An Adaptive Cooperative Relay Selection Algorithm for Fixed Relay Based Cellular Networks

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Abstract—**Cooperative relaying is accepted as a promising solution to achieve high data rates over large areas in the future 4G wireless system. In this paper, an adaptive cooperative relay selection algorithm (ACRSA) is presented for fixed relay based cellular networks. According to current user density in a certain cell, when two-hop transmission is adopted, ACRSA adapts selectively between two different cooperation schemes. These are realized either between the parallel transmission between the base station and a relay node, or by adopting parallel transmission between another mobile terminal and a relay node. Simulation results demonstrate that compared with fixed relay selection schemes, ACRSA can dynamically choose different cooperative strategies with respect to current user conditions in the cell. By fully utilizing cooperative communication, this effectively increases user capacity as well as improving system performance.**

Index Terms—**Relay selection; cellular network; cooperative relay; cooperative diversity**

I. INTRODUCTION

The recent proliferation of broadband and wireless communication techniques have profoundly transformed the working and entertaining styles of human beings [1-2]. Along with the advanced physical techniques adopted in the Physical Layer, relaying technology is also proposed as a promising solution to achieve high data rates over large areas in the future 4G wireless system. Although the advantages of multiple-input-multiple-output (MIMO) systems are well known, it may be impractical to equip very small nodes with multiple antennas. This is primarily due to the size and power limitations of these nodes. To overcome these issues, and embrace the benefits offered by the MIMO systems, the concept of cooperative relaying has been introduced. To this end, several cooperative diversity techniques have been studied.

In the cooperative relay network, a new form of diversity is obtained from virtual antenna arrays. These arrays consist of a collection of distributed antennas, which belong to different relays [3-4]. These can create additional paths for source-destination pairs which will increase the diversity against fading and interference, and allow spatial multiplexing between other nodes. Wang et al. [5] discuss a virtual MIMO based cooperative communication mechanism, and the channel capacity of virtual MIMO based system. Lee et al. [6] propose relay agents (RAs) based on heterogeneous cooperative cellular networks. In these networks, source nodes (SNs) are able to reap the benefits of cooperative communications by using relaying agents. Each of the SNs employ a dual-agent relaying mechanism (DARM) which utilizes two RAs, when available, in parallel transmission for the cooperative relaying of data from the SN.

However, in addition, further research results indicate that the performance of cooperative communications depend heavily on the selection of suitable relay nodes. Most of the recent research in this area suggests that the relay selection criteria are based on the received signal to noise ratio (SNR) or on the shortest distance. This presupposes that several relays, or a relay and Base Station (BS) are selected to constitute a virtual antenna array. Within a fixed relay nodes (FRNs) based cellular network, if there exists a Mobile Terminal (MT) located at the cell border which has a poor quality channel to the BS. So in order to obtain cooperative diversity by parallel transmission, the MT has to find at least two reliable FRNs or select two MTs. Considering the random arrival position of the MT, both of these might be difficult to realize. Moreover, when user density within the cell is comparatively small, the probability of simultaneously finding two cooperative MTs (among users) for cooperative transmission is also extremely small.

Inspired by the above circumstance, an adaptive cooperative relay selection algorithm (ACRSA) is proposed for the FRNs based cellular networks. According to the user density in a given cell, ACRSA selectively adapts between two differing cooperation schemes. One of these schemes is designed to realize the parallel transmission between a BS and a FRN, while the other scheme adopts a parallel transmission between a MT

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and a FRN. Based on the information received from the BS, and when current user density is small, a MT will act in a certain way. Basically, when wanting to perform cooperative relaying, the MT will select the BS and a FRN as cooperative candidates. On the other hand, when current user density becomes large enough, it will select another MT (referred to as Cooperative MT, CMT) to perform cooperative parallel transmission with a FRN. Compared with traditional relay selection schemes, ACRSA works in a distributed way to obtain virtual spatial diversity. It does this by dynamically choosing from different cooperative schemes, and with regard to current user conditions in the cell. This effectively increases user capacity as well as improving the system performance.

