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Enabling Network Programmability in LTE/EPC Architecture Using OpenFlow

Malla Reddy Sama, Siwar Ben Hadj Said, Karine Guillouard and Lucian Suciu
Orange Labs, Cesson-Sévigné, France
Emails: {mallareddy.sama, siwar.benhadjsaid, karine.guillouard, lucian.suciu}@orange.com

***Abstract*—Nowadays, mobile operators face the challenge to sustain the future data tsunami. In fact, today's increasing data and control traffic generated by new kinds of network usage puts strain on mobile operators', without creating any corresponding equivalent revenue. In our previous work, we analyzed the 3GPP LTE/EPC architecture and showed that a redesign of this architecture is needed to suit future network usages and to provide new revenue generating services. Moreover, we proposed a new control plane based on the OpenFlow (OF) protocol for the LTE/EPC architecture that enables flexibility and programmability aspects. In this paper, we are interested in the programmability aspect. We show how the data plane can be easily configured thanks to OF. In addition, we evaluate the signaling load of our proposed architecture and compare it to that of 3GPP LTE/EPC architecture. The preliminary findings suggest that managing the data plane with OF has little impact on the signaling load while the network programmability is improved.**

***Index Terms*—SDN, OpenFlow, Signaling load, 3GPP LTE/EPC architecture and NFV.**

I. INTRODUCTION

The fast growing population of users leads to an exponential increase in connectivity demands in mobile network. Cisco forecasts [1] shows that mobile data traffic will grow at a Compound Annual Growth Rate (CAGR) of 61% from 2013 to 2018. This significant growth will be driven by new mobile applications (e.g. location based check-in services, emerging mobile games, mobile multimedia services, etc.), high-end devices (e.g. Smartphones, tablets, etc.), and also ubiquitous high-bandwidth coverage such as Long Term Evolution (LTE).

The 3GPP Long Term Evolution / Evolved Packet Core (LTE/EPC) architecture has been designed to provide seamless IP connectivity between user equipment (UE) and external Packet Data Networks (PDNs). Nowadays, LTE/EPC architecture experiences a period of rapid and massive change due to dynamic traffic pattern [2]. Moreover, a recent study shows that network operators risk an "end of profit" sometime before mid-2015 [3]. Indeed, the cost to build, upgrade or operate the network is becoming too high while network operator' revenues are decreasing exponentially [4]. In the light of these predictions, mobile network operators are invited to revisit the design and capabilities of their architectures with a twofold objective of reducing expenses and introducing new revenue generating services.

Among the wide variety of mobile applications, several background text-messaging applications (e.g Facebook notifications and messages, Viber, Skype, WhatsApp, etc.) send keep-alive messages to their servers periodically. Establishing and maintaining mobility tunnels in the data plane to just transport these short messages increases the load in the LTE control plane. In fact, in LTE/EPC architecture, the User Equipment (UE) has two states: CONNECTED and IDLE states. In the first state, the UE is active and the data plane is established. In the second state, the UE has no active sessions and the data plane is released. Therefore, the UE should alternate between IDLE and CONNECTED states very often just to send the background application messages. This periodic alternation between states leads to exchanging a lot of control messages between the UE and the network [5]. A technical report from Nokia Siemens shows that smart phones and tablets consume 40% of the data traffic and generate 99% of the signaling traffic [6]. Such unexpected/extra signaling traffic may lead to periodic congestion in network and even network equipment failures [7].

In this context, network operators should investigate new solutions to manage the dynamic nature of future traffic in a cost-efficient manner. There have been several research papers ([8], [9], [10], [11], and [12]) and technical reports from standardization bodies such as ONF Wireless & Mobile group [13] and ETSI NFV [14] that address the challenge caused by mobile data traffic increase in LTE/EPC architectures. These papers highlighted the need for a more adaptive network connectivity. For instance, [10] proposed to send short sporadic data messages through the LTE/EPC control plane instead of establishing the data plane each time. This proposal reduces the signaling load related to the data plane establishment but it goes against the control and data plane separation principle that was introduced in LTE/EPC architecture specification.

Network operators recognize the opportunity to tap into advanced technologies such as server virtualization, efficient traffic management, and automation tools in order to reduce overall operating cost and provide Quality of Experience (QoE) adapted to user needs. The OpenFlow (OF) [15] protocol offers such a solution and is rapidly gaining attention.

In [16], we proposed an OF-based LTE/EPC architecture and explained how it enables flexibility and network programmability. Via two scenario uses case namely resiliency and load balancing, we showed that OpenFlow (OF) can greatly improve network flexibility . In this paper, we would rather focus on the programmability aspect. We show how OpenFlow enables network operator to easily parameterize the data plane according to the session nature and the user profile. As a first step of feasibility study, we evaluate the signaling load in our architecture and compare it to that in the current 3GPP LTE/EPC architecture. The preliminary findings show that managing the sessions with OF has little impact on signaling load while programmability is improved.

