

Green Dynamic Configuration in 4G Macrocell-Femtocell Heterogeneous Networks

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Abstract—With the increasing demand of broadband wireless communication networks, users have an increasing need of the wireless broadband service coverage and the wireless access quality. To alleviate this problem, several novel technologies are proposed. One of these technologies is femtocells. A femtocell can be used to increase the coverage of wireless broadband service indoors or at hotspots and raise both data transmission rate and access quality. Although the use of femtocells can greatly benefit, deploying large number of femtocells consumes tremendous energy. In order to respond to the problem of global climate change, energy saving is an important issue. This paper discusses how to minimize the energy consumption of femtocells, optimize the energy efficiency of femtocells, but still provide both the same data transmission rate and wireless broadband service coverage. In this work, considering path loss, modulation and coding schemes (MCSs) and group mobility, we propose a green handover and dynamic femtocell wake up approach. In default, femtocells are stay in idle mode when no user equipment (UE) connecting to it. A femtocell transits to active mode only when detecting UEs and the power efficiency of using the femtocell to transmit data is better than the macrocell. By this way, not only users can benefit from the femtocells but also femtocells can reduce unnecessary power consumption. Simulation results show that, in both 3G/4G wireless communication networks, our method performs better than the previous methods in power consumption, energy efficiency and throughput.

Keywords—femtocell; green communication networks; green handover; OFDMA; LTE/LTE-A; heterogeneous networks

I. INTRODUCTION

In wireless communication networks, users connect to peers through base stations (BSs) since the BS must be always available to provide users wireless access service, the power consumption of BSs is much more than that of user equipments (UEs). Recently, in response to the goal of energy reduction of BSs, the concept of green communication networks [1] is proposed. The authors of [1] presented that the future wireless communication network has to be energy efficient and the benchmark weighs the performance of energy efficiency of wireless communication networks should be employed. [2][3] investigated the energy efficiency issue of wireless networks and proposed a “Green Radio” solution, is can where BSs turn off their transceivers to achieve power saving when no users

are connecting to the BSs for data transmission. However, these studies do not take femtocells into account.

Femtocells can be deployed indoors or at hotspot to increase wireless broadband service coverage and raise data access quality. However, when large numbers of femtocells exist, if there’s no well-designed power saving mechanism, the total power consumption of femtocells will be tremendously large. Currently, there are several research works [4][5][6] discussing the green energy issue over the macrocell-femtocell heterogeneous network. Ashraf et al. [4][5] proposed a dynamic energy efficient solution to save the power consumption of femtocells, where a femtocell stays in idle mode in default until it detecting a transmitting UE entering its coverage. Thus, femtocells only have to wake up when serving users. However, this makes a femtocell frequently switch between idle and active modes whenever any transmitting user leaving or arriving at the femtocell, respectively, which is still not real power efficient. Chen et al. [6] propose a green handover protocol in two-tier OFDMA macrocell-femtocell networks, where a femtocell only wakes up when a moving UE enters its coverage area and the UE can transmit all the data through the femtocell during the dwell time, otherwise the femtocell keeps idle and the UE remains in macrocell. This causes additional energy consumption and handover cost when the user only has few amounts of data to deliver. To solve above drawbacks, this paper proposes a new green handover method for 4G OFDMA macrocell-femtocell heterogeneous networks. In the method, we take path loss and group mobility into consideration. To the best of our knowledge, this paper is the first one to consider these two factors in the energy efficient macrocell-femtocell heterogeneous network.

This paper considers a green handover problem over energy efficient macrocell-femtocell heterogeneous networks. In the heterogeneous network, to maintain service availability, macrocells are always on and thus the power consumption of macrocells is a fixed cost. For UEs, connecting to femtocells is energy conserving compared with connecting to macrocells. However, switching a femtocell cell from idle mode to active mode will increase the power consumption of the femtocell. Therefore, this is a trade-off problem and the objective of this paper is to maximize the power efficiency and reducing the total power consumption of the network including macrocells, femtocells and UEs. The contributions of this work are three

folds. First, we propose a green handover method which performs better energy efficiency and power consumption than previous methods. Second, this work does not have to predict the dwell time of a UE under a certain cell and consider both path loss and group mobility ([4][5][6] are a special case of group size equal to one), which is more realistic. Third, the performance of our method is evaluated over both 3G and 4G systems through simulations. Simulation results show that our proposed method outperforms the previous works on energy efficiency, throughput and total power consumption.

