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Adaptive Relay Selection Scheme for Minimization of the Transmission Time

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Abstract: As the installation of small cells increases, the use of relay also increases. The relay operates as a base station as well as just an amplifier. As the roles and types of relays become more diverse, appropriate relay selection technology is an effective way to improve communication performance. Many researches for relay selection have been studied to secure the reliability of relay communication. In this paper, the relay selection scheme is proposed for a cooperative system using decode-and-forward (DF) relaying scheme in the mobile communication system. To maintain the transmission rate, the proposed scheme classifies a candidate group considering the outage probability of multiple relays. For the applicable candidate group, the proposed scheme selects the relay considering the amount of data allocated to each user. Therefore, the proposed scheme defines the unit transmission time through each user's data and relay capacity. Finally, the proposed scheme selects a relay that minimizes the total transmission time through the relay transmission time that calculates the unit transmission time for all users. With this adaptive relay selection scheme, an optimal relay can be assigned for each user. For the same transmission rate and the amount of data, the proposed scheme improves the performance of transmission time and reliability. Simulation results show that the proposed scheme reduces the total transmission time for the same amount of data and signal to noise ratio (SNR).

Keywords: Relay selection; cooperative relay; MIMO; outage probability; transmission time

1 Introduction

In upcoming years, the usage of mobile traffic is expected to be massive, and throughput of communication is getting higher. As the usage of mobile data is increased, mobile network is needed to provide higher performance in terms of throughput, latency and reliability.

Current mobile network systems such as long-term evolution (LTE) and 5G new radio (NR) are deployed in a variety of ways to meet the actual needs and possibilities. Meanwhile, there are many cases where sufficient reliability and throughput are not guaranteed in the wireless communication system. For example, in the mmWave bands, although a shorter transmission time

interval can be used because of low frequency selectivity, the cell coverage would be limited because of higher path loss, which would inevitably lead to the use of small cell sizes [1]. Also, cells are overloaded due to increased space density and mobile devices [2]. Therefore, the design of a new cell is required.

The future communication network may be a heterogeneous layer network consisting of macrocells, traditional micro/picocells, new local small cells, and relay and other low-power nodes [3]. Specifically, the relay system can be used in various ways in the future wireless mobile communication network. The relay system is one of the techniques to provide sufficient coverage and reliability in the wireless communication system. The relay is used to overcome poor wireless link conditions in a cooperative communication system. By implementing a relay node, the relay node handles and routes data traffic between source and destination. Therefore, the SNR and capacity can be increased. Also, relays can improve the topology, network robustness and power consumption of mobile communication systems. As the wireless backhaul secures sufficient capacity, the mobile station can be a solution for the mobile communication systems that can configure a mobile cell architecture [4–6]. The relay supports mobile group access and can provide new services by supporting access nodes in the Internet of things (IoT) network [3,7].

There are many researches related to relay technologies [8–10]. A relay node can assist a pair of users with one-way (OW) or two-way (TW) traffic patterns [11]. For the same data rate, two-way relaying protocol improves transmission power consumption and spectral than one-way relaying protocol [12]. For this reason, two-way relaying protocols have been studied actively to improve performance [13].

To enhance the capacity and reliability, the multiple-input multiple-output (MIMO) relay system can be considered. MIMO techniques provide higher capacity gain using diversity and multiplexing in a relay system.

This paper proposes the adaptive relay selection scheme to enhance the transmission time of the wireless system. The proposed scheme not only considers the link capacity but also the buffered data traffic of active users. Specifically, the proposed scheme classifies the available relay group and then considers the amount of data assigned to each user. Therefore, the proposed scheme reduces the transmission time while the transmission rate is maintained.

This paper is organized as follows. Section 2 introduces the system model. Section 3 explains the conventional schemes. Section 4 describes the algorithm and advantage of the proposed scheme. Simulation results are shown in Section 5. Finally, Section 6 gives the brief conclusions.
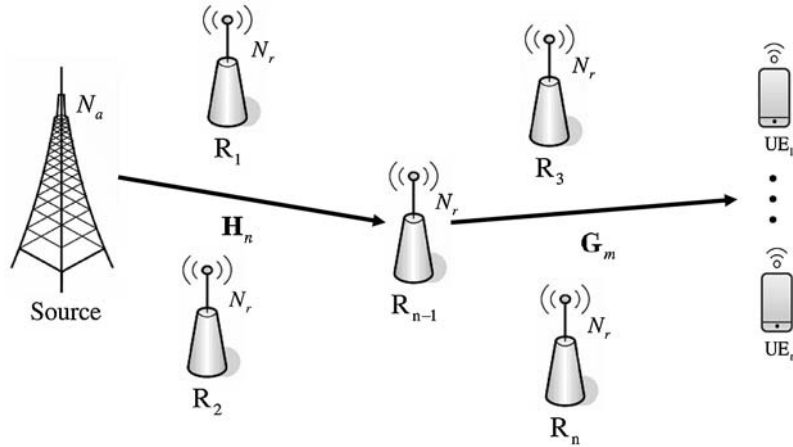
2 System Model

