Evaluation of Signaling Loads in NO Stack 5G Mobile Network

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Abstract: Present mobile communication system suffers from the exponentially increased mobile traffic and research on the fifth generation (5G) mobile network architectures is ongoing to solve this problem. We investigate the feasibility of the proposals used for the network architecture evolution from 4G to 5G and first propose a compatible network architecture, which decouples the management plane, the control plane and the user plane based on NO Stack framework proposed in our previous study. We mainly design detail procedures including UE attachment, service request and dedicated bearer activation/deactivation for our proposal network architecture. Finally, we establish a clear analytical mode of the application and system states to evaluate the signaling loads of new architecture. Simulation results show that our proposal network architecture with elaborated signaling procedures has much impact on the total signaling loads of system and could obviously decrease the signaling overhead compared with LTE.

Keywords: NO stack; signaling load; SDN; 5G

I. INTRODUCTION

Mobile Internet and Machine Type Communications are recognized as the main driving force of investigating the 5G for future mobile network. There is speculation that the volume of the global mobile data traffic is expected to increase more than 200 times from 2010 to 2020, while the number of the mobile communication terminals will reach 26 billion in 2020[1]. And the 5G network is expected to support a wide range of new services and applications with very diverse requirements, mainly including 3D video, Ultra HD screen, cloud computing, virtual reality, etc. These business scenarios need 5G network to provide higher traffic volume, low latency, the connection of huge number of devices, etc. In order to meet these challenges, 5G should not only improve the link capacities, but also need a more flexible and scalable architecture with the introduction of new technologies. Network Function Virtualization (NFV) and Software Defined Network (SDN) are two promising technologies to provide such flexibility and scalability for 5G network and are expected to play a significant role in the construction of 5G network architecture.

The main idea of NFV is the decoupling of physical network equipment from the functions that run on them. NFV promises Telecommunication Service Providers(TSPs) with more flexibility to expose their network capabilities and services to users and other services, and the ability to deploy or support new network services faster and cheaper so as

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to realize better service agility. SDN decouples control and data planes leveraging standard protocols enabling remote management and operation of data planes to third-party elements. The programmability and centralized control of SDN greatly improves the flexibility of networking, and simplifies network management. Then the 5G network architecture based on above two technologies is proposed. SoftRAN [2] has been studied the applicability of the SDN principles for the radio interface, which is a framework for decoupling of control and data planes inside the radio nodes. CHARISMA[3] presents a hierarchical, distributed-intelligence 5G architecture whose objective is the development of an open access, converged 5G network. In [4], the author proposed a 5G mobile network architecture based on SDN and NFV, which includes data layer, control layer and application layer. Among them, the control layer is consisted of Radio Access Network(RAN) and Core Network(CN) controller which is in charge of different control functions. [5] presents a two-layer architecture which is consisted of a radio network and a network cloud, and is integrating various enablers such as small cells, massive Multiple-Input Multiple-Output(MIMO)[14], control/user plane split, NFV and SDN. [6] introduces a SDN-based architecture which defines a harmonization layer that allows orchestrating radio and heterogeneous transport domains.

"NO Stack" is the abbreviation of "Not Only Stack"[7]. In NO Stack architecture, it pushes down the layer-by-layer protocol stacks and encapsulates all protocol layers as modules. Thus protocol stack is reserved and can be implemented by orchestrating associated modules. Further, we adapt the SDN principles to decouple the control/user/manage plane function of each protocol layer, thus the protocol layers of user plane are flat which can be reconstructed flexibly, the protocols of control plane are concentrated in the SDN controller so that the operators can control the network in a unified and coordinated manner, the management functions are communicate with control plane functions via the open North-Interface of SDN controller and is in charge of the customized needs of varied business.

Benefiting from these features, the proposed framework is very flexible and can support many new functions beyond conventional protocol stack.

