A Femtocell-Assisted Data Forwarding Protocol in Relay Enhanced LTE Networks

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Abstract—The femtocell networks, which is a small cellular base station in home and small business environment, is an attractive solution for operators to improve indoor coverage and network capability. In addition, relaying is one of the proposed technique for future releases of UTRAN Long Term Evolution (LTE) networks which aims to increase the coverage and capability of LTE networks. A LTE network is called as relay enhanced LTE network if the LTE network adopting the relays. A user can handover not only two relays, but also between relays and base stations, and two base stations. It is important to provide a seamlessly handover solution in the relay enhanced LTE network. During mobility, the packet loss problem is occurred if some packets are sent to the previous base station (or relay) when a user equipment (UE) is already handover to the current base station (or relay). To solve this problem, a data forwarding procedure is performed to redirect these buffered packets from the previous base station (or relay) to the current base station (or relay). In this paper, we develop a new data forwarding protocol with the assistance of femtocells, called as a femtocell-assisted data forwarding, in the relay enhanced LTE networks to provide a seamlessly handover result with the low packet loss rate and the high throughput. Finally, the simulation results illustrate that our proposed protocol outperforms the existing data forwarding scheme.

Keywords- LTE, handover, relay, femtocell, data forwarding.

I. INTRODUCTION

Long Term Evolution (LTE) is a new generation of mobile wireless broadband technology with the high throughput and the low latency. The LTE network has the good compatibility to connect with existing cellular technologies such as global system for mobile communications (GSM) and universal mobile telecommunications system (UMTS). The LTE network allows service providers through a more economical way to provide wireless broadband services. The LTE technology is beyond the current 3G wireless network performance, and brings a superior performance. The LTE has officially been the third generation mobile communications organizations, which is the project of the 3rd Generation Partnership Project (3GPP). The LTE technology carries out any extension service for operational planning. The LTE is a step toward the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile telephone networks. The 3G technology over the past refer to the same wireless network to provide voice and data communications, but in time the communication technology is turned into all-IP data networking architecture. The LTE technology is estimated that the maximum download rate of 100 Mbps and 50 Mbps of upload rate, which is faster than worldwide interoperability for microwave access (WiMAX). 3GPP specifications release 8 initially defines the LTE technology and 3GPP specification release 9 additionally includes new benefits and enhancements for LTE technology. The LTE technology adopts the network-based mobility mechanism, called Proxy MIPv6 (PMIPv6) [2]. In addition, relay technologies have been actively studied and considered in the standardization of the 3GPP LTE-advanced [3]. Relay technology effectively improves the service coverage and the system throughput. In the LTE-advanced, a relay node station helps a remote user equipment (UE) unit which is located far away from an evolved Node B (eNB), to effectively access the eNB [3]. Relaying technique is used to perform IP packet forwarding for remote UEs to increase the overall system capacity, improve the quality of service (QoS) and the link capacity. Femtocell is the small base station operating in the licensed cellular bands [4, 5]. The main purpose of deployment of a large number of femtocells in home network is to greatly grow the coverage and capacity of cellular networks. Femtocells are small and inexpensive base stations with the low power data transmission, that they are meant to be placed in individual homes and backhauled onto the core network of the mobile operator via the Digital Dunsribler Line (DSL) [6, 7] or cable [8, 9]. Example of femtocells is given in Fig. 1.

The Femto Forum recently standardized femtocells into Class 1 (typically residential), Class 2 (primarily indoor for enterprise), and Class 3 (rural, metro, and wider-area deployment) [10, 11]. Class 1 femtocell [11] typically services a residential environment with a range of up to 5,000 feet (about 1.5 km). Class 3 femtocell [11] is also called greater femtocell or superfemto which is the solution for wide areas providing a coverage area of up to 12 km. The femtocell is ideal for campuses, rural areas or metro with poor coverage. The wide area femtocells have a capacity of up to 16 cells and can either be mounted outdoors, or placed indoors with an external antenna, typically attached to the roof of the building. They are deployed very quickly. Although femtocells are often thought of for residential applications, there is a growing recognition that the advantages of the kinds of area. A femtocell has self
configuration features and backhauls via the internet. The picoChip PC8219E product is a solution for Class 3 femtocells [12]. The class 3 greater femtocell chip is implemented in picoChip company [13]. The cell radius is up to 2 km and the UE speeds up to 30 km/h [14]. The femtocells improve network planning and provides the basis for self organizing network (SON) functions [11][13]. This paper assumes the class 3 femtocell environment, which can be applied to campuses, rural areas or metro with the poor coverage. The class 3 femtocell has more user capacity and more range to support the eNB or RN to approach our protocol.

