_2\left(1 + \sum_{i=1}^{N}\sum_{m=1}^{M} \frac{P_i \left|h_{r_i e_m}\right|^2}{1 + P_j \left|h_{je_m}\right|^2}\right)\right)^+ \tag{5.32}$$

subject to $0 < \alpha_i < 1$ $for\ i = 1,2,...,N$; $P_s + \sum_{i=1}^{N} P_i + P_j = P_t$;

$$P_i = \alpha_i \frac{\left(P_t - P_s\right)}{N};\ P_j = (1-\alpha_i)\ (P_t - P_s);\ P_s = \frac{P_t}{N+1} \tag{5.32}$$

The secrecy rate

$$\log_2(1 + xP_r) - \log_2(1 + x_o P_r)$$

Assume $a = xP_r, b = x_o P_r$ (5.32)

Here $a = x_o\ \alpha_i$; $b = \dfrac{y_o \alpha_i}{y_1 - \alpha_i}$ (5.32)

$$x_o = \frac{(P_t - P_s)}{N}\left|h_{r_i d}\right|^2;$$

$$y_o = \sum_{m=1}^{M}\left(\frac{\left|h_{r_i e_m}\right|^2}{\left|h_{je_m}\right|^2}\right);\ y_1 = 1 + \frac{1}{\left((P_t - P_s)\sum_{m=1}^{M}\left|h_{je_m}\right|^2\right)} \tag{5.32}$$

The Lagrangian function is defined as follows

$$J = \log\left(\frac{1+a}{1+b}\right) - \lambda(P_r + P_j - P_T) \tag{5.32}$$

$$\frac{\partial J}{\partial \alpha_i} = 0 \Rightarrow \frac{(1+b)}{(1+a)} \frac{\partial}{\partial \alpha_i}\left(\frac{1+a}{a+b}\right) - \left(\frac{(1-N)}{N}\right)\lambda = 0 \tag{5.32}$$

$$\Rightarrow \frac{1}{(1+a)} \frac{\partial a}{\partial \alpha_i} - \frac{1}{(1+b)} \frac{\partial b}{\partial \alpha_i} = \left(\frac{(1-N)}{N}\right)\lambda \tag{5.32}$$

$$\frac{\partial a}{\partial \alpha_i} = x_o \,;\, \frac{\partial b}{\partial \alpha_i} = \frac{y_o y_1}{(y_1 - \alpha_i)^2} \tag{5.32}$$

$$\frac{x_o}{(1+x_o\alpha_i)} - \frac{y_o y_1}{(y_1 + (y_o - 1) = \alpha_i)(y_1 - \alpha_i)} = \left(\frac{(1-N)}{N}\right)\lambda \tag{5.32}$$

The polynomial equation in terms of α_i is given by

$$(d_1\lambda_1)\alpha_i^3 + (d_2\lambda_1 - e_1)\alpha_i^2 + (d_3\lambda_1 - e_2)\alpha_i + (d_4 - e_3) = 0 \tag{5.32}$$

Here $d_1 = x_o(1-y_o)$; $d_2 = (1-y_o) - (x_o y_1(2-y_o))$; $d_3 = x_o y_1^2 - y_1(2-y_o)$; $d_4 = y_1^2$;

$$e_1 = x_o(1-y_o)\,; e_2 = -2x_o y_1\,; e_3 = (x_o y_1^2) - (y_o y_1) \tag{5.32}$$

5.4.3 Proposed DE Algorithm based power allocation

Constraint optimization algorithms like linear programming (Lagrange Multiplier method) can be applied to solve this optimization problem, but there are no explicit methods to find the Lagrange Multipliers value. For this, we have to use iterative methods or numerical search methods which are computationally complex. In this context of reducing computational burden, soft computing optimization algorithms are preferred. Among soft computing algorithms, Differential Evolution algorithm is selected here. Differential evolution algorithm is an efficient and powerful stochastic optimized search algorithm with advantages like finding best global minimum in attentive of initial parameters, fast converges with only small number of control parameters [22]. Differential Evolution algorithm using nearly same operations like cross over and mutation like genetic algorithm. Because of individual parameters in decimal format, Differential Evolution algorithm computationally flexible compared to genetic algorithm. The flowchart of proposed DE based power allocation is shown in Fig.5.2 and Proposed DE algorithm explained in detail in Fig.5.3. The parameters in the flowchart shown in Fig. 5.3 are defined as follows G_d is the total number of generations; g is the individual generation; NP is the number of population members; D is the number of parameters of objective function; α_i is the power allocation of factor of each relay.

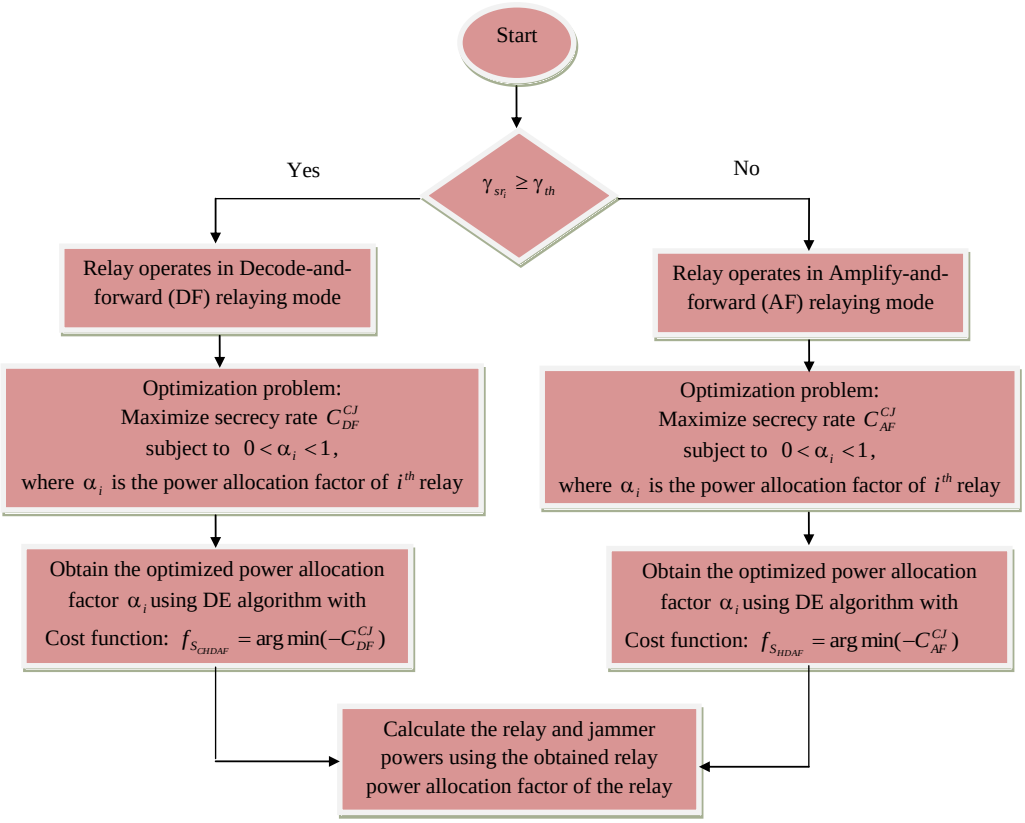


Figure 5.2 Flowchart for proposed power allocation algorithm using DE algorithm to find optimal relay and jammer powers

Fitness evolution: $E1 = f_{S_{HDAF}}^{g,n}\left(u^{g,n}\right)$ is the fitness (cost function value) of the nth individual in the gth generation of $u^{g,n}$ which is given as follows

If the relay operates in DF mode:

$$E1 = f_{S_{HDAF}}^{g,n}\left(u^{g,n}\right) = -C_{DF}^{CJ}(u^{g,n}) \tag{5.33}$$

If the relay operates in AF mode:

$$E1 = f_{S_{HDAF}}^{g,n}\left(u^{g,n}\right) = -C_{AF}^{CJ}(u^{g,n}) \tag{5.34}$$

$E2 = f_{S_{HDAF}}^{g,n}\left(\alpha^{g,n}\right)$ is the cost function value of the nth individual in the gth generation of $\alpha^{g,n}$ which is given as follows

If the relay operates in DF mode:

$$E2 = f_{S_{HDAF}}^{g,n}\left(\alpha^{g,n}\right) = -C_{DF}^{CJ}(\alpha^{g,n}) \tag{5.35}$$

If the relay operates in AF mode:

$$E2 = f_{S_{HDAF}}^{g,n}\left(\alpha^{g,n}\right) = -C_{AF}^{CJ}(\alpha^{g,n}) \tag{5.36}$$

where $\alpha^{g,n}$ is the target vector

$u^{g,n}$ is the trail vector obtained after mutation and cross over operations.

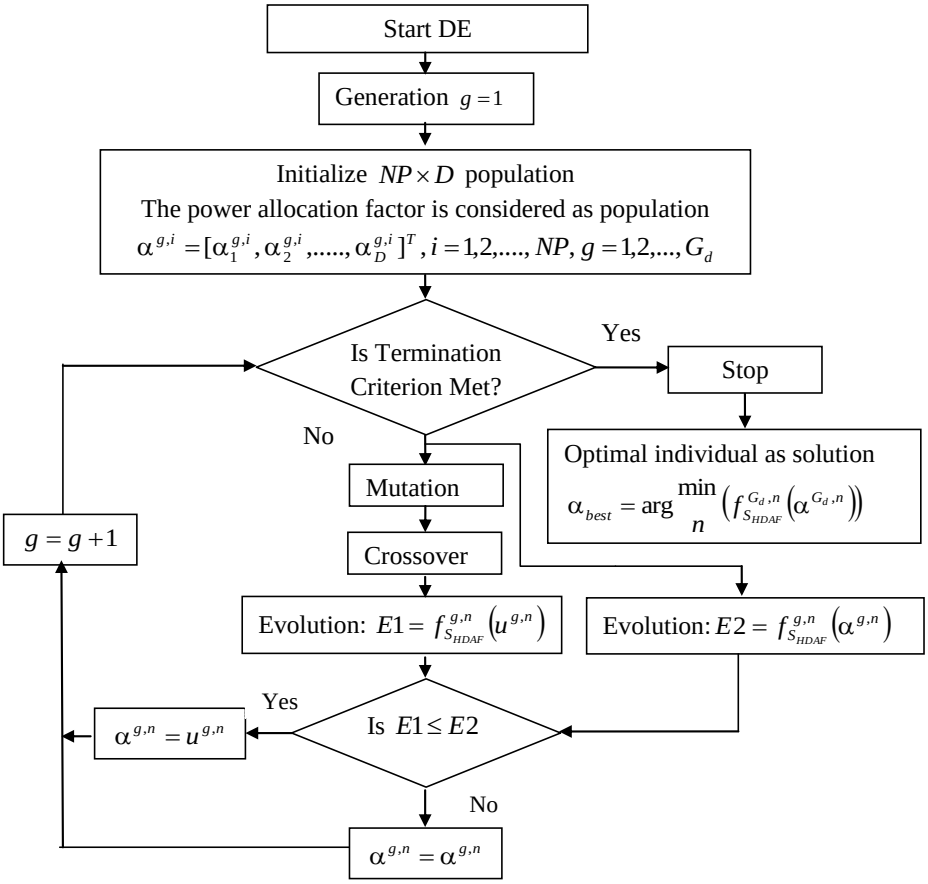


Figure 5.3 Flow chart for DE algorithm applied for power allocation optimization to find the optimal relay and jammer powers

Optimal solution: Finally after the termination criteria, the best optimal solution is the best individual which has minimum cost function value. The optimized power allocation factor α is given as

$$\alpha_{best} = \arg\min_n \left(f_{S_{HDAF}}^{G_d,n} \left(\alpha^{G_d,n} \right) \right), \; n = 1,2,...,NP \tag{5.37}$$

$f_{CHDAF}^{G_d,n} \left(\alpha^{G_d,n} \right)$ represents the optimal solution after meeting the termination criteria.

5.4.4 Proposed Invasive Weed Optimization (IWO) algorithm based power allocation

The IWO algorithm is introduced by Meharabian et al [142]. Due to the its advantages like fast convergence, reduced computational complexity and ability to solve complex and non differentiable functions, IWO algorithm turned as very good alternative to the other

optimization algorithms and found applications in different application domains. The basic steps involved in IWO algorithm are initialization, reproduction, spatial distribution and competitive exclusion. Hence, we prefer to use IWO algorithm here to optimize the relay and jammer powers to maximize secrecy rate. The proposed IWO algorithm based power allocation is explained in Fig.5.4 where the detailed IWO algorithm is shown in Fig.5.5 and the steps involved are explained briefly as follows

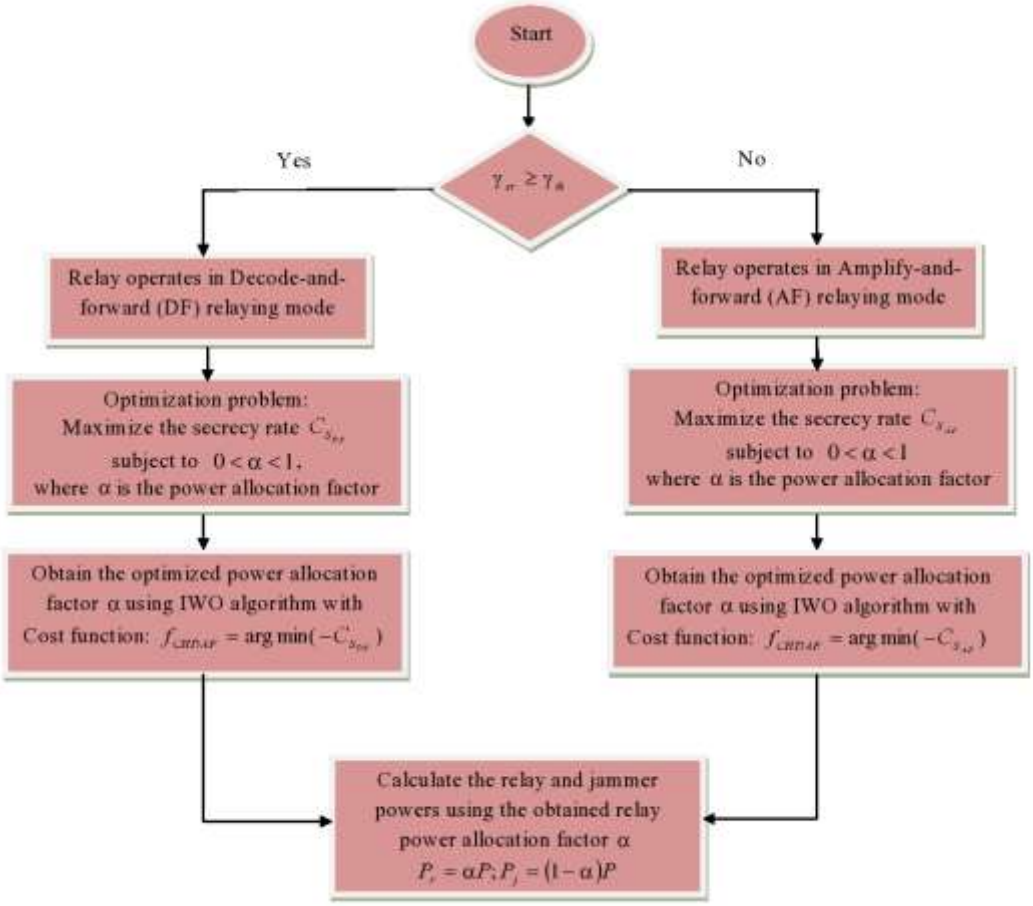


Figure 5.4 Flowchart for proposed power allocation algorithm using IWO algorithm to find optimal relay and jammer powers

Initialization: In this step, the initial solutions are a set of seeds which are randomly distributed over the entire search space. Here, the initial population consists N_I individual each individual having P number of variables. The nth individual in the population of ith iteration is given as $\alpha^{i,n} = [\alpha_1^{i,n}, \alpha_2^{i,n}, ..., \alpha_P^{i,n}]^T$.

