Performance Analysis of Four Different Downlink Data Relaying Schemes in Cellular Systems

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Abstract— **In this paper, we mathematically analyze the performance of four different relaying schemes in cellular systems. We assume a downlink cellular system with fixed relays and a mobile station is either directly connected to a base station and/or connected to a relay station. We consider four different downlink data relaying schemes: a direct scheme, a relay scheme, a selection scheme, and a cooperative scheme. Under the environment, we derive a closed-form solution or upper bound of the ergodic and outage capacities. We also analyze the system capacity in a multiuser diversity environment in which a maximum signal-to-noise ratio (SNR) scheduler is used at a base station. The analytical results agree well with computer simulation results. The result shows that the selection scheme outperforms the other three schemes in terms of link ergodic capacity, link outage capacity, and system ergodic capacity.**

I. INTRODUCTION

Knopp and Humblet [1] first introduced multiuser diversity as a means to provide diversity against channel fading in multiuser communication systems. The performance gain of multiuser diversity increases as the number of active users in the system becomes large [2]. When a base station (BS) selects one user with the maximum signal-to-noise ratio (SNR) value among multiple users, it has a more chance to capture users with higher SNR values as the number of users increases.

However, since users near cell-boundary or dead spots generally have lower SNR values, compared to users in an inner cell region, they are selected with lower probabilities by the scheduler at the BS. Therefore, studies on fixed or nomadic relays have been done [3] [4] [5]. When multiple relays are available in transmission, selecting one or multiple relays based on channel state information (CSI) is also another research issue [6]. A dual-hop transmission with fixed gain relays was investigated in terms of outage probability and average error probability [7]. More recently, a new relaying scheme that exploits multiuser diversity in multihop networks was proposed in [8] [9], in which multiuser diversity is exploited in each hop by selecting the next hop relay based on the instantaneous channel quality. However, most part of their study relies on simulation results and mathematical analysis on multiuser diversity and relay schemes was very limited.

Recently, a new form of spatial diversity has been introduced in [10] and [11] called *cooperative diversity*. The main idea of the cooperative diversity is to utilize multiple nodes as a virtual macro antenna array, realizing spatial diversity in a distributed manner. However, they have some impractical assumptions, such as perfect time synchronization, no peak power constraints, and perfect CSI at both the transmitter and the receiver.

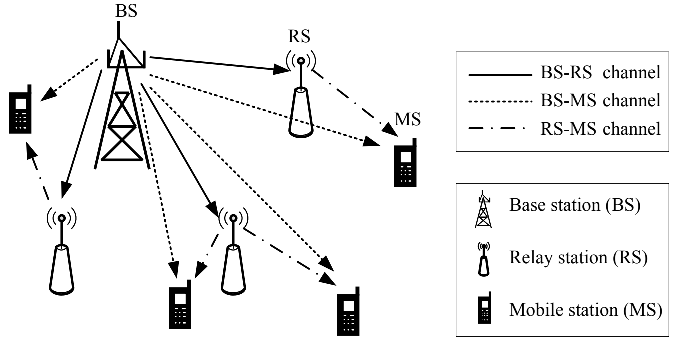


Fig. 1. System Model

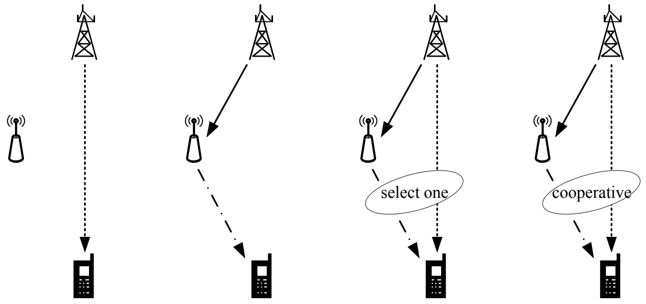
In [12], cooperative diversity and multiuser diversity in cooperative relay networks were mathematically analyzed. The result shows that both cooperative diversity and multiuser diversity are exploited in a system environment and the diversity increases as the number of source/destination pairs increases. However, the analysis is based on ad-hoc networks which have many source/destination pairs, and, thus, it is not suitable for cellular systems.

