Performance Analysis of Distributed Antenna Systems with Antenna Selection over MIMO Rayleigh Fading Channel

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Abstract

The downlink performance of distributed antenna systems (DAS) with antennas selection is investigated in Rayleigh fading multicell environment, and the corresponding system capacity and bit error rate (BER) analysis are presented. Based on the moment generating function, the probability density function (PDF) and cumulative distribution function (CDF) of the effective signal to interference plus noise ratio (SINR) of the system are first derived, respectively. Then, with the available CDF and PDF, the accurate closed-form expressions of average channel capacity and average BER are further derived for exact performance evaluation. To simplify the expression, a simple closed-form approximate expression of average channel capacity is obtained by means of Taylor series expansion, with the performance results close to the accurate expression. Besides, the system outage capacity is analyzed, and an accurate closed-form expression of outage capacity probability is derived. These theoretical expressions can provide good performance evaluation for DAS downlink. It can be shown by simulation that the theoretical analysis and simulation are consistent, and DAS with antenna selection outperforms that with conventional blanket transmission. Moreover, the system performance can be effectively improved as the number of receive antennas increases.

Keywords: Distributed antenna systems, transmit antenna selection, channel capacity, bit error rate, multiple receive antennas, outage capacity

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1. Introduction

As a promising technique for future wireless communications, the distributed antenna system has received considerable attention in recent years. It can significantly improve the system capacity and cell coverage, and reduce power consumption in comparison with traditional centralized antenna systems, and thus it has become one of the key technologies in next generation mobile communication systems such as 3G-LTE (long term evolution) and IMT-advanced, etc [1-3]. Antenna selection, another promising approach to provide performance benefits and to significantly reduce the hardware complexity and cost, has received considerable studies [4-5]. It can provide a good tradeoff among the performance, cost, and complexity, and can be realized at both ends. Therefore, effective combination of distributed antenna system and antenna selection techniques will receive much attention for practical purpose.

For the distributed antenna systems (DAS) uplink, the effect of maximal ratio combining (MRC)-based macrodiversity on the capacity of code division multiple access (CDMA) DAS is studied in [6]. The uplink capacity of DAS is analyzed in [7] and [8], the approximate expressions for the outage capacity and ergodic capacity are respectively derived, but the capacity analysis is limited in single-cell. By employing different cooperation strategies, the downlink capacity of DAS is investigated in [9], but the influence of noise is neglected. The downlink performance of DAS in multi-cell Rayleigh fading channel is investigated in [10], where closed-form ergodic capacity and outage capacity are derived receptively. However, the superiority of anenna selection in the above works is not considered. For this reason, the ergodic capacity of DAS with single antenna selection scheme in multicell environment is studied in [3], and the proposed antenna selection scheme is based on minimal propagation pathloss (MPP) criterion. A closed-form capacity expression is also shown there, but the expression has minor error. Based on maximum signal to interference plus noise ratio (SINR), the ergodic and outage capacity of DAS with single transmit antenna selection (TAS) are analyzed in [11]. Antenna placement for DAS with antenna selection is studied in [12], and the new algorithms are proposed to identify antenna locations for DAS in single cell and two cells. A novel two-step antenna selection scheme which combines the maximum path fading based antenna cluster selection with permutation and QR decomposition based in-cluster antenn selection is developed for DAS in single-cell [13], which can improve the average channel capacity. The bit error rate (BER) analysis of DAS over shadowed Rayleigh fading channels is provided in our previous paper [14], but the analysis is limited in single-cell case.

In all these studies above, the capacity performance of DAS is well analyzed. However, the BER performance of DAS is little studied in the existing literatures. Moreover, the above capacity analyses are basically limited in single receive antenna case for simplicity. Motivated by the above reasons, we will address the performance analysis of DAS with transmit antenna selection and multiple receive antennas in the multicell environment, and focus on the derivation of the average channel capacity, the average BER and the outage capacity of DAS downlink in multi-input multi-output (MIMO) Rayleigh fading channel. Based on maximum SINR (MSINR) criterion, an antenna selection scheme is presented, where only single distributed antenna or home base station (BS) is selected for data transmission. According to this antenna selection scheme and utilizing mathematical analysis, the probability density function (PDF) and cumulative distribution function (CDF) of the effective SINR of DAS in MIMO fading and multicell environment are respectively obtained, respectively. With the obtained CDF and PDF, the accurate closed-form expressions of average channel capacity and average BER of DAS are derived, respectively. By Taylor series expansion, an approximate closed-form expression of average channel capacity is also derived to simplify the calculation of accurate capacity expression. To analyze the outage performance of the system, we also derive an accurate closed-form expression of outage probability for DAS. Moreover, for a given outage probability, a practical iterative algorithm based on Newton method for calculating the system outage capacity is proposed. With these theoretical expressions, the capacity and BER performance of DAS downlink can be effectively evaluated. Simulation results show that our theoretical analysis can match the corresponding simulation well, and the system performance can be effectively improved by the application of multiple receive antennas. Besides, the system based on the MSINR criterion is superior to that based on the MPP criterion, and the DAS with antenna selection scheme outperforms that with blanket transmission scheme.

The notations throughout this paper are as follows. Bold upper case and lower case letters denote matrices and column vectors, respectively. $E\{\cdot\}$ denotes the expectation. The superscripts $(\cdot)^T$, $(\cdot)^H$ are used to stand for the transpose and Hermitian transpose respectively.

2. System Model

In this paper, a distributed antenna system with multiple receive antennas in a multicell environment is considered. The main processing modules are centralized at a central unit and are connected with distributed antennas (DA), and each of these DA is also called an access point (AP). Through coaxial cables, fiber optics or radio links, all the APs are connected with a home base station (BS). The structure of DAS can refer to **Fig. 1**, where a cell is covered by a small BS and six APs, but each mobile station (MS) has N receive antennas, which is different with [3] (where only one receive antenna is considered). The total transmit power in one cell is assumed to be P, that is, $\sum_{i=0}^{6} P_i^{(m)} = P$, where $P_i^{(m)}$ is the transmit power of the ith AP of the mth cell, the small BS of each cell is indexed by i=0, and home cell is indexed by m=0. Similar to [3], a single user scenario is considered for performance analysis by employing time division multiple access (TDMA), or frequency division multiple access (FDMA) technique.

