Journal of Computers Vol. 27, No. 4, 2016, pp. 69-84
doi:10.3966/199115592016122704006

Energy Efficient Dynamic Network Configuration in Two-Tier LTE/LTE-A Cellular Networks

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Received 20 April 2015; Revised 29 September 2015; Accepted 6 October 2016

Abstract. With the increasing demand of broadband wireless communication networks, users have an in-creasing need of the wireless broadband service coverage and the wireless access quality. To alleviate this problem, several novel techniques are proposed. One of these techniques is femtocells. A femtocell can be used to increase the coverage of wireless broadband service indoors or at hotspots and raise both data trans-mission 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 and optimize the energy efficiency of networks while still providing both the same data transmission rate and wireless broadband service coverage. In this work, considering path loss, modulation and coding schemes (MCSs), bit-error-rate (BER) 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) con-necting to it. A femtocell transits to active mode only when detecting UEs and the efficiency of using the femtocell 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 our method performs better than the previous methods in power consumption, energy efficiency and throughput in both 3G/4G wireless communication networks.

Keywords: energy-efficiency, femtocell, green communication networks, handover, heterogeneous networks, LTE/LTE-A, Orthogonal Frequency Division Multiple Access (OFDMA)

1 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 the net-work should be employed. Chen et al. and Han et al. [2-3] investigated the energy efficiency issue of wireless networks and proposed a "Green Radio" solution. In the solution, BSs can 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.

There are several works focusing on the handover issue over the long-term evolution (LTE) macrocell-femtocell heterogeneous networks. Ulvan et al. [4] and Zhang et al. [5] proposed novel handover mechanisms which make handover decisions based on the speeds of UEs and their Quality of Service (QoS). Three different mobile states were considered: low mobile state (0-15km/h), medium mobile state (15-

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30km/h), and high mobile state (>30km/h). In addition, for the real-time and non-real-time traffic, different strategies were adopted. The proposed methods were to reduce unnecessary handovers and the handover latency, but the energy consumption of femtocells was not considered. Since the transmission power of femtocells and macrocells are asymmetry, Moon et al. [6] proposed that the macrocells and femtocells shall be given different signal strength thresholds when determining whether to handoff from the macrocell to the femtocell or from the femtocell to the macrocell. However, it does not take the UE velocity into consideration. Wu et al. [7] proposed to consider both signal strength and the UE velocity in the handover algorithm. However, above studies do not take energy-saving issue into account.

Femtocells can be deployed indoors or at hotspot to increase wireless broadband service coverage and raise data access quality. However, when large number of femtocells exists, the total power consumption of femtocells will be tremendously large. Therefore, a well-designed power saving mechanism is needed. Currently, there are several research works [8-10] discussing the green energy issue over the macrocell-femtocell heter-ogeneous network. Ashraf et al. [8-9] 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, which is still not real power efficient. Chen et al. [10] propose a green handover protocol in two-tier OFDMA (Orthogonal Frequency Division Multiple Access) 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 energy efficient dynamic network configuration method for 4G OFDMA macrocell-femtocell heterogeneous networks. In the method, we take path loss, bit-error-rate (BER) and group mobility into consideration. To the best of our knowledge, this paper is the first one to consider these three factors in the energy efficient macrocell-femtocell heterogeneous network.

This paper considers a dynamic network configuration 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, leaving a femtocell always in active mode will increase unnecessary power consumption of the ne twork. Therefore, there exists a trade-off and the objective of this paper is to maximize the energy efficiency and reduce the total power consumption of the network including macrocells, femtocells and UEs. The contributions of this work are three folds. First, we propose a dynamic network configuration 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, BER and group mobility ([8-10] are a special case of group size equal to 1), 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.

2 System Model and Problem Definition

2.1 System model

The femtocell [11] is a low power, low cost, and user-deployed equipment. Compared to macrocells, the cover-age 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 transmis-sion 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 opera-tor's core network via DSL broadband backhaul. To save power, we propose that a femtocell will enter "idle mode" (see 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 (see Fig. 1 (3)).

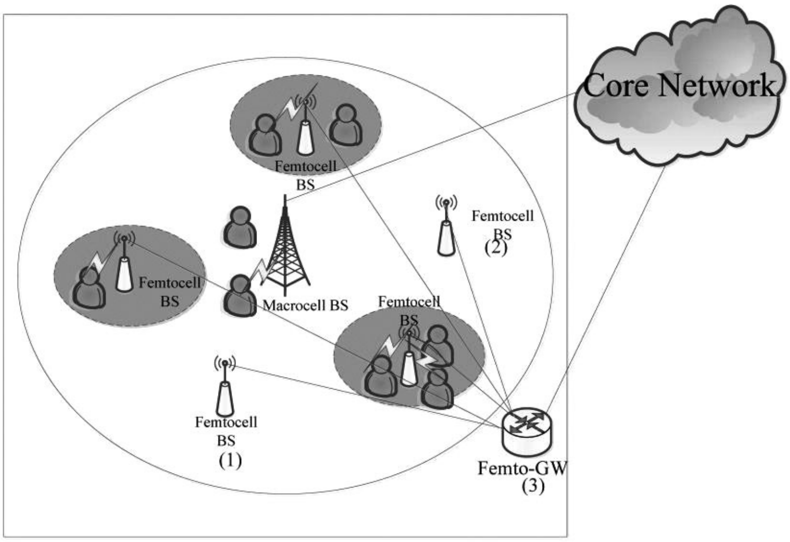


Fig. 1. Macrocell-femtocell heterogeneous network architecture

In heterogeneous networks, the femtocell has two spectrum allocation modes [10]: dedicated channel and co-channel modes as shown in Fig. 2 (a) and Fig. 2 (b), respectively. In the dedicated channel mode (Fig. 2 (a)), channels are divided into two parts. One part of the channels is only used by femtocells, the other part of channels is only used by macrocell. The advantage of the dedicated channel mode is the interference between macrocell and femtocells can be minimized, but this makes low spectrum efficiency. In the co-channel mode (Fig. 2 (b)), all free channels can be non-simultaneously shared by femtocells and macrocell (but still maintain a part of channels being only used by macrocell), the spectrum efficiency of the co-channel mode is better than that of the dedicated channel mode, but the potential interference between femtocells and macrocell increases. This paper assumes the co-channel mode for our designed method.

