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Abstract

The purpose in this research aims to investigate the algorithms of adaptive resource allocation on OFDM-based (Orthogonal Frequency Division Multiplexing) cooperative communication systems. To maximize the transmission rate of subcarriers and minimize the transmission power of subcarriers, dynamic resource allocation has been identified as one of the most important issue. The techniques of dynamic resource allocation can be broadly categorized into two parts: one is to maximize system throughput under total power and target bit error rate (BER) constraints and the other is to minimize bit error rate under total power and transmission rate constraints.

Firstly, we investigated the optimization problem of OFDM-based cooperative communication systems in the single source, destination and relay nodes environment. We used Lagrange multiplier with KKT (Karush-Kuhn-Tucker) conditions to solve the optimal power allocation for the subcarriers of the source node. Due to the computational complexity of the optimal algorithm, a suboptimal algorithm about subcarrier power allocation of the source node was designed to maximize system throughput and reduce computational complexity. The goal of the suboptimal algorithm under total power and target BER constraints is to maximize the total system throughput by power allocation at the subcarriers of the source node.

Secondly, we investigated the optimization problem of relay selection and power allocation at the subcarriers of source node for the OFDM-based cooperative communication systems in the single source, destination and multi-relay nodes environment. To reduce the computational complexity of optimal algorithm mentioned above, a suboptimal algorithm for power allocation at source node was designed. Initially, the suboptimal algorithm arranges the uniform power allocation at the source and relay nodes to decide the selection of transmission relay node. Then, the optimal power allocation at subcarriers of source node under total power and target BER constraints is performed to maximize the system throughput. Simulation results showed that the proposed algorithm can effectively increase the system throughput.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Cooperative Communication, Target Bit Error Rate

中文摘要

本計畫旨在探討具正交分頻多工(Orthogonal Frequency Division Multiplexing, OFDM)技術合作式通訊系統之適應性資源分配演算法。為了提升系統的子載波位元傳輸率和降低子載波傳送位元所需功率，動態資源分配儼然成為一個重要的議題。目前存在的動態資源分配議題，大致上分為以下兩類：在有限的功率與目標位元錯誤率限制下，最大化系統產出量 (Throughput)及在有限的功率與傳輸速率限制下，最小化位元錯誤率。本計畫將針對前者進行詳細研究。

首先，我們對單一來源端、目的端及中繼節點環境下，探討正交分頻多工技術之合作式通訊系統的最佳化問題。為了達到來源端子載波功率分配最佳化，我們導入拉格朗日乘數並利用 KKT (Karush-Kuhn-Tucker) 的條件法，成功推導出最佳化的來源端子載波功率分配。基於最佳化方法運算複雜度非常高，為了降低複雜度，並達到最大化系統產出量的目標，我們對來源端的子載波功率分配問題，設計其次佳化演算法。此次佳化演算法在有限的功率及目標位元錯誤率限制下，藉由調整來源端的子載波功率分配，仍可有效達到提升系統產出量的目標。

接著，我們針對單一來源端、目的端及多個中繼節點的環境中，探討中繼節點選擇及來源端子載波功率分配問題。為了降低前面所導出最佳化方法的運算複雜度，並有效提升系統產出量，而設計次佳化演算法。此演算法先對來源端及所有中繼節點做平均功率分配，決定一個中繼節點傳輸，再依據總功率和目標位元錯誤率限制下，對來源端子載波做功率分配，以達到最大化系統產出量。由模擬驗證，我們提出的演算法能夠在總功率及目標位元錯誤率的限制下，有效提升系統產出量。

關鍵字： 正交分頻多工、合作式通訊、目標位元錯誤率。

I. Introduction

1.1 Background

Nowadays wireless communications have become a remarkably fast technological evolution in the recently years. Although separated by only a few years, every new generation of wireless devices has brought significant improvements in terms of link communications including speed, device size, power needed, applications, etc. In wireless communications, the technological evolution has reached a point where researchers have begun to develop wireless network architectures that depart from the traditional idea of communicating on an individual point-to-point basis with a central controlling base station. Such as the ad-hoc and wireless sensor networks, where the traditional hierarchy of a network has been relaxed to allow any node to help forward signal from other nodes, thus establishing communication paths that involve multiple wireless nodes. One of the most appealing ideas within these new research paths is the implicit recognition that, contrary to being a point-to-point link, the wireless channel is broadcast by nature. This implies that any wireless transmission from an end-user, rather than being considered as interference, can be received and processed at other nodes for a performance gain. This recognition facilitates the development of new concepts on distributed communications and networking via cooperation [1].

The technological progress has seen with wireless communications following that of many underlying technologies such as integrated circuits, energy storage, antennas, etc. Digital signal processing is one of these underlying technologies contributing to the progress of wireless communications. Perhaps one of the most important contributions to the progress in recent years has been the advent of MIMO (multiple-input multiple-output) technologies. In general, MIMO technologies improve the received signal quality and increase the data communication speed by using digital signal processing techniques to shape and combine the transmitted signals from multiple wireless paths created by the use of multiple receive and transmit antennas.

Orthogonal frequency division multiplexing (OFDM) is a practical technique for the next generation of wireless communication systems. Digital audio broadcasting (DAB) and digital video broadcasting (DVB) are based on OFDM technique. It is also applied to IEEE 802.11a, IEEE 802.11g, IEEE 802.16, IEEE 802.16e and HiperLAN2 WLAN systems, and by asymmetric digital subscriber line (ADSL) systems.

Recently, the demand for high data rate transmission has been increasing in wireless communications. Orthogonal frequency division multiplexing (OFDM) is a promising technique for high data rate transmission. The OFDM wireless communication system that divides the high data rate stream to several low data rate streams that are transmitted simultaneously over all orthogonal subcarriers. The main idea of OFDM is to divide the given frequency band into multiple subcarriers, each of which is equally spaced. Because of orthogonality among subcarriers, the subcarriers can be very close to each other by carefully designed in the frequency spectrum without interfering each other. Therefore, the OFDM-based system is of spectrum efficient. Cooperative communications are a new paradigm that draws from the ideas of using the broadcast nature of the wireless channel to make communicating nodes help each other, of implementing the communication process in a distribution fashion and of gaining the same advantages as those found in MIMO systems. The end result is a set of new tools that improve communication capacity, speed, and performance; reduce battery consumption and extend network lifetime; increase the throughput and stability region for multiple access schemes; expand the transmission coverage area; and provide cooperation tradeoff beyond source–channel coding for multimedia communications.

Cooperative communications are a new communication paradigm which generates independent paths between the user and the base station by introducing a relay channel. The relay channel can be thought of an auxiliary channel to the direct channel between the source and destination. Since the relay node is usually several wavelengths to distant from the source, the relay channel is guaranteed to fade independently from the direct channel, which introduces a full-rank MIMO channel between the source and the destination. In the cooperative communications setup, there is a-priori few constraints to different nodes receiving useful energy that has been emitted by another transmitting node. The new paradigm in user cooperation is that, by implementing the appropriate signal processing algorithms at the nodes, multiple terminals can process the transmissions overheard from other nodes and be made to collaborate by relaying information for each other. The relayed information is subsequently combined at a destination node so as to create spatial diversity. This creates a network that can be regarded as a system implementing a distributed multiple antenna where collaborating nodes create diverse signal paths for each other.

Hence, cooperative communications are a new paradigm shift for the fourth generation wireless system that will guarantee high data rates to all users in the network, and we anticipate that it will be the key technology aspect in the fifth generation wireless networks.

1.2 Motivation

With the increasing needs for high speed wireless applications, future wireless networks, no matter infrastructure-based, such as cellular networks, or ad hoc, such as a disaster recovery network, will be required to provide reliable high data rate services in dynamic environments. The use of multiple antennas can improve the power and spectral efficiency greatly in single-link wireless communications [2]-[9]. In many instances, however, this may be impractical due to limitations on the size and power of the communication devices. Cooperative transmission, which utilizes the broadcast nature of the wireless medium and the numerous nodes in a network, is an efficient way to realize the benefits of multi-antenna transmission with only one antenna at each node.

The system performance is improved by the resource management, in an OFDM-based cooperative system, in which the link gain varies by several instantaneous rates of the subcarriers. When the channel coefficient differences among subcarriers are large, it is possible that subcarriers with good channel coefficient will be allocated most of the resource, i.e., bits and power for a significant portion time. The users with the worst channel coefficient may be unable to receive any data, since most of the time the resource will be assigned to users with good channel coefficients. The fairness issue of resource management is very important in OFDM-based cooperative communication systems. Some researches have focused on dealing with this resource management issue [10]-[11]. However, fairness issue is not considered in [12]-[20]. There is always a tradeoff between satisfaction of fairness and improvement of the system performance.

These challenges motivated us to investigate the performance of the adaptive resource allocation with total power and target BER constraints and design adaptive resource allocation algorithms which can be implemented to maximize the bits number at subcarriers in the OFDM-based cooperative communication environments. In our research, two different optimization problems are formulated:

1. Optimization problem for the cooperative OFDM-based communication systems with single relay environment.
2. Optimization problem for the cooperative OFDM-based communication systems with the relay selection in multi-relay environment.

1.3 Overview of cooperative communication systems

Generally, resource management in the cooperative OFDM-based communication systems is to allocate power under target BER and total power constraint. The major topic is to maximize the system capacity that is to maximize allocation bits number at source and the overall throughput. Resource allocation schemes for OFDM-based systems can be divided into two parts: one is fixed resource allocation, and the other is adaptive resource allocation. Fixed resource allocation includes time division multiple access and frequency division multiple access. However, this scheme is not optimal since it doesn’t consider the current channel state information (CSI). In the adaptive resource allocation scheme, the systems allocate the available power to the subcarriers that can best exploit it by using the instantaneous CSI. Therefore, adaptive resource allocation scheme obviously has better performance because each subcarrier’s CSI can be seen as independent. This property is called cooperation diversity.

In the cooperative OFDM-based system, the subcarrier allocates the power and the uniform power distribution should be based on the systems in order to maximize the allocation bits numbers. Consequently, we discuss necessary background on the two key principles that enable to archive high performance in the cooperative OFDM-based systems: adaptive modulation and power allocation to the single or multiple relay. Adaptive modulation is the means by which good channel conditions subcarriers can be exploited to achieve higher data rates. Power allocation to the single or multiple relays describes the gains available by subcarrier power allocation or subcarriers at the selected relay power allocation having good channel conditions. We will formulate the problem of allocating the resource for the cooperative OFDM-based systems, with certain constraints that needs to be satisfied, such as the source total power, relay total power, and target BER.

1.4 Organization of this report

This report is organized as follows. In Chapter I, Chapter II, the adaptive resource allocation for the cooperative OFDM- based communication systems are described. The cooperative OFDM-based system model and channel model are presented in Chapter 2.1. In Chapter 2.2, to evaluate the performance of multiuser OFDM system, an analytical model is studied, and optimization criteria are reviewed. In Chapter III, the adaptive resource allocation for dual-hop single-relay OFDM-based cooperative communication systems is presented.

In Chapter 3.1 the dual-hop single relay amplify-and-forward cooperative communication systems problem is introduced. In Chapter 3.2, the system model is describes. In Chapter 3.3, the optimization criteria of adaptive resource allocation for dual-hop single-relay OFDM-based cooperative communication system are presented. The suboptimal resource allocation algorithm is proposed in Chapter 3.4. The performance of the proposed suboptimal allocation algorithms for dual-hop single-relay OFDM-based cooperative communication system is analyzed and a series of simulations are compared in Chapter 3.4.

In Chapter IV, the adaptive resource allocation for dual-hop multi-relays OFDM-based cooperative communication system is introduced in Chapter 4.1. The optimization criterion multi-relay problem for OFDM-based cooperative communication system is formulated in Chapter 4.2. In Chapter 4.3 the proposed suboptimal adaptive resource allocation algorithm is discussed. In Chapter 4.4, the performance of dual-hop multi-relay OFDM-based cooperative system is analyzed. Finally, Chapter V summarizes the conclusions of this report and points the areas for future research.

II. System Model

2.1 System Model Description

In this chapter, a system model for the downlink transmission of OFDM system
is shown in Fig. 2.1. We assume that the system has N subcarriers. The available bandwidth B f the system is divided by N orthogonal narrowband subcarriers. In this report, an adaptive M-ary quadrature amplitude modulation (M-QAM) is used and ideal phase detection is employed. We also assume that each subcarrier has a bandwidth which is much smaller than the coherence bandwidth of the channel and that the instantaneous CSI of all subcarriers are known perfectly at the transmitter. Based on CSI of all users, the transmitter applies the resource management schemes include: bit and power allocation algorithm to assign different subsets of subcarriers, allocate the number of bits per OFDM symbol to be transmitted on each subcarrier, adjust the transmit power level across all subcarriers, respectively.

