# PROC_04_INTEGRATED_IEEE-TSP 2013

*By* Ardian Ulvan

# Integrated IMS-Femtocell Testbed

Ardian Ulvan, Melvi Ulvan, and Robert Bestak

***Abstract*— This paper conducted the integration deployment of IP Multimedia Subsystem and LTE-based femtocell network in a lab scale environment (test-bed). A feasible integration designs called the SIP/IMS-based integration with all-IP connectivity is proposed as a new design for the 4G wireless technology called the Next Generation Wireless Network (NGWN). The performance evaluations of integrated IMS – Femtocell were not conducted independently, but as one system. End-to-end test-bed simulation and measurements were conducted and analysed. Some test cases, i.e., the registration process to IMS core network and call setup between two IMS' clients were deployed in various testing time. The test cases included the measurements of generated traffics, jitter, max delta, and bandwidth usage. The analysis of packet stream considered five most common protocols in IMS system, i.e., SIP, HTTP, TCP, UDP and RTP. Despite having some issues, the simulation test-bed of integrated IMS-Femtocell network has been proven to working well.**

***Keywords*—4G, femtocell, IMS, NGWN, testbed**

## I. Introduction

In MOBILE and wireless networks, femtocell is an emerging mobile network technology that operates as a small-scale cellular base station. The main device of femtocell is known as *Femto Access Point* (FAP) which has a low-power to connect conventional, unmodified mobile terminals to a mobile operator's network [1]. Meanwhile, *IP Multimedia Subsystem* (IMS) is a new framework for providing *Internet Protocol* (IP) telecommunication services [2][3]. It provides system architecture to converge wired and wireless networks, therefore the integration of femtocell and IMS is worth to be investigated.

Current active standards describe the IMS functionalities in normal wireless network coverage such as macrocell and microcell. Femtocell is designed for use in residential or small business environments. It allows service providers to extend service coverage inside of our home, especially where the access is limited or unavailable. Though the IMS accommodates current and future services, however, it has not clear enough how the IMS system works on femtocell network environment hence the space for investigation and research is still open and challenging.

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A. Ulvan is with the University of Lampung, Department of Electrical Engineering, Indonesia, and Czech Technical University in Prague, Department of Telecommunication Engineering, Czech Republic (phone: +6281806700823; fax: +62721785508; e-mail: ulvan@unila.ac.id) .

M. Ulvan was with Czech Technical University in Prague, Department of Telecommunication Engineering, Czech Republic. She is now with the University of Lampung, Department of Electrical Engineering, Indonesia (e-mail: melvi_ulvan@unila.ac.id).

R. Bestak is with Czech Technical University in Prague, Department of Telecommunication Engineering, Czech Republic (e-mail: robert.bestak@fel.cvut.cz).

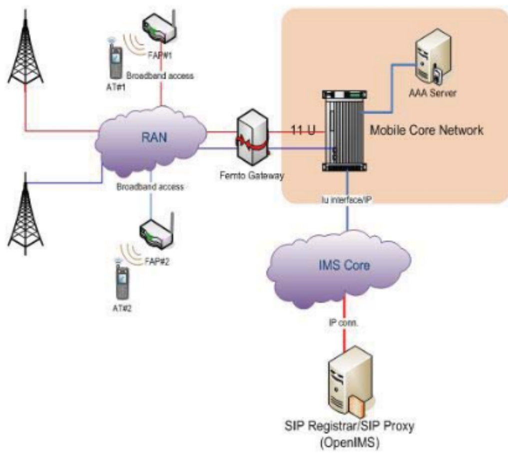


Fig. 1. Integrated architecture of macrocell, femtocell and IMS

This paper conducted the deployment of IMS service in femtocell environment. A feasible network integration designs called the SIP/IMS-based integration with all-IP connectivity is proposed as depicted in Figure 1. The work included the development of a test-bed of the proposed design. In addition, the IMS *Session Initiation Protocol* (SIP) signalling when it works on femtocell network is investigated, particularly during registration process and call setup.