The remainder of this paper is organized as follows. Section II presents the system model and description of ACRSA. The proposed ACRSA is then analyzed in Section III, and the performance evaluated in section IV. Section V concludes this paper.

I. II. SYSTEM MODEL AND DESCRIPTION OF ACRSA

Consider a two-hop fixed relay based cellular network employing orthogonal frequency-division multiple access (OFDMA) physical-layer with N subcarriers, where all the OFDM frames are time-synchronized. The assumption is that the network operates in a slow fading environment, and that channel estimation is possible. Furthermore, full channel state information (CSI) is available for both MTs and FRNs. Each cell focuses solely on uplink transmissions from the MT to the BS, either directly or via the FRNs. For the latter, this is according to availability and CSI. In addition, the assumption is that the inter-cell interference is negligible. The transmission in the time domain is on a frame-by-frame basis. Each frame consists of two consecutive time slots, where the MT transmits in the first timeslot, and the FRN forwards in the second timeslot. Decode-and-Forward (DF) forwarding is adopted by FRNs.

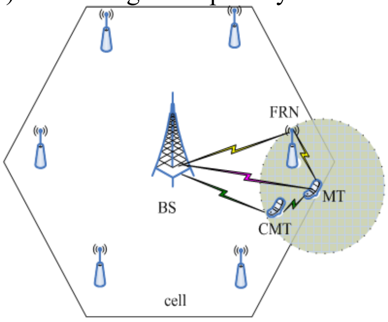

Figure 1. cooperative relay network architecture with ACRSA

Firstly, we define two cooperative modes: Base Station Cooperative Mode (BSCM) and User Cooperative Mode (UCM). BSCM is defined by that for each MT, besides the direct connection to the BS; one of the available FRNs will be chosen to construct a relay path. For UCM, a CMT within the transmission range of the MT will firstly be selected. Then the selected CMT together with a FRN will be employed simultaneously for cooperative relay of data from the MT to the BS.

Using a criterion based on SNR, each MT may select the best FRN or CMT and request them for parallel relaying [6]. Fig.1 illustrates cooperative relay network architecture with ACRSA. Consider a MT with a specified transmission range as shown in Fig.1. If there are one or more CMTs in the MT's transmission range, the MT may perform UCM by requesting the CMT and the FRN for relaying. Otherwise it may perform BSCM by only requesting the FRN for relaying. The more detailed procedure of ACRSA is as follows:

1) A BS periodically broadcasts pilot signals to assist MTs and FRNs in estimating the channel gain between them and the associated BS. The pilot signal sent by the BS also contains a current user density δ in the cell, on which MTs can adopt an appropirate cooperative scheme. Similarly, FRNs periodically broadcast pilot signals to assist MTs in estimating the channel gain between them and the neighboring FRNs. FRNs also broadcast information to surrounding MTs about their channel gains and their associated BS. Each MT takes advantage of such information to individually decide on relay selection.

2) If a MT needs to set up a new call with the BS, or to perform a handover to another cell, it checks for pilot signals from the BS and the FRNs in the cell. According to the information from channel gain between the FRNs and the associated BS, a MT will decide to either communicate with the BS directly or via a two-hop relay. If direct transmission to the associated BS is more beneficial, the MT sends a capacity request to the BS directly. The BS then decides whether to receive or reject its request according to admission control policy.

3) If the MT transmits via two-hop relays (e.g. two-hop relays can bring larger channel gain), it selects the best FRN from all the candidates to serve first as a two-hop relay node. In a distributed manner, the MT also calculates the threshold value Γ. This value denotes the minimum required user density where another CMT may locate in its effective cooperation area (ECA). It then independently decides to adopt BSCM or UCM to achieve cooperative diversity. Based on the current user density information δ contained in the pilot signals, if the value of δ falls below the threshold Γ (e.g. $\delta < \Gamma$), then MT adopts the BSCM to achieve cooperative diversity. Otherwise, it will try to find a CMT within its ECA, then perform UCM.