Fig. 1 shows the heterogeneous dense network consisting of multi-small cells. Fig. 2 is one of the small cells in Fig. 1. Also, Fig. 2 shows two-hop MIMO relay wireless system model in a wireless network. The system consists of one source node (S) node and each user UE_m ($m = 1, \ldots, M$). Fig. 3 shows the buffers for UE_m. The amount of data UE_m can be changed, and the buffer size can be changed accordingly. Also, UE_m requires different amount of data. The number of antennas on S and UE_m is the same as N_a. Furthermore, multiple relays exist in the system model. Each relay node is expressed as R_n ($n = 1, \ldots, N$). R_n has N_r antennas for the receiving and transmitting data. A set of R_n uses the decode-and-forward (DF) protocol. Since DF protocol demodulates received signal and re-encodes the signal before retransmission of the signal, the effect of noise can be reduced. Direct links ($S \rightarrow UE_m$) are assumed to be too weak and cannot support the transmission of high quality [13]. Therefore, direct links ($S \rightarrow UE_m$)

are not considered. Non-direct links $((S \to R_n)$ and $(R_s \to UE_m))$ are only available. In addition, it is assumed that each node operating as a transmitter knows channel state information (CSI) through feedback according to transmission of a pilot signal to the receiver node.
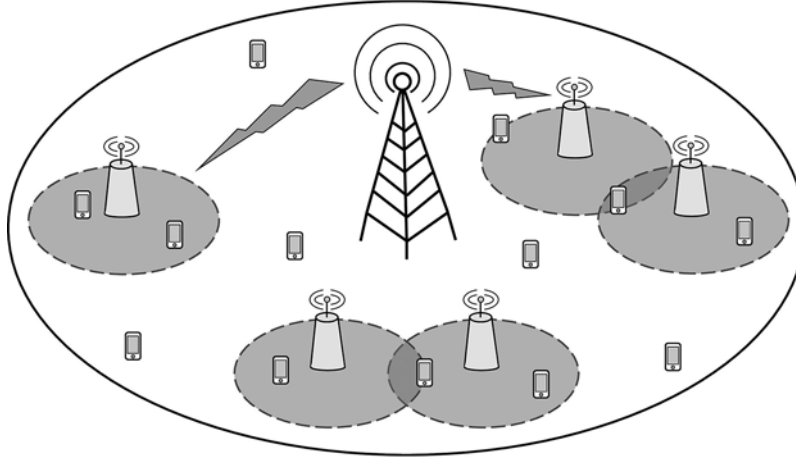
Figure 1: The heterogeneous network for multi-small cells


Figure 2: Two-hop MIMO relaying system

System model uses two time slots for signal transmission. S transmits signal to R_n during the first time slot. The received signal at R_n is as follows,

$$y_n = \mathbf{H}_n\mathbf{x} + \mathbf{n_r}, \tag{1}$$

where $\mathbf{x} \in \mathbb{C}^{N_a}$ is the transmitted signal vector from S. $\mathbf{H}_n$ is the $N_r \times N_a$ channel between S and R_n.

Furthermore, $\mathbf{H}_n$ is modeled as Rayleigh fading. $\mathbf{x}$ is a signal transmitted from S. And $\mathbf{n_r} \in \mathbb{C}^{N_r}$ is an additive white Gaussian noise (AWGN) vector with zero mean and variance N_0 at R_n.
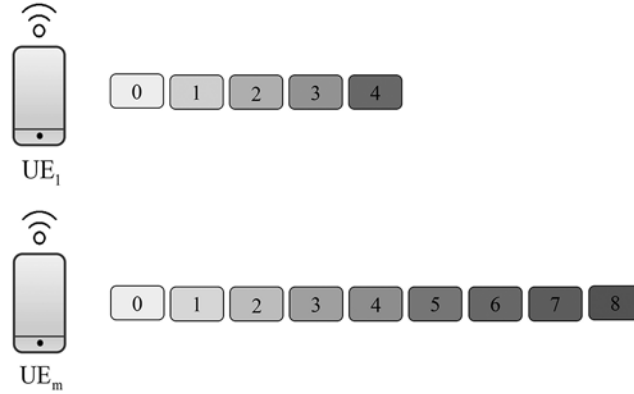
Figure 3: Assigned buffers for each user