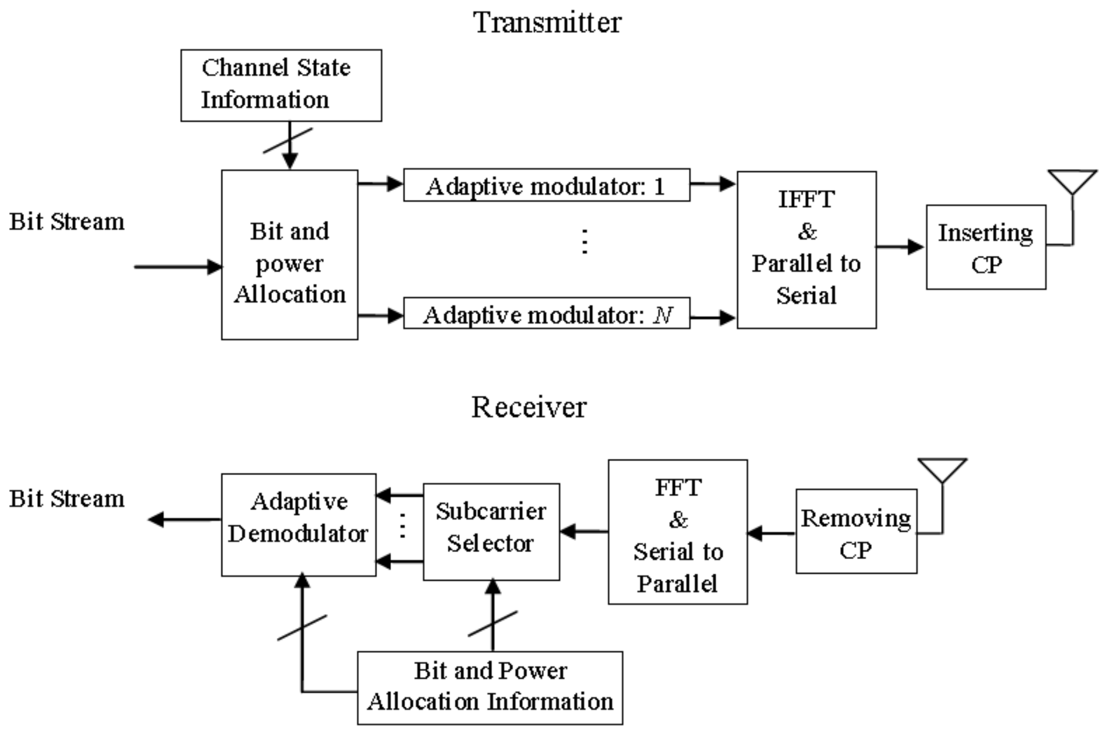

Fig. 2.1 The structure of OFDM system

Transmitter

In the transmitter, the serial data streams from users are fed into the subcarrier, bit, and power allocation block which allocates bits from different receivers to different subcarriers and then the subcarriers and bit allocation information are sent to each receiver through a separate control channel. When data need to be transmitted at the transmitter, the serial data streams are first arranged in parallel for each subcarrier and modulated independently. At each subcarrier, according to the number of the assigned bits, the adaptive modulator chooses the corresponding modulation scheme to form a modulated bit. The modulated bits per symbol and the allocated transmit power are denoted as T_i and P_{s_i} for the *i*th subcarrier, respectively. The modulated bits of all subcarriers are transformed into the time domain samples by the inverse fast Fourier transform (IFFT) to form a time domain OFDM bits per symbol. After IFFT operation, a cyclic prefix (CP) is inserted at the beginning of each time domain OFDM symbol and the length of CP is assumed to be longer than or equal to the maximum delay spread of the multipath channel, to prevent ISI. The transmit signal is then passed through different frequency selective fading channels to different subcarriers.

Channel Model

In this report, the channel is modeled to be a Rayleigh fading channel whose fading characteristic is assumed to be quasi-static so that the fading gains are constant during one OFDM symbol period, but vary from one symbol to another. At different subcarriers, the signal received from the transmitter is assumed to undergo frequency selective fading channel, independently. The channel impulse response for the ith subcarrier is given by (2.1) as follows [21]:

$$g_i(t) = \sum_{l=1}^{L} cg_i(l)\delta(t - \tau_l) \tag{2.1}$$

Where $\delta(\cdot)$ is the Dirac delta function, L is the number of resolvable paths; for the *l*th path, $cg_i(l)$ and τ_l denote the path gain and path delay, respectively. The path gains are independent for different paths. We assume that the symbol duration for each subcarrier is large relative to the multipath delay spread, τ_L; therefore, each subcarrier approximately experiences flat fading. The channel gain for the *i*th subcarrier, denoted as α_i, can be expressed as follows [22]-[23]:

$$\alpha_i = \sum_{l=1}^{L} cg_i(l)e^{-j2\pi il/N} \qquad i = 1,2,..., N \tag{2.2}$$

Receiver

At each receiver, after the CP is removed from the received time domain samples, the samples are transformed into frequency domain modulation symbols b the fast Fourier transformed (FFT). After propagation through a Rayleigh fading channel, if the transmitted signal is received by the ith subcarrier; hence, the signal received from the *i*th subcarrier can be expressed as

$$r = \sqrt{P_{s_i}}G_{s_i}T_i + w_i \tag{2.3}$$

Where w_i denotes the frequency domain additive white Gaussian noise (AWGN) with zero mean and variance σ^2.

The signals received from allocated subcarriers are obtained through the subcarriers allocation information, and then the signals are demodulated by using an adaptive demodulator which depends on bit allocation information to configure a orresponding demodulation scheme.

Cooperative OFDM-based

We consider that a dual-hop relay link consists of one source/destination pair and one amplified-forward relay. For broadband communication between the nodes OFDM-based system is used. The available bandwidth is divided into *N* subcarriers in which the channel is assumed to be frequency-flat. The channel coefficient of the *i*th subcarrier between source and destination, source and relay, relay and destination is denoted by g_{sd_i}, g_{sf_i} and g_{fd_i}, respectively. Fig. 2.2 shows the OFDM-based cooperative protocol. Where a half-duplex AF relay is employed to help the source-to-destination called SD link communication.

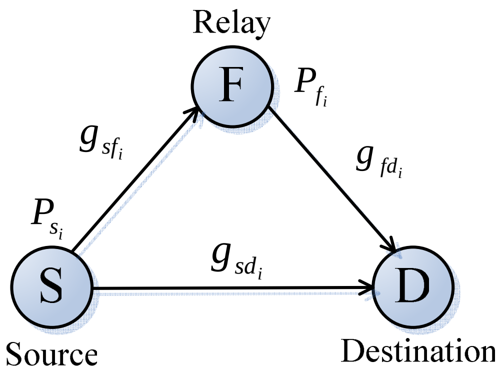

Fig.2.2 OFDM-based cooperative protocol

The source broadcasts its information to both the destination and the relay. In the phase 1, the received signals at the destination and relay can be expressed as

$$r_{sd_i} = \sqrt{P_{s_i}}\, g_{s_i} T_i + z_{sd_i} \tag{2.4}$$

$$r_{sf_i} = \sqrt{P_{s_i}}\, g_{sf_i} T_i + z_{sf_i} \tag{2.5}$$

in which P_{s_i} is transmitted power at the source of the *i*th subcarrier, T_i is the transmitted information symbol, and z_{sd_i} is additive noise. In (2.4) and (2.5), g_{sd_i} and g_{sf_i} are the channel coefficients from the source to the destination and the source to the relay respectively. They are model as zero-mean, complex Gaussian random variables with variances $\delta^2_{sd_i}$ and $\delta^2_{sf_i}$, respectively. The noise terms z_{sd_i} or z_{sf_i} is modeled as zero-mean, complex Gaussian random variance N_0.

For an Amplify and Forward cooperation protocol, the relay amplifies the received signal and forwards it to the destination with transmitted power P_{f_i}. In phase 2, the received signal at the destination from the relay can be expressed as

$$r_{fd_{i0}} = \frac{\sqrt{P_{f_i}}}{\sqrt{P_{s_i}\left|g_{sf_i}\right|^2 + N_0}} g_{fd_i} r_{sf_i} + z_{fd_i} \qquad (2.6)$$

where g_{fd_i} is the channel coefficient from the relay to the destination and z_{fd_i} is an additive noise.

We assume that the source sends data with power P_{s_i} on the *i*th subcarrier to relay and destination, while the relay retransmits an amplified signal of the received data to the destination. The relay received signal from the source can be expressed as follow

$$r_{sd_i} = (r_{sf_i} a_i) g_{fd_i} + z_{fd_i} \qquad (2.7)$$

Where a_i is a power scaling factor and can be expressed as

$$a_i = \frac{\sqrt{P_{f_i}}}{\sqrt{P_{s_i}\left|g_{sf_i}\right|^2 + N_0}} \qquad (2.8)$$

to ensure a relay transmit power on the *i*th subcarrier of P_{f_i}. The noise variance at the relay within one OFDM subcarrier is denoted by N_0.

The relay received the signals from the source that the SNR_{sf_i} can be expressed as

$$SNR_{sf_i} = \frac{P_{s_i}\left|g_{sf_i}\right|^2}{N_0} \qquad (2.9)$$

The destination received the signals from two ways that one is the source, the other one is the relay. If the destination received the signal from the source that the SNR_{sd_i} can be expressed as

$$SNR_{sd_i} = \frac{P_{s_i}\left|g_{sd_i}\right|^2}{N_0} \qquad (2.10)$$

The destination receives the signal from the relay that the SNR_{fd_i} can be formulated as

$$SNR_{fd_i} = \frac{1}{N_0} \frac{P_{s_i} |g_{sf_i}|^2 P_{f_i} |g_{fd_i}|^2}{P_{s_i} |g_{sf_i}|^2 + P_{f_i} |g_{fd_i}|^2 + N_0} \quad (2.11)$$

where signal to noise ratio (SNR) at the output of a temporal maximum ratio combiner SNR_{MRC_i} , which combines the signal contributions of both links at the destination is then given by

$$SNR_{MRC_i} = \frac{1}{N_0} \frac{P_{s_i} |g_{sf_i}|^2 P_{f_i} |g_{fd_i}|^2}{P_{s_i} |g_{sf_i}|^2 + P_{r_i} |g_{fd_i}|^2 + N_0} + \frac{P_{s_i} |h_{sd\,i}|^2}{N_0} \quad (2.12)$$

The noise variance at the destination within one OFDM-based subcarrier is denoted by N_0.

In this project, we consider that the M-QAM with Gray bit mapping is applied. The OFDM-based system applies adaptive modulation scheme in order to take advantage of fluctuations in the channel condition. The simple idea is that transmission rate as high as possible when the link condition is better, and transmission at a lower rate when the link condition is bad. Lower rates are achieved by using a small constellation, such as QAM. The higher rates are achieved with large constellations, such as 256-QAM. The expression for the BER of M-QAM as the SNR_{MRC_i} and the discrete number of bits which denotes by b_i can be approximated as [24]-[25],

$$\mathrm{BER}_i(SNR_{MRC_i}, b_i) \approx \frac{2}{b_i}\left(1 - \frac{1}{\sqrt{2^{b_i}}}\right) \times erfc\left(\sqrt{\frac{1.6 SNR_{MRC_i}}{2^{b_i} - 1}}\right) \quad (2.13)$$

However, this expression is not easily differentiable or invertible in its SNR or the number of bits. So[26] consider a different approximation with these properties. In [26], the authors find an approximation BER as

$$\mathrm{BER}_i(SNR_{MRC_i}, b_i) \approx 0.2 \exp\left(\frac{-1.6 SNR_{MRC_i}}{2^{b_i} - 1}\right) \quad (2.14)$$

In Fig. 2.3, the tightness of the standard formula (2.12) to the BER approximation (2.14) is shown. We can observe that the approximation of BER tight within 1 dB for $M \geq 2^2$ and $\mathrm{BER} \leq 10^{-2}$ at higher SNR.