The transmitters from home BS and six APs and the receivers from MS construct a macroscopic MIMO fading channel, and the channel matrix of the mth cell is expressed as

$$\mathbf{H}^{(m)} = \begin{bmatrix} (\mathbf{h}_1^{(m)})^T \\ (\mathbf{h}_2^{(m)})^T \\ \vdots \\ (\mathbf{h}_N^{(m)})^T \end{bmatrix} = \begin{bmatrix} h_{1,0}^{(m)}\sqrt{L_0^{(m)}} & h_{1,1}^{(m)}\sqrt{L_1^{(m)}} & \cdots & h_{1,6}^{(m)}\sqrt{L_6^{(m)}} \\ h_{2,0}^{(m)}\sqrt{L_0^{(m)}} & h_{2,1}^{(m)}\sqrt{L_1^{(m)}} & \cdots & h_{2,6}^{(m)}\sqrt{L_6^{(m)}} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N,0}^{(m)}\sqrt{L_0^{(m)}} & h_{N,1}^{(m)}\sqrt{L_1^{(m)}} & \cdots & h_{N,6}^{(m)}\sqrt{L_6^{(m)}} \end{bmatrix} \tag{1}$$

where the channel vector $\mathbf{h}_n^{(m)}$ is given by

$$\mathbf{h}_n^{(m)} = [h_{n,0}^{(m)}\sqrt{L_0^{(m)}} \quad \cdots \quad h_{n,6}^{(m)}\sqrt{L_6^{(m)}}]^T, \quad n=1,2,\ldots,N. \tag{2}$$

where $h_{n,i}^{(m)} = \alpha_{n,i}^{(m)} \exp(j\theta_{n,i}^{(m)})$ denotes the short-term fading from the *i*th AP to the *n*th receive antenna in the *m*th cell. For Rayleigh fading channel, $\{h_{n,i}^{(m)}\}$ are modeled as independent complex Gaussian random variables (r.v.s) with zero-mean and unit-variance. The channel is assumed to be static during one symbol duration. $L_i^{(m)}$ denotes the long-term fading corresponding to propagation pathloss from the *i*th AP in the *m*th cell, which can be expressed as

$$L_i^{(m)} = [d_i^{(m)}]^{-\beta} \tag{3}$$

where β is the pathloss exponent, $d_i^{(m)}$ denotes the normalized distance between the MS and *i*th AP in the *m*th cell.

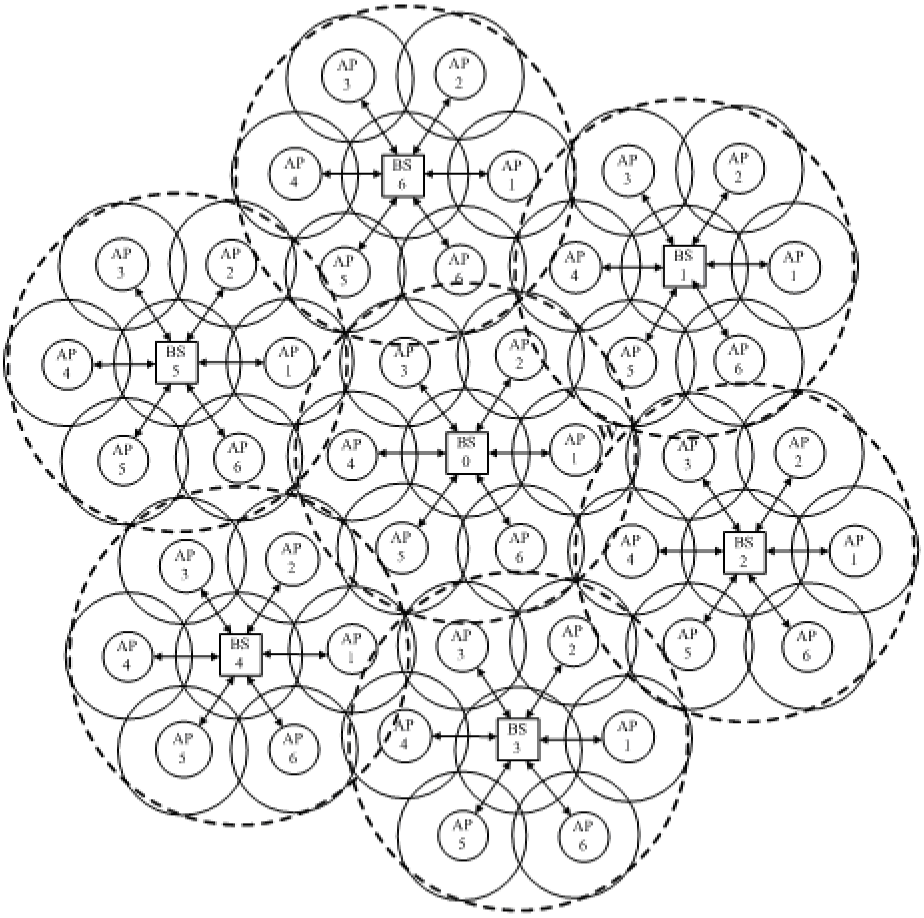


Fig. 1. Diagram of DAS structure, where **w**: example worst case location [3].

Let the transmitted signal vector be $\mathbf{s}^{(m)} = [s_0^{(m)}, \ldots, s_6^{(m)}]^T$, then when single transmit antenna *i* is employed, the received signal from the *n*th receive antenna at MS can be given by

$$y_n = h_{n,i}^{(0)}\sqrt{L_i^{(0)}}s_i^{(0)} + \sum\nolimits_{m=1}^{6} h_{n,b}^{(m)}\sqrt{L_b^{(m)}}s_b^{(m)} + w_n = D + I + w_n \tag{4}$$

where $s_i^{(m)}$ denotes the transmitted signal from the ith AP in the mth cell with $E\{|s_i^{(m)}|^2\} = P_i^{(m)}$. $D = h_{n,i}^{(0)}\sqrt{L_i^{(0)}}s_i^{(0)}$ is the desired signal. $I = \sum\nolimits_{m=1}^{6} h_{n,b}^{(m)}\sqrt{L_b^{(m)}}s_b^{(m)}$ is the interference signals from the other six cells, and b is randomly selected among $\{0, 1,\ldots,6\}$ according to the analysis in [3]. w_n is the additive Gaussian noise for receive antenna n, and it is a complex Gaussian r.v. with zero-mean and variance σ_w^2. When the interfering number is sufficiently large and interfering sources are independent of each other, the interference plus noise is assumed to be a complex Gaussian random variable z [3]. According to this, and using the Central Limit Theorem, the variance of z can be written as $\sigma_z^2 = \sum\nolimits_{m=1}^{6} L_b^{(m)}P_b^{(m)} + \sigma_w^2$.

