Jitter Analysis of LTE Traffic over MPLS Based Evolved Packet Core Network

Hussien M. Hussien and Hussein A. Elsayed
Electronics and Communication Eng. Dept.
Faculty of Engineering, Ain Shams University
Cairo, Egypt
E-mail: hussien.mahm@gmail.com, helsayed2003@hotmail.com

Abstract—3GPP Long Term Evolution (LTE) and Evolved Packet Core (EPC) are the most advanced technologies in the wireless and mobility field, since they provide high speed data and various sophisticated applications to Mobile Users. LTE is a key technology to various high speed applications, which require efficient performance. Packet Jitter is one of the most important performance parameters for those applications. Thus, several researches have been conducted in the LTE radio layer to study the Jitter performance, but they lack the EPC core network layer effect. This paper presents intensive simulation study of LTE-EPC traffic Jitter performance over Multiprotocol Label Switching (MPLS) core network using a Poisson Process traffic generator. MPLS is proposed in conjunction with the EPC to provide better efficiency in modern integrated networks in terms of packet Jitter variations, which is shown to be much better than IP routing trends. The simulation investigates both of the IP and MPLS models, and evaluates the end-to-end performance. The MPLS Model is simulated by MPLS core routers attached to the Packet Data Gateway (P-GW) EPC data plane, while the IP model uses IP core routers instead. These two models are fed by a Poisson traffic source, which matches the statistical properties of real-time IP Internet traffic. The Jitter performance of the two LTE-EPC models shows the enhancement caused by MPLS.

Keywords-LTE; EPC; MPLS; NS-3; Jitter.

I. INTRODUCTION

3GPP Long Term Evolution (LTE) [1][2][3] is the most advanced wireless technology implemented nowadays. LTE is a high speed wireless technology based on Orthogonal Frequency-Division Multiple Access (OFDMA) on downlink and Single Carrier Orthogonal Frequency-Division Multiple Access (SC-FDMA) in uplink. The advanced LTE technology in wireless access is integrated with the EPC, which is the core network data carrying all network related procedures (e.g., mobility management and session management, etc.). The 3GPP organization defines the EUTRAN [1] and EPC [2][3] as the main architecture of the LTE-EPC Network. As shown in Figure 1, LTE-EPC is composed of Evolved Node B (eNodeB), Mobility Management Entity (MME), Home Subscriber Server (HSS), Serving Gateway (S-GW), Policy Control Charging Rules Function (PCRF), and P-GW.

EPC supports various applications including web browsing, video streaming, machine-to-machine, peer-to-peer, VoIP applications, video conferences, and social networking. All of these emerging IP applications are pushing the research communities to produce optimized network simulation model, not only for the LTE radio but also for the corresponding core network [4], which is noticeable in the Advanced Long Term Evolution (LTE-A) research plans. In this paper, the end-to-end LTE-EPC research is studied using NS-3 simulator, which is an open source simulator with a satisfactory level of accuracy to run network simulation under Linux system machine [5]. A previously published work on LTE [6] is used to simulate UE, eNodeB, and S/P-GW with the user plane characteristics. The end-to-end LTE-EPC model is introduced by UDP transport between the source and the destination to test the EPC IP based solutions.

A realistic traffic model is introduced by Poisson process traffic source. This model generates a long range dependent traffic, which can be viewed as the asymptotic case of heavy-tailed on-off sources[7]. Normal Poisson source cannot be used to model mobile networks [12] because it fails to simulate Long Range Dependent (LRD) traffic streams used in broadband networks [8][10][11]. Therefore, a natural candidate is introduced to model the LRD packet data traffic streams. Modern research papers [13] proved that Poisson Pareto Burst Process (PPBP) model provides an accurate model of the aggregated mobile user traffic because of its observations of heavy tail behavior of flow volumes and durations in mobile networks [14].