Rearranging (2.14), the maximum achievable discrete bits transmitted by the *i*th subcarrier can be formulated as

$$b_i \approx \log_2\left(1+\frac{-1.6SNR_{MRC_i}}{\ln 5BER_i}\right) \quad (2.15)$$

The instantaneous rate where the maximum achievable discrete bits numbers can be formulated as of the communication between source and destination with the relay on the *i*th subcarrier is transmitted therefore can be formulated as

$$b_i \approx \left\lfloor \log_2\left(1+\frac{SNR_{MRC_i}}{\Gamma}\right)\right\rfloor \quad (2.16)$$

Where $\lfloor\cdot\rfloor$ denotes the floor operator and Γ is a constant for the ith subcarrier's target BER, denoted as *t*BER , the constant can be specified as

$$\Gamma = \frac{\ln(5tBER)}{-1.6} \quad (2.17)$$

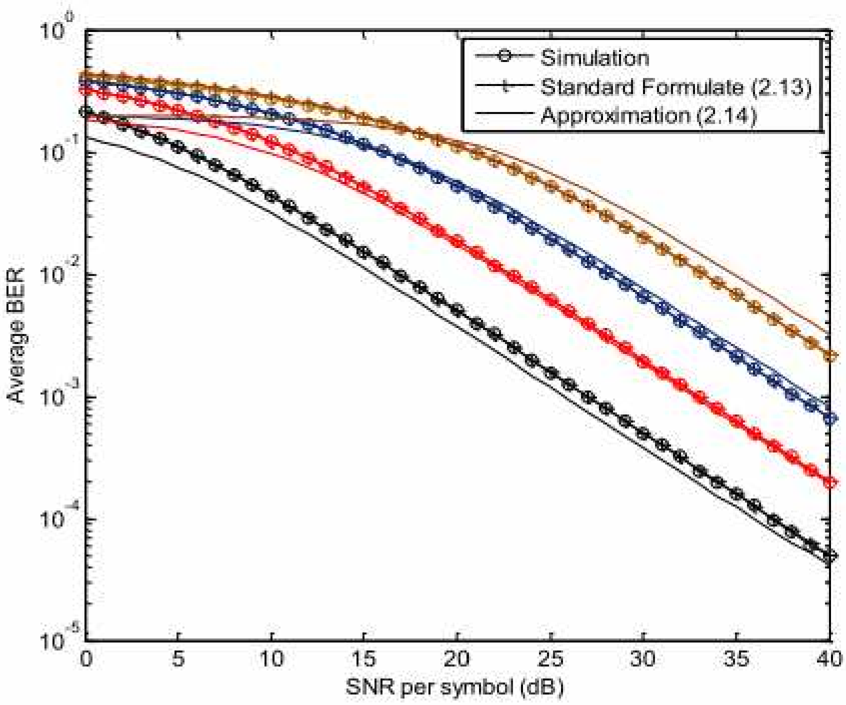

Fig. 2.3 BER approximation for M-QAM over Rayleigh fading channel

In [27], a simple adaptive modulation scheme was proposed, the modulation mode used is adapted on the instantaneous SNR under *t*BER constraint. Based on the instantaneous SNR, the Q-mode adaptive modulation scheme adjusts the transmission mode *q*, where $q = \{0,1,\ldots,Q\}$, to satisfy *t*BER constraint. Following the approach proposed in [27], the mode selection rule is given by

Select mode *q* when $BER(SNR_{MRC_i}, b_{n,q}) \le tBER < BER(SNR_{MRC_i}, b_{n,q+1})$, where $b_{n,q}$ is the number of discrete bits on the nth subcarrier corresponding to mode q. The $b_{n,Q}$ is the maximum discrete number of bits for the Q-mode adaptive modulation scheme.

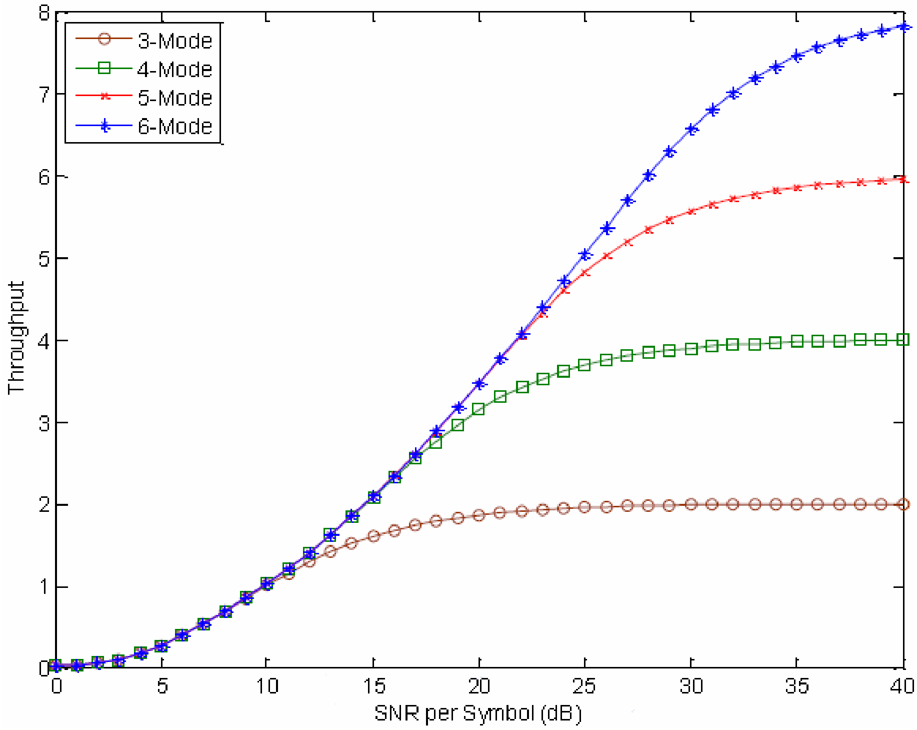

Fig. 2.4 Throughput versus SNR for various Q-mode over Rayleigh fading channel at $tBER = 10^{-3}$

In Fig. 2.4 the throughput for the various number of mode at $tBER = 10^{-3}$ is shown. It can be observed that throughput is significantly related the number of mode. As expected, the throughput increases as the number of mode increases.

2.2 Optimization Criteria

Fig. 2.2. presents the consideration of an OFDM-based downlink system for a single relay scheme. The source has all knowledge of the channel state information (CSI) through the feedback links from all subcarriers. The resource allocation problem, which includes subcarrier allocation and power allocation, provides subcarrier and bit allocation data to the source to form an OFDM symbol. In this following, the optimization problem formulation is considered, i.e., we would like to maximize the overall thoughput for a given power budget at the source. For an OFDM-based downlink system with N subcarriers, the optimization problem can be described. As to describe the optimization problems, various notations are introduced. Denote the data rate (number of bits transmitted over an OFDM symbol) of the ith subcarrier by b_i .Thus, the instantaneous data rate b_i can be expressed as

$$b_i \approx \left\lfloor \log_2\left(1+\frac{SNR_{MRC_i}}{\Gamma}\right)\right\rfloor \tag{2.18}$$

The resource allocation cooperative OFDM-based optimization problem was investigated, where the objective is to maximize the total instantaneous data rate of the OFDM-based system subject to total available transmission power at source, relay and target BER constraints.

Mathematically, the optimization problem is formulated as

$$\underset{p_s}{\mathrm{Max}} \sum_{i=1}^{N} b_i \tag{2.19}$$

subject to:

$$P_{s_i} = \frac{P_{s_{total}}}{N},\ i = 1,\ldots, N \tag{2.20}$$

$$\sum_{i=1}^{N} P_{f_i} = P_{f_{total}} \tag{2.21}$$

$$P_{f_i} \geq 0, i = 1,\ldots, N \tag{2.22}$$

$$BER_i \leq tBER,\ \ i = 1,\ldots, N \tag{2.23}$$

where N denotes the total number of subcarriers, P_{s_i} denotes the power allocated for ith subcarrier at the source, P_{f_i} denotes the power allocated for the ith subcarrier from relay to the destination. $P_{s_{total}}$ denotes the total power constraint at the source that divide by N denote uniform power allocation. $P_{f_{total}}$ denotes the total power constraint at the relay.

To obtain the optimal solution in (2.19), to allocation power on the ith subcarrier at source and relay should be allocated jointly. However, this causes a prohibitive high computational complexity. Separating the source and relay power allocation is a way to reduce the computational complexity. The transmission power for each subcarrier can be adapted by using Lagrange multiplier method with KKT conditions. The algorithm is demonstrated in [28]-[29] as the optimal solution for the problem that distributed power into parallel independent channels with a total available power constraint. After subcarrier allocation, the system employed Lagrange multiplier method to solve the optimization problem of (2.19), the KKT conditions by those constraints of follows for the uniform power allocation at the source node (equal power distribution), and total power and target BER constraints. With the subcarriers of the relay node must be transmitted by a signal or equal to zero. Use differentiate to solve Lagrange function for get the power distribution across subcarriers the optimal power allocation for subcarriers at relay P_{f_i} can be obtained by

$$P_{r_i} = \sqrt{\frac{\left(\frac{c_i}{\lambda \ln(2)} + \Gamma + a_i P_{s_i}\right)}{\left(\frac{c_i\sqrt{\Gamma + a_i P_{s_i}}}{b_i P_{s_i}}\right)^2 + \frac{c_i^2}{b_i p_{s_i}}} + \frac{\left(\frac{2(\Gamma + a_i P_{s_i})c_i}{b_i P_{s_i}} + c_i\right)^2}{4\left(\left(\frac{c_i\sqrt{\Gamma + a_i P_{s_i}}}{b_i P_{s_i}}\right)^2 + \frac{c_i^2}{b_i P_{s_i}}\right)^2}} - \frac{\frac{2(\Gamma + a_i + P_{s_i})}{b_i P_{s_i}} + c_i}{\left(\sqrt{\left(\frac{c_i\sqrt{\Gamma + a_i P_{s_i}}}{b_i P_{s_i}}\right)^2 + \frac{c_i^2}{b_i P_{s_i}}}\right)} \quad (2.22)$$

where α is a threshold, to be determined from the total available transmit power constraint.

We use Lagrange method by KKT conditions to obtain power allocation $\mathrm{P_F} = \left[P_{f_1}, P_{f_2}, ..., P_{f_N}\right]^T$ in Appendix A. The Karush-Kuhn-Tucker (KKT)conditions are sufficient for optimality.

III. Adaptive Resource Allocation for Dual-Hop Single-Relay OFDM-Based Cooperative Communication Systems

3.1 Introduction

Cooperative relaying strategies have become a major topic in the wireless research community. The first research on relay channels was obtained in the seventies in [30]-[32]. The interest in this topic was initiated recently by the conference papers [33]-[35] and triggered a large amount of work in this area [34].

Most of the literatures available today consider frequency-flat fading. In [36] cooperative diversity protocols are analyzed for combating multi-path fading and shadowing effects in a wireless network and thereby increasing the robustness of the wireless connection between source and destination. In [37] a form of spatial diversity is investigated, in which diversity gains are achieved via the cooperation of two mobile users that communicate with a base station. It is shown that cooperation leads not only to an increase in uplink rate for both users but also to a more robust system, where user rates are less sensitive to channel variations. In [38], [39] and [40] optimal power allocations between source and relay (regenerative and nonregenerative) are discussed for the case that both share a total amount of transmit power over the two time-slots required for relaying. In [41] the optimal gain allocation between multiple nonregenerative coherent relays is presented which maximizes the instantaneous rate for multiple nonregenerative coherent relays, retransmitting in the same bandwidth. This gain allocation can be interpreted as a distributed maximum ratio combining (MRC).

The case of cooperative relaying in frequency-selective fading channels is much less examined so far. In [42], the authors determine power allocations for multiple orthogonal nonregenerative relays which are the same as having one relay using OFDM to maximizing the average SNR of the maximum ratio combiner at the destination node. In [43] the information rate of OFDM and OFDMA networks consisting of one source/destination pair and multiple relays is examined. In the case of OFDM only one amplification gain is used for all subcarriers at the nonregenerative relay. Therefore, the rate is not optimized with respect to the frequency-selective channel. In the case of OFDMA only one nonregenerative relay is assigned to one subcarrier, which results in an optimization problem that can be solved by integer programming. In [44] distributed Alamouti coding [45] for OFDM relaying links is proposed. Furthermore, a closed form expression for the bit error ratio (BER) assuming BPSK, M-QAM, MPSK modulation is presented.

In this project, we focus on dual-hop AF with single or multiple relay for OFDM-based communication system. The transmitted signals are subject to frequency selective Rayleigh fading channels. We examine the possibilities of power allocation over the subcarriers at relay to maximize overall throughput that is the instantaneous rate of the link. It is assumed that source and relay have their own separate transmit power. The source and relay have total power and target BER constraints. We give the optimal power allocation at the source that maximizes overall throughput for a given relay power allocation. The KKT conditions has to be solved the optimal source power allocation. Therefore, the simulation results show that an alternate, optimization of the source power allocation and purpose suboptimal of the source power allocation are improved.

3.2 Analytical Model

We consider that a dual-hop relay link consists of single source/destination pair and single amplified-forward (AF) relay. For broadband communication between the nodes OFDM-based system is used to cooperative communications. The available bandwidth divided into subcarriers in which the channel assumed to be frequency-flat. The channel coefficient of *i*th subcarrier at the relay and destination node are denoted by g_{sd_i}，g_{sf_i}，and g_{fd_i}, Fig. 3.1 shows the OFDM-based cooperative system model.

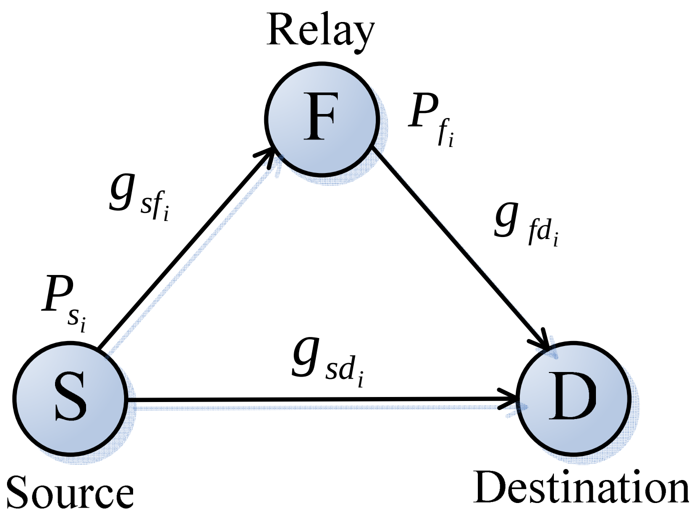

Fig.3.1 The OFDM-based cooperative system model

The cooperative OFDM-based communication system is used to transmit the information data bits/symbol over subcarriers. That can be implemented by employing the IDFT in the transmitter at the source and DFT in the receiver at the destination. A cyclic prefix can be employed for introducing the channel circulant property and mitigating the inter-symbol interference. The block diagram of the considered cooperative OFDM-based system model with single AF relay is shown in fig. 3.2. Where a half-duplex AF relay is employed to help the source-to-destination called SD link communication. Prior to transmission, the information bits are first fed into bit and power loading component to produce an $N \times 1$ symbol block $T_i = [T_1, T_2, ..., T_N]$，where T_i denotes the information bits/symbol or zero symbol sent by the source. Then these bits/symbol are mapped onto *N* subcarriers with the transmit power $\mathrm{P_S} = [P_{s_1}, P_{s_2}, ..., P_{s_N}]$，where P_{s_i} denotes the source power for the *i*th subcarrier. This block goes through the source to destination SD link and source to relay SF link, respectively.