4) If BSCM is adopted by the MT, it sends a data request to both the selected FRN and the BS in the first timeslot, and the FRN sends the received data request to the BS in the second timeslot. In this way, by combing the data request coming from two separate paths, effective cooperative diversity gain is obtained at the BS site. If the FRN fails to decode the received data request, or it has no available capacity for the MT, it rejects the MT's request. Given this, the MT will communicate with the BS directly as outlined in step 2.

5) If UCM is adopted by the MT, it initially finds a CMT within its ECA. Then it sends a data request to both the CMT and the selected FRN from the first timeslot. If the CMT and the FRN both correctly decode the data request, they can forward the received data request to the BS in the second timeslot. This is sent over two uncorrelated paths so as to achieve parallel relaying at the BS. If any of the relays (including the FRN and the CMT) fail to perform the forwarding, then the UCM is used as a back up with traditional two-hop relay schemes.

6) In the case of the UCM, if the MT fails to find a CMT within its ECA, then the MT accesses the BS through a FRN. This is part of the traditional relay network protocol.

II. ANALYSIS OF ACRSA

A. Analytical Model

The analytical model of ACRSA is described in Fig.2. Assume that a circle centered at position O and with a radius R denotes a cell. Within this cell, the BS is located in the center. The concentric circle in Fig. 2 with a radius R_0 represents the region where a direct transmission will be more beneficial than a relay transmission. In each cell, as the same model adopted in [8], six position fixed relay nodes are deployed with a distance of D far from the BS. Except for direct transmission, the rest region in the cell stands for relay transmission region. To simplify the analysis, we assume that at a certain time *t*, a MT located at position I in Fig. 2 can be referred to as MT_i and its distance to the BS is x. Furthermore, the transmission ranges of MT_i can be represented by a circle with a radius L which is centered at *I*. According to above description, the transmission rule of MT_i is as follows:

$$\begin{cases} Direct\ \ transmission & 0 < x \le R_0 \\ Two-hop\ \ transmission & R_0 < x \le R \end{cases} \tag{1}$$

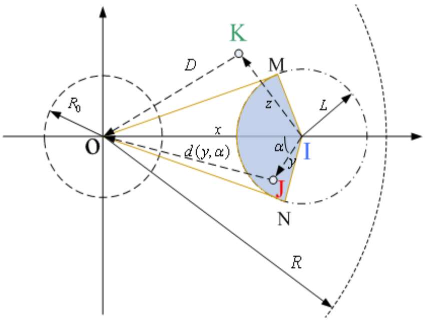

Figure 2. Analytical model

If MT_i locates in the direct transmission region, relaying is not necessary. However, if MT_i locates in the relay transmission area, it adopts a two-hop transmission scheme to access the BS. The shaded region within the MT_i 's coverage circle represents MT_i 's effective cooperation area (ECA) where $\angle OIM = \angle ONI = \pi/2$. Only if there exists at least another MT (referred to as node *J* in Fig.2) within the MT_i 's ECA, and this MT is eligible to be selected as a CMT, can MT_i adopt UCM. Otherwise, MT_i adopts BSCM and node *K* represents the selected FRN.

B. The value of threshold Γ

Suppose that all the MTs are evenly and independently distributed within the cell, and at a certain time *t*, the user density within the cell is δ. The average number of MTs which adopt two-hop transmission can be calculated as $\pi(R^2\text{-}R_0^2)\cdot\delta$. If $A_e(x)$ represents MT_i 's ECA, the probability that MT_i can find a CMT within its ECA is a function of a binomial distribution with parameters ($\pi(R^2\text{-}R_0^2)\cdot\delta$, $A_e(x)/\pi(R^2\text{-}R_0^2)$). In these parameters, $A_e(x)/\pi(R^2\text{-}R_0^2)$ denotes the probability that an arbitrary CMT is located in the MT_i 's ECA. This paper assumes that those MTs located in the direct transmission region will not act as CMTs for those MTs lying outside the direct transmission region. It is owing to that they can obtain high channel gain through direct transmission. According to [6], the value of $A_e(x)$ is given by:

$$A_e(x) = \pi L^2 \times \frac{\cos^{-1}(L/x)}{\pi} = L^2 \times \cos^{-1}(L/x) \tag{2}$$