There have been no rigorous mathematical analysis on the effect of multiuser diversity in cellular system with relays. In this paper, we mathematically analyze the ergodic capacity and the outage capacity for a single-link, multiuser environment. The analysis highlights the effect of multiuser diversity in various relay schemes. We investigate the effect of multiuser diversity, selection diversity, and cooperative diversity in a downlink cellular system with multiple fixed relays.

The rest of this paper is organized as follows. In Section II, we introduce a system and channel model under consideration. In Section III, we analyze the performance of downlink capacity in terms of ergodic capacity and outage capacity. In Section IV, the performance of the multiuser system with relays is also analyzed. Finally, conclusions are presented in Section V.

II. SYSTEM AND CHANNEL MODEL

Fig.1 shows a cellular downlink system with one BS located at the center of a cell, R relay stations (RS), and N mobile stations (MS). RSs do not have their own messages and are soley intended to assist the MSs and the BS to communicate



(a) Direct Scheme (b) Relay Scheme (c) Selection Scheme (d) Cooperative Scheme

Fig. 2. Transmission for four different schemes

with one another. We assume that the RSs are nomadic or fixed and are operated in half-duplex mode. We assume that at a given time each MS communicates with a BS through a nomadic or fixed relay station. There are three types of wireless channels in the model: a channel between a BS and an RS (BS-RS channel), a channel between a BS and an MS (BS-MS channel), and a channel between an RS and an MS (RS-MS channel). The capacity of BS-RS channels is assumed to be always better than that of RS-MS channels so that the capacity of a channel between the BS and an MS via an RS is always limited by the capacity of the channel between the RS and the MS. We assume that both the BS-MS and RS-MS channels follow Rayleigh distributions, and they are independent of each other. We also assume that all users have an identical channel environment for mathematical simplicity. Other-cell interference is also neglected in this single-cell mathematical analysis model.

We consider four downlink data relaying schemes: a direct scheme, a relay scheme, a selection scheme, and a cooperative scheme.

A. Direct Scheme

In the *direct scheme*, an MS communicates only with a serving BS directly without a relay system, as shown in Fig. 2-(a). The system is considered as a conventional cellular system without relays. The signal received at the i-th user is given by

$$y_i = h_{d,i} \cdot s_i + n_i \quad (1 \le i \le N), \tag{1}$$

where $h_{d,i}$ and n_i represent the BS-MS channel coefficient and the thermal noise at the i-th user, respectively. Since the BS-MS channel link is assumed to be Rayleigh distributed, i.e., $h_{d,i} \sim CN\left(0, \mu_{d,i}^2\right)$, and $n_i \sim CN\left(0, N_0\right)$, the signal s_i is transmitted from the BS and $\mathbb{E}\left[|s_i|^2\right] = P$. The term $\mu_{d,i}^2$ indicate the channel gain between the BS and the i-th MS, and it is the same regardless of MSs as noted before. Thus, we remove the user index i from now on. The received signal-to-noise ratio (SNR) of a user is given by $\gamma \triangleq |h_d|^2 P/N_0$. Thus, the probability density function (PDF) of the received SNR of the i-th user is given by

$$f\left(\gamma\right) = \frac{1}{\rho\mu_d} e^{-\frac{\gamma}{\rho\mu_d}}, \tag{2}$$

where $\rho = P/N_0$ denotes the input SNR at the BS.

B. Relay Scheme

In the *relay scheme*, an MS communicates only with its RS and the communication link between the BS and MS is assumed to be blocked, as shown in Fig. 2-(b). In this system, all MSs communicate with the BS via an RS. The signal received at user i is given by

$$\begin{aligned} y_{i,1} &= n_{i,1}, && \text{in } \textit{Phase I}, \\ y_{i,2} &= h_{r,i} \cdot s_i + n_{i,2}, && \text{in } \textit{Phase II}, \end{aligned} \tag{3}$$