In the LTE networks, the 900 MHz frequency band to be used in rural areas [15], supporting an optimal cell size of 5 km, 30 km sizes with reasonable performance, and up to 100 km cell sizes supported with acceptable performance [15]. The LTE cell sizes may range from the femtocell range for indoor or home coverage, to over 100 km [15]. A typical LTE cell size ranges from 1 to 5 km [15]. In addition, the relay node station cell sizes may range from several meters to several kilometers provided by the vendor.

The concept of a closed subscriber group (CSG) is introduced by 3GPP [16], which is used to identify a group of subscribers who are permitted to access one or more cells of the public land mobile network (PLMN) even though those cells operate in closed access mode. The 3GPP is also expected that the subscriber registered as owner of the femtocell or group of femtocells is able to update the subscribers that form part of the CSG under operator supervision [9]. The 3GPP is imperative that the femtocell (both Home Node B (HNB) and Home enhanced Node B (HeNB)) has the ability to control which UE has access to it. This access restriction is needed because some backhaul links for this type of deployment are not considered to provide adequate quality of service (QoS) to support large numbers of UEs [10]. The CSG concept is a useful way to group all UEs that is allowed access to one specific femtocell or a group of femtocells. The unique CSG identity is used and to broadcast by all femtocells that support access to UE belonging to the related CSG [9]. The UE stores the CSG identity to verify that accesses the femtocell.

In the 3GPP LTE standards, femtocells are called Home enhanced Node B (HeNB). A HeNB gateway (HeNB-GW) is introduced that concentrates a large number of HeNBs and appears as an gateway GPRS support node (GGSN) or mobility management entity (MME) to the HeNB. In the LTE, the same interface as regular base stations, the S1 interface is being reused [17]. There are basically three access control modes, open, closed, and hybrid, in which a femtocell could be operated [9][10][11]. In the closed mode [10], normal service is expected for the set of UE belonging to the CSG. Any UE that is not part of the CSG would not get access to the femtocell, except to make emergency calls if no other acceptable cell is available in any allowed PLMN/RAT (radio access technology) [10]. In the open mode [10], the UE may unconditionally camp on the femtocell, and all UEs are treated equally from a camping and also from a charging in its serving domain. In the hybrid mode, these femtocells are similar to closed access mode femtocells [10], users subscribed to the femtocell may get preferential charging in comparison with users not subscribed to the cell that receive service from the femtocell. The calls of UE not part of the CSG may be preempted or rejected in favor of a CSG member call. The network is required to provide the capability for differential charging of UE belonging to the CSG and UE not belonging to the CSG. Note that the user needs the ability to understand the different charging possibilities when using a hybrid access mode femtocell [9][10]. In this paper, the hybrid mode is adopted.

In this paper, a femtocell-assisted data forwarding protocol is developed in relay enhanced LTE networks. It is important to provide a seamlessly handover solution in the relay enhanced LTE network. During mobility, the packet loss problem is occurred if some packets are sent to the previous base station (or relay) when a user equipment (UE) is already handover to the current base station (or relay). To solve this problem, a data forwarding procedure is performed to re-direct these buffered packets from the previous base station (or relay) to the current base station (or relay). In this paper, we develop a new data forwarding protocol with the assistance of femtocells, called as a femtocell-assisted data forwarding, in the relay enhanced LTE networks to provide a seamlessly handover result with the low packet loss rate and the high throughput. Finally, the simulation results illustrate that our proposed protocol outperforms the existing data forwarding scheme.

The rest of this paper is organized as follows. Section 2 discusses the related works. Section 3 describes the system architecture and basic ideas. The proposed protocol is presented in section 4. The simulation results are shown in section 5. Finally, section 6 concludes this paper.

II. RELATED WORK
The LTE (Long Term Evolution) technologies defined by 3GPP is the last step toward the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile telephone networks. Mobility management for supporting seamless handover is the key issue for the next generation wireless communication networks [18]. In the LTE network without relaying, there is only one kind of handover which is the handover from one eNB to other eNB [34, 35, 36]. Relaying is one of the proposed technologies for future releases of UTRAN Long Term Evolution (LTE) networks. Introducing relaying is expected to further increase the coverage and capacity of LTE networks. To enable relaying, the architecture, protocol and radio resource management procedures of LTE, such as handover, have to be modified [19]. In the relay enhanced LTE networks [19], there is handover between an eNB and a relay node station or between two relay stations within the same or different cells.

