A Green Handover Protocol in Two-Tier OFDMA Macrocell-Femtocell Networks

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Abstract—Femtocells are a promising technology to improve network performance with the short-range, low-power, and cost-beneficial small base stations. A femtocell is a low-power wireless access point that operates in licensed spectrum to connect standard device to operator’s network using a digital subscriber line (DSL) connection. Most of the energy consumption of the telecommunication networks is caused by the base stations. It is important to reduce the energy consumption of the base stations for the green ICT (information and communication technology). A two-tier orthogonal frequency-division multiple access (OFDMA) macro-femtocell network is a key issue to significantly reduce the total power consumption of the base stations. In this paper, we develop a green handover protocol in two-tier OFDMA macrocell-femtocell networks. The green handover protocol allows the femtocell base station to completely switch off its radio communication and associated processing when not involved in an active all. To improve the energy efficiency of femtocell base station, the proposed green handover protocol intelligently switches on its radio communication and associated processing, or called as “wake up” from the idle mode, if the remainder data of a mobile host can be completely uploaded through the wake-up femtocell base station. Finally, the mathematical analysis and the performance simulation illustrate that the proposed protocol provides a more power-saving result compared with existing energy-saving handover protocols.

Index Terms—Green handover; energy-saving; femtocell; OFDMA; two-tier cellular networks.
INTRODUCTION

Over 90% of the power in mobile communications is consumed in the radio access network [1]. For the green communication, the power consumption of the radio access networks, including the base stations, must be reduced. Informa Telecoms & Media [2] expects the femtocell market to experience significant growth over the next few years, reaching just under 49 million femtocell access points (FAP) in the market by 2014 and 114 million mobile users accessing mobile networks through femtocells during that year. Assumed that each femtocell requires a power cost of 12W, the total energy consumption of all deployed femtocells amount to \(3.784 \times 10^9\) kWh/annum. Energy efficiency of femtocells becomes an urgent issue. In general, the femtocells in active mode usually produce in the order of 2.05 million tones of \(\text{CO}_2\) per year. To reduce the impact of information and communication technologies (ICTs) on environment, efforts for the energy efficiency recently have received lots of attention, and appearing a new concept – “Green Radio”, which means reducing the \(\text{CO}_2\) emissions in ICTs. One useful way is provide energy efficient protocol to reduce the unnecessary power consumption of femtocells.

While the next-generation wireless technologies continue to evolve, mobile communications have also transformed from traditional voice services to IP-based services. The LTE-advanced has been developed to redefine the traditional physical-layer air interface to bring the high transmission rate. With the emerging technology; such as Orthogonal Frequency Division Multiple Access (OFDMA) [3], LTE-advanced is expected to improve end-user throughputs and network capacity with the full mobility. In the LTE-advanced system, the total spectrum is partitioned into several pieces of spectrum which is denoted as “resource block (RB)” or “tile”. This work can be achieved with the IP mobility support. Existing IP mobility works being achieved in the IETF are classified into "host-based mobility approach", e.g., Mobile IPv6 and its extensions [4] and "network-based mobility approach" e.g., Proxy Mobile IPv6, [5, 6, 7].

A femtocell [8] is a low power, low cost, and user-deployed cellular base stations (BSs) with a small coverage range (e.g. 30 ~ 40 meters in diameter). A large number of femtocells are deployed in the coverage area of macrocells. The main purpose is to increase the indoor coverage for voice and high speed data service. A femtocell works on the licensed band and connects to the operator core network via DSL broadband backhaul. Fig. 1 shows a hierarchical radio access network which is a two-tier macrocell/femtocell network. The macrocell base station refers to eNB or MBS and the femtocell base station refers to HeNB or FBS in the two-tier cellular networks. In Fig. 1, the dark circle represented a FBS is in the IDLE mode and the light circle denoted a FBS is in the ACTIVE mode. All FBSs or HeNBs connect to the core network through FBS-GW (femto base station gateway).

There are three access control strategies in a femtocell; open, closed, and hybrid access modes. In the open access mode, all user equipments (UEs) can access any femtocells. In the closed access mode, any UE which is not member of the closed subscriber group (CSG) would not get access to
the femtocell. In the hybrid access mode, part of the femtocell resources is operated in the open access, while the remaining femtocells follow the CSG access mode. The femtocell has two spectrum allocation modes; co-channel and dedicated channel modes [9], as shown in Fig. 2. In the dedicated channel mode, the free frequency bands are divided into two parts. One part of channels is solely used by the femtocells, and another part of channels is only used by the macrocell. The advantage of the dedicated channel mode is that the potential interference between macrocell and femtocells can be minimized. The low spectrum efficiency and reuse will be. In the co-channel mode, all free channels can be non-simultaneously shared by femtocells and macrocell. The spectrum efficiency of the co-channel channel mode is high. This paper assumes the co-channel channel mode for our protocol design.

In this paper, a new green handover protocol is designed in two-tier OFDMA macrocell-femtocell networks. The green handover protocol can intelligently switch on the radio communication and associated processing, or “wake up” from the IDLE mode, of femtocell. The smart decision of “wake up” operation is based on the remainder data of a mobile host can be completely uploaded through the wake-up FBS.

The rest of this paper is organized as follows. Section 2 describes the related works and motivation. In section 3, the system model, problem formulation, and basic idea are described. Section 4 describes the proposed green handover protocol in OFDMA two-tier macrocell-femtocell networks. Simulation results are presented in section 5. Section 6 concludes this paper.

2 RELATED WORK

This section describes related works and motivation in subsection 2.1 and the problem formulation in subsection 2.2.

2.1 Related Work

The deployment of femtocells benefits both users and service providers. Subscribers accessing femtocells can achieve greater signal strength and better quality of service because of the short transmit-receive distance. The mobility managements [10, 11, 12], needed to be carefully addressed and investigated.

Existing results of the mobility management had been widely developed in OFDMA two-tier macrocell-femtocell networks [13, 14, 15, 16]. Table I gives four handover protocols without the power saving consideration [13, 14, 15, 16] and two handover protocols [18, 19], including our developed protocol, with the power saving consideration. First, Moon et al. [13] introduced a RSS-based handover decision protocol in hierarchical macro/femto-cell networks. The main idea is to combine the value of the received signal strength from a serving MBS and a target FBS with the consideration of the large asymmetry in their transmit powers. Not only considers the SNR, some other results further
considers the UE speed for handover protocol designs [14, 15, 16]. Wu et al. [14] proposed a handover algorithm in the two-hierarchy network by considering both of signal strength and velocity. Ulvan et al. [15] and Zhang et al. [16] recently proposed new handover algorithms in LTE-based femtocell networks based on the speed of UE and Quality of Service (QoS). Three different velocity environments have been considered in the algorithms, i.e. low mobile state (0-15 km/h), medium mobile state (15-30 km/h) and high mobile state (>30 km/h). In addition, the real-time and non-real-time traffics have been considered as QoS parameters. The main purpose of above mentioned algorithms is to achieve the seamless handover and reduce the handover latency. These algorithms consider signal-to-noise ratio (SNR) and velocity for designing the handover protocol, the power consumption of femtocell is not taken into account. However, these mobility protocols are not the power-saving solutions.