where h_r and n_i represent the RS-MS channel coefficient and the thermal noise at the i-th user, respectively. The transmit power of an RS is assumed to be the same as that of a BS. Due to the half-duplex nature of a relay transceiver, the transmission time should be divided into two phases: *Phase-I* for receiving data from the BS at the RS, and *Phase-II* for sending the data from the RS to the MS. $y_{i,j}(i \in N, j \in \{1,2\})$ represents the received signal of the i-th user at *Phase-j*. The time durations for two phases are the same. Since the RS-MS channel link is also assumed to be Rayleigh distributed, $h_{r,i} \sim CN\left(0, \mu_{r,i}^2\right)$, $n_i \sim CN\left(0, N_0\right)$. The received SNR of the i-th user at *Phase-II* is given by $\gamma_r \triangleq |h_r|^2 P/N_0$. Thus, the PDF $f_r(\gamma)$ of the received SNR at a user is given as

$$f_r\left(\gamma\right) = \frac{1}{\rho\mu_r} e^{-\frac{\gamma}{\rho\mu_r}}, \tag{4}$$

where $\rho = P/N_0$ denotes the input SNR at the BS.

C. Selection Scheme

Since a BS has two downlink paths: a BS-MS direct link and a BS-RS-MS relay link, the BS can achieve a larger capacity when it selects better link among the two communication links. In the *selection scheme*, the BS always checks which link is better from the achievable capacity point of view and chooses the better link to communicate with the MS, as shown in Fig. 2-(c). We assume that the channel coefficient h_d and h_r are known to the BS through the feedback from each user. In this scheme, the received signal is given by

$$\begin{aligned} &\text{(When the direct link is better)} \\ y_i &= h_d \cdot s_i + n_i, \\ &\text{(When the relay link is better)} \\ y_{i,1} &= n_{i,1}, \quad \text{in } \textit{Phase I}, \\ y_{i,2} &= h_r \cdot s_i + n_{i,2}, \text{in } \textit{Phase II}. \end{aligned} \tag{5}$$

The BS determines the better path based on the achievable capacities of two paths. The achievable capacities of the direct path and the relay path are given by $\log_2\left(1 + |h_d|^2 P/N_0\right)$ and $\frac{1}{2}\log_2\left(1 + |h_r|^2 P/N_0\right)$, respectively. Therefore, the BS can achieve $\log_2\left(\delta_s\right)$ where $\delta_s \triangleq \max\left(1 + |h_d|^2 P/N_0, \sqrt{1 + |h_r|^2 P/N_0}\right)$, and the PDF of

δ_s is given by

$$f_s(\delta) = \frac{1}{\rho\mu_d} e^{-\frac{\delta-1}{\rho\mu_d}} + \frac{2\delta}{\rho\mu_r} e^{-\frac{\delta^2-1}{\rho\mu_r}} - \left(\frac{1}{\rho\mu_d} + \frac{2\delta}{\rho\mu_r}\right) e^{-\frac{\delta-1}{\rho\mu_d} - \frac{\delta^2-1}{\rho\mu_r}}. \qquad (6)$$

D. Cooperative Scheme

Fig. 2-(d) shows the *cooperative scheme*. It also has two phases: *Phase-I* for receiving data from the BS at the RS and MS, and *Phase-II* for sending the data from the RS to the MS. Different from the previous relay scheme, the MS can receive data directly from the BS during Phase-I.

$$\begin{aligned} y_{i,1} &= h_d \cdot s_i + n_{i,1}, && \text{in } \textit{Phase I}, \\ y_{i,2} &= h_r \cdot s_i + n_{i,2}, && \text{in } \textit{Phase II}, \end{aligned} \qquad (7)$$

The channel coefficients h_d and h_r are assumed to be known to the MS so that the MS performs maximum ratio combining (MRC). The MRC received signal is given by $y_i = \left(|h_d|^2 + |h_r|^2\right) s_i + \left(h_d^* \cdot n_{i,1} + h_r^* \cdot n_{i,2}\right)$ so that the received SNR for the selection scheme is given by $\delta_s \triangleq \left(|h_d|^2 + |h_r|^2\right) P/N_0$, i.e., the sum of exponential random variables with different mean values, and its PDF is represented as

$$f_c(\gamma) = \frac{e^{-\frac{\gamma}{\rho\mu_d}} - e^{-\frac{\gamma}{\rho\mu_r}}}{\rho\left(\mu_d - \mu_r\right)}, \quad (\mu_d \neq \mu_r). \qquad (8)$$

III. PERFORMANCE ANALYSIS OF DOWNLINK CAPACITY

We first analyze the performance of a single link for each scheme described in Section II. In this section, we analyze the ergodic capacity and outage capacity of each scheme.