There are some kinds of relaying systems such as amplify-and-forward relays and decode-and-forward relays [6][7]. Relay stations can be performed in a conventional or cooperative fashion. In the conventional relaying, the UEs are directly receiving data from the serving eNB or the serving relay node (RN). In the cooperative relaying, the UEs receive and combine the signals from several RNs and eNBs. This paper develops a data-forwarding protocol under the conventional relaying system.

Recently, a handover mechanism between femtocell and macrocell for the LTE based networks is developed by Zhang et al. [20]. Modified signaling procedure of handover is presented in the Home eNodeB gateway based femtocell network architecture to reduce the unnecessary handovers and the number of handovers. Wang et al. recently designed mobility management schemes at radio network layer for LTE femtocells to reduce the signal costs [21]. In this work, an intermediate node called HeNB gateway (HeNB-GW) is proposed by Wang et al. [21] to be located between HeNBs and the mobile CN to solve the scalability and security problems.

It is observed that when a UE handover from a previous relay node (RN) or eNB to the next relay node (RN) or eNB, some data packets will be sent to the previous relay node (RN) or eNB before the handover procedure is completely completed. To overcome the packet loss problem, existing data forwarding protocols [37] exist to temporarily store these data packets in the buffer of the previous relay node (RN) or eNB and then these data packets are re-forward from the buffer of the previous relay node (RN) or eNB to the serving RN or eNB. Recently, Kitatsuji et al. [37] introduced direct and indirect data forwarding schemes for the tunnel-based mobility management. Direct data forwarding allows user data to be directly forwarded from a serving eNB to a new eNB, whereas indirect data forwarding takes the serving and new mobile access gateway (MAG) for forwarding user data from the serving eNB to the new eNB. The LTE network allows the direct data forwarding between serving and new eNBs. Consequently, this paper focus on discussing with the direct data forwarding schemes.

III. PRELIMINARIES AND BASIC IDEAS

This section introduces the relay enhanced LTE networks system architecture in subsection 3.1, and the basic ideas and challenges are then described in subsection 3.2. The system assumption is then given.

A. Relay Enhanced LTE Networks System Architecture

Fig. 2 shows the system architecture of the relay enhanced LTE networks [19], while LTE evolved packet core (EPC) is used, and eNB, relay node (RN) stations and femtocells [16] exist in the system architecture. Fig. 1 gives an E-UTRAN architecture with deployed HeNB-GW and a large number of HeNBs for broadly deployments of femtocells. A logical architecture is provided for a HeNB by using the S1 interface to connect the HeNB to the EPC [16][22]. The configuration and authentication entities can be same for HeNBs and HNBs. The HeNB-GW serves as a concentrator for the control plane (C-Plane), specifically the S1-MME interface. The S1-U interface from the HeNB may be terminated at the HeNB-GW, or a direct logical user plane (U-Plane) connection between HeNB and serving gateway (S-GW) may be used. The S1 interface is defined [4][5] as the interface

- between the HeNB-GW and the Core Network,
- between the HeNB and the HeNB-GW,
- between the HeNB and the Core Network,
- between the eNB and the Core Network.

The HeNB-GW appears to the MME as an eNB. The HeNB-GW appears to the HeNB as an MME. The S1 interface between the HeNB and the EPC is the same whether the HeNB is connected to the EPC via a HeNB-GW or not [23]. The HeNB-GW connects to the EPC in a way...
that inbound (femtocells to macrocells) and outbound (macrocells to femtocells) mobility to cells served by the HeNB-GW not necessarily require inter MME handovers. The function supported by the HeNB is same as those supported by an eNB. The procedure running between a HeNB and the EPC is same as those between an eNB and the EPC [16].

The HeNB hosts the same functions as an eNB [16]. The HeNB makes a discovery of a suitable serving HeNB-GW. HeNB shall only connect to a single HeNB-GW at one time. If the HeNB is connected to a HeNB-GW, the HeNB does not allow to simultaneously connect to another HeNB-GW, or another MME. The tracking area code (TAC) and PLMN ID used by the HeNB shall also be supported by the HeNB-GW. When the HeNB connects to a HeNB-GW, selection of an MME at UE attachment is hosted by the HeNB-GW instead of the HeNB. The target CSG ID is forwarded by the MME as part of the Handover Request message [16]. The HeNB-GW may use the list of CSG IDs, stored in the PAGING message, for the paging optimization. The MME hosts the following functions [24]. Access control for UEs that are members of closed subscriber groups (CSG). In case of handovers to CSG cells, access control is based on the target CSG ID provided to the MME by the serving E-UTRAN. Routing of handover messages towards HeNB GWs based on the tracking area identity (TAI) contained in the handover message.