Using MRC at the receiver and (4), the signal to interference plus noise ratio ρ_i can be expressed as

$$\rho_i = \sum\nolimits_{n=1}^{N} |h_{n,i}^{(0)}|^2 L_i^{(0)}P_i^{(0)} / \sigma_z^2 \ , \quad i=0, 1,\ldots,6 . \tag{5}$$

According to the above analysis, $\xi = \sum\nolimits_{n=1}^{N} |h_{n,i}^{(0)}|^2$ is a central χ^2 distributed r.v. with $2N$ degrees of freedom. Thus, with (5), the probability density function of ρ_i can be obtained as

$$f_{\rho_i}(\rho) = c_i^N \rho^{N-1}\exp(-c_i\rho)/\Gamma(N) \tag{6}$$

and the corresponding cumulative distribution function is expressed as

$$F_{\rho_i}(\rho) = 1 - \exp(-c_i\rho)\sum\nolimits_{j=0}^{N-1}(c_i\rho)^j / j! \tag{7}$$

where $c_i = \sigma_z^2/(L_i^{(0)}P_i^{(0)})$.

For the single transmit selection scheme, its basic principle is that only a transmit antenna (i.e., single AP or home BS) is selected for data transmission based on the maximal SINR criterion in the home cell (which is different from the minimal propagation pathloss criterion in [3]), while for other interference cell, the transmit antenna is randomly chosen. Thus, the SINR of the system ρ can be written as

$$\rho = \max\left(\rho_0, \rho_1, \ldots, \rho_6\right) \tag{8}$$

Using the order statistic [15] together with (6-8) and transformation of random variable, the CDF of ρ can be obtained as follows:

$$F(\rho)=\prod_{i=0}^{K-1}F_{\rho_i}(\rho)=\prod_{i=1}^{K}\left(1-\exp(-a_i\rho)\sum\nolimits_{j=0}^{N-1}(a_i\rho)^j/j!\right) \tag{9}$$

where K=7, and a_i=$c_{i\text{-}1}$, i=1,…K. Correspondingly, the PDF of ρ is given by

$$f(\rho)=\frac{dF(\rho)}{d\rho}=\sum_{k=1}^{K}[a_k^N\rho^{N-1}\exp(-a_k\rho)/\Gamma(N)]\prod_{i=1,\neq k}^{K}[1-\exp(-a_i\rho)\sum_{j=0}^{N-1}(a_i\rho)^j/j!] \tag{10}$$

For analytical convenience, we will use [16, (45)] to expand the Eq.(9). Thus, we have:

$$\begin{aligned}F(\rho)&=\sum_{v=0}^{K}(-1)^v\sum_{\tau(v,K)}\prod_{k=1}^{K}[\exp(-a_k\rho)\sum_{j=0}^{N-1}(a_k\rho)^j/j!]^{i_k}\\&=\sum_{v=0}^{K}(-1)^v\sum_{\tau(v,K)}\exp(-\sum_{k=1}^{K}a_ki_k\rho)\prod_{k=1}^{K}[\sum_{j=0}^{N-1}(a_k\rho)^j/j!]^{i_k}\end{aligned} \tag{11}$$

where $\tau(v,K)=\{(i_1,\ldots,i_K): i_k\in\{0,1\}, \sum_{k=1}^{K}i_k=v\}$. Substituting [16, (47)] into (11) yields

$$F(\rho)=\sum_{v=0}^{K}(-1)^v\sum_{\tau(v,K)}\exp(-\rho\sum_{k=1}^{K}i_ka_k)\sum_{u=0}^{U}D_{u,K}\rho^u \tag{12}$$

$$=1+\sum_{v=1}^{K}(-1)^v\sum_{\tau(v,K)}\exp(-\rho\sum_{k=1}^{K}i_ka_k)\sum_{u=0}^{U}D_{u,K}\rho^u \tag{13}$$

where $U=\sum_{k=1}^{K}T_k$, $T_k=i_k\left(N-1\right)$, $D_{u,K}=\sum_{\omega(u,K)}\prod_{k=1}^{K}(a_k)^{t_k}/t_k!$, and $\omega(u, K)$ is the set of K-tuples such that $\omega(u,K)=\{(t_1,\ldots,t_K): t_k\in\{0,1,\ldots,T_k\}, \sum_{k=1}^{K}t_k=u\}$.

With (13), the PDF of ρ can be obtained as

$$\begin{aligned}f(\rho)=&\sum_{v=1}^{K}(-1)^v\sum_{\tau(v,K)}\exp(-\rho\sum_{k=1}^{K}i_ka_k)\sum_{u=1}^{U}uD_{u,K}\rho^{u-1}\\&-\sum_{v=1}^{K}(-1)^v\sum_{\tau(v,K)}\exp(-\rho\sum_{k=1}^{K}i_ka_k)\sum_{k=1}^{K}i_ka_k\sum_{u=0}^{U}D_{u,K}\rho^u\end{aligned} \tag{14}$$

This PDF will be employed for the following performance analysis considering its simplicity.

3. BER performance of DAS with antenna selection

In this section, we will give the BER performance analysis of DAS with antenna selection (DAS-AS) in a Rayleigh fading multicell environment. For the given signal to interference plus noise ratio ρ, utilizing [17, Eq.(16)] and [18, Eq.(8)], the average BER of DAS-AS with MQAM and Gray coding is given by

$$P_e = E\{\sum_n \zeta_n erfc(\sqrt{g_n \rho})\} = \sum_n \zeta_n \int_0^{\infty} f(\rho) erfc(\sqrt{g_n \rho}) d\rho \tag{15}$$

where ζ_n and g_n are constants which depend on the constellation size Q, and the values of the constant sets $\{\zeta_n, g_n\}$ for MQAM can be found in [17, 19]. $erfc(x)$ is the complementary error function [20]. Using partial integration, (15) can be rewritten as

$$\begin{aligned} P_e &= \sum_n \zeta_n \int_0^{\infty} f(\rho) erfc(\sqrt{g_n \rho}) d\rho \\ &= \sum_n \zeta_n [F(\rho) erfc\left(\sqrt{g_n \rho}\right)\Big|_0^{+\infty} + \sqrt{g_n/\pi} \int_0^{+\infty} F(\rho) \rho^{-1/2} \exp(-g_n \rho) d\rho] \end{aligned} \tag{16}$$

Substituting (12) into (16) yields

$$\begin{aligned} P_e &= \sum_n \zeta_n \sqrt{\frac{g_n}{\pi}} \sum_{v=0}^{K} (-1)^v \sum_{\tau(v,K)} \sum_{u=0}^{U} D_{u,K} \int_0^{\infty} \exp\left(-\rho(g_n + \sum_{k=1}^{K} i_k a_k)\right) \rho^{u-1/2} d\rho \\ &= \sum_n \zeta_n \sqrt{\frac{g_n}{\pi}} \sum_{v=0}^{K} (-1)^v \sum_{\tau(v,K)} \sum_{u=0}^{U} D_{u,K} \frac{\Gamma\left(u+1/2\right)}{(g_n + \sum_{k=1}^{K} i_k a_k)^{u+1/2}} \end{aligned} \tag{17}$$

Equation (17) is an accurate closed-form expression of average BER of DAS-AS with MQAM in Rayleigh fading multicell environment. It is shown that this expression will match the simulation very well. With (17), the BER performance of DAS-AS with MQAM will be effectively evaluated.