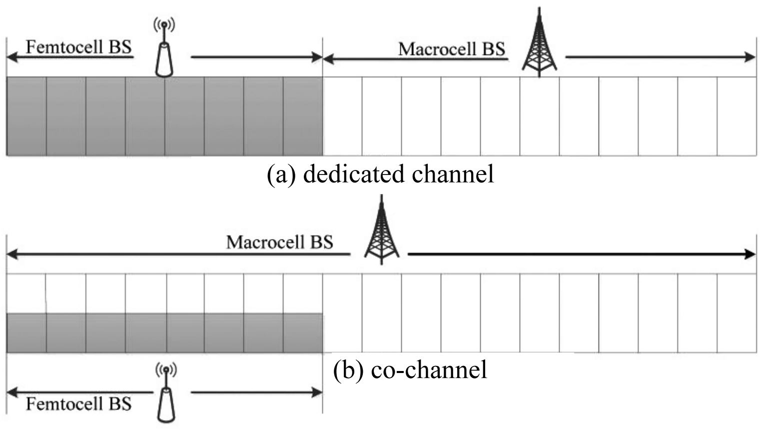
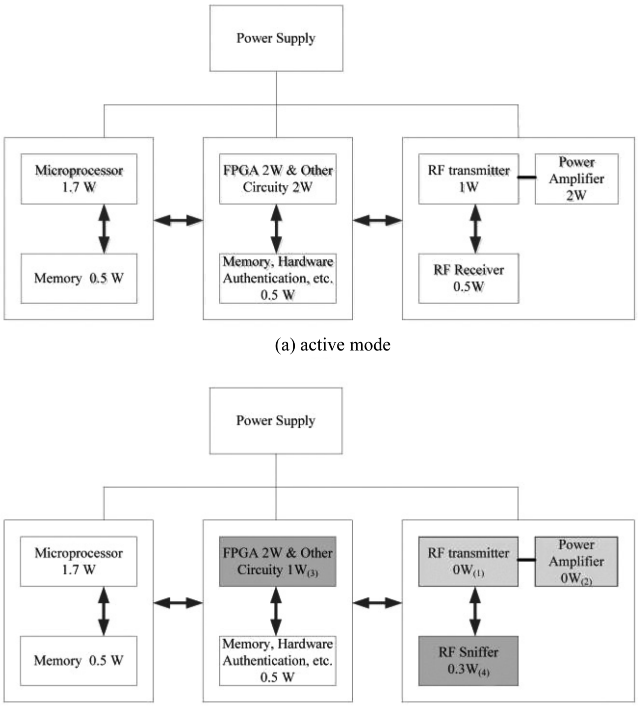


Fig. 2. Two spectrum assignment modes in heterogeneous networks

Fig. 3 (a) and (b) illustrate the power consumption of hardware modules of idle and active femtocells [10], re-spectively. The hardware modules are divided into three parts. The first part is random access memory compo-nents 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 (radio frequency) transceiver, including separate RF components for the packet transmission and reception, and the RF power amplifier (PA). Fig. 3 (a) shows the power consumption of each module when the femtocell is in the active mode and the total power consumption is 10.2W. On the other hand, Fig. 3 (b) shows the power consumption of each module when the femtocell switches to idle mode. Compared to the active femtocell, an idle femtocell can turn off its RF transceiver (Fig. 3 (b) (1)), power amplifier (Fig. 3 (b) (2)) and miscellaneous hardware



(a) idle mode

Fig. 3. Power consumption of femtocell hardware

components related to non-essential functionalities (Fig. 3 (b) (3)), such as data encryption and hard-ware authentication. Additionally, since femtocell is in idle mode, a radio sniffer ($P_{sniffer}$ = 0.3W) (Fig. 3 (b) (4)) module is switched on to measure the power of UE and macrocell. Totally, an idle femtocell consumes 6W power. The detail signaling flow of the handover procedure for the 4G macrocell-femtocell heterogeneous networks are given in Fig. 4 [5, 10], which are composed of three handover stages, including handover preparation, handover execution, and handover completion. Table 1 provides the power consumption of data transmission for the UE and the femtocell [10]. For an LTE UE and 3G UE, connecting to the macrocell spends 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. Hence 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. 3, a femtocell operating in active and idle modes spends 10.2W and 6W, rspectively. If a femtocell keeps staying in idle mode, the power saving is 4.2W.

Table 1. The power consumption for UE and femtocell

	Active	Idle	Power saving
femtocell	10.2 W	6 W	4.2 W

	Connect to macro-cell	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

LTE uses Channel Quality Indicators (*CQIs*) to report the current channel condition and each $CQI = k$, $k = 1 \ldots 15$, has its corresponding Modulation and Coding Scheme (*MCS*) (denoted by MCS ($CQI = k$)) and rate (denoted by *rate* ($CQI = k$), the unit is bits/TTI) [12]. Furthermore, for different CQI and different BER (ζ), it requires different Signal to Interference plus Noise Ratio (SINR). Fig. 5 shows the required SINR over different ζ for different *CQIs* [13]. With Fig. 5, we can get each UE *j*'s minimum required SINR, $\delta\left(CQI_i^j, \xi_j\right)$, accordingly, where ξ_j is *j*'s required BER and MCS(CQI_i^j) is the selected (or candidate) MCS between the communication pair, UE j and macrocell/femtocell *i*.

Assume the transmit power of node i is P_i, the received power of node *j*, $\widetilde{P}(i,j)$, can be written as