Fitness evaluation: $f_{S_{HDAF}}^{g,n}\left(\alpha^{g,n}\right)$ is the fitness of the nth individual in the gth generation of $u^{g,n}$ which is given as follows

If the relay chose DF mode: $E1 = f_{S_{HDAF}}^{g,n}\left(\alpha^{g,n}\right) = -C_{DF}^{CJ}(\alpha^{g,n})$ (5.38)

If the relay chose AF mode: $E1 = f_{S_{HDAF}}^{g,n}\left(\alpha^{g,n}\right) = -C_{AF}^{CJ}(\alpha^{g,n})$ (5.39)

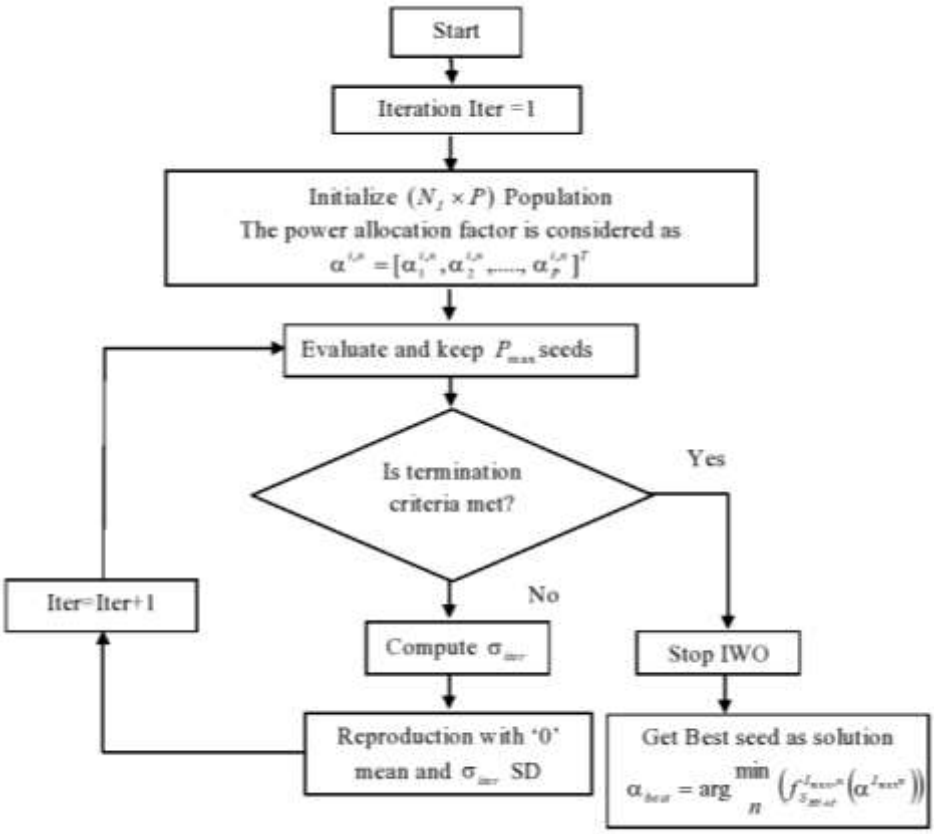


Figure 5.5 Flowchart for IWO algorithm applied for power allocation optimization

Reproduction and spatial dispersal: The nth plant generates S_n number of seeds with zero mean and σ_{iter} standard deviation. The generated seeds are proportional to their individual fitness value and they are dispersed over the search space. Based on the fitness value, all the plants are sorted in ascending order and assigned rank. The standard deviation at each iteration is given as

$$\sigma_{iter} = \left(\frac{I_{\max} - iter}{I_{\max}}\right)^r \left(\sigma_{initial} - \sigma_{final}\right) + \sigma_{final} \tag{5.40}$$

Competitive exclusion: At last, competitive mechanism is developed which eliminates undesirable plants with poor fitness function and allow fitter plants to produce new more seeds. This mechanism continues until maximum number of iteration limit is reached.

Optimal solution: After reaching the termination, the optimized power allocation factor α is given as $\alpha_{best} = \arg\min_n \left(f_{S_{HDAF}}^{I_{\max},n}\left(\alpha^{I_{\max}n}\right)\right),\ n = 1,2,\ldots,N_I$

$f_{S_{HDAF}}^{I_{\max},n}\left(\alpha^{I_{\max}n}\right)$ represents the final desired solution. (5.41)

5.5 Simulation results and analysis

In this study, the secrecy performance of the HDAF relaying for physical layer security in multi relay wireless network with control jamming is validated using MATLAB based computer simulations and compared with the conventional relaying schemes (AF & DF), non-jamming and jamming schemes. The parameters for this simulation study are shown in Table 5-2. The simulations are carried out in the cases as follows. The simulation environment of the proposed system is given in Fig.5.6.

Table 5-2 Simulation parameters

Parameters	Specification
Total no of bits	10^4
Relay network topology	2-D square topology
Area of the network	1×1 unit square
Locations of the nodes	Source $S=\{0,0\}$, Eavesdropper $E=\{0,1\}$, Destination $D=\{1,0\}$, Jammer $J=\{0.2,0.8\}$
SNR threshold of HDAF relaying scheme	$\gamma_{th}=2^{2R}-1$;Target rate $R=1$;
Channel	Flat Rayleigh fading
Modulation	Coherent QPSK
DE parameters	DE step size (F)=0.8 Crossover probability(CR)=0.5 D=1(number of parameters of objective function) NP(number of population members)=50*D Iterations=200
IWO parameters	Number of iterations $(I_{\max})=100$ Population size $(N_I)=50$ Number of seeds $(N_S)=85$ Search range $[0,1]$ Maximum number of seeds $(S_{\max})=5$ Minimum number of seeds $(S_{\min})=1$ Non linear modulation index $(r)=3$ Initial standard deviation $(\sigma_i)=0.1$ Final standard deviation $(\sigma_f)=0.00001$ Seed selection-rank based

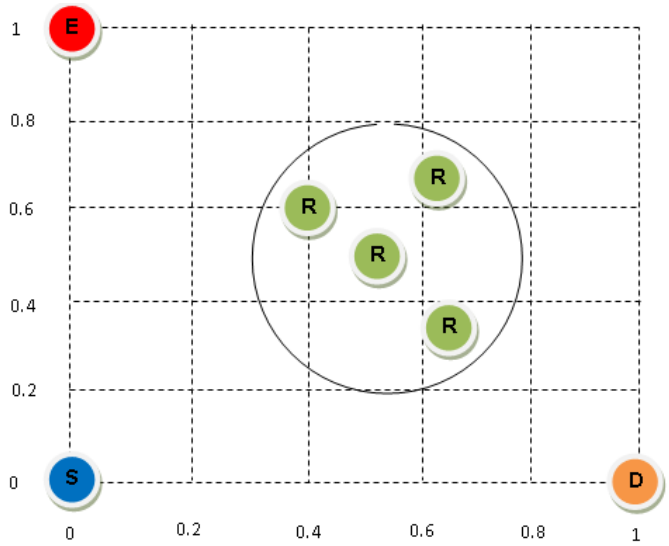
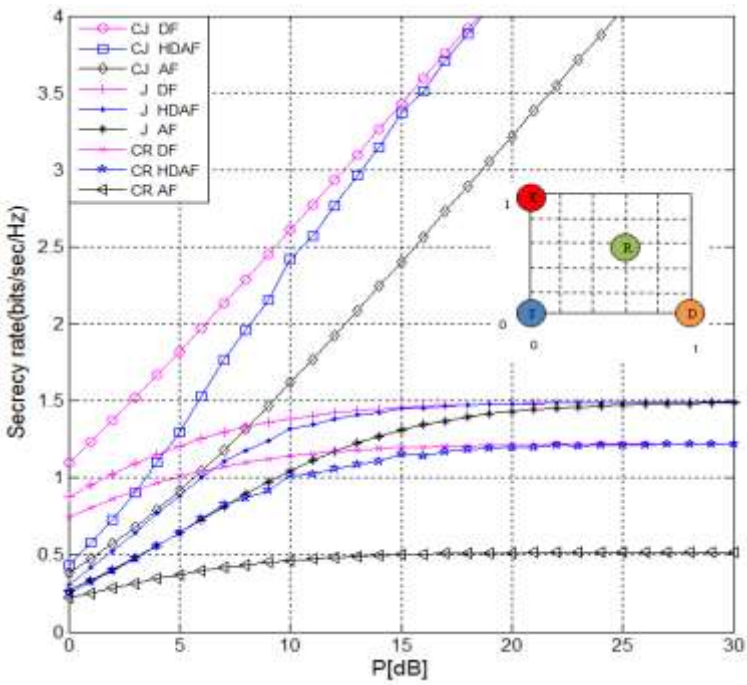
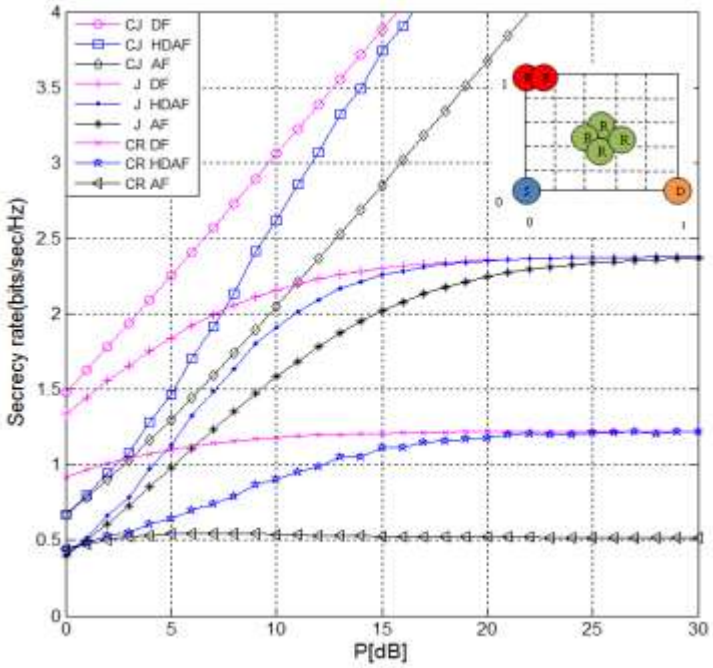


Figure 5.6 Simulation environment

The observations made from the Fig.5.7 (a) are that among the jamming and non jamming schemes, control jamming attains maximum secrecy rate. The HDAF relaying attains a secrecy rate of 3.4 bits/sec/Hz for control jamming case, 1.4 bits/sec/Hz for jamming case and 1.1 bits/sec/Hz for conventional relaying i.e without jamming case. Here the conventional relaying schemes AF and DF for control jamming case attain a secrecy rate of 2.4 bits/sec/Hz and 3.4 bits/sec/Hz respectively at a transmitted power of 15dB.



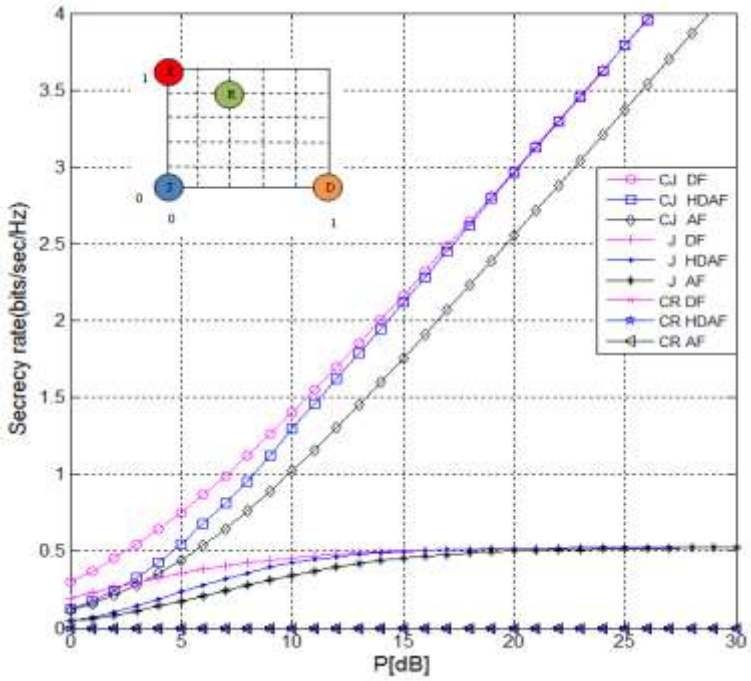
(a)



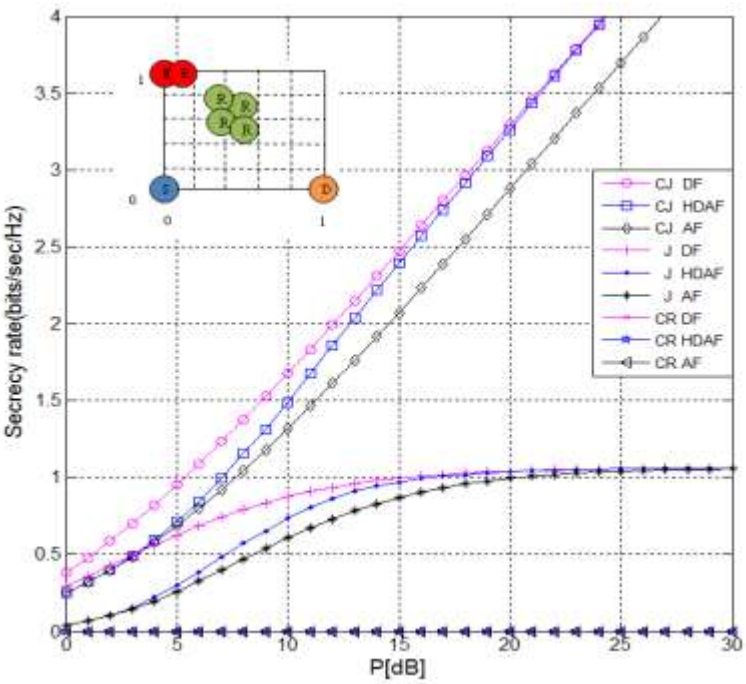
(b)

Figure 5.7 Secrecy rate versus transmitted power P for HDAF relays at middle (a) Single relay (b) Multiple relays

From Fg.5.7.(b), the four HDAF relays attain a secrecy rate of 3.8 bits/sec/Hz for control jamming case, 2.25 bits/sec/Hz for jamming case and 1.1 bits/sec/Hz for conventional relaying i.e without jamming case. Here the conventional relaying schemes AF and DF for control jamming case attain a secrecy rate of 2.8 bits/sec/Hz and 3.9 bits/sec/Hz respectively at a transmitted power of 15dB.