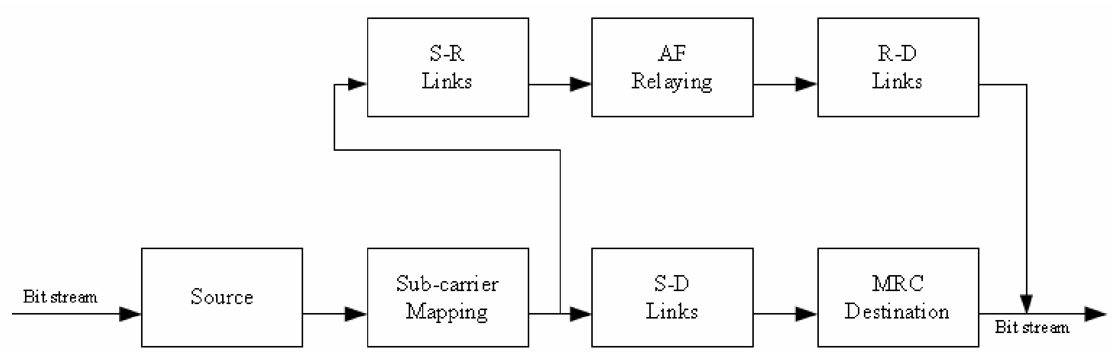

Fig.3.2 Block diagram of OFDM-based communication systems with single AF cooperative relay

Denoting g to be the frequency domain channel coefficient, the received bits/symbol on the ith subcarrier at the destination or relay. In the phase 1, the received signals at the destination and relay can be expressed as

$$r_{sd_i} = \sqrt{P_{s_i}} g_{sd_i} T_i + z_{sd_i} \tag{3.1}$$

$$r_{sf_i} = \sqrt{P_{s_i}} g_{sf_i} T_i + z_{sf_i} \tag{3.2}$$

Where P_{s_i} denote the transmitted power at the source of the ith subcarrier, T_i denotes the transmitted information symbol, and z_{sd_i} or z_{sf_i} denote additive noise. In (3.1) and (3.2), g_{sd_i} and g_{sf_i} are the channel coefficients received by destination and relay from source to destination and source to relay respectively. They are modeled as zero-mean, complex Gaussian random variables with variances $\delta^2_{sd_i}$ and $\delta^2_{sf_i}$ respectively. The noise terms z_{sd_i} or z_{sf_i} is modeled as zero-mean, complex Gaussian random variable with N_0.

For an Amplify and Forward cooperation protocol, the relay amplifies the received signal and forwards it to the destination with transmitted power P_{f_i}. In phase 2, the received signal at the destination from the relay can be expressed as

$$r_{fd_i} = \frac{\sqrt{P_{f_i}}}{\sqrt{P_{s_i}\left|g_{sf_i}\right|^2 + N_0}} g_{fd_i} r_{sf_i} + z_{fd_i} \tag{3.3}$$

where g_{rd_i} denote the channel coefficient from the relay to the destination and z_{sd_i} is an additive noise.

We assume that the source sends data with power P_{s_i} on the ith subcarrier to relay and destination, after amplified the received signal the relay forward signals to destination. In the phase 2, the received signal at destination from the relay can be expressed as

$$r_{fd_i} = (r_{sf_i} a) g_{fd_i} + z_{fd_i} \tag{3.4}$$

Where a_i is a power scaling factor can be expressed as

$$a_i = \frac{\sqrt{P_{f_i}}}{\sqrt{P_{s_i} \left| g_{sf_i} \right|^2 + N_0}} \tag{3.5}$$

to ensure a relay transmit power on the ith subcarrier of P_{f_i} . The noise variance at the relay within one OFDM subchannel is denoted by N_0.

In the phase 1, the received SNR at the relay and destination can be formulated as

$$SNR_{sf_i} = \frac{P_{s_i} \left| g_{sf_i} \right|^2}{N_0} \tag{3.6}$$

the destination received signals from two ways that is source and relay. If destination only received the signal from source where SNR_{sd_i} can be formulated as

$$SNR_{sd_i} = \frac{P_{s_i} \left| g_{sd_i} \right|^2}{N_0} \tag{3.7}$$

If the destination only received signal from relay where SNR_{fd_i} can be formulated as

$$SNR_{fd_i} = \frac{1}{N_0} \frac{P_{s_i} \left| g_{sf_i} \right|^2 P_{f_i} \left| g_{fd_i} \right|^2}{P_{s_i} \left| g_{sf_i} \right|^2 + P_{f_i} \left| g_{fd_i} \right|^2 + N_0} \tag{3.8}$$

where signal to noise ratio (SNR) at the output of a temporal maximum ratio combiner SNR_{MRC_i} . In the phase 2, the received SNR at destination using maximum ratio combiner (MRC) can be formulated as

$$SNR_{fd_i} = \frac{1}{N_0} \frac{P_{s_i} \left| g_{sf_i} \right|^2 P_{f_i} \left| g_{fd_i} \right|^2}{P_{s_i} \left| g_{sf_i} \right|^2 + P_{f_i} \left| g_{fd_i} \right|^2 + N_0} + \frac{P_{s_i} \left| g_{sd_i} \right|}{N_0} \tag{3.9}$$

the noise variance at the destination within one OFDM-based subcarrier can be denoted by N_0.

The expression for the BER of M-QAM in terms of the SNR_{MRC_i} and the number of bits which denotes by b_i can be approximated as

$$\mathrm{BER}_i(SNR_{MRC_i}, b_i) \approx \frac{2}{b_i}\left(1 - \frac{1}{\sqrt{2^{b_i}}}\right) \times erfc\left(\sqrt{\frac{1.6SNR_{MRC_i}}{2^{b_i} - 1}}\right) \tag{3.10}$$

However, the above expression is not easily differentiable or invertible in its SNR or the number of bits. Considering a different approximation with these properties, an approximation BER is presented as

$$\mathrm{BER}_i(SNR_{MRC_i}, b_i) \approx 0.2\exp\left(\frac{-1.6SNR_{MRC_i}}{2^{b_i} - 1}\right) \tag{3.11}$$

For a given target BER (tBER), the maximal achievable bits transmitted by the ith subcarrier can be approximated as

$$b_i \cong \log_2\left(1 + \frac{SNR_{MRC_i}}{\Gamma}\right) \tag{3.12}$$

where $\Gamma = \dfrac{\ln(5tBER)}{-1.6}$ is a constant.

In this project, we consider the M-QAM with Gray bit mapping is applied. The OFDM-based system applies adaptive modulation scheme in order to take advantage of fluctuations in the channel condition. The main idea of this chapter would be the transmission rate as high as possible when the link condition better, and transmission at a lower rate when the link condition bad. Lower rates are achieved by using a small constellation, such as QAM. The higher rates are achieved with large constellations, such as 256-QAM.

3.3 Optimization Criteria

The objective of proposed optimization problem is to maximize throughput by power allocation at source node. An OFDM-based downlink system for a single relay scheme is considered. The constraint to this problem is total transmission power at source node which include subcarrier and power allocation, provides subcarrier and bit allocation data to the source for an OFDM symbol.

To optimize the transmit power allocation of the relay and/or source over the N subcarriers with respect to separated sum power constraints at both nodes as

$$\sum_{i=1}^{N} P_{s_i} = P_{s_{total}} \tag{3.13}$$

$$\sum_{i=1}^{N} P_{f_i} = P_{f_{total}} \tag{3.14}$$

The values of the transmit power over the subcarriers are thereby stacked in the vectors can be define as $\mathrm{P_S} = [P_{s_1}, P_{s_2}, ..., P_{s_N}]^{\mathrm{T}}$ and $\mathrm{P_F} = [P_{f_1}, P_{f_2}, ..., P_{f_N}]$ ，respectively. We assume that all parameters which are not subject of the current optimization problem are known to the optimizing node. This includes channel coefficients and noise variances. We derive the optimal transmit PA over the subcarriers at the source assuming a given uniform power transmit power allocation at the relay. Then propose an alternating optimization of source transmit power allocation. To optimization of source power allocation we assume that the vector P_s is defined.

To maximize the overall throughput for a given uniform power at the relay node and optimal power allocation at the source node with allocation algorithms. For an OFDM-based downlink system with N subcarriers that the objective is to maximize the total continuous data rate of the OFDM-based system subject to total available transmission power at source under total power and target BER constraints.

Mathematically, the optimization problem can be formulated as

$$\underset{p_s}{\text{Max}} \sum_{i=1}^{N} b_i \tag{3.15}$$

subject to :

$$\sum_{i=1}^{N} P_{s_i} = P_{s_{total}} \tag{3.16}$$

$$P_{s_i} \geq 0, \quad i = 1,..., N \tag{3.17}$$

where N is the total number of subcarriers, P_{s_i} is the power allocated for *i*th subcarrier at the source. $P_{s_{total}}$ is the total power constraint at the source.

To obtain the optimal solution in (3.12), to allocation power on the *i*th subcarrier at source and relay should be allocated jointly. However, this causes a prohibitive high computational complexity. Separating the source and relay power allocation is a way to reduce the computational complexity. The transmission power for each subcarrier can be adapted by using Lagrange multiplier method. The algorithm can be demonstrated in [37]-[38] as the optimal solution for the problem that distributed power into parallel independent channels with a total available power constraint. After subcarrier allocation, the system employed Lagrange multiplier method to solve the optimization problem of (3.15) the optimal power allocation can be obtained by appendix B. We can use the Lagrange method to determine the solution of the optimization problem with the Lagrange function $L(P_{s_1},..., P_{s_N}, \alpha, \varepsilon_1,..., \varepsilon_N)$ as

$$
\begin{aligned}
&L(P_{s_1},..., P_{s_N}, \alpha, \varepsilon_1,..., \varepsilon_N) \\
&= \sum_{i=1}^{N} b_i + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) + \sum_{i=1}^{N} \varepsilon_i P_{s_i} \\
&= \sum_{i=1}^{N} \log_2\left(1 + \frac{SNR_{MRC_i}}{\Gamma}\right) + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) + \sum_{i=1}^{N} \varepsilon_i P_{s_i} \\
&= \sum_{i=1}^{N} \log_2\left(1 + \frac{\frac{1}{N_0} \frac{P_{s_i}\left|g_{sf_i}\right|^2 \frac{P_{f_{total}}}{N}\left|g_{fd_i}\right|^2}{P_{s_i}\left|g_{sf_i}\right|^2 + \frac{P_{f_{total}}}{N}\left|g_{fd_i}\right|^2 + N_0} + \frac{P_{s_i}\left|g_{sd_i}\right|^2}{N_0}}{\Gamma}\right) + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) + \sum_{i=1}^{N} \varepsilon_i P_{s_i}
\end{aligned} \tag{3.18}
$$

The Lagrange function can be rewrited as

$$
L(P_{s_1},..., P_{s_N}, \alpha, \varepsilon_1,..., \varepsilon_N) = \sum_{i=1}^{N} \log_2\left(1 + \frac{\left(a_i P_{s_i} + \frac{b_i P_{s_i} c_i \frac{P_{f_{total}}}{N}}{1 + b_i P_{s_i} + c_i \frac{P_{r_{total}}}{N}}\right)}{\Gamma}\right) + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) \tag{3.19}
$$

$$
+ \sum_{i=1}^{N} \varepsilon_i P_{s_i}
$$

Where $a_i = \frac{\left|h_{sd_i}\right|^2}{N_0}$, $b_i = \frac{\left|h_{sf_i}\right|^2}{N_0}$, $c_i = \frac{\left|h_{fd_i}\right|^2}{N_0}$

The solution $\mathrm{P_S} = \left[P_{s_1}, P_{s_2},..., P_{s_N}\right]^{\mathrm{T}}$ satisfies the following conditions:

$$
\nabla_{\mathrm{P_S}} L(\mathrm{P_S}, \alpha, \varepsilon_1,..., \varepsilon_N) = 0 \tag{3.20}
$$

$$
\sum_{i=1}^{N} P_{s_i} - P_{s_{total}} = 0 \tag{3.21}
$$

$$
\varepsilon_i P_{s_i} = 0 \quad \text{for } i = 1,..., N \tag{3.22}
$$

$$
P_s \geq 0 \quad \text{for } i = 1,..., N \tag{3.23}
$$

$$\varepsilon_i \geq 0 \quad \text{for} \quad i = 1,...,N \tag{3.24}$$

Then we differentiate the Lagrange function $L(\mathrm{P}_s, \alpha, \varepsilon_1,...,\varepsilon_N)$ with respect to P_{s_i} and set each derivative to 0.

