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Performance Study of a Resource Allocation Scheme with Fairness Consideration in Multihop Systems over Nakagami-m Channels

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Abstract: In this study, we consider the design of a radio resource allocation technique for an Orthogonal Frequency Division Multiple Access (OFDMA) based Multiple Input Multiple Output (MIMO) multihop network. To avoid the inter-hop interference, the half-duplex orthogonal relay channel construction method and related multihop transmission scheme are designed. Over Nakagami-m fading channels, we propose a low-complexity resource allocation algorithm using Meijer G-function. And, the long term fairness performance is also investigated. Simulation shows that the proposed analytical algorithm is efficient and with good accuracy to Monte Carlo results. And, simulations also demonstrate that the spatial diversity gain offered by relay antenna array can effectively balance the tradeoff between the fairness performance and the system throughput.

Key words: Multihop system, decode-and-forward, Nakagami-m channel, resource allocation

INTRODUCTION

As a promising approach for next generation wireless networks, multihop technology has been attracting much interest. The fundamental principal is that multihop relay nodes are exploited to relay information from source station to another in a distributed manner until the message is received by the receiver. Multihop relay can increase system throughput, improve fairness performance and enhance network coverage (Le and Hossain, 2007).

In last few years, multiple antenna techniques have been studied and applied to multihop networks. In these networks, multihop relay nodes can function as a virtual antenna array. The resulting Multiple-Input Multiple-Output (MIMO) spatial diversity gain can be used to reduce power consumption and increase capacity. There is already an extensive literature on MIMO multihop systems (Bölcskei *et al*., 2006; Dohler *et al*., 2006; Roh and Paulraj, 2002). In particular, a detailed analysis of multi-antenna multihop communication schemes is presented by Pabst *et al*. (2004). They show that MIMO relay technology can both reduce infrastructure deployment costs and combat shadow fading especially. And, the outage capacity of multihop networks employing terminals with multiple antennas is studied by Fan and Thompson (2005).

In multihop networks, wireless resource allocation is a key design issue. There have been many studies on this open topic (Sadr *et al*., 2007; Ahmed and Yanikomeroglu, 2006). And, the fairness consideration on resource allocation is one of the most important design goals since some multihop relay nodes achieve more radio resource (e.g., bandwidth) and inevitably starve others. A hierarchical radio resource allocation scheme for multihop mesh networks, which fairly assign subcarriers and power to multiple mesh clients, is studied by Lee and Leung (2006). A distributed and fair access (DFA) Medium Access Control (MAC) protocol for multihop wireless networks is proposed by Suliman *et al*. (2005). This design can offer stations more transmission opportunities without incurring extra overhead to the current data transmission.

In this study, we consider to design a decode-and-forward MIMO-OFDMA multihop transmission mechanism and an orthogonal relay channel construction method. Over frequency-selective Nakagami-m fading channels, a low-complexity time-subcarrier resource allocation algorithm is derived. Besides, the long term fairness consideration on the resource allocation is also discussed. And, two multihop resource allocation schemes are proposed and compared. One is for the fair resource assignment and another is for the throughput maximization. The fairness index and throughput performance are evaluated in various MIMO multihop relay scenarios and channel conditions.

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MULTIHOP SYSTEM DESCRIPTION

The general OFDMA-based MIMO multihop network model is described here. And, a half-duplex decode-and-forward multihop transmission mechanism is designed.

System description: The multihop relay network architecture is depicted in Fig. 1. The Base Station (BS), relay nodes and the destination Subscriber Station (SS) constitute the multihop system, which is divided into T hop stages. At each hop stage, relay nodes are grouped into clusters to form a multi-antenna transmitter and a multi-antenna receiver. Thus, a virtual MIMO antenna array channel is formed by these relay nodes and used to connect the BS and SS. The spatial diversity of the MIMO array can increase system throughput, decrease communication error and adjust system fairness performance. Here, in this study, we consider the transmission in the downlink (left to right) direction.

Orthogonal relay channel construction: To avoid complicated inter-hop interference cancellation processing of multihop networks, in this study, the resources allocated for different hop stages must be orthogonal. By using the OFDMA technique in MIMO multihop systems, we can exploit the two-dimensional time-frequency resource to build up a multihop relay channel, as shown in Fig. 2.

In Fig. 2a, the MIMO multihop system comprises a set of hop stages, e.g., T_{stage} {1,2,..., t..., T_{hop}}, where, t is referred as the t^{th} hop stage number. And, T_{hop} is the t^{th} hop stage number. In this study, the system is assumed to have an even number of hop stages. The extension to an odd number of hop stages is obvious.

Figure 2b illustrates the time-frequency resource allocation for constructing an orthogonal multihop relay hannel. And, the subset of OFDM subcarriers allocated to one hop stage is referred as a subchannel. For each hop stage, the transmission scenario may be different. Therefore, the number of subcarriers assigned to each stage is variable and adjustable to maximize the entire multihop system throughput.

Multihop transmission mechanism: Since all relay nodes operate in a half-duplex mode, the multihop transmission procedure for the downlink is separated into two time periods.