The performance of the proposed system is analysed and examined by mean of simulation and testbed experimental measurements. The testbed is composed of two IMS'clients which are registered separately into IMS core network through the FAPs. Session establishment procedure of integrated LTE-based femtocell and IMS networks is also investigated. The network performance characteristic of integrated system is evaluated on the developed testbed.

Organisation of this paper is as follows. In section II, the overview on some related works is presented. Section III describes the testbed, the determination of IMS and femtocell interworking, and a brief description of test cases conducted in the testbed. Section IV presents the first test case results in term of SIP signalling analysis. Furthermore, the result and discussion on evaluation of network performance characteristics as the second test case are described in Section V. The work is concluded in Section VI.

## II. Related Works

The IMS operation and femtocell network in telecommunication systems has been concerned in several research works. The optimization of efficient route for femtocell-based all IP networks is carried out in [4]. The works were carried out due to the fact that when the femtocell is connected through the broadband public network, a secure tunnel (where the media data are sent and received) is established between the femtocell and the security gateway located in the mobile core network. If the security gateway is far away from the femtocell and those femtocells are in close proximity with each other, the routing path of the media data between users becomes redundant.

Authors in [5] use testbed-based experiments to investigate a possible integration of femtocells into WiFi and WiMAX systems. The authors provide the measurements of vertical handover delay where the vertical handover functionalities are deployed via SIP protocol. It is concluded that the substantial delay is incurred by the DHCP mechanism, the authentication process in WiMAX and the probing process in WiFi. However, there is no a clear description how WiFi and WiMAX systems can be integrated, particularly at the MAC layer.

Developing a femtocell-based testbed called the Cell-Lab was carried out in [6]. It is designed to support virtualization to enable multiple experiments simultaneously on top of femtocell base stations, such as transport-layer protocols for cellular, scheduling algorithms at base station, and handover mechanisms. Despite the Cell-Lab is able to interworking with existing wired testbeds, there is no clear indication that the testbed can be interworking with the IMS.

The functionality of IMS in femtocell network was first studied in [7]. Two architectural designs to integrate femtocell system and IMS core network, i.e. through a mobile core network and direct integration using all IP connectivity was proposed and investigated. Another critical issue such as the delay properties of session establishment signalling of source and correspondent nodes is also taken into account. The works have been extended by examining and determining the IMS' signalling in femtocell network [8]. The 3GPP Long Term Evolution (LTE) based femtocell network was integrated with IMS as system architecture. Session establishment procedure was taken into account to analyse the IMS signalling call flows in femtocell network. Signalling performance was analyzed by mean of Session Initiation Delay properties.

Apparently, the space for investigation and research is still open and challenging. In this paper, the testbed of integrated IMS core network and femtocell system is described and examined.

## III. The Testbed

The testbed, in fact, composes two main systems i.e., the femtocell system and IMS system. However, due to the unavailability of LTE equipment in the commercial market, the FAP in this testbed is based on the advanced 3G technology.

This advanced 3G-based femtocell system consists of the *Femto User Equipment* (F-UE) which is connected to mobile core network (*Evolved Packet Core* – EPC) through the FAP. The functionality of the *Radio Access Network* (RAN) such as the *Radio Network Controller* (RNC), *Serving GPRS Support Nodes* (SGSN) *and Gateway GPRS Support Nodes* (GGSN) can be integrated into the FAP. The femto gateway (FGW) that provides standard *Iu* interface to integrate the FAP into EPC, responsible for protocol conversion, and creates a virtual RNC interface to the legacy network, is assumed to be located in the mobile operator premises. The FAP, in this testbed, is connected to the mobile core network through a DSL connection.

Furthermore, IMS system is divided into three layers, i.e., connectivity layer, control layer, and service layer [9]. The connectivity or access layer is used to transport signalling traffic and media streams. This layer contains switches, router, and media processing entities such as *media gateways* (MGWs), *signalling gateways* (SGWs), *media resource function controls* (MRFCs), and *media resource function processors* (MRFPs). Since IMS is designed to be access independent, it can connect to different types of existing and emerging access networks as long as they have IP connectivity. In this testbed, IMS core network is connected to mobile core network by using a standard internet connection. The control layer comprises network control servers for managing call or session set-up, modification and release. Interworking with other operators' networks and or other types of networks is handled by border gateways. The heart of the control layer consists of the *Call Session Control Function* (CSCF) servers, also known as SIP servers. This layer also includes the *home subscriber server* (HSS) database, *subscriber location function* (SLF) database, *policy decision function* (PDF), and *breakout gateway control function* (BGCF). The application layer comprises application and content servers to execute value-added services for the user.