Mobility from eNB/HeNB to a HeNB’s CSG/hybrid cell takes place with the S1 Handover procedure. The handover procedure is performed from source evolved universal terrestrial radio access network (E-UTRAN), which is an eNB or a HeNB, to a target HeNB. Source E-UTRAN includes the target E-UTRAN cell global identifier (E-CGI) and the CSG ID in the Handover Required message sent to the MME. The MME performs UE access control to the CSG cell based on the CSG ID received in the Handover Required message and the stored CSG subscription data for the UE. The MME determines the CSG Membership Status of the UE handing over to the hybrid cell. The MME sends the Handover Request message to the target HeNB including the target CSG ID received in the Handover Required message. Finally, the target HeNB sends the Handover Request Acknowledge message to the MME via the HeNB-GW [16][25].

GPRS tunnelling protocol (GTP) tunnels are used between two nodes communicating over a GTP based interface, to separate traffic into different communication flows [10]. A GTP tunnel is identified in each node with a tunnel endpoint identifier (TEID), an IP address and a UDP port number. For the control plane, each end-point of a GTP-C tunnel, the TEID-C shall be unique per packet data network-connection (PDN-Connection) on GTP based SS/SS interface. GTP-U is a relatively simple IP based tunnelling protocol which permits many tunnels between each set of end points. When used in the UMTS, each subscriber has one or more tunnel, one for each packet data protocol context (PDP context), the others possibly separate tunnels for specific connections with different quality of service requirements [26]. The separated tunnels are identified by a TEID in the GTP-U messages, which should be a dynamically allocated random number. If this random number is of cryptographic quality, then this mechanism provides a measure of security against certain attacks. Even so, the requirement of the 3GPP standard is that all GTP traffic, including user data should be sent within secure private networks, not directly connected to the Internet. When the S5/S8 interface is based on the GPRS tunnelling protocol [26], the S-GW has GTP tunnels on all its UP interface. When the S5/S8 interface uses proxy mobile IP (PMIP), the S-GW performs the mapping between IP service flows in S5/S8 interface and the GTP tunnels in S1-U interface, and connects to PCRF (Policy Charging and Rules Function) to receive the mapping information as illustrated in Fig. 3. During mobility between eNBs, the S-GW acts as the local mobility anchor. The MME commands the S-GW to switch the tunnel from one eNB to another. The MME also requests the S-GW to provide tunnelling resources for the data forwarding if there is a need to forward data from source eNB to target eNB or HeNB (through HeNB-GW) during the handover. For all data flows belonging to a UE in connected mode, the S-GW relays the data between eNB and PDN-GW. If the S-GW receives data packets from PDN-GW, the S-GW buffers the packets, and requests the MME to initiate paging of the UE. Paging causes the UE to reconnect, and when the tunnels are re-connected, the buffered packets are sent on. The SGW monitors data in the tunnels, and may also collect data needed for accounting and user charging. The S-GW includes the functionality of Lawful Interception, which means the capability to deliver the monitored user’s data to authorities for further inspection. The UE architecture and the protocol stack is mainly based on the LTE specification [16]. The network layer contains the GPRS tunnelling protocol (GTP), non-access stratum (NAS) and the radio resource control (RRC) to handle the tunnel establishment, the authentication and the mobility function.

B. Motivation and Basic Ideas

When the UE moves from the source eNB to the target eNB in LTE networks, the mobility handover mechanism is
are forwarded from the source eNB to the next eNB and the target eNB. The buffered data is re-routed and transmitted through the next eNB. The data forwarding is triggered from the network. The UE receives the buffered data from the source eNB through femtocells. The buffered data is forwarded to the UE. Before the UE receiving the buffered data, the UE usually suffers a long delay time to decrease the system throughput. The system capacity would also be decreased if there is a large amount of buffered data in the eNB. Existing handover protocol cannot effectively solve the above problem. This is motivated to develop a new handover protocol in relay enhanced LTE networks. The main idea of our work is to utilize the assistance of femtocells to pre-transmit the buffered data to the UE.

The total receiving time of receiving data packets through the next eNB, the remaining data packets that were sent by the UE received the data packets from CN. Let $\alpha$ denote as the buffered data transmitted to the UE. The total receiving time, $T_{\text{receive}}$, of receiving $B(i + 1.1 + n)$ and $D(i + n + 1. m)$ of the $UE$ is $T_{B(i+1. i+n)} + T_{D(i+n+1. m)}$ if using Teyeb scheme. It is interesting to observe that if the $UE$ can receive $B(i + 1.1 + n)$ in the duration of handover if using femtocell-assisted scheme. Let $T_{femtocell-assisted}$ denote the total receiving time of receiving $B(i + 1.1 + n)$ and $D(i + n + 1. m)$ of the $UE$, such that $T_{femtocell-assisted} < T_{\text{receive}}$. This is the main idea of this work.