The rest of the paper is structured as follows. Section II briefly introduces the LTE/EPC architecture. In Section III, we provide details of our designed architecture. Since we should ensure that the session management procedures in the new architecture do not incur more signaling load, we define and develop the signaling costs related to each approach in Section IV. Numerical results are presented and discussed in Section V. Finally, Section VI concludes the paper and outlines some future work.

II. OVERVIEW OF THE 3GPP LTE/EPC ARCHITECTURES

A. Architectural model

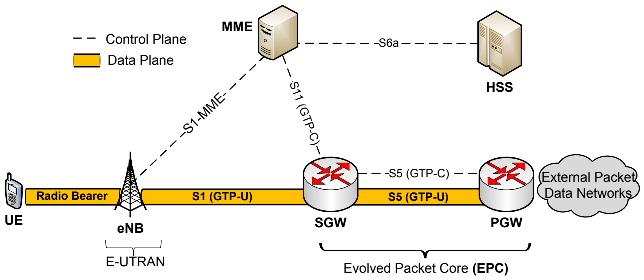

Fig. 1. LTE/EPC architecture.

The LTE/EPC architecture is composed of the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the EPC core (Fig.1). The E-UTRAN includes eNodeBs (eNBs). The EPC core consists of four network elements namely Serving Gateway (SGW), PDN Gateway (PGW), Mobility Management Entity (MME), and Home Subscriber Server (HSS) [17]. The eNBs are right connected to MME and SGW by means of S1-MME and S1-U interfaces, respectively. The MME acts as the manager of the network connectivity. It is responsible for UE authentication and authorization, UE session setup, and intra-3GPP mobility management. The SGW and PGW are responsible for data forwarding, IP mobility and QoS control at the data plane. The QoS level that should be affected to each bearer is decided by the PGW. When the UE is in IDLE state, the radio data bearer (i.e. between UE and eNB) and the S1 data bearer (i.e. between eNB and SGW) are released. The S5 data bearer (i.e. between SGW and PGW) is maintained as long as the UE is registered to the network. The data traffic forwarding between the eNB, the SGW and the PGW is based on the GPRS Tunneling Protocol (GTP).

B. Data plane management

In our study, we are interested in three main procedures related to the data plane management namely initial attachment, access bearer setup, and access bearer release.

1) Initial Attachment: enables the UE registration to the network during the UE initial power on [17] (see Fig.2). The UE sends an *Attach Request* message to eNB, which includes its identity. The eNB forwards this message to MME. After a successful authentication, the MME starts the default bearer setup by sending *Create Session request* to SGW which creates a new entry in its table and sends the same message to PGW. Similarly, the PGW creates new entry in its table and returns to the SGW *Create Session Response* message. The SGW updates the entry related to this UE and sends the same message to MME. Therefore, the S5 data bearer is setup. Then, the MME sends to the eNB the *Attach Accept* message piggybacked with the *Initial Context Setup Request* message to setup the S1 data bearer. The eNB establishes the radio data bearer, forwards the *Attach Accept* message to the UE and sends back to the MME the *Initial Context Setup Response* message. At this time, the MME sends to the SGW the *Modify Bearer Request* message. In case the UE hands over from non-3GPP access such as WiFi access to the LTE access, the MME should insert Handover Indication in the *Modify Bearer Request* message and the SGW should inform the PGW through the *Modify Bearer Request* message. This will prompt the PGW to start forwarding the UE packet to current LTE access. At the end of this procedure, the UE is in CONNECTED state.

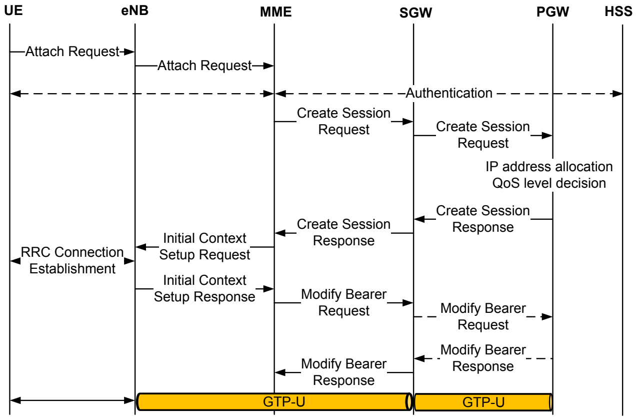

Fig. 2. Initial attachment procedure.

2) Access Bearer Setup: is performed when the UE wants to move from IDLE to CONNECTED state (see Fig.3). As the S5 data bearer is maintained even when the UE is in IDLE state, this procedure will just establish the radio and S1 data bearers. Upon receiving *NAS Service Request* message from UE, the eNB transparently relays the NAS message to the MME. This latter initiates the UE authentication when no UE context exists. The MME sends to eNB the *Initial Context Setup Request* message. The eNB establishes the radio data bearer and sends back to the MME the *Initial Context Setup Response* message. The MME and the SGW exchanges *Modify Bearer Request* and *Modify Bearer Response* messages. At the end of this procedure, radio and S1 data bearers are established and the UE is in CONNECTED state.