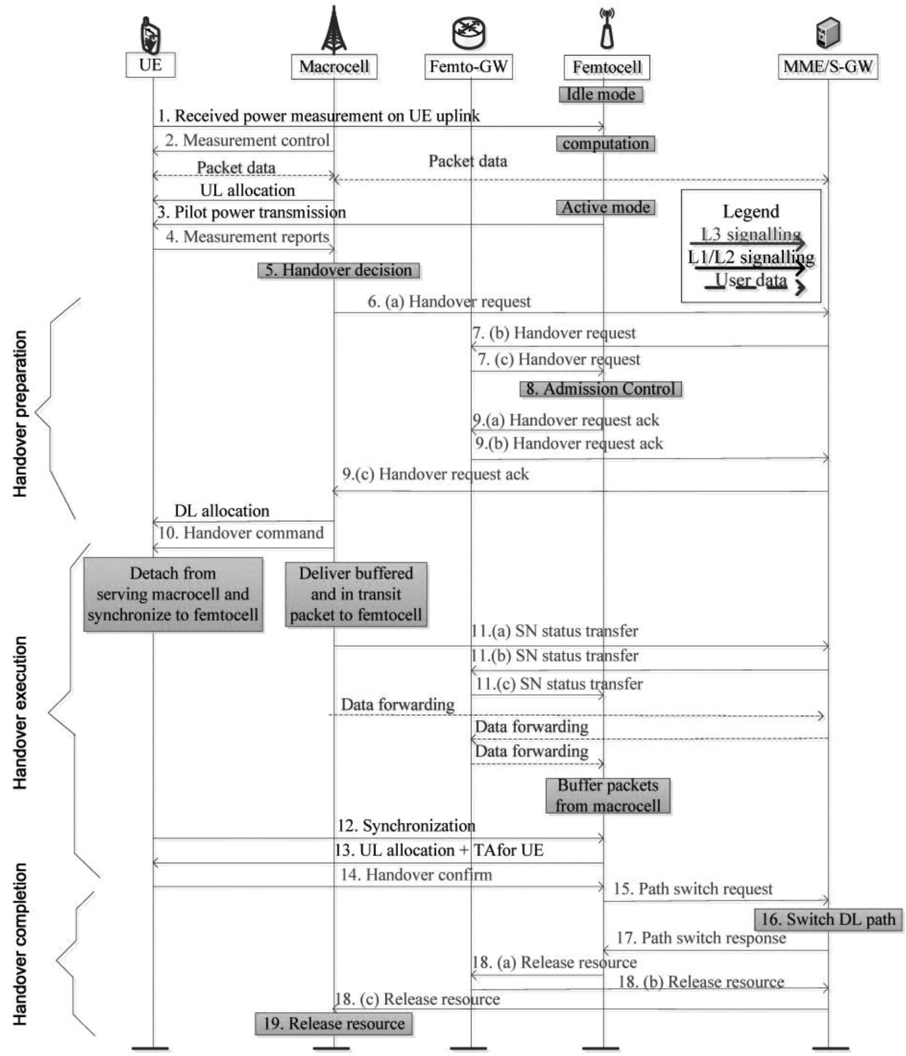


Fig. 4. The 4G handover signaling flow in macrocell-femtocell heterogeneous networks

$$\widetilde{P}(i,j) = \frac{G_i \times G_j \times P_i}{L_{i,j}} \quad \textbf{(1)}$$

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

$$\text{SINR}(i,j) = 10\log_{10}\frac{\widetilde{P}(i,j)}{B \times N_0 + I(i,j)} \quad \textbf{(2)}$$

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 $I_{i,j} = \sum_{l \neq i} \widetilde{P}(i,j)$. Note that $\text{SINR}(i,j) \geq \delta(CQI_i^j, \xi_j)$ must be guaranteed, where $\delta(CQI_i^j, \xi_j)$ is the required minimum SINR when CQI_i^j and ξ_j are applied by link (i,j).

2.2 Motivation and problem definition

Ashraf et al. [8-9] 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

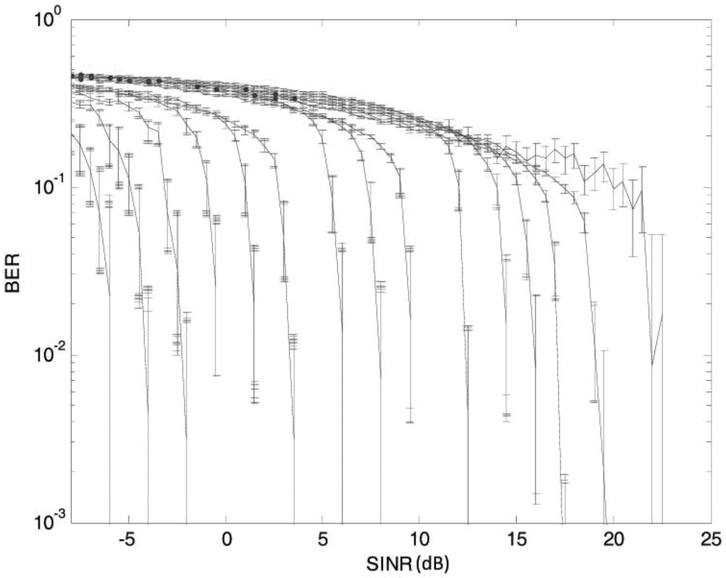


Fig. 5. BER for different *CQIs* (the 99% confidence intervals are depicted in red)

is required. On the other hand, Chen et al. [10] 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, BER and group mobility, which are omitted in previous work. The problem is stated as follows.

This paper aims to design an energy efficient dynamic network configuration method for 4G OFDMA macro-cell-femtocell heterogeneous networks and the assumptions are as below. (1) There is a group of *N* UEs moving in the radio access network, where $N \geq 1$. There are *M* femtocells; some are in idle mode (no user connection exists); the others are in active mode (there are UEs connecting to the femtocells). (2) For each UE j, j = 1, …, N, this paper considers path loss ($L_{i,j}$), different system types (3G/4G), required BER (ξ_j), maximum transmit power (P_{MAX}), and multiple MCSs (MCS (CQI_i^j = 1, …, 15), where CQI_i^j = 1, …, 15). The co-channel allocation mode is used, where all free channels are non-simultaneously shared by femtocells and macrocell. The problem is to determine (1) whether an idle femtocell shall wake up or not when a group of *N* UEs pass by or enter its coverage area and (2) whether the group of *N* UEs shall handover from macrocell to femtocell or not. The objective is to maximize the energy efficiency (E) of overall communication network and maintain both high throughput and low total power consumption.

3 Energy Efficient Dynamic Network Configuration Method

This section introduces our proposed scheme. Review that we assume a group of *N* UEs move together (where 1 $N \geq 1$). The whole field is covered by the macrocell and *M* femtocells. Each femtocell is initially open (active) with probability *P* or sleep (idle) with probability (1-*P*), where $0 \leq P \leq 1$. 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, j = 1…N, by R_{macro}^j (in bit/s) and R_{macro}^j (in bit/s) when connecting to the macrocell and femtocells, respectively, where R_{macro}^j and R_{femto}^j depend on the channel quality. R_{macro}^j can be obtained by the following equation:

$$R^j_{macro} = H_j \times 12 \times 7 \times F(MCS^i_j) \quad \textbf{(3)}$$

where H_j is the amount of "physical resource block" (PRB) per second reserved to UE *j* (note that each PRB is composed of 12 subcarriers $\times$ 7 symbols), MCS^j_k is UE *j*'s available highest channel rate MCS, and $F(MCS^j_k)$ represents the symbol data rate of MCS^j_k. The MCS^j_k that UE *j* can use, is able to be obtained by the following

$$\delta\left(CQI^j_i = (k+1), \xi_j\right) > SINR(i,j) \geq \delta\left(CQI^j_i = k, \xi_j\right) \quad \textbf{(4)}$$

where *SINR(i, j)* represents the SINR between UE *j* and the BS *i*, *SINR(i, j)* can be derived by Eq. (2), and $\delta\left(CQI^j_i = (k+1), \xi_j\right)$ and $\delta\left(CQI^j_i = k, \xi_j\right)$ are the required minimum SINRs of MCS^j_{k+1} and MCS^j_k respectively. So, $MCS^j_k = MCS_k$. 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, this is out of the scope of this paper and thus we do not discuss this here.