Transmission in first time period: In the first time period, all odd number hop stages 1,3,..., (T_{hop}-1) are in operation. For example, in the 1st hop stage, BS transmits its data to the relay nodes in the first-cluster, while subchannel U_1 is used for the 1st hop stage as shown in Fig. 2b. Based

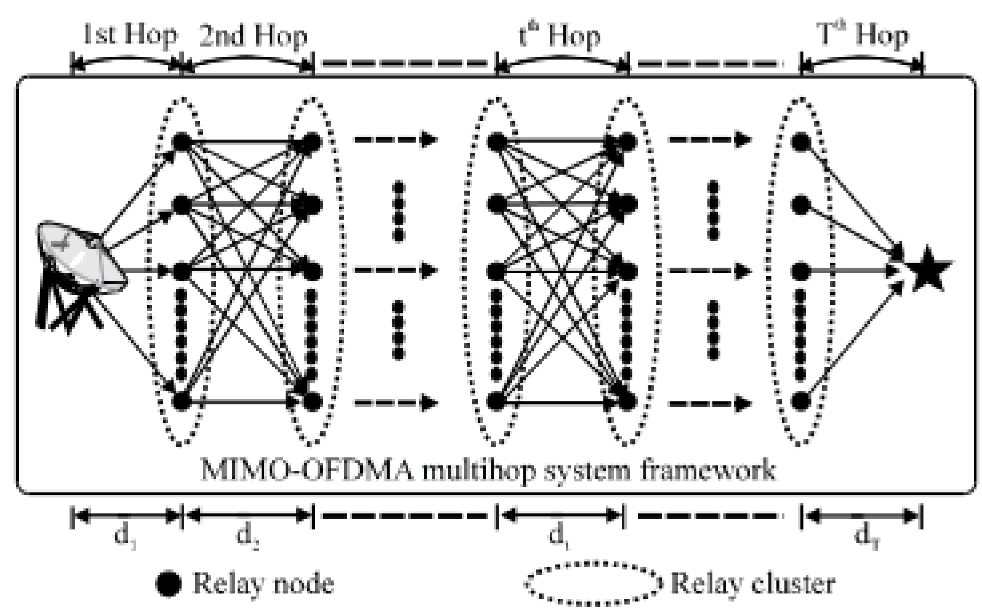

Fig. 1: OFDMA-based MIMO multihop network under consideration

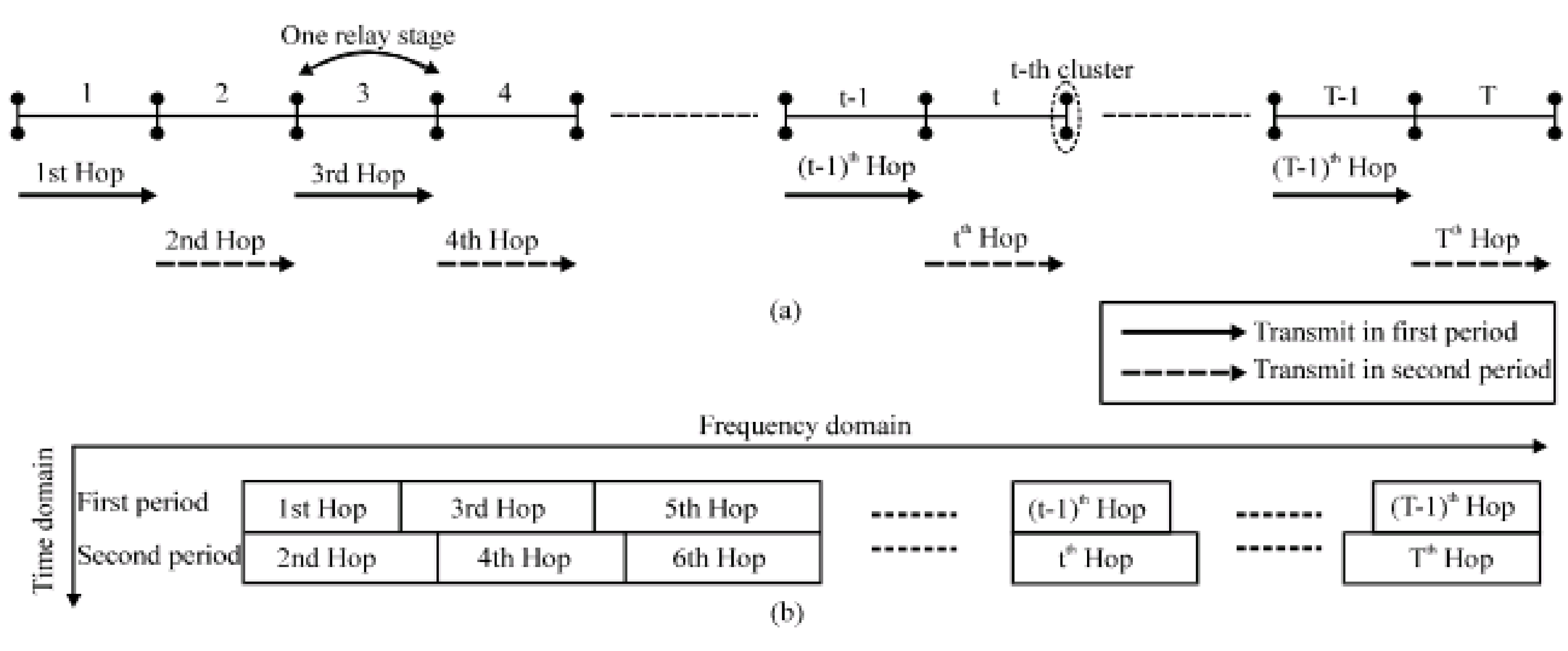

Fig. 2: Multihop transmission model, (a) multihop relay mechanism, (b) subcarrier/time allocation for orthogonal relay channel

on the proposed resource allocation criteria and long term fairness performance consideration, we do not address the complicated physical subcarrier permutation scheme for each subchannel. So, we assume consecutive physical subcarriers:

$$S_{PHY}(U_1) = \{0,1,\cdots,N_c^{(1)}-1\} \tag{1}$$

are assigned to subchannel U_1, where, $N_c^{(1)}$ is the number of subcarriers allocated in the 1st hop stage. Next, the first-cluster nodes receive signals from BS and decode the received information.

For other odd numbered hop stages, the transmission operates in a similar manner. However, only remaining subcarriers can be employed, that causes $S_{PHY}(U_j) \cap S_{PHY}(U_i) = \emptyset$, where, $j \neq i$ for $j, i \in \{1,3,5...(T-1\}$. The amount of subcarriers and transmission time allocated to each stage should be calculated according to various multihop transmission scenarios. In this study, we will investigate how to optimally assign the time-subcarrier resource to maximize the mean throughput of entire multihop system.