The developed testbed configuration is depicted in figure 2. In addition, the specification of the commercial FAP, the F-UE and other components in the testbed system, are shown in Table 2.

The length of an average UDP packet was 22 bytes and the packet transmission time interval (TTI) was 10 milliseconds using G.729 voice codec. The network was constructed with IPv4 and an FGW based on strongSwan [10] was used in conjunction with RADIUS server [11]. P-CSCF, I-CSC, S-CSCF and HSS were implemented based on OpenIMS [12]. The transit delay emulator between the FGW and both FAPs was set in the router in the mobile core network. To develop a real network environment in the testbed, a commercial traffic generator tool was used to generate 5 different network traffics i.e., SIP, UDP, TCP, RTP, and HTTP. A Wireshark [13] packet analyser was used to capture and analyse the packets. End-to-end test-bed simulation and measurements, as depicted on Figure 2, from the F-UE1 (source) to F-UE2 (destination) were conducted and analysed.

The test case scenarios in the testbed include the analysis of session establishment during registration and call setup process, and the evaluation of network performance characteristic. It included the measurements of generated traffics, jitter, and max delta, during a call session establishment. The evaluation results and discussion are presented in section V.

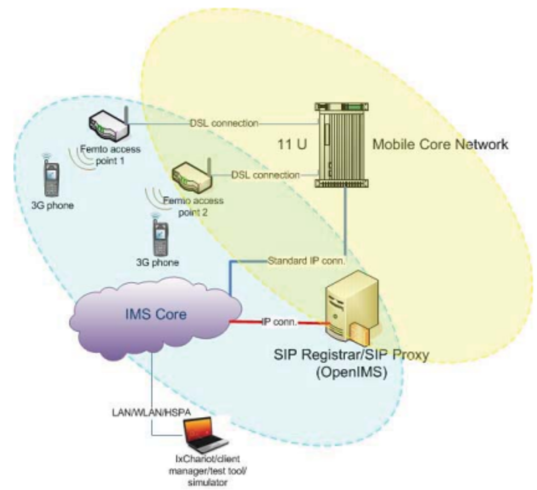


Fig. 2. Testbed configuration

TABLE I.
SPECIFICATION OF COMPONENTS

| Node | Specification |
|---|---|
| F-UE | • GSM/GPRS/EDGE 850/900/1800/1900 MHz;<br>• UMTS/HSPA 2100 MHz |
| FAP | • Energy consumption <5W;<br>• UMTS operating and network listen bands: Band I (2100), Band II (1900), Band V (850);<br>• GSM network listen bands: Band III (1800) & Band VIII (900);<br>• Maximum transmit power: UMTS +10 dBm];<br>• Interference management: Fully automatic: real-time cognitive radio;<br>• HSPA performance: Up to 14.4Mbps downlink & 5.7Mbps uplink;<br>• Core network interface: GAN, SIP, 3GPP luh and IMS;<br>• Broadband security: IPSec;<br>• Device security & authentication: Certificate or SIM;<br>• Remote device management: DSL Forum TR-069. |
| DSL | • Application Layer: DHCP, DNS (Proxy), HTTP, RTP, Passes UPnP;<br>• Application Gateway Details: FTP (TCP: 20, 21), PPTP (TCP: 1723), PPTP_TUNNEL (GRE: 0)<br>• Transport Layer: RSVP, TCP, UDPv4, UDPv6;<br>• Network Layer: ARP, ICMP, IGMP, IPv4, IPv6, IPv6 client/server/relay, IP fragmentation and reassembly, NAT/PAT, RT QoS;<br>• Data Link Layer: ATM (8 PVCs), QoS on ATM, Bridging, PPP, IPSec & VPN, Pass-through, Static, Routing, PPTP Port Forwarding, 802.1d, Spanning tree;<br>• Physical Layer: Ethernet:10BaseT/100BaseT |
| FGW | • Strong Swan |
| IMS | • OpenIMS (SIP registrar/SIP proxy/HSS)<br>• AAA Radius server |
| Client Manager | • IxChariot traffic generator<br>• Wireshark packet analyser |
| Generated Traffic | • SIP, UDP, TCP, HTTP, RTP |

## IV. SIGNALLING ANALYSIS

In integrated IMS-Femtocell system, there are two individual registration procedures. The first is the attach procedure of F-UE into mobile core network, and followed by the registration of IMS's client at F-UE into IMS core network.