A. Ergodic Capacity

Under the assumption that the channel is stationary and ergodic, we can obtain the ergodic capacity of a single link for each scheme. Ergodic capacity is define as $C = \mathbb{E}\{\log_2(1+\gamma)\}$, where γ is the received SNR of the channel.

In the direct scheme, the ergodic capacity is obtained as:

$$\begin{aligned} C &= \int_0^\infty \log_2(1+\gamma) \frac{1}{\rho\mu_d} e^{-\frac{\gamma}{\rho\mu_d}} d\gamma \\ &= -\log_2(e)\, e^{\left(\frac{1}{\rho^2\mu_d}\right)} E_i\left(-\frac{1}{\rho^2\mu_d}\right), \end{aligned} \qquad (9)$$

where $E_i(\cdot)$ represents the exponential integral function [14].

The ergodic capacity of the relay scheme is similarly obtained in a closed-form by

$$\begin{aligned} C_r &= \int_0^\infty \frac{1}{2} \log_2(1+\gamma) f_r(\gamma)\, d\gamma \\ &= -\frac{1}{2} \log_2(e)\, e^{\left(\frac{1}{\rho^2\mu_r}\right)} E_i\left(-\frac{1}{\rho^2\mu_r}\right). \end{aligned} \qquad (10)$$

The term $\left(\frac{1}{2}\right)$ is added at the $\log_2$ term because the channel utilization of the system is reduced to one-half.

In the selection scheme, the ergodic capacity for a single link cannot be obtained in a closed-form. Hence, we obtain the upper bound of the ergodic capacity using Jensen's inequality [15]. That is, $\mathbb{E}\{\log_2(x)\} \leq \log_2(\mathbb{E}\{x\})$ since $\log_2$ function is a concave function.

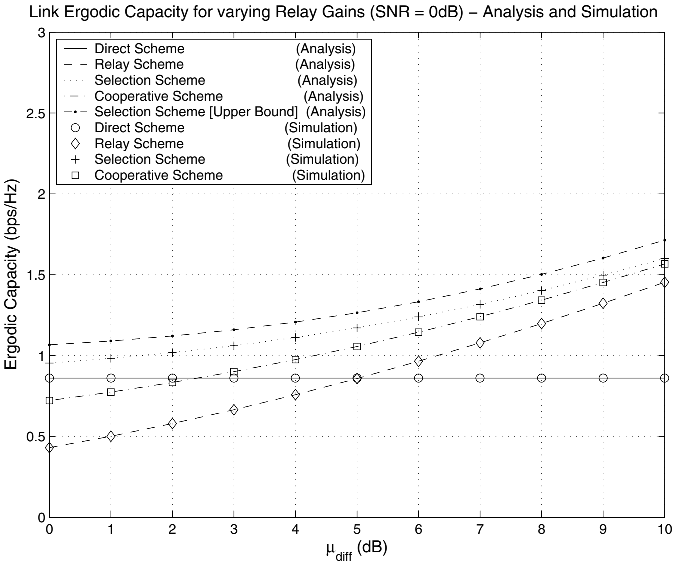


Fig. 3. Link ergodic capacities for four different schemes

$$\begin{aligned} C_s = &\int_1^\infty \log_2(\gamma) f_s(\gamma)\, d\gamma \\ \leq\ & \log_2\left(\mathbb{E}\{\gamma_s\}\right) \\ =\ & \log_2\left\{1 + \rho\mu_d + \frac{1}{2}\sqrt{\pi\rho\mu_r}\, e^{\frac{1}{\rho\mu_r}} \left[1 - \text{erf}\left(\sqrt{\frac{1}{\rho\mu_r}}\right)\right]\right. \\ & \left. -\frac{1}{2}\sqrt{\pi\rho\mu_r}\, e^{\frac{1}{4}\frac{(2\rho\mu_d+\rho\mu_r)^2}{\rho^3\mu_d^2\mu_r}} \left[1 - \text{erf}\left(\frac{1}{2}\frac{2\rho\mu_d + \rho\mu_r}{\rho\mu_d\sqrt{\rho\mu_r}}\right)\right]\right\}, \end{aligned} \qquad (11)$$

where $\text{erf}(\cdot)$ is the error function [14].