The majority of the existing NS-3 LTE research papers target the radio mobility [15] and related procedures, such as handover scenarios, algorithms [16], and LTE schedulers [17], which are concentrated at the eNodeB interfaces like S1-U interface. It is clear that such researches lack the core EPC connectivity and performance with respect to the radio interface technology. However, due to the higher layers services demand, the behavior of the network as end-to-end is mandatory to our design. Since it is obvious that all-IP evolution has been the trend of LTE-EPC, LTE EPC user plane [18][19] is used this paper and integrated with the MPLS technology with the appropriate traffic model. PPBP is selected as an Internet traffic type to analyze its characteristics with respect to traffic Jitter, which is evaluated in case of IP network without MPLS. MPLS is a well-known technology, which is widely used in modern network design as a replacement for the traditional IP networks since it copes the IP network shortcomings [20]. In fact, to the best of our knowledge, there is no previously published MPLS-based approach for LTE-EPC core networks with PPBP IP Internet traffic performance

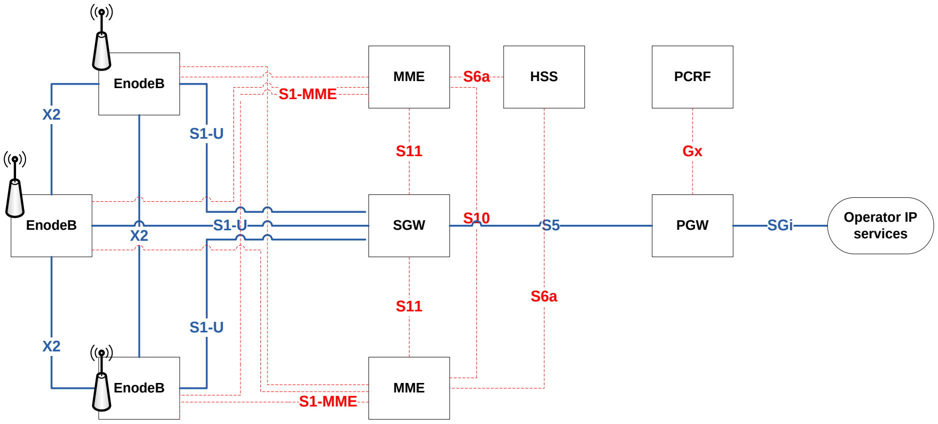

Figure 1. LTE-EPC Architecture

evaluation. But, previous work was done on integrating MPLS with UMTS [21].

The ultimate objective of the presented simulation is to become widely accepted evaluation reference for LTE-EPC and MPLS integration systems. LTE-EPC architecture, which was already developed by [6] is integrated with MPLS core network traffic engineering strategies and investigated the performance with PPBP Internet traffic to have an end-to-end vision. Poisson parameters were modeled based on real life network readings, which can be changed from one network to another based on the operator and country profiles.

The rest of the paper is consists of four sections. Section II explains the high level design aspects of the proposed EPC architecture, and the NS-3 limitation with respect to the LTE technology, the EPC connectivity and the used uplink/downlink traffic design, while Section III details our design implementation steps in terms of LTE radio parameter values, Poisson source design, MPLS architecture, and EPC NS-3 configuration. The simulation results and analysis are provided in section IV. Finally, Section V concludes the paper.

II. DESIGN CRITERIA AND ARCHITECTURE

The EPC-MPLS module that is presented in this paper aims to evaluate and compare the Jitter of the two investigated modes under realistic traffic source. The Internet traffic model is Poisson, which is based on overlapped multiple bursts with heavy-tailed distributed lengths. The focus here is on the EPC data plane, the EPC control plane is currently outside our scope. The simulation focus is on EPS connection management (ECM) connected mode; ECM idle mode is not a part of the simulation. The uplink and downlink are separated in two different Traffic Flow Types (TFT). IPv4 is considered in this simulation but IPv6 is not yet included. One S/P-GW is selected in the design to simplify the simulation model without affecting the conclusive results.

