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Resource Allocation for OFDM Systems Based On Sub-Carrier Pairing

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***Abstract*- Orthogonal Frequency Division Multiplexing (OFDM) is a form of multicarrier modulation. Different symbols are transmitted over different subcarriers. The use of relays increase the coverage area, improve spectral efficiency and also the network lifetime. On the basis of the amplify and forward relaying mode, a two hop multi relay system is proposed with joint relay selection, subcarrier assignment. The subcarrier pairing enhances system performance. The resource allocation for individual power constraints and total power are solved using optimal and suboptimal algorithm. Further the system performance is improved by means of increasing the number of subcarrier pairs.**

***Index Terms*- OFDM, subcarrier, resource, relay**

I. Introduction

OFDM is a promising candidate for achieving high data rate transmission in mobile environment. The application of OFDM to high data rate mobile communication system is being investigated by many researchers. Orthogonal frequency-division multiplexing (OFDM), essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT), is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method[1]. A large number of closely-spaced orthogonal sub-carriers are used to carry data. The data is divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth[2] .OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, wireless networking and broadband internet access.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters [3, 4]. Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal.

Bo Gui, [5] selective OFDMA relaying is proposed, where the relay selection is performed in a per-subcarrier manner, and selective OFDM relaying is proposed, where one best relay among the *L* potential relays is selected to relay the entire OFDM block, are compared in a two-hop random network. Megumi Kaneko,[6]a generic relay and subcarrier allocation schemes were proposed for Multi Carrier (MC) system with Amplify and Forward (AF) relays. Different relay allocation schemes using the AF protocol are designed and analyzed. As the amount of channel information increases in a MC system, scheme should be designed while considering the tradeoff between the performance and the required amount of information [7, 8]. Ingmar Hammerstrom, [9] a two-hop MIMO-OFDM communication system with a source, an amplify-and-forward relay and destination is considered.

The objective is to maximize the end-to-end transmission rate subject to individual or total power constraints. Based on the intuition derived from the optimal algorithm, the thesis further proposes two suboptimal algorithms for the problem with individual power constraints. They have lower complexity but can achieve close to optimal performances. To maximize the end-to-end transmission rate by:

The use of relay which improve the system performance in OFDM systems.

Analyzing the relative distance between the source to relay and relay to destination.

The rest of this paper is organized as follows. In section II, a typical OFDM system is given and the problem is formulated. Then the three types of resources namely relay, subcarrier and power are explained. in Section III. In section IV, the performance of OFDM signals are studied and evaluated using the proposed scheme through computer simulations, followed by conclusions in section V.

II. OFDM Overview

The OFDM concept is based on spreading the data to be transmitted over a large number of carriers, each being modulated at a low rate. The carriers are made orthogonal to each other by appropriately choosing the frequency spacing between them. In contrast to conventional Frequency Division Multiplexing, the spectral overlapping among sub-carriers are allowed in OFDM, since orthogonality will ensure the subcarrier separation at the receiver, providing better spectral efficiency and the use of steep band pass filter was eliminated.

OFDM transmission system offers possibilities for alleviating many of the problems encountered with single carrier systems.

An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another[10]. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.

III. Resource Allocation in OFDM System

Resource allocation [2] schemes for OFDM systems can benefit by taking account of various forms of diversity such as frequency diversity and multi user diversity. Frequency diversity refers to different subcarriers within a wireless link having different channel gains due to the frequency selective nature of the channel. Multiuser diversity [3] refers to different users experiencing different channel conditions due to their different locations in the network. These diversities imply that a subcarrier that is in a deep fade for one user may not be in deep fade for the other users. By allocating the subcarriers to users based on the channel conditions the users see on the subcarriers, these diversities can be exploited.

A.RELAY

Relay-assisted communication has become very promising in various wireless systems, such as ad-hoc, mesh, and cellular networks. It is able to boost the overall system performance by means of improving the spectral efficiency, extending the coverage area, and/or prolonging the network lifetime. Optimal resource allocation in relay-assisted orthogonal frequency division multiplexing (OFDM) communication systems involves even more technical challenges. The relays may facilitate transmission by first decoding the transmitted codeword, then forwarding the decoded codeword to the destination using a strategy known as "decode-and-forward" (DF). Alternatively, a relay may simply amplify its received signal and employ a so-called "amplify and- forward" (AF) strategy [4].