Cell power consumption issues are recently raised more attentions [17, 18, 19]. The 3GPP TS 36.927 (release 10) [17] defines potential solutions for energy saving for E-UTRAN, which indicates that the cell can be totally switched off during the energy saving (ES) procedure. The ES procedure may be triggered in case of the light traffic or no traffic. Since there are thousands of femtocells within a macrocell area, the femtocell deployments may increase energy consumption except for the case of low femtocell/user densities and the use of femtocells with “idle” mode. Ashraf et al. [18, 19] recently proposed an improving energy efficiency of femtocell base station via user activity detection. The proposed energy-saving procedure allows the femto BS to completely switch off its radio transmissions and associated processing when not involved in an active call. From our point of view, this method is not really power-efficient of the femtocell power consumption. This is because that when the signal power of a UE is just bigger than a threshold value if the UE approaches to the coverage of femtocell, the femto base station is waked up to performs the handover procedure. It may causes the femtocell frequently switches between “wake up” and “sleep”. In addition, a dense two-tier macrocell-femtocell network is considered, implies that thousands of femtocell is deployed within a fixed macrocell area. In such scenario, the pilot signal of femtocell can radiate outside the premises, and hence provide undesired external coverage, moving UEs face up to the continual handovers when they pass along buildings. A frequent handover of UE suffers the increased signaling cost and low system performance. Therefore, it is important to design a new green handover by avoiding the undesired handover to reduce the unnecessary power consumption.

2.2 Motivation

The motivation of this work is stated as follows. Fig. 3 illustrates a drawback of Ashraf protocol [18, 19]. Ashraf et al. [18, 19] provided a dynamic energy-efficient solution to the power consumption of femtocell. However, it may possibly produce an undesired handover problem as follows. A FBS must be wake up from the “idle” state, only if the received signal strength of a moving UE from the FBS exceeds a predetermined threshold. We observed that if a moving UE cannot completely transmit all of the remainder data through the “wake-up” FBS, then the total power consumption may
be higher than that of the FBS under the FBS is not “wake up”. For the more power-saving purpose, efforts will be done to intelligently make the decision of wake-up and handover.

Table II provides the fact that the power consumption of data transmission between femtocell and UE [18, 19]. The LTE UE and GSM UE connecting to macrocell spend about 0.2 W and 2 W, but LTE UE and GSM UE connecting to femtocell spend about 0.0001 mW and 3.2 mW. The extra power consumption of LTE UE and GSM UE are about 0.2 W and 1.9968 W if UE is adopted the MBS for the data transmission. The femtocell operating in the ACTIVE mode spends 10.2 W and operating in the IDLE mode spends 4.2 W. If LTE UE communicates with macrocell and femtocell keeps the IDLE mode, then the power-saving is equal to 4.2 W = 10.2 W = 6 W. In such situation, it is more power-saving since 4.2 W > 0.2 W and 1.9968 W. That is to say, if we try to keep the femtocell at the IDLE mode as possible, the more power-saving will be.

To overcome the mentioned drawback, a new green handover procedure is developed to minimize the power consumption of FBS and the handover cost. The objective of the paper is: (1) the overall system power consumption of the two-tier macrocell-femtocell network, is minimized by intelligently switching on/off its radio communication and associated processing, which aims to keep the femtocell at the IDLE mode as far as possible, (2) a handover decision protocol is designed to reduce the handover number and the signaling cost during the UE mobility.

3 PRELIMINARIES

This section describes the system model, problem formulation, and basic idea in subsections 3.1, 3.2, and 3.3.

3.1 System Model

The system model of a two-tier OFDMA macrocell-femtocell network is illustrated in Fig. 4. A large number of femtocells are deployed in the coverage area of macrocells. Let $MBS_i$ denote any one of macro base stations, where $1 \leq i \leq M$, and $M$ is the maximum number of macro base stations of the coverage area of macrocells. Given $MBS_i$, let $FBS_j$ denote as one femto base station, where $1 \leq j \leq N$, where $N$ is the total number of femtocells within the coverage area of $MBS_i$. Both $MBS_i$ and $FBS_j$ adopt OFDMA technology under the co-channel model [9] to share all spectrum bands. The $MBS_i$ connects to the core network through MME$_i$/S-GW$_i$ (Mobility Management Entity/Serving Gateway) or ASN/GW$_i$ (Access Service Network/Gateway) for LTE/LTE-advanced or WiMAX networks. The $FBS_j$ connects to core node through F-GW (femtocell-Gateway).

For example as shown in Fig. 4, $FBS_5$ and $FBS_6$ share the spectrum bands of $MBS_1$, and $FBS_7$ and $FBS_8$ share the spectrum bands of $MBS_2$. In addition, $FBS_1$, $FBS_2$, $FBS_3$, and $FBS_4$, are deployed in the overlap area of $MBS_1$ and $MBS_2$. Dark and light circles denote the
IDLE FBS and ACTIVE FBS, where a FBS is called as an IDLE FBS if the FBS is in the IDLE mode, and a FBS is called as an ACTIVE FBS if the FBS is in the ACTIVE mode. Each FBS has a small signal coverage (e.g. 30~40 meters in diameter) determined by the maximum transmit power of the base station. An ACTIVE FBS may have multiple connected UEs. We follow the model of [18, 19]. An IDLE FBS allows the FBS to switch off all pilot transmissions and the processing associated with the wireless reception, when no user is involved in an active call. Due to the two-tier macro-cell-femtcell network model is considered, the underlay macrocell coverage is required for enabling the IDLE mode procedure since it relies on detecting transmission from a UE to a macrocell. If there is an idle UE within FBS in the two-tier macrocell-femtcell network, the synchronization of idle UEs is still guaranteed by the macro BS.

Fig. 5 illustrates the power consumption of hardware modules of IDLE FBS and ACTIVE FBS. We follow the same model of [18, 19]. All of the hardware modules are divided into three parts. The first part is random access memory components connected to the microprocessor required for data handling functions. The second part is a field-programmable gate array (FPGA) and integrated circuitry to implement 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. A RF power amplifier (PA) is also needed to pass a high-power signal to the transmitting antenna. Fig. 5(a) shows the power consumption for all components of ACTIVE FBS and Fig. 5(b) shows the power consumption of IDLE FBS. The two modes are only different in the power consumption of all modules. When switching to IDLE mode, a FBS switches off the PA, RF transmitter, RF receiver, and miscellaneous hardware components related to non-essential functionalities, such as data encryption, hardware authentication. Followed the power consumption of the chipset [17, 25], a radio sniffer ($P_{\text{sniffer}} = 0.3$ W) function is switched on to received power measurement of MBS and UE. The power consumption of ACTIVE FBS is about 10.2 W. The power consumption of IDLE FBS is 6 W. When a FBS switching from ACTIVE to IDLE mode, the power saving is about 4.5 W.

3.2 Problem Formulation

The problem of designing a green handover protocol in two-tier OFDMA macrocell-femtocell networks is formally described as follows: (1) A UE is moving from $MBS_i$ to $MBS_{k+1}$, the UE passes through many FBSs. Assumed that the UE enters the coverage of an IDLE $FBS_j$, the UE detects the pilot power of the IDLE $FBS_j$ is larger than that of the serving $MBS_i$, a smart handover procedure is initiated to make a decision to wake up the $FBS_j$ from IDLE to ACTIVE modes or not, to avoid the undesired “wake up” and handover process. (2) The heavy handover signaling costs cause the system burden due to the occurring the undesired handovers. This problem is considered in our protocol. (3) The total power consumption is high if IDLE $FBS_j$ makes the wrong decision of “wake up” and handover. This smart decision is based on estimated values of $t_{\text{dwell}}$ and $t_{\text{expected}}$, where $t_{\text{dwell}}$ is the dwell time of a UE of keeping the communication with $FBS_j$, where
the UE is in the coverage of $FBS_j$ and $t_{\text{expected}}$ is the expected transmission time of data of the UE. If a UE cannot completely transmit all of the data within the $t_{\text{dwell}}$, then IDLE $FBS_j$ should not become as ACTIVE $FBS_j$ and cannot handover from $MBS_i$ to $FBS_j$.