$$\frac{\partial L}{\partial P_{s_i}} = \frac{\dfrac{\Gamma b_i + 2a_i P_{s_i} b_i + a_i c_i \dfrac{P_{f_{total}}}{N} + a_i c_i \dfrac{P_{f_{totsl}}}{N}}{\Gamma\left(b_i P_{s_i} + c_i \dfrac{P_{f_{total}}}{N}\right)} - \dfrac{\Gamma b_i^2 P_{s_i} + \Gamma b_i c_i \dfrac{P_{f_{total}}}{N} + a_i b_i^2 P_{s_i}^2 + a_i b_i P_{s_i} c_i \dfrac{P_{f_{total}}}{N} + b_i^2 P_{s_i} c_i \dfrac{P_{f_{total}}}{N}}{\Gamma\left(b_i P_{s_i} + c_i \dfrac{P_{f_{total}}}{N}\right)^2}}{\dfrac{\Gamma\left(b_i P_{s_i} + c_i \dfrac{P_{f_{total}}}{N}\right) + a_i P_{s_i}^2 b_i + a_i P_i c_i \dfrac{P_{f_{total}}}{N} + b_i P_{s_i} c_i \dfrac{P_{f_{total}}}{N}}{\Gamma\left(b_i P_{s_i} + c_i \dfrac{P_{f_{total}}}{N}\right)}} + \alpha$$

$$= 0 \tag{3.25}$$

$$\frac{\partial L}{\partial P_{s_i}} = 0 \Rightarrow \frac{a_i b_i^2 P_{s_i}^2 + 2a_i b_i c_i \dfrac{P_{f_{total}}}{N} P_{s_i} + a_i c_i^2 \left(\dfrac{P_{f_{total}}}{N}\right)^2 + b_i c_i^2 \left(\dfrac{P_{f_{total}}}{N}\right)^2}{\left[\left(b_i P_{s_i} + c_i \dfrac{P_{f_{total}}}{N}\right)\left(\Gamma + \alpha_i P_{s_i}\right) + b_i P_{s_i} c_i \dfrac{P_{f_{total}}}{N}\right]\left(b_i P_{s_i} + c_i \dfrac{P_{f_{total}}}{N}\right)} + \alpha = 0 \tag{3.26}$$

The KKT conditions by the constraints of above for the uniform power allocation by the subcarriers of relay node (equal power distribution). To solve the Lagrange function with the KKT conditions by the differentiate above equation to get the power distribution across subcarriers. We get the power distribution at the *i*th subcarrier can be formulated as

$$P_{s_i} = \sqrt{\frac{-\alpha - \alpha j_i - m_i}{e_i^2 + \alpha f_i^2} + \left(\frac{v_i + \alpha k_i}{e_i^2 + \alpha f_i^2}\right)^2} - \frac{v_i + \alpha k_i}{e_i^2 + \alpha f_i^2} \tag{3.27}$$

The constant α can be solved by summing above N equations to equal total transmission power.

$$P_{s_{total}} = \sum_{i=1}^{N}\left(\sqrt{\frac{-\alpha - \alpha j_i - m_i}{e_i^2 + \alpha f_i^2} + \left(\frac{v_i + \alpha k_i}{e_i^2 + \alpha f_i^2}\right)^2} - \frac{v_i + \alpha k_i}{e_i^2 + \alpha f_i^2}\right)^+ \tag{3.28}$$

Purpose the optimization of source power Allocation Algorithm as follows:

Optimal Power Allocation Algorithm

1) Optimal power allocation at source

   1.a) Obtain α from (3.28)

   1.b) Use α , (3.27) to find P_{s_i} for all i

   1.c) Calculate b_i to allocate the bits number for all subcarriers

$$b_i = \log_2\left(1 + \frac{SNR_{MRC_i}}{\Gamma}\right)$$

2) Terminate algorithm

In this subsection, we discuss a suboptimal of source power allocation algorithm where equal power distribution at the relay has been described. The proposed algorithm for the source power allocation use (2.18) list below

$$b_i = \log_2\left(1 + \frac{SNR_{MRC_i}}{\Gamma}\right)$$

The subcarrier of the source power allocation can be formulated from (2.18) to the solution as

$$b_i \cong \log_2\left(1 + \frac{\frac{1}{N_0}\frac{P_{s_i}\left|g_{sf_i}\right|^2 \frac{P_{f_{total}}}{N}\left|g_{fd_i}\right|^2}{P_{s_i}\left|g_{sf_i}\right|^2 + \frac{P_{f_{total}}}{N}\left|g_{fd_i}\right|^2 + N_0} + \frac{P_{s_i}\left|g_{sd_i}\right|^2}{N_0}}{\Gamma}\right)$$

Where $d_i = \Gamma(2^{b_i} - 1), l_i = d_i b_i - a_i - a_i c_i - b_i c_i$ substitute into above equation as

$$P_{s_i} = \frac{-l \pm \sqrt{l_i^2 + 4a_i b_i\left(d_i + d_i c_i \frac{P_{f_{total}}}{N}\right)}}{-2a_i b_i} \quad (3.29)$$

Suboptimal Power Allocation Algorithm

1) Initialization

1.a) Let $b_i = b_{MAX}$ for all i

1.b)N={1,2,…,N}

2) Source power allocation

2.a) Obtain P_{s_i} from (3.29) for all i

2.b) If $\sum_{i=1}^{N} P_{s_i} > P_{s_{total}}$ go to next step, else set final allocation and terminate algorithm

2.c) Compute $P_{s_i}^*$ from (3.29) for all i using $b_i - 1$

2.d) Select the subcarrier i^* that has the maximum cost to reduce one bit:

$$i^* = \arg\max_{i \in \mathrm{N}} P_{s_i} - P_{s_i}^*$$

2.e) Let $b_{i^*} = b_{i^*} - 1$

2.f) Compute $P_{s_{i^*}}$ from (3.29) for i^*

2.g) If $b_{i^*} = 0$ then $\mathrm{N} = \mathrm{N} \setminus i^*$

2.h) go to step 2.a

3.4 Simulation Results

The proposed suboptimal algorithms were applied to the Single Source, destination and relay cooperative OFDM-based system with the following parameters: number of subcarriers N=16; and $tBER = 10^{-3}$ for all users. The channels were assumed to be fixed during one OFDM symbol period and six taps independent Rayleigh multipath channels with exponentially decaying power profile.

For comparison purposes in the single source power allocation problem, we have considered two other power allocation methods. One of them is applied equal power allocation among all subcarriers. Another is purpose optimal power allocation algorithm to distribute power among all subcarriers.

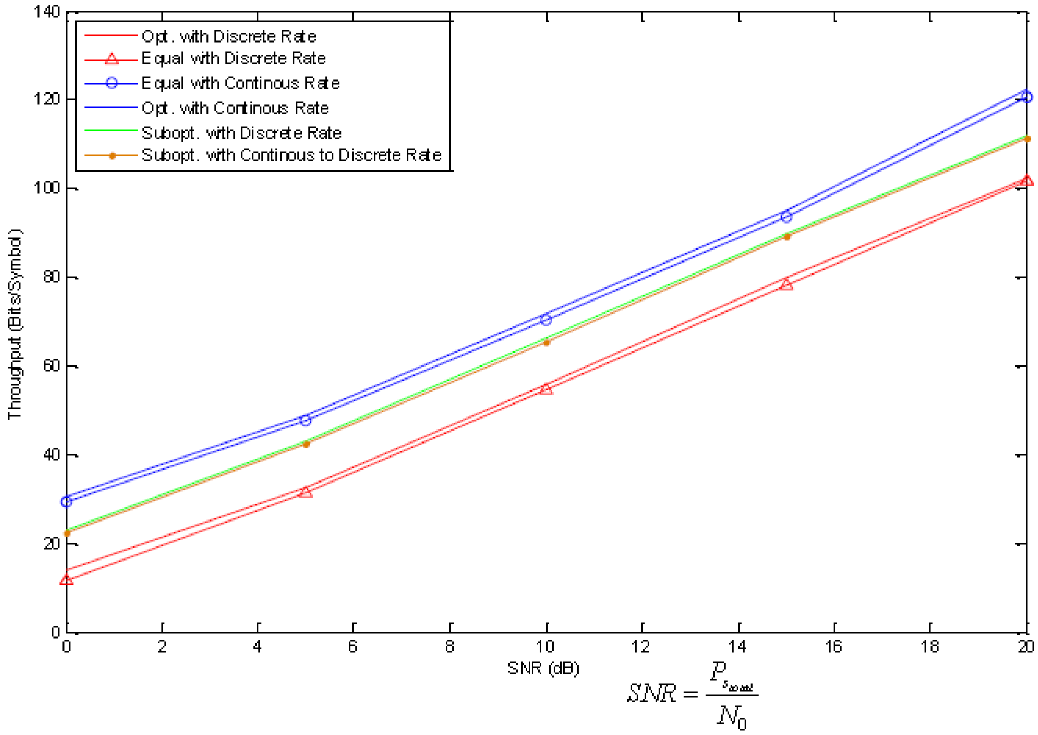

Fig. 3.3 Total throughput for different power allocation algorithm with N = 16 and *tBER* = 0.01

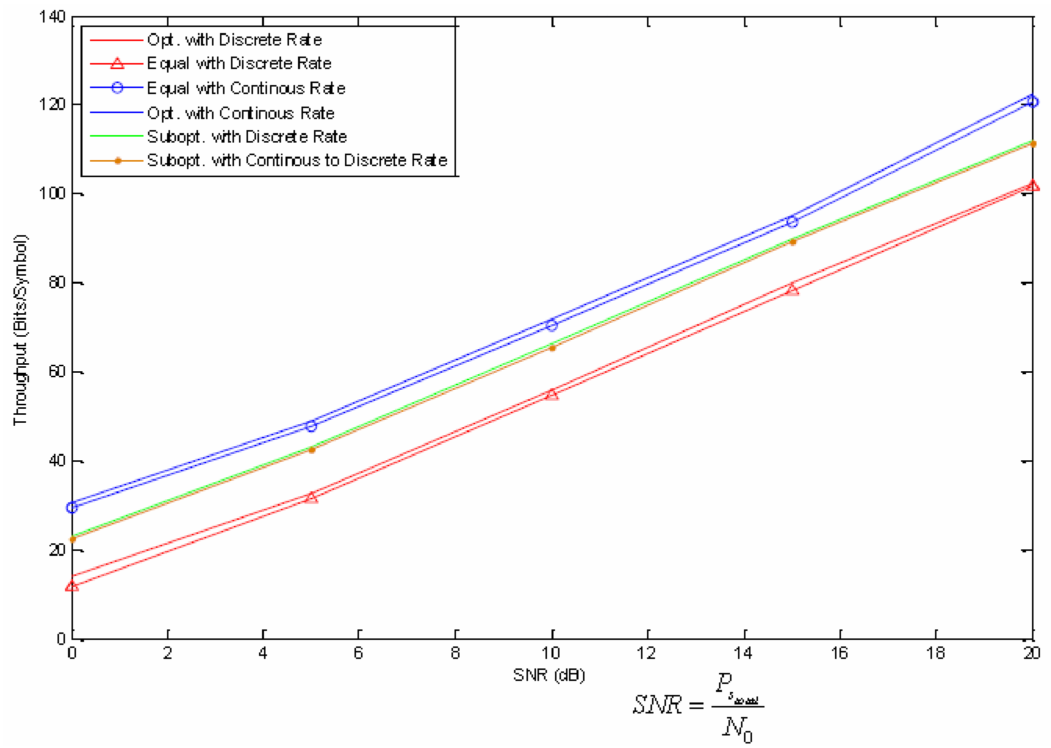

Fig. 3.4 Total throughput for different power allocation algorithm with N = 16 and *tBER* = 0.005

3.5 Summary

This chapter introduces the resource allocation for the powe allocation at subcarrier of source node that is in the single relayand single source-destination OFDM-based cooperative systems. To improve the system performance according to relay power allocation optimization criteria, the suboptimal allocation algorithm are proposed, respectively. In the suboptimal algorithm, subcarrier and power allocation are carried out separately for both source (using uniform power distribution) and relay optimization problems. From simulation results, we can observe that the proposed suboptimal algorithms have better performance close to the optimal environments whether above problems.

IV. Adaptive Resource Allocation for Dual-Hop Multi-Relay OFDM-Based Cooperative Communication Systems

4.1 Introduction

Cooperative relaying technique has become a powerful topic of the next-generation wireless communication systems for its ability of extending coverage and improving capacity. One of the important relaying strategies of amplify and forward (AF) is proved to be usable in practical scenario [50]. Amplify and forward (AF) mode is simple as the received signal at relay to amplify and forward without any decoding or demodulation process. A lot of research has been done to analyze the related performance.