The simulation is done once with IP static Routers as shown in Figure 2; and secondly, with MPLS routers, as in Figure 3. Both of the simulation scenarios run on the same throughput and PPBP parameters; therefore, the IP and MPLS cases are compared at the same conditions. The

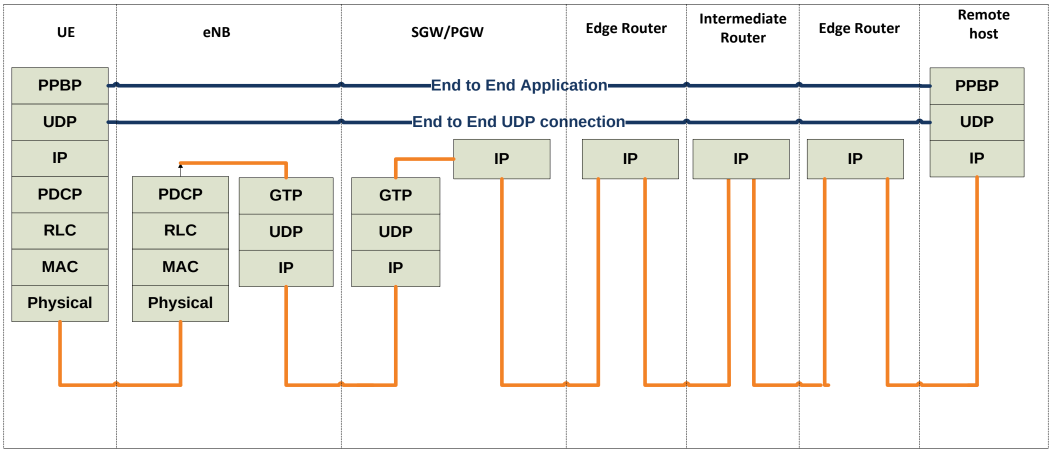

Figure 2. End to End LTE-EPC with IP core Network

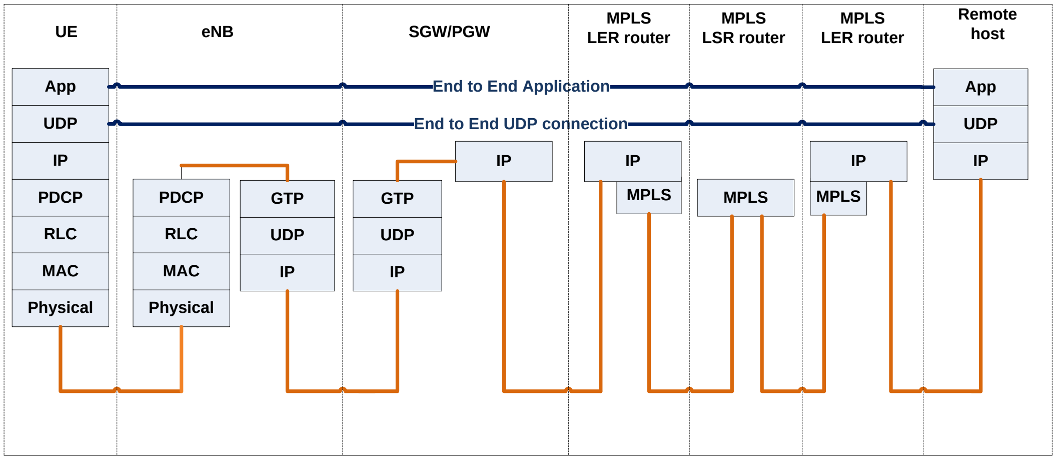

Figure 3. End to End LTE-EPC with MPLS core Network

network topology supported by the proposed simulation is composed of two parts: the LTE-EPC part and MPLS part. LTE-EPC model includes, as in [18][19], the radio protocol stack (PDCP, RLC, MAC, and physical) and the core part. As shown in Figure 3, MPLS portion is composed of three parts namely, LER, LSR, and LER; and finally, the application server running over UDP protocol.