Transmission in second time period: In the second time period, all even number hop stages operate in a similar manner. For example, in the 2nd hop stage, the first-clusters relay nodes regenerate and transmit forward the decoded information of the 1st hop stage. After the T^{th} hop stage, the destination SS will receive the BS information. And, the similar design is also studied in our previous work (Zhou *et al*., 2009).

RESOURCE ALLOCATION SCHEME

Here, we focus on studying the multihop resource allocation algorithm for throughput maximization. The fairness consideration on multihop resource allocation is also investigated.

System throughput analysis: According to information theory, the end-to-end throughput of multihop system, depicted in Fig. 1, can be given by Dohler *et al*. (2006):

$$\Re^{all}_{throughput} = \theta_{norm} \max_{N_c^{(t)},P_{Tx}^{(t)}} \min \left\{ \begin{array}{l} \Re^{(1)}_{throughput}, \Re^{(2)}_{throughput}, \\ \cdots \Re^{(t)}_{throughput}, \cdots \Re^{(T_{hop})}_{throughput} \end{array} \right\}, \quad t \in \{1,2,\cdots T_{hop}\} \tag{2}$$

where, $\Re^{all}_{throughput}$ denotes the end-to-end throughput of entire multihop system. The unit of $\Re^{all}_{throughput}$ is defined as bits/s/Hz. $\Re^{all}_{throughput}$ is the throughput of t^{th} hop stage, which can be determined by:

$$\Re^{(t)}_{throughput} = T^{(t)}C^{(t)} = \begin{cases} T_1C^{(t)} & t = 1,3,5,\cdots \\ T_2C^{(t)} & t = 2,4,6,\cdots \end{cases} \tag{3}$$

where, $C^{(t)}$ is the ergodic capacity of t^{th} hop stage. T_1 is the transmission time of the first relay period. T_2 is the time of the second relay period. And:

$$T^{(t)} = \begin{cases} T_1 & t = 1,3,5 \\ T_2 & t = 2,4,6 \end{cases}$$

Note that, in this study, for fair comparison with a traditional direct transmission scheme, θ_{norm} is the normalization factor for half-duplex multihop transmission mode. According to the proposed multihop transmission scheme:

$$\theta_{norm} = \frac{1}{2}$$

because multihop transmission is divided into two time periods.

Then, the throughput of the half-duplex multihop system can be obtained as follows:

$$\Re^{all}_{throughput} = \frac{1}{2} \max_{N_c^{(t)},T^{(t)},P_{Tx}^{(t)}} \min \left\{ T_1C^{(1)}, T_2C^{(2)}, \cdots T_tC^{(t)}, \cdots T_2C^{(T_{hop})} \right\} \tag{4}$$

subject to

$$\begin{cases} \mathbb{C}1: & \sum_{t=1,3,5,\cdots}^{T_{hop}-1} N_c^{(t)} = N_c \\ \mathbb{C}2: & \sum_{t=2,4,6,\cdots}^{T_{hop}} N_c^{(t)} = N_c \\ \mathbb{C}3: & T_1 + T_2 = 2 \\ \mathbb{C}4: & \sum_{t=1}^{T_{hop}} P_{Tx}^{(t)} \le P_{total} \end{cases} \tag{5}$$

In the above, $\mathbb{C}1$ and $\mathbb{C}2$ describe the limited subcarriers resource constrains. $N_c^{(t)}$ is the number of subcarriers assigned to the relay nodes at the t^{th} hop stage. N_c is the total subcarrier number of the OFDM system. And, $\mathbb{C}3$ corresponds to the time resource constrains. $\mathbb{C}4$ is the transmit power constrain. $P_{Tx}^{(t)}$ is the transmit power for the t^{th} hop stage. P_{total} stands for the total transmit power.

For subcarrier resource constraints:

$$\sum_{t=1,3,5\cdots}^{T_{hop}-1} N_c^{(t)} = N_c$$

and

$$\sum_{t=2,4,6,\cdots}^{T_{hop}} N_c^{(t)} = N_c$$

can also be expressed as:

$$\sum_{t=1,3,5,\cdots}^{T_{hop}} \frac{N_c^{(t)}}{N_c} = \sum_{t=1,3,5\cdots}^{T_{hop}} \Psi_c^{(t)} = 1 \tag{6}$$

$$\sum_{t=2,4,6,\cdots}^{T_{hop}} \frac{N_c^{(t)}}{N_c} = \sum_{t=2,4,6\cdots}^{T_{hop}} \Psi_c^{(t)} = 1 \tag{7}$$

where, $\Psi_c^{(t)}$ is the ratio of subcarrier number of t^{th} hop stage to all OFDM subcarrier number.

Resource allocation for throughput maximization: Here, we study the resource allocation algorithm to achieve the throughput maximization.

Here, the channel is assumed quasi-static in time, remaining constant within the duration of a data block. And, the OFDM cyclic prefix is longer than the delay spread of the channel. The transmission power is distributed equally across all antennas and OFDM subcarriers. Then, the ergodic capacity $C^{(t)}$ of t^{th} stage is given by:

$$C^{(t)} = E\left\{\frac{1}{N_c}\sum_{k\in S_{PHY}(U_t)} \log_2\left[\det\left(I_M + \tilde{\rho}_{Rx}^{(t)}\tilde{H}_k^{(t)}\left(\tilde{H}_k^{(t)}\right)^{+}\right)\right]\right\} \tag{8}$$

where, S_{PHY} (U_t) denotes the subcarriers for the t^{th} hop stage. $\tilde{H}_k^{(t)}$ is the channel transfer matrix in the frequency domain of t^{th} hop stage. And:

$$\tilde{\rho}_{Rx}^{(t)} = \frac{P_{Rx}^{(t)}}{N_{Tx}^{(t)} N_c \sigma_k^2}$$

Here, $\tilde{H}_k^{(t)}$ addresses the small-scale fading, following a Nakagami-m probability density function (pdf).