During the second time slots, R_s transmits a signal to UE_m. R_s $(s = 1, \ldots, S)$ is selected as a relay among a set of R_n. The received signals at UE_m are as follows,

$$\mathbf{y}_m = \mathbf{G}_m^s \hat{\mathbf{x}}^s + \mathbf{n}_d, \tag{2}$$

where transmitted signal from a set of R_s is $\mathbf{y}_m = [\mathbf{y}_1, \ldots, \mathbf{y}_m]^T$. $\mathbf{G}_m^s$ is the $N_a \times N_r$ compound channel between UE_m and a set of R_s. A compound channel is a combination of channels between relays that can be used to transmit to the same destination. Furthermore, $\mathbf{G}_m^s = [\mathbf{g}_m^1, \ldots, \mathbf{g}_m^S]^T$ is modeled as Rayleigh fading. $\hat{\mathbf{x}}^s = [\hat{\mathbf{x}}^1, \ldots, \hat{\mathbf{x}}^S]$ is retransmitted signal from R_s. N_a of UE_m receives different signals. $\mathbf{n}_d \in \mathbb{C}^{N_a}$ is an AWGN vector.

3 The Conventional Relay Selection Schemes

This section describes two conventional relay selection schemes. Many researchers have studied for the methods to select relays in different communication environments [14–16]. In each research, there are various schemes for selecting relays, but eventually the relay with the best channel conditions is selected. In other words, the channel condition of R determines the communication performance. Accordingly, the most conventional schemes use channel magnitude from R. Among the conventional schemes, the relay selection schemes that provide the basis for other researches are as follows.

3.1 The Frobenius Norm-Based Selection Scheme

Norm usually uses the Frobenius norm, which is L_2-norm, to indicate the distance from the origin. The Frobenius norm is defined for a channel matrix of R as follows,

$$\|R\|_F = \left(\sum_{i=1}^{N_r} \sum_{j=1}^{N_a} |a_{ij}|^2 \right)^{\frac{1}{2}}, \tag{3}$$

where $\|R\|_F$ means the Frobenius norm of R. a_{ij} is an element of $\mathbf{H}_n$ consisting of $N_r \times N_r$. a_{ij} with the absolute value is expressed as $|a_{ij}|$. The Frobenius norm of R is the square root of a sum of all $|a_{ij}|^2$.

$$\|R\|_F = tr(\mathbf{H}_n^T \mathbf{H}_n) \tag{4}$$

And the diagonal entry in $\mathbf{H}_n^T\mathbf{H}$ is the sum of the squares of each column of $\mathbf{H}_n$. Therefore, the sum of the diagonal entries of $\mathbf{H}_n^T\mathbf{H}$ is equal to the total sum of $|a_{ij}|^2$. Furthermore, it is same with the sum of an eigenvalue $\mathbf{H}_n^T\mathbf{H}$. σ_i^2 means the square of the singular value of $\mathbf{H}_n$. Eq. (5) presents the singular value decomposition (SVD) of $\mathbf{H}_n$. $\mathbf{H}_n$ can be described as follows,

$$\mathbf{H}_n = \mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^H, \tag{5}$$

where U and V are unitary matrix. $\boldsymbol{\Sigma}$ is a diagonal matrix with the singular value. σ_i is a component of $\boldsymbol{\Sigma}$. The sum of an eigenvalue $\mathbf{H}_n^T\mathbf{H}$ is equal to the sum of σ_i^2. In other words, the Frobenius norm depends on singular value. The Frobenius norm-based selection scheme calculates Eq. (3) for each candidate relay channel and selects the relay with the largest Frobenius norm.

