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IMS Signalling in LTE-based Femtocell Network

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Abstract—The IP Multimedia Subsystem functionality is designed to work on various wireless access technologies and in all network coverage such as macrocell, microcell and femtocell. This paper describes the study of IP Multimedia Subsystem signalling in femtocell network. The 3GPP Long Term Evolution-based femtocell integrated with IP Multimedia Subsystem core network is considered as the system architecture. Session establishment signalling procedure is taken into account to analyse the IP Multimedia Subsystem signalling call flows in femtocell network. Signalling performance is analyzed by mean of Session Initiation Delay properties.

Keywords - Femtocell, IMS Signalling, 3GPP LTE, SIP.

I. INTRODUCTION

The Internet protocol Multimedia Subsystem (IMS) is a framework that specified for the third generation (3G) mobile networks, to provide Internet Protocol (IP) telecommunication services. The IMS standard was specified by the Third Generation Partnership Project (3GPP) in the specification Release 5 [1] and Release 6 [2]. The standard supports multiple access types, e.g., Global System for Mobile (GSM), Wideband Code Division Multiple Access (WCDMA), CDMA2000, or IEEE802.11 Wireless Fidelity (WiFi) [3].

The present active standard describes the IMS functionalities for classical wireless network coverage such as macrocell and microcell. As a new emerging wireless network which has a very small coverage, the standardization for femtocell is still under development.

In a femtocell network, the Femto Access Point (FAP) is defined as a small cellular base station designed to be used in the house, residential or in the office. The FAP allows service providers to improve indoor coverage mainly where access is limited or even unavailable. In the 3GPP terminology, the FAP is called as Home Node B (HNB) [4]. Though the IMS can accommodate current and future services in wired and wireless networks, however, the IMS-femtocell interoperability is still a challenging issue.

In the IMS network, the communication between the IMS core network (IMS-CN) and its clients is performed on the basis of request/response signalling messages. At the first step, client sends a Session Initiation Protocol (SIP) message specific for the given request when requiring a service from the IMS-CN. The IMS-CN responds by sending the particular SIP message with regard to the received request.

¹ The SIP is used as a signalling protocol in the IMS environment. It is defined in RFC 3261 [5] which have functionalities on registration, session establishment, session management and participant invocation (including creating, modifying, a terminating sessions with one or more participants). SIP signalling is the primary method for user registration and session control in the IMS architecture [6]. The Call Session Control Function (CSCF) is the core signalling server in the IMS networks architecture. It acts as both a SIP Registrar and a SIP proxy server [7].

Many research and scientific works consider either femtocell or IMS, but none of them concern on the interworking between IMS and femtocell. Accordingly, this paper is concern with this issue. The main focus is to investigate the effective and efficient IMS' SIP signalling mechanism when it works on femtocell environment. The all-IP connection integration between IMS-CN and FAP is described. In addition, another critical issue such as the delay properties of session establishment signalling of source and correspondent nodes is also taken into account. The IMS clients in femtocell environment are based on the 3GPP LTE.

The paper is organized as follow. Section II summarizes the related work regarding IMS and femtocell environment. Section III describes the integration architecture between IMS and FAP. Some literatures and technical aspects in IMS are portrayed, as well as the LTE-based femtocell. Section IV explains the proposed IMS signalling mechanism in femtocell network. The new messages flow is also depicted. End-to-end delay in the proposed messages flow is studied. Finally, Section V concludes our paper.