As a result, the probability that MT_i finds k CMTs within its ECA is written as:

$$\phi(k) = \begin{pmatrix} \pi(R^2\text{-}R_0^2)\times\delta \\ \mathrm{k} \end{pmatrix} \cdot \left(\frac{L^2}{\pi(R^2\text{-}R_0^2)} \times \cos^{-1}(L/x) \right)^{k} \cdot \left(1 - \frac{L^2}{\pi(R^2\text{-}R_0^2)} \times \cos^{-1}(L/x) \right)^{\pi(R^2-R_0^2)\delta-k} \tag{3}$$

As mentioned above, at a certain time *t*, if a MT can successfully find another MT in its ECA, according to ACRSA, UCM shall be adopted to achieve cooperative communication. This is given by the following formula:

$$1-\phi(0) \ge \phi(0) \tag{4}$$

Substituting (3) into (4), we have:

$$\left(1 - \frac{L^2\cos^{-1}(L/x)}{\pi(R^2-R_0^2)} \right)^{\pi(R^2-R_0^2)\delta} \ge \frac{1}{2} \tag{5}$$

In this formula, the minimal value of δ that satisfies (5) is set as an initial threshold Γ. In order to suit the changing current user density, this value can be updated by each MT individually. For instance, given a time period *T*, if a MT wanting to adopt UCM always finds a CMT in its ECA, then it dynamically decreases the value of Γ. Conversely, if a MT wanting to adopt UCM can rarely find a CMT in its ECA, then the value of Γ should be increased. This is done to ensure that the MT can take advantage of cooperative diversity by adopting BSCM. The revised process of Γ is given by the following formula:

$$\Gamma = \begin{cases} 1/2\cdot(1+(\Gamma_0-\delta)/\Gamma_0) & \delta \le \Gamma_0 \\ 1/2\cdot(1-(\delta-\Gamma_0)/\delta) & \delta > \Gamma_0 \end{cases} \tag{6}$$

In this formula, Γ_0 stands for the initial value of Γ, and is obtained by solving the expression in (5).

C. Average achievable rate with/without ACRSA

- Direct transmission

Firstly, assume that the coordinate of each node in a cell in a polar-coordinate system can be represented as (r,θ). In this polar-coordinate system, then $(0<r<R, 0<\theta<2\pi)$. Also consider a mobile terminal MT_i located at $I(x,0)$ as shown in Fig.2. Suppose that relaying is not used during its transmission with the BS which is located at position $O(0,0)$, then the upper bond r_i^d of the average achievable rate C_i^d per subcarrier of bandwidth W at power level P_i is given by:

$$C_i^d(x) < r_i^d(x) = W\log_2\left(1+\frac{P_iG_i(x)c_3}{\sigma^2}\right) \tag{7}$$

Without loss of generality, M-ary quadrature amplitude modulation (MQAM) is adopted as it is a modulation method with high spectrum efficiency. According to the bit-error rate (BER) of MQAM which is a function of rate and the SNR given in [7], we now have $c_3 = 1.5/\ln(0.2/BER)$ .In Eq. (7), $G_i(x)$ stands for the channel gain between MT_i and the BS, whereas σ^2 denotes the thermal noise power of the subcarrier.