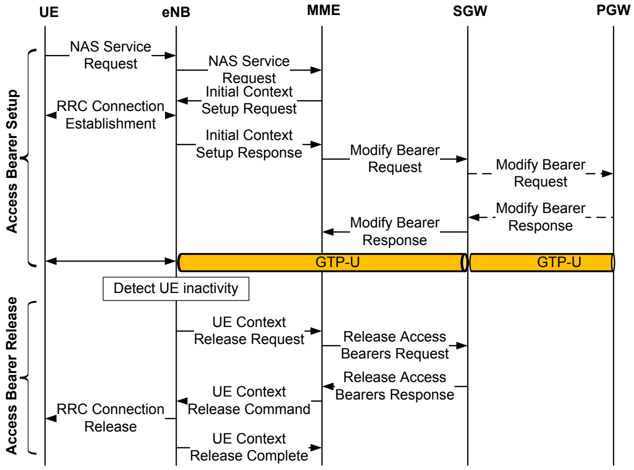

Fig. 3. Access bearer setup and release procedures

3) Access Bearer Release: is triggered when the eNB detects the UE inactivity (see Fig.3). The eNB sends to MME the *UE Context Release Request* message. The MME requests the SGW to release the S1 data bearer by sending the *Release Access Bearers Request* message. Upon receiving the SGW response, the MME commands the eNB to release the Radio and S1 data bearers. Therefore, this procedure results in releasing access bearers (i.e. radio and S1 data bearers) and puts the UE in IDLE state.

C. Drawbacks

The major drawbacks of these data plane management procedures are:

- The initial attachments lead to a systematic establishment of the data plane (i.e. GTP tunnel between eNB, SGW and PGW) even when there is no data traffic to be sent.
- The data plane parameters are unaware of the session type. For instance, the UE inactivity timer is locally preconfigured in the eNB and has static value. However, according the same value for all type of sessions is not adequate. In fact, some background applications connect periodically to the network. If the UE inactivity timer expires before the application reconnection, an extra signaling load is generated to setup again the data plane. For applications that rarely connect to the network, maintaining the data plane is a waste of network resources. Therefore, the UE inactivity timer should be adapted to the session profiles

To address the above issues, we proposed an OF-based LTE/EPC architecture [16]. In this architecture, the UE inactivity timer is decided centrally according to the session profile. In the next section, we give an overview of this architecture.

III. OF-BASED LTE/EPC ARCHITECTURE

A. Architectural model

To enable flexibility and network programmability, we proposed a new control plane for the LTE/EPC architecture. In our proposal, we replaced the control protocols that run on S1-MME (between MME and eNB) and S11 (between MME and SGW) interfaces by the OF protocol [18] as shown in Fig.4. Then, we separated out all control functions from the data forwarding function in SGWs of the same pool area. As a result, the whole SGW intelligence (SGW-C software) is centralized and runs on top of the OpenFlow Controller (OF-ctr) as an application. The data forwarding function is performed by the SGW data plane (SGW-D). Also, the MME software is converted to an application that runs on top of the OF-ctr. In short, our architecture is composed of the following entities:

- **OpenFlow Controller (OF-ctr)**: is the main component of our architecture as it manages the forwarding plane of eNB and SGW-D. The OF-ctr is responsible for user session establishment and load monitoring at the data plane.
- **MME**: is responsible for UE authentication and authorization, and intra-3GPP mobility management. In our architecture, the MME is no more responsible for the SGW and PGW selection. The MME communicates with the OF-ctr using Application Programming Interface (API). The 3GPP interface between the MME and HSS is still maintained.
- **SGW control plane (SGW-C)**: represents the SGW's intelligence part. It is responsible for GTP tunnel establishment including TEIDs allocation. The SGW-C allocates *unique TEID value per session for the uplink traffic within the S1-U interface*. It allocates also *unique TEID value for the downlink traffic within S5-U interface*. With the OF protocol, the Of-ctr can set counters in the SGW-Ds in order to get periodic load statistics. By comparing the received load statistics with the SGW-D capability, the OF-ctr can easily get the load status of each SGW-D and therefore perform more efficient load balancing (i.e. based on the current load of SGW-Ds).
- **SGW data plane (SGW-D)**: represents an advanced OF switch that is able to encapsulate/decapsulate GTP packets. This switch applies the rules received from the OF-ctr. It is responsible for packet forwarding between the eNB and PGW.
- **eNB**: keeps the same radio functions as specified in 3GPP standards. It is enabled with the OF protocol for data plane management. Therefore, the data plane is programmed according to instructions received from the OF-ctr. For instance, the OF-ctr may decide the *Release Timer* of the OF entry in eNB. This parameter represents the OF entry lifetime (i.e. the period during which the S1 bearers is maintained). Then, the OF-ctr transfers this parameter to eNB via the OF protocol. The eNB maintains the radio and S1 bearers as long as the session is active. Upon detecting UE inactivity, the radio bearer is released and the S1 bearer is maintained (i.e. the OF entry is maintained) as long as the Release Timer is not expired. The Release timer is configured according to the

traffic pattern (e.g. session type, session duration, periodic connection request, etc.).