II. RELATED WORK

There are many published papers exposing the femtocells in terms of increasing the network capacity, saving energy, supporting high-speed data rate, and providing benefits from the social and economic side. Authors in reference [8] simulated the deployment of femtocells in residential scenario to study their effects on the service experienced by users connected to a macrocell. They found out no significant impact on the dropped call rate when auto-configuration is deployed in the femtocells. In [9], Chandrasekhar and Andrews addressed the reduced cost of deploying macrocell and femtocell users in a shared region of spectrum. They proposed a link quality protection algorithm to progressively reduce the target Signal-to-

Interference Noise Ratio (SINR). This two-tier distributed power control algorithm ensured minimal network overhead on femtocells. In addition to energy saving and coverage issues, Claussen *et al.* [10] proposed the mobility event based self-optimization and coverage adaptation method for femtocell deployment. As the result, the total number of mobility events caused by femtocells deployment is significantly reduced. Moreover, the femtocell's indoor coverage is improved as well. Other technical and business advantages of femtocell deployment as well as the technology state-of-the-art and its challenges have been overviewed and described in [11]. Generally, those papers discuss benefits and technical issues of femtocell deployment, however very few papers address the integration of femtocells into IMS architecture.

In addition to IMS research and technological development, several works have been addressed, mostly in terms of system performances of session establishment procedure. The works in [12] and [13] provided the SIP-based IMS signalling delay for IMS session establishment procedure. In [12], A. Munir analyzed the end-to-end delay where both source node and correspondent node are the combination of 3G/UMTS and WiMAX networks. The signalling delay is analyzed separately as transmission, processing and queue delays. However, the paper only shows the delay as a whole. It was not described which delay part that contributed the most significant delay.

More comprehensive analysis of session establishment procedure was carried out in [13] where the delay properties in each delay entities were investigated. The structure of session establishment signalling that is based on the standard was presented. The authors also examined which delay among the transmission, processing and queuing delays that contributed the most significant delay in the system.

The optimization of SIP session setup delay for voice over IP (VoIP) service in 3G wireless networks is studied in [14]. The authors evaluated SIP session setup performances with various underlying protocols transport control protocol (TCP), user datagram protocol (UDP), radio link protocols (RLPs) as a function of the frame error rate (FER). The adaptive retransmission time was proposed to optimizing the delay. In addition [15], the analysis of SIP-based mobility management in 4G wireless network was carried out. Despite they were not concern session establishment procedure, but some delay issues, particularly the delay on radio link protocol (RLP) and non-RLP have been carried out.

The optimization of efficient route for femtocell-based all IP networks is carried out in [16]. The Session Initiation Protocol (SIP) signalling routes and packet route of FAP resided in IP domain was compared with the FAP connected to IMS-CN through a Radio Access Network. For this purpose, the authors created the testbed for each FAP scenario. The end-to-end system delays were measured and reported.

III. THE OVERVIEW OF IMS – FEMTOCELL INTEGRATION

A. The Operational Concepts of IMS

The IMS is not about services, but the concept providing access to all services regardless of the media type. It uses a common control architecture that works well for all media. Functionalities that are required for supporting multimedia real time services, such as service creation, registration, invocation and execution are incorporated in the service architecture of IMS. Among these entities, IMS contains multiple SIP proxies called Call Session Control Functions (CSCFs) with following roles:

- Proxy-CSCF (P-CSCF) which is the first contact point in IMS and interacts with GGSN (Gateway GPRS Support Node), i.e., the access point from UMTS to external networks, for policy control and resources allocation.
- Interrogating-CSCF (I-CSCF) which acts as a SIP Registrar and is responsible for routing sessions to appropriate Serving-CSCF (S-CSCF).
- S-CSCF which performs session control and service trigger.

The IMS provides an efficient service provisioning capability compare to circuit-switched (CS) and packet-switched (PS) networks. When a client registers into IMS network, a Subscriber Service Profile (SSP) is downloaded by the S-CSCF from the HSS.

The SSP contains service-related information and identifies the services that need to be provisioned. If multiple services need to be implemented, it determines the order in which they are provisioned. The SSP also includes the address of the servers that must execute the subscriber's request. This approach allows IMS to serve as a re-usable service infrastructure by letting providers control and manage the complexities involved in service filtering, triggering, and interaction.