The coordinate of MT_i $I(x,0)$ depends on the distance between MT_i and its BS, which is subjected to the following probability distribution function (PDF):

$$f(x)=\begin{cases} 2x/R^2,\ \textit{direct transmission} & 0<x<R \\ 2x/(R^2-R_0^2),\ \textit{relay transmission} & R_0<x<R \\ 0,\ \textit{otherwise} \end{cases} \tag{8}$$

Combining Eq. (7) and Eq. (8), the average achievable rate per subcarrier of an arbitrary MT_i and one with a direct transmission, is written as:

$$C_i^d < r_i^d = \int_0^R \left(W\log_2\left(1+\frac{P_iG_i(x)c_3}{\sigma^2}\right)\frac{2x}{R^2}\right)dx \tag{9}$$

- Traditional two-hop transmission

Consider a two-hop transmission from MT_i to the BS via a FRN located at position K. Assuming that the distance between the FRN and MT_i is z as demonstrated in Fig.2, then from the results given in [8], we assume z is obtained if the radius of a relay coverage region is known. The upper bond $r_i^r(z;x)$ of the average rate $C_i^r(z;x)$ per subcarrier of bandwidth W is given by:

$$C_i^r(z;x) < r_i^r(z;x) = \frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ir}(z)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_rG_{rb}(D)c_3}{\sigma^2}\right)\right\} \tag{10}$$

Here, $G_{ir}(z)$ and $G_{rb}(D)$ stand for the channel gain between MT_i and the FRN, as well as the channel gain between the FRN and the BS, respectively. P_r denotes the transmission power of FRN.

- Cooperative relay transmission using BSCM

According to [9-10], for cooperative relay transmission using BSCM, the upper bond $r_i^{bc}(z;x)$ of the average rate $C_i^{bc}(z;x)$ per subcarrier is derived as:

$$\begin{aligned} &C_i^{bc}(z;x) < r_i^{bc}(z;x) \\ &= \frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ir}(z)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_iG_{ib}(x)c_3}{\sigma^2}\right)+\log_2\left(1+\frac{P_rG_{rb}(D)c_3}{\sigma^2}\right)\right\} \end{aligned} \tag{11}$$

Where $G_{ib}(x)$ stands for the channel gain between MT_i and BS, Eq. (11) can be represented as:

$$\begin{aligned} &C_i^{bc}(z) < r_i^{bc}(z) = \\ &\int_{R_0}^{R}\left(\frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ir}(z)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_iG_{ib}(x)c_3}{\sigma^2}\right)+\log_2\left(1+\frac{P_rG_{rb}(D)c_3}{\sigma^2}\right)\right\}\frac{2x}{R^2-R_0^2}\right)dx \end{aligned} \tag{12}$$

- Cooperative relay transmission using UCM

Suppose another MT referred to as MT_j is located at position J and its coordinate is $J(y,\alpha)$. As shown in Fig. 2, and with respect to the location of MT_i , the distance between MT_i and MT_j is expressed as $d(y,\alpha)=\sqrt{x^2+y^2-2yx\cos\alpha}$. According to the closed-form solutions for the performance of single-user MIMO systems as given in [11], if a maximal ratio combining (MRC) is used at the BS, then the upper bond $i_i^{uc}(z;y,\alpha)$ of the average rate $C_i^{uc}(z;y,\alpha)$ per subcarrier is given by:

$$\begin{aligned} C_i^{uc}(z;y,\alpha) < i_i^{uc}(z;y,\alpha) &= \frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ir}(z)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_rG_{rb}(D)c_3}{\sigma^2}\right)\right\} \\ &+\frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ij}(y)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_jG_{jb}(d(y,\alpha))c_3}{\sigma^2}\right)\right\} \end{aligned} \tag{13}$$