Based on the test case result, there are several stages conduct for the attach procedure and session establishment as follows [8]:

**Stage-1:** FAP acquisition; the both FAPs are switched on, and then conduct the registration and acquisition procedures.
**Stage-2:** F-UE attach; Once the procedure in stage-1 completed, the FAP is ready to serve the F-UE. The *Attach Request* message is send by the F-UE to the FAP together with a *Packet Data Network (PDN) Connectivity Request* for the PDN (IP) on the established RRC connection.
**Stage-3**: SIP registration procedure; the registration procedure in IMS starts with the *SIP REGISTER* message request is being sent to the P-CSCF by the UE. After the I-CSCF sends a *User-Authorization-Request* (UAR) to the HSS, which returns to available S-CSCF addresses, the I-CSCF selects one S-CSCF and forwards the SIP REGISTER message. The S-CSCF sends a *200 OK* message to inform the UE of successful registration.
**Stage-4**: SIP invitation procedure; originating F-UE1 generates a SIP INVITE request and sends it to the P-CSCF. The P-CSCF processes the request and passes it to I-CSCF. The 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 at F-UE2. After a few more round trips, both sets of F-UE1 and F-UE2 complete session able to start the actual application (e.g., voice calls).
**Stage-5**: Media transfer; upon completed the session establishment procedure, both F-UE1 and F-UE2 can start the communication using the assigned transfer and communication protocols.

Figure 3 shows the detail signaling flows of session establishment process conducted in the testbed. The comprehensive explanation of the LTE attached procedure and the registration process on IMS core network can be found in [14].

## V. THE CHARACTERISTICS OF NETWORK PERFORMANCE

Example of measurements parameters and results of packet streams in term of traffic, jitter and max delta are depicted consecutively in Figure 4, Figure 5, and Figure 6. In addition, some example of measured values and result on packet stream analysis is presented in Table II.

Packet stream analysis conducted in this paper considers five most common protocols in IMS system, i.e., SIP, HTTP, TCP, UDP and RTP (see Figure 4). Although there is no traffic filtering mechanism employed, so that the test-bed system acts like in the real network, the plotted of Figure 4 represents the considered protocols only. As we can see, SIP, UDP and RTP protocols dominated the packet traffic. SIP has

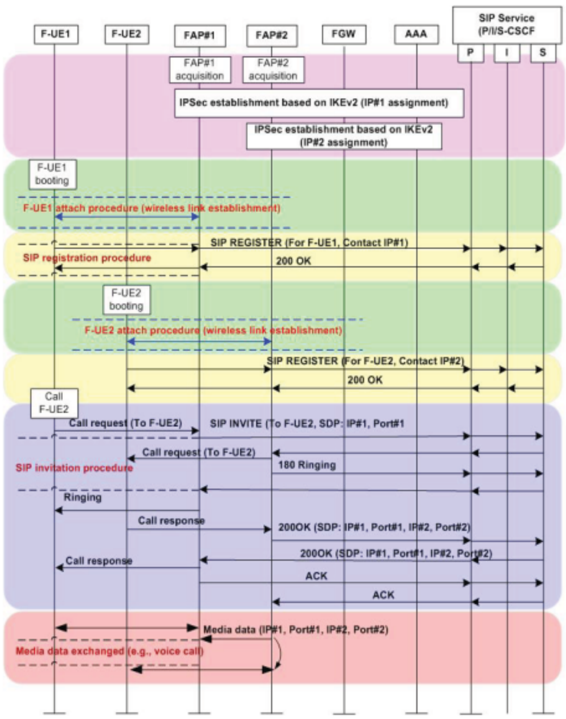


Fig. 3. Signalling flows of session establishment procedure in integrated LTE-based femtocell and IMS network [14]