The similar strategy can be extended to OFDM systems, wherein we select one relay based on the channel condition of the whole OFDM symbol. Subcarrier-based relay selection as illustrated in Figure.1and 2, which selects one best relay for each subcarrier, to exploit both node diversity and frequency diversity. Such scheme can be regarded as subcarrier-to-relay assignment.

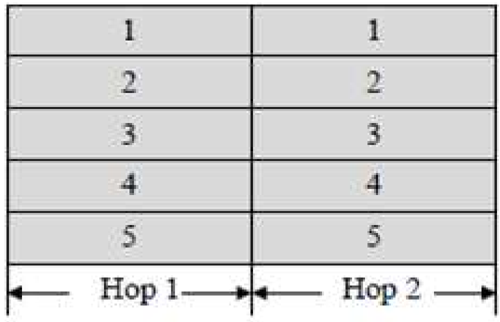


Figure1 OFDM symbol based relay selection

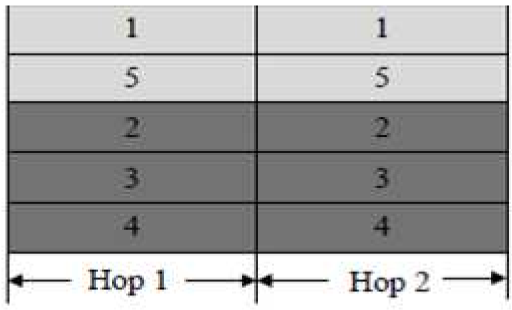
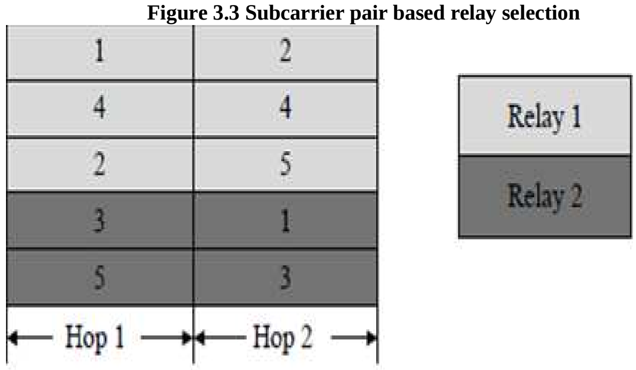


Figure 3.2 Subcarrier based relay selection

The subcarrier-to-relay assignment usually assumes that signals received over one subcarrier, say subcarrier i, is amplified (or decoded) and forwarded by the relay also over subcarrier $i$in the next hop. However, this is not optimal in terms of system performance. A better performance can be achieved if subcarriers in the first and second hops are paired according to their channel conditions. An illustrative example is shown in Figure.3.

Figure 3.3 Subcarrier pair based relay selection



Subcarrier pairing is done per subcarrier basis and requires that the signals received by the same relay on different subcarriers are processed individually. Therefore, such subcarrier-by-subcarrier based pairing may not be sufficient for DF protocol, where the information from one set of subcarriers in the first hop can be decoded and re-encoded jointly and then transmitted over a different set of subcarriers in the next hop.

B.POWER

Power allocation among subcarriers and among source and relay nodes also plays an important role in optimizing the performance of relay-based OFDM systems. In this paper a two-hop AF relay link using OFDM modulation is focused. The transmitted signals are subject to frequency-selective fading channels. The thesis examines the possibilities of power allocation over the frequency sub channels at source and relay to maximize the instantaneous rate of this link. It is assumed that source and relay have their own separate transmit power constraint. The optimal power allocation at the relay (or source) that maximizes the instantaneous rate for a given source (or relay) power allocation is chosen. Furthermore, it is shows an alternate, separate optimization of source and relay PA converges to the solution of the joint optimization of source and relay power allocation.

C.SUBCARRIER ALLOCATION

Orthogonal frequency division multiplexing (OFDM) based systems have been proposed as a solution for broadband wireless access [12]. Simultaneous downlink transmission of data to different user terminals can be provided using wireless OFDM by assigning different subcarriers to different users. A good subcarrier allocation scheme should account for channel fading characteristics and balance user quality of service (QoS) requirements.

Consider a single cell with a base station (BS) employing an OFDM based multiple access schemes to transmit data to K users. In a wireless environment, the channels between the OFDM system at the BS and the users vary both with time and across frequency. Further, due to geographical location differences, users experience different channel conditions even though on the same subcarrier frequency.