The system architecture shown in Figure 3 represents an end-to-end LTE-EPC with MPLS core network and UDP server. Our case study is to evaluate the MPLS design flow and the end-to-end data delivery for LTE traffic. The MPLS uplink traffic is assigned with label different from the MPLS downlink traffic such that each Label Edge Router (LER) pushes a different label to the packets depending on the their flow. The Label Switch Router (LSR) does a packet swap to replace the initially pushed label with an intermediate one. At the other end, LER removes the labels and deliver the packets to the destination.

III. IMPLEMENTATION

LTE-EPC diagram is divided into three different layers, as illustrated in Figure 4. The first layer is the LTE radio layer, which involves the UE connectivity to UE’s. The EPC core is the second one and it involves the eNodeB IP connectivity to S/P-GW. Finally, the third layer is the application, which involves the S/P-GW connectivity to the application part. The following subsections describe those layers.

A. Poisson Traffic Generator

The used traffic source is Poisson traffic generator [7], which is a process based on multiple overlapping bursts, where the burst lengths follow a heavy-tailed distribution. So, it appears to reflect the basic properties of at least some aggregated data traffic; and it is based on the models that are closely related to the M/G/∞ models as shown in Eq. (1), where the bursts arrive according to a rate (λ). The packet length follows a Pareto distribution characterized by Hurst parameter H, typically between 0.5 and 0.9, and a mean burst time length T_{on}. Each burst is modeled by a flow of constant bit rate (r), as shown in Eq. (2), and overlapping bursts form aggregated long range dependent traffic with burst length of infinite variance [14]. For our design, the PPBP mean burst arrival is selected to be 10, and the mean burst time length to be 0.1, which matches the statistical properties of selected real-life IP Internet traffic. Thus, the burst data rate equals to the bursts arrival rate λ as shown in Eq. (3). The data rate speed is simulated from 1Mbps up to a maximum throughput of 17.568 Mbps, which is selected based on the radio interface design;

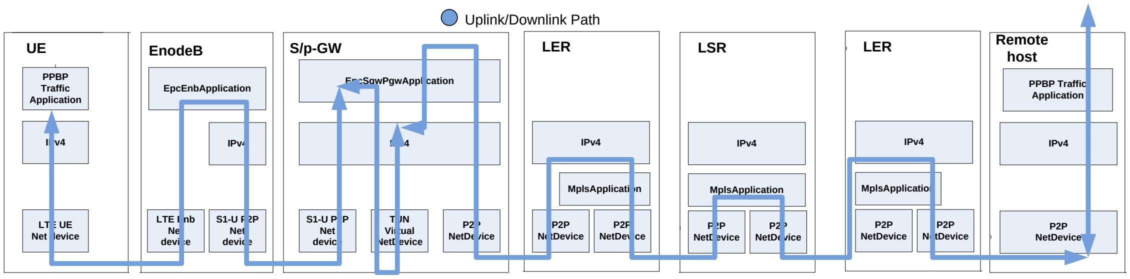

Figure 4. Internal processes for Two Single Path MPLS Sites with Traffic Engineering

ISBN: 978-1-61208-439-8

$$E[n] = T_{on} \times \lambda_p \tag{1}$$

$$\lambda = T_{on} \times \lambda_p \times r \tag{2}$$

Thus,

$$\lambda = r \tag{3}$$

where 1Mbps < r <17.568 Mbps and λ_p is the mean burst arrival, T_{on} is the mean burst time length, λ is the bursts arrival rate.

B. LTE Radio layer

Significant radio parameters are used to simulate real traffic. NS3 Proportional Fair MAC Scheduler (PF) is used and the path loss is based on Friis spectrum propagation loss mode. The uplink/downlink bandwidth and related physical parameters are illustrated in TABLE I. The user is simulated at a negligible distance, i.e., zero downlink distance with MCS 28 (modulation and coding scheme) and transport block size (tbs) 26. From tables 7.1.7.2.1-1 of 3GPP 36.213 [23] one user at 24 Physical Resource Block (PRB), tbs 26 and packet size of 2196 would give a maximum throughput of 2196000 bytes/sec that is 17.568 Mbps. Therefore, all of our simulations would have a maximum throughput of 17.568Mbps.