the largest number of packets due to its signalling characteristics, i.e., sending the signalling messages for each created sessions. We can also see that from the period 240s to 264s the considerable number of RTP packets increased. It means during that time period the call session is established in the system. Figure 5 and Figure 6 shows the performance of call session in RTP packet. All traffic packets were captured in both forward and reverse streams. Forward stream means all traffic packets from IMS' clients F-UE1 to F-UE2, whereas the reverse stream is the traffic packet in opposite direction. Maximum delta, as shown in Figure 5 represents the maximum gap between two consecutive packets. According to RFC 3550, the common value of max delta for G.729 codec, which is used in this case, is 20 ms. Therefore, the ideal condition should be close to this value. However, our test-bed system does not have such particular value. The max delta is 60.00 ms at packet no. 2000. Apparently, the packets in our simulated system are not sent at a constant rate. In the real network, the max delta of 220ms on packet is big issue because it causes the voice quality of the stream as heard on the terminals end to deteriorate. Filtering the unessential packets in the network or changing the codec to G.711 might solve the issue.

In addition, jitter is a variation in packet transit delay caused by particular circumstances on the path through the network. It is a smoothed derivative of the inter-arrival delta. So it will not get nearly as high as the deltas itself, unless

TABLE II.
PACKET STREAM ANALYSIS (FORWARD PACKET STREAM ONLY)

| Packet | Sequence | Max delta (ms) | Jitter (ms) | Skew (ms) | IP B/W (kbps) |
|---|---|---|---|---|---|
| 1984 | 51942 | 29.80 | 0.93 | 0.09 | 18.35 |
| 1986 | 51943 | 30.13 | 0.88 | -0.04 | 18.35 |
| 1988 | 51944 | 31.26 | 0.90 | -1.29 | 18.35 |
| 1990 | 51945 | 29.09 | 0.90 | -0.38 | 17.70 |
| 1992 | 51946 | 29.66 | 0.87 | -0.04 | 17.50 |
| 1993 | 51947 | 0.50 | 2.03 | 19.46 | 17.84 |
| 1995 | 51948 | 29.54 | 1.93 | 19.92 | 17.84 |
| 1997 | 51949 | 29.87 | 1.82 | 20.05 | 18.18 |
| 2000 | 51950 | 60.00 | 1.71 | 20.05 | 17.84 |
| 2004 | 51952 | 1.01 | 2.65 | 19.04 | 17.68 |
| 2006 | 51953 | 29.05 | 2.54 | 19.99 | 17.46 |
| 2008 | 51954 | 30.00 | 2.38 | 19.99 | 17.23 |
| 2010 | 51955 | 29.65 | 2.26 | 20.33 | 17.01 |
| 2015 | 51957 | 30.03 | 3.18 | -0.06 | 17.01 |
| 2017 | 51958 | 29.65 | 3.00 | 0.29 | 17.01 |
| 2019 | 51959 | 30.51 | 2.85 | -0.22 | 17.01 |
| 2021 | 51960 | 29.81 | 2.68 | -0.04 | 17.01 |
| 2023 | 51961 | 29.87 | 2.52 | 0.09 | 17.01 |
| 2025 | 51962 | 29.76 | 2.38 | 0.34 | 17.01 |
| 2027 | 51963 | 30.10 | 2.24 | 0.24 | 17.01 |
| 2029 | 51964 | 29.99 | 2.10 | 0.25 | 17.01 |
| 2031 | 51965 | 30.30 | 1.98 | -0.05 | 17.01 |

fluctuation of deltas are very frequent and has high amplitude over a longer period of time. In Table II we can see that the maximum jitter is 3.18 ms with the average jitter of 2.03 ms. Figure 6 shows the characteristic of jitter, in both forward and reverse streams, on the test-bed system during 21 seconds period of measurement time. The jitters in forward stream fluctuated as the effect of queuing, contention or serialisation effects in the network. In contrast, the reverse jitters are considerably constant. It is not due to the better packets streaming from F-UE2 to F-UE1, but the reason is only those received packets have been captured at the captured port. Providing the proper size of jitter buffer might solve the issue.