Since femtocells provide high data rate and good channel quality, we assume that UEs can use the most efficient MCS, when MCS_H connecting to femtocells, R^j_{femto} can be calculated as follows.

$$R^j_{femto} = H_j \times 12 \times 7 \times F(MCS_H) \quad \textbf{(5)}$$

When a group of UEs pass a femtocell, the femtocell will evaluate the energy efficiency to determine whether it shall allow the group of UEs to handover to it from the serving macrocells. If the femtocell is in idle mode, it will also decide whether to stay in idle mode or transit to active mode according to the evaluation. In the evaluation, we first conduct the energy efficiency of accessing the macrocell (E_{macro}) by the following equation:

$$E_{macro} = \frac{N \times R^j_{macro}}{N \times P^{UE}_{macro}} = \frac{R^j_{macro}}{P^{UE}_{macro}} \quad \textbf{(6)}$$

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:

$$E_{femto} = \begin{cases} \dfrac{N \times R^j_{femto}}{\left(P^{femto}_{active} - P^{femto}_{idle}\right) + N \times P^{UE}_{femto}}, & \textit{when initially idle} \\ \dfrac{N \times R^j_{femto}}{N \times P^{UE}_{femto}} = \dfrac{R^j_{femto}}{P^{UE}_{femto}}, & \textit{otherwise} \end{cases} \quad (7)$$

where $\left(P^{femto}_{active} - P^{femto}_{idle}\right)$ 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 energy instead of the macrocell; on the contrary, if $E_{femto} \leq E_{macro}$, handover to the femtocell is not worthy.

Based on this principle, our method is designed as follows.

(1) Once a femtocell 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.

(2) Evaluate the energy efficiency of accessing the macrocell and femtocell. If $E_{femto} > E_{macro}$, i.e., $\dfrac{N \times R^j_{femto}}{R^j_{macro}} > \dfrac{+\left(P^{femto}_{active} - P^{femto}_{idle}\right) N \times P^{UE}_{femto}}{P^{UE}_{macro}}$, 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.

(3) If $E_{femto} > E_{macro}$, i.e., $\frac{R^j_{femto}}{R^j_{macro}} > \frac{P^{UE}_{femto}}{P^{UE}_{macro}}$, the femtocell determines to allow the UE's handover requests and wait for their requests and go to Step 4; otherwise, i.e., $E_{femto} \le E_{macro}$, the femtocell decides to reject the UE's handover, thus the UEs will continue to stay in macrocell, and go back to step 1.

(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.

(5) The femtocell provides radio access service for the UEs.

(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.

Fig. 6 shows the flow charts of the proposed energy efficient dynamic network configuration method when the femtocell is initially in the idle mode.

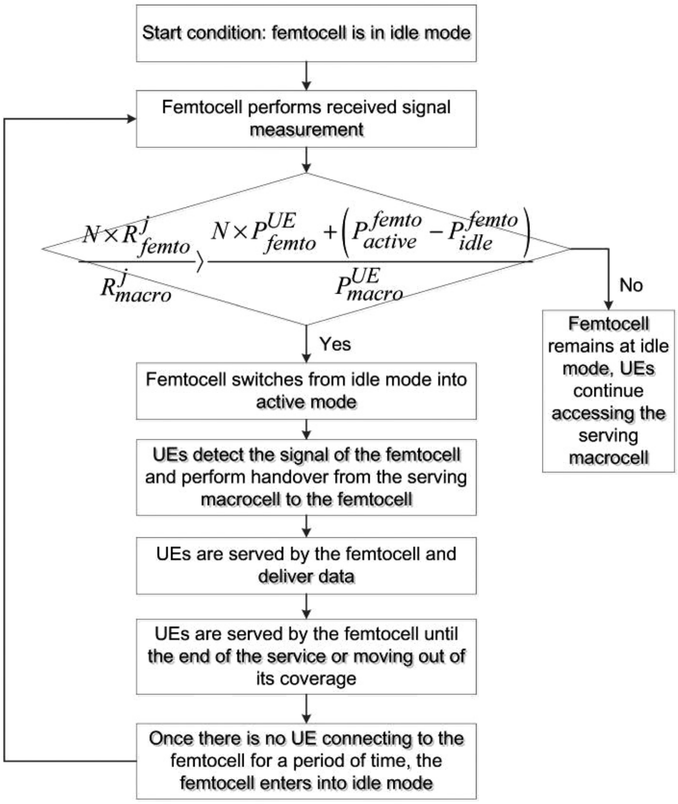


Fig. 6. The flow chart of the proposed algorithm for an idle femtocell

4 Simulation Results

To evaluate the proposed energy efficient dynamic network configuration method, we develop a simulation platform by the C programming language. System parameters are as shown in Table 2 [14-16]. The network size is $1300\sqrt{2}m \times 1300\sqrt{2}m$ with one macrocell in the center and $n_f \times n_f$ femtocells uniformly deployed. All femtocells connect to the core network through the femtocell gateway (F-GW) (Fig. 7 (3)). The transmission power of the macrocell and the femtocell is 46dBm and 20dBm, respectively. The macrocell supports six MCSs ($QPSK1/2$, $QPSK3/4$, $16QAM1/2$, $16QAM3/4$, $64QAM2/3$, and $64QAM3/4$), while the femtocells always use 64QAM3/4 to communicate with UEs because of the short communication distance between UEs and femtocells. Each femtocell is initially active with probability *P* (with users connecting to it, Fig. 7 (2)) and idle with proba-bility (1-*P*) (no user connection, Fig. 7 (1)). 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 1. We simulate a group of *N* UEs moving in the network. Each simulation result is derived by averaging 1000 experiments. We compare our scheme to Ashraf [8-9] and Chen [10] with the following performance metrics: (1) total amount of extra energy consumption (in $W \cdot$ sec): the total amount of energy consumption minus the fixed con sumption of ini-tially active femtocells, (2) throughput (in MByte): the amount of total delivered data from macrocell/femtocells to the UEs, (3) energy efficiency (in bit/joule): the amount of total delivered data from macrocell/femtocells to the UEs divided by the total amount of extra energy consumption, (4) handover frequency, including handovers from macrocell to femtocell and femtocell to macrocell. In the following, we will evaluate the performance of our proposed scheme, Ashraf and Chen under the saturated and non-saturated traffic conditions in the subsection 4.1 and 4.2.

Table 2. Simulation parameters

System parameters	
Network size	$1300\sqrt{2}m \times 1300\sqrt{2}m$
Macrocell support MCS	$QPSK1/2,\ QPSK3/4,\ 16QAM1/2,$ $16QAM3/4,\ 64QAM2/3,\ 64QAM3/4$
Femtocell coverage range	55.78 m
Mobility UEs (N)	1 – 10
Velocity of UEs	1m/s – 10m/s
Deployment Number of femtocell	$n_f \times n_f\ (n_f = 1-15)$
Thermal noise	-174dB$_m$/Hz
Path loss	
Macrocell-macro UE $PL_{db} = 15.3 + 37.6\log_{10} R$	
Femtocell-femto UE different buildings $PL_{db} = \max(38.46 + 20\log_{10} R, 15.3 + 37.6\log_{10} R) + 0.7d_{2D,indoor}$	
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	0dB$_i$
Noise figure	7dB