C. EPC Core Layer

As per [6], UE is assigned a public IPv4 address in the 7.0.0.0/8 network and the PGW is getting address 7.0.0.1, which is used as a gateway to all UEs to the Internet. All of the eNodeB is implemented with a set of point-to-point links towards the S/P-GW. By default, a 10.x.y.z/30 subnet is assigned to each point-to-point link. Different TFT instances are assigned based on local/remote IP address, and port number for uplink and downlink. Each TFT is mapped to a special packet and a special class creating two separate bearers for uplink and downlink traffic. This would add the advantage for traffic segregation on the LTE Radio, EPC core, and furthermore, on the MPLS core layer.

TABLE I. LTE RADIO INTERFACE PARAMETERS.

Radio Parameter	Value
UlBandwidth	25MHz
DlBandwidth	25MHz
DlEarfcn	100
UlEarfcn	18100

D. MPLS Core layer

The third layer adds an end-to-end IP communication using MPLS core site. Subnet 192.168.1.0/30 is allocated between router and remote host, subnet 192.168.1.4/30 is allocated between router and S/P-GW, and private subnets 10.1.1.0/24 and 10.1.3.0/24 are assigned internally between MPLS routers. The MPLS process implemented by NS-3 simulator is powerful as it simulates the main rule of the MPLS label switching such as the Forwarding-Equivalence-Class to Next-Hop-Label Forwarding-Entry (FEC-to-NHLFE) map, which is a mapping from the FEC of any incoming packets to corresponding NHLFEs. The main task is the Next Hop Label Forwarding Entry (NHLFE), which represents an entry containing next-hop information (interface and next-hop address) and label manipulation instructions. It also contains all information required for processing packets such as label encoding, L2 encapsulation information, and others. The second main task is the Incoming Label Map (ILM) that maps the incoming labels to corresponding NHLFEs, which is mainly found in the intermediate nodes for fast label switching such as LSR.

IV. DATA SIMULATION AND VERIFICATION

The simulation is composed of two parts: the LTE-EPC part and MPLS part. The NS-3 LTE-EPC model includes the radio protocol stack (PDCP, RLC, MAC, and physical) and the core part resides with S-GW and P-GW; and it includes the GTP protocol. The MPLS nodes include the three types, LER, LSR, and LER. The application server, which runs over UDP protocol, represents the traffic source. Figure 4 represents the end-to-end LTE-EPC with MPLS core network and UDP server. This setup allows us to validate the MPLS network efficiency from the user plane point of view. The user traffic is a PPBP UDP client-server model. The simulation is done with a normal MPLS routing versus a normal IP routing protocol, as in Figure 2 and Figure 3. The MPLS traffic is separated into uplink/downlink traffic in different paths via the traffic engineering with VPN label designed.

A. Simulation Inputs

Regarding to the simulation inputs, the simulation time is 5 seconds, the maximum speed supported by the NS-3 simulator RLC model is 17.568 Mbps according to the used scheduling technique. Accordingly, specific values are selected for verification from a speed of 10Mbps up to 17Mbps with a step of 1Mbps.The packet size is selected to be 512 Bytes; the mean burst arrivals to be 10, and the mean burst time length to be 0.1, which matches the statistical properties of real-life selected IP Internet traffic.

B. Simulation Results

This paper provides the Jitter histogram comparison between the two introduced architectures at different selected data throughputs. The throughput is selected to be 13Mbps, 15Mbps and 17 Mbps. The effect of MPLS is clearly noticeable with respect to the Jitter variation of the packets. The packets received by the UDP server using MPLS technology is having higher values at lower Jitter counts and the histogram is concentrated at the lower Jitter values, as shown in Figures 5, 6, and 7.