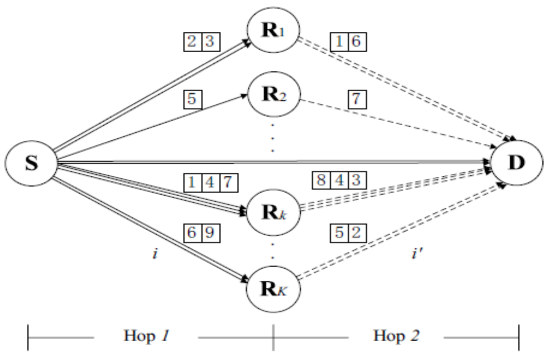


Figure 4 System model

In a naive fixed equal subcarrier allocation scheme, a fixed equalised set of subcarriers is allocated to each of the users. The time-frequency channel variations can however be exploited for multiuser diversity gains by allocating the OFDM subcarriers to the users as follows. Assuming that the BS has knowledge of each of the user's channel condition. A subcarrier (or a group of subcarriers) is allocated to the user that has the best instantaneous channel condition. Sub channel assignment clearly leads to a larger system capacity as compared to the fixed allocation scheme. There is a need for a subcarrier allocation scheme with the following characteristics:

- Exploit multiuser diversity offered by variations across the time, frequency and spatial domains of the user channels.
- Apportion transmissions to users in a fair manner.
- Handle delay requirements of real-time traffic.

D.SYSTEM MODEL

A multi-relay assisted cooperative OFDM system is considered, where the source node communicates with the destination node via the help of K relay nodes. Each relay node operates in a time division half-duplex mode using the AF protocol. The transmissions are based on OFDM modulation, thus each channel is logically divided into Northogonal subcarriers with flat fading. All the channel state information in the network is assumed perfectly known at a central controller, which can be embedded with the source or the destination. The transmission from the source to the destination is on a time-frame basis with each frame consisting of multiple OFDM symbols. Each frame transmission is further divided into two time slots. In the first slot, the source transmits the signals on all subcarriers while the destination and all the relay nodes listen.

E. DISTRIBUTED RELAY SELECTION

With selective relaying [6], at each hop, the best relay should be selected based on the received SNRs, or equivalently, the measured channel gains. If a central control node is available (such as a base station in a cellular network or an access point in a mesh network), it can collect all the channel information and then assign the transmission. This selection, however, can also be performed in a distributed way. In a distributed relay selection was proposed, where each relay sets a timer based on its measured channel gain. The larger the channel gain is, the shorter the timer should be. In this way, the timer of the relay with the best channel will expire first.

F. SUB OPTIMAL ALGORITHMS

(i) Equal Power Allocation based sub carrier-pairing and relay assignment

In this suboptimal algorithm, the subcarrier pairing and relay assignment based on metrics obtained by assuming equal power allocation is determined. Without loss of generality, let all the transmit nodes be subject to the same individual power constraint.

The transmit power per node in (dBm) is given by:

$$p_{i,k,1} = P/N, \ \forall i, k. \quad (3.2)$$

$$p_{i,k,2} = KP/N, \ \forall i, k. \quad (3.3)$$

Where,

p is the transmit power per node (dBm)
K is the number of relays

Once the subcarrier pairing and relay assignment are obtained, the power allocation over subcarriers at each transmit node remains to be uniform as in, except that for each relay node, the individual power equally distributed over its assigned subcarriers in the second hop. Compared with the optimal algorithm, this suboptimal algorithm does not need to update the dual variables. Hence its complexity is lower.

IV. Simulation Results

The transmission rate of the OFDM system can be increased by increasing the number of relays between the source and destination and also by decreasing the number subcarriers in the OFDM system. The parameters for the simulations are as found in table 4.1.

Table 4.1 Simulation parameters

PARAMETERS	DETAILS
Subcarrier	32
Relay	8,16,24&32
Path loss exponent(∝)	3.5
Transmit power per node(p)	0:40(dBm)
Relative distance(d)	0.1:0.9
Tools used	MATLAB 7.9

The resource allocation for individual power constraints and total power constraints are solved using optimal and suboptimal algorithm**.** The optimal resource allocation algorithm is much complex when compared with the suboptimal algorithm. There are two types of suboptimal methods which are used for resource allocation. They are Equal power allocation based scheme and fixed subcarrier pairing scheme.

In equal power allocation scheme, subcarrier pairing and relay assignment are based on metrics obtained by assuming equal power allocation. Once the subcarrier pairing and relay assignment are obtained, the power allocation over subcarriers at each transmit node remain to be uniform. It has been found that the performance of this scheme is slightly lower when compared with the fixed subcarrier pairing scheme.