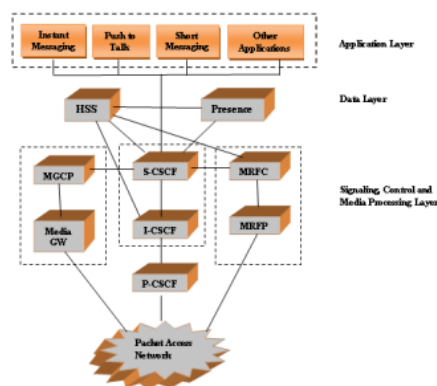


Figure 1. Layer architecture of IMS

Both PS and CS networks can be integrated into a single session by the network operator, accordingly, users can add multimedia services to existing services in real time. Fig. 1 represents how IMS logical function interacts to support a few sample applications.

B. Femtocell Network

1) LTE-based Femtocell

Based on 3GPP specification [17] the LTE-based FAP (HNB) provides the Radio Access Network (RAN) connectivity using Iuh interface, support the macrocell NodeB and most of the Radio Network Controller (RNC) functions, FAP authentication, Femto-Gateway (F-GW), FAP registration and Femto User Equipment (F-UE) registration over Iuh. Furthermore, the F-GW serves the purpose of a RNC and present to the mobile CN as a concentrator of FAP connections that provides concentration function for the control plane and user plane. Logical architecture of LTE-based FAP can be seen in Fig. 2.

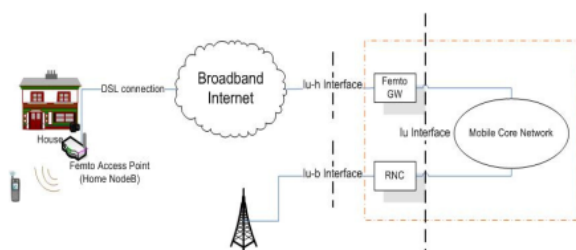


Figure 2. Logical architecture of LTE-based femtocell

2) LTE Advanced-based Femtocell

Additionally, in the basis of LTE-A [17], the evolved RAN (or Evolved UMTS Terrestrial Radio Access Network/E-UTRAN) is the key element since it provides all system functionalities included the Physical (PHY), Medium Access Control (MAC), Radio Link Control (RLC), and Packet Data Control Protocol (PDCP) [18]. It consists a single node, i.e., evolved Node B (eNodeB) or Home evolved Node B (HeNB)/FAP. It also provides radio resource control (RRC) functionality that corresponds to handover procedure.

E-UTRAN interacts with the Evolve Packet Core (EPC) system that consist the Mobility Management Entity (MME), Serving Gateway (SGW) and F-GW. The interaction between all functional elements of EUTRAN and EPC is depicted in Fig. 3.

The FAP supports the same functions as those supported by an eNodeB. The procedures between FAP and EPC run as same as those between macrocell eNodeB and the EPC. The F-GW serves as a concentrator for the control-plane, specifically the S1-MME interface. The F-GW may optionally terminate the user-plane towards the FAP and towards the SGW. Moreover, the F-GW provides a relay

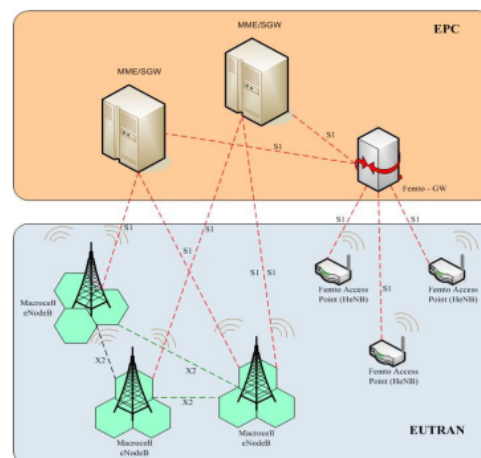


Figure 3. Logical architecture of LTE-A based femtocell

function for relaying user plane data between the HeNB and the SGW.