## VI. CONCLUSION

The testbed development conducted in this work is a lab scale of integrated IMS and femtocell network. Two test cases, i.e., registration process to IMS, and call setup between two IMS' clients were conducted to analyse the performance of the system. It included the measurements of generated traffics, jitter, max delta, and bandwidth usage.

The analysis of packet stream considered five most common protocols in IMS system, i.e., SIP, HTTP, TCP, UDP and RTP. Despite having max delta and jitter issues, the simulated testbed, the proposed SIP/IMS-based integration with all-IP connectivity, and session establishment procedure of integrated IMS-Femtocell network as the next generation wireless network platform have been proven to working well.

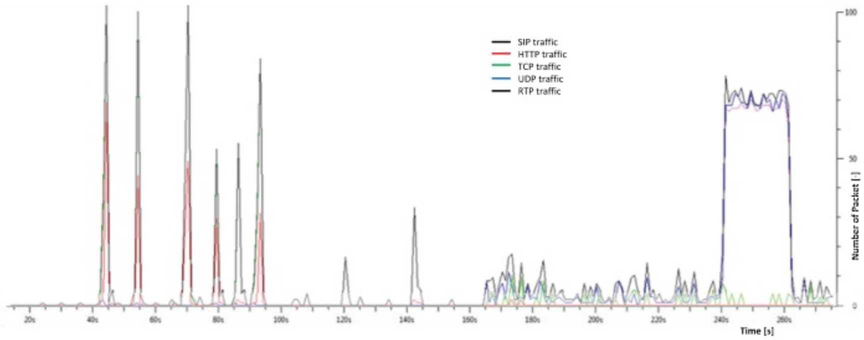


Fig. 4 Example of traffic characteristic on integrated IMS and Femtocell network (passed through the FAP)

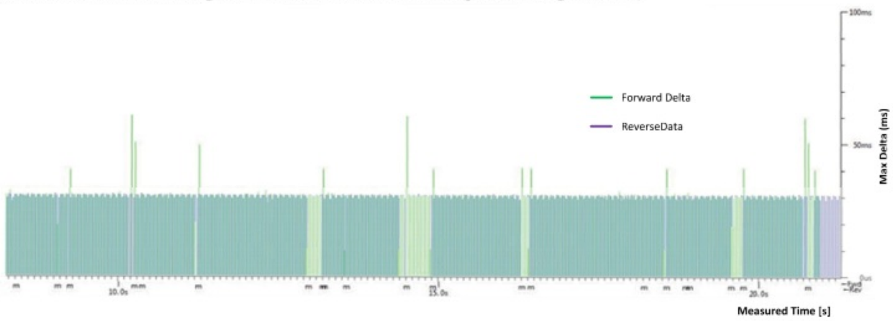


Fig. 5. Example of max delta; forward stream (F-UE1 to F-UE2), reverse stream (F-UE2 to F-UE1)

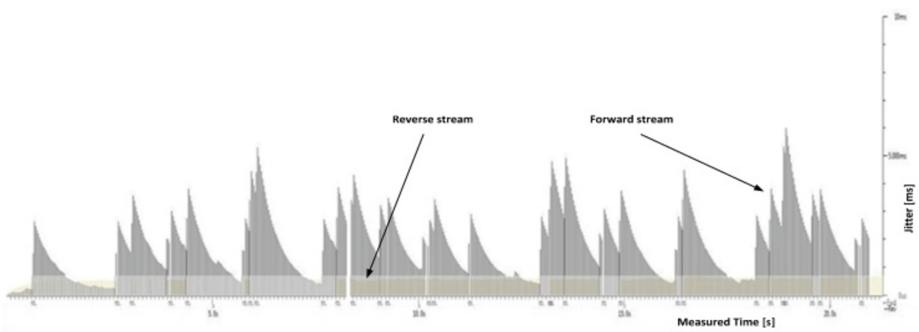


Fig. 6. Example of jitter characteristic; forward stream (F-UE1 to F-UE2), reverse stream (F-UE2 to F-UE1)

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