The MPLS Jitter variation is enhanced with a much narrower curve and higher probability of low Jitter, this effect is mainly concentrated at lower speed values. As shown in Figure 5, at 13 Mbps, MPLS had a maximum Jitter value of 0.032, and the IP had a maximum Jitter value of 0.036, i.e., MPLS has a better performance than IP. Furthermore, at higher data throughputs, MPLS effect is clearly noticeable. As shown in Figure 6, at 15 Mbps, MPLS Jitter increased to 0.42 while IP increased to 0.49. The difference between MPLS maximum Jitter and IP maximum Jitter increased at 17 Mbps, which is shown in Figure 7 with 0.051 for MPLS Jitter and 0.083 for IP Jitter.

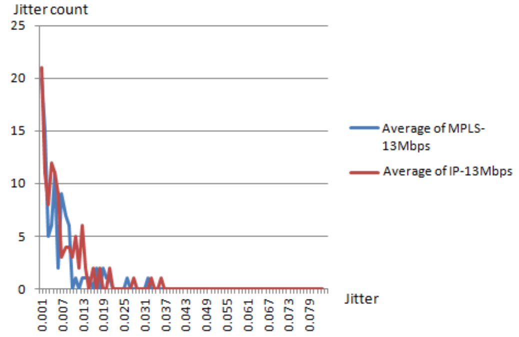

Figure 5. Jitter histogram at 13Mbps

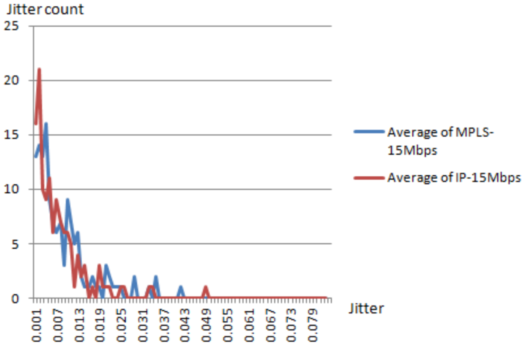

Figure 6. Jitter histogram at 15 Mbps

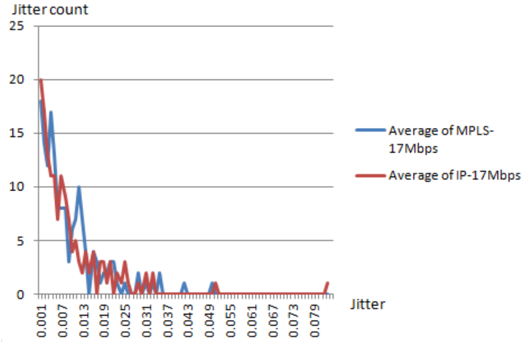

Figure 7. Jitter histogram at 17Mbps

A mathematical calculation is done to prove the MPLS advantage with respect to IP routers. For each of the simulation trials, the maximum Jitter is calculated and counted for the IP and the MPLS system as in TABLE II. Furthermore, TABLE II defines Jitter Enhancement Percentage (ρ) and in the average, it is calculated to be the difference between IP maximum Jitter and MPLS maximum Jitter as shown in Eq.(4). The IP maximum Jitter is assumed to be (β), and the MPLS maximum Jitter is assumed to be (α).

Thus,

$$\rho = \frac{100*(\beta-\alpha)}{\beta} \tag{4}$$

The Jitter enhancement percentage is calculated through multiple simulation trial. The Maximum value is 38.55 % at 17Mbps and the lowest values is 16% at 11 Mbps. The average value is calculated over the simulation trials and it is found to be 19.9%, which is a reasonable effect. Thus, the packet Jitter increases with the throughput for both the IP and MPLS, where for the IP it is increasing more rapidly and for the MPLS the curve is more declined with a lower Jitter.

TABLE II. MAXIMUM JITTER VALUE.