In the cooperative scheme, a closed-form ergodic capacity is obtained as

$$\begin{aligned} C_c &= \int_0^\infty \frac{1}{2} \log_2(1+\gamma) f_c(\gamma)\, d\gamma \\ &= \frac{\log_2(e)\mu_r e^{\frac{1}{\rho\mu_r}} E_i\left(-\frac{1}{\rho\mu_r}\right) - \mu_d e^{\frac{1}{\rho\mu_d}} E_i\left(-\frac{1}{\rho\mu_d}\right)}{2\left(\mu_d - \mu_r\right)}. \end{aligned} \qquad (12)$$

Fig 3 shows the result of the ergodic capacities for four different schemes when μ_d is set to $0\ dB$. We define the mean value difference in dB between μ_r and μ_d as $\mu_{diff}(dB) \triangleq \mu_r(dB) - \mu_d(dB)$. The result shows the ergodic capacity for varying μ_{diff} values. When μ_{diff} is large, the BS-MS channel is better than the RS-MS channel for an MS. For example, if μ_{diff} is set to $3\ dB$, it represents that the RS-MS channel is two times better in the average SNR than the BS-MS channel. From the result, we can observe that the selection scheme outperforms all the other schemes in the entire range of the mean value difference. The relay scheme and the cooperative scheme outperform the direct scheme when the SNR difference is larger than $5\ dB$ and $2\ dB$,

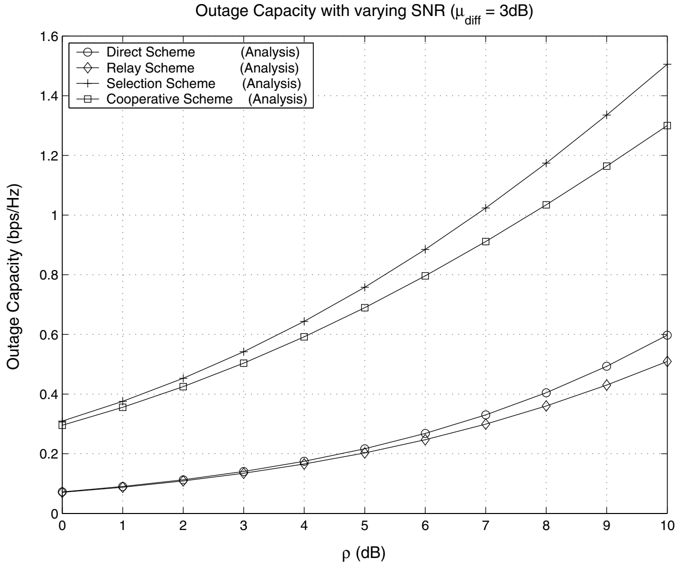


Fig. 4. Outage capacities for four different schemes for varying input SNR values

respectively. The selection scheme yields the best performance due to the fact that it can obtain transmission diversity by selecting a better channel between the BS-MS channel and the RS-MS channel. In addition, the cooperative scheme always yields a better capacity than the relay scheme because each MS receives the data in Phases I and II in the cooperative scheme, while each MS receives the data only in Phase II in the relay scheme.

Therefore, when there is a sufficient number of RSs in a cell so that RS-MS channels are generally at least two times better than BS-MS channels, both the selection scheme and the cooperative scheme perform well due to their transmission diversity.

B. Outage Capacity

In this subsection, we obtain the outage capacity for four different schemes. Outage capacity is here defined as $C_\epsilon \triangleq \log_2\left(1+G^{-1}\left(1-\epsilon\right)\right)$, where G is the complementary cumulative distribution function of $|h|^2$, i.e., $G\left(x\right) \triangleq P\left\{|h|^2 > x\right\}$ [13].