(a)

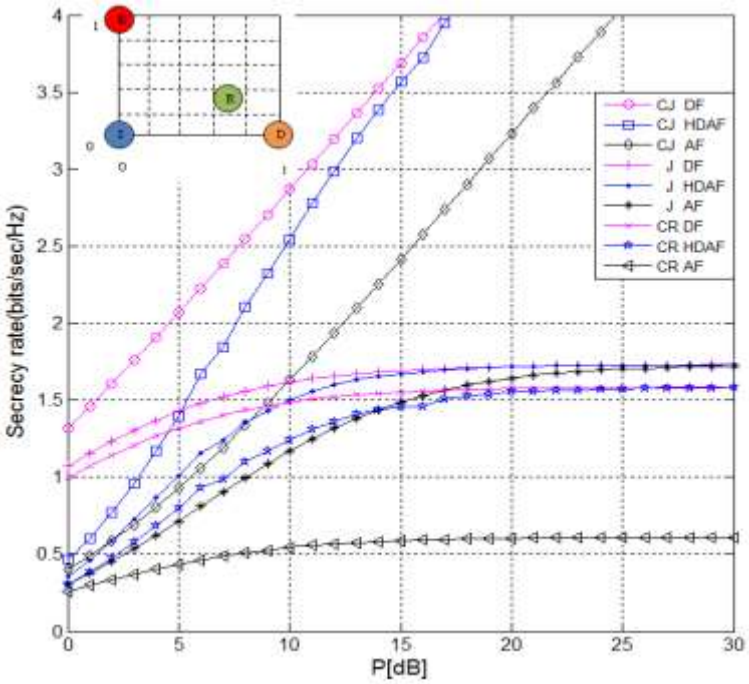


(b)

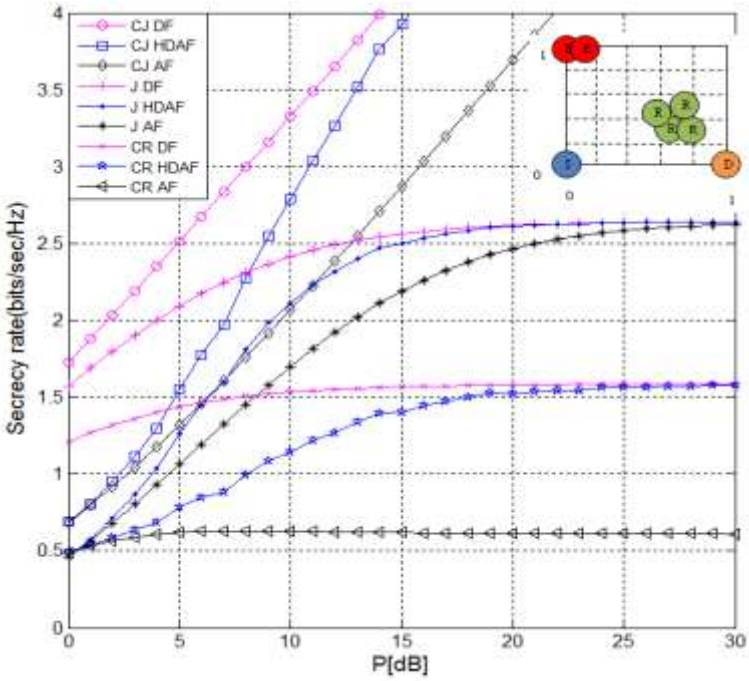
Figure 5.8 Secrecy rate versus transmitted power P when HDAF relays at close to eavesdroppers (a) Single relay (b) Multiple relays multiple eavesdroppers

The secrecy rate performance of proposed HDAF relaying for relay close to eavesdropper case is shown in Fig.5.8. (a). Here it is observed that the proposed HDAF relaying attains a secrecy rate of 2.15 bits/sec/Hz for control jamming case, 0.5 bits/sec/Hz for jamming case and nearly zero for conventional without jamming case at a transmitted power of 15dB. In this particular case (where the relay-to-eavesdropper link is strong), the performance of non jamming conventional HDAF relaying scheme is very poor. Here by confusing the eaves, jamming schemes attain considerable secrecy rate. The secrecy rate performance due to four HDAF relays when they are close to eavesdropper is shown in Fig.5.8. (b). Here it is determined that the proposed HDAF relaying scheme attains a secrecy rate of 2.5 bits/sec/Hz for control jamming case, 1 bits/sec/Hz for jamming case and nearly zero for conventional without jamming case at transmitted power of 15dB. In this particular case, (where links between relay and eaves are strong ;), the performance of HDAF relays without jamming is very poor. Here by confusing the eaves, jamming schemes attain considerable secrecy rate. In Fig.5.9 (a), the proposed HDAF relaying obtains a secrecy rate of 3.5 bits/sec/Hz for control jamming, 1.65 bits/sec/Hz for jamming and 1.5 bits/sec/Hz for conventional non jamming case. Here due to the strong link between the relay and the destination, both jamming and non jamming schemes perform better compared to all relay locations. In Fig.5.9 (b), the proposed HDAF relaying obtains

a secrecy rate of 3.8 bits/sec/Hz for control jamming, 2.4 bits/sec/Hz for jamming and 1 bits/sec/Hz for conventional non jamming case. Here due to the strong link between the relays and destination, both jamming and non jamming schemes perform better in this case compared to the remaining relay locations.



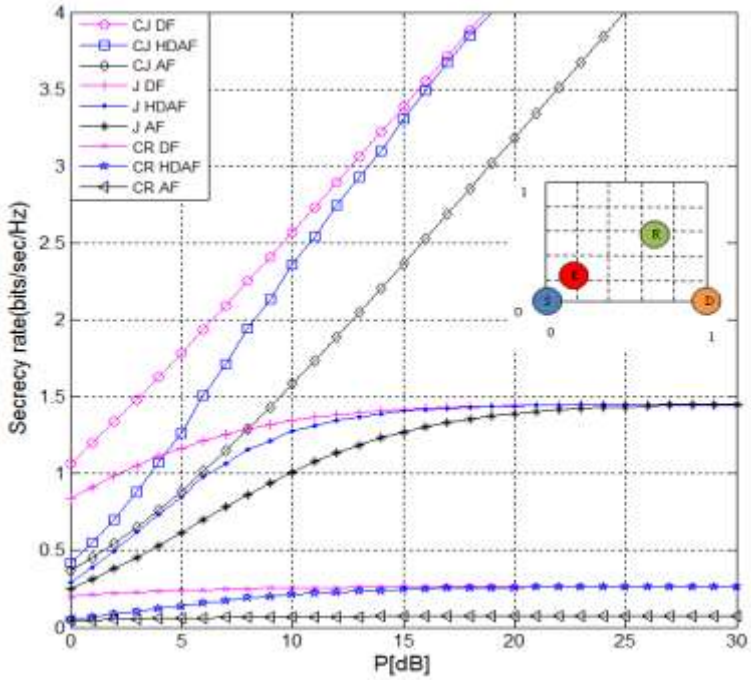
(a)



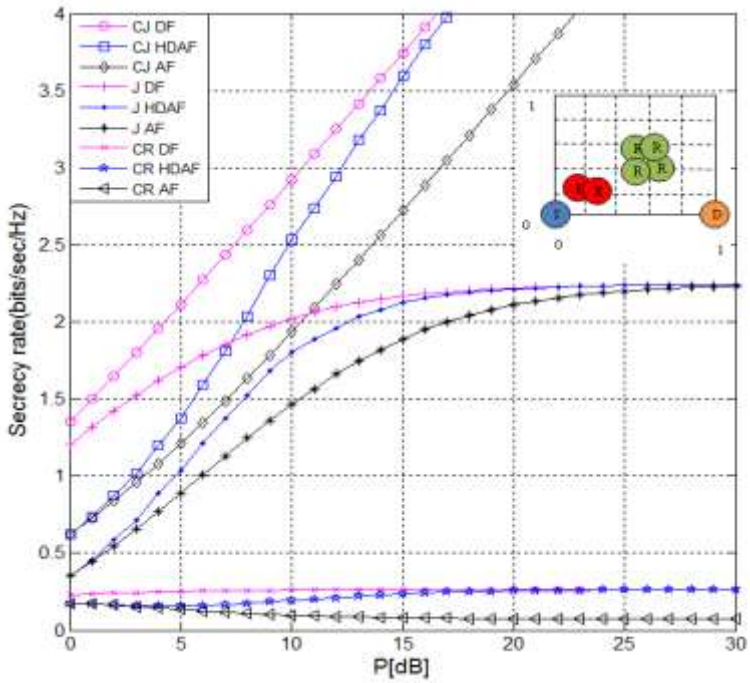
(b)

Figure 5.9 Secrecy rate versus transmitted power P when HDAF relays at close to destination (a) Single relay (b) Multiple relays multiple eavesdroppers

In Fig.5.10 (a), it is clear that both jamming and non jamming schemes attain a notable secrecy rate. Even though the eavesdropper is close to the source, there is no much impact of the evavesdropper on the secrecy due to the location of jammer is also nearer to the source. Here, the HDAF relaying obtains a secrecy rate of 3.3 bits/sec/Hz for control jamming, 1.35 bits/sec/Hz for jamming and 0.2 bits/sec/Hz for without jamming case.



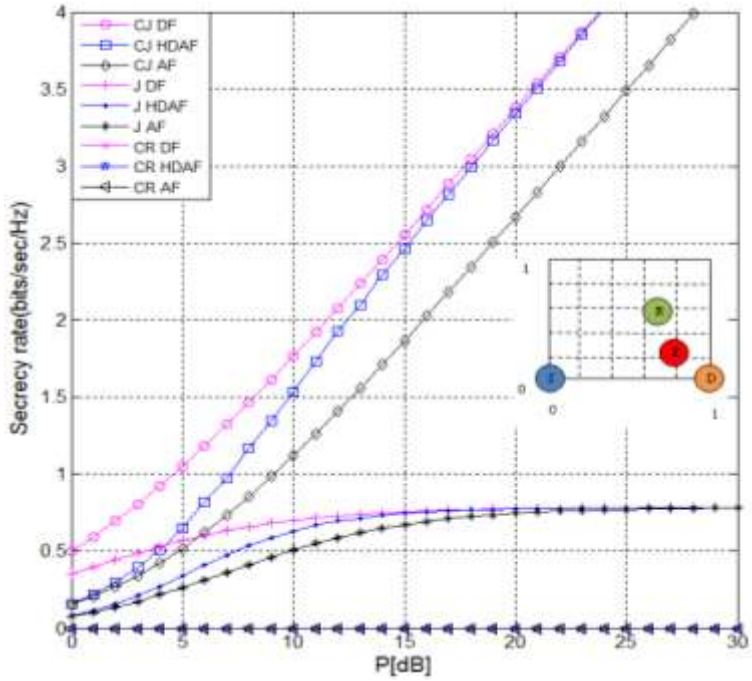
(a)



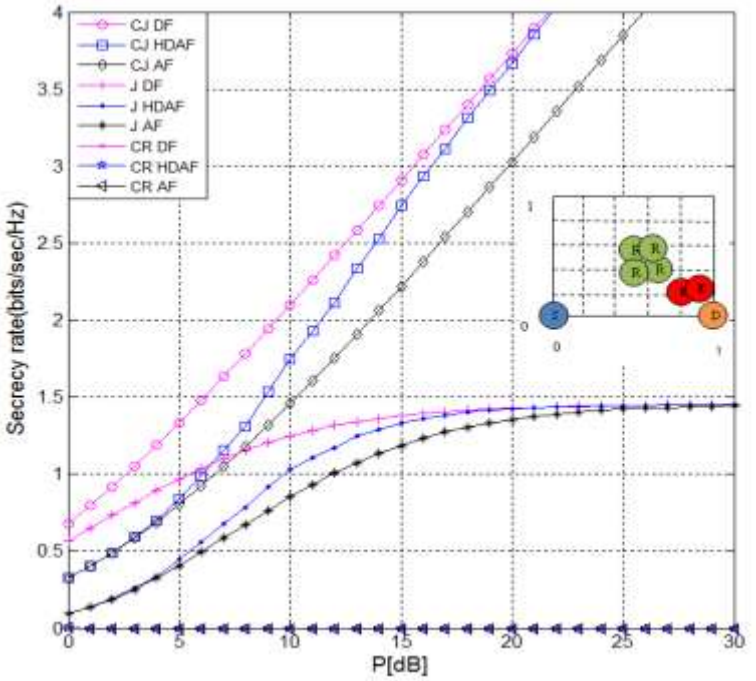
(b)

Figure 5.10 Secrecy rate versus transmitted power P when eavesdroppers are close to source (a) Single relay (b) Multiple relays multiple eavesdroppers

In Fig.5.10 (b), it is clear that both jamming and non jamming schemes attain a notable secrecy rate. Here, the HDAF relays obtains a secrecy rate of 3.6 bits/sec/Hz for control jamming, 2.2 bits/sec/Hz for jamming and a nearly zero secrecy rate for without jamming case.



(a)



(b)

Figure 5.11 Secrecy rate versus transmitted power P when eavesdroppers are close to destination (a) Single relay (b) Multiple relays multiple eavesdroppers

From Fig.5.11 (a), it is observed that the performance of the proposed HDAF relaying for non jamming case performance is very poor and obtain zero secrecy rate where as it

attains a considerable secrecy rate for the jamming cases. The proposed HDAF relaying obtains a secrecy rate of 2.4 bits/sec/Hz for control jamming and 0.7 bits/sec/Hz for jamming case. From Fig.5.11. (b), it is observed that the performance of proposed HDAF relaying for non jamming case is very poor and obtains zero secrecy rate where as it attains a considerable secrecy rate for the jamming cases. The proposed HDAF relaying obtains a secrecy rate of 2.2 bits/sec/Hz for control jamming and 0.8 bits/sec/Hz for jamming case.

The impact of the number of relays and SNR threshold on the HDAF relaying for physical layer security is analyzed in Fig.5.12 and Fig.5.13 respectively. From the Fig.5.12 (a), it is observed that as the number of HDAF relays increases, the secrecy rate decreases with equal power allocation scheme for all jamming and non jamming schemes. Fig.5.13 shows that as the SNR threshold increases, the HDAF relaying switches from DF relaying to AF relaying.