3.2 The MIMO Capacity-Based Selection Scheme

Among the relay selection schemes, the scheme using MIMO relay channel capacity is frequently used [17–19]. The MIMO channel capacity of the k-th relay is as follows,

$$C_n = \log_2\left(\det\left(\mathbf{I} + \frac{\rho}{N_a}\mathbf{H}_n\mathbf{H}_n^H\right)\right), \tag{6}$$

where $\mathbf{I}$ denotes the identity matrix. ρ denotes average SNR at each antenna of the relay as $\frac{P_t}{N_0}$. P_t is the transmitting power of the signal and N_0 is noise power. $\mathbf{H}_n^H$ means the Hermitian conjugate transpose matrix of $\mathbf{H}_n$. Therefore Eq. (6) can be approximated as follows,

$$C_n = \sum_{i=1}^{N_a}\log_2\left(1 + \sigma_i^2\rho\right). \tag{7}$$

As a σ_i^2 increases, available channel capacity also increases. The MIMO capacity-based selection scheme selects relay with the largest capacity using Eqs. (6) or (7).

4 The Proposed Selection Scheme

The relay selection scheme to reduce the total transmission time is proposed. The selection process consists of two selection steps. In the first step, the transmitter organizes a relay group by selecting qualified relays. According to the result of the first step, in the second step, relays for transmission are selected to minimize the total transmission time. The selection process is described in the following subsection.

4.1 Classification of Relay Candidate Group

For reliability of relaying, qualified R_n is selected. For the selection, S calculates probability that outage does not happen for each R_n based on reported CSI. Residual capacity of the links between S and each R_n is calculated as follows,

$$\varepsilon_n = \max\left(C_n - \beta, 0\right), \tag{8}$$

where C_n denotes normalized channel capacity of $\mathbf{H}_n$. β is the number of bits in $\mathbf{x}$. ε_n is the residual capacity of the link between S and R_n. If outage happens, ε_n becomes zero. In other words, S decides that the link is valid when the C_n is greater than $\mathbf{x}$. Among the R_n, the relay

that meets the non-zero condition of Eq. (8) is defined as R_g $(g = 1, \ldots, G)$. The group of the qualified relays is expressed as follows,

$$\mathbb{G} = \left\{ R_g \mid \varepsilon_g > 0 \right\}. \tag{9}$$

The selection process is summarized as follows:

(1) Inputs:

     β, $\mathbf{H}_n$, $n = 1, \ldots, N$

(2) initialize:

     C_n, ε_n, $g \leftarrow 0$

     $\mathbb{G} \leftarrow \{\}$

(3) for $n = 1 : N$

(4)   if $\varepsilon_n > 0$ then

(5) $g \leftarrow g + 1$

(6) $R_g \leftarrow R_n$

(7) $\mathbb{G} \leftarrow R_g$

(8)   end if

(9) end for

(10) if $G < 2$ then

(11)   break

(12) R_n with largest C_n is selected as R_s

(13) else

(14)   Go to the second process

(15) end if

The line of (10) explains processing for low SNR environment. The low SNR environment can make every ε_n zero and outage happens in all links. In this case, S can stop transmission until qualified link is detected.

However, to prevent waste of bandwidth, in proposed algorithm, S selects the most favorable relay as R_s in the coherence time. If any non-correctable errors occur, the relay should notify necessity of retransmission.

4.2 Relay Selection to Minimize the Transmission Time

In this section, the process to allocate relays to users is performed for minimization of the total transmission time. In this process, two cases are considered. The cases are determined according to G. If G is lower than two, the case is low SNR case. In the low SNR case, the most favorable relay is determined as R_s and the data of all users is transmitted through the selected relay. In other words, the transmission time is optimized only if the number of G is larger than one. In the low SNR case, the transmission time is as follows,

$$T_{tot} = \sum_{m=1}^{m} \frac{B_m}{C_{m,s}}, \tag{10}$$

where $C_{m,s}$ is normalized channel capacity between R_s and UE_m.

In the other case, S optimizes the transmission time by using the CSI between the qualified relays and the users. The transmission time between R_g and UE_m is defined as follows,

$$T_{m,g} = \frac{B_m}{C_{m,g}}, \tag{11}$$

where B_m $(m=1, 2, \ldots, M)$ is the amount of data from UE_m. The amount is considered as random variable and generally the distribution of B_m is modeled by Poisson distribution. $C_{m,g}$ $(g=1, 2, \ldots, G)$ denotes normalized channel capacity between R_g and UE_m. According to Eq. (10), the total transmission time can be described as follows,

$$T_{tot} = \sum_{m=1}^{M} T_{m,g_m}. \tag{12}$$

In other words, T_{tot} is the total time required to transmit data of all users. To minimize T_{tot}, g_m is determined as follows,

$$g_m = \arg \max_{R_g \in \mathbb{G}} \left\{ C_{m,g} \right\}. \tag{13}$$

The detailed description is summarized as follows:

(1) Inputs:

    $\mathbb{G}$, B_m $(m=1, \ldots, M)$

(2) Initialize:

    $C_{m,0} \leftarrow 0$

(3) for $m=1:M$

(4) $g_m \leftarrow 0$

(5)   for $g=1:G$

(6)   If $C_{m,g} > C_{m,g-1}$

(7) $g_m \leftarrow g$

(8)   end for

(9) end for

The proposed scheme classifies a candidate relay group with non-outage. For a configured group of candidate relays, the relay with the minimum transmission time is selected. The proposed scheme can select a relay that reduces the transmission time while the BER performance through two steps is improved.

5 Simulation Results

Tab. 1 shows the simulation parameters. The proposed scheme is simulated with 64 symbols and a 7-path Rayleigh fading channel. Two different modulation schemes of QPSK and 16-QAM are used to analyze the performance according to the modulation order. The zero-forcing (ZF) scheme is used to simplify signal detection. Three distance ranges are used to compare the performance effect of distance and outage. The first distance range is divided into S to R_n and R_n

to UE_m based on 0.25. The second distance range is divided into S to R_n and R_n to UE_m based on 0.5. The third distance range is divided into S to R_n and R_n to u based on 1. The maximum total distance of the first and second range is normalized to 1. The third distance range has a higher channel variation than the other distance ranges. R_n has a random distribution within each distance range. The number of users is two and uses single-user detection by ZF. The number of R_n is four and eight to compare the performance according to the number of relays. The number of all antennas is fixed as 2 to exclude the performance change according to the number of antennas. The simulations iterate 10,000 times for statistics on performance.

Table 1: Simulation parameters

Number of symbols	64	
Modulation	QPSK, 16-QAM	
Channel	Rayleigh fading	
MIMO detection	Zero forcing	
Distance rate	Random distribution	
	Source to relay	Relay to destination
	0 to 0.25	0.25 to 1
	0 to 0.5	0.5 to 1
	0 to 1	0 to 1
Transmit power	Normalization to 1	
Number of users	2	
Number of relays	4, 8	
N_r, N_a, N_m	2	