Where P_j is the transmission power of MT_j ; then $G_{ij}(y)$ represents the channel gain between MT_i and MT_j , $G_{jb}(d(y,\alpha))$ represents the channel gain between MT_j and the BS. The coordinate of MT_j is related to the ECA of MT_i and its probability distribution function (PDF) is obtained as:

$$f(J(y,\alpha))=\begin{cases} \dfrac{y}{L^2\times\cos^{-1}(L/y)}, & \begin{matrix} 0<y<L \\ \pi-\cos^{-1}(L/y)<\alpha<\pi+\cos^{-1}(L/y) \end{matrix} \\ 0,\ \textit{otherwise} \end{cases} \tag{14}$$

By substituting Eq. (14) into Eq. (13), we have:

$$\begin{aligned} C_i^{uc}(z) < i_i^{uc}(z) &= \int_{R_0}^{R}\left(\frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ir}(z)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_rG_{rb}(D)c_3}{\sigma^2}\right)\right\}\frac{2x}{R^2-R_0^2}\right)dx \\ &+\int_0^L\int_{\pi-\cos^{-1}(L/y)}^{\pi+\cos^{-1}(L/y)}\left(\frac{W}{2}\min\left\{\log_2\left(1+\frac{P_iG_{ij}(y)c_3}{\sigma^2}\right), \log_2\left(1+\frac{P_jG_{jb}(d(y,\alpha))c_3}{\sigma^2}\right)\right\}\frac{y}{L^2\times\cos^{-1}(L/y)}\right)d\alpha dy \end{aligned}$$

(15)

III. SIMULATION RESULTS OF ACRSA

A. SimulationParameters

Consider an OFDMA cellular system working over 3.5GHZ bands. A 3.2-MHz band is divided into 128 subcarriers. Each transmitter is synchronized with respect to the receiver's clock reference to make the tones orthogonal. It is assumed that $R = 500m, R_0 = 150m, L = 50m$ and $D = 2/3R$ .The transmission power of a MT per subcarrier and that of FRN is $P_{MT} = 500mW$, $P_{FRN} = 1W$, respectively. The thermal noise power is $\sigma^2 = 10^{-10}W$, and the desired BER is 10^{-3} .

$$\begin{cases} Passloss[dB] = 38.4 + 35\log_{10}(d) + 20\log_{10}(f_c/5) + X_{\sigma NLOS} & MT \rightarrow BS, MT, \sigma = 8dB \\ Passloss[dB] = 36.5 + 23.5\log_{10}(d) + 20\log_{10}(f_c/2.5) + X_{\sigma LOS} & FRN \rightarrow BS, \sigma = 3.4dB \\ Passloss[dB] = 41 + 22.7\log_{10}(d) + 20\log_{10}(f_c/5) + X_{\sigma LOS} & MT \rightarrow FRN, \sigma = 2.3dB \end{cases} \quad (16)$$

The propagation links between FRN and BS and between FRN and MT are assumed to be LOS (Light-Of-Sight), while assumed to be NLOS (Non-Light-Of-Sight) for other conditions. According to [12], the path-loss model for the links between LOS and NLOS is shown in Eq. (16). We use independent lognormal random variables to model the shadow fading in the LOS and NLOS conditions. The random variables have a standard deviation of $X_{\sigma LOS} = 3.4\text{dB}, X_{\sigma LOS} = 2.3\text{dB}$ and $X_{\sigma NLOS} = 8\text{dB}$.

B. *Simulation RESULTS*

Fig.3 shows the probability that a different number of CMTs can be found within a MT's ECA. This is taken as a function of user density, where $\phi(0)$ denotes the possibility that an arbitrary MT finds no CMT in its ECA. The user density δ in a cell ranges from $10^{-5}/m^2$ (corresponding to 7 CMTs) to $5\times10^{-3}/m^2$ (corresponding to 3571 CMTs). According to the expression in (5), we can obtain Γ_0 is equal to $1.9891\times10^{-4}/m^2$. From Fig.3, it is observed that when the density of a user is about $2\times10^{-4}/m^2$, then the probability of finding at least one CMT in a MT's ECA is close to 0.5. This is in accordance with the analysis value. When the user density is approximately $2\times10^{-3}/m^2$, there exists at least one CMT in a MT's ECA. Moreover, it can be seen that the updating value of a threshold Γ accords with user density.