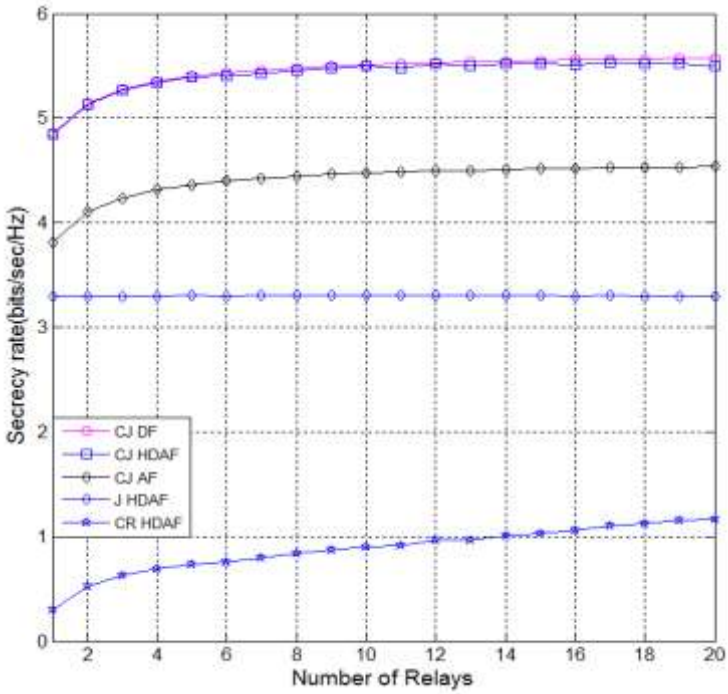


Figure 5.12 Number of relays versus secrecy rate

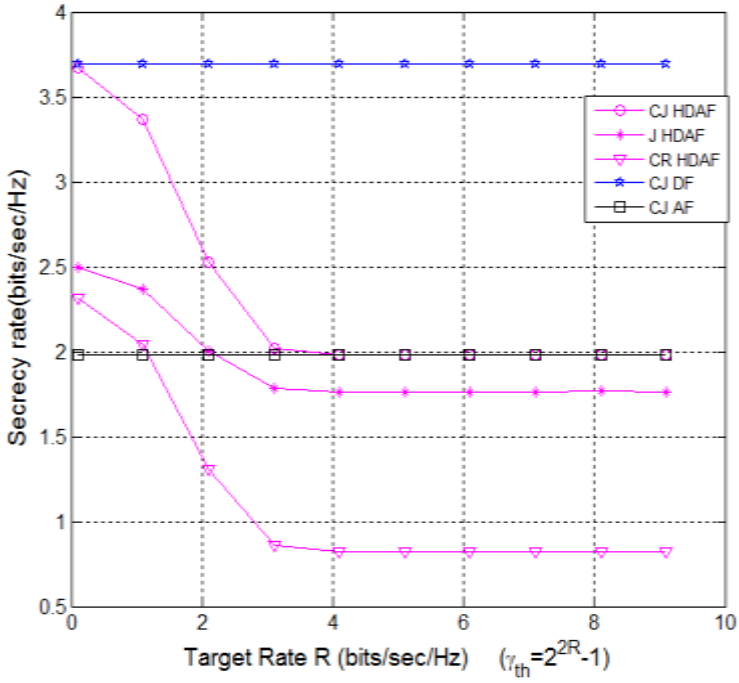
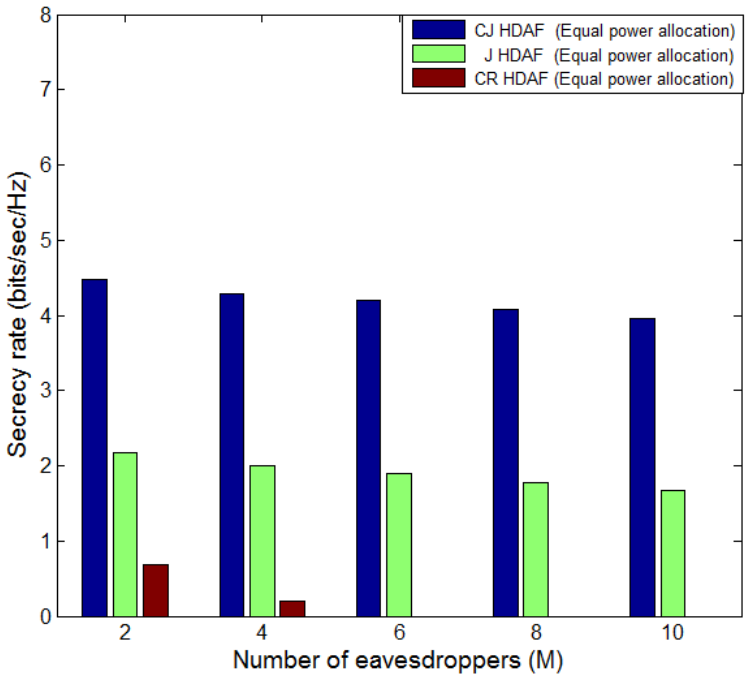
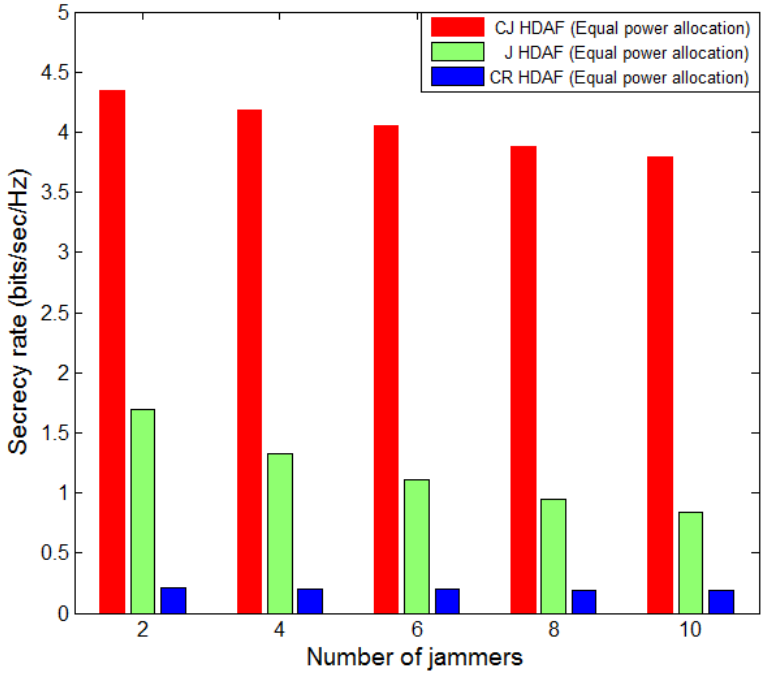


Figure 5.13 Target rate versus secrecy rate

The impact of the number of eavesdroppers and jammers on the sercey rate of four HDAF relay based wireless cooperative network for physical layer security is analyzed in both Fig 5.14 (a) and (b) respectively.



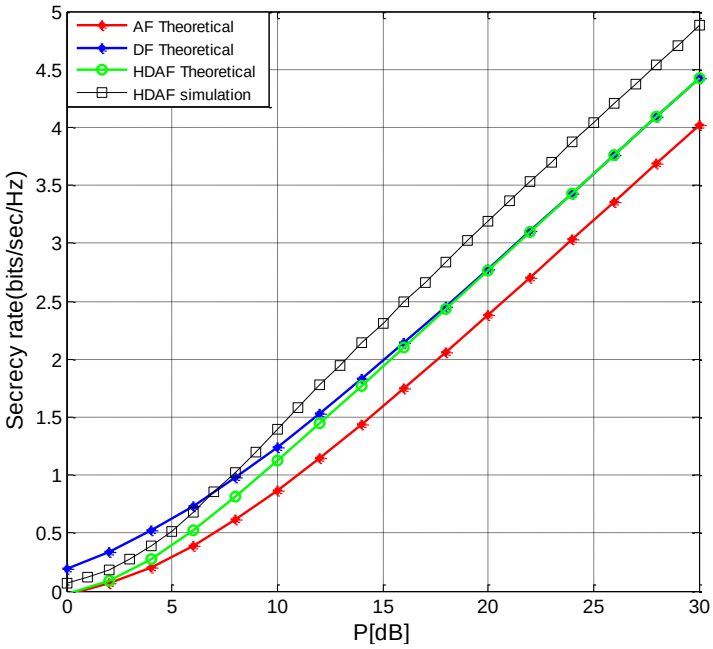
(a)



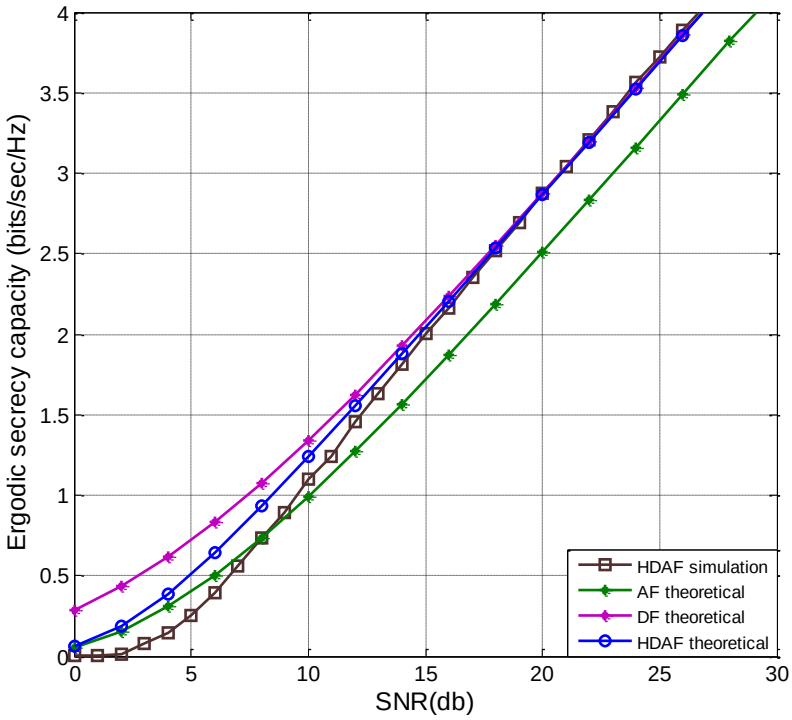
(b)

Figure 5.14 (a) Number of eavesdroppers versus secrecy rate (b) Number of jammers versus secrecy rate

From the Fig.5.14 (a), the secrecy rate decreases with increase in the number of eavesdroppers, it is due to that as the overhearing users increase, the SNR at the destination decreases. In Fig.5.14.(b) , as the number of jammers increases, the secrecy rate reduces which is due to the fact that the power allocated for jammers is decreases with increase in the number of jammers. So, the noise generated by the jammers reduces which result poor secrecy rate.



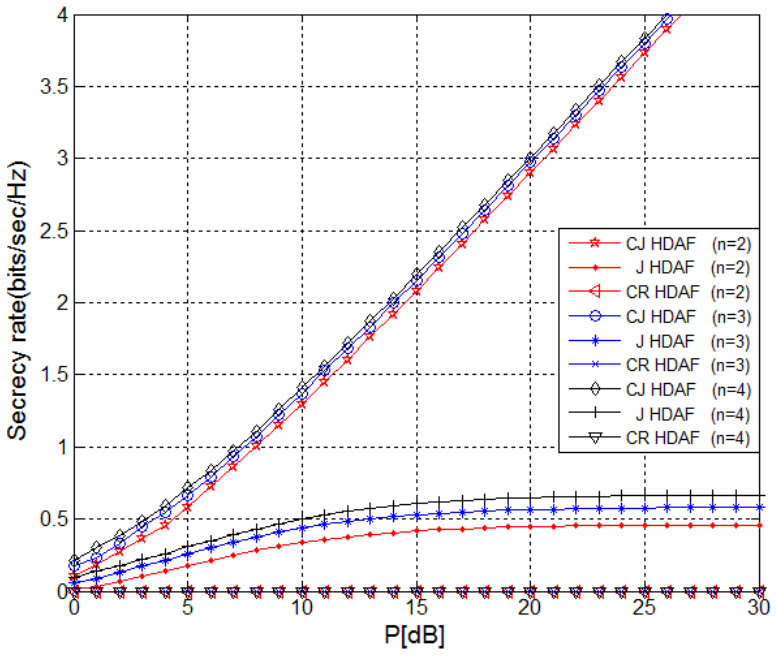
(a)



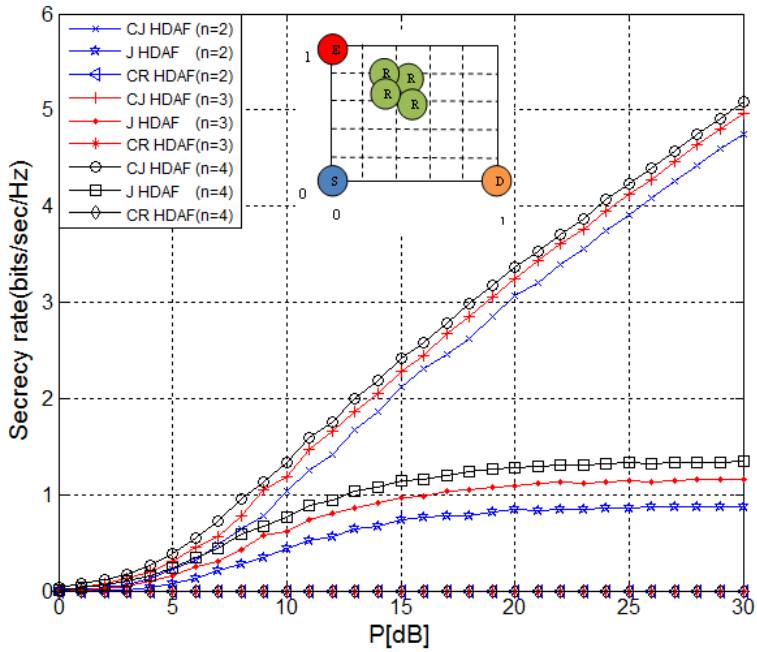
(b)

Figure 5.15 Ergodic secrecy rate (theoretical) versus SNR for fixed relay location (a) Single relay (b) Multiple relays & multiple eavesdroppers

In Fig.5.15 (a) and (b), the analytical approximation of Ergodic capacity of proposed HDAF relaying in wireless cooperative network is compared with the simulation result and also with the theoretical approximations of conventional relaying schemes. It is observed that the simulation results closely follow the analytical approximations.



(a)



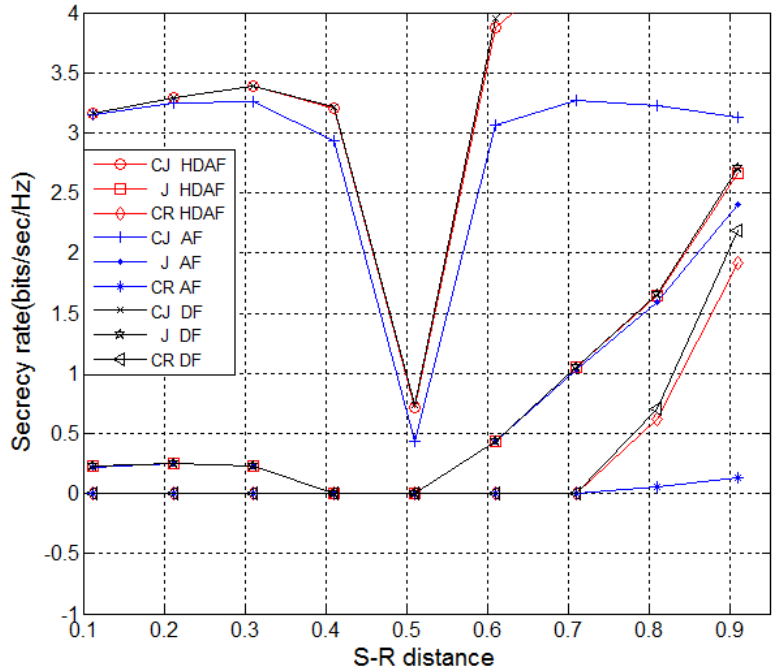
(b)

Figure 5.16 Impact of path loss exponent. Secrecy rate versus P for fixed relay location (a) Single relay (b) Multiple relays & multiple eavesdroppers

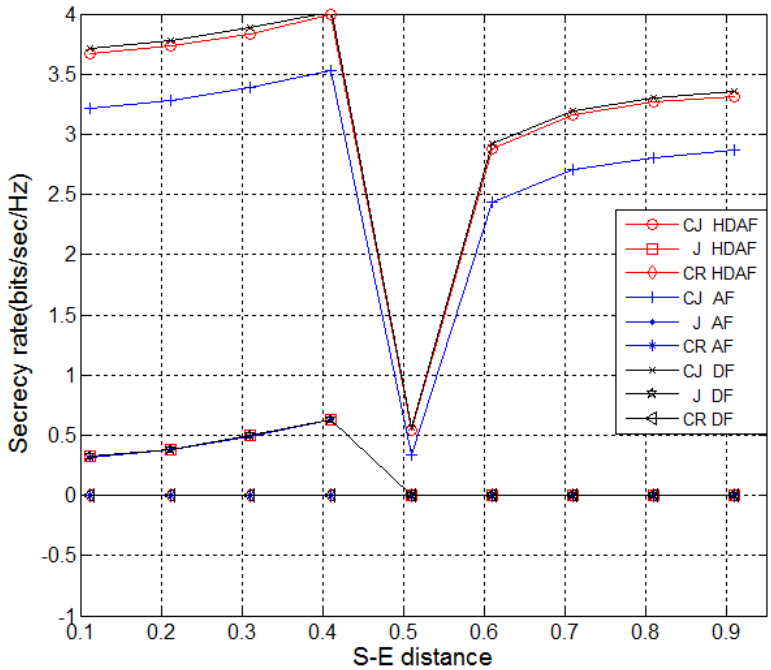
The effect of path loss on the secrecy rate of the proposed system is analyzed in Fig.5.16 (a) & (b). As the path loss exponent increases, the secrecy rate also increases for both single relay and general multi relay multiple eavesdroppers case.

5.5.1 Simulation results when the network follows linear topology

To demonstrate the effect of HDAF relaying for physical layer security, a one dimensional network model which contains a single destination pair, four HDAF relays and two eavesdroppers are placed linearly for line-of-sight communication between all the nodes. Here it is assumed that the normalized distance between source and distance is one. Firstly, the secrecy rate of HDAF relaying scheme is compared with conventional relaying schemes AF and DF for jamming and non jamming cases as the HDAF relay moves from source to the destination. From the Fig.5.17 (a), it is observed that control jamming attains higher secrecy rate compared to all other jamming and non jamming schemes. Except the case, where the relay located close to eavesdropper, all the schemes attain a non-zero secrecy rate as the relay moves from the source to the destination. In the second case, the HDAF relay is located at the middle between the source and the destination. The position of the eavesdropper is varied from 0.11 to 0.9 where the jammer is located at normalized distance of 0.4.