3.3 Basic Idea

Before describing the basic idea, some notations are defined as follows. As mentioned before, an energy-saving handover is developed based on the estimated values of $t_{\text{dwell}}$ and $t_{\text{expected}}$.

**Definition 1.** $t_{\text{dwell}}$ (dwell time). Given an UE and a FBS, let $t_{\text{dwell}}$ denote as the time period from the UE starting to communicate with the FBS to the UE stopping to communicate with the FBS, where the UE is in the coverage of the FBS. The UE may communicate with a corresponding node (CN) through FBS, within the $t_{\text{dwell}}$.

**Definition 2.** $t_{\text{expected}}$ (average expected transmission time). Let $t_{\text{expected}}$ denote as the expected transmission time between the UE and the FBS, where $t_{\text{expected}}$ is equal to the remainder data of the UE divided the average transmission rate between the UE and the FBS, within $t_{\text{dwell}}$.

**Definition 3. Green handover.** A handover is called as a green handover if the handover is an energy-saving handover with the minimized power consumptions of base station and the UE during the handover period. The base station switches off its hardware modules for the power-saving if no active user is resident in the coverage of base station.

The basic idea of the green handover is to keep the FBS at the IDLE mode as far as possible. To achieve the purpose, $t_{\text{dwell}}$ and $t_{\text{expected}}$ are needed to be calculated as illustrated in Fig. 6. It is observed that a FBS switches from IDLE mode into ACTIVE mode only if $t_{\text{expected}} < t_{\text{dwell}}$. But if $t_{\text{expected}} \geq t_{\text{dwell}}$, then the FBS should not be wake up from the IDLE mode, and the UE still connects with the MBS and do not perform the handover procedure.

To state the basic idea of our protocol, and the key difference of our protocol with Ashraf protocol [18, 19] are compared in Fig. 3. Fig. 3(a) illustrates Ashraf protocol [18, 19] by introducing the IDLE mode to the normal femtocell operation to disable the pilot transmissions and the associated radio processing if there is no active call. When a UE located inside the coverage range of the FBS, and the UE already makes a call to the MBS, FBS sniffs a rise in the received power on the uplink frequency band. If the received signal strength from UE of a FBS exceeds a predetermined threshold, then a wake-up and handover operations of the FBS are performed. By the experience, it is difficult to determine optimal threshold value.

Fig. 3(b) illustrates the basic idea of our proposed scheme by an example. When a UE moves from left to right, the UE passes through two FBSs; $FBS_1$ and $FBS_2$. When the UE enters the coverage of $FBS_1$, the uplink signal power of the UE is received by $FBS_1$. The $FBS_1$ constructs the free
spectrum bands, denoted as $FBS_{\text{available}}$, by sending a request to/from neighbor FBSs and serving MBS. The $FBS_1$ calculates times of $t_{\text{dwell}}$ and $t_{\text{expected}}$ to estimate the required bandwidth which can completely transmit the reminder data through $FBS_1$ within the $t_{\text{dwell}}$, which is denoted as $t_{\text{request}}^{\text{UE}}$. If $t_{\text{available}}^{FBS_1} \geq t_{\text{request}}^{\text{UE}}$, $FBS_1$ is wake-up to perform the handover operation from serving MBS to $FBS_1$. If $t_{\text{available}}^{FBS_1} < t_{\text{request}}^{\text{UE}}$, then the $FBS_1$ is not wake-up, and the UE still transmit the reminder data through the serving MBS. Our scheme provides a more accurately wake-up decision scheme to reduce the times of un-necessary wake-up and handover operations to reduce the total power consumptions. It is observed that if the UE continually enters the coverage of $FBS_2$, then $FBS_1$ must re-enter the IDLE mode. It surely takes more power consumption to wake up the $FBS_1$ and perform the handover operation from MBS to $FBS_1$ if the data transmission cannot be completely done through $FBS_1$. The aims of this work is to provide an accurately wake-up decision scheme to reduce the times of un-necessary wake-up and handover operations to reduce the total power consumptions.

The main contribution of this paper is to achieve energy saving for the overall radio access network by keeping the femtocell at IDLE mode as far as possible. In the two-tier OFDMA macro-cell-femtocell network, a large number of FBSs are deployed in the MBS networks but some FBSs are no needed to be switch on. The total number of handovers and the power consumption can be significantly reduced if we intelligently keep possible FBSs in the IDLE mode. The main work is to develop a new green handover protocol to intelligently keep FBSs in the IDLE mode to significantly improve the total number of handovers and the power consumption.

4 A GREEN HANOVER PROTOCOL

We first give an overview of our green handover protocol in OFDMA two-tier macro-cell-femtocell networks. The main function of the green handover protocol is to make an intelligent decision of accurately wake-up the FBS from IDLE mode into ACTIVE mode at the right time and at the right place. This is mainly based on the prediction of the dwell time $t_{\text{dwell}}$ and average expected transmission time $t_{\text{expected}}$ of the UE. The detailed flow chart of the green handover protocol is firstly shown in Fig. 7. The developed protocol consists of three phases: free spectrum configuration, transmission time estimation, and green handover decision phases, which are described below.

1. **Free spectrum configuration** phase: This phase is to identify a configuration of the free spectrum band for a $FBS_j$, assumed that the $FBS_j$ is considered to be switched from IDLE mode into ACTIVE mode, and $FBS_j$ is located at the overlapped area between $MBS_i$ and $MBS_{i+1}$, where $MBS_i$ is serving MBS and $MBS_{i+1}$ is the next MBS. By using the co-channel channel mode [9], the $FBS_j$ can access all free spectrum bands of $MBS_i$ or $MBS_{i+1}$, but cannot simultaneously use the same frequency band due to avoiding the interference problem. In addition, the $FBS_j$ also cannot simultaneously use the same frequency band of all neighboring $FBS_j$. This phase identify the free and useful spectrum bands by excluding
all used spectrum bands of \( MBS_i \) (or \( MBS_{i+1} \)), and all neighboring \( FBS_j \). It is observed that our work also can be successfully applied that the \( FBS_j \) is not located at overlapped area between \( MBS_i \) and \( MBS_{i+1} \). By the co-channel channel mode [9], all the spectrum bands of \( MBS_i \) and \( MBS_{i+1} \) are different, therefore we just need to consider to avoid the used spectrum bands of \( MBS_i \) or \( MBS_{i+1} \).

2. Transmission time estimation phase: The task of the phase is to calculate the dwell time \( t_{dwell} \) and average expected transmission time \( t_{expected} \) by \( FBS_j \) before the UE performing a wake-up decision and a handover procedure from \( MBS_i \) to \( FBS_j \).

3. Green Handover decision phase: The phase makes a wake-up and handover decision based on the dwell time \( t_{dwell} \) and average expected transmission time \( t_{expected} \). The simple concept for the green handover decision is check if the remainder data of UE can completely transmitted by \( FBS_j \) (i.e., \( t_{expected} \leq t_{dwell} \)), then \( FBS_j \) should be wake-up from the IDLE mode and enters the ACTIVE mode to perform the handover procedure for the inbound mobility (mobility from macrocell to femtocell).

The detailed operations of the free spectrum configuration, transmission time estimation, and the green handover decision phases are described as follows.