Similarly, we may employ the above analytical method to derive the BER expression of DAS-AS with MPSK, i.e.,

$$\begin{aligned} P_e &\cong \frac{1}{\max(\log_2 Q,\ 2)} \sum_{n=1}^{\max(Q/4,1)} \int_0^{\infty} f(\rho) erfc\left(\sqrt{\rho} \sin(\frac{2n-1}{Q}\pi)\right) d\rho \\ &= \frac{\pi^{-1/2}}{\max(\log_2 Q,\ 2)} \sum_{n=1}^{\max(Q/4,1)} \sin(\frac{2n-1}{Q}\pi) \sum_{v=0}^{K} (-1)^v \sum_{\tau(v,K)} \sum_{u=0}^{U} \frac{D_{u,K}\Gamma\left(u+1/2\right)}{(\sin^2((2n-1)\pi/Q) + \sum_{k=1}^{K} i_k a_k)^{u+1/2}} \end{aligned} \tag{18}$$

This is a tighly approximate closed-form expression of the average BER of DAS-AS with MPSK in Rayleigh fading multicell environment. It is well known that the BERs of BPSK and QPSK over Additive White Gaussian Noise (AWGN) channel are $P_e(\rho) = 0.5 erfc(\sqrt{\rho})$ and $P_e(\rho) = 0.5 erfc(\sqrt{0.5\rho})$, respectively. Hence, eqation (18) are also accurate closed-form expressions of average BER of DAS-AS with BPSK and QPSK.

4. Capacity performance of DAS with antenna selection

In this section, we will give the capacity analysis of DAS-AS in a Rayleigh fading mulicell environment. Firstly, the average channel capacity is derived. Then, the outage probability and the corresponding outage capacity are analyzed.

4.1 Average channel capacity

The average channel capacity can be expressed as

$$C_{ac} = E\{C\} = E\{\log_2(1+\rho)\} = (1/\ln 2)\int_0^{\infty} f(\rho)\ln(1+\rho)\,d\rho \tag{19}$$

where channel capacity $C=\log_2(1+\rho)$.

Substituting (14) into (19) gives

$$\begin{aligned} C_{ac} = (1/\ln 2)\Bigg\{ &\sum_{v=1}^{K}(-1)^v \sum_{\tau(v,K)} \sum_{u=1}^{U} u D_{u,K} \int_0^{\infty} \rho^{u-1}\ln(1+\rho)\exp\Big(-\rho\sum_{k=1}^{K} i_k a_k\Big)d\rho \\ &- \sum_{v=1}^{K}(-1)^v \sum_{\tau(v,K)} \sum_{k=1}^{K} i_k a_k \sum_{u=0}^{U} D_{u,K} \int_0^{\infty} \rho^{u}\ln(1+\rho)\exp\Big(-\rho\sum_{k=1}^{K} i_k a_k\Big)d\rho \Bigg\} \end{aligned} \tag{20}$$

By utilizing [21, (7)] and a series of derivation, (20) can be rewritten as:

$$\begin{aligned} C_{ac} = &\frac{1}{\ln 2}\sum_{v=1}^{K}(-1)^v \sum_{\tau(v,K)} \sum_{u=1}^{U} \frac{u D_{u,K}\Gamma(u)}{q^u}\Big\{\mathcal{P}_u(-q)E_1(q) + \sum_{l=1}^{u-1}\mathcal{P}_l(q)\mathcal{P}_{u-l}(-q)/l\Big\} \\ -&\frac{1}{\ln 2}\sum_{v=1}^{K}(-1)^v \sum_{\tau(v,K)} \sum_{u=0}^{U} \frac{D_{u,K}\Gamma(u+1)}{q^u}\Big\{\mathcal{P}_{u+1}(-q)E_1(q) + \sum_{l=1}^{u}\mathcal{P}_l(q)\mathcal{P}_{u+1-l}(-q)/l\Big\} \end{aligned} \tag{21}$$

where $q=\sum_{k=1}^{K} a_k i_k$, $\mathcal{P}_n(x)=\sum_{l=0}^{n-1} x^l e^{-x}/l!$ is the Poisson distribution, and $E_1(\cdot)$ denotes the first order exponential integral function [20]. Eq.(21) is an accurate closed-form expression of average channel capacity of DAS-AS in Rayleigh fading multicell environment. It is shown that this theoretical formula will have good agreement with simulation result.

To simplify the calculation in (21), we will provide a simple approximate capacity expression by means of Taylor series expansion. Firstly, we calculate the nth derivative of $G(\rho)=\ln(1+\rho)$ with respect to ρ as

$$G^{(n)}(\rho) = (-1)^{n-1}(n-1)!(1+\rho)^{-n},\ n\geq 1. \tag{22}$$

Then, we expand $G(\rho)$ in a Taylor series at the expectation value of ρ (i.e., $\rho = E(\rho)$) as follows:

$$G(\rho) = \ln(1+\rho_0) + \sum_{n=1}^{\infty}(-1)^{n-1}(\rho-\rho_0)^n/[n(1+\rho_0)^n) \tag{23}$$

After that, taking the expectation to $G(\rho)$, the second-order approximation of $E\{\ln(1+\rho)\}$ can be given by

$$\begin{aligned} E\{G(\rho)\} &\cong \ln(1+\rho_0)+E\{\rho-\rho_0\}/(1+\rho_0)-E\{(\rho-\rho_0)^2\}/[2(1+\rho_0)^2] \\ &= \ln(1+\rho_0)-0.5(E\{\rho^2\}-\rho_0^2)/[2(1+\rho_0)^2] \end{aligned} \tag{24}$$

where

$$\begin{aligned} \rho_0 &= E\{\rho\}=\int_0^\infty \rho f(\rho)d\rho \\ &= \sum_{v=1}^{K}(-1)^v \sum_{\tau(v,K)}\sum_{u=1}^{U} uD_{u,K}\frac{\Gamma(u+1)}{q^{u+1}}-\sum_{v=1}^{K}(-1)^v\sum_{\tau(v,K)}\sum_{u=0}^{U}D_{u,K}\frac{\Gamma(u+2)}{q^{u+1}}, \end{aligned} \tag{25}$$

and

$$\begin{aligned} E\{\rho^2\} &= \int_0^\infty \rho^2 f(\rho)d\rho \\ &= \sum_{v=1}^{K}(-1)^v \sum_{\tau(v,K)}\sum_{u=1}^{U} uD_{u,K}\frac{\Gamma(u+2)}{q^{u+2}}-\sum_{v=1}^{K}(-1)^v\sum_{\tau(v,K)}\sum_{u=0}^{U}D_{u,K}\frac{\Gamma(u+3)}{q^{u+2}}. \end{aligned} \tag{26}$$