The rest of the paper is organized as follow. Section 2 describes the system model and problem definition. Section 3 presents our proposed green handover method. Simulation results are shown in Section 4. Section 5 concludes this paper.

II. SYSTEM MODEL AND PROBLEM DEFINITION

A. System Model

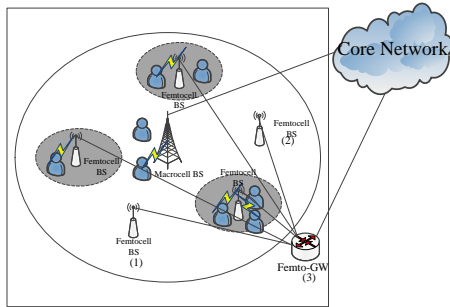


Fig. 1. Macrocell-femtocell heterogeneous network architecture.

The femtocell [7] is a low power, low cost, and user-deployed equipment. Compared to macrocells, the coverage of femtocells is smaller (e.g. 30~40 m in diameter). For UEs, femtocells can provide good signal quality because of the short distance. Deploying femtocells can increase coverage for hotspots, improve data transmission rate and offload data traffic for macrocells. Fig.1 shows the system architecture of a macrocell-femtocell heterogeneous network. The same as macrocells, femtocells work on the licensed band and connect to the operator's core network via DSL broadband backhaul. To save power, a femtocell will enter idle mode (Fig.1 (1)(2)) when no UEs connecting to it, otherwise it will stay in active mode. Femtocells connect to the core network through a femto-gateway (Fig.1 (3)).

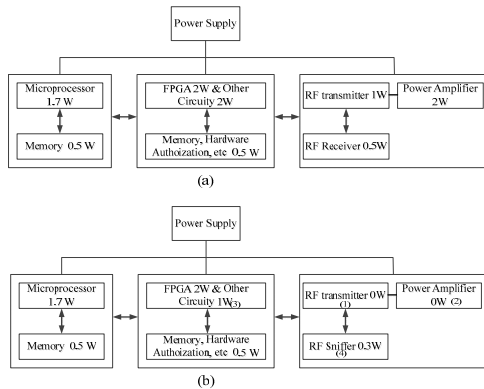


Fig. 2. Power consumption of femtocell hardware: (a) active and (b) idle modes.

TABLE I. THE POWER CONSUMPTION FOR UE AND FEMTOCELL

| | Active | Idle | Power saving |
|-----------|----------------------|----------------------|--------------|
| femtocell | 10.2 W | 6 W | 4.2 W |
| | Connect to macrocell | Connect to femtocell | Power saving |
| LTE UE | 0.2 W | 0.0001 mW | ≈ 0.2 W |
| 3G UE | 1 W | ≈ 3.2 mW | ≈ 1 W |

TABLE II. MCS AND RECEIVER REQUIRED OF SINR

| Index | MCS | SINR (dB) |
|---------|------------|-----------|
| MCS_1 | QPSK 1/2 | 2 dB |
| MCS_2 | QPSK 3/4 | 5.5 dB |
| MCS_3 | 16 QAM 1/2 | 7.9 dB |
| MCS_4 | 16 QAM 3/4 | 12.2 dB |
| MCS_5 | 64 QAM 2/3 | 15.3 dB |
| MCS_6 | 64 QAM 3/4 | 17.5 dB |

Fig.2 (a) and (b) illustrate the power consumption of hardware modules of idle and active femtocells[6], respectively. The hardware modules are divided into three parts. The first part is random access memory components connect to the microprocessor data handling function. The second part is a field-programmable gate array (FPGA) which implements the data encryption, the hardware authentication and the network time protocol. The third part is the RF transceiver, including separate RF components for the packet transmission and reception, and the RF power amplifier (PA). Fig.2 (a) shows the power consumption of each module when the femtocell is in the active mode and the total power consumption is 10.2W. Moreover Fig.2 (b) shows the power consumption of each module when the femtocell switches to idle mode. Compared to the active mode femtocell, an idle mode femtocell can turn off its power amplifier (Fig.2 (b) (2)), RF transceiver (Fig.2 (b) (1)) and miscellaneous hardware components related to non-essential functionalities (Fig.2 (b) (3)), such as data encryption and hardware authentication. Additionally, since femtocell is in idle mode, a radio sniffer ($P_{sniffer} = 0.3W$) (Fig.2 (b) (4)) module is switched on to measure the power of UE and macrocell. Totally, an idle mode femtocell consumes 6W power. Table I provides the power consumption of data transmission for UE and femtocell [6]. For an LTE UE and 3G UE, connecting to the macrocell spends about 0.2W and 1W, respectively, but connecting to the femtocell spends an LTE UE and 3G UE only about 0.0001mW and 3.2mW, respectively. The power savings of the LTE UE and 3G UE are about 0.2W and 1W, respectively, if UEs adopt femtocells instead of macrocells. As what has been show in Fig.2, a femtocell operating in active and idle modes spends 10.2W and 6W, respectively. If a femtocell keeps staying in idle mode, the power saving is 4.2W. Table II shows each (Modulation and Coding Scheme (MCS)) technique and its required received (Signal to Interference plus Noise Ratio (SINR)) [8][9][10]. Assume the transmission power of node i is P_i , the received power of node j , $\tilde{P}(i, j)$, can be written as