4.1 Phase I: Free Spectrum Configuration

This paper inherits existing resource sharing result from [20, 21, 22], which is stated as follows. Initially, the FBS choses the spectrum band of a MBS under the co-channel model. The MBS allocates its spectrum resources to MBS UEs and FBSs, and then the FBS re-allocates its allocated spectrum resources to FBS UEs. The spectrum band means the available bandwidth which can be access by UEs. The \( FBS_j \) cannot simultaneously connect to another FBS GW and another MME. This phase is to identify the free spectrum for IDLE \( FBS_j \). Let \( G \) denote as the set of spectrum sharing group, let \( MBS_i, 1 \leq i \leq m \) denote as the \( i \)-th MBS, let \( FBS_{j'}^{o}, 1 \leq i' \leq n \) denote as the neighboring FBSs of \( j \)-th FBS.

Let \( S_{MBS_i} = \{T_1, T_2, \ldots, T_{\beta}\} \) denote as the set of the original unused spectrum bands of \( MBS_i \), and let \( SB_{MBS_i} = \{o_1, o_2, \ldots, o_i, \ldots, o_{2}\} | o_i \in S_{MBS_i}, z \leq \beta \} \) denote as the set of occupied sub-bands by \( MBS_i, 1 \leq i \leq m \). Let \( SB_{FBS_j} = \{o_{1}', o_{2}', \ldots, o_i', \ldots, o_{z'} \} | o_{i}' \in S_{MBS_i}, z' \leq \beta \} \) denote as the set of occupied sub-band by \( FBS_{j'}^{o}, 1 \leq i' \leq n \). As mentioned before, \( t_{available}^{FBS_j} \) is denoted as the free spectrum bands of \( FBS_j \). The detail steps of the free spectrum configuration are described as follows.

1. Given a UE, considered the serving \( MBS_i \) and IDLE \( FBS_j \), and all neighboring FBSs of
An UE tries to perform the in-bound mobility operation from FBS \( F_{BS_j} \), and the FBS \( F_{BS_j} \) requests the information of \( SB_{MBS_i} = \{o_1, o_2, \ldots, o_l \mid o_i \in S_{MBS_i}, z \leq \beta \} \) from MBS \( i \) via F-GW. In addition, the FBS \( F_{BS_j} \) requests the information of \( SB_{FBS'_{FBS_j}} = \{o''_1, o''_2, \ldots, o''_{n'} \mid o''_i \in S_{MBS_i}, z' \leq \beta \} \) from all neighboring FBSs of FBS \( F_{BS_j} \) via the backhaul network.

3. Let \( S_{\text{occupied}} \) denote as the union of occupied spectrum bands of MBS \( i \) and all occupied spectrum bands of \( FBS'_{FBS_j} \), for \( 1 \leq i' \leq n \). Therefore, \( S_{\text{occupied}} = SB_{MBS_i} \bigcup \bigcup_{i'=1}^n SB_{FBS'_{FBS_j}} \). Then

\[
\text{l}_{\text{available}}^{FBS_j} = S_{MBS_i} - S_{\text{occupied}}.
\]

Fig. 8 shows an example of the free spectrum configuration, the total spectrum resource of \( S_{MBS_i} \) is \( \{T_1, T_2, \ldots, T_{13}\} \) and \( SB_{MBS_i} = \{T_1, T_2, \ldots, T_7\} \). Let FBS \( F_1 \) and FBS \( F_2 \) be in IDLE mode and FBS \( F_3 \) and FBS \( F_4 \) be in ACTIVE mode. The neighboring FBSs of FBS \( F_1 \) are \( FBS'_{FBS_1} = FBS_2 \), \( FBS'_{FBS_2} = FBS_3 \), and \( FBS'_{FBS_3} = FBS_4 \). An UE tries to perform the in-bound mobility operation from MBS \( i \) to FBS \( j \). Initially, we have \( SB_{MBS_i} = \{T_1, T_2, \ldots, T_7\} \), \( SB_{FBS_2} = \{T_{10}, T_{11}, T_{12}\} \), and \( SB_{FBS_3} = \{T_{13}, T_{14}, T_{15}\} \). Observe that, \( SB_{FBS_4} = \{\} \) because that FBS \( F_4 \) is operating in IDLE mode. The total occupied spectrum band is \( S_{\text{occupied}} = \{T_1, T_2, \ldots, T_7, T_{10}, \ldots, T_{15}\} \), then \( l^{FBS_j}_{\text{available}} = S - S_{\text{occupied}} \), so \( SB_{FBS_4} = \{T_8, T_9\} \).

### 4.2 Phase II: Transmission Time Estimation

This phase calculates the dwell time \( t_{\text{dwell}} \), the average expected transmission time \( t_{\text{expected}} \), and \( l_{\text{required}}^{\text{UE}} \) for a UE trying to perform the in-bound mobility from MBS \( i \) to FBS \( j \), where \( l_{\text{required}}^{\text{UE}} \) denotes the bandwidth of UE required to completely upload reminder data within the dwell time \( t_{\text{dwell}} \). This phase also is a positioning problem to estimate if a moving UE can be completely upload reminder data within the dwell time \( t_{\text{dwell}} \) or not.

Initially, the dwell time \( t_{\text{dwell}} \) is calculated as follows. The dwell time is the time period from a UE starts to communicate with FBS \( F_{BS_j} \) to the UE leaving the FBS \( F_{BS_j} \). Let \( SNR_{\text{UE,FBS}_j} \) denote the signal power between the UE and FBS \( F_{BS_j} \). Let \( SNR_{\text{UE,MBS}_i} \) denote the signal power between the UE and MBS \( i \) and let \( SNR_{\text{MBS,FBS}_j} \) denote the signal power between MBS \( i \) and FBS \( j \). This work assumes to avoid the effect of fast fading and shadowing. The path loss model is considered. Some existing avoiding fast fading and shadowing can be additionally adopted to enhance the accuracy of estimating \( t_{\text{dwell}} \). The procedure of calculating \( t_{\text{dwell}} \) is given as follows.

1. If an UE enters the coverage of the FBS \( j \) at time \( t_e \), there are three values of signal power, \( SNR_{\text{UE,FBS}_j} \), \( SNR_{\text{UE,MBS}_i} \), and \( SNR_{\text{MBS,FBS}_j} \), can be received at FBS \( j \). With three values of signal power, the distances between UE and FBS \( j \) (denoted as \( d_{\text{U,F}_j} \)), between UE and MBS \( i \) (denoted as \( d_{\text{U,M}_i} \)), and between MBS \( i \) and FBS \( j \) (denoted as \( d_{\text{M,F}_j} \)) can be ob-
tained. The values of $SNR_{UE,FBS_j}$ and $SNR_{MBS,FBS_j}$ can be directly obtained by $FBS_j$. The value of $SNR_{UE,MBS_i}$ is obtained from $MBS_i$ to $FBS_j$ through via the backhaul network.

2. If the UE continually moves along the moving direction by the fixed speed, we may similarly obtain three distance values of $d'_{U,F_j}$, $d'_{U,M_i}$, and $d'_{M_i,F_j}$ at time $t_{i+1}$.

3. An angle $\theta_i$ between $d_{M_i,F_j}$ and $d_{U,F_j}$ at time $t_i$ and an angle $\theta_{i+1}$ between $d'_{M_i,F_j}$ and $d'_{U,F_j}$ at time $t_{i+1}$ can be calculated. An angle $\theta_C$ is equal to $\theta_{i+1}$ minus $\theta_i$ between $d_{U,F_j}$ and $d'_{U,F_j}$. With the angle $\theta_C$, an angle $\theta$ between $d_{U,F_j}$ and the moving direction of the UE can be determined.

