On Channel Capacity of Two-Way Multiple-hop MIMO Relay System with Specific Access Control

Pham Thanh Hiep, Nguyen Huy Hoang and Ryuji Kohno

Abstract For the high end-to-end channel capacity, the amplify-and-forward (AF) scheme multiple-hop MIMO relays system is considered. The distance between each transceiver and the transmit power of each relay node are optimized to prevent some relays from being the bottleneck and guarantee the high end-to-end channel capacity. However, when the system has no control on Mac layer, the interference signal should be taken in account and then the performance of system is deteriorated. Therefore, the specific access control on MAC layer is proposed to obtain the higher end-to-end channel capacity. The optimum number of relays for the highest channel capacity is obtained for each access method. However, there is the trade-off of channel capacity and delay time.

Keywords Multiple-hop MIMO relays system · MAC-PHY cross layer · Optimization distance · Optimization transmit power · Specific access control · Channel capacity-delay time tradeoff · Outdated channel state information

1 Introduction

In order to achieve the high performance, the multiple-hop relays system is considered. [1–3]. However, in these papers the SNR at receiver(s) is assumed to be fixed and the location as well as the transmit power of each transmitter(s) are not dealt. In the multiple-hop MIMO relay system, when the distance between the source (Tx) and the destination (Rx) is fixed, the distance between the Tx to a relay

P. T. Hiep (✉) · R. Kohno
Graduate School of Engineering, Yokohama National University, Yokohama, Japan
e-mail: hiep@kohnolab.dnj.ynu.ac.jp

N. H. Hoang
Le Quy Don Technical University, Ha Noi, Viet Nam

J. J. (Jong Hyuk) Park et al. (eds.), *Multimedia and Ubiquitous Engineering*,
Lecture Notes in Electrical Engineering 240, DOI: 10.1007/978-94-007-6738-6_105,

(RS), RS to RS, RS to the Rx called the distances between transceivers, is shorten. Consequently, according to the number of relay and the location of the relay, the SNR and the capacity are changed. Hence, to achieve the high end-to-end channel capacity, the location of each relay meaning the distance between each transceiver needs to be optimized. We have analyzed the one-way AF scheme multiple-hop MIMO relay system (MMRS) in case the interference is taken in account and optimized distance between each transceiver to obtain the high end-to-end channel capacity [4]. However, in order to achieve the higher end-to-end channel capacity when the interference is taken in account, the specific access control on Mac layer for multiple-hop MIMO relay system needs to be analyzed. In this paper, we propose the specific access control on MAC layer for one-way multiple-hop relay system and apply this method into two-way multiple-hop relay system. The proposed access control is compared to the existing method using network coding technology [5, 6]. The end-to-end channel capacity, the delay time and the relation of them is analyzed. Note that the channel capacity which is analyzed in this paper is the ergodic channel capacity. The rest of the paper is organized as follows. We introduce the concept of MMRS in Sect. 2. Section 3 shows specific access control on MAC layer. The two-way MMRS is described in Sect. 4. Finally, Sect. 5 concludes the paper.

2 Multiple-hop MIMO Relays System

The MMRS is described in details in [4]. However we choose some important parts to help the reader understand easier.

2.1 Channel Model

Let M, N and K_i ($i = 1,\ldots,m$) denote the number of the antenna at the Tx, Rx and RS_i, respectively. The distance between each transceivers is denoted by d_i ($i = 0,\ldots,m$). The distance between the Tx and the Rx is fixed as d. The Tx and all the relays employ amplify-and-forward strategy. Mathematical notations used in this paper are as follows. x and X are scalar variable, $\boldsymbol{x}$ and $\boldsymbol{X}$ are vector variable or matrix variable $(\bullet)^H$ is conjugate transpose. In order to easily describe, the Tx, Rx are also be denoted as the RS_0 and RS_{m+1}, respectively. Since the path loss is taken into consideration, channel matrix is a composite matrix and we model as $\sqrt{l_i}H_i, i = 0,\ldots,m$, of which l_i and H_i represent the path loss and the channel matrix between the RS_i and the RS_{i+1}, respectively. H_i is a matrix with independent and identical distribution (i.i.d.), zero mean, unit variance, circularly symmetric complex Gaussian entries. We assume that the transmit power of the Tx (E_{tx}), the Rx (E_{rx}) and the total transmit power of relays (E_{rs}) are fixed and are not affected by the change in the number of relays and antennas at each relay. In order to simplify the composition of relay and demonstrate the effect of optimizing the distance and the transmit power of each relay, we assume that the transmit power of each relay is equally divided into each antenna and the number of antenna in each relay is the same. Moreover, the perfect channel state information is assumed to be available and the zero forcing algorithms is applied to both the transmitter and the receiver.