The function G for the direct scheme is given by

$$G_d^{-1}\left(x\right) = -\ln\left(x\right)\rho\mu_d, \tag{13}$$

and for the relay scheme,

$$G_r^{-1}\left(x\right) = -\ln\left(x\right)\rho\mu_r. \tag{14}$$

For the selection and cooperative schemes, we numerically obtain $G_s^{-1}\left(x\right)$ and $G_c^{-1}\left(x\right)$.

Fig 4 shows the result of the outage capacities with $\epsilon = 0.05$ for the four different schemes. The result shows the relationship between the outage capacity for the four schemes and input $\rho = P/N_0$. The result is obtained under the condition that μ_{diff} is set to 3 dB, which means that the RS-MS channel is two times better in terms of average SNR than the BS-MS channel. The selection scheme again outperforms the three other schemes in terms of outage capacity. The outage capacities of the selection and cooperative schemes are much better than those of the direct and relay schemes because the first two schemes exploiting the transmit diversity yield low outage performance. For a low SNR region, the cooperative scheme has almost the same outage capacity as the selection scheme.

IV. SYSTEM PERFORMANCE ANALYSIS WITH MULTIUSER DIVERSITY

In this section, we analyze the system performance with multiple links for four different schemes. In the system performance analysis, we assume that there exist N MSs in a cell and all MSs communicate with one BS at the center. It is also assumed that all N BS-MS channels are i.i.d. Rayleigh channels with an average channel gain of μ_d, and all N RS-MS channels are i.i.d. Rayleigh channels with mean μ_r. In this multiuser system, a maximum SNR scheduling scheme is used.

We estimate the ergodic capacity of a system with N users using the expression $C\left(N\right) = \mathbb{E}\left\{\log_2\left(1+\gamma_{\max}\right)\right\}$, where $\gamma_{\max} = \max\left\{\gamma_1, \gamma_2, \cdots, \gamma_N\right\}$ and γ_i represents the SNR of the i-th user. From order statistics, we obtain $F_{\max}\left(\gamma\right) = \left\{F\left(\gamma\right)\right\}^N$ given that all γ_is are i.i.d. and have their individual cumulative distribution function (CDF), $F\left(\gamma\right)$.

In the direct scheme, the multiuser ergodic capacity is obtained in a closed-form.

$$\begin{aligned} C\left(N\right) &= \int_0^\infty \log_2\left(1+\gamma\right) f_{\max}\left(\gamma\right) d\gamma \\ &= N\log_2\left(e\right)\cdot\sum_{k=0}^{N-1}\left\{\left(\begin{array}{c} N-1 \\ k \end{array}\right)\left(-1\right)^k \frac{1}{k+1}\cdot\right. \\ &\qquad \left. e^{\frac{k+1}{\rho\mu_d}} E_1\left(\frac{k+1}{\rho\mu_d}\right)\right\}, \end{aligned} \tag{15}$$

where $f_{\max}\left(\gamma\right) = N\left[F\left(\gamma\right)\right]^{N-1} f\left(\gamma\right)$ and $f\left(\gamma\right)$ is defined in Eq. (2).

Similarly, in the relay scheme, the multiuser ergodic capacity is obtained in a closed-form.

$$\begin{aligned} C_r\left(N\right) &= \int_0^\infty \frac{1}{2}\log_2\left(1+\gamma\right) f_{r,\max}\left(\gamma\right) d\gamma \\ &= \frac{N\log_2\left(e\right)}{2}\cdot\sum_{k=0}^{N-1}\left\{\left(\begin{array}{c} N-1 \\ k \end{array}\right)\left(-1\right)^k \frac{1}{k+1}\cdot\right. \\ &\qquad \left. e^{\frac{k+1}{\rho\mu_r}} E_1\left(\frac{k+1}{\rho\mu_r}\right)\right\}, \end{aligned} \tag{16}$$

where $f_{r,\max}\left(\gamma\right) = N\left[F_r\left(\gamma\right)\right]^{N-1} f_r\left(\gamma\right)$ and $f_r\left(\gamma\right)$ is defined in Eq. (4).