4. Let the expected maximum signal power of the UE at time $t_{i+1}$ be denoted as $SNR_{MAX}$. We first consider the effect of the path loss. The path loss model [23] is adopted, such that $PL(d) = 38.46 + 20 \log_{10} d + 0.7d_{2D}$, where $d$ is the distance of the UE and $FBS_j$, and $0.7d_{2D}$ is the penetration loss due to internal walls. In the case, $R \sin \theta$ is the shortest distance between UE and $FBS_j$, thus the signal power becomes $SNR_{PL} = SNR_{UE} - PL(R \sin \theta)$, where $SNR_{UE}$ is the original SNR of the UE at time $t_{i+1}$. Further, the effects of the fast fading and shadowing are considered, the expected maximum received signal strength can be represented as $SNR_{MAX} = \frac{1}{\sqrt{2\pi \sigma_{dB}^2}} \exp \left[-\frac{(SNR_{PL} - \mu)^2}{2\sigma_{dB}^2}\right]$, from [24], where $\sigma_{dB}$ is the standard deviation of shadowing and $\mu$ is the average power.

5. The $t_{dwell}$ is predicted as follows. A passing time, denoted as $t_{tp}$, from the UE entering the coverage of the $FBS_j$ to leaving the coverage of the $FBS_j$, is accurately calculated as follows. Let $\alpha = \frac{\int_R^r SNR_{MAX}}{\Delta t}$ denote as the average variation of SNR at $\Delta t$, where $R$ and $r$ are the distances between UE and $FBS_j$ at times $t_i$ and $t_{i+1}$ and $\Delta t = t_{i+1} - t_i$, respectively. The half of $t_{tp}$ is $SNR_{MAX} \alpha$, so $t_{tp} = 2 \times SNR_{MAX} \alpha$. Finally, the $t_{dwell}$ is equal to $t_{tp} - \Delta t = t_{tp} - (t_{i+1} - t_i)$.

For example as illustrated in Fig. 9, the dwell time starts from time $t_1$ until the UE leaving the coverage of $FBS_1$. An UE is moving and keeping the communication with $MBS_1$ in the coverage of $FBS_1$. The $FBS_1$ received $SNR_{UE,FBS_1}$, $SNR_{UE,MBS_1}$ and $SNR_{MBS_1,FBS_1}$ at $t_0$ and $t_1$. A first triangle is composed of $d_{U,F_1}$, $d_{U,M_1}$ and $d_{M_1,F_1}$ at $t_0$. The angle $\theta_0 = \cos^{-1} \frac{d_{M_1,F_1}^2 + d_{U,F_1}^2 - d_{U,M_1}^2}{2d_{M_1,F_1}d_{U,F_1}}$. The second triangle is composed of $d'_{U,F_1}$, $d'_{U,M_1}$ and $d'_{M_1,F_1}$ at $t_1$. Therefore, angle $\theta_1 = \cos^{-1} \frac{d_{M_1,F_1}^2 + d'_{U,F_1}^2 - d_{U,M_1}^2}{2d_{M_1,F_1}d'_{U,F_1}}$. Then, $\theta_C = \theta_1 - \theta_0$. We may have
\[ d_{o,j} = \sqrt{d_{o,F_1}^2 + d_{o,F_1}^2 - 2d_{o,F_1}d_{o,F_1} \cos \theta C} \]. Then, \( \theta = \cos^{-1} \frac{d_{o,F_1}^2 + d_{o,j}^2 - d_{o,F_1}^2}{2d_{o,F_1}d_{o,j}} \) is obtained.

The variation of SNR per unit time, \( \alpha = \frac{\int_{d_{o,F_1}}^{d_{o,j}} SNR_{UE} - (38.46 + 20 \log_{10}(d) + 0.7d_{2D})d(d)}{t_1 - t_0} \). Therefore, \( t_{tp} = 2 \times \frac{SNR_{MAX}}{\alpha} \) and \( t_{dwell} = t_{tp} - (t_1 - t_0) \).

Second, the \( t_{UE}^{required} \) is needed to calculated as follows. We revise the result of the radio resource management from [25] to provide the probability of the packet delay and the probability of infraction used in this work. Let \( l \) denote as a tile number. Let \( n \) denote as the bit number of a tile \( (n \) bits). Let \( \delta \) denote as an effective bandwidth determined by the arrival process and the service process. The procedure of calculating \( t_{UE}^{required} \) is given as follows.

1. Considered a UE, an IDLE \( FBS_j \) initially allocates \( l \) (= 1) tile for the UE. Let \( E_B^{UE}(\phi) \) [25] denote the effective bandwidth of the UE which specifies the maximum constant service rate required by a given arrival process subject to a given \( \phi \), where the \( \phi \) is the indicator of QoS guarantees that can be provided by the \( FBS \). Let \( E_C^{(UE,l)}(\phi) \) denote the effective capacity of the UE which is allocated by \( l \) tiles. Find the solution of \( \phi \) such that \( E_B^{UE}(\phi) = E_C^{(UE,l)}(\phi) = \delta \), where the effective capacity \( E_C^{(UE,l)}(\phi) = -\frac{1}{\phi} \log(e^{-n\phi}) \) [25]. Go to step 3.

2. Based on the result of [25], if \( l \neq 1 \), the effective capacity is \( E_C^{(UE,l)}(\phi) = l\omega lE_C^{(UE,1)}(l\omega l\phi) \), where \( l\omega l \) denote as the reliable tile as \( l\omega l = l - \sum_{g=0}^{\min(l,(1-\eta\psi)\rho M)} g \frac{C^l}{(1-\eta\psi)\rho M} \) [25], where the \( M \) denote as the original unused spectrum bands of \( MBS_i \), the \( \rho \) denote as the proportion of the occupied tile by \( MBS_i \) in the \( S_{MBS} \), the \( \eta \) denote as the probability of \( MBS_i \) still occupies this tile, the \( \psi \) denote as the percentage of still occupied tile of \( l\omega l \) and \( g \) denote as the number of unoccupied tile.

3. The delay bound probability \( Pr\{Delay > t_{dwell}\} = e^{-\delta t_{dwell}} \) which is the probability of the UE can be completely uploading through the \( FBS_j \) within the \( t_{dwell} \).

4. If \( Pr\{Delay > t_{dwell}\} = e^{-\delta t_{dwell}} > e^{UE} \), then \( l \) is increased and repeatedly perform step 2 to reduce the value of the delay bound probability \( Pr\{Delay > t_{dwell}\} \), where \( e^{UE} \) is the infraction probability of UE. Otherwise, \( t_{UE}^{required} \) is obtained.

For instance, we initially allocate \( l = 1 \) tile for an UE. The \( \phi \) is founded such that \( E_B^{UE}(\phi) = E_C^{(UE,l)}(\phi) = 5 \), where \( \phi = 0.05 \). The delay bound violation probability is
\[ \Pr\{\text{Delay} > 10\} = e^{-0.05 \times 5 \times 10} = 0.08, \] if 0.08 < 0.09, the number of tiles for the UE is 10, so \[ l_{\text{required}}^{\text{UE}} = 10. \]

Third, the \( t_{\text{expected}} \) is calculated as follows. Let \( R_{\text{average}} \) denote as the average transmission rate of the UE provided by \( FBS_j \). Let \( PL_{\text{average}} \) denote the as the average path loss of the UE during passing the coverage of \( FBS_j \). Let \( D_{\text{transmitted}} \) denote as the data which is already transmitted by \( MBS_i \). Let \( l_{\text{total}} \) denote as the total transmitted data of the UE. The \( RSSI_{\text{dB}} \) is the received signal strength indicator. The procedure of calculating \( t_{\text{expected}} \) is given below.