In addition, 3GPP also specified two standard interfaces, i.e., X2 and S1 interface, for the Evolved Packet System (EPS). The X2 interface provides capability to support radio interface mobility and shall support the exchange of signalling information between eNodeB macrocells. Therefore, for handover between eNodeB macrocells, the procedure is performed without EPC involvement. Preparation and exchange of signalling flows in the handover procedure are directly between eNodeB using X2 interface. On the other hand, the S1 interface supports many-to-many relations between EPC's elements (MME/SGW) and eNodeB. Moreover S1 is also used for the communication between FAP/HeNodeB with the MME/SGW through the F-GW. Specifically, the connection to MME is using S1 control plane (S1-C) interface and the connection to SGW is using S1 user plane (S1-U) interface.

C. SIP/IMS-based Integration

Introducing the femtocells obviously extends the wireless access directly into the homes. However, how to integrate thousands of FAPs with the existing mobile infrastructure is still challenged. There are several different ways of achieving this integration. In December 2007, Femto Forum proposed thirteen different network architectures [19] for the integration of femtocell with existing network infrastructures. Those proposals can be classified into three categories, i.e., cellular-based integration, SIP/IMS-based integration, and Unlicensed Mobile Access (UMA)-based integration. In this paper, the SIP/IMS-based integration has been considered to analyse the IMS signalling. The architecture of integrated system is depicted in Fig. 4.

In this architecture, the FAPs integrated directly with the IMS core through all-IP connectivity. Alternative architecture under this category includes softswitch-based implementations where the FAPs are integrated to a softswitch via SIP interface.

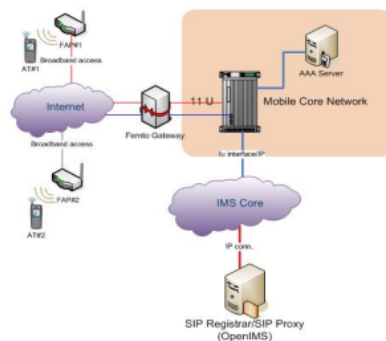


Figure 4. IMS-Femtocell integrated system architecture

This architecture leverages a SIP based VoIP network for cost-effective delivery since it is interworking with a cellular core to extend legacy circuit switched services. The signals (2G/3G) from legacy mobile stations (MSs) are converted into appropriate SIP messages over IP by FAP. Afterwards, they are interfaced to a SIP-MSC inter-working function (IW5) which connects to IMS-CN through internet.

Integrating femtocells directly with the IMS core offers definite advantages [20], i.e., there is no scalability issue since the mobile core network is completely offloaded, and the requirements for upgrading the mobile core network infrastructure can be avoided as the FAP has the functionality of Radio Access Network (RAN), it can scale the traffic. Traffic latency challenges are mitigated as the number of hops is minimal. In addition, the use of all-IP in the core network significantly reduces the operational expenditures for carriers.

Nevertheless, the SIP/IMS integration seems has some limitations, i.e., the lack of standards-based support for security, mobility, and supplementary services. The security procedures need to be concerned, particularly in the authorization, authentication and accounting (AAA) phases during the network entry process. Two types of authorization may be applied, i.e., the conventional network-based authorization and a novel scenario that allow the subscriber to perform the authorization procedure to another subscriber (as on the Bluetooth pairing procedure).

On the mobility side, several requirements have to be met in order to achieve a seamless FAP-to-FAP and FAP-to-macrocell handovers. At last, this architecture should also be interworked with the existing circuit switch network to allow the continuity implementation of existing supplementary services such as call barring, call waiting, call forwarding, voicemail, SMS, etc.