The simulation graphs show the total transmission time and the maximum performance is normalized to 1. The proposed scheme is compared with the two conventional selection schemes, and the comparison schemes are mentioned in Section 3. The number of R_n is four in Figs. 4–6. When the number of R_n is eight, performance is shown in Figs. 7–9. Figs. 4 and 7 use 0.25 distance range and Figs. 5 and 7 use 0.5 distance range. Figs. 6 and 9 use 1 distance range. All simulation graphs show the performance of 16-QAM and QPSK modulation scheme. The proposed scheme improves the total transmission time than the capacity and Frobenius norm-based scheme. In the same parameter, the capacity and Frobenius norm-based scheme have the same performance.
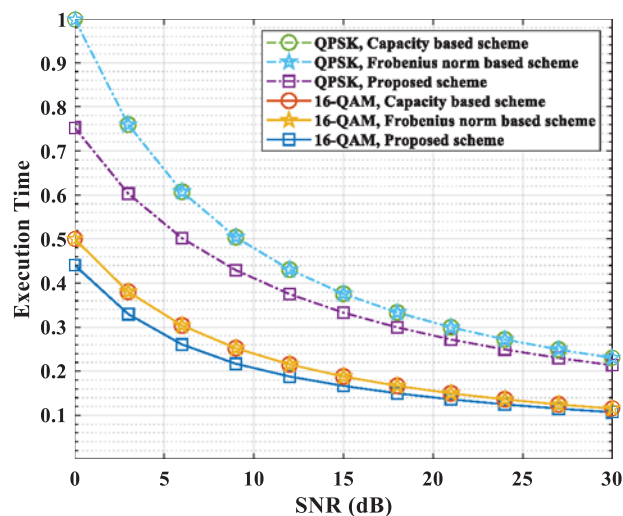
In Fig. 4, the proposed scheme using QPSK modulation shows about 1.5 times faster performance at low SNR than the comparison scheme. At mid-SNR, the proposed scheme using QPSK modulation has about 1.3 times faster performance than the comparison scheme. As SNR increases, the occurrence of outages also decreases and the gain of time performance decreases. The proposed scheme using QAM modulation has about 1.5 times faster performance at low SNR. At mid-SNR, the proposed scheme using QAM modulation has about 1.3 times faster performance than the comparison scheme.
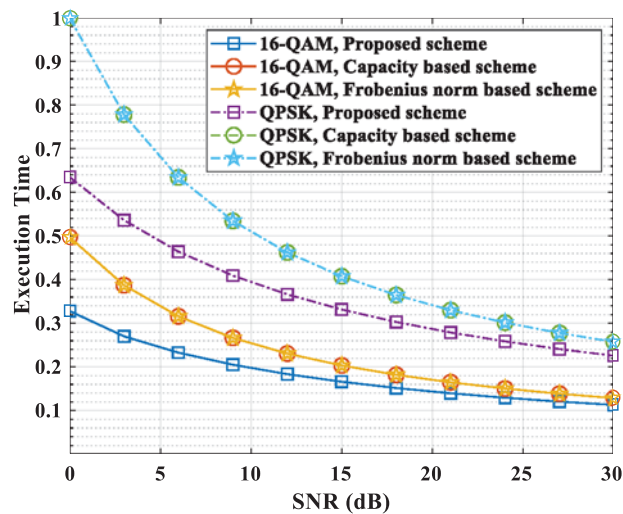
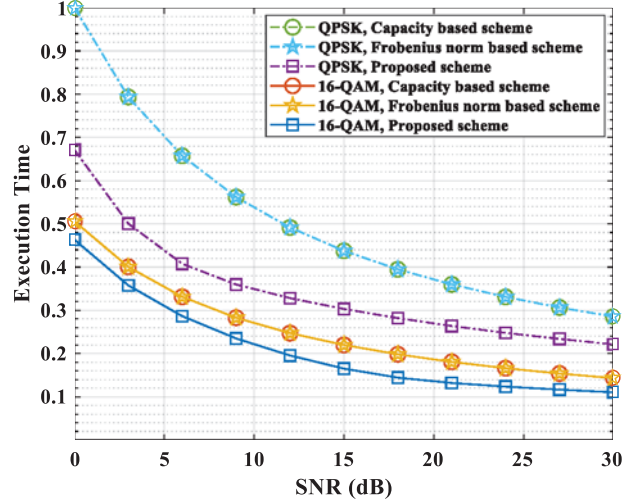**Figure 4:** Total time performance (4 relays 0.25 distance)

In Fig. 5, the proposed scheme using QPSK modulation is about 1.3 times faster than the comparison scheme at low SNR. The proposed scheme using QAM modulation is about 1.15 times faster than the comparison scheme at low SNR. In the middle SNR, all performance gains are reduced between the proposed scheme and the comparison schemes. As the distance between the S and R_n is averaged, the performance gain of the proposed scheme is reduced.

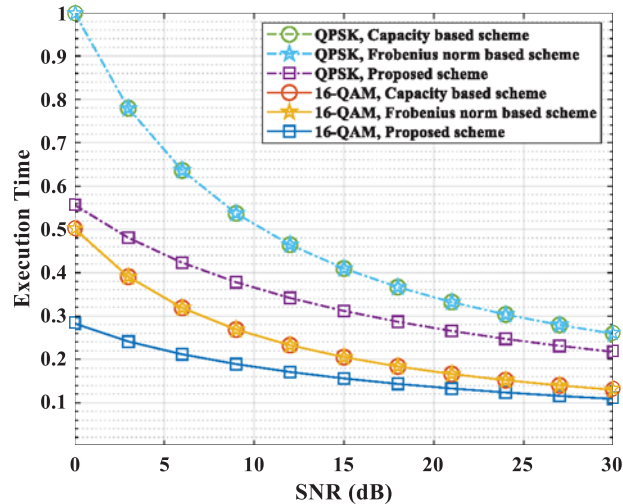**Figure 5:** Total time performance (4 relays 0.5 distance)

Fig. 6 shows that the proposed scheme using QPSK modulation has 1.5 times faster performance gain than the comparison schemes of low SNR. At mid-SNR, the proposed scheme using QPSK modulation shows about 1.4 times faster than the comparison schemes. Compared to Fig. 5, the performance gain of the proposed scheme using QAM modulation is similar at low

SNR, but increases at medium SNR. When a distance range is 1, the proposed scheme using QPSK modulation has performance improvement at low SNR.