- **PGW**: still has the same function as in the 3GPP standards.

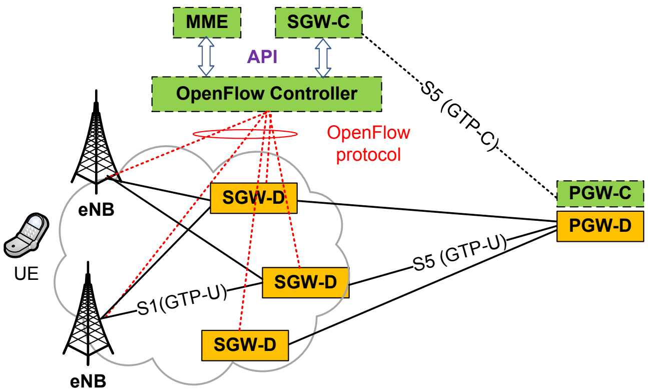

Fig. 4. OF-based LTE/EPC architecture.

B. Data plane management

In OF-based LTE/EPC architecture, the data plane management includes mainly two procedures namely *OF Initial attachment* and *OF Access Bearer Setup*. Due to the *Release Timer* parameter, the access bearer release procedure is not required in our proposal.

1) OF Initial Attachment: The UE uses this procedure to register to the network and get an IP address. This IP address is required for the further data plane establishment. Compared to the 3GPP LTE/EPC initial attachment procedure, the data plane is not established systematically. The UE sends the Attach Request message to the eNB. The eNB piggybacks the Attach Request message into OFPT_PACKET_IN message[1] and sends it to OF-ctr (see Fig.5). The OF-ctr forwards the Attach Request message to the MME. This triggers the authentication and authorization exchanges in the software MME. The authentication exchanges between the MME and the UE go through the OF-ctr. After successful authentication, the OF-ctr triggers the SGW-C to select the default SGW-D and PGW. The SGW-C selects a default SGW-D for this UE and generates an SGW-TEID value for the downlink traffic in S5 interface. Then, it stores these parameters in its table. Moreover, the SGW-C sends these parameters to the selected PGW via the classic GTP-C message "Create Bearer Request". The PGW stores the received parameters in its table. Therefore, whenever the PGW receives a packet destined to this UE, it knows where to send it and the GTP header to add. The PGW allocates an IP address for this UE and generates a PGW-TEID value for the uplink traffic in the S5 interface. These parameters are sent to the SGW-C via the classic GTP-C message "Create Session Response". Then, the SGW-C updates its table with the received parameters. The SGW-C informs the MME about the UE IP address via the OF-ctr. Consequently, the MME include this IP address in the Attach Response message and sends it to the UE. After successfully completing the initial attachment procedure, the UE is authorized to use the LTE/EPC access and has an IP address.

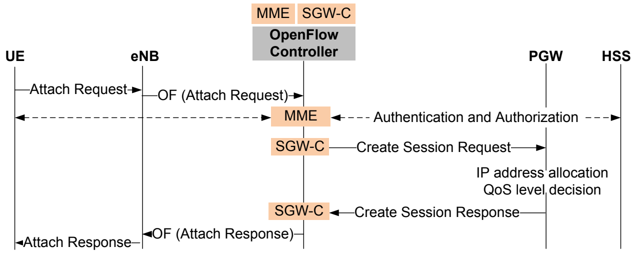

Fig. 5. OF Initial attachment procedure.

2) OF Initial Access Bearer Setup: This procedure is required for each newly launched session (see Fig.6). The UE sends to the eNB the initial packet. First, the eNB checks its flow tables. As no flow entry exists for this initial packet, the eNB sends to the OF-ctr the packet header via the OFPT_PACKET_IN message. Also, the eNB includes in this message the eNB-TEID value for the downlink traffic in S1 interface. The OF-ctr analyzes the packet header to identify the source IP address, the destination IP address and the session type. The OF-ctr presents these information to the SGW-C. The SGW-C sends back to the OF-ctr the SGW-D IP address, the SGW-TEID values and the QoS level. The OF-ctr creates a flow entry for the subsequent packets related to the same session and sends it to the eNB via the OFPT_PACKET_OUT message[2]. The action field of this flow entry includes the SGW-D IP address, and the SGW-TEID for the uplink traffic in the S1 interface. Similarly, the OF-ctr creates and sends to the SGW-D a flow entry related to this session via the OFPT_PACKET_OUT message. The action field of the flow entry includes the eNB IP address, the eNB-TEID, the SGW-TEID for the uplink traffic in the S1 interface, the PGW IP address, the PGW-TEID, and the SGW-TEID for the downlink traffic in S5 interface.