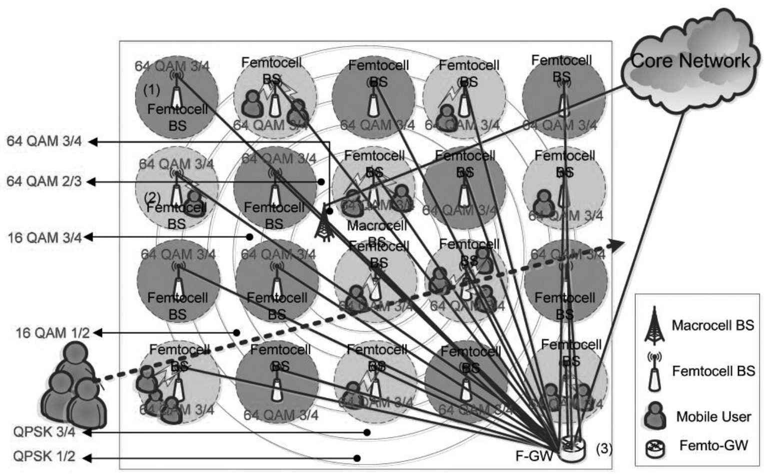


Fig. 7. The simulation environment

4.1 Performance evaluation under the saturated traffic condition

The Effect of *P*. Fig. 8, 9 and 10 show the effect of femtocell open probability, *P*, on total amount of extra energy consumption, energy efficiency and average handover frequency, respectively. In the simulation, we set $N = 5$, $n_f = 10$ and the moving speed of UEs is 1m/s. Fig. 8 (a) and (b) show the impact of *P* on total amount of extra energy 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 net-works than 4G networks. This is because for UEs, connecting to femtocells can save 1W power compared to connecting to macrocells in the 3G network, while the power saving is only 0.2W in the 4G network, i.e., choosing femtocells in 3G network is a smart strategy but it may not work in 4G networks. Fig. 9 (a) and (b) 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* increases, 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. 10 (a) and (b) 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 be-cause 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 de-creases such that our scheme tends to use femtocells and the average handover frequency increases then.

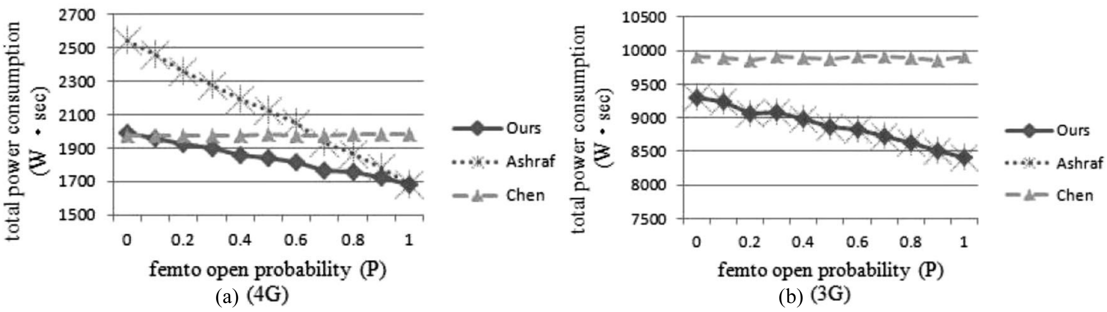


Fig. 8. The effect of *P* on extra energy consumption

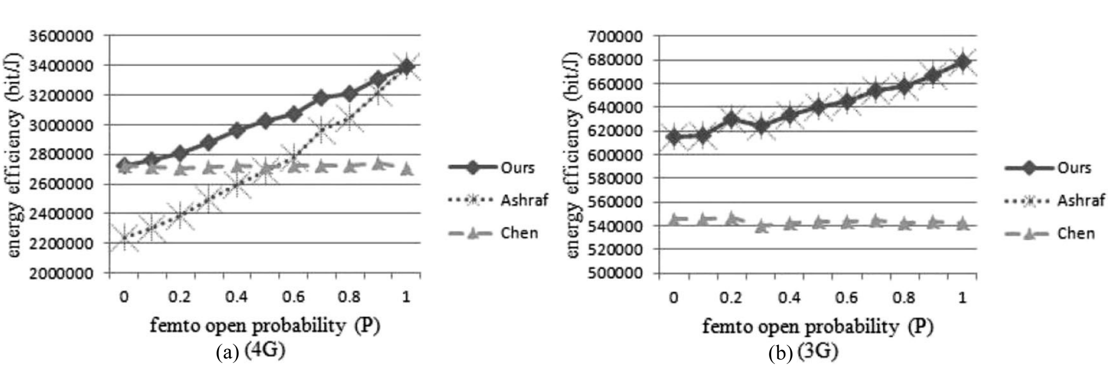


Fig. 9. The effect of *P* on energy efficiency

The effect of *N*. Fig. 11 represents the effect of *N* on the total amount of extra energy consumption per UE over 4G networks. As we can see from the figure, our scheme performs the best. As shown in Fig. 11 (a), when *N* increases, the total amount of extra energy consumption per UE decreases for our method and Ashraf. This is because that more UEs share the extra energy spent by the femtocells when *N* increases. Fig. 11 (b) illustrates the impact of *N* on the throughput over 4G networks. As we can see from the fi gure, the throughput increases when *N* rises. Our scheme shows slightly better throughput than the other two schemes. Fig. 11 (c) shows the impact of *N* on the energy efficiency over 4G networks. For all