IV. FEMTOCELL-ASSISTED DATA FORWARDING PROTOCOL

This section presents the femtocell-assisted data forwarding protocol in relay enhanced LTE networks. The protocol is split into three phase: (1) femtocell registration, (2) femtocell discovery phase, and (3) the femtocell-assisted data forwarding phase, as follows.

- **Femtocell registration procedure**: If a femtocell, located in the overlapped area, it registers its own information to the home subscriber server (HSS).
- **Femtocell discovery procedure**: The UE chooses the best suitable femtocell from all possible femtocells.
- **Femtocell-assisted data forwarding phase**: The UE receiving $B(i + 1.1 + n)$ through selected femtocell.

A. Femtocell Registration Phase

Each femtocell must perform a registration operation to provide the information to the home subscriber server (HSS) [16][27]. Each UE obtains the necessary information from the HSS to search for the most suitable femtocell for the data forwarding. Before describing the femtocell registration operation, some notations are defined. Let previous eNB and RN denote as $eNB_t$ and $RN_t$, respectively. Let the next eNB and RN denote as $eNB_{t+1}$ and $RN_{t+1}$, respectively. Considered a $UE_t$, $1 \leq t \leq m$, the $UE_t$ selects the most suitable $HeNB_j$, from a candidate set of eNB= $\{HeNB_1, HeNB_2, \ldots, HeNB_n\}$, where $1 \leq j \leq n$. Therefore, the main purpose of femtocell registration phase is to provide the enough information of the candidate set of HeNBs for each $UE_t$. Let the HeNB candidate set denote as $\delta$.
Initially, the $UE_i$ has no HeNB in the HeNB candidate set, \( \delta = \{ \varphi \} \), $UE_i$ inserts suitable HeNBs into set $\delta$.

The detail steps of the femtocell registration operation and construction of HeNB candidate set are described below.

1) **Femtocell registration operation**: Given a $UE_i$, initially let $z = 1$. For all $HeNB_x$, and each $HeNB_x$ located in the overlapped area of $cNB_i$ and $cNB_{i+1}$, each $HeNB_x$ automatically performs the registration operation to HSS server, by sending out the information of the SSID of CSG ID, coverage radius, location information, and idle status to HSS.

2) **Construction of HeNB candidate set**: Given a $UE_i$, $UE_i$ requests the construction of HeNB candidate set to HSS server by providing the location of $UE_i$. The HSS server searches for all appropriate $HeNB_x$ and forms a candidate set $\delta$. A $HeNB_x$ can be a candidate $HeNB_x$ to be inserted into $\delta$ if the $HeNB_x$ must be idle status information and is not the closed femto-AP, and the CSG ID is verified by $UE_i$. Finally, the HSS server returns the candidate set $\delta$ to $UE_i$.

Example is given for the femtocell registration procedure. There are $HeNB_{B_1}$, $HeNB_{B_2}$, $HeNB_{B_3}$, and $HeNB_{B_4}$ in the overlapped area. The $UE_i$ requests the the candidate set $\delta$ from HSS server and $\delta = \{ HeNB_{B_1} \}$.

**B. Femtocell Discovery Phase**

After constructing a HeNB candidate set $\delta = \{ HeNB_{B_1}, HeNB_{B_2}, \ldots, HeNB_{B_t} \}$ for $UE_i$, then $UE_i$ performs the femtocell discovery operation to search for the most suitable HeNB from set $\delta$ for the data forwarding. A HeNB in set $\delta$ is selected to be the selected HeNB if the $UE_i$ can stays at the selected HeNB with the longest retention period. Each HeNB is assumed to have the same coverage radius. This is to guarantee that the data forwarding can be completed before it can be possibly switching to other HeNBs. The femtocell discovery procedure is given as follows.

**The femtocell discovery procedure:**

1) Given a $UE_i$ and a HeNB candidate set $\delta = \{ HeNB_{B_1}, HeNB_{B_2}, \ldots, HeNB_{B_j}, \ldots, HeNB_{B_n} \}$, $UE_i$ computes with $\theta$ as follows. Let $\theta$ be the included angle of $\vec{i}$ and $\vec{v}$, where $\vec{i} = (i_x, i_y)$ is a vector from $UE_i$ to $HeNB_{B_j}$ and $\vec{v} = (v_x, v_y)$ is the direction vector of the $UE_i$. Let $\theta$ be greater than or equal to $-\frac{\pi}{2}$ and be less than or equal to $\frac{\pi}{2}$ because the candidate $HeNB_{B_j}$ should be located at the same moving direction of $UE_i$.