$$\tilde{P}(i, j) = \frac{G_i \times G_j \times P_i}{L(i, j)}, \quad (1)$$

where G_i and G_j are node i and node j antenna gains, respectively, $L(i,j)$ is the path loss. With $\tilde{P}(i,j)$, the received SINR of node j can be derived as follows.

$$SINR = 10 \log_{10} \left(\frac{\tilde{P}(i,j)}{B \times N_0 \times I(i,j)} \right), \quad (2)$$

where B is the bandwidth, N_0 is the thermal noise, and $I(i,j)$ is the interference caused by other transmitters which can be presented as below.

$$I(i,j) = \sum_{l \neq i} \tilde{P}(l,j).$$

Above model can help us to evaluate the channel qualities between UE and macrocell/femtocell and establish simulation platform.

B. Motivation and Problem Definition

Ashraf et al. [4][5] proposed to improve energy efficiency by setting femtocells to idle mode when the channel is idle, while switching femtocells to active mode when detecting the signal power of UEs is large than a threshold, thus UEs can always deliver data through femtocells if any femtocell exists. However, femtocells are not always the most energy efficient way to deliver data and additional handover cost is required. On the other hand, Chen et al. [6] proposed a green handover protocol in which each idle femtocell will detect the entry of transmitting UEs and predict UEs, dwell time. If the dwell time is long enough for UEs to transmit all the data via the femtocell, then the femtocell will wake up and UEs handover from the serving macrocell to the femtocell; otherwise, the femtocell will stay idle. Although above method reduces the handover cost, but the energy efficiency is still a problem. This motivates us to propose our solution to maintain an energy efficient communication network with high throughput and low total power consumption. Moreover, we consider path loss, MCSs and group mobility, which are omitted in previous works. The problem is stated as follows.

This paper aims to design a green handover method for 4G OFDMA macrocell-femtocell heterogeneous networks and the assumptions are as below. (1) There is a group of N UEs moving in the radio access network. There are M femtocells; some are in idle mode (no user) connection exists; the others are in active mode (there are UEs connection to the femtocells). (2) This paper considering path loss, system type (3G/4G) and multiple assumes co-channel allocation mode is used [11], where all free channels are non-simultaneously shared by femtocells and macrocell. MCSs are available, the problem is to determine whether an idle femtocell shall wake up or not when a group of UEs pass by or enter its coverage area and whether the group of UEs shall handover from macrocell to femtocell or not such that the energy efficiency of overall communication network can be maximized and maintain both high throughput and low total power consumption.

III. A GREEN HANDOVER METHOD

This section introduces our proposed green handover algorithm. Review that we assume a group of N UEs move together. The whole field is covered macrocells and M

femtocells, are deployed with open (active) probability P and idle probability $(1-P)$. For femtocells, the power consumptions are P_{idle}^{femto} and P_{active}^{femto} when in idle and active modes, respectively. For UEs, the power consumptions of connecting the macrocell and femtocell are P_{macro}^{UE} and P_{femto}^{UE} , respectively. We denote the available channel data rate of UE j by R_{macro}^j (in bit/s) and R_{femto}^j (in bit/s) when connecting to macrocells and femtocells, respectively, where R_{macro}^i and R_{femto}^i depend on the channel quality. R_{macro}^i can be obtained by the equation below:

$$R_{macro}^j = H_j \times 12 \times 7 \times F(MCS_k^j), \quad (3)$$

where H_j is the amount of physical resource block (PRB) per second reserved to UE j (not that each PRB is composed of 12 subcarriers \times 7 symbols), MCS_k^j is UE j 's available highest channel rate MCS, and $F(MCS_k^j)$ represents the symbol data rate of MCS_k^j . The MCS_k^j that UE j can use is able to be obtained by the following equation:

$$\delta(MCS_{k+1}) > SINR(i,j) \geq \delta(MCS_k), \quad (4)$$

where $SINR(i,j)$ represents the SINR between UE j and the BS i , $SINR(i,j)$ can be derived by Eq. (2), and $\delta(MCS_k)$ and $\delta(MCS_{k+1})$ are the required minimum SINRs of MCS_k and MCS_{k+1} , respectively. So, $MCS_k^j = MCS_k$. For simplicity, no matter UE j is connecting to macrocells or femtocells, we let UE j 's available resource is always H_j . Although frequencies are spatial reusable, but this is out of the scope of this paper and we will not discuss this.

Since femtocells provide high data rate and good channel quality, we assume that UEs use MCS_6 (64QAM 3/4) when connecting to femtocells. R_{femto}^j can be calculated as follows.

$$R_{femto}^j = H_j \times 12 \times 7 \times F(MCS_6). \quad (5)$$

When UEs passes the femtocell, the will evaluate femtocell the energy efficiency to determine whether it shall allow the UEs to handover to it from the serving macrocells. If is in idle mode, it will also decide whether to stay in idle mode or transit to active mode according to the evaluation. To do evaluation, we first conduct the energy efficiency of accessing the macrocell by the following equation:

$$E_{macro} = \frac{N \times R_{macro}}{N \times P_{macro}} = \frac{R_{macro}}{P_{macro}}, \quad (6)$$

where we assume the group of N UEs have the same H_j and similar channel conditions to simplify the problem. The energy efficiency of accessing the femtocell can be derived by the following equation:

$$E_{femto} = \begin{cases} \frac{N \times R_{femto}}{(P_{active}^{femto} - P_{idle}^{femto}) + N \times P_{femto}^{UE}}, & \text{when initially idle} \\ \frac{N \times R_{femto}}{N \times P_{femto}^{UE}} = \frac{R_{femto}}{P_{femto}^{UE}}, & \text{otherwise} \end{cases}, \quad (7)$$

where $(P_{active}^{femto} - P_{idle}^{femto})$ is the extra power consumption for an idle femtocell switching from idle mode to active mode. If $E_{femto} > E_{macro}$, represent that accessing the femtocell is a more energy efficient way than the macrocell for the UEs, i.e., accessing the femtocell, the UEs can deliver more data by spending per joule instead of the macrocell; on the contrary, if $E_{femto} \leq E_{macro}$, handover to the femtocell is not worthy. Based on this principle, we design a green handover algorithm as follows.

Step 1. Once detecting any UE's entry of the femtocell's coverage area, if the femtocell is in idle mode, go to Step 2; otherwise, go to Step 3.

Step 2. Evaluate the energy efficiency of accessing the macrocell and femtocell. If $E_{femto} > E_{macro}$, i.e., $\frac{N \times R_{femto}}{R_{macro}} > \frac{(P_{active}^{femto} - P_{idle}^{femto}) + N \times P_{femto}^{UE}}{P_{macro}^{UE}}$, the femtocell switches to active mode, waits for the UEs handover requests, and go to Step 4; otherwise, i.e., $E_{femto} \leq E_{macro}$, the femtocell keeps staying in idle mode, and go back to Step 1.

Step 3. If $E_{femto} > E_{macro}$, i.e., $\frac{R_{femto}}{R_{macro}} > \frac{P_{femto}^{UE}}{P_{macro}^{UE}}$, the femtocell determines to allow the UE's handover requests and wait for their handover requests will allow and go to Step 4; otherwise, i.e., $E_{femto} \leq E_{macro}$, the femtocell decides to reject the UE's handover the femtocell, let the UEs continue to stay in macrocell, and go back to Step 1.

Step 4. Upon receiving the handover requests of the UEs (here we assume UEs prefer accessing femtocells then macrocells), accept the handover requests and go to Step 5.

Step 5. The femtocell provides radio access service for the UEs.

Step 6. Once the femtocell discovers that there is not radio connection existing, set an OFF timer and switch back to idle mode if there's no connecting request before timeout.