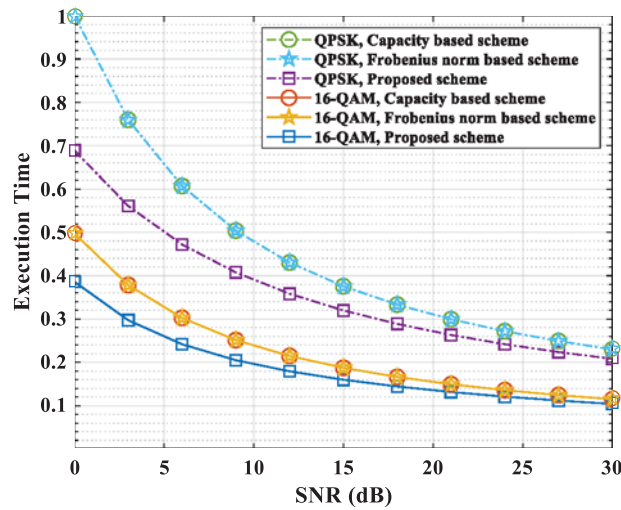**Figure 6:** Total time performance (4 relays 1 distance)

All schemes in Figs. 4 and 7 have almost similar performance gain. Fig. 7 shows that the only proposed scheme has 1.2 times performance gain than the proposed scheme in Fig. 4. Although the number of R_n increases, the diversity gain is not linearly increased because the number of R_s is one. For the same reason, the performance of Fig. 8 is similar to Fig. 5.
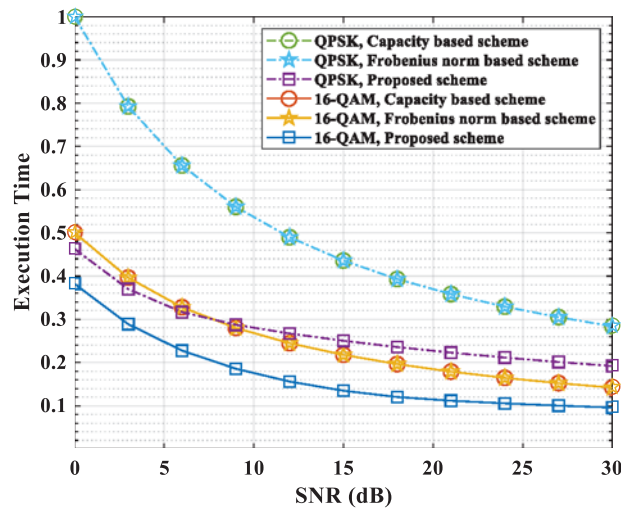

Figure 7: Total time performance (8 relays 0.25 distance)

In Fig. 9, the proposed scheme using QAM modulation is 1.3 times faster than the comparison schemes. The proposed scheme using QPSK modulation has 2 times performance improvement at low SNR than the comparison schemes. At mid-SNR, the proposed scheme using QPSK modulation has 1.8 times performance improvement at low SNR than the comparison schemes.

The proposed scheme using QPSK modulation has 1.4 times performance improvement at low SNR compared to Fig. 6. At mid-SNR, the proposed scheme using QPSK modulation has 1.4 times performance improvement compared to Fig. 6. The performance of the proposed scheme using QAM modulation is similar to Fig. 6. The proposed scheme using QPSK modulation has a different form of performance gain than other Figures. With the QPSK modulation scheme, signal demodulation is easier than the QAM modulation scheme even when the outage occurs.

Figure 8: Total time performance (8 relays 5 distance)

Figure 9: Total time performance (8 relays 1 distance)

The simulation results show that the proposed scheme reduces the performance of the total time than the comparison schemes. As the low SNR, the proposed scheme has higher performance gain. Depending on the distance range, the performance gain of the comparison schemes is same but the performance gain of the proposed scheme can be improved. Especially for distance ranges

of 0.25 and 1, the proposed scheme has a performance gain. The performance gain can be increased with more users.

6 Conclusions

In this paper, a relay selection scheme is proposed for reducing the transmission time. The proposed scheme gets the performance gain from two steps. The available relays in the first step are classified as candidate relay group. According to the result of the first step, the second step is executed. When an applicable case exists, the second step determines a relay considering the transmission time of each user. Through this process, the proposed scheme shows that the total transmission time is improved even at low SNR. Simulation results show that the proposed scheme improves the total transmission time when the same data are transmitted.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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