IV. IMS SIGNALLING IN FEMTOCELL NETWORK

A. IMS Signalling Procedure

In IMS system everything is controlled using one common signalling method. The signalling allows network

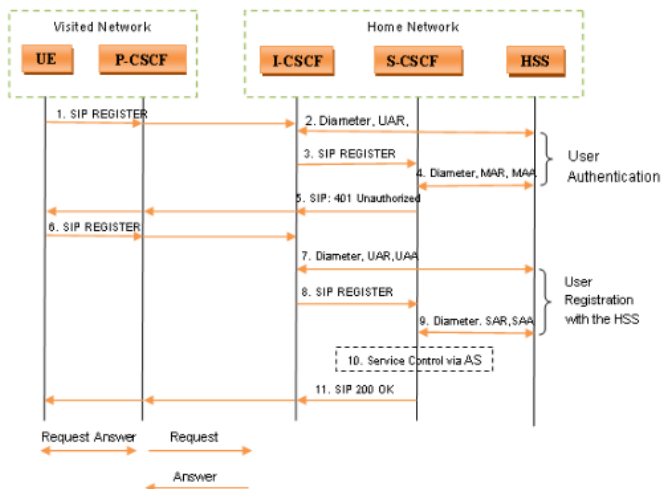


Figure 5. Signalling messages flow in registration procedure

entities to communicate with one another as well as application servers (ASs).

As the comparison, in the legacy Integrated Service Digital Network (ISDN), Signalling System #7 (SS7) is the signalling method used to connect facilities in the telephone network. SS7 connects different operators' networks with one another, and connects all of the switches within the network with one another. In IMS, SS7 is replaced with a new signalling method: SIP, which is used to control everything in the network.

SIP signalling is the primary method for user registration and session control in the IMS architecture. The CSCF is the core signalling server in the IMS networks. It acts as both a SIP Registrar and SIP proxy server. Fig. 5 depicts the signalling procedures for registration in the IMS Core.

The procedure starts with the user's SIP REGISTER request being sent to the visited P-CSCF. Due to air interface bandwidth limitation, messages are compressed before being sent out by the user and decompressed at the P-CSCF. If multiple S-CSCFs exist in the user's home network, an I-CSCF needs to be deployed for selecting an S-CSCF for serving the user session. In this case, the P-CSCF resolves the address of the user's home I-CSCF using the user's home domain name and forwards the REGISTER to the I-CSCF. After the I-CSCF sends a User-Authorization-Request (UAR) to the HSS, which returns available S-CSCF addresses, the I-CSCF selects one S-CSCF and forwards the REGISTER message.

B. Session Establishment Signalling in Femtocell

In IMS, there are three forms of messaging, i.e., immediate messaging, session-based messaging and deferred delivery messaging. Session establishment is part of session-based messaging. The procedure involves an end-to-end signalling message exchange.

There are several signalling messages that take part in the session establishment procedure as shown in Table 1.

1
 Originating F-UE1 generates a SIP INVITE request and sends it to the P-CSCF. The P-CSCF processes the request: for example, it decompresses the request and verifies the F-UE1's identity before forwarding the request to the S-CSCF. The S-CSCF processes the request, executes service control which may include interactions with ASs and eventually determines the entry point of the home operator of F-UE2 based on F-UE2's identity in the SIP INVITE request. I-CSCF receives the request and contacts the HSS to find the S-CSCF that is serving F-UE2. The request is passed to the S-CSCF. The S-CSCF takes charge of processing the terminating session, which may include interactions with ASs and eventually delivers the request to the P-CSCF. After further processing (e.g., compression and privacy checking), the P-CSCF delivers the SIP INVITE request to F-UE2.

TABLE I. SESSION ESTABLISHMENT MESSAGES

Session establishment message	Type of message	Compressed size (byte)
INVITE	Request	810
100 TRYING	Response	260
183 SESSION PROGRESS	Response	260
PRACK	Request	260
200 OK	Response	100
UPDATE	Request	260
180 RINGING	Response	260
ACK	Request	60