The pdf of the amplitude of each entry

$$\tilde{H}_{i,j}^{k} = \left|\tilde{H}_{k,i,j}^{(t)}\right|$$

is given by:

$$P_r\left(\tilde{H}_{i,j}^{k}\right) = \frac{2m^m}{\Omega^m \Gamma(m)}\left(\tilde{H}_{i,j}^{k}\right)^{2m-1} \exp\left(-\frac{m}{\Omega}\left(\tilde{H}_{i,j}^{k}\right)^2\right) \tag{9}$$

where, $\Gamma(m)$ is the gamma function, m is the fading parameter with $m \geq ½$ and

$$\Omega = E\left[\left(\tilde{H}_{i,j}^{k}\right)^2\right]$$

is the mean power.

And we also define $\tilde{n}^{(t)} = \max\{M_{Rx}^{(t)}, N_{Tx}^{(t)}\}$ and $\tilde{m}^{(t)} = \min\{M_{Rx}^{(t)}, N_{Tx}^{(t)}\}$. Then, the corresponding channel capacity of one hop becomes:

$$C^{(t)} = \frac{1}{N_c}\sum_{k\in S_{PHY}(U_t)} \left\{E\left\{\sum_{i=1}^{\tilde{m}^{(t)}} \log_2\left(1+\tilde{\rho}_{Rx}^{(t)}\tilde{\eta}_k^{(t)}\right)\right\}\right\} \tag{10}$$

where, $\tilde{\eta}_k^{(t)}$ is the eigenvalue of

$$\tilde{H}_k^{(t)}\left(\tilde{H}_k^{(t)}\right)^{+}$$

at the k^{th} subcarrier of t^{th} hop stage.

The MIMO capacity approximation over Nakagami channels is (Zhong *et al*., 2009):

$$E\left\{\sum_{i=1}^{\tilde{m}^{(t)}} \log_2\left(1+\tilde{\rho}_{Rx}^{(t)}\tilde{\eta}_k^{(t)}\right)\right\} \leq \frac{\tilde{m}^{(t)}}{\Gamma\left(\tilde{n}^{(t)}m\right)\ln 2} G_{3,2}^{1,3}\left(\frac{P_{Tx}^{(t)}}{2N_{Tx}^{(t)}\sigma_k^2}\frac{\Omega}{m}\middle|_{1,0}^{1-\tilde{n}^{(t)}m,1,1}\right) \tag{11}$$

Our objective is to optimize the allocation of time-subcarrier resource to ensure that the throughput of each hop stage is equal to others, that is:

$$\Re_{throughput}^{(t)} = \Re_{throughput}^{(t+1)} \tag{12}$$

where,

$$\Re_{throughput}^{(t)} = T^{(t)}C^{(t)} = T^{(t)}\Psi_c^{(t)}E\left\{\sum_{i=1}^{\tilde{m}^{(t)}} \log_2\left(1+\tilde{\rho}_{Rx}^{(t)}\tilde{\eta}_k^{(t)}\right)\right\} = \Phi^{(t)}E\left\{\sum_{i=1}^{\tilde{m}^{(t)}} \log_2\left(1+\tilde{\rho}_{Rx}^{(t)}\tilde{\eta}_k^{(t)}\right)\right\}$$

(13)

Based on (11), (12) and (13), the resource allocation scheme can be shown as follows:

$$\frac{\Phi^{(t)}}{\Phi^{(t+1)}} \approx \frac{\tilde{m}^{(t+1)}\Gamma\left(\tilde{n}^{(t)}m^{(t)}\right)G_{3,2}^{1,3}\left(\frac{P_{Tx}^{(t+1)}}{2N_{Tx}^{(t+1)}\sigma_k^2}\frac{\Omega}{m^{(t+1)}}\middle|_{1,0}^{1-\tilde{n}^{(t+1)}m^{(t+1)},1,1}\right)}{\tilde{m}^{(t)}\Gamma\left(\tilde{n}^{(t+1)}m^{(t+1)}\right)G_{3,2}^{1,3}\left(\frac{P_{Tx}^{(t)}}{2N_{Tx}^{(t)}\sigma_k^2}\frac{\Omega}{m^{(t)}}\middle|_{1,0}^{1-\tilde{n}^{(t)}m^{(t)},1,1}\right)} \tag{14}$$

This numerical calculation has low complexity using standard softwares like Mathmatica and Matlab. The expression reveals the impacts of system parameters and channel condition, such as Nakagami fading severity parameter m, MIMO antennas deployment, etc. on the resource allocation for throughput maximization. Evaluation in the next section shows that this algorithm has good agreement with Monte Carlo simulation results.

From Eq. 5 and 14, we can obtain the subcarrier allocation ratio and transmission time. This multihop resource allocation scheme for throughput maximization is referred as Max-Rate Scheme.

Long term fairness consideration: Fairness is an important design objective in wireless networks, which can help users efficiently utilize the limited radio resources. Based on Eq. 14, the resource allocation strategy can obtain the optimized end-to-end system throughput. However, this scheme needs to know the system topological structure, cooperative relay nodes information and update channel state information of each hop stage. Moreover, this scheme may cause the unevenness of radio resource assignment among relay nodes. Some relay nodes would suffer from the starvation of resource allocation, which impacts on the system parameters, such as OFDMA subchannel size, maximum payload block length and power allocation, etc.