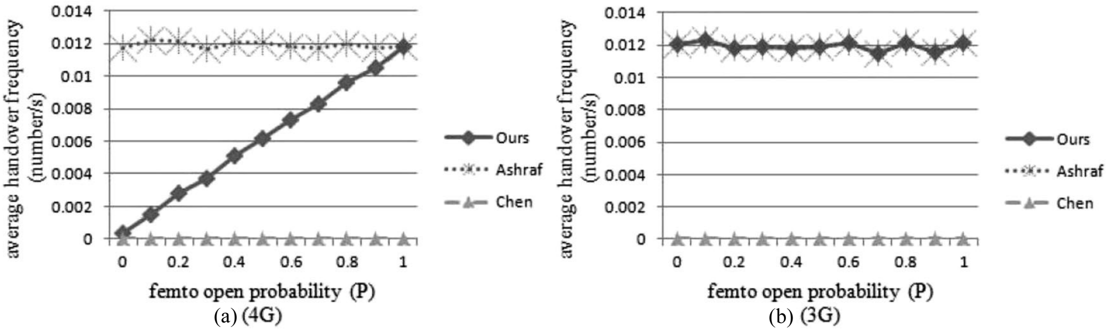


Fig. 10. The effect of *P* on average handover frequency

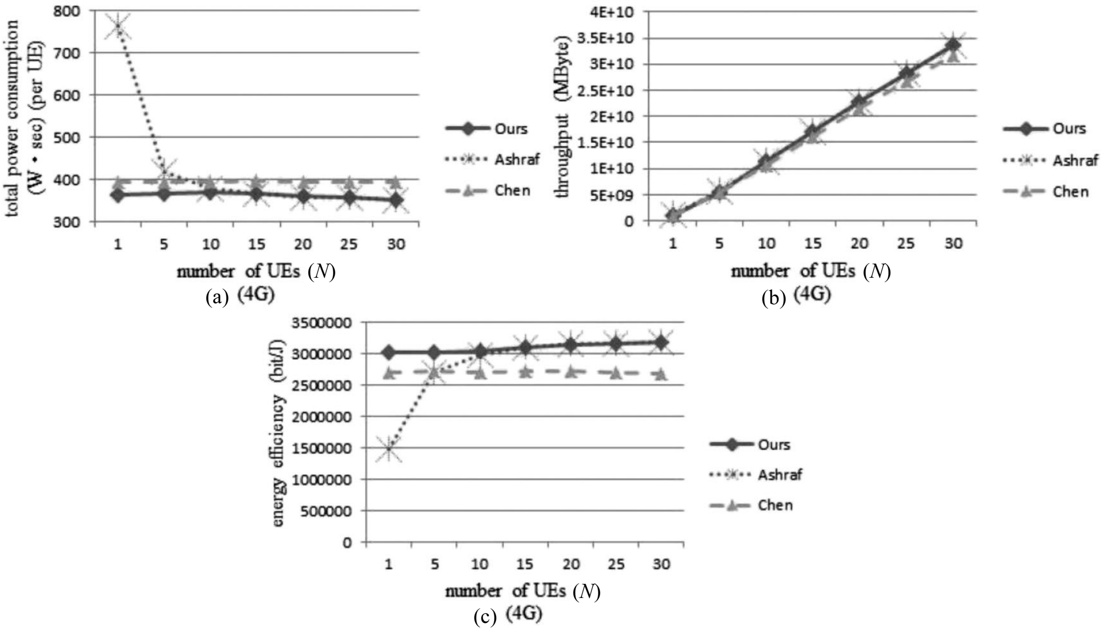
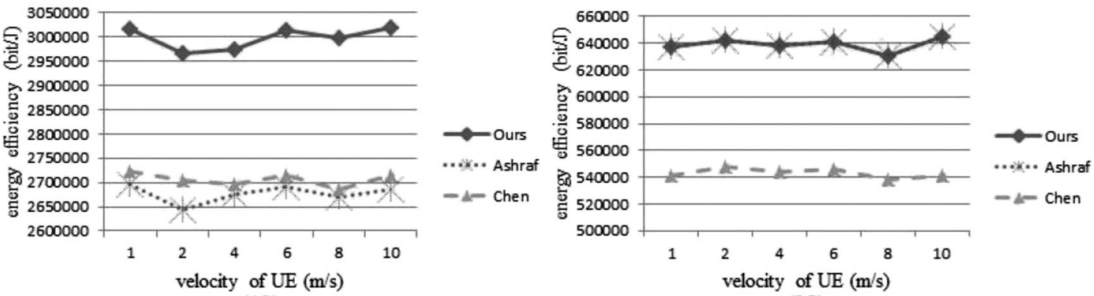


Fig. 11. The effect of *N* on (a) extra energy consumption, (b) throughput, and (c) energy efficiency over 4G networks

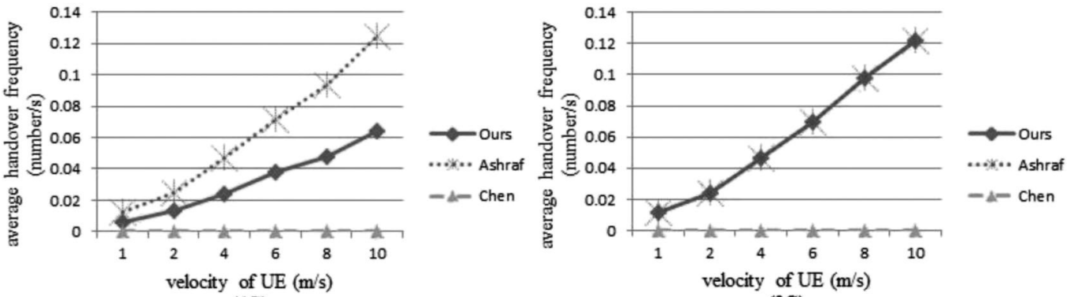
the values of *N*, our scheme always performs the best. Overall, our scheme shows better energy efficiency, total power consumption and throughput than the other two schemes.

The effect of the velocity of UE(s). Fig. 12 and 13 show the effect of UE velocity on energy efficiency and average handover frequency, respectively. As we can see from Fig. 12, our method outperforms Ashraf and Chen. Ashraf always selects femtocells if femtocells exist, while Chen always connects to the macrocell because of the saturated traffic condition. Our proposed method intelligently selects an energy-saving way for UEs to deliver data. That is, if femtocells are more energy efficient than the macrocell, then choose femtocells; otherwise, stay in the macrocell. Ashraf performs better in 3G networks than 4G networks because for UEs, connecting to femtocells can save 1W power compared to connecting to the macrocell, but the power saving is only 0.2W when connecting to femtocells instead of the macrocell in 4G networks. Fig. 13 (a) and (b) show the impact of UE velocity on the average handover frequency over 4G and 3G networks, respectively. As UE velo city increases, we can see that the handover frequency increases for our method and Ashraf, but our method performs better than Ashraf. This is because that our method does not always select femtocells when moving into the coverage of femtocells. Chen always connects to the macrocell so the handover frequency is 0. Our method performs poorer in 3G networks than 4G networks because for UEs, connecting to femtocells in 3G networks can save more power than that in 4G networks, thus increasing the number of handover events. When UE velocity increases, the average handover frequencies of our met hod and Ashraf both increase. The reason is that UEs spend less time in the network, but the average amount of handover events is the same.



(a) (4G) (b) (3G)

Fig. 12. The effect of UE velocity on energy efficiency



(a) (4G) (b) (3G)

Fig. 13. The effect of UE velocity on average handover frequency

4.2 Performance evaluation under the non-saturated traffic condition

The effect of *P*. Fig. 14 shows the effect of femtocell open probability, *P*, on normalized extra energy consump-tion, normalized energy efficiency and normalized average handover frequency over 4G net-works. In the simulation, we set $N = 5$, the moving speed of UEs is 1m/s and $n_f = 10$. Fig. 14 (a) shows that our method consumes less energy than both Ashraf and Chen. Ashraf and Chen always select femto-cells if active femtocells exist. Chen selects femtocells because under an unsaturated traffic condition, a UE can deliver all its buffered data if the residence time is long enough. Our proposed method intelli-gently selects an energy -saving way for UEs to deliver data. That is, if femtocells are more energy effi-ciency efficient than the macrocell, then choose femtocells; otherwise, choose to stay in the macrocell. Fig. 14 (b) shows the impact of *P* on the normalized energy efficiency over 4G networks. Again, our scheme performs better than Ashraf and Chen. Ashraf and Chen present the same results. This is because the femtocells consume less extra energy to serve the group of *N* UEs. Fig. 14 (c) shows the impact of *P* on the normalized average handover frequency over 4G networks. Our scheme performs better than Ash-raf and Chen. Ashraf and Chen perform the worst because they always choose to co n-nect to the femto-cells no matter the femtocells are originally idle or active if femtocells exist. So Ashraf and Chen get the same results. The average handover frequency of our scheme increases as *P* increases. This is be-cause the extra energy cost to access a femtocell decreases such that our scheme tends to use femtocells and thus increasing the average handover frequency.