In this paper, we first propose a compatible

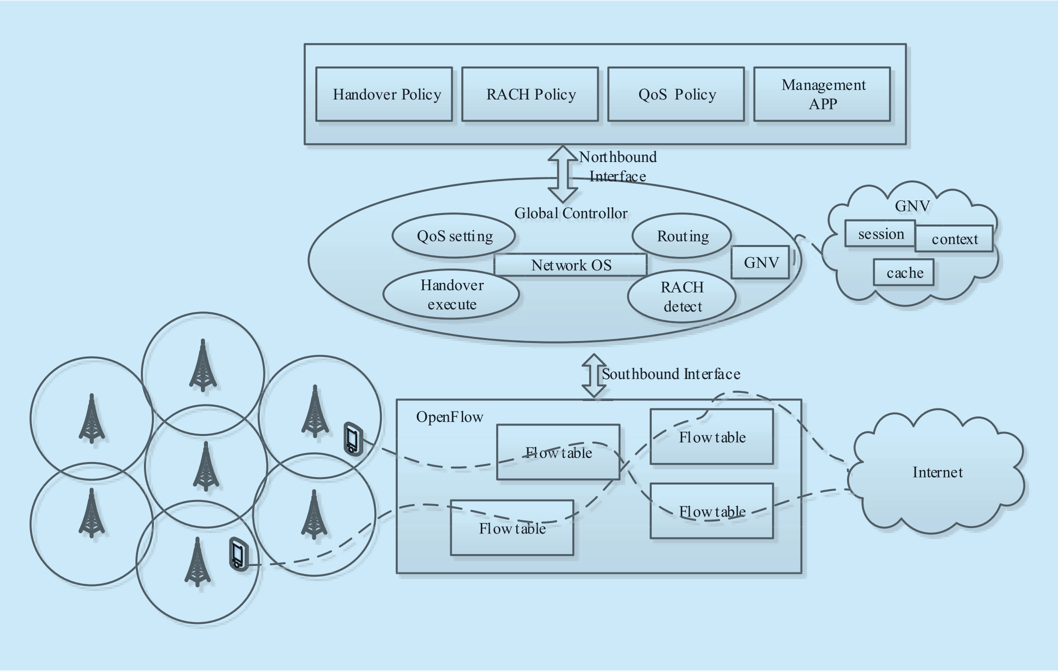

Fig. 1 *General framework of NO stack*

network architecture, which decouples the management plane, the control plane and the user plane based on NO Stack, a Software Defined Network enabled framework. And then we mainly make detail procedures for the attachment, service request and dedicated bearer activation/deactivation for our proposal network architecture. Finally, in order to evaluate signaling loads of the procedures compare with the legacy Long Term Evolution(LTE) architecture[16][17], we establish a clear analytical mode of the application and system states. Simulation results show that our proposal network architecture with elaborated signaling procedures has much impact on the signaling loads compare with the additional LTE architecture.

The rest of the paper is organized as follows. Our proposal network architecture and the major modified procedures are presented in the Section II and Section III respectively. Section IV gives a clear analytical model of the signaling loads for the new network architecture. Section V is the simulation results and evaluation under the signaling loads model. And we draw our conclusion in the Section VI.

II. U/C/M Decoupled Architecture

To enable intelligent flexibility and network programmability, inspired by NO Stack that explained briefly above, we propose a U/C/M (User/Control/Management) decoupled LTE/EPC architecture. Our proposal, as showed in Fig.2, follows the line with the SDN (Software Define Network) principle and provides a high level functional view of novel architecture.