Substituting (24) into (19) yields the approximate capacity as

$$C_{ap} \cong (1/\ln 2)\{\ln(1+\rho_0)-0.5(1+\rho_0)^{-2}[E\{\rho^2\}-\rho_0^2]\} \tag{27}$$

Here, we use second-order approximation to approach the average channel capacity. This is because the expectation and second-order moment of ρ are easily obtained. Moreover, the resultant approximate capacity has good agreement with the accurate capacity (21), which will be verified by the following simulation results. Equation (27) is an approximate closed-form expression of average channel capacity of DAS-AS in Rayleigh fading multicell environment, and it has simpler form than the accurate capacity. Thus, the derived (27) will achieve the effective tradeoff between the performance and complexity.

4.2. Outage capacity

For the given outage capacity C_{oc}, $P(C_{oc})$ is defined as the probability that the channel capacity C falls below C_o. Thus, the outage capacity probability at a given location of the target mobile station can be expressed as

$$P(C_{oc})=\Pr(C\le C_{oc})=\Pr(\log_2(1+\rho)\le C_{oc})=\Pr(\rho\le\rho_{th})=F(\rho_{th}) \tag{28}$$

where $\rho_{th}=2^{C_{oc}}-1$. Substituting (9) into (28) yields

$$\begin{aligned} P(C_{oc}) &= \prod_{i=1}^{K}[1-\exp(-a_i\rho_{th})\sum_{j=0}^{N-1}(a_i\rho_{th})^j / j!] \\ &= \prod_{i=1}^{K}[1-\exp(-a_i(2^{C_{oc}}-1))\sum_{j=0}^{N-1}(a_i(2^{C_{oc}}-1))^j / j!] \end{aligned} \tag{29}$$

This is an accurate closed-form expression of outage probability of DAS-AS in Rayleigh fading multicell environment.

In what follows, we will give the outage capacity analysis. For a given outage probability $\varepsilon=P(C_{oc})$, we propose a Newton method based iterative algorithm to calculate the outage capacity C_{oc}. Substituting $\varepsilon=P(C_{oc})$ into the first equality of (29) yields:

$$\prod_{i=1}^{K}[1-\exp(-a_i\rho_{th})\sum_{j=0}^{N-1}(a_i\rho_{th})^j / j!] = \varepsilon \tag{30}$$

Thus, with (30), we can obtain the outage capacity $C_{oc}=\log_2(1+\rho_{th})$ by finding the root of the following equation $\psi(\rho_{th})=0$ as

$$\psi(\rho_{th}) = \prod_{i=1}^{K}[1-\exp(-a_i\rho_{th})\sum_{j=0}^{N-1}(a_i\rho_{th})^j / j!] - \varepsilon \tag{31}$$

where ε is the given outage probability. Differentiating $\psi(\rho_{th})$ with respect to ρ_{th} gives

$$\psi'(\rho_{th}) = \frac{d\psi(\rho_{th})}{d\rho_{th}} = \sum_{k=1}^{K}[a_k^N \rho_{th}^{N-1}\frac{e^{-a_k\rho_{th}}}{\Gamma(N)}]\prod_{i=1,\neq k}^{K}[1-e^{-a_i\rho_{th}}\sum_{j=0}^{N-1}\frac{\rho_{th}^j}{j!}] > 0 \tag{32}$$

It is shown that the derivative $\psi'(\rho_{th})$ is positive. Thus $\psi(\rho_{th})$ is a strictly monotonically increasing function of ρ_{th}. According to (31), and considering the outage probability $\varepsilon \in (0, 1)$, we can obtain $\psi(0) = -\varepsilon < 0$ and $\psi(\infty) = \lim_{\rho_{th}\to\infty}\psi(\rho_{th}) = 1-\varepsilon > 0$.

Based on the above analysis, the equation $\psi(\rho_{th})=0$ will have a unique solution for $\rho_{th}>0$. There are many methods such as bisection for finding the root of a strictly monotonic function. We propose to use Newton method to find the root iteratively because it has the quadratic convergence rate. Newton method is described as follows.

$$\rho_{th,l+1} = \rho_{th,l} - \psi(\rho_{th,l}) / \psi'(\rho_{th,l}) \tag{33}$$

where $\rho_{th,l}$ is the l-th iteration value of ρ_{th} . $\psi(\rho_{th,l})$ and $\psi'(\rho_{th})$ are computed by (31) and (32), respectively.

Using the obtained ρ_{th}, we can calculate the outage capacity as follows:

$$C_{oc} = \log_2(1+\rho_{th}) \tag{34}$$

This is an outage capacity of DAS-AS in Rayleigh fading multicell environment.