1. The average transmission rate \( R_{\text{average}} \) of the UE is \( R_{\text{average}} = l_{\text{required}}^{\text{UE}} \times \log_2(1 + RSSI_{\text{dB}}) \) by Shannon theory [26], where \( R_{\text{average}} \) is obtained by calculating \( l_{\text{required}}^{\text{UE}} \). The accurate value of \( RSSI_{\text{dB}} \) considers the effect of the path loss model, \( RSSI_{\text{dB}} = SNR_{FBS_j} - PL_{\text{average}} \), where the average path loss is \( PL_{\text{average}} = \frac{1}{2R} \int_0^R 38.46 + 20 \log_{10}(d_{U,F_j}) + 0.7d_2dU_{F,F_j} \), where the \( R \) is the radius of \( FBS_j \), the \( d_{U,F_j} \) is the distance between UE and \( FBS_j \) and 0.7\( d_2D \) is the penetration loss due to internal walls.

2. The remainder data \( D_{\text{remainder}} = D_{\text{total}} - D_{\text{transmitted}} \), and \( MBS_i \) sends the information to \( FBS_j \) via the backhaul network. Consequently, the expected transmission time is
\[
 t_{\text{expected}} = \frac{D_{\text{remainder}}}{R_{\text{average}}}.
\]

For instance, the average transmission rate of \( FBS_1 \) is \( 360kHz \times \log_2(1 + 7) = 1Mbps \), where \( RSSI_{\text{dB}} = 20 - 12.9718 = 7\text{dB} \). The average expected transmission time is
\[
 t_{\text{expected}} = \frac{D_{\text{remainder}}}{1M} = \frac{10M}{1M} = 10s,
\]
where the user remainder data as \( D_{\text{remainder}} = 15M - 5M = 10M \).

### 4.3 Phase III: Green Handover Decision

This phase finally makes a green handover decision as follows. The procedure of the green handover decision is given below.

1. If \( l_{\text{available}}^{FBS_j} \geq l_{\text{required}}^{\text{UE}} \) and \( t_{\text{dwell}} \geq t_{\text{expected}} \), then the IDLE \( FBS_j \) is wake-up and enters the ACTIVE mode to perform the handover procedure of the in-bound mobility from \( MBS_i \) to ACTIVE \( FBS_j \).

2. If \( l_{\text{available}}^{FBS_j} \geq l_{\text{required}}^{\text{UE}} \) and \( t_{\text{dwell}} < t_{\text{expected}} \), or if \( l_{\text{available}}^{FBS_j} < l_{\text{required}}^{\text{UE}} \), then the UE still communicates with the CN through \( MBS_i \).

Fig. 10 gives an example for the green handover decision. The \( FBS_1 \) computes the \( l_{\text{required}}^{\text{UE}} \) and
and \( t^{\text{FBS}_1} \). The \( FBS_1 \) operates in the IDLE mode if \( t_{\text{dwell}} < t_{\text{expected}} \). Then, the \( FBS_2 \) computes the \( t_{\text{UE}}^{\text{required}} \) and \( t^{\text{FBS}_2} \). If \( t^{\text{FBS}_2} \geq t_{\text{request}} \) and \( t_{\text{dwell}} \geq t_{\text{expected}} \), then \( FBS_2 \) switches from IDLE mode to ACTIVE mode. The UE handovers from \( MBS_1 \) to \( FBS_2 \). Finally, the detailed flow charts of the handover procedure [27], including the handover preparation, execution, and completion, are given in Fig. 11.

5 Performance Analysis

In this section, a simple analytic model is developed to mainly analyze the average energy consumption of data transmission of UE for inbound mobility by the proposed scheme. We begin by defining a few symbols.

- \( P_{nj} \): The probability of a handover which is not occurred from \( MBS_i \) to \( FBS_j \).
- \( P_{ej} \): The probability of the remainder data of UE which cannot be completely uploaded through \( FBS_j \).
- \( E_{\text{active}} \): The energy consumption of the ACTIVE \( FBS_j \) and an UE.
- \( E_{\text{idle}} \): The energy consumption of the IDLE \( FBS_j \) and an UE.
- \( E_A \): The average energy consumption for the data transmission of an UE using Ashraf protocol.
- \( E_G \): The average energy consumption for the data transmission of an UE using our proposed green handover protocol.

The average energy consumption of the data transmission of an UE during an in-bound mobility of Ashraf protocol [18, 19] is initially derived as follows.

**Lemma 1** The average energy consumption for the data transmission of an UE performing the in-bound mobility of existing protocol [18, 19] is

\[
E_A = E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{\text{idle}} + (1 - e^{-\lambda_j T_j}) \times E_{\text{active}}).
\]

**Proof.** In general, the Poisson distribution is represented as \( P(k, T) = \frac{(\lambda T)^k}{k!} e^{-\lambda T} \), where the \( k \) is the event number (the handover number in the analysis), \( T \) is the period time, and \( \lambda \) is the average proportion of the event happened. In this work, the \( P(k, T) \) denotes as the probability of \( k \) handover events occurred within the period time \( T \). The Poisson distribution is to observe the probability of the handover number occurred within a period of time \( T \). We assume that \( P(k,T_j)=P(0,T_j) \) is equal to \( P_{nj} = e^{-\lambda_j T_j} \) to represent as the probability of a handover which is not occurred within time \( T_j \), where \( k = 0 \). The probability of an inbound mobility not occurred from \( MBS_i \) to \( FBS_j \) is \( P(k,T_j)=P(0,T_j)=P_{nj} = e^{-\lambda_j T_j} \) under the Poisson distribution model, where
\( \lambda_j = \frac{1}{t_j} \) and \( t_j \) is the time period of the received SNR of \( FBS_j \) from the UE is large than the threshold value. The \( \lambda_j T_j \) is the average handover number within the time duration \( T_j \), where \( T_j \) is equal to \( t_{up} \). The probability of handover is \( 1 - P_{nj} = 1 - e^{-\lambda_j T_j} \). The average energy consumption \( E_A = E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{active}) \), where \( E \) is the average energy consumption of the data transmission of an UE before entering the coverage of \( FBS_j \). \[ \text{Lemma 2}\] The average energy consumption of the data transmission of an UE performing the in-bound mobility of our proposed protocol is

\[
E_G = E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times (e^{-\lambda_j t_{dwellj}} \times E_{idle} + (1 - e^{-\lambda_j t_{dwellj}}) \times E_{active}))(2)
\]

**Proof.** The probability of a handover which is not occurred within time \( T_j \) is \( P_{nj} = e^{-\lambda_j T_j} \) which is same as Lemma 1, but the probability, \( 1 - P_{nj} = 1 - e^{-\lambda_j T_j} \), of a handover within time \( T_j \) is further divided into two probabilities; the probabilities of the remainder data can and cannot be completely uploaded through the \( FBS_j \). The probability of the remainder data of UE cannot be completely uploaded within time \( t_{dwellj} \) through the \( FBS_j \) is \( P_{cj}(0, t_{dwellj}) = P_{cj} = e^{-(\lambda_j t_{dwellj})} \),

where the \( \hat{\lambda}_j = \frac{1}{t_{expectedj}} \) is the average number of completely uploading within time \( t_{expectedj} \),

where \( t_{expectedj} \) is the average expected transmission time using \( FBS_j \) and the \( t_{dwellj} \) is the time starting from UE communicates with \( FBS_j \) and stopping to communicate with \( FBS_j \). Let the probability of the remainder data of UE can be completely uploaded through the \( FBS_j \) be