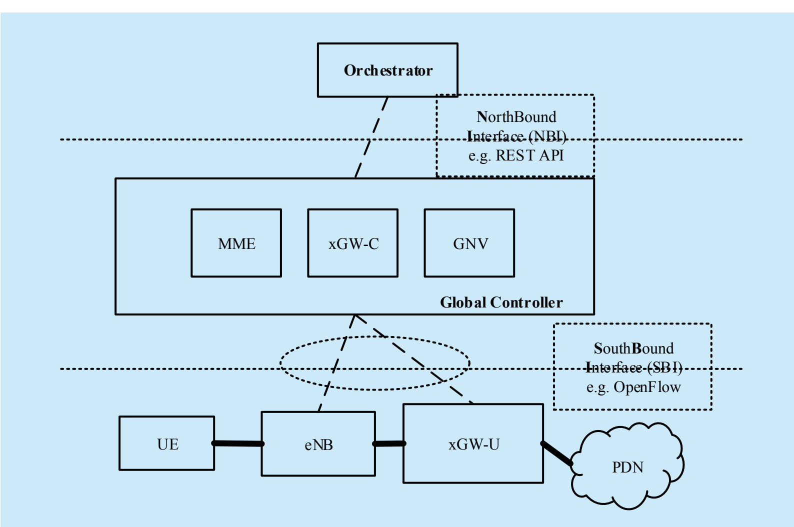

Fig. 2 *U/C/M decoupled LTE/EPC architecture*

We separate out control functions from the data forwarding function of the S-GW and P-GW, and combine the control plane function of S/P-GW as well as user plane function of S/P-GW. As a result, the new xGW-C (X Gateway control plane) is centralized and runs on top of the Global Controller as an application when the xGW-U (X Gateway user plane) represents an advanced logical entity controlled by the xGW-C in the Global Controller.

Also, the Mobility Management Entity(MME), core control entity in LTE, is converted to an application that runs on top of Global Controller, the Global Network View(GNV) module is a general database application similarly. We reconstruct the functions of the management plane function into Orchestrator.

What's more, we replace the control protocols that run on S1-MME and S11 interface with the SBI (Southbound Interface) protocol[8]. Openflow is a popular protocol for the southbound interface and can be employed on the SBI[15]. The Global Controller communicates to Orchestrator by the NBI (Northbound Interface), such as REST (Representational state transfer) API (Application Programming Interface).

The architecture is composed of the following entities:

2.1 Global controller

Global Controller is the main component of our architecture as it controls the user traffic forwarding plane of the Evolved Node B(eNB) and GW-U. The Global Controller is responsible for user session establishment and loads monitoring on the user plane. Global Controller is an openflow controller and a collection of applications (e.g. MME, GW-C, GW-M and GNV) built on top the Global Controller over the inner API or over the REST API.

MME is the main control entity for the E-UTRAN[9]. It communicates with a HSS for user authentication and user profile download, and provides User Equipment(UE) with Evolved Packet System(EPS) Mobility Management (EMM) and EPS Session Management (ESM) functions using Non Access Stratum(NAS) signaling. In our architecture, the MME communicates with the Global Controller using the Controller intra API. The 3GPP interface between the MME and HSS is still maintained.

xGW-C (X Gateway control plane): represents the control functionality of the S-GW and P-GW. It is responsible for resource management for bearer resources and IP address, Tunnel Endpoint Identifier (TEID) assignment for GTP-U. The xGW-C allocates unique TEID value per session within S1-U interface between eNB and GW-C. With the openflow protocol, the Global Controller can set counters for the number of xGW-Us in order to get periodic load statistics. By comparing the received load statistics of the xGW-U capability, the Global Controller can easily get the load status of each xGW-U and therefore perform more efficient load balancing.

GNV acts as HSS entity where user profiles are stored, provides authentication information and profiles to the MME in the Global Controller. Different to HSS, GNV also stores the information and states of the user plane, such as sessions, contexts, buffered data.

2.2 xGW-U

xGW-U (X Gateway user plane) represents an advanced logical entity controlled by the xGW-C in the Global Controller. And the advanced openflow switch that is able to encapsulate and decapsulate GTP packets can be enabled technology to implement logical entity. This switch applies the rules received from the Global Controller. It is responsible for packet forwarding between the eNB and PDN (Packet Data Network).