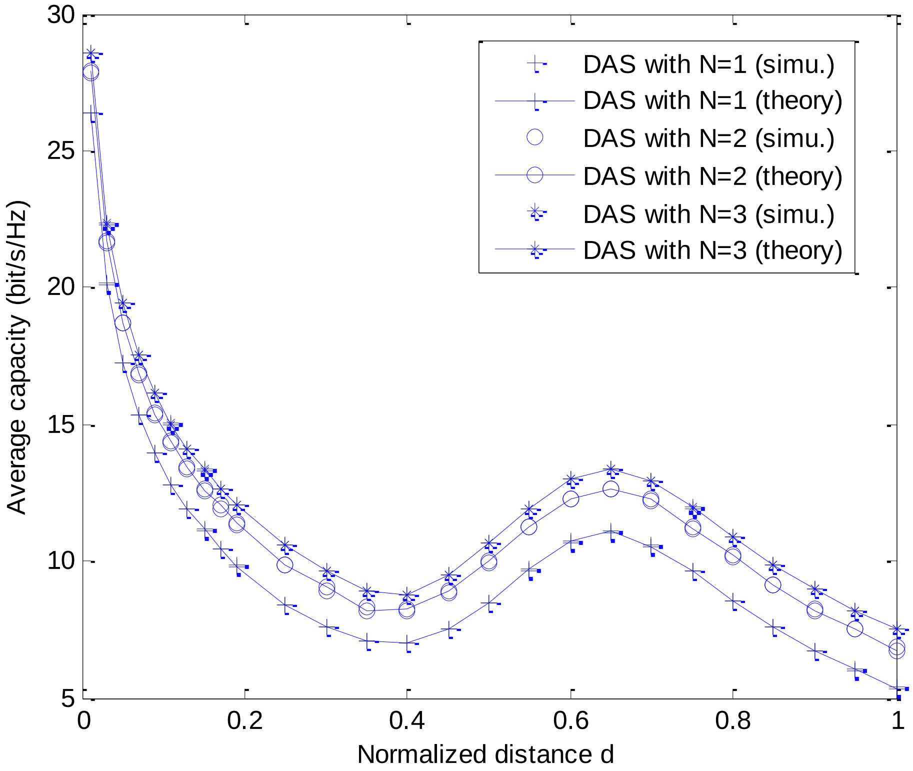


Fig. 2. Average capacity versus the normalized distance from the home BS for DAS with antenna selection and different receive antennas

5. Simulation Results

In this section, we will provide the performance simulation results of DAS with antenna selection in Rayleigh fading channel to evaluate the validity of the derived theoretical formulae. The pathloss exponent β is set as to 4, the transmit power of each AP is $0.1P$, and the transmit power of the home BS is $0.4P$ in DAS. The total power to noise ratio P/σ_n^2 is set as to 10dB, and Monte-Carlo method is employed for simulation. The accurate and approximate values of average channel capacity are calculated by (21) and (27), respectively. The outage probability and capacity are computed by (29) and (34), respectively. The theoretical average BER is calculated by (17). The normalized distance from the home BS to the direction of the worst position **W** (this position can refer to **Fig. 1**) on the cell boundary is indexed by d ($0 \le d \le 1$). 16QAM and 64QAM are used for performance evaluation.

Fig. 2 shows the average channel capacity versus the normalized distance from home BS d for DAS-AS with different receive antennas. As shown in **Fig. 2**, the theoretical analysis is in good agreement with the simulation result. It is found that the system with three receive antennas (N=3) outperforms that with two receive antennas (N=2) because the former has greater diversity than the latter. Due to the same reason, the system with two receive antennas is superior to that with single receive antenna (N=1). From **Fig. 2**, we can also observe non-monotonic relationship between the capacity and the normalized distance *d*. Namely, when MS is far away from the home BS, and moves around *d*=0.4, the capacity is decreasing since the received signal quality of MS starts to become worse. Whereas when MS moves from *d*=0.4 to *d*=0.6, the signal from an AP becomes dominant, and the corresponding capacity is increasing. However, when MS moves from *d*=0.6 to *d*=1, the capacity is decreasing because the interference signal from neighbor cell starts to become strong. The above results show that the derived expression of avearage channel capacity is valid.

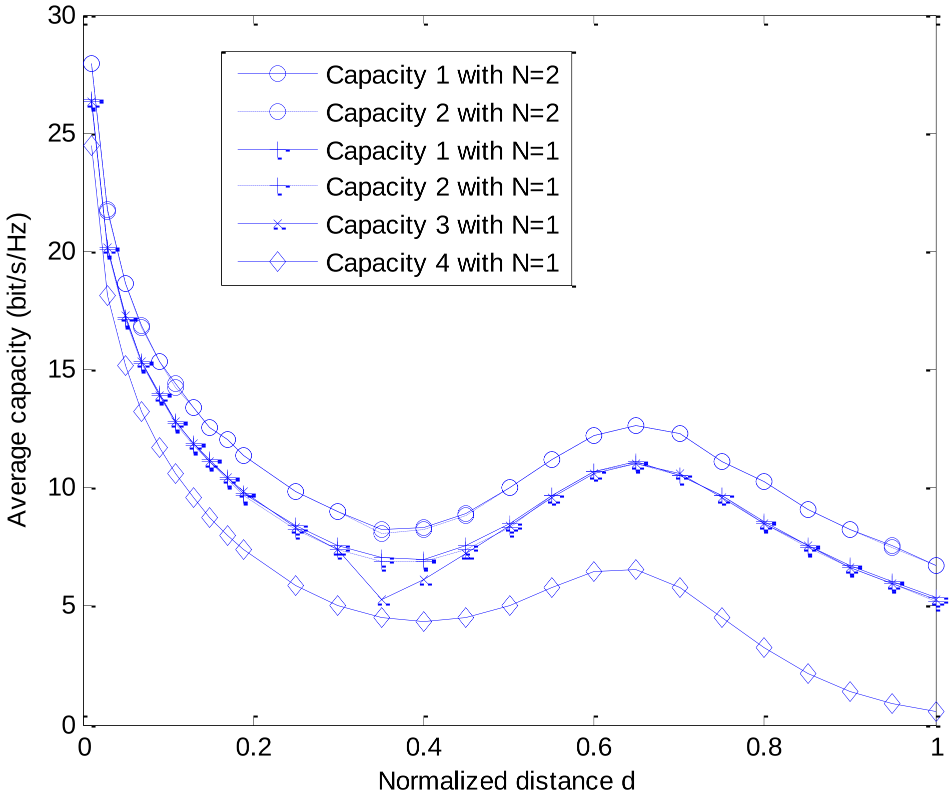


Fig. 3. Avearge capacity comparison for different DAS with two/one receive antennas.

In **Fig. 3**, we plot the accurate and approximate average capacity of DAS-AS with different receive antennas. The derived accurate and approximate capacity are referred as 'capacity 1' and 'capacity 2', respectively. For comparison, the capacity of DAS with TAS based on minimal propagation pathloss (MPP) criterion, and the capacity of DAS with blanket transmission scheme (i.e., all APs and home BS are used to transmit the signals) from [3] are also provided, they are referred as 'capacity 3' and 'capacity 4', respectively. It is found that the DAS-AS based on MSINR criterion is slightly superior to that based on MPP criterion since the former can make full use of the channel state information. Moreover, they both perform better than DAS with blanket transmission scheme (BTS) because of macroscopic selection diversity and the other-cell interference reduction. Besides, the approximate 'capacity 2' can obtain the values very close to accurate 'capacity 1' due to better approximation, but the former has lower calculation complexity than the latter. So this approximate expression can be used for the performance evaluation of DAS capacity.