$\theta = \cos^{-1} \left( \frac{\vec{i} \cdot \vec{v}}{||\vec{i}|| \cdot ||\vec{v}||} \right) \quad -\frac{\pi}{2} \leq \theta \leq \frac{\pi}{2}$

(1)

2) The $UE_i$ obtains the projection $\tilde{p}$ of $\vec{i}$ on the direction vector $\vec{v}$ by the orthogonal projection matrix.

$\tilde{p} = \begin{pmatrix} i_x \\ i_y \end{pmatrix} = \begin{pmatrix} v_x & v_y \\ v_x & v_y \end{pmatrix} \begin{pmatrix} 1_x \\ 1_y \end{pmatrix}$

(2)
3) Let $r_{\text{cov}}$ denote as the coverage radius of the $\text{HeNB}_j$. The projection distance of $\text{UE}_i$ and $\text{HeNB}_j$ is $r_{\text{dis}}$, equation $r_{\text{dis}} \leq r_{\text{cov}}$ must be satisfied, where

$$r_{\text{dis}} = \sqrt{\|\mathbf{r}\|^2 - \|\mathbf{\tilde{r}}\|^2}.$$  \hspace{1cm} (3)

4) The magnitude of the projection vector $\mathbf{\tilde{r}}$ of $\text{HeNB}_j$ is $\|\mathbf{\tilde{r}}\| = \sqrt{\|\mathbf{r}\|^2 - \|\mathbf{\tilde{r}}\|^2}$. Finally, $\text{UE}_i$ selects the $\text{HeNB}_j$ with the maximum magnitude of the projection vector $\mathbf{\tilde{r}}$.

An example is given in Fig. 5 of the femtocell discovery result. In the overlapped area, $\text{UE}_i$ finds best HeNB from and the HeNB candidate set $\delta = \{\text{HeNB}_1, \text{HeNB}_2, \text{HeNB}_3, \text{HeNB}_4\}$. $\text{UE}_i$ computes the projection of the direction vector of $\text{UE}_i$ and $\text{HeNB}_j$, $1 \leq j \leq 4$. First, $\text{HeNB}_1$ and $\text{HeNB}_2$ are removed because the calculated $\hat{\theta}$ of $\text{HeNB}_1$ and $\text{HeNB}_2$ are not satisfied the requirement of $-\frac{\pi}{4} \leq \hat{\theta} \leq \frac{\pi}{4}$. Then, $\text{UE}_i$ computes the projection of the direction vector of $\text{UE}_i$ and $\text{HeNB}_3$ and $\text{HeNB}_4$, while $\mathbf{\tilde{y}}$ and $\mathbf{\tilde{z}}$ are vectors of $\text{HeNB}_3$ and $\text{HeNB}_4$. Thus, we have projection vectors

$$\begin{align*}
\mathbf{\tilde{y}} &= \begin{pmatrix} y_x \\ y_y \\ y_z \end{pmatrix} = \begin{pmatrix} 1 \\ y_x' \\ y_y' \\ y_z' \end{pmatrix} \\
\mathbf{\tilde{z}} &= \begin{pmatrix} z_x \\ z_y \\ z_z \end{pmatrix} = \begin{pmatrix} 1 \\ z_x' \\ z_y' \\ z_z' \end{pmatrix}
\end{align*}$$

and

$$r_{\text{dis}} = \sqrt{\|\mathbf{y}\|^2 - \|\mathbf{\tilde{y}}\|^2} \quad \text{and} \quad r_{\text{dis}} = \sqrt{\|\mathbf{z}\|^2 - \|\mathbf{\tilde{z}}\|^2} \leq \sqrt{\|\mathbf{r}\|^2 - \|\mathbf{\tilde{r}}\|^2}$$

is less or equal to $r_{\text{cov}}$. We have the result of $r_{\text{dis}} \leq r_{\text{cov}}$ and $r_{\text{dis}} \leq r_{\text{con}}$. Then, the length of the projection vector $\|\mathbf{\tilde{y}}\| = \sqrt{y_x'^2 + y_y'^2 + y_z'^2}$ and $\|\mathbf{\tilde{z}}\| = \sqrt{z_x'^2 + z_y'^2 + z_z'^2}$ are computed, we finally have $\|\mathbf{\tilde{y}}\| > \|\mathbf{\tilde{z}}\|$. Thus, $\text{HeNB}_3$ is the final selected HeNB.