In the selection scheme, there is no closed-form for the multiuser ergodic capacity. Thus, we obtain a upper bound as follows [15]:

$$\begin{aligned} C_s(N) &= \int_1^\infty \log_2(\delta)\, f_{s,\max}(\delta)\, d\delta && (17)\\ &\le \log_2\left(\mu_s + \frac{N-1}{\sqrt{2N-1}}\sigma_s\right), && (18) \end{aligned}$$

where $f_{s,\max}(\delta) = N\left[F_s(\delta)\right]^{N-1} f_s(\delta)$ and $f_s(\delta)$ is given in Eq. (6). The terms μ_s and σ_s denote the mean and standard deviation of δ_s and are expressed as

$$\begin{aligned} \mu_s &= 1+\mu_d+\frac{1}{2}\sqrt{\pi\mu_r}\exp\left(\frac{1}{\mu_r}\right)\left(1-\mathrm{erf}\left(\sqrt{\frac{1}{\mu_r}}\right)\right)\\ &\quad -\frac{1}{2}\sqrt{\pi\mu_r}\exp\left(\frac{1}{4}\frac{(2\mu_d+\mu_r)^2}{\mu_d^2\mu_r}\right)\cdot\\ &\quad \left\{1-\mathrm{erf}\left(\frac{1}{2}\frac{(2\mu_d+\mu_r)}{\mu_d\sqrt{\mu_r}}\right)\right\}. && (19)\\ \sigma_s^2 &= 2\left(1+\mu_d+\mu_d^2\right)+\mu_r\\ &\quad +\frac{\sqrt{\mu_r}}{2\mu_d}\left[\mu_r\sqrt{\pi}\exp\left(\frac{1}{4}\frac{(2\mu_d+\mu_r)^2}{\mu_d^2\mu_r}\right)\cdot\right.\\ &\quad \left\{1-\mathrm{erf}\left(\frac{1}{2}\frac{(2\mu_d+\mu_r)}{\mu_d\sqrt{\mu_r}}\right)\right\}\\ &\quad \left.-2\sqrt{\mu_r}\mu_d-\frac{2\mu_d}{\sqrt{\mu_r}}\right]-\mu_s^2. && (20) \end{aligned}$$

The upper bound given above was derived in [15] and can be applied to any set of i.i.d. random variables.

Finally, in the cooperative scheme, a closed-form for the multiuser ergodic capacity is obtained as follows:

$$\begin{aligned} C_c(N) &= \int_0^\infty \frac{1}{2}\log_2(1+\gamma)\, f_{c,\max}(\gamma)\, d\gamma\\ &= \frac{N\log_2(e)}{2\rho(\mu_d-\mu_r)}\cdot\sum_{k=0}^{N-1}\left[\binom{N-1}{k}\left(\frac{1}{\mu_r-\mu_d}\right)^k\cdot\right.\\ &\quad \sum_{i=0}^{k}\left\{(-1)^i\mu_r^i\mu_d^{k-i}\left(\mathbf{I}\left(\frac{i+1}{\rho\mu_r}+\frac{k-i}{\rho\mu_d}\right)\right.\right.\\ &\quad \left.\left.\left.-\mathbf{I}\left(\frac{i}{\rho\mu_r}+\frac{k-i+1}{\rho\mu_d}\right)\right)\right\}\right], && (21)\\ \mathbf{I}(a) &\triangleq \int_0^\infty \ln(1+\gamma)\, e^{-a\gamma}\, d\gamma\\ &= -\frac{1}{a}e^{a}E_i(-a). \end{aligned}$$

Figs. 5 and 6 show the ergodic capacities for the four different schemes with N users in a cell when μ_{diff} is set to $3dB$ and $9dB$, respectively. From the two figures, we can find the effect of multiuser diversity and selection diversity. In Fig 5, the selection scheme yields the best performance over all ranges and the selection diversity improves the performance of the selection scheme by approximately 20%, compared with that of the direct scheme in the case of $N = 1$. As the number of users increases, both the selection and direct schemes exploit multiuser diversity as discussed in [13]. In our analysis, the ergodic capacities of the two schemes are almost the same as the number of users increases. From this result, we conclude that the multiuser diversity in the selection scheme is more dominant than its own selection diversity because the system has no big difference in the performance, compared to the direct scheme which only exploits the multiuser diversity. Therefore, for a system with low μ_{diff} values, the direct scheme achieves the best multiuser ergodic capacity when N is more than 10. In addition, since the direct scheme does not require any RS and high scheduling complexity, it has some advantage over other complex schemes.