2.3 eNB

eNB is an intersection point of the access network and core network. It keeps the same radio functions in 3GPP standards while is enabled with the openflow protocol for data plane management. Therefore, the data plane is programmed according to instructions received from the Global Controller. eNB sends and receives user IP packets through a Packet Data Convergence Protocol (PDCP) and IP mapping table (kind of flow table). When eNB receives IP packets, it checks destination IP address. In the downlink, if matching entries available in the PDCP and IP mapping table, eNB sends packets on the particular PDCP connection, over the radio interface. In the uplink, packets are forwarded to the network through connected xGW.

2.4 Orchestrator

In legacy LTE network, the P-GW performs policy enforcement, packet filtering and charging based on the Policy and Charging Control(PCC) rules provided by a Policy and Charging Rules Function (PCRF)[10]. On preliminary stage, we consider reconstructing these management functions into Orchestrator. Therefore, when Global Control wants to obtain Quality of Service(QoS) and charging rules for the xGW-C, it could request the unified RESTful API to Orchestrator. Then Orchestrator handles the request and responses the demanded QoS and charging rules into popular format, such as JSON.

III. LTE Based No Stack Signaling Flows

In this section, we describe briefly procedures related to signaling analysis based on our system model refer to the LTE standard. Important use case is that UE or PDN originate the services. Before explaining these situations, it is important to show how UE is initially attached to the system and at least, we also describes that dedicated bearer Activation/Deactivation procedure as supplement for service with QoS guarantee. In general, protocols of the LTE access network remain unchanged in the proposal. In contrast, the protocols related to network elements which are replaced in NO Stack architecture are redefined or delete.

3.1 UE Attach procedure

UE attach diagram is shown in Fig.3. Unused network elements of LTE are removed from the figure where new additions are shown by dotted lines. Firstly, Global Controller gets the update location information of UE from GNV when UE sends an attachment request and this will happen after the Identity/Authentication/Ciphered successful checking. And the checking procedure is responsible for MME module integrated in the Global Controller. In the update location information, IP address assigned to UE is provided as a Served Party IP address. Fig.3 does not show detail procedure inside of Global controller due to none one message existing here. Although these procedures do not appear as a form of signaling interaction, a series of internal API is invoked in the Global Controller instead.

In the traditional case, MME is responsible to create a unique link interface address. But in the new architecture, UE creates a unique address and verify the duplication. And all requests are considered as data plane traffic and are routed to the Global Controller by a flow table in xGW-U. The new proposal uses Initial Context Setup message only for creating a context between Global Controller and eNB. RRC connection reconfiguration message is a response from eNB for UE attach a message After the UE attachment is completed from eNB to Global Controller. Global Controller will first store or update UE state provided by MME module. Thus, UE is considered as EMM-REGISTERED and ECM-CONNECTED state and prepare to transmit or receive data flow with xGW-U on the data plane. So far, the UE attach procedure is complete.