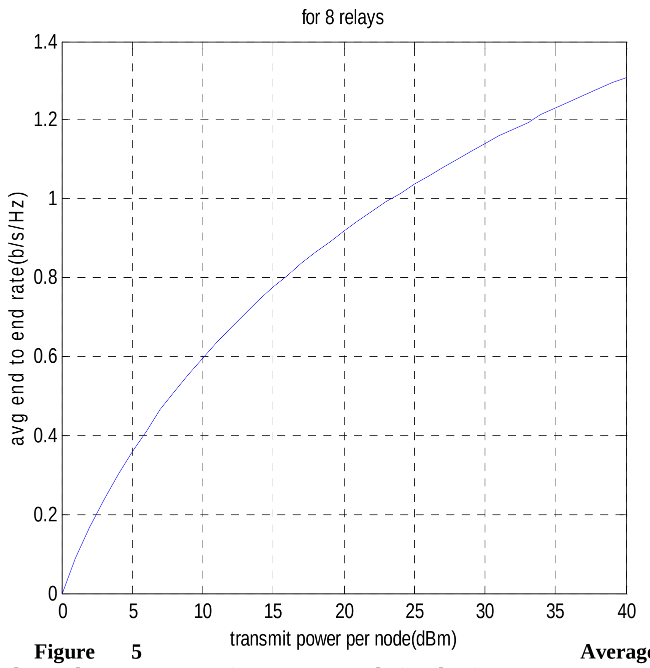


Figure 5 Average end to end rate Vs Transmit power per node (8 relays)

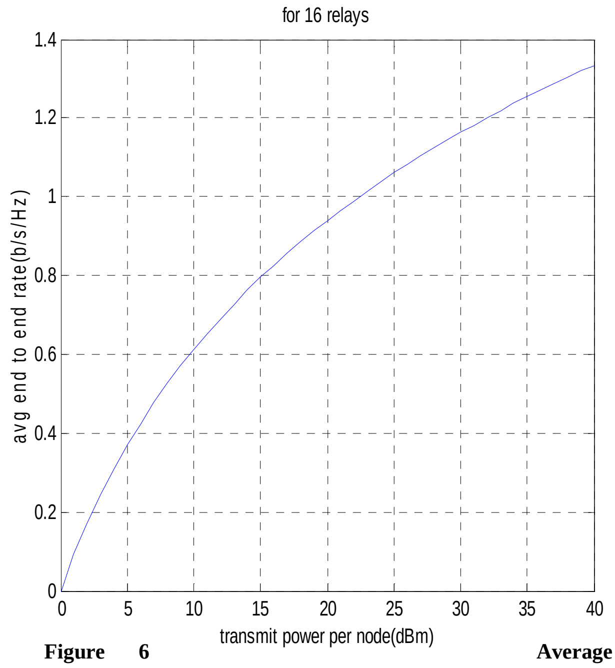


Figure 6 Average end to end rate Vs Transmit power per node (16 relays

In this scheme the subcarrier pairing is pre-fixed. The signal transmitted by the source on one subcarrier is forwarded on the same subcarrier by a relay to the destination. The fixed subcarrier pairing scheme is much complex than the equal power allocation based scheme, but the performance is better when compared with the EPA based scheme. The system performance is better when the subcarrier pairings are increased. Hence when the subcarrier pairings are fixed, then also the performance is better.

In general when the number of relays between the source and destination are increased, the transmission rate achieved is high. In the simulation results we have used 8, 16, 32 and 64 relays. Hence for 64 relays the achieved transmission rate is high when compared with other relays. The figure 5 depicts the transmission rate achieved for 8 relays for the EPA based scheme. The figure illustrates that when the transmit power increases for each node, the average end to end rate also increases. For 8 relays the average end to end rate is 1.3 b/s/Hz and the corresponding transmit power per node is 40 dBm.