To quantify the fairness performance of the proposed radio resource allocation scheme, we use the Jain's fairness index (Jain, 1991), that is:

$$\mathbb{F}_{Index} = \frac{\left(\sum_{n=1}^{N_{node}} X_n\right)^2}{N_{node} * \sum_{n=1}^{N_{node}} (X_n)^2} = \frac{\left(\sum_{n=1}^{N_{node}} \Psi_c^{(n)} T^{(n)}\right)^2}{N_{node} * \sum_{n=1}^{N_{node}} \left(\Psi_c^{(n)} T^{(n)}\right)^2} \qquad (15)$$

where, $0 \le \mathbb{F}_{Index} \le 1$. And, x_n is the amount of resource to n^{th} user. N_{node} is the total number of relay nodes. $\Psi_c^{(n)}$ is the subcarrier resource ratio assigned for n^{th} relay node. $T^{(n)}$ is the time resource for n^{th} relay node. And, we let $X_n = \Psi_c^{(n)} T^{(n)}$, which represents the OFDMA time-subcarrier resource block shared to n^{th} relay node, depicted as Fig. 2b. For simplicity, the amount of resource assigned to each relay node of one cluster is the same in one hop stage.

Here, we define a Fairness Index = 1 Scheme, which evenly provides the time-subcarrier among all relay nodes with $\mathbb{F}_{Index} = 1$. It has several advantages, such as preventing the severe starvation problem on multihop resource assignment, avoiding excessive control signaling for multihop resource allocation. This scheme is also useful with lack of MIMO channel information.

Clearly, this scheme provides a simple and fair sharing of radio resource. However, with limited radio resource, increasing the system throughput and maintaining the fairness are always conflicting. Fairness Index = 1 Scheme is at the expense of system throughput.

PERFORMANCE EVALUATION

Here, the system throughput and the fairness performance are evaluated under the proposed MIMO-OFDMA multihop network.

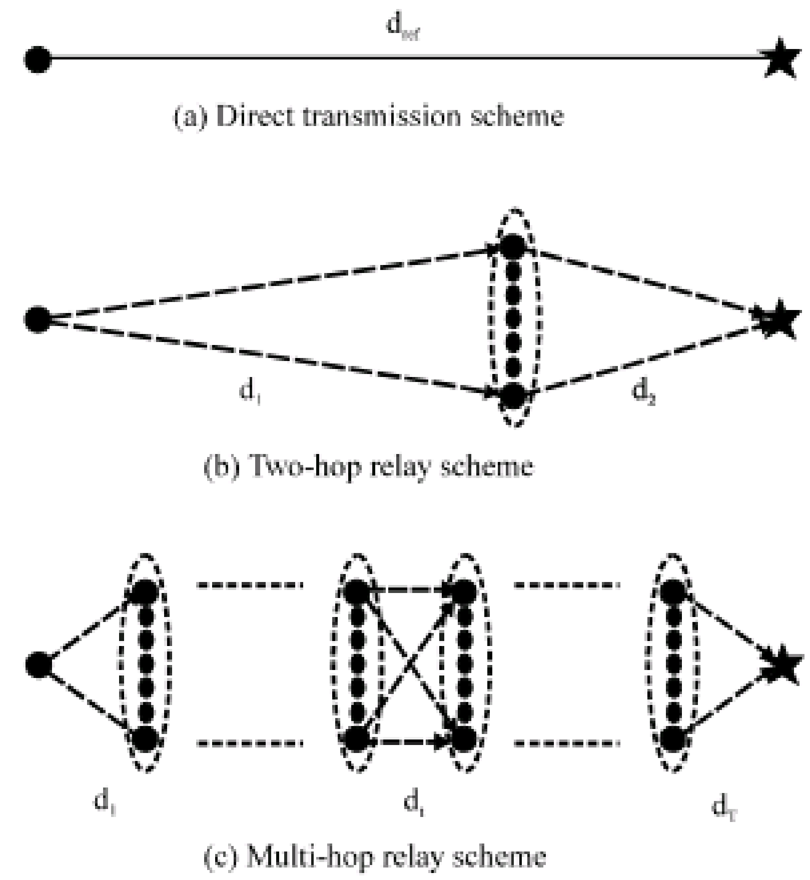

Fig. 3: Simulation scenario

The simulation scenario is depicted in Fig. 3, where, d_{ref} is the reference distance for the traditional direct transmission scheme. Figure 3b shows a two-hop relay scheme. And, the general multihop scheme is illustrated in Fig. 3c. Here, the propagation path loss exponent is 4. The number of multi-path is 6. And, in all simulations, we set the exponent of power delay profile to 0.4. In the remainder, the MIMO scheme adopted in the multihop system is referred as:

$$\left(N_{Tx}^{(1)} \times M_{Rx}^{(1)}\right) \text{and} \left(N_{Tx}^{(2)} \times M_{Rx}^{(2)}\right) \text{and} \cdots \left(N_{Tx}^{(t)} \times M_{Rx}^{(t)}\right) \text{and} \cdots \left(N_{Tx}^{(T)} \times M_{Rx}^{(T)}\right)$$

For example, (1×4) and (4×1) denotes a two-hop system. The 1st hop stage has (1×4) MIMO antenna deployment and the 2nd hop stage adopts a (4×1) MIMO scheme.

Simulation 1: Throughput performance is compared for various multihop schemes. The accuracy of proposed resource allocation analytical algorithm is also investigated with simulation results. The simulation scenario is conducted with two-hop, four-hop, six-hop and direct transmission schemes. The related MIMO deployments are (1×1), (1×2) and (2×1), (1×2) and (2×1), (4×2) and (2×1), (1×1) and (1×2) and (2×4), (4×8) and (8×4) and (4×2) and (2×1).

Figure 4 shows that the analytical algorithm is in good agreement with Monte Carlo simulation results. And, Fig. 4 also shown that, in low SNR region, the system throughput is improved with increment of multihop stage number. For instance, when the throughput is 2 bits/s/Hz, the two-hop scheme has 4.1 dB SNR gain compared with the direct transmission scheme.