Due to the spectrum efficiency robustness in multi-path propagation environments and ability to combat the inter symbol interference the orthogonal frequency division multiplexing (OFDM) is considered an effect technique in the broadband wireless communication system. The combination of the relaying and OFDM is an even promising way to improve system capacity and extend coverage. Different from single carrier system, multi-relay OFDM-based systems channel transfer function may vary in different relay links because of the propagation environment. In conventional cooperative OFDM-based AF relaying systems, no additional relay selection operation is done in relay. To utilize the independence of different relay links, recently single relay without direct SD link is discussed to improve the capacity of both AF [51]-[52] and DF relaying [53]-[54]. The basic idea is to pair the subcarriers of the first hop (SD link) and the second hop (RD link) in the order of channel gain for data transmission. However, these researches only focus on single relay scenario. When systems are with multiple relays less than one source are concerned, relay selection should be taken into consideration, referring to which relay is selected to forward signal on a certain relay links. In [55], jointly subcarrier matching and relay selection with multiple parallel without direct SD link, AF relays has been studied. However, no power allocation with regard to multiple relays has been studied, which is crucial for capacity enhancement.

In this chapter, we consider a two-hop AF relaying system where a source communicates with its destination through multiple relay nodes. To maximize the allocation bits at the subcarriers, we formulate the optimal solution for selected relay and optimization of multi-relay ubcarriers assignment and power allocation as a mixed binary integer programming problem. Due to the high complexity of the problem, a suboptimal solution is proposed to solve relay and power allocation problems. Simulation results show that the proposed algorithm with relay selection and optima bits power allocation achieves are very close to optima compared to the optimal solution.

4.2 System Model

A downlink single source-destination multi-relay OFDM-based cooperative system which consists of a transmitter, N subcarrier and M relay is shown in Fig. 4.1.

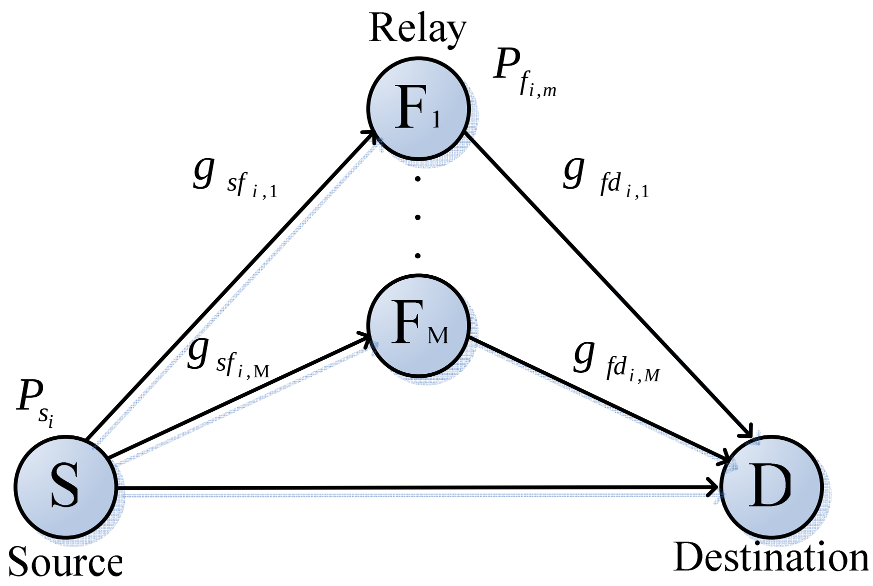

Fig. 4.1 Multi-Relay OFDM-Based cooperative system with single source and Destination

In the phase 1, the received signals at the destination and the *m*th relay can be expressed as

$$r_{sd_i} = \sqrt{P_{s_i}}\, g_{sd_i} T_i + z_{sd_i} \tag{4.1}$$

$$r_{sf_{i,m}} = \sqrt{P_{s_i}}\, g_{sf_{i,m}} T_i + z_{sf_{i,m}} \tag{4.2}$$

in which P_{s_i} is the transmitted power at the source of the *i*th subcarrier, T_i is the transmitted information bits per symbol, and z_i is additive noise. In (4.1) and (4.2) , g_{sd_i} and $g_{sf_{i,m}}$ are the channel coefficients from the source to the destination and the source to the selected mth relay respectively. They are model as zero-mean, complex Gaussian random variables with variances $\delta^2_{sd_i}$ and $\delta^2_{sf_{i,m}}$, respectively. The noise terms z_i is modeled as zero-mean, complex Gaussian random variance N_0 .

For an Amplify-and-Forward cooperation protocol, the *m*th relay amplifies the received signal and forwards it to the destination with transmitted power $P_{f_{i,m}}$. In the phase 2, the received signal at destination from the mth relay can be expressed as

$$r_{f_{i,m}d_i} = (y_{sf_{i,m}} a_{i,m}) g_{f_{i,m}d_i} + z_{f_{i,m}d_i} \tag{4.3}$$

where $a_{i,m} = \sqrt{P_{f_i} \Big/ \left(P_{s_i} \left| g_{sf_{i,m}} \right|^2 + N_0 \right)}$ is a power scaling factor.

In the phase 1, the received SNR at the *m*th relay and destination can be formulated respectively as

$$SNR_{sf_{i,m}} = \frac{P_{s_i} \left| g_{sf_{i,m}} \right|^2}{N_0} \tag{4.4}$$

$$SNR_{sd} = \frac{P_{s_i} \left| g_{sd_i} \right|^2}{N_0} \tag{4.5}$$

In the phase 2, the received SNR at destination from the selected mth the relay that the $SNR_{f_{i,m}d_i}$ can be formulated as

$$SNR_{f_{i,m}d_i} = \frac{1}{N_0} \frac{P_{s_i} \left| g_{sf_{i,m}} \right|^2 P_{f_{i,m}} \left| g_{f_{i,m}d_i} \right|^2}{P_{s_i} \left| g_{sf_{i,m}} \right|^2 + P_{f_{i,m}} \left| g_{f_{i,m}d_i} \right|^2 + N_0} \tag{4.6}$$

In the phase 2, the received SNR at destination using maximum ratio combiner (MRC) can be formulated as

$$SNR_{MRC_{i,m}} = \frac{1}{N_0} \frac{P_{s_i} \left| g_{sf_{i,m}} \right|^2 P_{f_{i,m}} \left| g_{f_{i,m}d_i} \right|^2}{P_{s_i} \left| g_{sf_{i,m}} \right|^2 + P_{f_{i,m}} \left| g_{f_{i,m}d_i} \right|^2 + N_0} + \frac{P_{s_i} \left| g_{sd_i} \right|^2}{N_0} \tag{4.7}$$

4.3 Optimization Criterion

Considered the single source, destination and multi-relay OFDM-Based cooperative systems is to allow selected *m*th relay node reliably receive data from the *m*th relay of the *i*th subcarrier. The throughput of ith subcarrier is determined by the data rate (number of bits transmitted over an OFDM symbol) of the ith subcarrier by b_i. Thus, the instantaneous data rate $b_{i,m}$ can be expressed as

$$b_{i,m} = \log_2 \left(1 + \frac{SNR_{MRC_{i,m}}}{\Gamma} \right) \tag{4.8}$$

In multi-relay OFDM-based cooperative systems the transmission ability is dependent on each relay. To choose the maximize throughput relay from multi-relay environment would be better than single relay systems. The relay selection will be more important than single relay systems. Let $P_{s_i} = \frac{P_{s_{total}}}{N}$, $P_{f_{i,m}} = \frac{P_{f_{total}}}{N}$ define the uniform power distribution at source and relay subcarriers. The rule of relay selection can be describe as

$$m^* = \arg\max_{m=1,\dots,M} b_{i,m}$$
$$b_{i,m} = \log_2\left(1 + \frac{SNR_{MRC_{i,m}}}{\Gamma}\right) \quad (4.9)$$

where the m^* denotes the maximum transmission bits per symbol of the relay node with uniform power allocation at source and relay.

Optimization Problem

The objective is to maximize the overall throughput under target BER of all subcarriers and total available power constraints by optimizing the power allocation $P_{s_{i,m^*}}$.

With the above notations, the optimization problem of the multi-relay at subcarriers can be formulated as

$$\operatorname*{Max}_{P_s} \sum_{i=1}^{N} b_{i,m^*} \quad (4.10)$$

Subject to:

$$\sum_{i=1}^{N} P_{s_i} = P_{s_{total}} \quad (4.11)$$

$$P_{s_i} \geq 0 \quad i = 1,\dots,N \quad 4.12)$$

After subcarrier allocation, the system employed Lagrange multiplier method to solve the optimization problem of (4.10), the optimal power allocation can be obtained by appendix B. We can use the Lagrange method to determine the solution of the optimization problem with the Lagrange function $L(P_{s_1},\dots,P_{s_N},\alpha,\varepsilon_1,\dots,\varepsilon_N)$ as

$$\begin{aligned}
&L(P_{s_1},\dots,P_{s_N},\alpha,\varepsilon_1,\dots,\varepsilon_N) \\
&= \sum_{i=1}^{N} b_i + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) + \sum_{i=1}^{N} \varepsilon_i P_{s_i} \\
&= \sum_{i=1}^{N} \log_2\left(1 + \frac{SNR_{MRC_i}}{\Gamma}\right) + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) + \sum_{i=1}^{N} \varepsilon_i P_{s_i} \\
&= \sum_{i=1}^{N} \log_2\left(1 + \frac{\frac{1}{N_0}\frac{P_{s_i}\left|g_{sf_i}\right|^2 \frac{P_{f_{total}}}{N}\left|g_{fd_i}\right|^2}{P_{s_i}\left|g_{sf_i}\right|^2 + \frac{P_{f_{total}}}{N}\left|g_{fd_i}\right|^2 + N_0} + \frac{P_{s_i}\left|g_{sd_i}\right|^2}{N_0}}{\Gamma}\right) + \alpha\left(\sum_{i=1}^{N} P_{s_i} - P_{s_{total}}\right) + \sum_{i=1}^{N} \varepsilon_i P_{s_i}
\end{aligned} \quad (4.14)$$

To solve the problem of (4.10), the optimal source power allocation can be obtained by appendix B and the subcarriers of the selected mth relay power allocation on $p_{s_{i,m^*}}$ can be formulated as

$$P_{s_{i,m^*}} = \sqrt{\frac{-\alpha - \alpha j_i - m_i}{e_i^2 + \alpha f_i^2} + \left(\frac{g_i + \alpha k_i}{e_i^2 + \alpha f_i^2}\right)^2} - \frac{g_i + \alpha k_i}{e_i^2 + \alpha f_i^2} \quad (4.15)$$

Optimal source Power Allocation Algorithm

1) Relay selection

1.a) Select the maximum transmission bits numbers of the source using

$$m^*_{\max} = \arg\max_{m=1,\ldots,M} \sum_{i=1}^{N} b_{i,m^*}$$

2) Optimal power allocation at source

2.a) obtain α from (3.28)

2.b) use α , into (3.27) to get P_{s_i} for all *i*

2.c) calculate b_{i,m^*}, to allocate the bits number for all subcarriers

$$b_{i,m^*} = \log_2\left(1 + \frac{SNR_{MRC_{i,m^*}}}{\Gamma}\right)$$

3) Terminate algorithm

The $P_{s_{i,m^*}}$, denotes the power allocation from *i*th subcarrier of source node to selected *m*th relay node. The source power allocation can be formulated from (2.18) to the solution as

$$P_{s_i} = \frac{-v \pm \sqrt{(v^2 + 4ac(a + adP_{f_i}))}}{-2bc} \quad (4.16)$$

The suboptimal of source power allocation algorithm can be described as

Suboptimal source Power Allocation Algorithm

1) Initialization

1.a) let $b_{i,m^*} = b_{MAX}$ for all *i*

1.b) N={1,2,…,*N*}

2) Source power allocation

2.a) Obtain P_{s_i} from (4.16) for all i

2.b) If $\sum_{i=1}^{N} P_{s_i} > P_{s_{total}}$ go to next step, else set final allocation and terminate algorithm

2.c) Compute $P_{s_i}^*$ from (4.16) for all i using b_{i,m^*} - 1

2.d) Select the subcarrier i^* that has the maximum cost to reduce one bit:

$$i^* = \arg\max_{i \in \mathrm{N}} P_{s_i} - P_{s_i}^*$$

2.e) Let $b_{i^*,m^*} = b_{i^*,m^*}$ - 1

2.f) Compute $P_{s_{i^*}}$ from (4.16) for i^*

2.g) If $b_{i^*} = 0$ then N=N\ i^*

2.h) go to step 2.a

4.4 Simulation Results

In this section, we consider a multi-relay cooperative OFDM-based system with the following parameters: number of subcarriers N=16 ; and $tBER$ = 0.01and 0.005 for all users. In the simulations, six independent Rayleigh multipath channels with an exponentially decaying power profile are discussed.