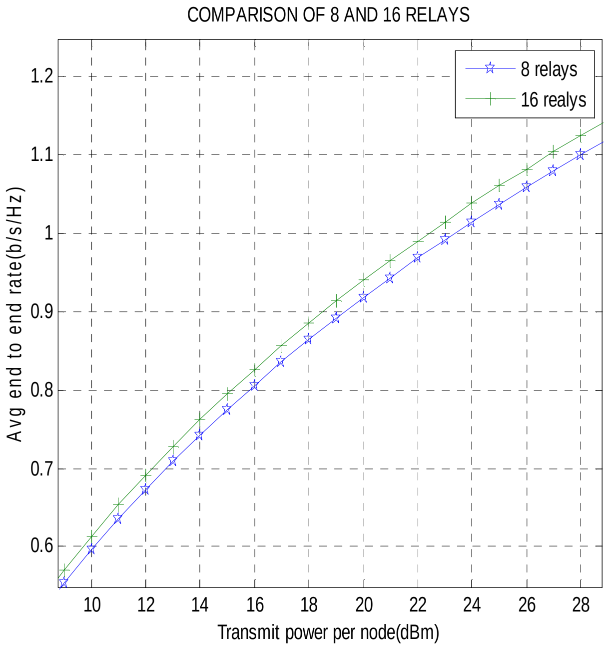


Figure 7 Comparison of 8 and 16 relays

Figure 6 denotes the transmission rate achieved for 16 relays for the EPA based scheme. The figure illustrates that when the transmit power increases for each node, the average end to end rate also increases. For 16 relays the average end to end rate is 1.35 b/s/Hz and the corresponding transmit power per node is 40 dBm. By comparing the two figures 5 and 6 it is found that the average end to end rate for 16 relays is higher than the 8 relays.

Now the comparison of the average end to end rate for both 8 relays and 16 relays in is shown in the figure 7.Figure 8 represents the average end to end rate achieved for various numbers of relays. In our analysis we have used 8, 16, 24 and 32 relays. For 32 relays the average end to end rate is higher compared with 8, 16, and 24 relays. Hence it implies that when the number of relays increases between the source and destination the transmission rate also increases considerably.

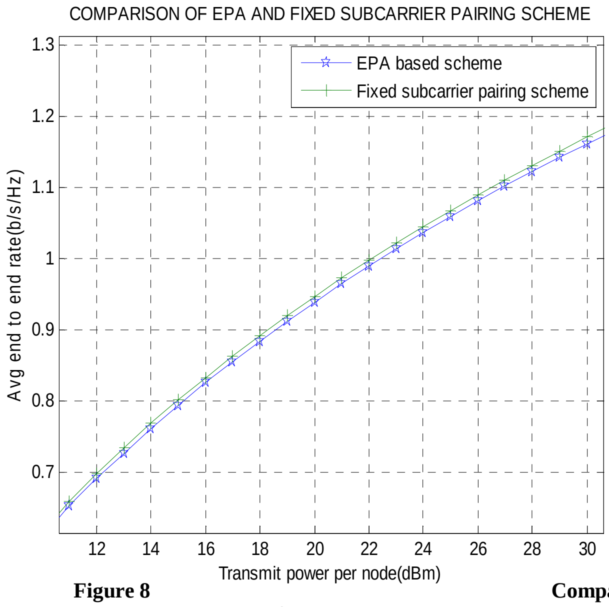


Figure 8 Comparison of various relays

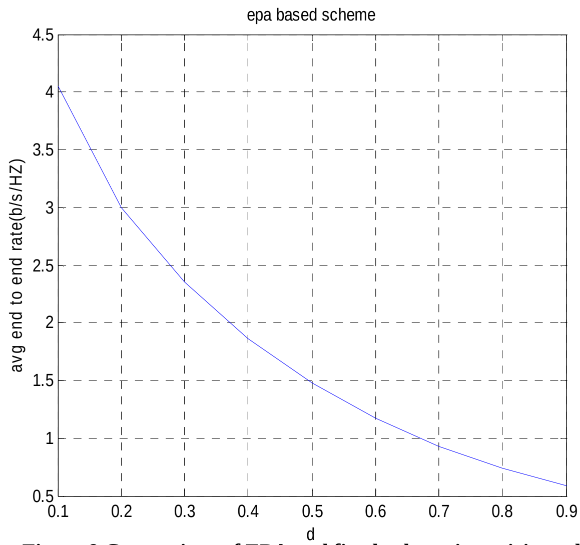
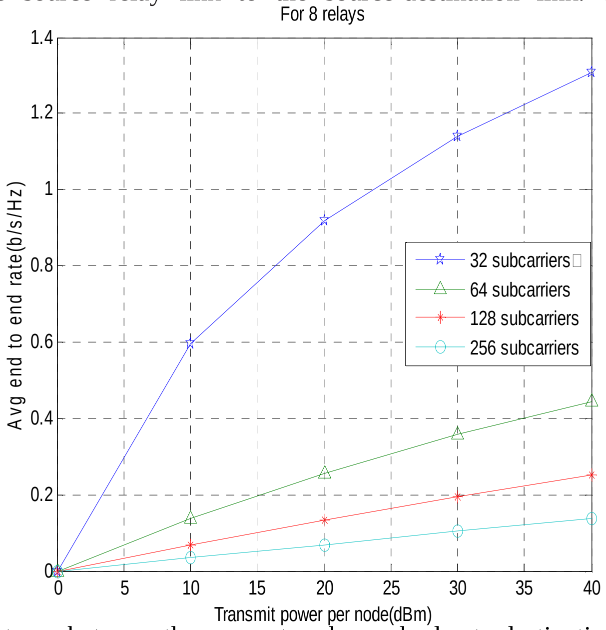