One of the OF properties consists in associating a *Release Timer* for each flow entry. Therefore, the flow entry in the network equipment enabled with OF will be deleted at the timer expiration without generating any signaling load. In our proposal, we consider the same property. After performing the OF Initial Access Bearer Setup for one session, the OF-enabled eNB and SGW maintain the flow entry for this session as long as the related *Release timers* are not expired. Thus, when the UE reconnect to the LTE access for the same type of session before the *Release timer* expiration, it need just to re-establish the radio data bearer as shown in Fig. 7. This *Release Timer* corresponds to the *UE inactivity timer* in 3GPP LTE/EPC architecture. Unlike in 3GPP standards,

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[1] This message is a standard OpenFlow protocol message [18]. When a packet arrives and no flow entry matches to this packet, the OF switch sends the packet header to the OF controller via this message

[2] This message is a standard OpenFlow protocol message. The OF controller uses this message to send to the OF switch flow entries

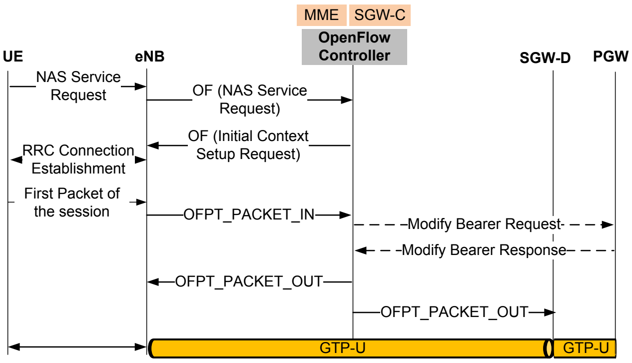

Fig. 6. OF Initial Access Bearer Setup procedure.

the *Release Timer* is decided by the OF-ctr according to the session profile. If the related-application has a periodic pattern (i.e. the application connects to the network at each period T), the *Release Timer* will be equal to this period (i.e. T). If the related-application connects very rarely to the network, the network equipments will be configured to release the network resource as soon as the UE inactivity is detected.

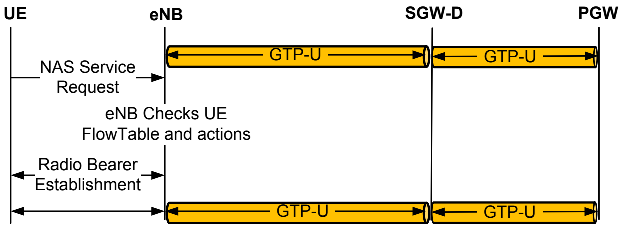

Fig. 7. Access Bearer Setup procedure when the S1 and S5 are maintained.

IV. SIGNALING COST ANALYSIS

In this section, we quantify the signaling load generated by the data plane management procedures in both of 3GPP and OF-based LTE/EPC architectures. We assume that each UE is a smart phone supporting n sessions, for example browsing, email, SMS and voice calls, etc. Let λ_n be the average arrival rate of type-n sessions per UE and μ_n^{-1} be the average session duration in the network. Further, let $D_{e,c}$, $D_{c,s}$, $D_{s,p}$, and $D_{c,p}$ denotes the hop distances, i.e. the number of hops, between (eNB, MME/OF-ctr), (MME/OF-ctr, SGW/SGW-D), (SGW, PGW), and (OF-ctr, PGW) respectively. The hop distance is assumed to be symmetric ($D_{e,c}$ = $D_{c,e}$, $D_{c,s}$ = $D_{s,c}$, $D_{s,p}$ = $D_{p,s}$). In our evaluation, we do not consider the authentication, attach request/response, and NAS service requests messages as we assume that their sizes stay the same in the two architectures. In addition, the signaling related to the radio bearer setup (e.g. RRC Connection establishment messages) is not considered in our evaluation.

Table I provides the 3GPP LTE/EPC message sizes which are determined from 3GPP specifications [17], [19] and [20]. Table II provides the OpenFlow LTE/EPC message sizes.

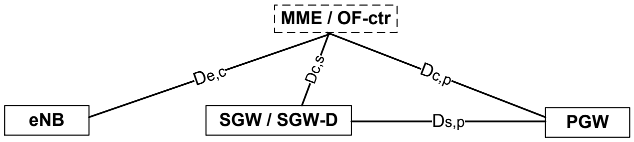

Fig. 8. System model.

These messages are extension to OpenFlow protocol [18] with respect to 3GPP specifications.