C. Femtocell-Assisted Data Forwarding Phase

If a HeNB is selected from a HeNB candidate set $\delta = \{\text{HeNB}_1, \text{HeNB}_2, \ldots, \text{HeNB}_m\}$, then the femtocell-assisted data forwarding operation is performed as follows. As recalled before, a $\text{UE}_i$ should receive the $D(1,m)$ from CN, where $D(1,m)$ represents as $n$ data packets with sequence number from $S_1$ to $S_m$. The $\text{UE}_i$ received the data packets $D(i)$ from $\text{HeNB}_i$ (if relay node is used), data packets $B(i + 1,i + n)$ = $D(i + 1,i + n)$ are forwarded through the selected HeNB the duration of handover, the remaining data packets $D(i + n + 1,m)$ are re-route and transmitted through the $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$ (if relay node is used). Example is given in Fig. 6 to show that $D(1,24)$ is received by UE through source eNB and source RN. $D(1,24)$ will be still sent to source eNB and need to forward to UE through the target eNB and the target RN. The femtocell-assisted data forwarding procedure is present below.

Femtocell-assisted data forwarding procedure:

1) Handover preparation phase: The $\text{UE}_i$ is already performed the femtocell discovery procedure to have the best HeNB which is selected from the HeNB candidate set $\delta = \{\text{HeNB}_1, \text{HeNB}_2, \ldots, \text{HeNB}_m\}$ for $\text{UE}_i$. If the source $\text{RN}_i$ of $\text{eNB}_i$ makes the handover decision based on measurement report and radio resource management (RRM) information provided by the $\text{UE}_i$, the source $\text{RN}_i$ of $\text{eNB}_i$ sends a handover request message and the necessary information to the target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$ to request and reserve the resource for handover. When the source $\text{RN}_i$ of $\text{eNB}_i$ receives the handover request acknowledgement from the target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$, the source $\text{RN}_i$ of $\text{eNB}_i$ sends a handover command message to the $\text{UE}_i$ through $\text{eNB}_i$.

2) Handover execution phase: The $\text{UE}_i$ immediately detaches the connection from $\text{HeNB}_i$ of $\text{eNB}_i$, if the $\text{UE}_i$ receives the handover command message. The $\text{UE}_i$ simultaneously sends out a path switch message to the MME of LTE core network to switch the downlink path from the source eNB to selected HeNB. When the MME receives path switch message from $\text{UE}_i$, the MME then switches the downlink path route to the Serving-GW of the selected HeNB, such that data packets $B(i + 1,i + n)$ = $D(i + 1,i + n)$ are downloaded from Serving-GW, through HeNB-GW (femto-GW) and then are forwarded to the selected HeNB by digital subscriber line (DSL) or cable broadband connections. The $\text{UE}_i$ performs the synchronization operation to the target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$ to recover the connection by re-connecting with the target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$.

3) Handover completion phase: When the $\text{UE}_i$ has successfully accessed the target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$, the $\text{UE}_i$ sends the Connection Complete message and cell radio network temporary identifier (C-RNTI) to the target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$ to confirm the handover, and indicate that the handover procedure is completed for $\text{UE}_i$. The target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$ verifies the C-RNTI sent in the Connection Complete message. The target $\text{RN}_{n+1}$ of $\text{eNB}_{n+1}$ sends the user plane update request to the MME for the downloading path switch. The MME sends a command to the Serving-GW to change the downlink path from the HeNB to the target eNB. The MME sends a handover complete acknowledgement message to the target $\text{RN}_{n+1}$ and $\text{eNB}_{n+1}$ and release the resource occupied by $\text{RN}_i$ and $\text{HeNB}_i$. Consequently, the remaining data packets
are transmitted from Serving-GW to $UE_2$, through the $eNB_1$, and $RN_{1}$, to $UE_1$.

Example of the femtocell-assisted data forwarding phase is given in Fig. 6. When $UE_1$ moves from $eNB_1$ to $eNB_2$, $UE_1$ enters the overlapped area and chooses the most suitable HeNB. Fig. 7 shows that $D(i+n+1..m)$ is received by $UE_1$ through PDN-GW, Serving-GW, HeNB-GW, and HeNB. Finally, $D(41..)$ is received by $UE_1$ through PDN-GW, Serving-GW, target eNB2, target $RN_2$. Simulation Results

Our paper presents a femtocell-assisted data forwarding protocol. To evaluate our femtocell-assisted data forwarding protocol (denoted as FAD in our simulation), our femtocell-assisted data forwarding protocol is simulated compared to Teyeb scheme [19] without the assistance of femtocells. All protocols are implemented using network simulator-2 (NS-2) [32], PMIPv6 module and EURANE module [33] to build up a LTE like simulation environment, while the EURANE module mainly supports the high-speed downlink packet access (HSDPA) module. Let FAD-A denote as the analyzed result derived from the mathematical analysis. Table 1 gives all simulation parameters.