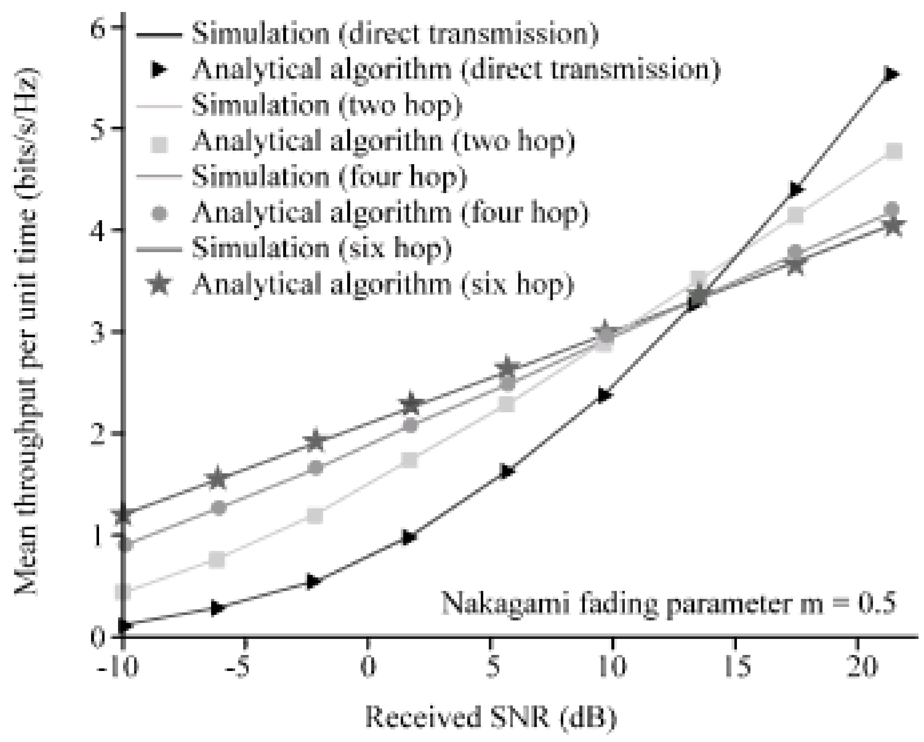

Fig. 4: Throughput comparison for various multihop schemes (m = 0.5)

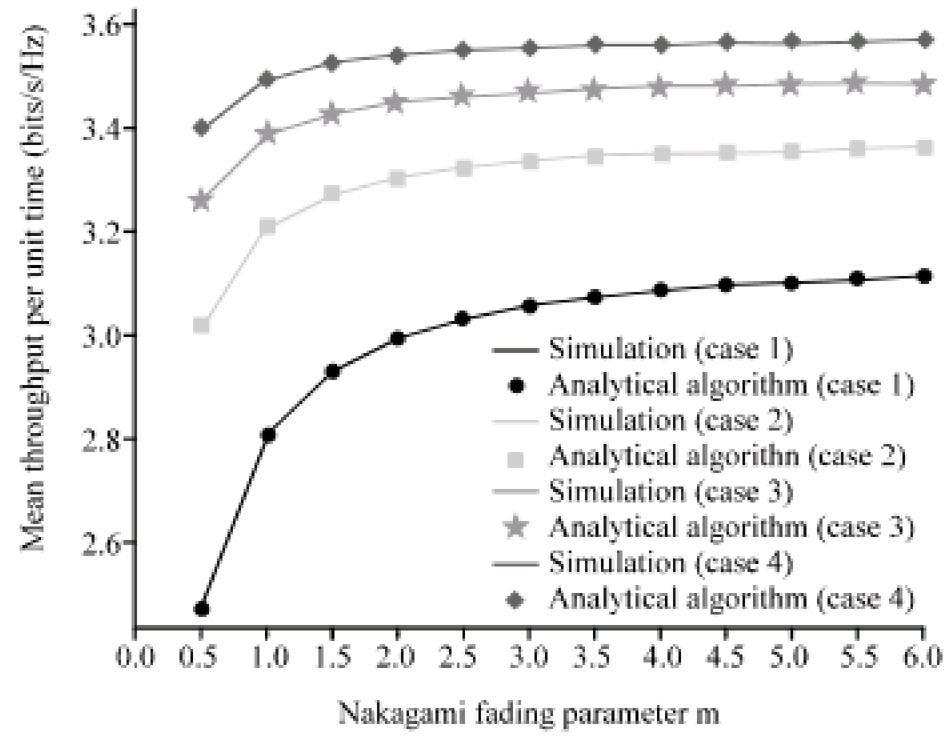

Fig. 5: Impact of Nakagami-m fading parameter on system throughput

And, the 2.7 dB SNR gain is between four-hop and two-hop scheme. However, in high SNR region, the throughput of one-hop direct transmission scheme grows gradually and exceeds those of multihop schemes.

Simulation 2: The effect of Nakagami-m fading on system throughput is evaluated in Fig. 5. And, the simulation scenarios are two-hop systems. Here, case 1 corresponds to (1×1) and (1×1) scheme. (1×2) and (2×1) is case 2.(1×3) and (3×1) is case 3. And, (1×4) and (4×1) is case 4. Results show that the system throughput degrades with decreasing fading parameter m. Moreover, such degradation becomes more significant in low parameter m region, which represents the severe fading environment. But, Fig. 5 shows degradation can be eliminated by increasing the relay nodes number. For instance, when fading parameter m is 0.5, case 4 can achieve 0.97 bits/s/Hz throughput enhancement compared with case 1.

Besides, Fig. 5 also shows that the difference between analytical results and simulation is inappreciable. From Fig. 4, 5, it is indicated that the proposed analytical algorithm is efficient and can be used as a reasonable reference to the multihop system performance.