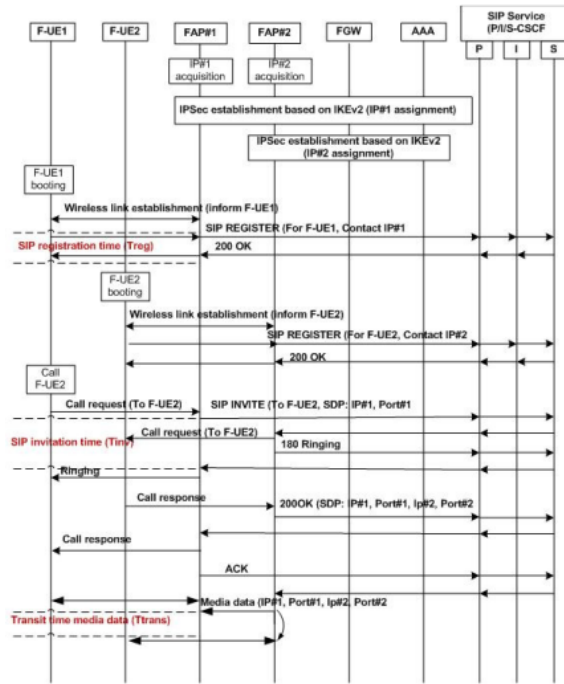


Figure 6. Session establishment signalling in femtocell

2
 Correspondent F-UE2 generates a response – 183 Session Progress – which traverses back to F-UE1 following the route that was created on the way from F-UE1 (i.e., F-UE2 → FAP2 → F-GW → MME/SGW → P-CSCF → S-CSCF → I-CSCF → S-CSCF → P-CSCF → MME/SGW → F-GW → FAP1 → F-UE1). After a few more round trips, both sets of F-UE1 and F-UE2 complete session establishment and are able to start the actual application (e.g., voice calls).

1
 Detail on IMS session establishment procedure can be seen in [13]. The complete signalling flow diagram of IMS session establishment procedure on femtocell network is depicted in Fig. 6.

C. Signalling Analysis and Performance

The Session Initiation Delay (SID) is often used to analyze the performance of session establishment signalling. SID is a user QoS parameter that 1 can be defined as the period between the instant the F-UE1 triggers the initiate session command and the instant the F-UE1 receives the message that is alerted by F-UE2.

Obviously, there are many factors that influence the SID. In this paper we distinguish the delay into three categories, i.e., IMS connections delay, processing delay and queue delay. Thus, it can be approximated as:

$$SID = D_{IMS_conct} + D_{proc} + D_{queue} \quad (1)$$

IMS connection delays are influenced mostly by the message propagation delay in the air interface (F-UE to FAP) and the transmission delay through the backhaul links and backbone network. In wireless transmission, the Radio Link Control (RLC) is used to improve the performance of frame error rate (FER) due to bandwidth availability and channel condition. The channel bandwidth (B/W) is assumed as 5 MHz, 10 MHz, 15 MHz and 20 MHz. Later, the channel rate (R) can be calculated by considering 3GPP TS. 36. 213 and TS 36. 306.

2
 Furthermore, the number of frame a packet (k) is required to be calculated for every specified channel rates. The RLC frame duration or inter-frame time (τ) is assumed 10 ms for downlink access. Then number of bytes in each 1 frame can be calculated as $R \times \tau \times \frac{1}{8}$. Subsequently, the value of k for particular signalling messages as shown in Table 1 can be calculated as [12]:

$$k = \frac{\text{number of byte}}{\text{message size}} \quad (2)$$

Since the detail operation of LTE-based femtocell radio link is not specified yet, the RLC 2 delay analysis given by [15] is assumed to be used. The analysis of transport delay when transmitting a packet over the RLC is approximated as [15]:

$$D_{RLC} = D_{prop} + (k-1)\tau + \frac{k[P_f - (1-p)]}{P_f^2} \times \left[\sum_{j=1}^n \sum_{i=1}^j P(C_{ij}) \left[2jD_{prop} + \left(\frac{j(j+1)}{2} + i \right) \tau \right] \right] \quad (3)$$

The open-air operation radio access network is vulnerable to noise influenced that generate packet loss. In Eq. 3 above, the effective packet loss is noted by P_f , and can be calculated as follow [14] [15]:

$$P_f = 1 - p + \sum_{j=1}^n \sum_{i=1}^j P(C_{ij}) = 1 - p[2 - p]^{n(n+1)/2} \quad (4)$$

where k is number of frames, n is number of RLC retransmission trials, p the probability of a RLC frame being in error in the air link, D_{prop} is end-to-end propagation delay over the air interface, τ is the interframe time and $P(C_{ij})$ is the first frame received correctly at destination as the i^{th} retransmission frame at the j^{th} retransmission.