Throughput (Mbps)	IP Max. Jitter (β)	MPLS Max. Jitter (α)	Jitter Enhancement Percentage (ρ)
11	0.025	0.021	16.00
13	0.036	0.032	11.11
15	0.049	0.042	14.29
17	0.083	0.051	38.55

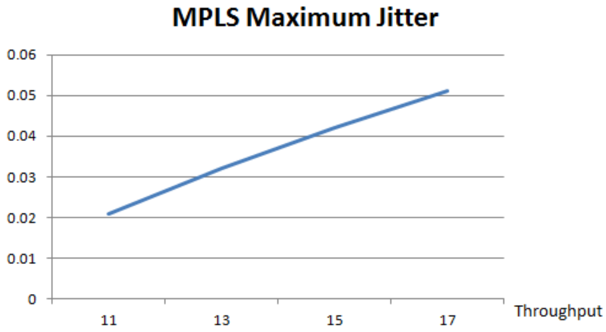

Figure 8. MPLS Maximum Jitter Values

MPLS maximum Jitter is plotted versus the simulation throughput in Figure 8. It is found that the MPLS maximum Jitter is increasing slightly with respect to the throughput, which is much better than the IP trends

V. CONCLUSION AND FUTURE WORK

The introduced core MPLS network approach is a novel one. This paper provided an overview of the design criteria using an MPLS label switching and normal IP routing to provide the LTE-EPC network manufacturer detailed analysis. MPLS packet Jitter variation is better than the normal IP routing trends. The Jitter simulation results proved that the effect of the MPLS is clearly noticeable, where the MPLS have a better performance with respect to UDP server received packets with lower Jitter and minimum variance. MPLS clearly enhanced the packet Jitter variations as already discussed in the simulation graphs. A mathematical analysis is done, which shows that MPLS improves the network Jitter enhancement percentage parameter with average 19.9 %. This is not only the gain because MPLS has a lot of add features as well. If more MPLS features are added, such as load balancing, service resilience, and QoS support of LTE-EPC network, MPLS will be much more efficient with respect to packet forwarding through the MPLS labels, better load balancing through the MPLS traffic engineering, and better service resilience with respect to restoration of core networks disaster. Moreover, MPLS end-to-end QoS is enhanced compared to that of IP.

Further research point can address the challenges for Wi-Fi and LTE-U with MPLS technology. This point should be important one for LTE-U, which is a new LTE technology developed for the unlicensed band [24].

REFERENCES

[1] 3GPP. TS 36.300, "E-UTRA and E-UTRAN overall description".

[2] 3GPP. TS 23.401, "GPRS enhancements for E-UTRAN access".

[3] 3GPP. TS 23.402, "Architecture enhancements for non-3GPP accesses".

[4] S. Jimaa, K. Chai, Y. Chen, and Y. Alfadhl, "LTE-A an overview and future research areas," Wireless and Mobile Computing, Networking and Communications (WiMob), 2011 IEEE 7th International, Oct. 2011, pp. 395–399, ISSN: 2160-4886, ISBN: 978-1-4577-2013-0, Wuhan (China).

[5] The Network Simulator NS-3. [Online]. Available from: http://www.nsnam.org 2015.10.01.

[6] The Network Simulator LENA Project. [Online]. Available from: http://iptechwiki.cttc.es/LTE-EPC 2015.10.01.

[7] D. Ammar, T. Begin, and I. Lassous, "A new tool for generating realistic Internet traffic in NS-3," The 4th International ICST Conference on Simulation Tools and Techniques (SIMU Tools 11), March 2011, pp. 81-83, ISBN: 978-1-936968-00-8, Barcelona (Spain).

[8] J. Beran, R. Sherman, M. S. Taqqu and W. Willinger, "Long-range dependence in variable-bit-rate video traffic," Communications, IEEE Transactions on 43, no. 2/3/4 (1995): 1566-1579.

[9] W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson, "On the self-similar nature of Ethernet traffic (extended version),"IEEE/ACM Transactions on Networking, vol. 2, no. 1, Feb. 1994, pp.1-15.