Fig. 4.2-9 shows total throughput for different power allocation algorithm with different number of relay for M = 5, 10, 15, 20 and target BER $tBER$ = 0.01 and 0.005. The different suboptimal algorithms shows the purpose suboptimal algorithm with discrete rate and same algorithm with continuous rate to catch the discrete rate for the power reallocate after decimal point value by floor operate method

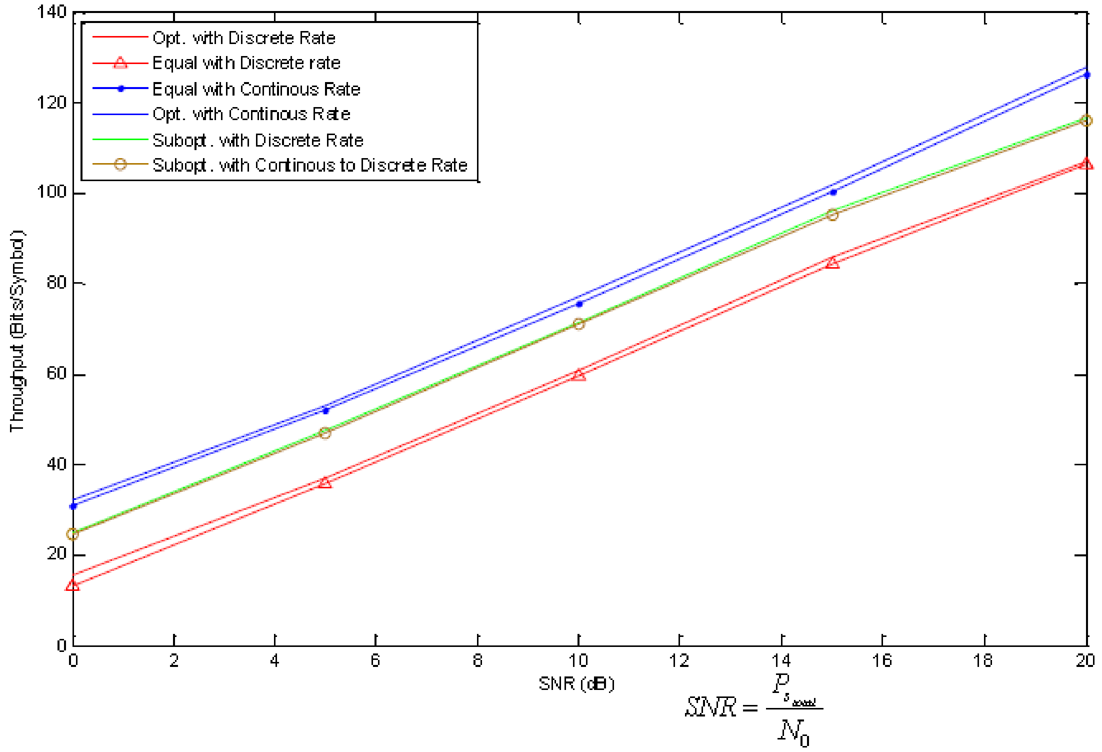

Fig. 4.2 Total throughput for different power allocation algorithm with M = 5, N = 16 and *t*BER = 0.01

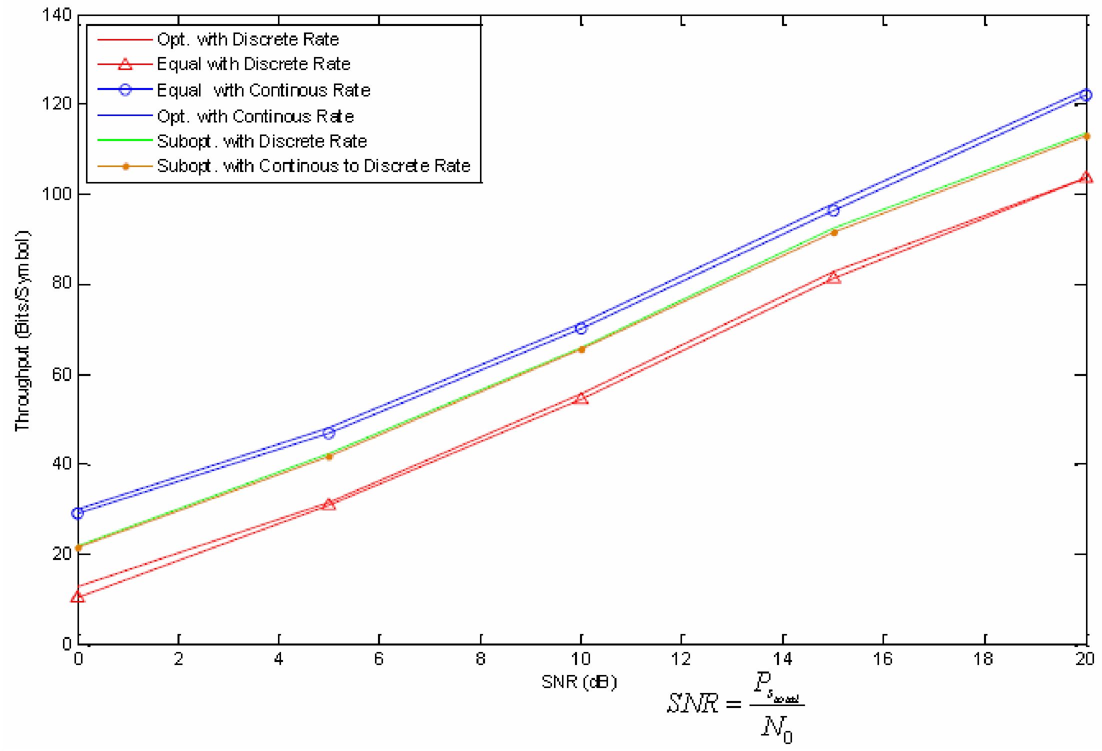

Fig. 4.3 Total throughput for different power allocation algorithm with M = 5, N = 16 and tBER = 0.005

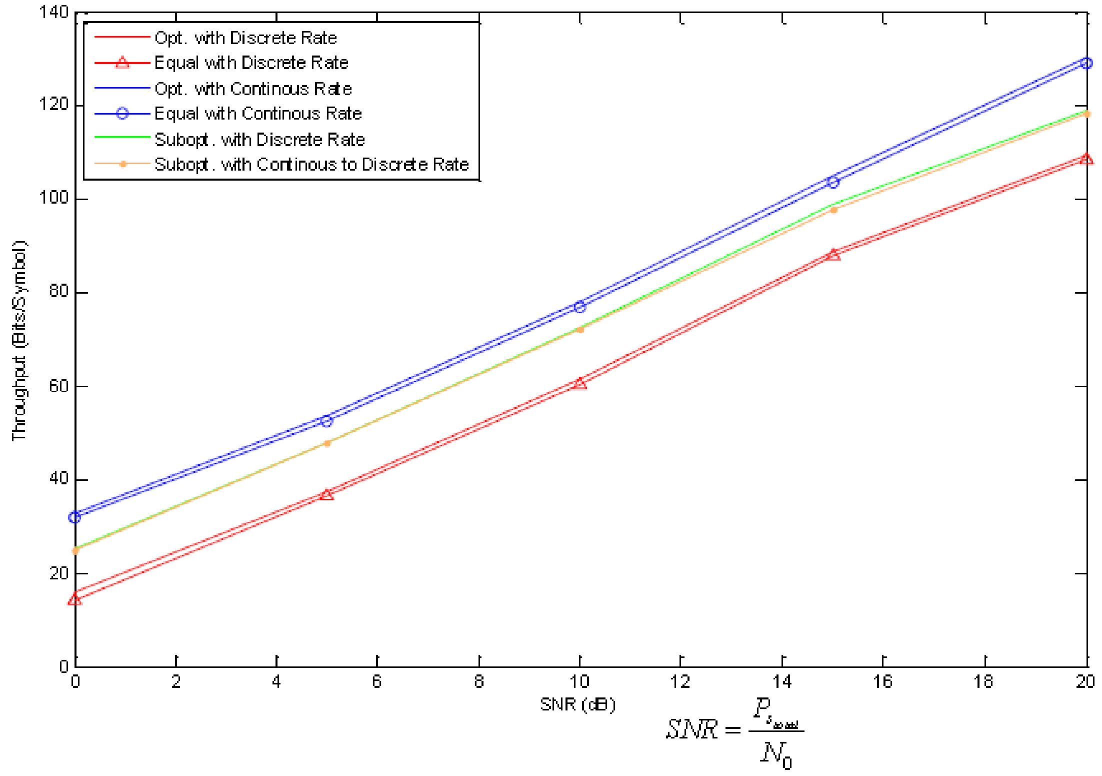

Fig. 4.4 Total throughput for different power allocation algorithm with M = 10, N = 16 and tBER = 0.01

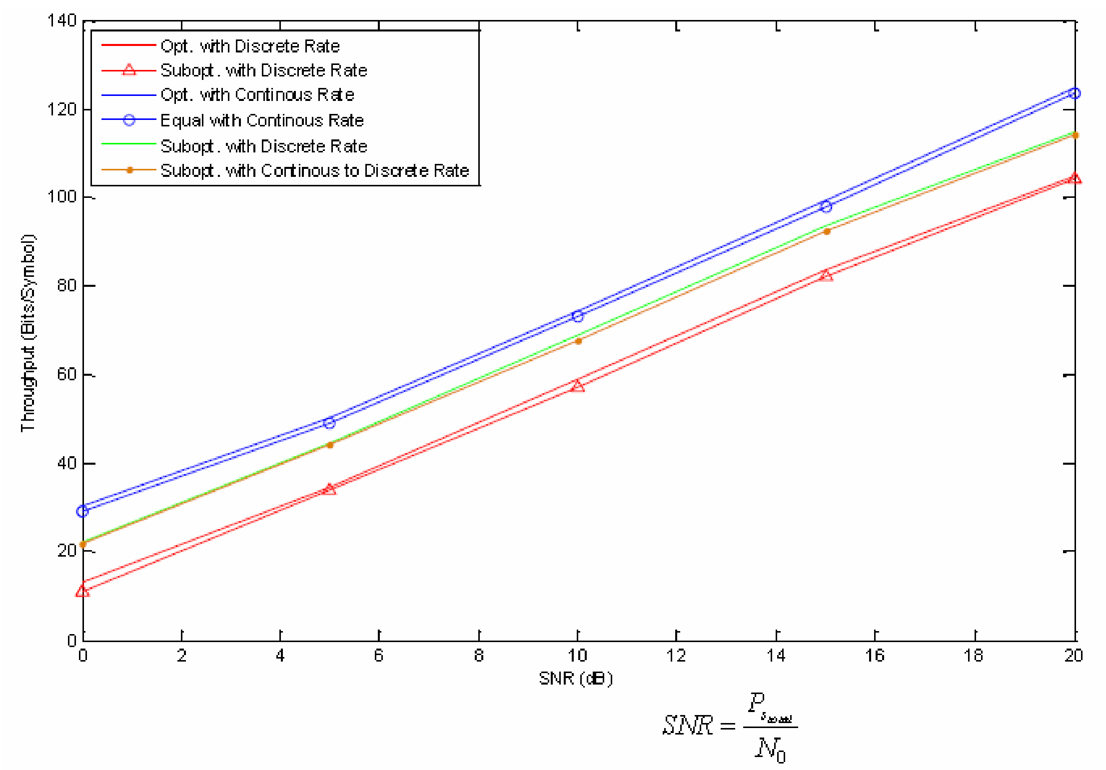

Fig. 4.5 Total throughput for different power allocation algorithm with M = 10, N = 16 and tBER = 0.005

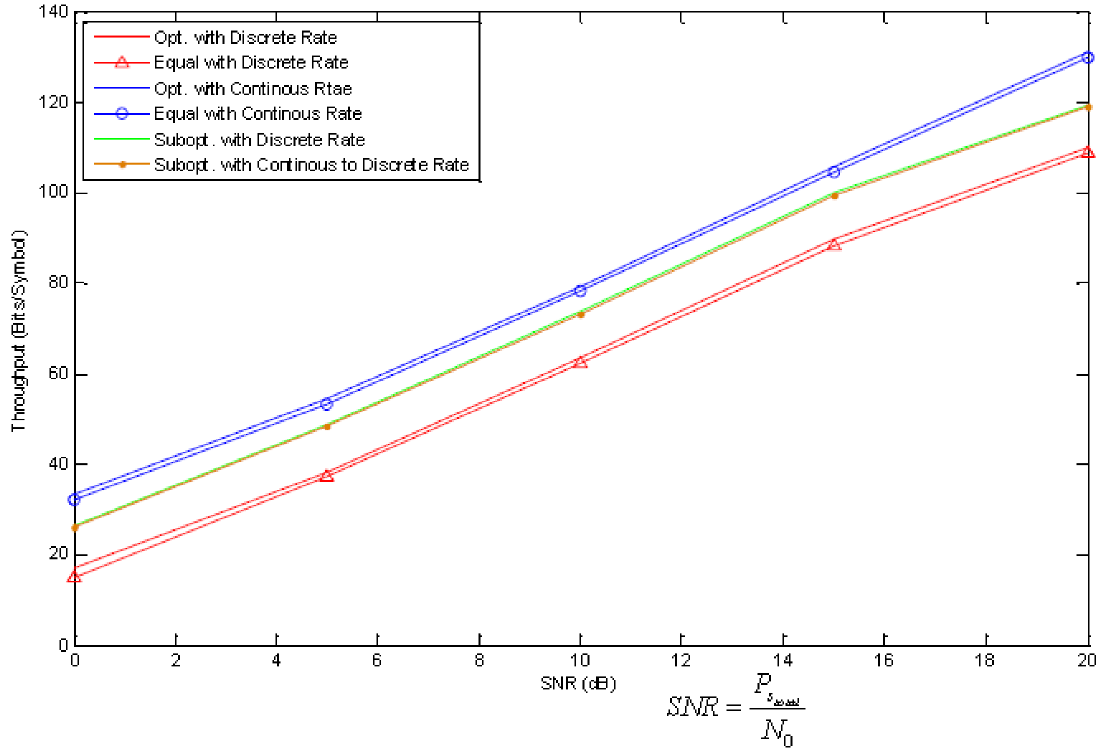

Fig. 4.6 Total throughput for different power allocation algorithm with M = 15, N = 16 and tBER = 0.01