Fig. 4 shows the average BER versus the normalized distance *d*, where 64QAM is used for signal modulation. It is shown in **Fig. 4** that the theoretical BER and the simulation are very close to each other. The system with three receive antennas outperforms that with two receive antennas or with single receive antenna because the former has greater diversity than the latter two. From **Fig. 4**, we can see non-monotonic relationship between the BER and the normalized distance *d*. Namely, the BER firstly increases when MS is far away from the home BS, and then the BER decreases when MS moves to around *d*=0.6. Finally, the BER increases again when MS moves to the cell boundary. This is because the signal from an AP becomes dominant near *d*=0.6. The above results show that the derived BER expression of DAS is effective.

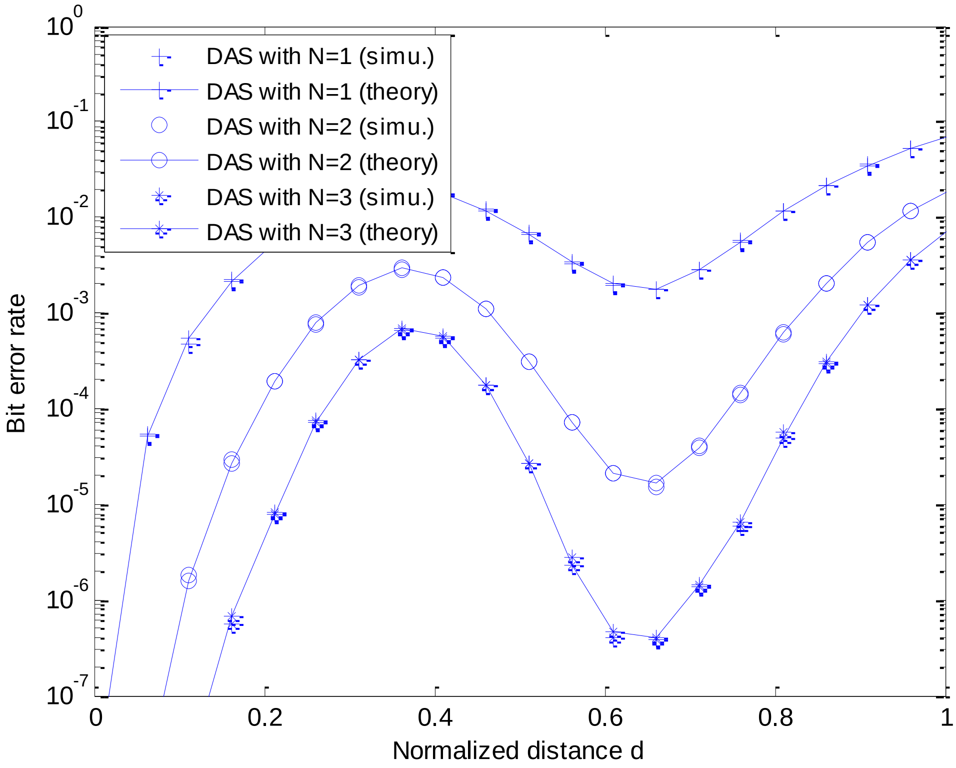


Fig. 4. BER versus the normalized distance from the home BS for DAS with antenna selection and different receive antennas

In **Fig. 5**, we provide the average BER of DAS with single receive antenna and 16QAM, where DAS-AS based on MSINR criterion, DAS-AS based on MPP criterion, and DAS with BTS are compared. From **Fig. 5**, we can observe that DAS with TAS has lower BER than that with BTS, and DAS with TAS based on MSINR criterion slightly outperforms DAS with TAS based on MPP criterion due to the reason analyzed in **Fig. 3**. Comparing the results of **Fig. 4** and **Fig. 5**, it is found that the BER performance of DAS with 64QAM in **Fig. 4** is worse than that with 16QAM in **Fig. 5** since high-order modulation is adopted.

Fig. 6 gives the outage performance of DAS-AS with different receive antennas based on MSINR criterion. In **Fig. 6 (a)**, the system outage probability is evaluated, where the outage capacity C_{oc} equals 6bit/s/Hz. It is shown that the outage probability of DAS with two receive antennas is lower than that with single receive antenna as expectd. This is because the former employs more receive antennas. Moreove, the theoretical outage probability can match the correponding simulation very well, which verfies the effectiveness of the derived theoretical formula. Besides, some results similar to **Fig. 4** can be observed, that is, the outage probability firslty increases, then deceases, and finally inceases.