(a)



(b)

Figure 5.17 Secrecy rate comparisons of HDAF relays with conventional relaying schemes (a) Secrecy rate vs S-R distance (b) Secrecy rate vs S-E distance

From the Fig 5.17.(b), it is observed that HDAF relaying scheme attains a secrecy rate close to the DF relaying which outperforms the remaining jamming and non jamming (conventional relaying schemes without jamming) cases. The eavesdroppers located close-to-the source case obtains more secrecy rate compared to eavesdroppers located close-to - the destination case, it is due to the fact that the jammer is located close to the source

which weaken the eavesdropper to verhear. So, in this case jamming schemes perform better than without jamming scheme.

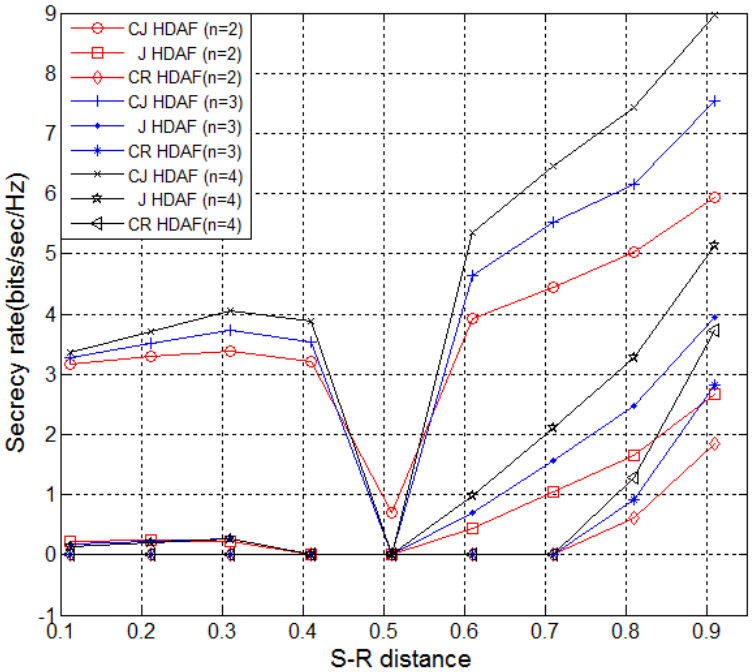
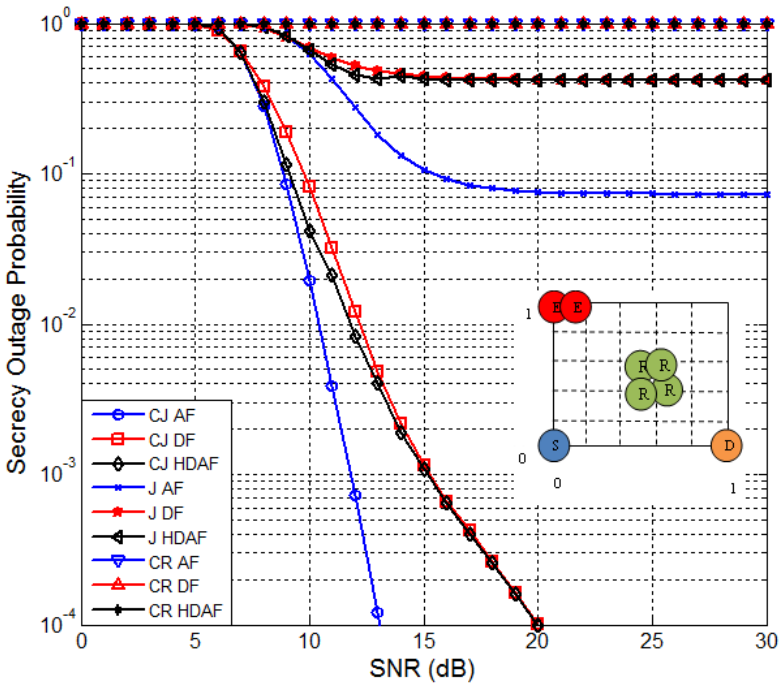


Figure 5.18 Secrecy rate versus S-R distance with path loss exponent as parameter

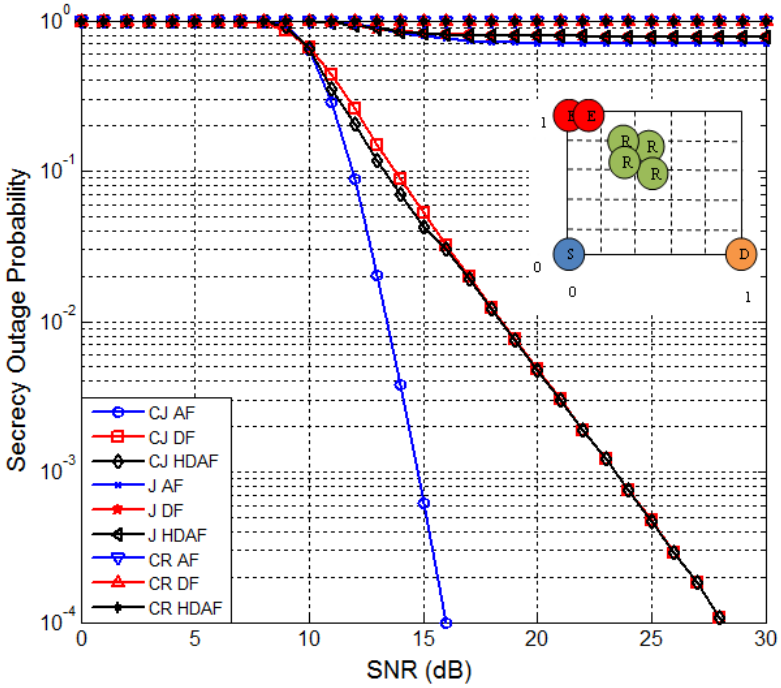
Finally, the impact of path loss exponent on the secrecy rate of the system is analyzed in Fig.5.18. The secrecy rate as a function of source-to-relay distance has plotted for different values of path loss exponent n=2, 3 & 4. The eavesdroppers are located at middle which is a normalized distance of 0.5 from the source. It is observed that the secrecy rate performance increases as the path loss exponent increases.

5.5.2 Simulation results of secrecy outage

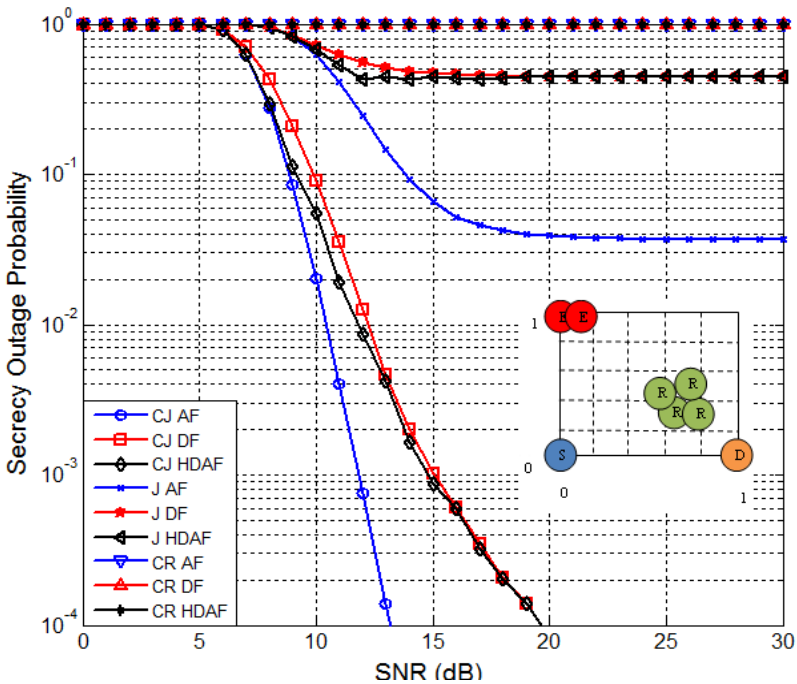
The secrecy outage of the proposed system is analyzed for three cases, relays located at middle, relays close to the source and relay close to the destination. Here, we considered the cooperative network which consists of four HDAF relays in the presence of two eavesdroppers. From Fig.5.19 (a), it is observed that the jamming schemes attain lower secrecy outage probability compared to the conventional relaying schemes without jamming case. The AF relaying attains lower secrecy outage probability compared to the DF relaying. Based on the SNR threshold (here it is assumed that R=1bits/sec/Hz), the HDAF relaying switch to operate either in the AF relaying to DF relaying mode. The secrecy outage due to control jamming outperforms the jamming and without jamming schemes.


Secrecy Outage Probability
SNR (dB)
CJ AF
CJ DF
CJ HDAF
J AF
J DF
J HDAF
CR AF
CR DF
CR HDAF
E
R
S
D

(a)


Secrecy Outage Probability
SNR (dB)
CJ AF
CJ DF
CJ HDAF
J AF
J DF
J HDAF
CR AF
CR DF
CR HDAF
E
R
S
D

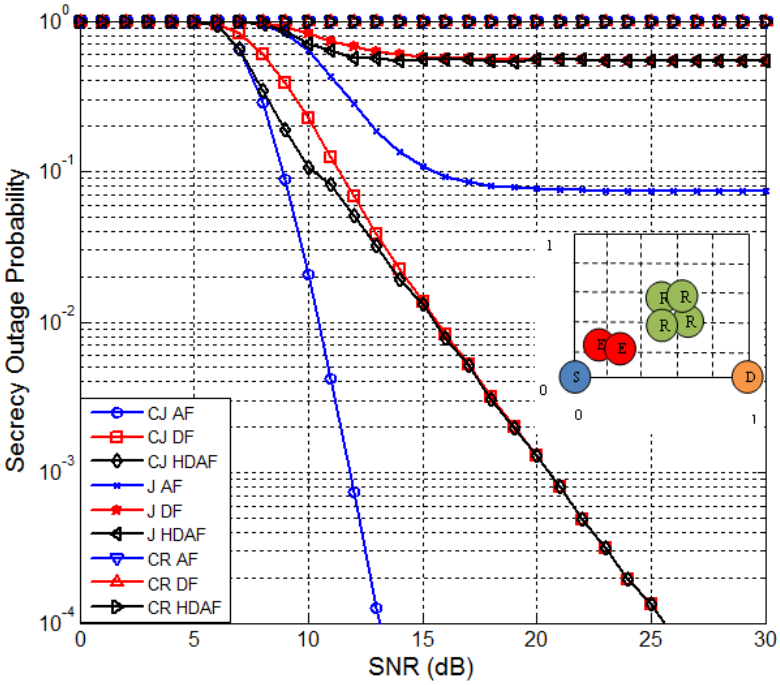
(b)



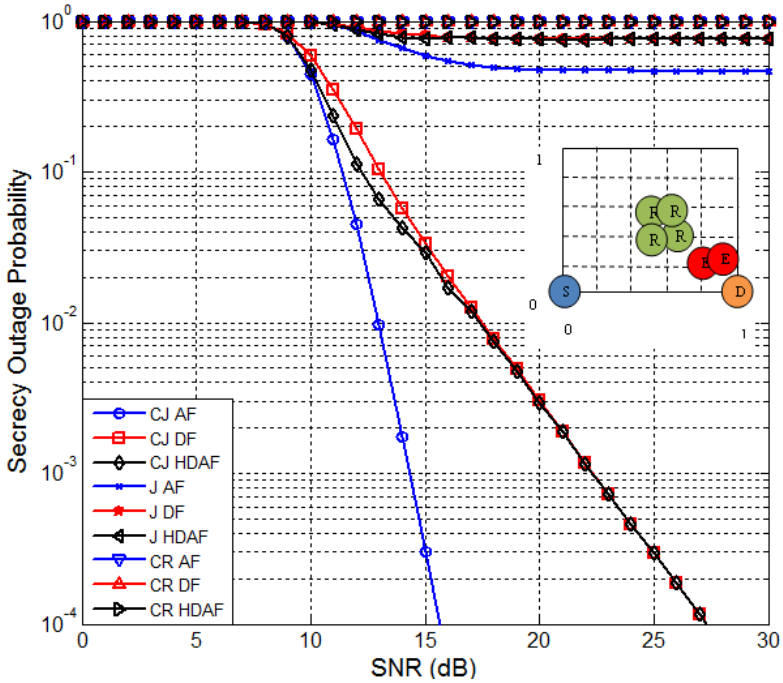
(c)

Figure 5.19 Secrecy outage probability comparison of HDAF relays with conventional relaying schemes where (a) Relays at middle (b) Relays close to the eavesdropper (c) Relays close to the destination

Fig.5.19 (b) shows the secrecy outage probability when the HDAF relays are located close-to-the eavesdropper. The control jamming outperforms the jamming and without jamming schemes. The overhearing of the relay transmission is more when the relays are located close the eavesdropper which results in poor secrecy outage compare to the remaing relay locations. Fig.5.19 (c) shows the secrecy outage probability when the HDAF relays are located close to the destination. It is observed that the jamming schemes perform better than without jamming case. The secrecy outage performance of relays close to the destination out performs remaining two relay locations (relays close to source and relay close to eavesdropper). The sercey outage due to HDAF relays with control jamming obtain a secrecy outage of $10^{-3.5}$ where the conventional relaying schemes AF and DF with control jamming attain secrecy outage of 10^{-4} and $10^{-3.5}$ respectively. HDAF relays with jamming obtain a secrecy outage of $10^{-0.2}$ where the conventional relaying schemes AF and DF with control jamming attain secrecy outage of $10^{-1.5}$ and $10^{-0.2}$ respectively. It is due to the fact that the relays are located close to destination and jammer located close to source, reduces the impact of eavesdropper on relay transmission. Fig.5.20. (a) and (b) show the impact of eavesdropper location on the secrecy outage probability.



(a)



(b)

Figure 5.20 Secrecy outage probability comparison of HDAF relays with conventional relaying schemes where (a) The eavesdropper are located close to the source (b) The eavesdroppers are located close to the destination

The observation made from the Fig.5.20 (a) are that the jamming scheme performs better than the without jamming case. Even though the eavesdroppers are located close to the source due to the fact that the jammer also located close to the source reduces the impact of eavesdroppers on the secrecy transmission. From Fig.5.20 (b), it is confirmed that all relaying schemes with control jamming outperform than the jamming and without

jamming cases. All relaying schemes with jamming attain poor outage performance than control jamming and better performance than without jamming case. It is because of the location of eavesdroppers are close to the destination where as the location of jammer is close to the source, the overhearing of eavesdroppers is more.