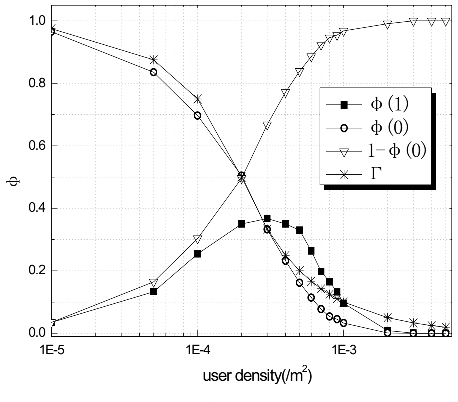

Figure 3. ϕ versus user density

Fig.4 shows the average achievable rates per subcarrier as a function of user density. To make a comparison, a two-hop Relay Selection (TRS) scheme which only selects one best FRN from all available FRNs is also displayed. The TRS scheme applies where an MT requests relaying, and is achieved in a simulation without using cooperative transmission. As user density increases, ACRSA greatly improves the average achievable rate compared with that of TRS. When user density is approximately $1\times10^{-3}/m^2$, the performance of ACRSA is close to saturation. Furthermore, with the adaptive threshold Γ , the performance of ACRSA is more improved than the fixed threshold Γ_0 . The simulation results in Fig.4 demonstrating that, even though there is small user density within the cell (e.g. $\delta = 10^{-5}/m^2$), ACRSA can improve the average achievable rate. This is achieved by cooperative transmission using BSCM. When the user density becomes lager, since a MT is more likely to find a CMT in the ECA, ACRSA will effectively improve the average achievable rates by cooperative transmission through using UCM. Intuitively, the reason that UCM outperforms BSCM seems to be due to NLOS transmission, and a cell-edge MT's direct transmission to the BS undergoes bigger pass loss and shadowing compared with its transmission to a CMT.

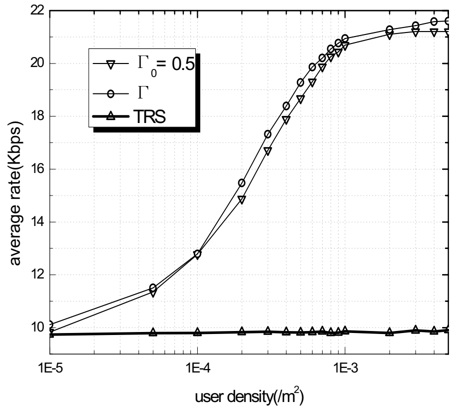

Figure 4. average achievable rate of a MT per subcarrier versus user density

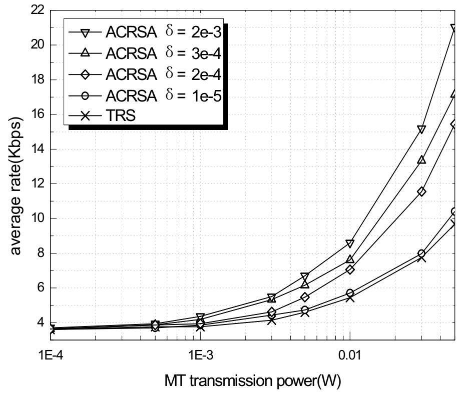

Figure 5. average achievable rate of a MT per subcarrier versus MT transmission power

Fig.5 and Fig.6 show the average achievable rates per subcarrier versus the MT/Relay transmission powers respectively. Four typical values for user density δ are simulated for ACRSA. It is observed that regardless of whether ACRSA is used, the average achievable rates increase as power increases. In addition, with the increasing of δ, USM is more likely to be adopted compared with BSCM, which results in larger diversity gain and hence greater average achievable rates.