IV. SIMULATION RESULTS

TABLE III. SIMULATION PARAMETERS

| System parameters | |
|--|--|
| Network size | $1300\sqrt{2} \text{ m} \times 1300\sqrt{2} \text{ m}$ |
| Macrocell support MCS | QPSK1/2, QPSK3/4, 16QAM1/2, 16QAM3/4, 64QAM2/3, 64QAM3/4 |
| Femtocell coverage range | 55.78 m |
| Mobility UEs | 1~10 |
| Velocity of UE | 1m/s~10m/s |
| Deployment Number of femtocell | $n_f \times n_f$ ($n_f=1 \sim 15$) |
| Thermal noise | $-174 \text{ dB}_m / H_z \cdot \text{dB}_m / H_z$ |
| Path loss | |
| Macrocell-macro UE | $PL_{dB} = 15.3 + 37.6 \log_{10} R$ |
| Femtocell-femto UE different buildings | $PL_{dB} = \max(38.46 + 20 \log_{10} R, 15.3 + 37.6 \log_{10} R) + 0.7 d_{2D, indoor}$ |
| Penetration loss | 20dB |
| Macrocell parameters | |
| Maximum transmit power | 46dB _m |

| Maximum antenna gain | 14dB _i |
|------------------------|-------------------|
| Noise figure | 5dB |
| Femtocell parameters | |
| Maximum transmit power | 20dB _m |
| Maximum antenna gain | 0dB _i |
| Noise figure | 7dB |
| UE parameters | |
| Maximum transmit power | 23dB _m |
| Maximum antenna gain | 0 dB _i |
| Noise figure | 9dB |

To evaluate the proposed green handover method, we develop a simulation platform by the C programming language. System parameters are as shown in Table III [8][9][10]. The network size is $1300\sqrt{2} \times 1300\sqrt{2}$ with one macrocell in the center and $n_f \times n_f$ femtocells uniformly deployed. Each femtocell is initially active with probability P (with users connecting to it) and idle with probability $(1-P)$ (no user connection). The transmission power of the macrocell is 46dB_m, with that of the femtocells is 20dB_m. The macrocell supports six MCSs (QPSK1/2, QPSK3/4, 16QAM1/2, 16QAM3/4, 64QAM2/3, and 64QAM3/4), while the femtocells use 64QAM3/4 to communicate with UEs because of the short communication distance between UEs and femtocells. The power consumption of active and idle femtocells is 10.2W and 6W, respectively. The power consumption of 3G and LTE UEs is as shown in Table I. We simulate a group of N UEs moving in the network. For each UE, it always has data buffered in the network side destined to it. We compare our scheme to Ashraf [4][5] and Chen [6] with the following performance metrics: (1) total power consumption (in W·sec): the amount of total power consumption of the macrocell, N UEs and the extra energy spent by femtocells to serve the group of N UEs, (2) throughput (in MByte): the amount of total delivered data from macrocell/femtocells to the UEs, (3) energy efficiency (in bit/joule), (4) handover frequency, including handovers from macrocell to femtocell and femtocell to macrocell.

A. The Effect of P over 3G and 4G Networks

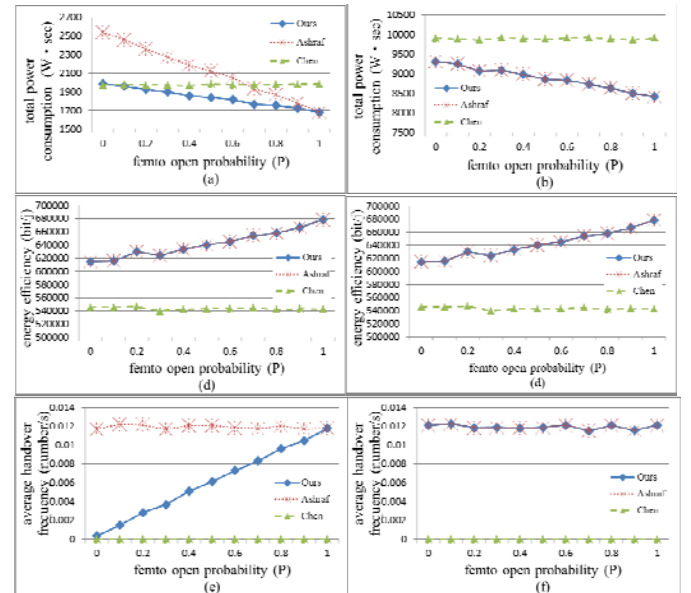


Fig.3. the effect of P on (a). total power consumption (4G). (b). total power consumption (3G). (c). energy efficiency (4G). (d). energy efficiency (3G). (e). average handover frequency (4G). (f). average handover frequency (3G).