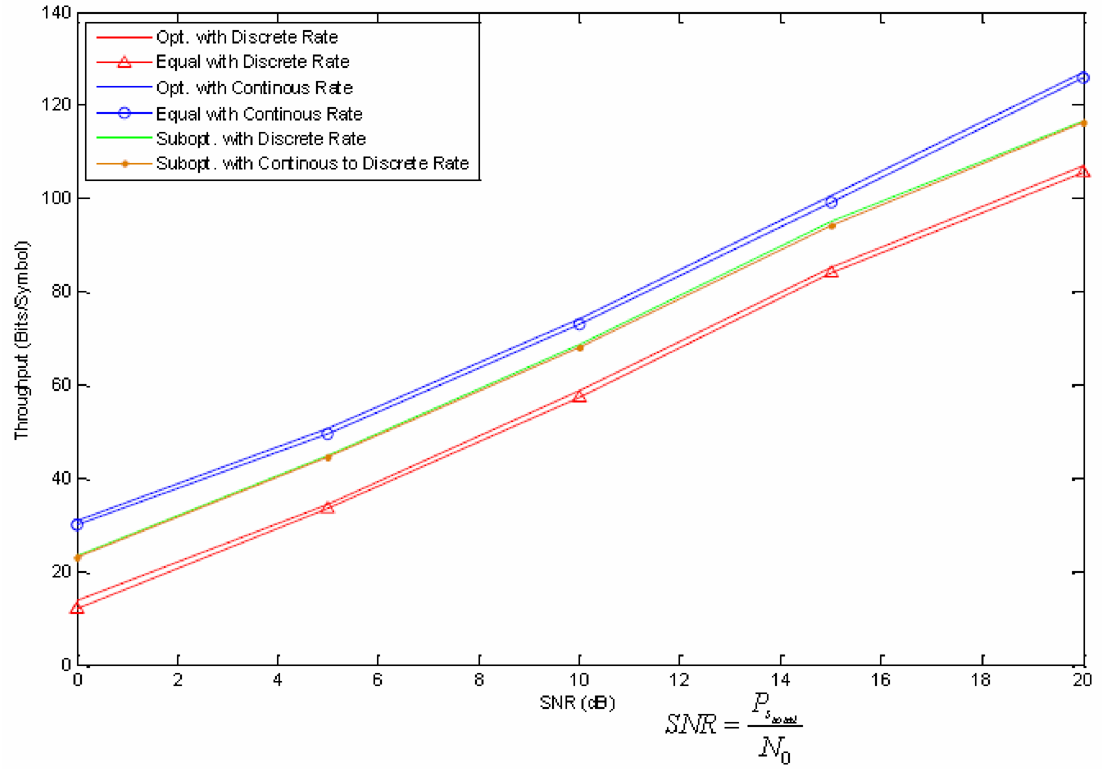

Fig. 4.7 Total throughput for different power allocation algorithm with M = 15, N = 16 and tBER = 0.005

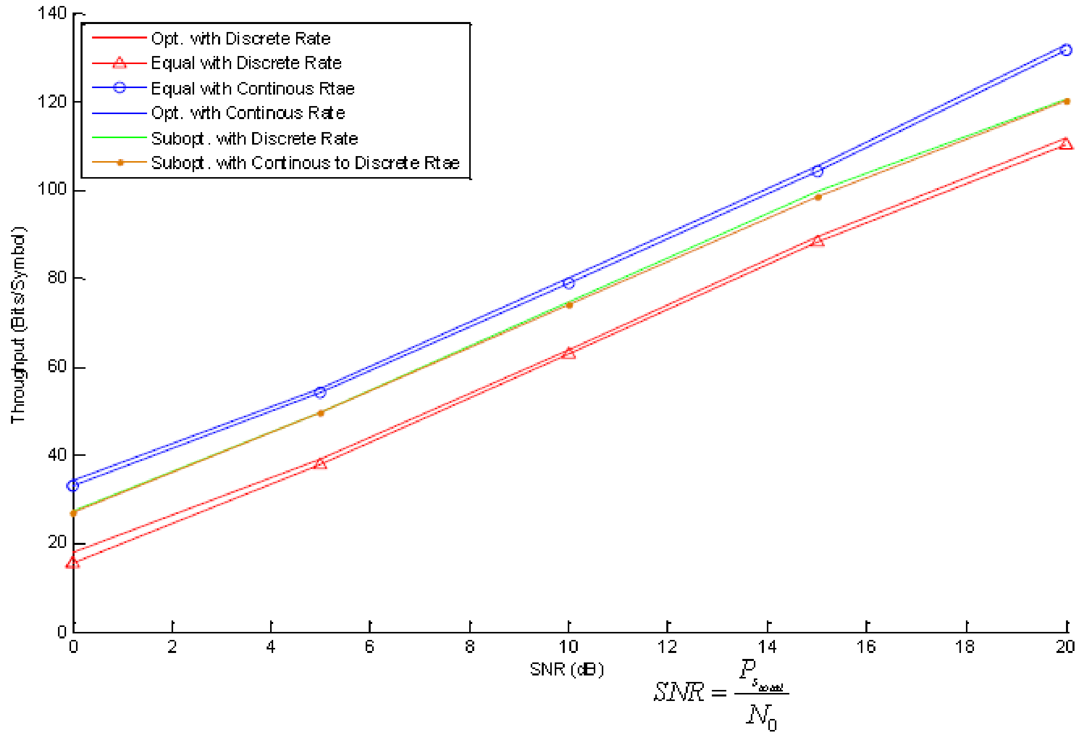

Fig. 4.8 Total throughput for different power allocation algorithm with M = 20, N = 16 and tBER = 0.01

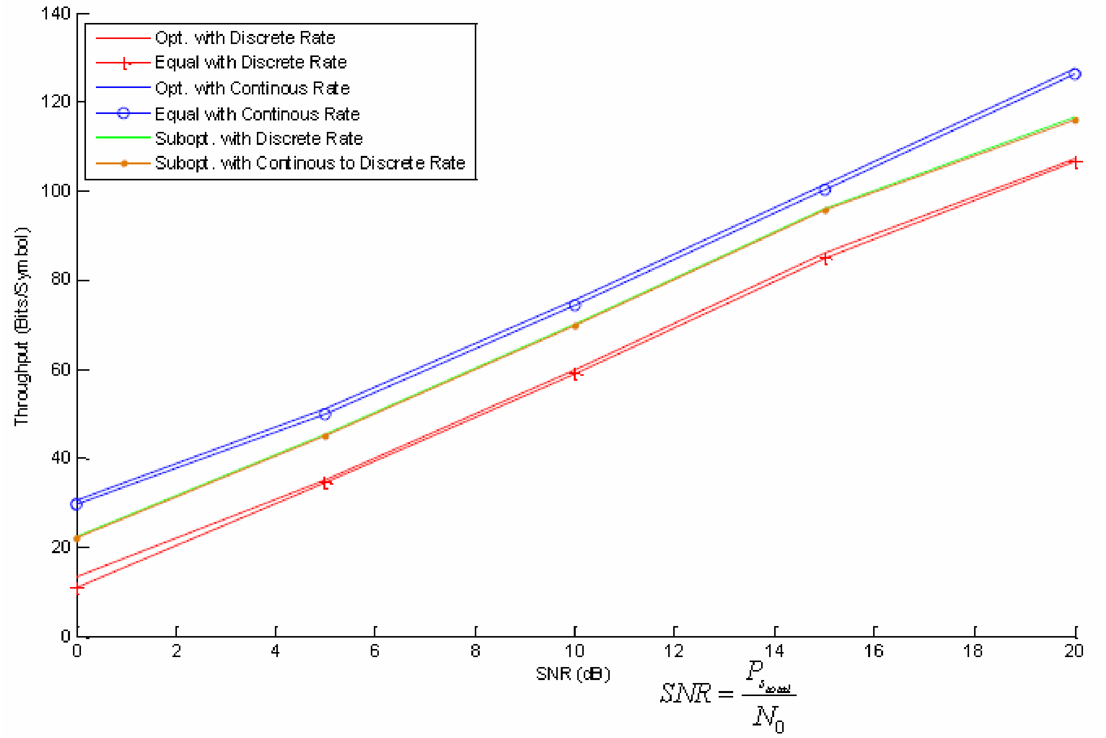

Fig. 4.9 Total throughput for different power allocation algorithm with M = 20, N = 16 and tBER = 0.005

4.5 Summary

This chapter presented the resource allocation for the power allocation at subcarriers of the selected node that to the multi-relay in the single source-destination OFDM-based cooperative systems. We first formulated the relay selection problem. Secondly, based on subcarriers power allocation at selected relay node, we proposed relay power allocation algorithms for effective throughput maximization. As mentioned in simulation results, it is also observed that the system effective throughput is significantly improved by using our proposed algorithms.

V. Summary and Conclusions

Resource management is an important issue in OFDM-based cooperative communication systems. In this project, we considered maximizing throughput and allocation bits per symbol over source node subcarriers with the power consumption optimization problems. Furthermore, we created a framework for designing and evaluating resource allocation algorithms.

The first part of the report provides a framework for the optimization problems in OFDM-based cooperative systems. For the optimization problems, we considered the single source, relay and destination in the OFDM-based cooperative communication system. We can observe that the optimization problems become convex optimization problems. Hence, we proposed an appropriate resource allocation algorithm which is based on Lagrange multiplier method to solve convex optimization problems. The proposed algorithm solved to find optimal solution. We can observe that the proposed suboptimal algorithms have better performance in the source power allocation to maximize bits per symbol on the subcarriers.

Secondly, the single relay OFDM-based cooperative system was extended to a multi-relay transmission. We proposed appropriate resource allocation algorithms for the maximizing throughput. The proposed algorithm is based on bit loading algorithm to obtain bit allocation among subcarriers. In another algorithm, the Lagrange multiplier method was exploited to solve optima allocation at the subcarriers at source compared with suboptimal algorithm. The simulation results showed that a remarkable performance improvement can be achieved Rayleigh fading channels.

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國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■ 達成目標

□ 未達成目標（請說明，以 100 字為限）

　□ 實驗失敗

　□ 因故實驗中斷

　□ 其他原因

說明：

1. 本計畫工作皆已達成預定目標。

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 ■未發表之文稿 □撰寫中 □無

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本計劃有已接受尚未發表期刊論文 1 篇；已發表會議論文 2 篇；已接受尚未發表會議論文 3 篇；審查中會議論文 3 篇。

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

學術成就

本計畫探討具正交分頻多工技術合作式通訊系統之適應性資源分配演算法，並使用動態資源分配之方法提升系統的子載波位元傳輸率和降低子載波傳送位元所需功率。目前存在的動態資源分配議題，大致上分為以下兩類：在有限的功率與目標位元錯誤率限制下，最大化系統產出量(Throughput)及在有限的功率與傳輸速率限制下，最小化位元錯誤率。本計畫針對前者進行詳細研究與分析。

技術創新

我們對單一來源端、目的端及中繼節點的環境與單一來源端、目的端及多個中繼節點的環境下，探討正交分頻多工技術之合作式通訊系統的最佳化問題。為了達到來源端子載波功率分配最佳化，我們導入拉格朗日乘數並利用 KKT （Karush-Kuhn-Tucker） 的條件法，成功推導出最佳化的來源端子載波功率分配。基於最佳化方法運算複雜度非常高，為了降低複雜度，並達到最大化系統產出量的目標，我們對來源端的子載波功率分配問題，設計其次佳化演算法。此次佳化演算法在有限的功率及目標位元錯誤率限制下，藉由調整來源端的子載波功率分配，仍可有效達到提升系統產出量的目標。

社會影響

目前正交分頻多工技術已被許多的無線通訊標準所採用，該技術除了有高效率的頻譜使用率外，也能有效地對抗頻率選擇性衰減，因此如果能適當的結合合作式通訊技術，將能提升無線通訊系統的效能。然而在實際的通訊系統中，傳送訊號都會有傳送功率的限制。因此，為了在有限的功率下改善系統的效能，使得功率分配在無線通訊中是一個相當重要的研究議題。我們在本計畫中提出之適應性資源分配演算法可對產業界在研發正交分頻多工技術相關產品時提供一個極佳的解決參考，另外優良的資源分配演算法亦可降低能源消耗，進而達到促進產業發展與節能減碳之目的。