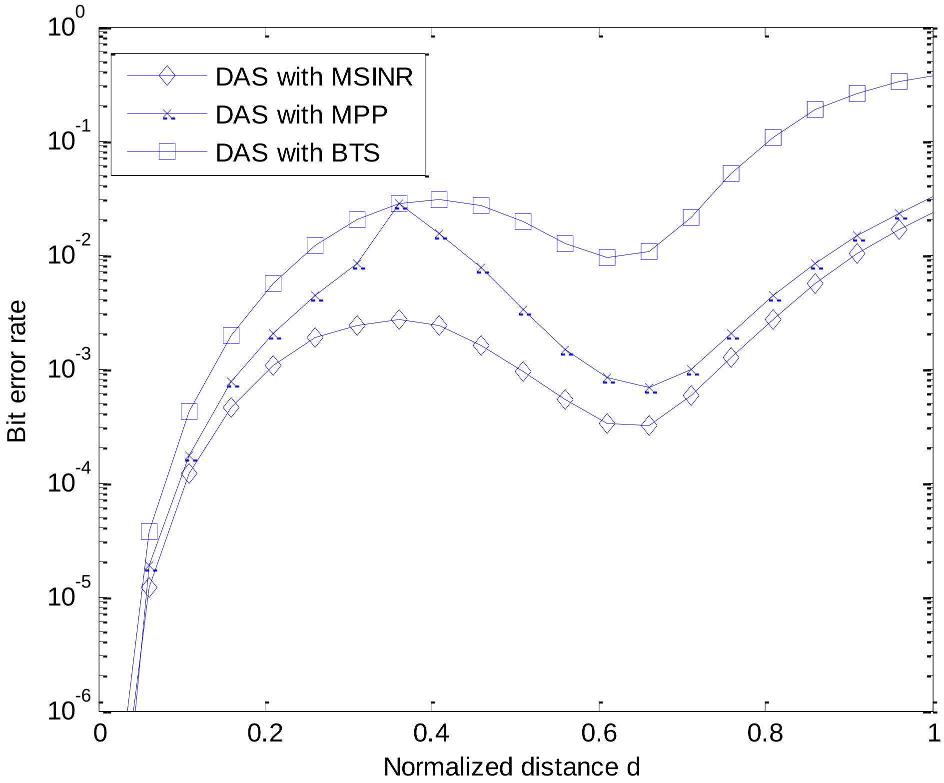
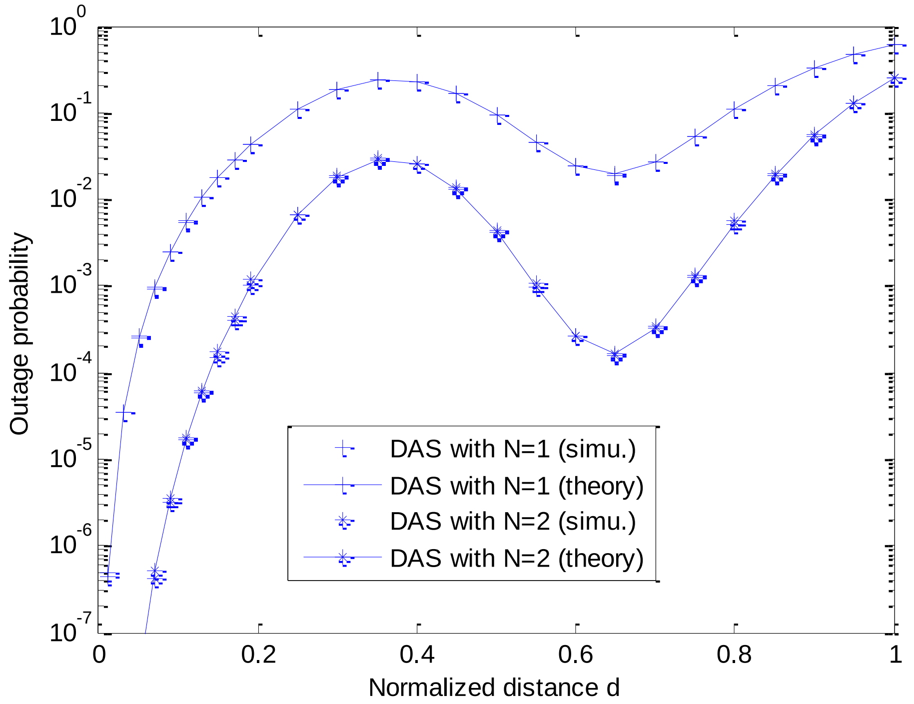
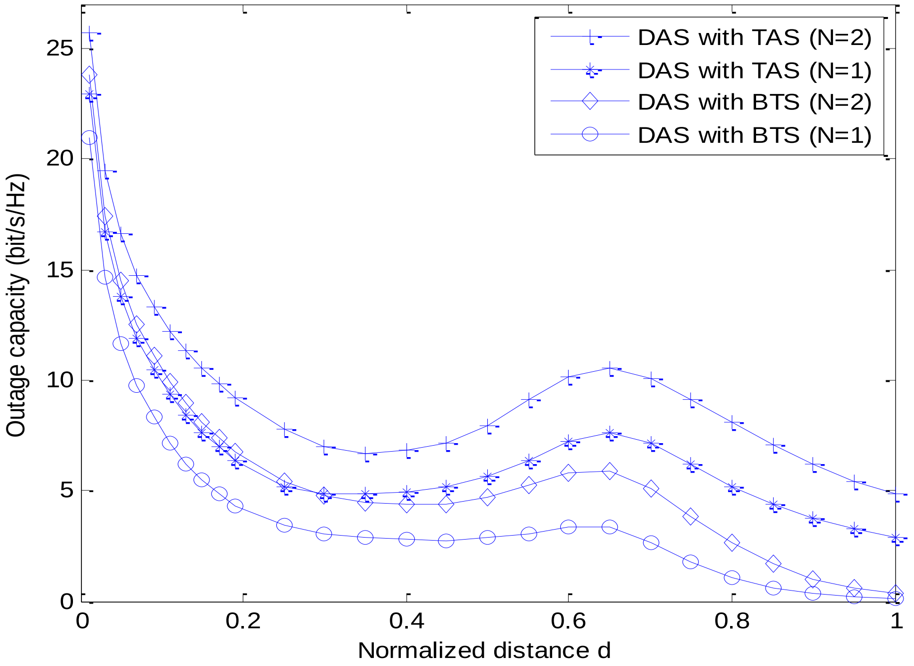


Fig. 5. BER comparison for different DAS with single receive antenna

In **Fig. 6(b)**, we give the outage capacity performance of the system, where the outage probability is set equal to 0.05. For comparison, the outage capacity of DAS with blanket transmission scheme is also provided. From **Fig. 6(b)**, we can see that the outage capacity of DAS with tranmist antenna slection is obviously higher than that of DAS with blanket transmission scheme, the reason is analyzed in Fig.2. Moreover, some results similar to **Fig. 2** are found. Namely, the outage capacity firslty decreases, then inceases, and finally deceases. Comparing the results of **Fig. 6(b)** and **Fig. 2**, we can find that the outage capacity is lower than the corresponding average channel capacity due to the limitation of the outage probability. Besides, the more the receive antennas, the larger is the outage capacity, which accords with the exising knowledge as well.



(a) Outage probability



(b) Outage capacity

Fig. 6. Outage probability and capacity versus the normalized distance from the home BS for DAS with antenna selection and different receive antennas

6. Conclusion

We have investigated the BER and capacity performance of downlink DAS with transmit antenna selection and multiple receive antennas in Rayleigh fading multicell environment. The PDF and CDF of the system SINR are derived by means of the theoretical analysis and mathematical calculation. With the derived PDF and CDF, the accurate closed-form expressions of the average BER and the channel capacity of DAS are obtained, and an approximate closed-form expression of channel capacity is also derived to simplify the calculation of accurate capacity expression. Based on the outage capacity analysis, a closed-form expression of outage probability is derived. Newton method is proposed to find the outage capacity for a given outage probability. Simulation results show that the DAS with antenna selection scheme outperforms that with blanket transmission scheme, and that the system performance can be effectively improved by increasing the number of receive antennas. Moreover, the system using MSINR criterion has better performance than that using MPP criterion. Besides, the derived theoretical expressions are in good agreement with the corresponding simulations. Thus, these expressions can provide good performance evaluation for DAS in Rayleigh fading multicell environment, and avoid the conventional requirement for numerical integration or Monte Carlo simulation.

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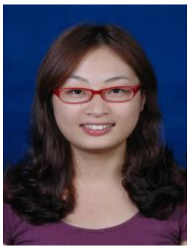

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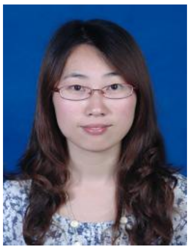

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