Simulation 3: The impact of relay nodes on the system throughput and long term fairness performance is examined. This simulation scenario is in four-hop network. The received SNR is 10 dB. Here, the relay nodes in each hop cluster are the same, that is:

$$M_{Rx}^{(1)} = N_{Tx}^{(2)} = M_{Rx}^{(2)} = N_{Tx}^{(3)} = M_{Rx}^{(3)} = N_{Tx}^{(4)}$$

Figure 6a shows that, with increment of relay node number, the system throughput is increased. But, on the

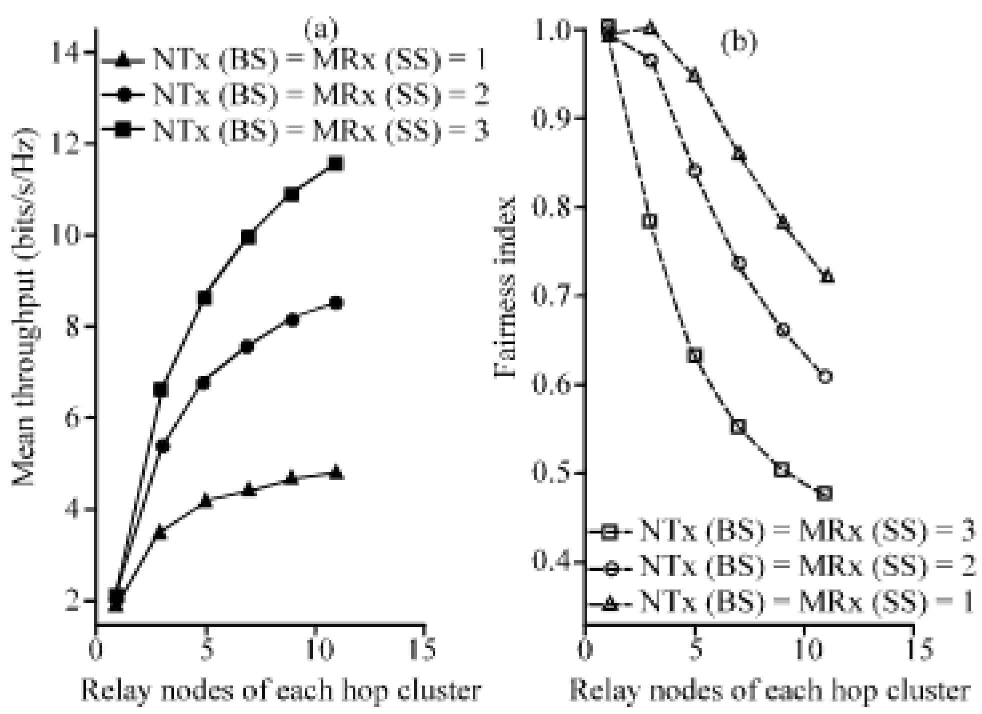

Fig. 6: Impact of relay nodes on system performance (m = 0.5)

contrary, the fairness index performance decreases significantly, shown in Fig. 6b. The reason is that, by increasing the relay nodes number, more spatial diversity gain can be obtained in the middle relay stage. But, due to antennas deployment restriction, the diversity gain at destination SS is limited. To achieve throughput maximization, the subcarrier and time resource can not be evenly assigned according to Eq. 14, which causes the unfairness. The more spatial diversity gain in the relay stage, the worse fairness performance becomes. This simulation reveals that, by adjusting relay nodes number, we can achieve the tradeoff between system throughput and fairness performance. Figure 6 also shows the system throughput and fairness performance can be improved by increasing the antennas number on BS and SS, that is $N_{Rx}^{(1)}$ and $M_{Rx}^{(4)}$.

Simulation 4: The starvation problem on unfair subcarrier allocation of relay nodes is analyzed. Two application cases are analyzed for six-hop system. Case 1 is that each hop stage has the same distance interval, that is

$$d_i = \frac{1}{6} d_{ref} \quad i = 1,2,3,4,5,6$$

Case 2 is for the system with unequal distance interval as $d_1 = 2d_2 = 4d_3 = 4d_4 = 2d_5 = d_6$ Here, six-hop MIMO scheme is (1×2) and (2×4) and (4×8) and (8×4) and (4×2) and (2×1). And, the reference received SNR is 10 dB.

Firstly, to case 1, the simulation results are illustrated in Fig. 7a. If the odd hop stages in the first time period is examined, it shows that 1st hop occupies the largest amount of subcarriers and that subcarriers for the 3rd hop are least. And, this causes the starvation problem on subcarriers assignment. The reason is that the ergodic capacity of a (1×2) MIMO deployment is less than that of (4×8) and (4×2) MIMO deployment. And, more subcarriers are required so that the throughput of 1st hop is same as that of other hop stages.

Secondly, to case 2, Fig. 7b shows that the starvation problem becomes worse compared with case 1. The reason is that 3rd hop has the shortest transmission distance. And, lowest subcarriers assignment is required for 3rd hop to obtain the same throughput as that of other hops. We know that the starvation problem has influence on system parameters, such as the OFDMA subchannel size, payload length, etc. And, these can be solved by properly adjusting transmission power and MIMO deployment, etc., which will be addressed in further study.