Fig.3 shows the effect of femtocell open probability, P , on total power consumption, energy efficiency and average handover frequency over 3G and 4G networks. In the simulation, $N=5$, the moving speed of UEs is 1m/s and $n_f=10$. Fig.3 (a) and (b) show the impact of P on total power consumption over 4G and 3G networks, respectively. As we can see from the figures our method outperforms Ashraf and Chen. Ashraf always selects femtocells if active femtocells exist, while Chen always connects to the macrocell because we assume there is always data in the network for the UEs. Our proposed method intelligently selects an energy-saving way for UEs to deliver data. That is, if femtocells are more energy efficiency than the macrocell, then chooses femtocells; otherwise, choose macrocell. Ashraf performs better in 3G networks than 4G networks because for UEs, connecting to femtocells can save 1W power compared to connecting to macrocells, while the power saving is only 0.2W in 4G networks, i.e., choosing femtocells in 3G network is a smart strategy but it may not work in 4G networks. Fig.3 (c) and (d) show the impact of P on the energy efficiency over 4G and 3G networks, respectively. Again, our scheme performs better than Ashraf and Chen over both 4G and 3G networks. As P increase, both the energy efficiency of our scheme and Ashraf increase. This is because the femtocells consume less extra energy to serve the group of N UEs. Fig.3 (e) and (f) show the impact of P on the average handover frequency over 4G and 3G networks, respectively. Chen performs the best because it always chooses to connect to the macrocell. Ashraf performs the worst because it always chooses to connect to the femtocells if femtocells exist. The average handover frequency of our scheme increases as P increases in the 4G case. This is because the extra energy cost to access a femtocell decreases such that our scheme tends to use femtocells and the average handover frequency increases then.

B. The Effect of N

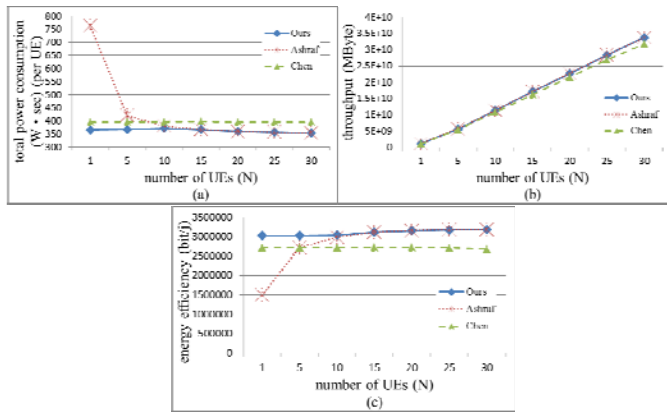


Fig.4. (a). total power consumption V.S. number of UEs (4G). (b). total transmission data V.S. number of UEs (4G). (c). energy efficiency V.S. number of UEs (4G)

Fig.4 (a) represents the effect of N on the total power consumption per UE over 4G networks. As we can see from the figure, our scheme performs the best. As N increases, the total power consumption per UE decreases for our method and Ashraf. This is because that more UEs share the extra power spent by the femtocells when N increases. Fig.4 (b) illustrates

the impact of N on the throughput over 4G networks. As we can see from the figure, the throughput increases when N rises. Our scheme shows slightly better throughput than the other two schemes. Fig.4 (c) shows the impact of N on the energy efficiency over 4G networks. For all the values of N , our scheme always performs the best. Overall, our scheme shows better energy efficiency, total power consumption and throughput than the other two schemes.

V. CONCLUSION

This paper designs a green handoff method for 4G OFDMA macrocell-femtocell heterogeneous networks. When there are no users connecting to femtocells, they turn off the transceivers and the related circuits and switch to idle mode to save power. Once an idle femtocell detects moving UEs, a green handoff method is executed to determine whether it shall wake up and allow the UEs to handover from macrocell to femtocell or not (for an active femtocell, it also has to decide whether to accept the UEs or not). Our method evaluates the energy efficiency of connecting to the macrocell and the femtocells and makes decision, accordingly. To design a general solution, the proposed method takes group mobility, path loss, MCSs and the type of networks into account. Simulation results show that our scheme outperforms previous works in energy efficiency, total power consumption and throughput regardless of 3G and 4G systems.

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