In our simulation scenario, there are two eNBs with relay nodes, the MME and the Serving-GW element, each eNB locates at a different subnetwork. This simulation assumes that the transmission range and the link bandwidth of eNB are 50 km and 100 Mbps, respectively. A cbr traffic application with udp agent type is used to generate continuous data packets per 0.01 second for the connection between a pair of UE and CN. The transmission range of HeNB is assumed to be 2km. The simulation scenario is that the UE in the source eNB serving domain moves to the target eNB serving domain, under the UE continuously connects with the CN. When the UE enters the overlapped area, the UE initiates the handover procedure to switch the connection with CN from the source eNB to the target eNB is using Teyeb scheme without the assistance of femtocells. The UE receives forwarding data from the HeNB if using the femtocell-assisted data forwarding scheme. The performance metrics to be observed are:

- Handover latency (HL): the time period between a UE changing its association from the current association eNB/RN to another one.
- Throughput (TP): is the total number of data packets which can be transmitted and received between a pair of UE and CN per unit time.
- Packet loss (PL): the total number of packets that are lost during the handoff procedure for a UE.
- Message overhead (MO): is the total number of control messages during the handover procedure.

It is worth mentioning that an efficient data forwarding protocol is achieved with low HL, high TP, low PL, and low MO. In the In the following, we illustrate our simulation results for handover latency (HL), throughput (TP), packet loss (PL) and message overhead (MO) from several aspects.

D. Handover Latency (HL)

Initially, Fig. 9 illustrates the sequence number vs. time of FAD (femtocell-assisted data forwarding) and Teyeb schemes [19]. We observed that from the start handoff time to handoff time of FAD and Teyeb schemes, the FAD scheme receives packets from the CN earlier than does the Teyeb scheme. This is because that some data packets are forwarded through HeNB for FAD scheme. All of these data packets must be forwarded by the next RN/eNB. The curves
of FAD and Teyeb start the handoff at a time of 0.6 s. The FAD scheme receives the new packets at a time of 0.62 s which was lower than the Teyeb scheme at a time of 0.73 s. This implies that FAD scheme can receive all forwarding data more earlier than that of Teyeb scheme due to the assistance of femtocells.

Figure 10 illustrates the handover latency (HL) vs. packet size (byte), ranging from 1000 bytes to 5500 bytes, of FAD and Teyeb schemes. In general, the HL of FAD and Teyeb schemes are same, this result illustrates that the main purpose of FAD scheme is not to reduce the HL. Our FAD scheme keeps the same HL with Teyeb scheme.

E. Throughput (TP)

The simulation results of the TP under various data sizes as shown in Fig. 11. Fig. 11 shows the observed TP under various data sizes, ranging from ranging from 1000 bytes to 5500 bytes, of FAD and Teyeb schemes. The TP of the proposed FAD scheme drops as the data sizes decreases, which was nearly equal to the FAD-A. Fig. 11 also shows that the curve of the TP of our scheme is higher than that of Teyeb scheme, under various data sizes. This is because that our scheme has the assistance of femtocells.

F. Packet Loss (PL)

The simulation results of the PL under various data sizes as shown in Fig. 12. Fig. 12 shows the observed PL under various data sizes, ranging from ranging from 1000 bytes to 5500 bytes, of FAD and Teyeb schemes. The PL of the proposed FAD scheme drops as the data sizes decreases. Fig. 12 also shows that the curve of the PL of our scheme is lower than that of Teyeb scheme, under various data sizes.

G. Message Overhead (MO)

The simulation results of the MO under various velocity, ranging from 20 km/hr to 120 km/hr. The MO of the proposed FAD scheme drops as the velocity decreases. It shows that Teyeb scheme has higher MO than our scheme because that the assistance of femtocell is useful to improve the MO. It is verifies that the MO of our proposed scheme is lower than that of FAD scheme.

V. CONCLUSIONS

In this paper, we have developed a new data forwarding protocol with the assistance of femtocells in the relay enhanced LTE networks to provide a seamlessly handover result with the low packet loss rate and the high throughput. A mathematical analysis is conducted to derive the performance analysis of the proposed protocol. Finally, the simulation results illustrate that our proposed protocol outperforms the existing data forwarding scheme.

ACKNOWLEDGMENT

This research was supported by the National Science Council of the R.O.C. under grants NSC-99-2219-E-305-001 and NSC-97-2221-E-305-003-MY3.

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