3 Specific Access Control on MAC Layer

3.1 Multiple-Phases Transmission

The transmission of each relay in the system can be divided into the multiple-phases. The relays in the same phases transmit the signal in the same time and the allocation time (t_i). In the other phases, the relay keeps the silence or receives the signal. Since the neighbor relay transmits the signal in different phases, the interference signal is weaker than that of the system without control.

Figure 1 shows 2 phases and 3 phases transmission protocol. The 2 phases transmission protocol is explained as follows. The even-number relays and the odd-number relays transmit the signal in phase 1 and phase 2, respectively. The system has no control on MAC layer can be seem as the system with 1 phase transmission protocol. Therefore, the end-to-end channel capacity of the system with n phases can be written as

$$C = \log_2\left(\det\left(I_M + \frac{HH^H\left(\sum_{i=0}^{m} l_i p_i\right)}{\sigma^2 + \sum_{i=1}^{m+1-n} l_{i-1i+n}p_{i-1} + \sum_{i=0}^{m-1-n} l_{ii+1+n}p_{i+1+n}}\right)\right) \quad (1)$$

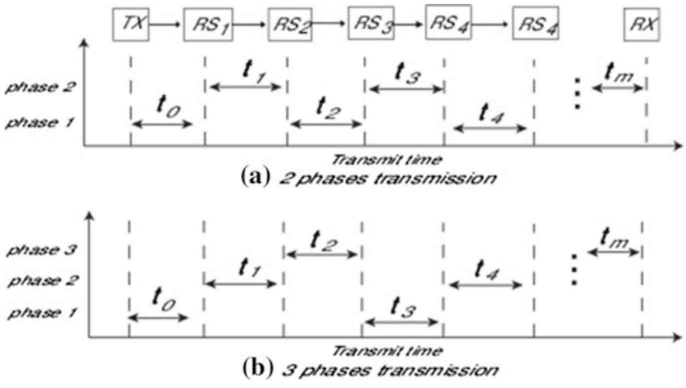

Fig. 1 2 phases and 3 phases transmission protocol

Compare the interference component of system has no control to that of the system with n phases transmission protocol (1), the distance from interference relay is longer and the number of interference relay is also larger. Hence, we can say that according to the control on MAC layer, the power of interference is decreased, thus the end-to-end channel capacity is expected to be higher.

3.2 Comparing to the existing method

The access control for one-way was proposed in Sec. 3.1. For two-way transmission, the transmission of downlink and uplink is assumed to alternate. Therefore, although the delay time increases 2 times, this transmission protocol can be extended for two-way transmission. The uplink end-to-end channel capacity is the same as the channel capacity of downlink in (1). We compare the proposed access method with existing once.The access method for two-way have being considered. There are some methods using the network coding technologies [5, 6]. In case of interference from 2d (2 times of distance), the transmission of all transmitters is divided into 3 phases. It means the delay time in this case is 3 s if we assume that the transmission time on each phase is 1 s. Moreover, in the proposed access method, the 1 phase method with MIMO beamforming to cancel the interference from uplink has the interference from 2d. However, it needs only 2 phases for two-way. It means the delay time is 2 s, smaller than the delay time of network coding method. Similarly, in case of interference from 3d, the delay time is 4 s for network coding method. In the proposed method, the 2 phases has the same distance of interference and the same delay time for two-way.

3.3 Numerical Evaluation for Proposed Access Method

In order to obtain the high end-to-end channel capacity, the distance and the transmit power should be optimized. The mathematical optimization method is explained in [4]. However, the mathematical method is complicated in case the channel model between each transceiver is different. Hence, the particle filter method is applied to optimize the distance and the transmit power simultaneously. The system parameter is summarized in Table 1.

Table 1 Numerical parameters

Antennas at *TX*, *RX*, *RS*	4
Transmit power of *TX* (mW)	100
Transmit power of *RX* (mW)	10
Total transmit power of *RS* [mW]	100
Noise power (mW)	6.12e-011
Reflection factor	0.38
Distance between *TX*-*RX* (m)	3000