The effect of femtocell numbers. Fig. 15 shows the effect of femtocell numbers on the normalized extra ener-gy consumption, normalized energy efficiency and normalized average handover frequency over 4G networks. In the simulation, we set $N = 5$, the moving speed of UEs is 1m/s and $P = 0.5$. Fig. 15 (a) shows the impact of n_f on the normalized extra energy consumption. When the number of deployed fem-tocells inc reases, we can see that our method improves more compared to Ashraf and Chen. Ashraf and Chen always select femtocells if femtocells exist. On the contrary, our proposed method intelligently selects an energy saving way for UEs to deliver data. That is, if femtocells are more energy efficient, then choose femtocells; otherwise, stay in the macrocell. Fig. 15 (b) shows the impact of n_f on the normalized energy efficiency. Again, our scheme performs better than Ashraf and Chen. This is because that an en-ergy efficient femtocell consumes less extra energy to serve the group of *N* UEs compared to the macro-cell, but an energy consuming femtocell wastes much power than the macrocell. Our method tends to access the former type of femtocells but skip the later one. On the other hand, Ashraf and Chen always

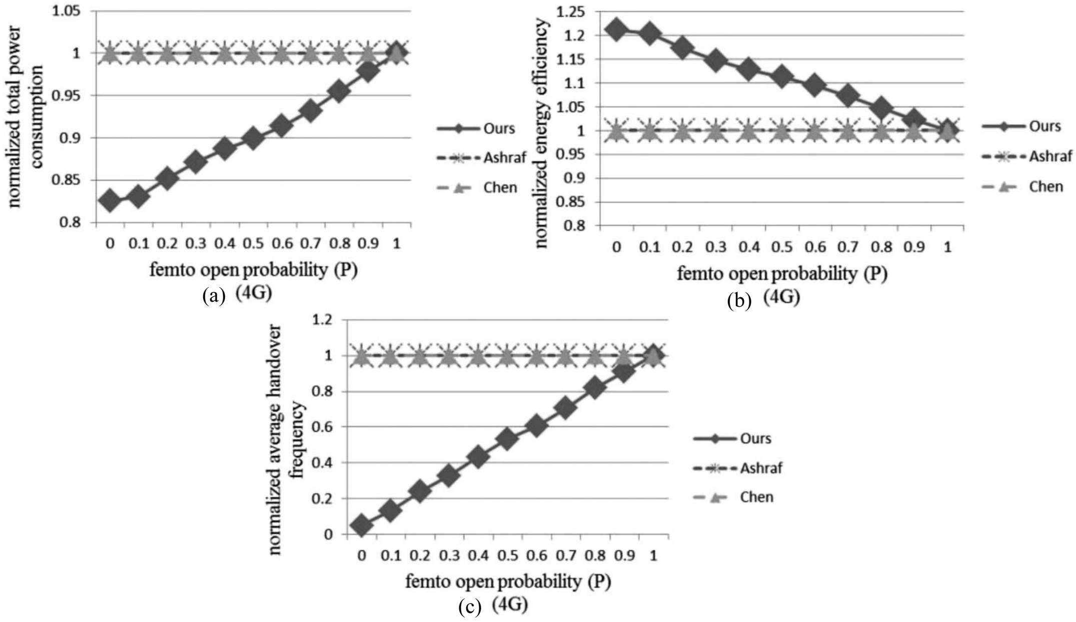


Fig. 14. The effect of P on (a) normalized extra energy consumption, (b) normalized energy efficiency, and (c) normalized average handover frequency over 4G networks

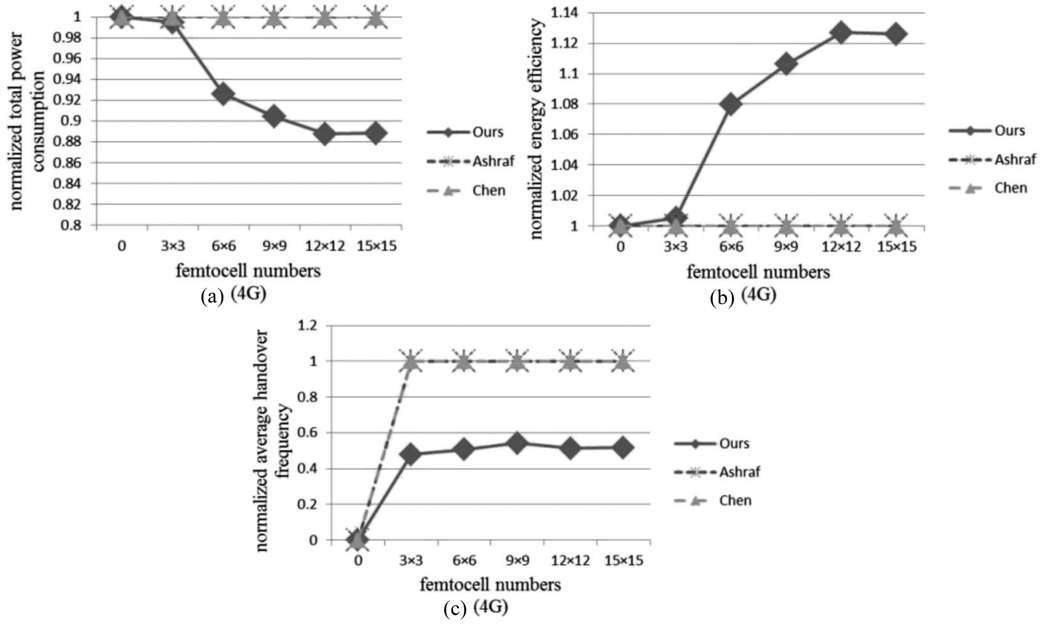


Fig. 15. The effect of femtocell numbers on (a) normalized extra energy consumption, (b) normalized energy efficiency, and (c) normalized average handover frequency over 4G networks

select femtocells no matter the femtocells are energy efficient or energy consuming ones. Fig. 15 (c) shows the impact of n_f on the normalized average handover frequency. Our scheme performs better than Ashraf and Chen. Ashraf and Chen perform worse than our scheme because they always choose to connect femtocells if femtocells exist. The handover frequency of our scheme increases as n_f increases. This is because the probability of encountering a femtocell increases and thus increasing the average handover frequency.