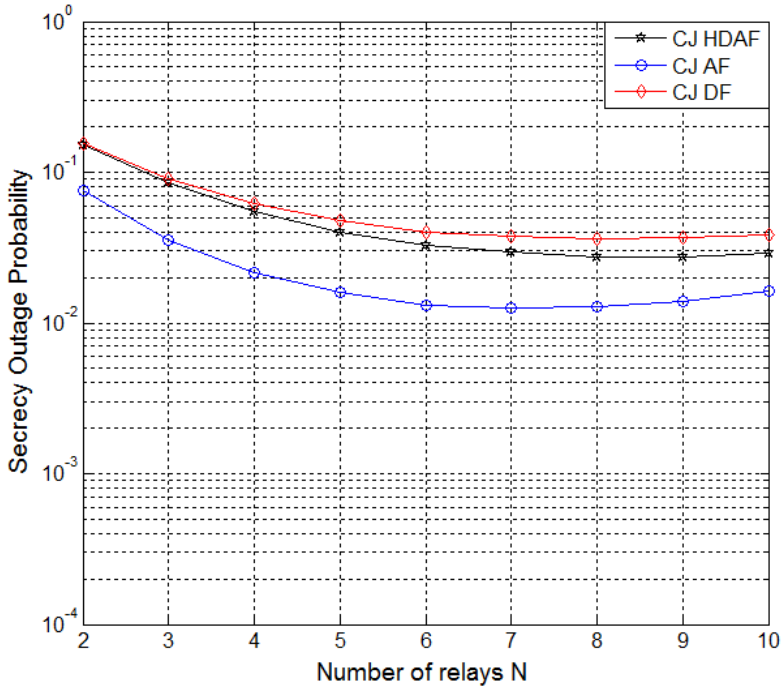
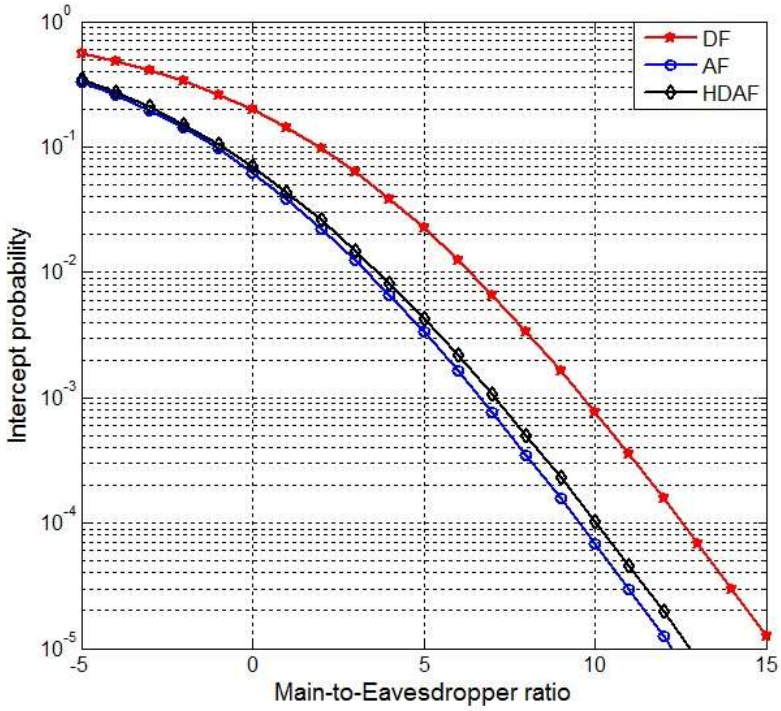


Figure 5.21 Secrecy outage probability versus Number of relays

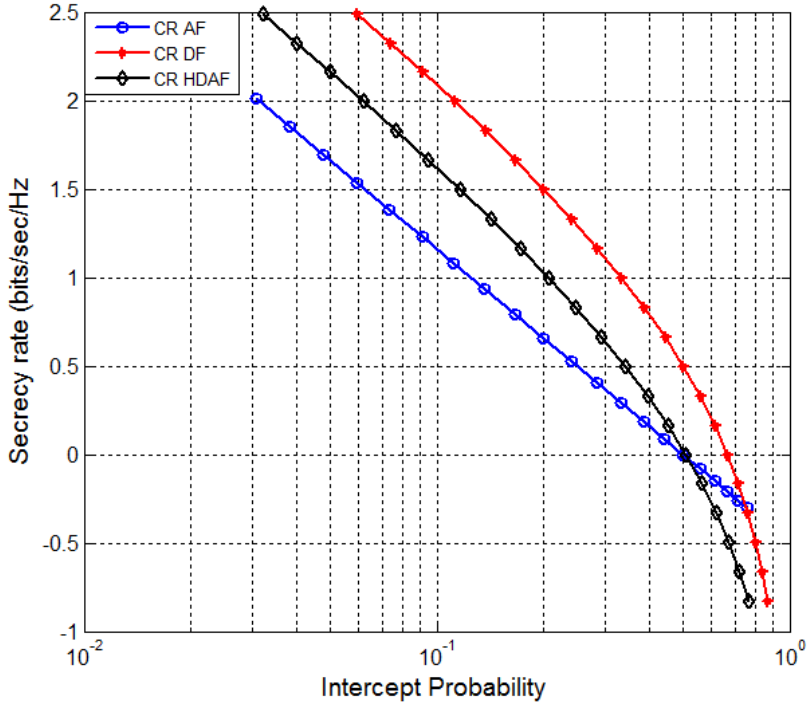
The secrecy outage probability versus number of relays is shown in Fig.5.21. It is observed that as the number of HDAF relays increases the outage probability reduces for all jamming and without jamming cases.

5.5.3 Intercept probability

The intercept probability performance of the proposed network is analyzed when the relay are located at middle and shown in Fig.5.22. Here the assumptions made are that main-to-eavesdropper ratio is $\lambda_{de} = \sigma_{sd}^2 / \sigma_{se}^2$; $\alpha_{r_i d} = \frac{\sigma_{r_i d}^2}{\sigma_{sd}^2}$ & $\alpha_{r_i e} = \frac{\sigma_{r_i e}^2}{\sigma_{se}^2}$; $for\ i = 1,2,...,N$. From the Fig.5.22 (a), it is observed that the AF relaying outperforms the DF and HDAF relaying schemes, where the HDAF relaying provides nearly close performance to AF relaying.



(a)

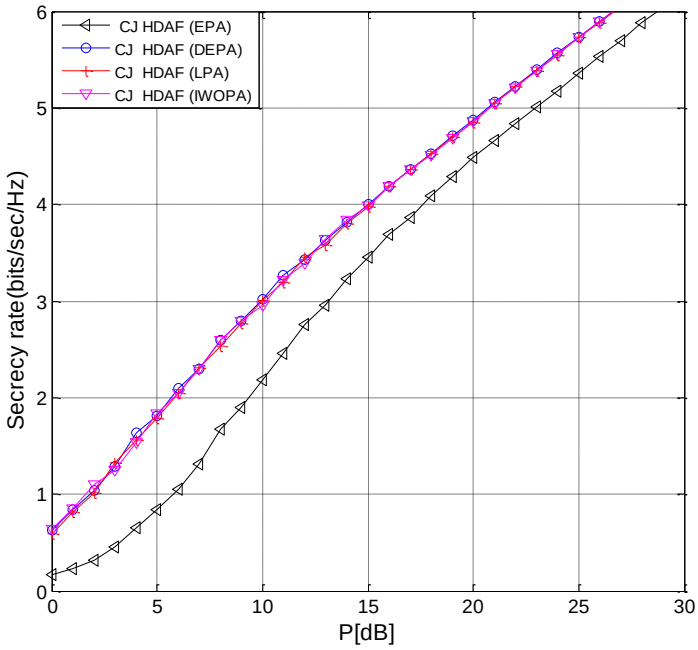


(b)

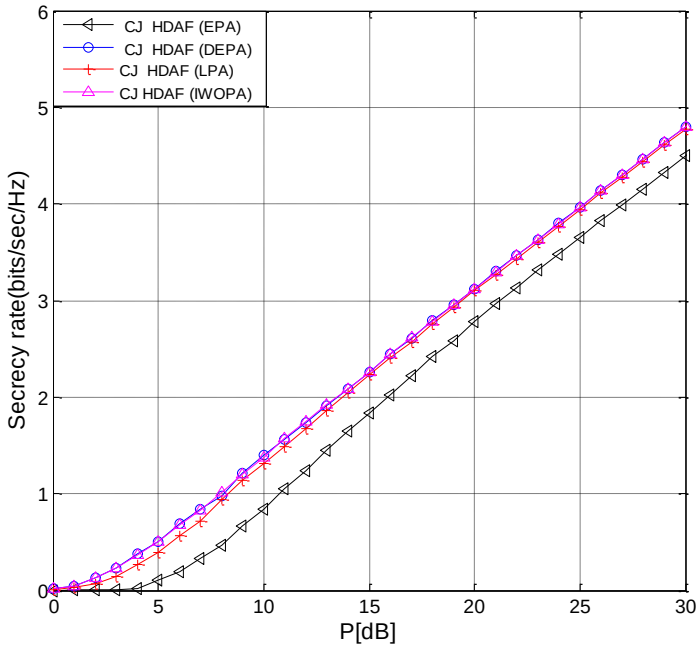
Figure 5.22 (a) Secrecy intercept probability vs MER where the relays are located at middle (b) Secrecy rate vs intercept probability trade off

The tradeoff between the secrecy rate and intercept probability are analyzed analytically and shown in Fig.5.22. (b). The observations made are that DF relays performs better than AF and HDAF in terms of secrecy rate where as AF relays performs better than DF and HDAF in terms of intercept probability. It is confirmed that SNR based HDAF relaying is

better option for physical layer security in multi relay wireless cooperative network than the conventional relaying schemes in terms of both secrecy rate and outage probability.



(a)

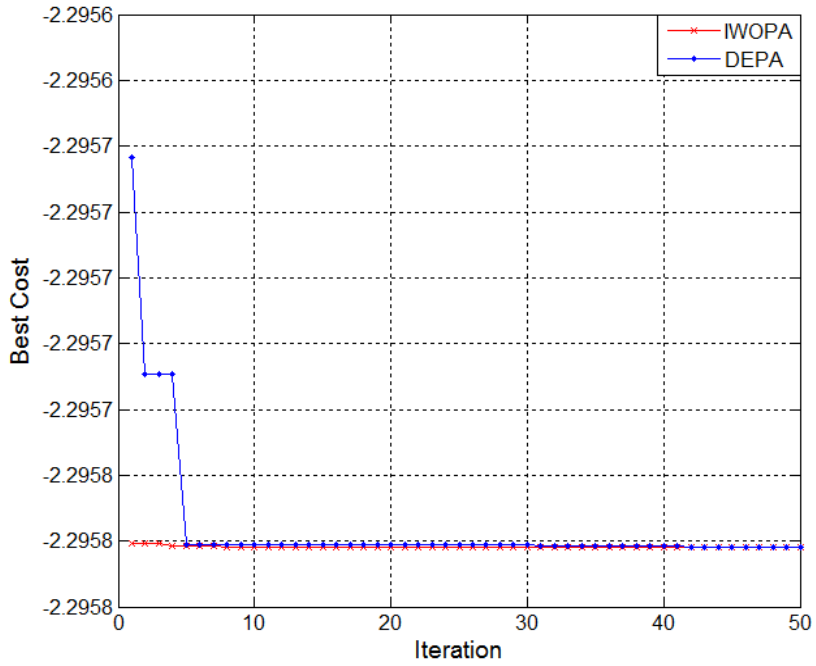


(b)

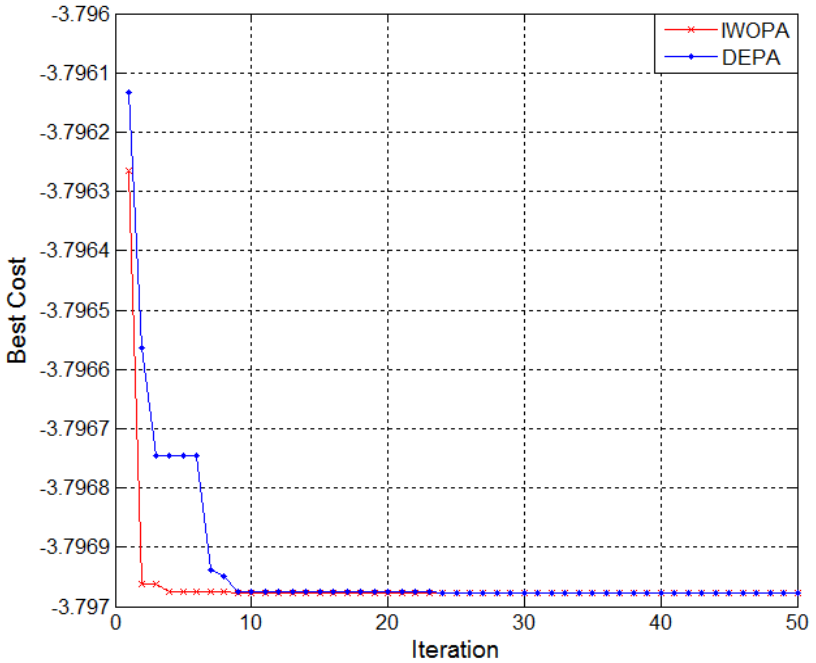
Figure 5.23 Secrecy rate versus transmitted power (a) Relay at middle (b) Relay close to eavesdropper

The performance of proposed DE based power allocation is compared with the conventional equal power allocation for the cases when the relay at middle and when the relay close- to-eaves are shown in Fig.5.23 (a) and (b) respectively. From the Fig.5.23 (a),

the proposed DE based power allocation achieves a gain of 1.39 for control jamming, 1.9 for jamming and 1 for conventional relaying without jamming over the equal power allocation at transmitted power of 15dB. In Fig.5.23 (b), when the relay close to eaves dropper, the proposed DE based power allocation provides a gain of 1.2 for control jamming and nearly again of 2 for jamming case over the equal power allocation case at transmitted power of 15dB.



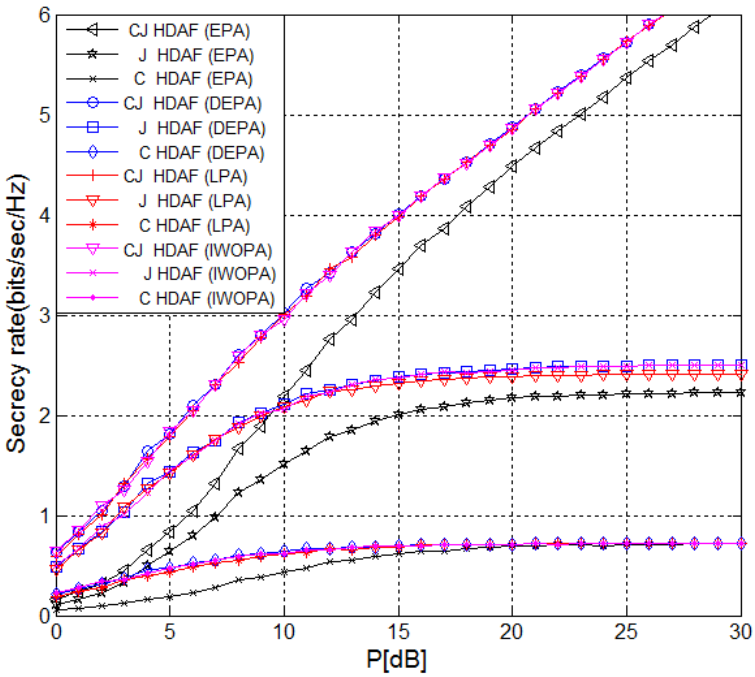
(a)



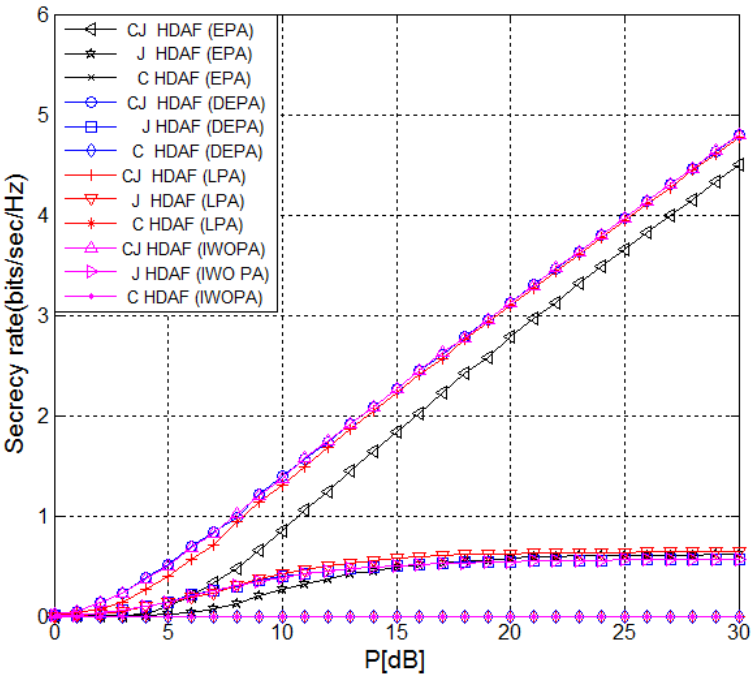
(b)

Figure 5.24 Convergence analysis of proposed power allocation schemes when HDAF relay operate in (a) AF mode (b) DF mode at a SNR of 20dB

From the Fig.5.24, it is observed that IWO based power allocation converges fast compared to the DE based power allocation scheme. The performance of the proposed DE based power allocation is compared with the conventional equal power allocation for the cases where the relays are located at the middle and when the relays are located close- to-the eavesdropper are shown in Fig.5.25 (a) and (b) respectively.