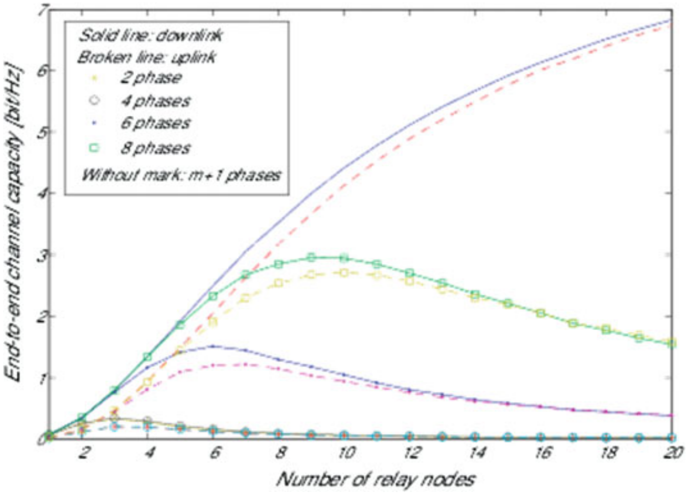

Fig. 2 The end-to-end channel capacity of two-way transmission under access control on MAC layer, the interference from both uplink and downlink

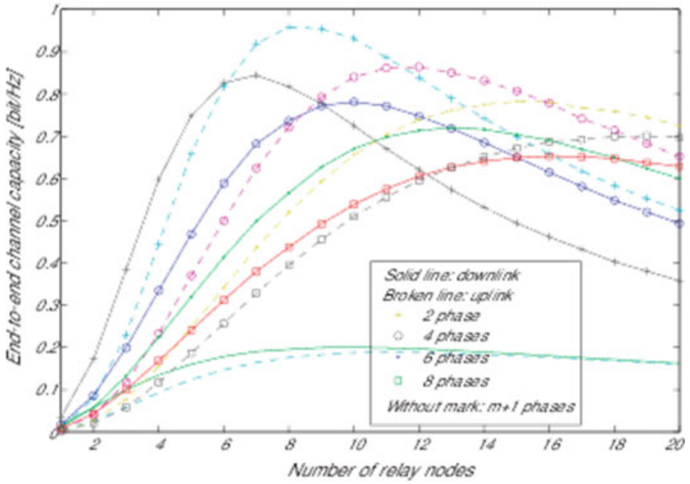

Fig. 3 The end-to-end channel capacity in case the transmission time is normalized

The end-to-end channel capacity of two-way under control on MAC layer is shown in Fig. 2. There is the optimum number of relays that has the maximum end-to-end channel capacity. In addition, the end-to-end channel capacity of the high number of phases is higher than that of the low number of phases. However, according to the transmission environment and the access method, the optimum number of relays is changed. Moreover, the allocation time for each phase was assumed as 1 s. Thus, the delay time of each access method increases when the number of phases increases. It means that there is the trade-off between channel capacity and delay time. In case the transmission time of the system is normalized meaning the transmission time from the *Tx* to the *Rx* is 1 s, the end-to-end channel capacity is shown in Fig. 3. According to the channel model (the transmission environment, the transmit power and so on), the optimum number of relays and the number of phases is changed for the highest end-to-end channel capacity

4 Conclusion

The access control method on MAC layer for two-way MMRS is proposed based on the access method of one-way and compared to the existing method. There are the trade-off of channel capacity-delay time and the optimum number of relays for highest end-to-end channel capacity. According to the channel model and the number of phases, the optimum number of relays is different. In this paper, we have optimized the distance and the transmit power for each transmission protocol on MAC layer to obtain the highest end-to-end channel capacity. However, the combination of physical layer and MAC layer is not optimized. Additionally, the perfect channel state information is assumed and the ergodic channel capacity is analyzed. In the future, the system with the imperfect channel state information and the instantaneous channel capacity will be analyzed.

References

1. Gastpar M, Vetterli M (2005) On the capacity of large Gaussian relay networks. IEEE Trans Inf Theor 51(3):765–779
2. Levin G, Loyka S (2010) On the outage capacity distribution of correlated keyhole MIMO channels. IEEE Trans Inf Theor 54(7):3232–3245
3. Peyman R, Yu W (2009) Parity forwarding for multiple-relay networks. IEEE Trans Inf Theor 55(1):158–173
4. Hiep PT, Kohno R (2010) Optimizing position of repeaters in distributed MIMO repeater system for large capacity. IEICE Trans Commun E93-B(12):3616–3623
5. Katti S, Rahul H, Hu W, Katabi D, Mdard M, Crowcroft J (2006) Xors in the air: practical wireless network coding, Proceedings of the 2006 conference on applications, technologies, architectures, and protocols for computer communications, vol 36, no 4, pp 243–254
6. Popovski P, Yomo H (2007) Physical network coding in two-way wire- less relay channels, IEEE International Conference on Communications (ICC07), pp 707–712
7. Kita N, Yamada W, Sato A (2006) Path loss prediction model for the over-rooftop propagation environment of microwave band in suburban areas (in Japanese) IEICE Trans Commun J89-B(2):115–125
8. Edwards HM (1997) Graduate texts in mathematics: Galois theory, Springer, New York