Based on Fig. 6, it can be assumed that there are A messages involve in the session establishment processes between F-UE1 and P-CSCF of the visited IMS network. In addition, there are also B messages involve between P-CSCF of the terminating IMS network and F-UE2. Therefore the IMS connection delay (D_{IMS_conct}) is given as:

$$D_{IMS_conct} = (A + B) \text{ messages} \times D_{RLC} \quad (5)$$

Furthermore, the processing delay (D_{proc}) is determined at all entities in the IMS signalling path, i.e., P-CSCF, I-CSCF, S-CSCF in both home and visited networks, plus the HSS. It included the queue delay and address lookup table delay.

If number of messages processed in each entity is denoted as C , the delay in each entity (D_{proc}) can be approximated as:

$$D_{proc} = (C_{F-UE1} \times D_{F-UE1}) + (C_{PCSCF} \times D_{PCSCF}) + (C_{SCSCF} \times D_{SCSCF}) + (C_{ICSCF} \times D_{ICSCF}) + (D_{HSS}) + (C_{F-UE2} \times D_{F-UE2}) \quad (6)$$

Finally, the queuing delay for IMS session establishment signalling is determined in every network entities. The end-to-end packet delay from F-UE1 to F-UE2 depends on the

number of the packets at each queue as well as the applied queue model (i.e. M/M/1, M/D/1, etc.).

By assuming that the transmission buffer at the network node is delay free, thus the queue delay is considered only at the receive buffer of F-UE1 and F-UE2. They can be approximated:

$$D[\omega_{F-UE1}] = \frac{\rho_{F-UE2}}{\mu_{F-UE2}(1 - \rho_{F-UE2})} \quad (7)$$

where $\rho_{F-UE2} = \frac{\lambda_{e-F-UE2}}{\mu_{F-UE2}}$ represents the

utilization at originating terminal queue, μ_{F-UE2} denotes the service rate at originating terminal queue, λ_{e-CT} represents the effective arrival rate at originating terminal queue, which can be calculated as follow:

$$\lambda_{e-F-UE2} = \sum_{i \in N_{F-UE2}} \lambda_i \quad (8)$$

where N_{F-UE2} denotes the number of active sessions including the considered IMS session. Moreover, by determine the utilization at a network node, the effective arrival rate λ_e at that node can be obtained. In the same way to other network nodes, the λ_e at queue can be calculated. The expression can be determined for the expecting waiting time at other network entities.

Similar with the processing delay, if the number of messages processed in each entity is denoted as C , thus the queue delay for the IMS session establishment in femtocell network (D_{queue}) can be approximated as:

$$D_{queue} = (C_{F-UE1} \times D\omega_{F-UE1}) + (C_{PCSCF} \times D\omega_{PCSCF}) + (C_{SCSCF} \times D\omega_{SCSCF}) + (C_{ICSCF} \times D\omega_{ICSCF}) + (D\omega_{HSS}) + (C_{F-UE2} \times D\omega_{F-UE2}) \quad (9)$$

V. CONCLUSION

In this paper, the IMS signalling in femtocell network has been studied and analyzed. The LTE-based femtocell is considered for the integration with the IMS core network. The session establishment signalling procedure has is described and analyzed in order to show the IMS signalling functionality in femtocell network. We proposed the particular signalling call flows for session establishment procedure. In addition, the signalling performance is intended to be determined by mean of delay properties. The IMS connection delay, processing delay and queue delay are suggested to be considered as the delay properties of Session

Initiation Delay. The further work on simulation may corroborate the proposed mechanism and solution.

ACKNOWLEDGMENT

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