TABLE I
THE 3GPP LTE/EPC DATA PLANE MANAGEMENT MESSAGES AND SIZES

Message	src-dst	Notation	Size (bytes)
	Initial Attachment procedure		
Initial Context Setup Request	MME - eNB	M_{icsq}	145
Initial Context Setup Response	eNB - MME	M_{icsr}	86
Create Session Request	MME - SGW	M_{csq}	335
Create Session Response	SGW - MME	M_{csr}	241
Create Session Request	SGW - PGW	$M_{csq'}$	335
Create Session Response	PGW - SGW	$M_{csr'}$	224
Modify Bearer Request	MME - SGW	M_{mbq}	101
Modify Bearer Response	SGW - MME	M_{mbr}	81
Modify Bearer Request	SGW - PGW	$M_{mbq'}$	67
Modify Bearer Response	PGW - SGW	$M_{mbr'}$	81
	Access Bearer Setup (Idle to connect state)		
Initial Context Setup Request	MME - eNB	MT_{icsq}	145
Initial Context Setup Response	eNB - MME	MT_{icsr}	86
Modify Bearer Request	MME - SGW	MT_{mbq}	104
Modify Bearer Response	SGW - MME	MT_{mbr}	106
Modify Bearer Request	SGW - PGW	$MT_{mbq'}$	65
Modify Bearer Response	PGW - SGW	$MT_{mbr'}$	81
	Access Bearer Release (S1 Release Message)		
UE Context Release Request	eNB - MME	M_{crq}	67
UE Context Release Command	MME - eNB	M_{crd}	67
UE Context Release Complete	eNB - MME	M_{crte}	65
Release Access Bearers Request	MME - SGW	M_{rabq}	65
Release Access Bearers Response	SGW - MME	M_{rabr}	66

TABLE II
THE OF-BASED LTE/EPC DATA PLANE MANAGEMENT MESSAGES AND SIZES

Message	src-dst	Notation	Size (bytes)
	OF Initial Attachment procedure		
Create Session Request	SGW - PGW	$M_{csq'}$	335
Create Session Response	PGW - SGW	$M_{csr'}$	224
	OF Initial Access Bearer Setup		
OF Initial Context Setup Request	OF-ctr - eNB	M_{Oicsq}	78
OFPT_PACKET_IN	eNB - OFctr	M_{OPin}	104
OFPT_PACKET_OUT	OFctr - eNB	M_{OPout}	178
OFPT_PACKET_OUT	OFctr - SGWD	$M_{OPout'}$	178
Modify Bearer Request	OF-ctr - PGW	$M_{mbq'}$	67
Modify Bearer Response	PGW - OF-ctr	$M_{mbr'}$	81

A. 3GPP LTE/EPC architecture

1) Unit signaling cost: We consider the initial attachment, access bearer setup and access bearer release procedures to assess the unit signaling load related to the current LTE/EPC architecture. Each time, we assume that the session is successfully established and no failure arises during any session management procedure. The unit signaling load is evaluated at four scenario and calculated as the product of the transmitted message size and the traveled hop distance [21].

Scenario 1: The UE is not registered with the network. The session arrival triggers the UE initial attachment process as shown in fig.2. The unit signaling cost of this scenario is given by

$$\begin{aligned} SC_1^{3gpp} &= (M_{icsq} + M_{icsr})D_{e,c} \\ &+ (M_{csq} + M_{csr} + M_{mbq} + M_{mbr})D_{c,s} \\ &+ ((M_{csq'} + M_{csr'} + (M_{mbq'} + M_{mbr'})P_{ho})D_{s,p} \end{aligned} \tag{1}$$

Where P_{ho} denotes the probability that the UE hands over from non-3GPP access to 3GPP access.

Scenario 2: The UE is successfully registered with the network but is in IDLE state. The session arrival triggers the access bearer (i.e. radio and S1 data bearers) setup procedure as shown in fig.3. The S5 data bearer is already established. The unit signaling cost SC_2^{3gpp} of this scenario is given by

$$\begin{aligned} SC_2^{3gpp} &= (M_{icsq} + M_{icsr})D_{e,c} \\ &+ (M_{mbq} + M_{mbr})D_{c,s} \\ &+ ((M_{mbq'} + M_{mbr'})P_{ho})D_{s,p} \end{aligned} \tag{2}$$

Scenario 3: The UE is successfully registered with the network and is in CONNECTED state. The new session uses the existing bearer. Therefore, this scenario generates no signaling load ($SC_3^{3gpp} = 0$).

Scenario 4: The UE is in CONNECTED state. The end of the ongoing sessions triggers the access bearer release procedure and moves the UE from CONNECTED to IDLE states. The unit signaling cost for access bearer release process is given by

$$\begin{aligned} SC_4^{3GPP} &= (M_{crq} + M_{crd} + M_{crte})D_{e,c} \\ &+ (M_{rabq} + M_{rabr})D_{c,s} \end{aligned} \tag{3}$$

2) Total signaling cost: We assume that each UE supports N types of application such as web browsing, SMS/MMS, Email, voice call, etc. Let λ_n be the average arrival rate of type-n session at the UE and μ_n denotes the average type-n session duration. The total signaling cost per UE is calculated as follows:

$$\begin{aligned} SC_{total-ue}^{3gpp} &= \lambda_n\{(SC_1^{3gpp} + SC_4^{3gpp})P_1^{3gpp} \\ &+ (SC_2^{3gpp} + SC_4^{3gpp})P_2^{3gpp} + SC_3^{3gpp}P_3^{3gpp}\} \end{aligned} \tag{4}$$