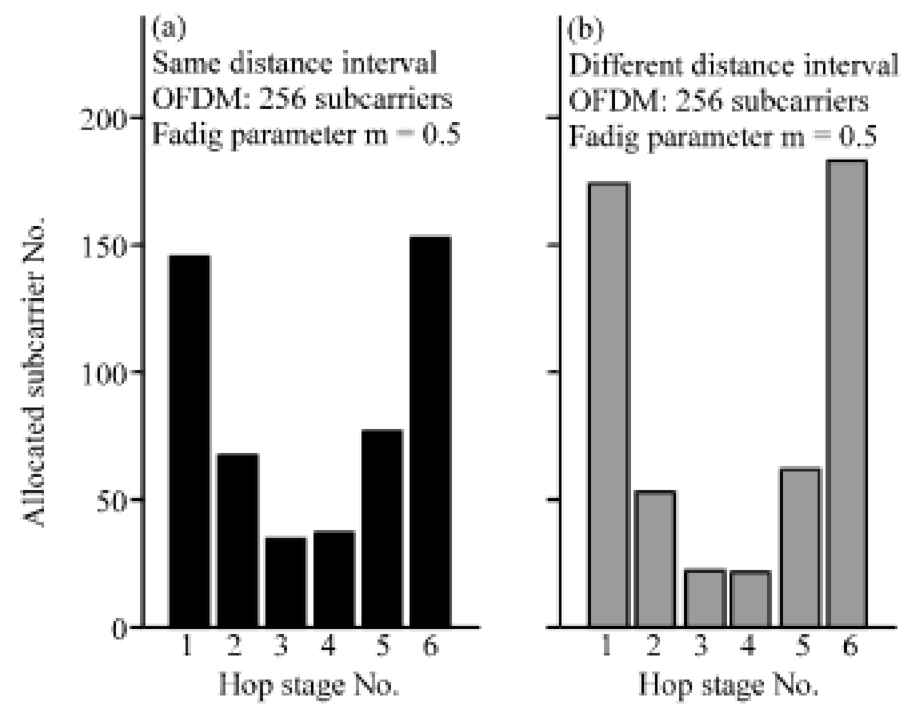

Fig. 7: Impact of distance interval on subcarrier allocation (m = 0.5)

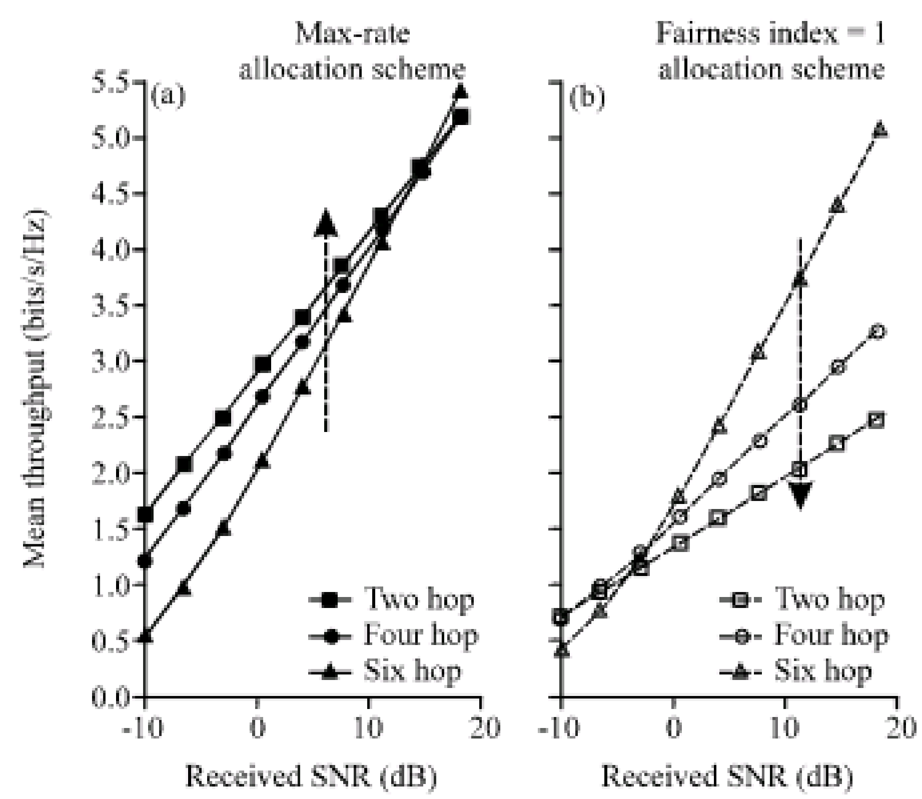

Fig. 8: Throughput comparison for two allocation schemes (m = 1.0)

Simulation 5: The throughput of two resource allocation schemes, that are Max-Rate Scheme and Fairness Index = 1 Scheme, is compared. Two-hop, four-hop and six-hop system scenarios are considered respectively. The related MIMO schemes are (1×3) and (3×1), (1×3) and (3×6) and (6×3) and (3×1), (1×3) and (3×6) and (6×9) and (9×6) and (6×3) and (3×1).

Figure 8 shows that, based on the flexible resource allocation method, Max-Rate Scheme can achieve higher throughput than Fairness Index = 1 Scheme. Moreover, with increment of multihop stage number, the throughput of Max-Rate Scheme is increased. For instance, if received SNR is 2 dB, there is 0.57 bits/s/Hz throughput gain between four-hop and two-hop scheme. And, the throughput of six hop has 0.28 bits/s/Hz performance gain compared with that of four-hop scheme.

According to Fig. 8b, to Fairness Index = 1 Scheme, it is worth noting that the system throughput degrades greatly with increase of multihop stage number in high SNR region. The reason is that Fairness Index = 1 Scheme does not satisfy the optimal resource allocation criteria. But, Fairness Index = 1 Scheme has several advantages, such as avoiding excessive control signaling and having no starvation problem. So, the tradeoff between Max-Rate scheme and Fairness Index = 1 Scheme is quite necessary. And, these simulation results give reference to the tradeoff design in multihop systems.

CONCLUSIONS

This study investigated a decode-and-forward MIMO-OFDMA multihop system. The relay transmission strategy, system throughput, long term fairness performance was considered. We derived a low-complexity analytical algorithm for multihop time-subcarrier allocation over Nakagami-m channels. We also proposed two multihop radio resource allocation schemes. One is for the fair resource assignment and another is for the throughput maximization. Monte Carlo simulations demonstrated the effectiveness of the proposed resource allocation algorithm. Besides, the multihop system throughput and fairness index performance was evaluated over various scenarios and channel conditions. Numerical results have confirmed that the proposed technique can bring benefits of high throughput, good fairness performance and flexible network deployment to multihop systems.

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