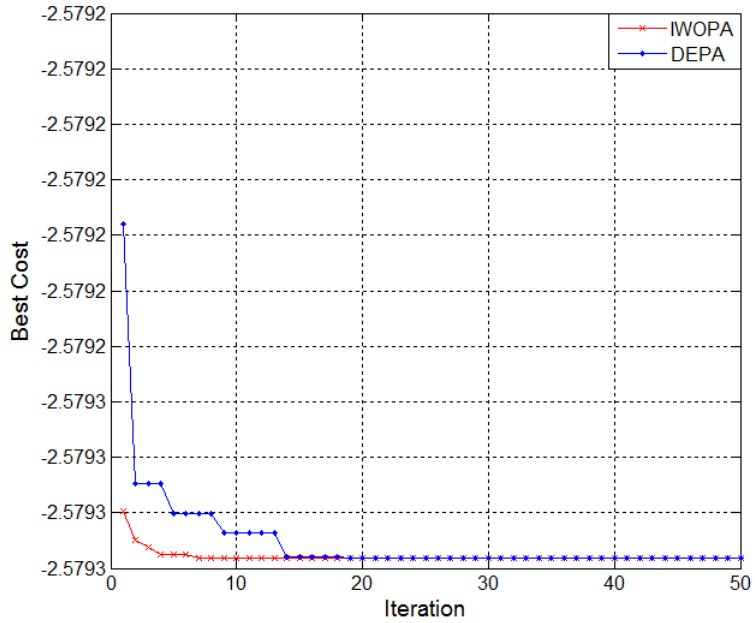
(a)



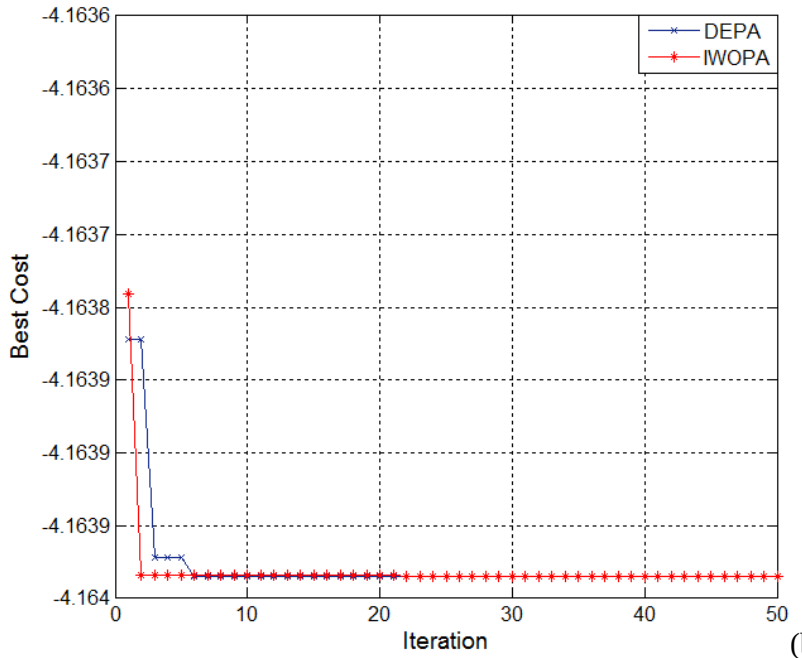
(b)

Figure 5.25 Secrecy rate versus transmitted power P (a) Relays at middle (b) Relays close to the eavesdropper

From the Fig.5.25 (a), the proposed DE based power allocation achieves a gain of 1.39 for control jamming, 1.9 for jamming and 1 for conventional relaying without jamming over the equal power allocation at transmitted power of 15dB. In Fig.5.25 (b), when the relay close to eavesdropper, the proposed DE based power allocation provides a gain of 1.2 for control jamming and nearly again of 2 for jamming case over the equal power allocation case at transmitted power of 15dB. Finally the effectiveness of proposed DE based power allocation is verified using convergence analysis which is shown in Fig.5.26.



(a)



(b)

Figure 5.26 Convergence analyses of proposed schemes for multi HDAF relay case (a) when operate in AF mode (b) when operate in AF mode

The observations made from the Figure 5.26 are that the IWO algorithm based power allocation converges faster than the DE based power allocation scheme. The secrecy rate for a cooperative network with jamming and non jamming schemes for single and multi HDAF relays are shown in Table 5-3. It is observed that as the number of relays increases secrecy rate also increased.

Table 5-3 Secrecy rate for single and multiple number of HDAF relay based cooperative network

Relay & Eavesdropper location	Relaying scheme	Secrecy rate (bits /sec/Hz) (N=1)			Secrecy rate (bits /sec/Hz) (N=4)		
		CJ	J	CR	CJ	J	CR
Middle	DF	3.45	1.45	1.25	3.9	2	1.3
	HDAF	3.4	1.4	1.2	3.8	2.25	1.25
	AF	2.4	1.35	0.5	2.8	2	0.65
Relays close to eavesdropper	DF	2.25	0.5	0	2.5	1	0
	HDAF	2.15	0.5	0	2.4	0.95	0
	AF	1.8	0.4	0	2.1	0.8	0
Relays close to destination	DF	3.7	1.7	1.6	4.1	2.6	1.65
	HDAF	3.6	1.65	1.4	3.9	2.5	1.45
	AF	2.45	1.5	0.6	2.8	2.2	0.65
Eaves close to source	DF	3.4	1.4	0.25	3.75	2.25	0.25
	HDAF	3.35	1.35	0.2	3.65	2.2	0.2
	AF	2.4	1.25	0.1	2.75	1.85	0.1
Eaves close to destination	DF	2.6	1.75	0	2.8	1.35	0
	HDAF	2.5	1.7	0	2.75	1.2	0
	AF	1.8	1.65	0	2.25	1.1	0

The optimized relay and jammer powers for four HDAF relay based wireless cooperative network with control jamming using both DE algorithm and Lagrange multiplier method are given in Table 5-4 & 5-5 for the cases relays located at middle and located close to the source. It is observed that there is change in jammers than relay power.

Table 5-4 The optimized transmit powers at the nodes when the relay located at middle

Four HDAF relays are located at middle in between the source and the destination and the locations of the nodes at a transmitted power $P_t = 15\,dB$ are given as follows Source $S = \{0,0\}$, Eavesdropper $E = \{0,1\}$, Destination $D = \{1,0\}$, Jammer $J = \{0.2,0.8\}$, Relays $R = \{0.7,0.3\}$			
Power allocation	Source power P_s	Each relay power P_i	Jammer power P_j
EPA	2.5	2.5	2.5
DEPA	1.7783	2.9181	0.2069
LPA	1.7783	2.7472	0.3778

Table 5-5 The optimized transmit powers at the nodes when the relay located closed to eavesdropper

Four HDAF relays are located at middle in between the source and the destination and the locations of the nodes at a transmitted power $P_t = 15\,dB$ are given as follows Source $S = \{0,0\}$, Eavesdropper $E = \{0,1\}$, Destination $D = \{1,0\}$, Jammer $J = \{0.2,0.8\}$, Relays $R = \{0.4,0.8\}$			
Power allocation	Source power P_s	Each relay power P_i	Jammer power P_j
EPA	2.5	2.5	2.5
DEPA	1.7783	2.2956	0.8294
LPA	1.7783	2.6184	0.5066

5.6 Summary

The performance of SNR based HDAF multi relay wireless cooperative network providing physical layer secrecy in terms of performance parameters such as secrecy rate, secrecy outage probability and intercept probability are studied in detail. Here, the comparisons are made for the proposed HDAF relaying schemes with both the conventional relaying schemes AF and DF.Among the conventional relaying schemes, DF relays achieve more secrecy rate than the AF and HDAF relaying schemes, whereas according to the secrecy outage probability and intercept probability, AF relays performs better than the DF relays. Based on the tradeoff between the secrecy and intercept probability, SNR based HDAF relaying proves to be a better option from reliability and security. The simulation study results demonstrated that the jamming schemes are effective for scenarios with strong eavesdroppers link. The worst secrecy rate for all jamming and without jamming cases is obtained when the relays are located close to the eavesdropper and also when the eavesdroppers are located close to the destination. As the number of eavesdroppers and jammers increases, the performance of the system degrades. The relaying schemes are in-efficient in without jamming case. Jamming schemes are preferred as the jammers have the ability to confuse the eavesdropper by noise forwarding. The secrecy performance improves significantly. Among all, the control jamming attains more secrecy rate and better outage performance as the destination has the knowledge of jamming noise prior. Finally, from the all the simulation study results and the tradeoff between secrecy rate and intercept probability, it is concluded that the HDAF relaying is a better option than than the conventional relaying schemes such as AF and DF in terms of both the secrecy rate and outage performance. In addition, propoer relay and jammer power allocation schemes

are proposed for single and multi HDAF relay based wireless cooperative network with controlled jamming help to enhance the secrecy performance using evolutionary algorithms and Lagrange multiplier algorithm. These proposed schemes are compared with the conventional equal power allocation scheme for both jamming and non jamming cases. It is demonstrated that these proposed power allocation schemes outperform the equal power allocation scheme in terms of secrecy performance.

5.7 Appendix

A1:

The analysis of secrecy rate for this conventional HDAF relaying scheme when operate in AF relay mode without jamming in the presence of eaves dropper is given as follows

$$C_{AF}^{S} = 0.5*\log_2(1+\gamma_D^S) - 0.5*\log_2(1+\gamma_E^S) \tag{5.42}$$

The received signal at the ith HDAF relay is represented as by $y_{sr_i} = \sqrt{P_s}h_{sr_i}x + n_{sr_i}$;

The received signal from the ith HDAF relay at the destination is given by

$$\begin{aligned} y_{r_id} &= \beta_i h_{r_id}\left(\sqrt{P_s}h_{sr_i}x + n_{sr_i}\right) + n_{r_id} \\ &= \underbrace{\beta_i\sqrt{P_s}h_{sr_i}h_{r_id}x}_{signalcomponent} + \underbrace{\beta_i h_{r_id}n_{sr_i} + n_{r_id}}_{noisecomponent} \end{aligned} \tag{5.43}$$

The signal to noise ratio at the destination when the ith HDAF relay operate in AF mode

$$\gamma_{D_i}^S = \frac{\beta_i^2 P_s\left|h_{sr_i}\right|^2\left|h_{r_id}\right|^2}{\left(\beta_i^2\left|h_{r_id}\right|^2+1\right)N_o}$$; By substituting $\beta_i = \sqrt{\frac{P_i}{P_S\left|h_{sr_i}\right|^2 + N_o}}$; $N_o = 1$;

$$\gamma_{D_i}^S = \frac{P_sP_i\left|h_{sr_i}\right|^2\left|h_{r_id}\right|^2}{P_s\left|h_{sr_i}\right|^2 + P_r\left|h_{r_id}\right|^2 + 1} \tag{5.44}$$

The signal to noise ratio at the destination due to the N number of HDAF relays operate in AF mode is $\gamma_D^S = \sum_{i=1}^{N}\gamma_{D_i}^S = \sum_{i=1}^{N}\frac{P_sP_i\left|h_{sr_i}\right|^2\left|h_{r_id}\right|^2}{P_s\left|h_{sr_i}\right|^2 + P_i\left|h_{r_id}\right|^2 + 1}$ (5.45)

The signal to noise ratio at the eavesdropper also given by

$$\gamma_E^S = \sum_{i=1}^{N}\sum_{m=1}^{M}\frac{P_sP_i\left|h_{sr_i}\right|^2\left|h_{r_ie_m}\right|^2}{P_s\left|h_{sr_i}\right|^2 + P_i\left|h_{r_ie_m}\right|^2 + 1} \tag{5.46}$$

By substituting values of γ_D^S and γ_E^S in eq.(a1),

we get

$$C_{AF}^S = \left(0.5 * log_2 \left(1 + \sum_{i=1}^{N} \frac{P_s P_i \left| h_{sr_i} \right|^2 \left| h_{r_i d} \right|^2}{P_s \left| h_{sr_i} \right|^2 + P_i \left| h_{r_i d} \right|^2 + 1} \right) - 0.5 * log_2 \left(1 + \sum_{i=1}^{N} \sum_{m=1}^{M} \frac{P_s P_i \left| h_{sr_i} \right|^2 \left| h_{r_i e_m} \right|^2}{P_s \left| h_{sr_i} \right|^2 + P_i \left| h_{r_i e_m} \right|^2 + 1} \right) \right)^+ \tag{5.47}$$

A2:

The analysis of secrecy rate for this conventional HDAF relaying scheme in multi relay wireless cooperative network with a jammer in the presence of eaves dropper is given as follows

Derivation for $C_D^J(R, J)$ with jamming

The received signal at the destination is the summation of signals from both i^{th} relay and jammer is given by $y_{d_i} = y_{r_i d} + y_{jd}$ (5.48)

where

$$y_{r_i d} = \beta_i h_{r_i d} y_{sr_i} + n_{r_i d} \,;\, y_{jd} = \sqrt{P_j} h_{jd} x_1 + n_{jd}$$

$$y_{d_i} = \beta_i h_{r_i d} \left(\sqrt{P_s} h_{sr_i} x + n_{sr_i} \right) + n_{r_i d} + \sqrt{P_j} h_{jd} x_1 + n_{jd}$$

$$= \beta_i \sqrt{P_s} h_{sr_i} h_{r_i d} x + \beta_i h_{r_i d} n_{sr_i} + n_{r_i d} + n_{jd} + \sqrt{P_j} h_{jd} x_1$$

$$= \underbrace{\beta_i \sqrt{P_s} h_{sr_i} h_{r_i d} x}_{signal component} + \underbrace{\sqrt{P_j} h_{jd} x_1}_{jamming\ component} + \underbrace{\beta_i h_{r_i d} n_{sr_i} + n_{r_i d} + n_{jd}}_{noise component n_d} \tag{5.49}$$

Here the equivalent noise at the destination n_d is a zero mean complex Gaussian random variable with a variance N_d which is given by

$$N_{d_i} = (\beta_i h_{r_i d} + 2)\, N_o$$

The signal to noise ratio at the destination due to i^{th} relay for the jamming case is defined as $\gamma_{D_i}^J = \dfrac{\left| \beta_i \sqrt{P_s} h_{sr_i} h_{r_i d} \right|^2}{P_j \left| h_{jd} \right|^2 + Nd_i}$;

By substituting

$$\beta_i = \sqrt{\frac{P_i}{P_S \left| h_{sr_i} \right|^2 + N_o}} \,;\, N_o = 1;$$

$$\gamma_D^J = \sum_{i=1}^{N} \gamma_{D_i}^J = \sum_{i=1}^{N} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i d}\right|^2}{P_s \left|h_{sr_i}\right|^2 \left(2 + P_j \left|h_{jd}\right|^2\right) + P_i \left|h_{r_i d}\right|^2 + P_j \left|h_{jd}\right|^2 + 2} \tag{5.50}$$

The channel capacity of the source to destination link via HDAF relay in AF mode with jamming is given by

$$C_D^J = 0.5 * \log 2\left(1 + \gamma_D^J\right) = \left(0.5 * log_2\left(1 + \sum_{i=1}^{N} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i d}\right|^2}{P_s \left|h_{sr_i}\right|^2 \left(2 + P_j \left|h_{jd}\right|^2\right) + P_i \left|h_{r_i d}\right|^2 + P_j \left|h_{jd}\right|^2 + 2}\right)\right) \tag{5.51}$$

Further, the signal to noise ratio at the eaves dropper γ_E^J also obtained in the same way and with that

$$C_E^J = 0.5 * \log 2\left(1 + \gamma_E^J\right)$$

$$= \left(0.5 * log_2\left(1 + \sum_{i=1}^{N} \sum_{m=1}^{M} \frac{P_s P_i \left|h_{sr_i}\right|^2 \left|h_{r_i e_m}\right|^2}{P_s \left|h_{sr_i}\right|^2 \left(2 + P_j \left|h_{je}\right|^2\right) + P_i \left|h_{r_i e}\right|^2 + P_j \left|h_{je_m}\right|^2 + 2}\right)\right) \tag{5.52}$$

Finally, the secrecy rate is obtained as $C_{AF}^J = C_D^J(R, J) - C_E^J(R, J)$

A3:

The secrecy rate of HDAF relaying with control jamming is the difference of the C_D^{CJ} and C_E^{CJ}.

$$C_{AF}^{CJ} = \left(C_D^{CJ}(R, J) - C_E^{CJ}(R, J)\right)^+ \tag{5.53}$$

In control jamming, the destination knows about the jamming nodes and the eavesdropper is unaware of it. Hence only destination can decode the jamming signal but not eavesdropper. So here $C_D^{CJ}(R, J)$ is same as Eq. (5.45) and $C_E^{CJ}(R, J)$ is same as Eq. (5.52). By substituting the values, we get the secrecy rate.