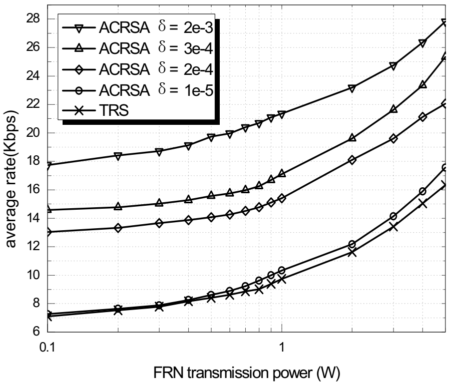

Figure 6. average achievable rate of a MT per subcarrier versus MT transmission power

In Fig.7 the average achievable rates per subcarrier for both mechanisms versus the desired BER is shown. Theoretically, the average achievable rate increases if the desired BER increases, and this phenomenon is observed in Fig.7. Once again, it is found that with the increasing value of δ, the performance of ACRSA becomes better as compared with that of TRS.

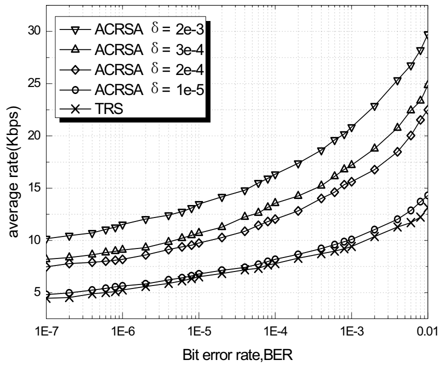

Figure 7. average achievable rate of a MT per subcarrier versus BER

Fig.8 shows the average achievable rates per subcarrier versus *L/R*, i.e. the ratio between the transmission radius and the cell radius. In the figure, under a certain user density δ, the average achievable rate of ACRSA firstly increases as *L/R* increases, and then gradually becomes stable. This phenomenon can be explained by the fact that as *L/R* grows larger, the ECA of an arbitrary MT also becomes larger. This means that the possibility of finding a CMT within the MT's ECA increases. However, when *L/R* achieves a certain value, the performance of ACRSA approaches saturation. This occurs within the probability of close to 1 for a MT finding a CMT within the ECA. The results of Fig.8 also demonstrate that ACRSA can significantly improve the average achievable rate under medium user density, even though the radius of the transmission range, relative to the cell radius, is small.

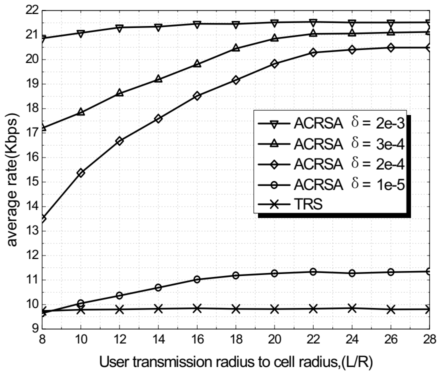

Figure 8. average achievable rate of a MT per subcarrier versus L/R

IV. CONCLUSIONS

This paper presents an adaptive cooperative relay selection algorithm (ACRSA) for fixed relay based cellular networks. According to current user density in a certain cell, ACRSA adapts selectively between two different cooperation schemes. This is done to either realize the parallel transmission between the BS and a FRN, or to adopt a parallel transmission between an MT and a FRN. Based on the information received from the BS, when current user density is small, a MT wanting to perform cooperative commutation will select the BS and a FRN as the cooperative candidates, since it is difficult to find another CMT within the MT's transmission range. On the other hand, when the current user density becomes large enough, a MT will firstly find an effective CMT within transmission range. The selected CMT will then perform cooperative parallel transmission together with a FRN. Compared with traditional relay schemes, ACRSA can dynamically choose different cooperative schemes according to current user conditions in the cell. This is achieved by fully utilizing cooperative communication to accomplish a virtual MIMO-based cooperative communication scheme, which effectively increases user capacity as well as improving system performance.

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