On the other hand, in Fig 6, for a given system with $\mu_{diff} = 9dB$, since the RS-MS channel is much better than

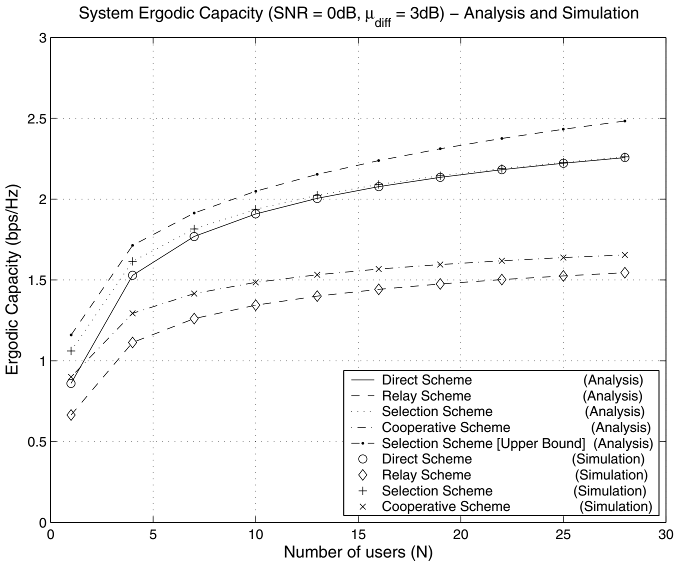


Fig. 5. System capacities for four different schemes for varying N values when μ_{diff} is set to 3 dB.

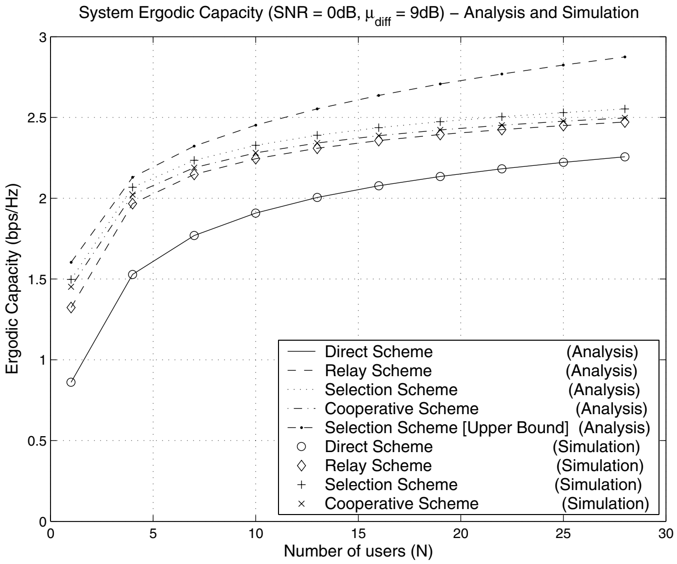


Fig. 6. System capacities for four different schemes for varying N values when μ_{diff} is set to 9 dB.

the BS-MS channel, the selection scheme again has the best performance. In this case, the relay scheme achieves almost the best performance as described in the previous case. Multiuser diversity in the selection scheme is dominant and the direct scheme also exploits multiuser diversity well, and, thus, the performance of both schemes is similar for a large number of users.

The selection scheme outperforms all the other schemes in a multiuser environment, while the direct scheme and the relay scheme almost achieve the performance of the selection scheme due to dominant multiuser diversity at low μ_{diff} values and high μ_{diff} values, respectively.

V. CONCLUSIONS

We mathematically analyze the ergodic and outage capacities in downlink for four different data relaying schemes: a direct scheme, a relay scheme, a selection scheme, and a cooperative scheme. Furthermore, we derive a closed-form solution or upper bound of the ergodic capacity for each scheme. The analytical results agree well with computer simulation results. The results show that the selection scheme outperforms the other three schemes in terms of link ergodic capacity, outage capacity, and system ergodic capacity. It is also noticeable that the direct scheme and the relay scheme almost achieve the performance of the selection scheme at low μ_{diff} values and high μ_{diff} values, respectively.

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