\( P_{cj} = 1 - e^{-(\lambda_j t_{dwellj})} \). The probabilities of the remainder data can and cannot be completely uploaded through the \( FBS_j \) are \( e^{-(\lambda_j t_{dwellj})} \) and \( 1 - e^{-(\lambda_j t_{dwellj})} \), respectively. The energy consumption of probability of the handover occurred if using our scheme is \((1 - e^{-\lambda_j T_j}) \times (e^{-\lambda_j t_{dwellj}} \times E_{idle} + (1 - e^{-\lambda_j t_{dwellj}} \times E_{active})\). Therefore, the average energy consumption of the data transmission of an UE during an in-bound mobility of our proposed protocol is \( E_G = E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times (e^{-\lambda_j t_{dwellj}} \times E_{idle} + (1 - e^{-\lambda_j t_{dwellj}} \times E_{active}))) \)

For example, \( E \) is 0.2W, \( E_{idle} \) is 6.2W, and \( E_{active} \) is 10.2W from Table II, \( E_G = 0.2 + \frac{1}{1} \sum_{j=1}^{n} e^{-0.5 \times 10} \times 6.2 + (1 - e^{-0.5 \times 10}) \times (e^{0.1 \times 12} \times 6.2 + (1 - e^{-0.1 \times 12}) \times 10.2) = 9.18W. \)
Theorem 1: Based on the results of lemma 1 and lemma 2, the average energy consumption of our proposed protocol is smaller than that of existing protocol [18, 19], $E_G < E_A$, i.e.,

$$E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times (e^{-\hat{\lambda}_j T_j \text{dwell}_j} \times E_{idle} + (1 - e^{-\hat{\lambda}_j T_j \text{dwell}_j}) \times E_{active})) <$$

$$E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{active})$$

(3)

Proof. Based on Lemma 1, the average energy consumption of existing protocol [18, 19] is $E_A = E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{active})$. Based on Lemma 2, the average energy consumption of our proposed protocol is $E_G = E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{active})$. It is easily seen that $E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{active}) < E + \frac{1}{n} \sum_{j=1}^{n} (e^{-\lambda_j T_j} \times E_{idle} + (1 - e^{-\lambda_j T_j}) \times E_{active})$.

Consequently, the average energy consumption of our proposed protocol is smaller than that of Ashraf protocol [18, 19], since $E_G = 9.18W < E_A = 10.37W$.

6 Simulation Results

Our paper presents a green handover protocol in two-tier OFDMA macrocell-femtocell networks. To evaluate our green handover protocol, Ashraf et al.’s IDLE mode protocol [18], all these protocols are mainly implemented using the Network Simulator-2 (NS2) [28] and 3GPP module [29]. The system parameters are given in Table IV. To discuss the effect of simulation results, our simulation considers the networks size of 1000 m\(^2\) and six FBSs are deployed in the overlapped area between the serving and next MBSs. The communication radius of the FBS and the MBS assume to be 50 m and 1000 m, respectively. The data size changes from 10M bytes to 15M bytes and the velocity of a user changes from 30 to 80 km/hr. The power consumption of the ACTIVE FBS assumes to be 10.2 W and the IDLE FBS assumes to be 6 W. The power consumption of LTE UE is mainly based on Table II. The simulation scenario is that a UE is moving from the left to right. In this situation, the UE is passing six FBSs. It noted that some of them are IDLE FBS. When the UE is passing the coverage of the IDLE FBS, the IDLE FBS makes a decision to wake up to perform the handover procedure, or not to wake up and not to perform the handover procedure. The performance metrics to be observed are:

- **Power consumption** (PC): the total power consumption of all MBS, FBSs and the UE.
- **Handover latency** (HL): the time period between a UE changing its association from the current
association MBS/FBS to another one.

- **Packet loss ratio** (PLR): the total number of lost packets divided by the total number of transmitted packets during the handover period for a UE

- **Signaling cost of handover** (SC): the total number of signal packets, including request packets and the responses packets communicating between MBS with FBS.

It is worth mentioning that a green handover protocol is achieved with low PC, low HL, low PLR, and low SC. In the following, we illustrate our simulation results for power consumption (PC), handover latency (HL), packet loss ratio (PLR), and signaling cost of handover (SC) from several aspects.

### 6.1 Power consumption (PC)

To illustrate the influence of the PC, Fig. 12(a) shows the simulation result of PC under the various data size (ranging from 10 Mbytes to 15 Mbytes). The simulated result illustrates that our green handover protocol significantly achieves the energy saving. This is because that our protocol offers the non-frequently occurrence of the handover event to try to keeping the FBS at the IDLE mode. In general, the PC drops as the data size increases as illustrated in Fig. 12(a). It indicates that more power saving result will be. This power-saving result also shows that Ashraf protocol [18, 19] has more handover events than our protocol. The power consumption of Ashraf protocol is fixed at 42 W. The power consumption of our green handover protocol is less than 42 W. Fig. 12 (b) illustrates the simulation result of PC vs. the velocity (ranging from 30 km/hr to 80 km/hr). The power consumption of our green handover protocol is lower than that of Ashraf protocol [18, 19]. It is observed that the PC drops as the velocity increases. For instance, the power consumption is about 46 W if the velocity is 30 km/hr, and the power consumption is about 41.28 W if the velocity is 80 km/hr. This shows that the IDLE FBS has the high probability of keeping the FBS IDLE under the high speed environment.

### 6.2 Handover latency (HL)

Figure 13 gives the simulation results of the average handover latency (HL). The lower the number of handovers is, the lower the average handover latency will be. Fig. 13 (a) shows the HL vs. the data size (ranging from 10 Mbytes to 15 Mbytes). In general, the HL drops as the data size increases. For instance, the HL is 325 ms if the data size is 10 Mbytes, and the HL is 74 ms if the data size is 15 Mbytes of our green handover protocol, while the HL of Ashraf protocol [18, 19] is fixed at 360 ms. This is because that the less frequently number of handover events occurs. Fig. 13 (b) provides the simulation result of the average handover latency (HL) vs. the velocity of the UE (ranging from 30 km/hr to 80 km/hr). We observed that the HL drops as the velocity increases. For instance, the HL is 275 ms if the velocity is 30 km/hr and the HL is 125 ms if the velocity is 80 km/hr of our green handover protocol, while Ashraf protocol [18, 19] is fixed at 360 ms. According to the simulation
result, the HL of the proposed protocol is better than the Ashraf protocol [18, 19].

6.3 Packet loss ratio (PLR)

The simulation results of the packet loss ratio (PLR) under various data size and velocity are illustrated in Fig. 14. Fig. 14 (a) shows the simulation result of PLR vs. the data size (ranging from 10 Mbytes to 15 Mbytes). The packet loss occurs when the handover is executed. In general, the PLR increases as the data size increases. For instance, the PLR of our protocol and Ashraf protocol is about 7% if the data size is 10 Mbytes. The PLRs of our protocol and Ashraf protocol are 11.67% and 11.5 and 13.4% if the data size is 15 Mbytes. The PLR of our protocol is smaller than that of Ashraf protocol under various data size implied that the packet loss ratio is less than that of Ashraf protocol. Fig. 14 (b) shows the simulation result of the PLR vs. the velocity of the UE (ranging from 30 km/hr to 80 km/hr). In general, the PLR increases as the velocity increases. The PLR of our protocol is smaller than that of Ashraf protocol under the various velocity implied that the packet loss ratio is less than that of Ashraf protocol. For instance, the PLR is 29% if the velocity is 80 km/hr using Ashraf protocol. Consequently, the packet loss ratio of the green handover protocol is smaller than that of Ashraf protocol.