Figure 9 Comparison of EPA and fixed subcarrier pairing scheme

Compared with the equal power allocation scheme, the fixed subcarrier pairing scheme performance is slightly better, but the complexity is high for fixed subcarrier pairing scheme compared to the EPA based scheme. So mostly the equal power allocation scheme is preferred than the fixed subcarrier pairing method. The comparison of equal power allocation and fixed subcarrier pairing scheme is shown in figure 9.

It is assumed that the multiple relay nodes in the network form a cluster and lie approximately on the line connecting the source and destination. The radius of the relay cluster is much smaller than the distance from the source to the destination. Then, the channel statistics experienced by different relays can be assumed identical. Let'd' denote the distance ratio of the source relay link to the source-destination link. The



distance between the source to relay and relay to destination is called as the

Figure 10 Relative distance Vs Average end to end rate

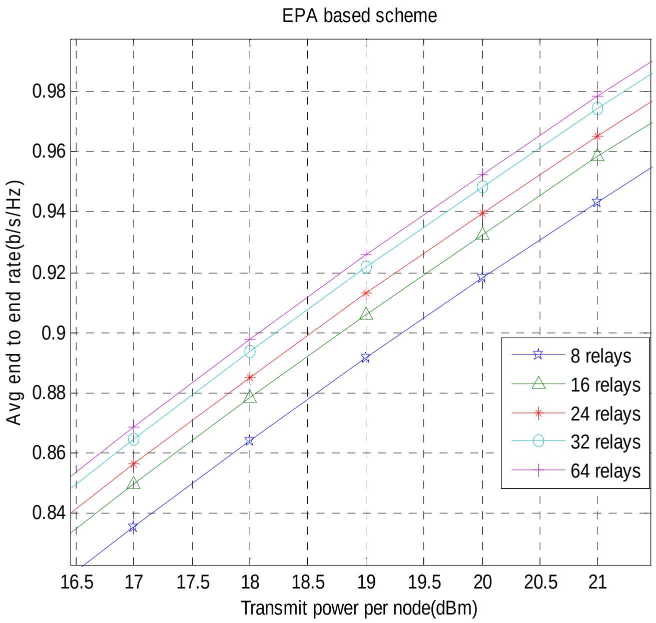


Figure 11Average end to end rate Vs Transmit power per node (For various subcarriers)

relative distance (d). As the relative distance (d) increases, the average end to end rate will decrease (b/s/Hz) for the EPA based scheme. The graph for the relative distance and average end to end rate shown in figure 10.

Generally when the number of subcarriers is increased, the transmission rate decreases considerably. The system performance is analyzed by increasing the number of subcarriers for the EPA based scheme. In the simulation 32, 64, 128 and 256 subcarriers were used.

Figure 4.7 represents how the average end to end rate gets decreased with increase in the number of subcarriers. In the simulation the number of relays is fixed to be 8.For 32 subcarriers the average end to end rate is high. As we increase the number of subcarriers to 64, 128 and 256, it is seen that the transmission rate starts to decrease. For the effective transmission of the signal the number of subcarriers used should be minimum. The graph is shown below in the figure 11.

V. Conclusion

The simulation results prove that the transmission rate has increased considerably by the use of suboptimal algorithms. The complexity of the suboptimal algorithm is less when compared to the optimal algorithm.

By using the EPA based scheme the transmission rate of the system has been increased by increasing the number of relays. It is also shown that the transmission rate could be increased by decreasing the number of subcarriers. It is analyzed that the fixed subcarrier pairing scheme offers slightly better performance than the EPA based scheme. But the complexity related with the EPA based scheme is less than the fixed subcarrier pairing scheme. In the thesis the EPA based scheme is analyzed in detail. The relative distance between the source to relay and relay to destination is also considered. It is proved that the transmission rate decreases with increase in the relative distance.

VI. References

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