[10] V. Paxson and S. Floyd, "Wide-area traffic: The failure of Poisson modeling, "IEEE/ACM Transactions on Networking, vol. 3, no. 3, June 1995.

[11] W. Willinger, M. S. Taqqu, R. Sherman, and D. V. Wilson, "Self similarity through high-variability: Statistical analysis of Ethernet LAN traffic at the source level, "IEEE/ACM Transactions on Networking, vol. 5, no. 1, Feb 1997.

[12] M. Ivanovich, T. Neame, and P. Fitzpatrick, "Modeling GPRS Data Traffic," IEEE Global Telecommunications Conference, GLOBECOM '04, Dec. 2004, pp. 3300 – 3304, ISBN: 0-7803-8794-5, Sydney(Australia).

[13] K. Madseny, H. P. Schwefely, M. B. Hansenz, J. R. Prasady, "Traffic Modeling in GPRS Networks," The Eight International Symposium on Wireless Personal Multimedia Communications (WPMC '05), Sept. 2005, Aalborg (Denmark).

[14] M. Zukerman, T. D. Neame, and R. G. Addie, "Internet Traffic Modeling and Future Technology Implications," IEEE Twenty-Second Annual Joint Conference of the IEEE Computer and Communications (INFOCOM 2003), April2003, pp. 587-596, ISBN 0-7803-7752-4, California (USA).

[15] B. Herman, N. Baldo, M. Miozzo, M. Requena, and J. Ferragut, "Extensions to LTE mobility functions for ns-3,"The 2014 Workshop on (WNS3 '14), May 2014, ISBN: 978-1-4503-3003-9, New York (USA).

[16] N. Baldo, M. Requena-Esteso, M. Miozzo and R. Kwan, "An open source model for the simulation of LTE handover scenarios and algorithms in ns-3," The 16th ACM international conference on Modeling, analysis & simulation of wireless and mobile systems (MSWiM '13), Nov.2013, Pages 289-298, ISBN: 978-1-4503-2353-6, New York (USA).

[17] D. Zhou, N. Baldo, M. Miozzo, "Implementation and validation of LTE downlink schedulers for ns 3," The 6th International ICST Conference on Simulation Tools and Techniques (SimuTools '13), March 2013, pp. 211-218, ISBN: 978-1-4503-2464-9,Brussels(Belgium).

[18] N. Baldo, M. Requena-Esteso, J. Nin-Guerrero, and M. Miozzo, "A new model for the simulation of the LTE-EPC data plane," In ICST Workshop on ns-3 (WNS3), March 2012, Sirmione (Italy).

[19] N. Baldo, M. Miozzo, M. Requena-Esteso, and J. Nin-Guerrero, "An open source product-oriented LTE network simulator based on ns-3," The 14th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems (ACM MSWiM), Oct. 2011, pp. 293-298, Florida (USA).

[20] A. Ayyangar and D. Sidhu, "Analysis of MPLS based Traffic Engineering Solution," IEEE International Conference on ATM and High Speed Intelligent Symposium, Apr. 2001, pp. 21–27, ISBN 0-7803-7093-7, Seoul (South Koria).

[21] H. Chueh and K. Wang, "An all-MPLS approach for UMTS 3G core networks," Vehicular Technology Conference, IEEE 58th IEEEVTC, Oct. 2003, pp. 2338-2342, ISSN: 1090-3038, ISBN: 0-7803-7954-3, Florida (USA).

[22] Cisco Visual Networking Index, "Global Mobile Data Traffic Forecast Update," 2013–2018,whitepaper, [Online]. Available from: www.cisco.com 2015.10.01.

[23] 3GPP. TS 36.213, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures,".

[24] A. Al-Dulaimi, S. Al-Rubaye, N. Qiang and E. Sousa, "5G Communications Race: Pursuit of More Capacity Triggers LTE in Unlicensed Band," IEEE, Vehicular Technology Magazine, March 2015, pp. 43–51, ISSN 1556-6072 , Toronto(Canada).