Where P_1^{3gpp}, P_2^{3gpp} and P_3^{3gpp} denotes the probability that the session begins when the UE is in Scenario 1, Scenario 2 and Scenario 3 respectively. Actually, P_2^{3gpp} and P_3^{3gpp} correspond to the probability that the UE is in IDLE and CONNECTED states, respectively. To compute these two probabilities, we note that the process (X_n, Y_n) can represent CONNECTED and IDLE states related to type-n session with $E[X_n] = \mu^{-1}$ and $E[Y_n] = \lambda^{-1}$. From the theory of alternating renewal process and independence assumption of applications, we have $P_2^{3gpp} = P_{idle} = \prod_{n=1}^{N} \frac{\mu_n}{(\lambda_n + \mu_n)}$. Moreover, the UE is in CONNECTED state if it has at least one active session. Therefore, we have $P_3^{3gpp} = 1 - P_2^{3gpp}$.

If we consider N_{ue} users, the total signaling cost is given by:

$$SC_{total}^{3gpp} = N_{ue} SC_{total-ue}^{3gpp} \tag{5}$$

B. OF-based LTE/EPC architecture

1) Unit signaling cost: In the proposed architecture, we consider the OF Initial Attachment and Initial Access Bearer Setup procedures. The units signaling cost is evaluated at three scenarios:

Scenario 1: The UE is not registered with the network. The session arrival triggers the Initial Attachment and Initial Access Bearer setup procedures as shown in Fig.5 and Fig.6. The unit signaling cost of this scenario is given by

$$\begin{aligned} SC_1^{of} &= (M_{Oicsq} + M_{OPin} + M_{OPout})D_{e,c} \\ &+ M_{OPout'}D_{c,s} \\ &+ (M_{csq'} + M_{csr'} + (M_{mbq'} + M_{mbr'})P_{ho})D_{c,p} \end{aligned} \tag{6}$$

Scenario 2: The UE is already registered with the network but has no data bearer maintained in the network (i.e. S1 and S5 data bearers). Therefore, the session arrival triggers the Initial Access Bearer setup procedure as shown in Fig.6. This scenario represents the first time the application is launched. After that, the S1 and S5 data bearers will be maintained. The unit signaling cost related to this scenario is given by

$$\begin{aligned} SC_2^{of} &= (M_{Oicsq} + M_{OPin} + M_{OPout})D_{e,c} \\ &+ M_{OPout'}D_{c,s} \\ &+ ((M_{mbq'} + M_{mbr'})P_{ho})D_{c,p} \end{aligned} \tag{7}$$

Scenario 3: The UE is registered with the network. It is in IDLE state but the S1 and S5 data bearers are maintained in the network. The session arrival triggers just the radio data bearer setup as shown in Fig. 7. This scenario represents the cases where the application has used the network. The new session related to the same application uses the existing S1 and S5 data bearers and generates no signaling load at eNB-MME and MME-SGW interfaces ($SC_3^{of} = 0$).

2) Total signaling cost: The total signaling cost per UE is calculated as follows:

$$SC_{total-ue}^{of} = \lambda_n(SC_1^{of}P_1^{of} + SC_2^{of}P_2^{of} + SC_3^{of}P_3^{of}) \tag{8}$$

where P_1^{of}, P_2^{of} and P_3^{of} denotes the probability that the session starts when the UE is in Scenario 1, Scenario 2 and Scenario 3 respectively. P_2^{of} is calculated as the probability that the UE is in IDLE state (P_{idle}) by the probability that the S1 and S5 data bearers are not established in the network ($P_{no\ S1\ \&\ S5\ bearers}$). This last probability represents the first launch of the application.

$$P_2^{of} = P_{idle} P_{no\ S1\ \&\ S5\ bearers} \tag{9}$$

Similarly, If we consider N_{ue} users, the total signaling cost is given by

$$SC_{total}^{of} = N_{ue} SC_{total-ue}^{of} \tag{10}$$

V. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we present and discuss the numerical results showing the impact of using OpenFlow in LTE/EPC architectures. The default values of the system parameters are assumed to be as follows: $D_{e,c} = 3$, $D_{c,s} = 1$, $D_{s,p} = 1$, $P_1^{3gpp} = P_1^{of} = 0.2$, $P_{no\ S1\ \&\ S5\ bearers} = 0.1$, and $P_{ho} = 0$ (i.e we assume that no handover takes place during our evaluation).

First, we investigate the impact of the UEs number on the signaling load. We vary the number of UEs from 0 to 1000 as shown in Fig 9. As we expected, the proposed architecture does not increase the signaling load compared to the 3GPP LTE/EPC architecture. On the contrary, it could even decrease the signaling load.