6.4 Signaling cost of handover (SCH)

Figure 15 shows the simulation results of the signaling cost of handover (SCH). The high the number of handover is, the large the SCH will be. Fig. 15 (a) shows the simulation result of the SCH vs. the data size (ranging from 10 Mbytes to 15 Mbytes). The SCH indicates the number of information exchanging between UE and FBS. The SCH of our proposed scheme is smaller than Ashraf scheme because of our proposed protocol efficiently reduces the undesired handover events. In general, the SCH decreases as the data size increases. For instance, the SCH is 1512 bits if the data size is 10 Mbytes and the SCH is 300 bits if the data size is 15 Mbytes. The SCH of the proposed protocol is smaller than that of Ashraf protocol under various data size. Fig. 15 (b) offers the simulation result of the SCH vs. the velocity of the UE (ranging from 30 km/hr to 80 km/hr). In general, the SCH decreases as the velocity increases, because that the number of handovers events is decreased. The SCH of the proposed protocol is smaller than that of Ashraf protocol under the various velocity. For instance, the SCH is fixed 1700 bits under various velocity using Ashraf protocol. In addition, the SCH of our protocol is extremely lower than that of Ashraf protocol at 80 km/hr.

7 CONCLUSIONS

In this paper, we have developed a green handover protocol in two-tier OFDMA macro-cell-femtocell networks. A green scheme allows the femtocell base station to completely switch off its radio communication and associated processing when not involved in an active all. To improve the energy efficiency of femtocell base station, the proposed green handover protocol can intelli-
gently switch on its radio communication and associated processing to wake up from the idle mode, if the remainder data of a mobile host can be completely uploaded through the wake-up femtocell base station. We have provided the mathematical analysis and the performance simulation to illustrate that the proposed protocol can significantly offer a more power-saving result compared with the existing energy-saving handover protocols.

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REFERENCES


Table I: Comparison of existing handover protocols for OFDMA two-tier macrocell-femtocell networks.

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<td>Zhang protocoll [15]</td>
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<td></td>
<td>Ashraf protocoll [17]</td>
<td>The proposed protocol</td>
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<td>Signal strength</td>
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Table II: Power consumption of femtocell and UE.

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<td>3.2m</td>
<td>1.9968</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSM UE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table III: Definition of notation.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$MBS_i$</td>
<td>The $i$-th macro base station</td>
</tr>
<tr>
<td>$FBS_j$</td>
<td>The $j$-th femto base station</td>
</tr>
<tr>
<td>$FBS_j^i$</td>
<td>The neighboring FBSs of $j$-th FBS</td>
</tr>
<tr>
<td>$t_{dwell}$</td>
<td>User dwell time in the coverage of $FBS_j$</td>
</tr>
<tr>
<td>$t_{expected}$</td>
<td>Average expected transmission time of UE</td>
</tr>
<tr>
<td>$S_{MBS_i}$</td>
<td>the set of the original unused spectrum bands of $MBS_i$</td>
</tr>
<tr>
<td>$SB_{MBS_i}$</td>
<td>the set of occupied sub-bands by $MBS_i$</td>
</tr>
<tr>
<td>$SB_{FBS_j^i}$</td>
<td>the set of occupied sub-band by $FBS_j^i$</td>
</tr>
<tr>
<td>$S_{occupied}$</td>
<td>Total occupied spectrum band</td>
</tr>
<tr>
<td>$l_{available}^{FBS_j}$</td>
<td>Available bandwidth of $FBS_j$</td>
</tr>
<tr>
<td>$t_{tp}$</td>
<td>Total passing time of UE</td>
</tr>
<tr>
<td>$l_{required}^{UE}$</td>
<td>Required bandwidth of UE</td>
</tr>
<tr>
<td>$R_{average}$</td>
<td>Average transmission rate</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>the average variation of SNR at $\Delta t$</td>
</tr>
<tr>
<td>$SNR_{MAX}$</td>
<td>Maximum transmission power is received by $FBS_j$</td>
</tr>
<tr>
<td>$\xi^{UE}$</td>
<td>Infraction probability of UE</td>
</tr>
<tr>
<td>$E_{B}^{UE}(\phi)$</td>
<td>Effective bandwidth of UE</td>
</tr>
<tr>
<td>$E_{C}^{(UE, l)}(\phi)$</td>
<td>Effective capacity of the UE which is allocated by $l$ tiles</td>
</tr>
<tr>
<td>$RSSI_{dB}$</td>
<td>Received signal strength indicator</td>
</tr>
<tr>
<td>$PL_{average}$</td>
<td>Average path loss of UE in the coverage of $FBS_j$</td>
</tr>
<tr>
<td>$D_{total}$</td>
<td>Total data of UE</td>
</tr>
<tr>
<td>$D_{transmitted}$</td>
<td>Data transmitted by $MBS_i$</td>
</tr>
<tr>
<td>$D_{remainder}$</td>
<td>Remainder data of UE</td>
</tr>
</tbody>
</table>

### Table IV: Simulation parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Networks size</td>
<td>1000 m x 1000 m</td>
</tr>
<tr>
<td>MBS transmission range</td>
<td>1000 m</td>
</tr>
<tr>
<td>FBS transmission range</td>
<td>50 m</td>
</tr>
<tr>
<td>Velocity of UE</td>
<td>30-80 km/hr</td>
</tr>
<tr>
<td>Number of FBSs</td>
<td>6</td>
</tr>
<tr>
<td>Data size</td>
<td>10-15 Mbytes</td>
</tr>
<tr>
<td>Packet rate</td>
<td>1000 packets/sec.</td>
</tr>
<tr>
<td>Packet size</td>
<td>1000 bytes</td>
</tr>
<tr>
<td>Simulation time</td>
<td>20-40 sec.</td>
</tr>
</tbody>
</table>
Fig. 1. Two-tier OFDMA macrocell-femtocell networks.

Fig. 2. Channel operation of two-tier networks. (a) Co-channel operation. (b) Dedicated channel operation.
Fig. 3. Comparison of the power consumption and the number of handovers. (a) Ashraf protocol. (b) Our proposed protocol.

Fig. 4. The two-tier OFDMA macrocell-femtocell networks architecture.
Fig. 5. Power consumption of the femtocell hardware. (a) ACTIVE mode. (b) IDLE mode.

Fig. 6. The dwell time and the average expected transmission time.
Fig. 7. The flow chart of the green handover protocol.

Fig. 8. The free spectrum configuration.
Fig. 9. The computation of the dwell time.

Fig. 10. The green handover decision.
Fig. 11. The handover signaling flow of the proposed handover protocol. (a) Handover preparation. (b) Handover execution. (c) Handover completion.
Fig. 12. (a) Power consumption vs. data size. (b) Power consumption vs. velocity.

Fig. 13. (a) Handover latency vs. data size. (b) Handover latency vs. velocity.
Fig. 14. (a) Packet loss ratio vs. data size. (b) Packet loss ratio vs. velocity.

Fig. 15. (a) Signaling cost of handover vs. data size. (b) Signaling cost of handover vs. velocity.