Chapter 6

Conclusion and Scope of Future Work

6.1 Introduction

Recently, with the increased interest in wireless cooperative networks, different cooperative schemes are proposed with different design issues. Types of relaying and power allocation are two major interesting issues which affect the network performance. However, security at physical layer is a major concern. New types of relaying schemes have to be introduced to overcome the limitations of the conventional relaying schemes in these regards. As it is noticed in existing literature, HDAF (hybrid decode-amplify-forward) relaying scheme has considerable advantages over the conventional relaying schemes in improving the performance of the system [34]. Further, to enhance the performance, proper relay power allocation schemes have to be proposed based on the channel conditions and relay locations. By optimizing the power allocation source and relay nodes in a wireless cooperative network, the performance significantly improves but it suffers from increased system complexity. So it is important to introduce the power allocation schemes which provide better performance with less computational burden. These issues serve as motivation for the proposed research in this thesis. Detailed performance analysis with derivation of analytical expressions is under taken for a multi HDAF relay based cooperative wireless network. In addition, efficient power allocation schemes are also proposed for this network. The performance metrics considered in this study are SER, outage probability and average channel capacity. Further, physical layer security is another important issue which has been addressed. So role of HDAF relay based cooperative network for physical layer security is analyzed in terms of secrecy rate, intercept probability and secrecy outage probability. Efficient power allocation schemes under the total power constraint are proposed based on the performance parameters such as SER, average channel capacity and secrecy rate. Relay and jammer power optimization problems are sloved using convex optimization; i.e, Lagrange multiplier method. But as the Lagrange multiplier method suffers from the several limitations which discussed in Section 4.5.2, evolutionary approaches have been attempted here. The main contributions

from each chapter of the thesis are discussed in Section 6.2 and the some of limitations of the proposed work and future direction of this research are presented in Section 6.3.

6.2 Summary of the thesis

Chapter 2 of this thesis introduced HDAF relaying for distributed Alamouti coded cooperative network. The proposed system model consists of a source, destination and two HDAF relays which are subjected to flat Rayleigh fading channel condition. The detailed performance study is done theoretically and validated using simulation results. The performance metrics considered for this study are SER, outage probability and average channel capacity. For the proposed system model, HDAF relaying scheme is compared with performance of the conventional AF and DF relaying schemes. From this comparative study it is found that the SER performance of HDAF is close to AF at low SNR conditions and close to DF at high SNR condtions. Regarding another performance metric, i.e., outage probability, HDAF performs better than DF but not same as AF. At low SNR values, for the proposed system using HDAF relays provides average channel capacity nearly which is same as of AF relays and increases as the SNR value increases and finally, it becomes almost the same as the capacity due to DF relays. Impact of relay location on the performance is demonstrated in terms of SER and average channel capacity. It is observed that the preferable relay location based on SER performance is relays at the middle for low SNR values as the relay switch to AF mode. Another preferable location is when the relays are located close to the source for high SNR condition as the relays switch to DF relaying mode.

In Chapter 3, efficient power allocation schemes for multi HDAF relay based wireless cooperative network are proposed Power allocation schemes proposed are maximized average channel capacity based power allocation, minimized SER based power allocation and total power minimization to maintain quality of service (QoS). Average channel capacity based power allocation for multi HDAF relay based wireless cooperative network using Differential evolution algorithm is proposed. The closed form expression for average channel capacity with the tight approximation is derived. Relay power optimization problem has been formulated in terms of power allocation factor and solved using Differential Evoltuion (DE) alogrithm. From the simulation analysis, it is observed that the proposed DE based power allocation scheme performs better than the existing equal power allocation scheme. Section 3.4.2 introduced the minimized SER based power

allocation for multi HDAF relay based wireless cooperative network using both Lagrange multiplier method and Differential Evolution (DE) algorithm. The optimization problem is defined based on the lower bound of SER and the power allocation factor. The SER performance of proposed power allocation schemes are compared with the equal power allocation. Here the findings reveal that both the maximized channel capacity based and minimzed SER based power allocations schemes perform better than equal power allocation and attain nearly same SER and average channel capacity as shown in Table 6-1 but differ in computational complexity. Section3.4.3 introduced total power minimization to maintain quality of service using Lagrange multiplier method and it performs better than equal power allocation.

Table 6-1 Comparison of proposed power allocation schemes

Power allocation scheme	Average channel capacity (bits/sec/Hz)	SER
Maximized channel capacity based power allocation using DE algorithm	1.3108	2.5000e-05
Minimized SER based power allocation using Lagrange multiplier method	1.3095	2.900e-05
Minimized SER based power allocation using DE algorithm	1.3105	2.5750e-05

In chapter 4, physical layer security of DF relay based wireless cooperative network with control jamming is addressed. The constrained optimization problems are defined and solved using Lagrange multiplier method and Differential Evolution (DE) algorithm to optimize the relay and jammers powers such that the secrecy rate is to be maximized subjected to the total power constraint. The performance of proposed power allocation schemes are validated using Monte Carlo simulations and compared with the conventional equal power allocation for both jamming and non jamming cases. Further, the impact of locations of relays and eavesdropper on the secrecy performance of the system is analyzed. When the relays are located close to the eavesdropper, the system exhibits poor secrecy performnace. The non jamming schemes get poor secrecy rate when the eavesdropper is located close to the source and close to the destination as the evavesdropper overhears more compared to the relays in between the source and destination. Amongst all, the control jamming achieves better secrecy rate compared to non jamming schemes as the destination node have prior knowledge of jamming signal as shown Table 6-2 and 6-3. The secrecy rate increases with increase in path loss exponent.

From the multiple eavesdroppers case, it is determined that the non collaborative eavesdroppers as individualy try to decode the signlas attain more secrecy rate compared to the collaborative eavesdroppers. From all these findings, it is confirmed that the proposed power allocation schemes outperform the conventional equal power allocation in all jamming and non jamming cases in a single relay and multiple eavesdroppers scenario.

Table 6-2 Control jamming gain over jamming and non jamming schemes for proposed relay power allocation scheme

Multiple eavesdroppers	Jamming scheme	Secrecy rate (bits/sec/Hz) Equal power allocation	Secrecy rate (bits/sec/Hz) Proposed power allocation	Gain of control jamming in dB
collaborative	CJ	2.75	3	
	J	1.55	1.6	2.73
	CR	0.1	0.15	13.0103
Non collaborative	CJ	3.1	3.4	
	J	1.9	2	2.3045
	CR	0.35	0.356	9.8003

Table 6-3 Control jamming gain over jamming and non jamming schemes for proposed relay and jammer power allocation scheme

Multiple eavesdroppers	Jamming scheme	Secrecy rate (bits/sec/Hz) Equal power allocation	Secrecy rate (bits/sec/Hz) Proposed power allocation	Gain of control jamming in dB
collaborative	CJ	3	3.25	
	J	0.6	0.75	6.3682
	CR	0.01	0.027	20.8052
Non collaborative	CJ	2.8	3.05	
	J	0.48	0.65	6.7139
	CR	0.008	0.0091	25.1808

In chapter 5, various the performance parameters such as secrecy rate, secrecy outage probability and intercept probability of SNR based HDAF multi relay wireless cooperative network for physical layer security are analysed mathematically and validated with the simulation results. Consider a tradeoff between the secrecy rate and intercept probability as shown in Table 6-2, the SNR based HDAF relaying proves to be a better option in comparison to AF and DF schemes.

Table 6-4 Comparison among conventional relaying schemes

The channel variances of jammer-to-eavesdropper link, jammer-to-destination link and source to relay link are assumed as $\sigma_{je}^2 = 1, \sigma_{jd}^2 = 1 \& \sigma_{sr}^2 = 1$. The transmitted powers of source node relay node and jammer node are given as $P_S = P_r = P_j = 10dB$.				
Channel variances	Secrecy rate of controlled jamming (OSCJ) in bits/sec/Hz		Intercept probability	
	AF	DF	AF	DF
Both relay-to-eavesdroppers and relay-to-destination links have the same variance $\sigma_{re}^2 = 1, \sigma_{rd}^2 = 1$	1.37787	1.7297	0.5	0.6667
When Relay-to-eavesdropper channel link is good $\sigma_{re}^2 = 10, \sigma_{rd}^2 = 1$	0.0719	0.0072	0.9091	1.6667
When Relay-to-destination link is good $\sigma_{re}^2 = 1, \sigma_{rd}^2 = 10$	1.8387	3.3907	0.0909	0.5238

Worst secrecy perfomrnace is obatnined for all jamming and without jamming cases when the relays are located close to the eavesdropper and when the eavesdroppers are located close to the destination. As the number of eavesdroppers and jammers increases, the performance of the system degrades. The control jamming scheme attains more secrecy rate and better outage performance with respect to jamming and with out jamming scenario. The secrecy rate increases with increase in path loss exponent. It is due to the fact that as the path loss exponent increases, the direct link capacity increases where as eavesdropper link capacity decreases as shown in Table 6-5 such that secrecy rate is improved.

Table 6-5 Link capacity comparison with path loss exponent

Path loss exponent (n)	Direct link capacity (bits/sec/Hz) (Relay-to-destination)	Eavesdropper link capacity (bits/sec/Hz) (Relay-to-eavesdropper)
2	4.13	0.8269
3	0.5504	0.5504
4	0.3402	0.3402

Further, power allocation schemes are proposed to maximize the secrecy rate of multi HDAF relay cooperative network with control jamming in the presence of multi eavesdroppers. The optimal power allocation factor using both convex optimization (Lagrange multiplier method) and evolutionary algorithms (DE and IWO algorithms) is

calculated. The proposed power allocations schemes are preferred compared to the existing equal power allocation scheme for jamming and non jamming cases. The three proposed power allocation schemes offer the same secrecy performance but differ in computational complexity.

Table 6-6 Computational complexity

Power allocation Algorithm	Number of operations per iteration	
	Additions	Multiplications
LPA	3N+2	9N+2
DEPA	(8N-7) NP	(4N-1) NP

From Table 6-6, even though Lagrange multiplier method obtains optimal powers with high accuracy but suffers with complexiy burden and slow convergence. To overcome these, DE and IWO algorithms are utilized.

6.3 Limitations and future scope of work

- Apart from power allocation, relay selection is also an important issue which affects the performance of the wireless cooperative network significantly. Even though the participation of more number of relays in cooperation may increase the diversity order, it suffers with the limitation of spectral efficiency. So, proper selection of relay nodes as well as number of relay nodes required to maintain QoS are the key design issues which are to be focused. So, the joint relay selection and power allocation may be attempted which will enhance the system performance further.
- In this thesis, all the power allocation schemes are proposed based on assumption that the system has perfect channel state information. But in practical scenario, prior channel estimation is to be carried out to predict the channel conditions at the relay and destination under different fading environment.
- New optimization techniques for power allocation problem in a multi relay wireless cooperative network may be attempted.
- The relays considered in ressech are half duplex in nature. Relays that operate in full duplex mode can be considered to increase the over all throughtput.

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List of Publications

Journals

1. Kiran Kumar Gurrala, Susmita Das, "Maximized Channel Capacity Based Power Allocation Technique for Multi Relay Hybrid Decode-Amplify-Forward Cooperative Network" ***Wireless Personal Communication (Springer),*** vol.87, no.3, pp: 663-678, 2016. DOI 10.1007/s11277-015-2622-9.
2. Kiran Kumar Gurrala, Susmita Das, "Hybrid Decode-Amplify-Forward relaying scheme in **d**istributed Alamouti coded cooperative network" ***International Journal of Electronics (Taylor & Francis),*** vol. 102, no 5, pp: 725-741, 2014. DOI**:** 10.1080/00207217.2014.938252.
3. Kiran Kumar Gurrala, Susmita Das, "Performance Study of Hybrid Decode-amplify-forward (HDAF) Relaying Scheme for Physical Layer Security in Wireless Cooperative Network", (*Wiley)* ***International Journal of Communication Systems***, (accepted) (Manuscript ID: IJCS150676.R2).
4. Kiran Kumar Gurrala, and Susmita Das. "Impact of Relay Location on the Performance of Multi-relay Cooperative Communication." ***International Journal of Computer Networks and Wireless Communications,*** vol. no. 2, pp.226-231, 2012.

Communicated

1. Kiran Kumar Gurrala, Susmita Das, "Performance Analysis and Power Allocation for Hybrid Decode-Amplify-Forward (HDAF) Multi Relay Secure Wireless Cooperative Network" ***Wireless Personal Communication (Springer)*.**

Conferences

1. Kiran Kumar Gurrala, Susmita Das**, "**Maximized Secrecy Rate Based Power Allocation for Wireless Cooperative Network with Control Jamming", in proceedings of *IEEE Malaysia International Conference on Communications (**IEEE MICC 2015**)*, Kuching, Malasiya, 23-25 Nov 2015 (Accepted).
2. Kiran Kumar Gurrala, Susmita Das**,** "Minimized SER based power allocation for multi relay HDAF relay cooperative network using Differential Evolution algorithm", in *IEEE annual India conference (**IEEE INDICON 2014**)*, pp.1-6, Pune, 11-13 Dec 2014.
3. Kiran Kumar Gurrala, Susmita Das**,** "Study of channel capacity for hybrid decode-amplify-forward (HDAF) scheme in distributed Alamouti coded cooperative network", in proceedings of IEEE International Conference on *Circuits, Controls and Communications (**IEEE CCUBE 2013**)*, pp.1-5, Bangalore, 27-28 Dec 2013. (DOI: 10.1109/CCUBE.2013.6718548).
4. Kiran Kumar Gurrala, Susmita Das**,** "Performance study of hybrid decode-amplify-forward (HDAF) scheme in distributed Alamouti coded cooperative network", in proceedings of IEEE International Conference on *Advances in Computing, Communications and Informatics (**IEEE ICACCI 2013**)*, pp.271-276, Mysore, 22-25 Aug 2013. (DOI: 10.1109/ICACCI.2013.6637183).

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Major Research Areas

Wireless Communciation, Resource Allocation in Wireless Cooperative Networks, Optimization Techniques.

Publications

- 4 journals
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