The effect of N**.** Fig. 16 (a) represents the effect of N on the normalized extra energy consumption over 4G networks. As we can see from the figure, our scheme performs the best. As N increases, the total extra energy consumption of our method performs closer to Ashraf and Chen. This is because that more UEs share the extra power spent by the femtocells, which switch from the idle to active modes when N increases. Fig. 16 (b) illustrates the impact of N on the normalized energy efficiency over 4G networks.

As we can see from the figure, when N increases, more UEs share the extra power spent by the femtocells to switch from the idle mode to the active mode. So, for a large N, UEs in our scheme tend to choose femtocells no matter the femtocells are originally idle or active and the performance of the three schemes becomes the same. Fig. 16 (c) shows the impact of N on the normalized average handover frequency over 4G networks. For all N, our scheme performs better than or equal to the other two schemes.

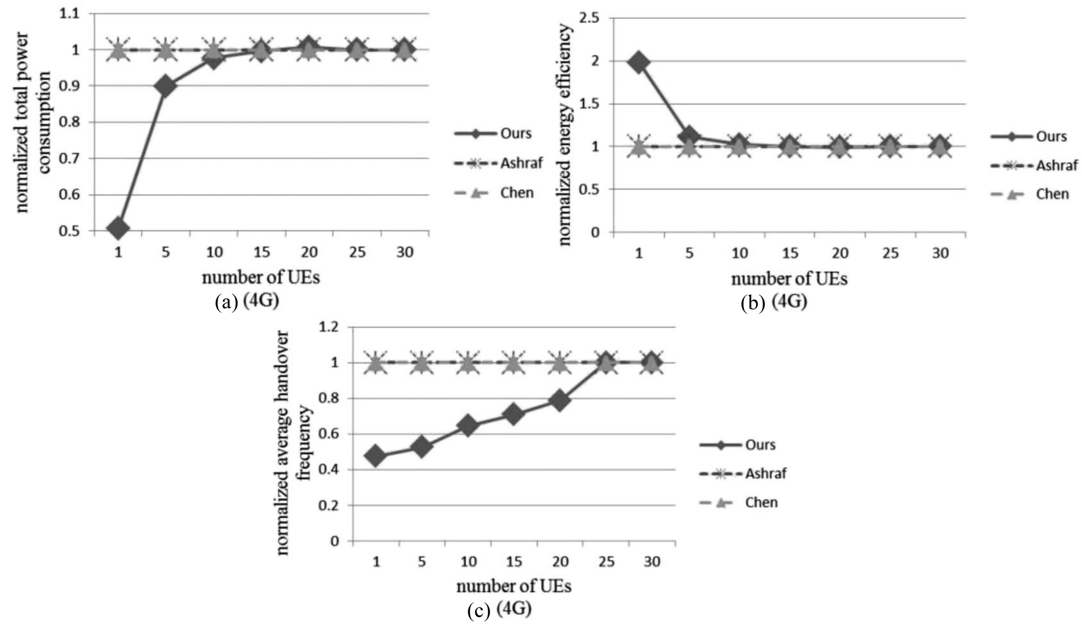


Fig. 16. The effect of N on (a) normalized extra energy consumption, (b) normalized energy efficiency, and (c) normalized average handover frequency over 4G networks

The effect of the velocity of UE(s). Fig. 17 shows the effect of UE velocity on the normalized extra energy consumption, normalized energy efficiency and normalized average handover frequency over 4G networks. In the simulation, N = 5, n_f = 10 and the femtocell open probability is P = 0.5. Fig. 17 (a) shows the impact of UE velocity on the normalized extra energy consumption over 4G networks. As we can see from the figure, our scheme performs the best. Fig. 17 (b) shows the impact of UE velocity on the normalized energy efficiency over 4G networks. As we can see from the figure, our method outperforms Ashraf and Chen. Ashraf and Chen always select femtocells if femtocells exist. On the contrary, our method intelligently selects an energy-saving way for UEs to deliver data. That is, if femtocells are more energy efficient than the macrocell, then choose femtocells; otherwise, stay in the macrocell. Fig. 17 (c) shows the impact of UE velocity on the normalized average hand over frequency over 4G networks. We can see that our method performs better than Ashraf and Chen.

5 Conclusion

In this paper, an energy efficient dynamic network configuration method is designed 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, the dynamic network configuration scheme 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, BER, maximum transmit power and the type of networks into account. In the performance evaluation, we test both saturated and non-saturated traffic conditions. Simulation results show that our scheme outperforms previous works in energy efficiency, total power consumption and throughput regardless of 3G and 4G systems.

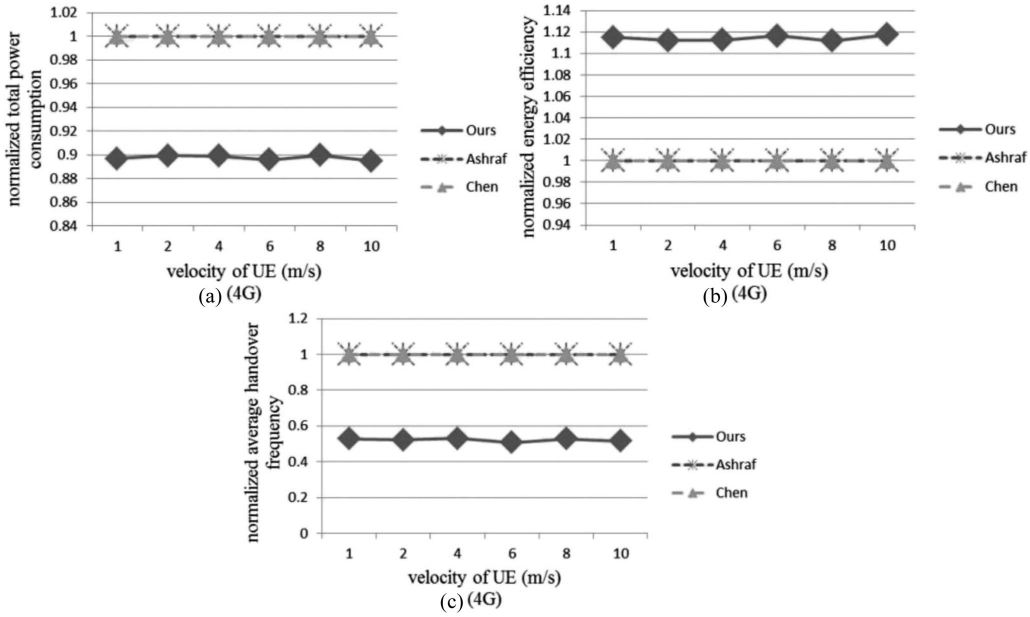


Fig. 17. The effect of the velocity of UE(s) on (a) normalized extra energy consumption, (b) normalized energy efficiency, and (c) normalized average handover frequency over 4G networks

Acknowledgement

This research is co-sponsored by MOST grants 103-2221-E-024-005- and 104-2221-E-024-005-.

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