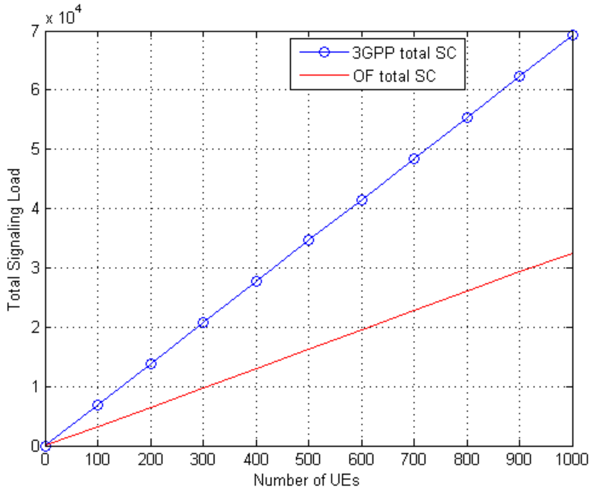

Fig. 9. The impact of N_{ue} on SC ($\lambda_n = 0.05$).

We assume two different types of background applications namely Chat and Email applications with their associated session durations $\mu_1 = 0.01$ and $\mu_2 = 0.05$, respectively. Actually, the Chat applications sends notifications periodically to update contacts' status such as in Skype or Whatsapp. The Email application connects periodically to their server to get new emails. To examine the impact of the average session arrival rate of each of these applications on the signaling cost, we vary λ_n from 0 to 0.1 per second.

Fig. 10 compares the signaling load for both architectures. As we expect, the signaling load increases with the increase of the average session arrival rate. We note that the signaling load in 3GPP LTE/EPC architectures varies according to the application types. This reveals the impact of the session duration on the signaling load. As we can see, signaling load increases with the decrease of the session duration. For instance, the Chat application presents more signaling load than Email application. Indeed, for application with longer session duration, the UE presents less alternation between CONNECTED and IDLE states (i.e. the UE more often stays connected) whereas for application with shorter session duration, the UE will more often come back to idle state before a new session arrives. Indeed, the alternation between CONNECTED and IDLE states takes places more frequently with applications presenting short session duration. Therefore, in 3GPP LTE/EPC, the access bearers are released and re-established more often for this type of applications leading to higher signaling load.

We note that our proposal presents almost the same signaling load for each type of applications (Fig. 10). This trend is due to adapting the data plane *Release Timer* to the flow IDLE period in eNB and SGW. For example, the eNB and SGW maintain the S1 data bearer as long as the application is in IDLE state, i.e. the data plane *Release Timer* is slightly higher than the average application IDLE period. Therefore, when a new session related to the same application arrives, the UE just establishes the radio data bearer with eNB without inducing extra signaling load at the network side. Obviously, maintaining the data plane parameters (flow entries in eNB and SGW-D) for a long period drives the need for memory spaces in network equipment. Consequently, the controller should set for each flow entry the optimal value of the Release Timer that generates less signaling load and avoid the unnecessary usage of the memory space.

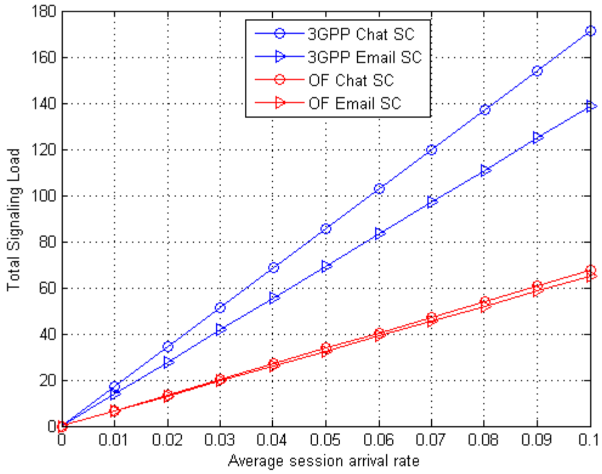

Fig. 10. The impact of λ_n on SC.

VI. CONCLUSION AND PERSPECTIVES

In this paper, we replaced the current control protocols in eNB-MME and MME-SGW interfaces by OpenFlow in order to introduce flexibility and programmability aspects. Through the signaling cost analysis, we showed the interest of our proposal. Particularly, the signaling load is significantly reduced with OpenFlow because the UE S1 and S5 data bearer parameters are kept in the network equipment during the application IDLE period. The controller should set for each flow entry the optimal release timer that incurs low signaling load and avoids the extra memory space usage in network equipment.

This work has many perspectives. Firstly, the impact of the OpenFlow on the memory space may be assessed. Also, the identification of the optimal release timer for each flow entry may be determined. Then, the analytical analysis of the proposed scheme could be extended to evaluate its robustness when the application behavior is bursty and non-deterministic. Finally, our proposal may be extended by removing the SGW-PGW control interface and enabling the OpenFlow Controller to program entries in PGW via the OpenFlow protocol.

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