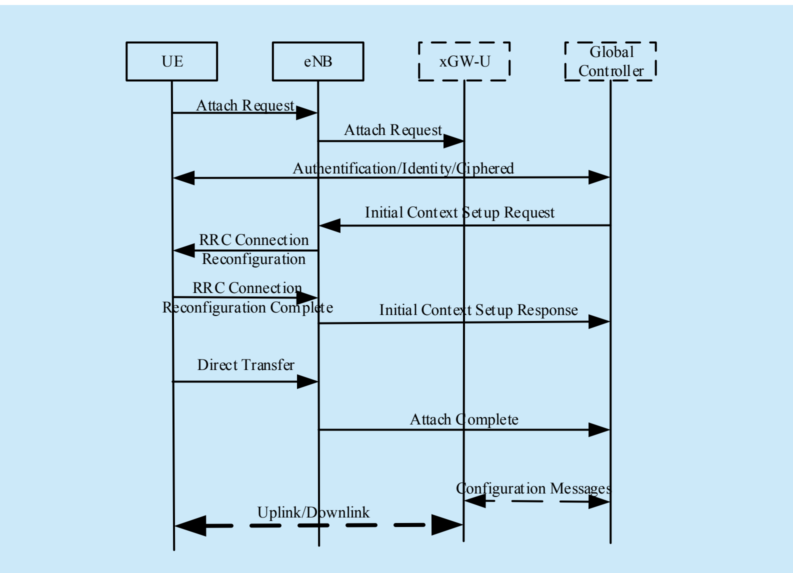

Fig. 3 *Attach procedure*

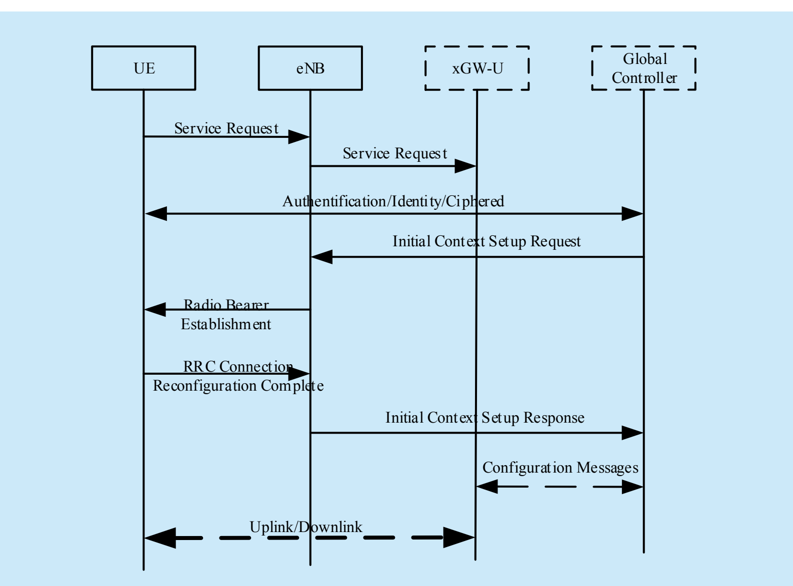

Fig. 4 *UE triggered Service request procedure*

3.2 Service Request triggered by the UE

When data traffic is emitted by a UE in IDLE state (ECM-idle and RRC-idle) [11], the UE performs the procedure illustrated in Fig.4. Firstly, signalling related to RRC connection setup is sent interactively between UE and eNB, which are reserved for the traditional procedure. After the connection is established, UE sends Service Request to Global Controller passing through the eNB. Next step, Global Controller process this request involving MME module and GNV and respond Initial Context Setup Request to eNB. At least, after eNB sends the AS Security Setup and RRC connection Reconfiguration to UE, it can forward the data flow coming from UE to xGW-U. Meanwhile, Global Controller process the flow table request and distribute new flow table entry which can steer data flow from UE to PDN to each xGW-Us. Thus, all connectivity is set up in the control plane and user plane, allowing the UE to receive and send data traffic.

3.3 Network Triggered Service Request

Similar to service triggered by UE, this case occurs when UE is ECM-idle or RRC-idle state, and data is coming from the PDN, Global Controller needs to originate corresponding signaling of paging to wake up the UE through the eNB. In the new architecture, xGW-U receives the data and looks for matched flow table entries under the guidance of the openflow protocol. Since UE stand in idle states, there will be no flow table entries to steer data flow to UE. Therefore, xGW-U will inform the Global Controller with incoming data and no UE routes. As a result, Global Controller calls the MME module performing the paging request with UE ID and IP address. This call flow is shown in Fig. 3, while receiving the paging request, UE initiates the UE triggered Service Request procedure upon reception of paging indication from eNB. The relevant procedure is not discussed here. In this phase, Global Controller adds flow table entries to xGW-U. In ideal condition that xGW-U can store buffering packets until it receives the response from Global Controller and now xGW-U has flow entries to forward data flow to UE.

3.4 Dedicated Bearer Activation/ Deactivation

There are two types of EPS bearers in traditional LTE: default and dedicated. Our proposal also supports two types of EPS bearers through the new network entity Orchestrator. When a UE attaches to the network, an IP address to be used in a PDN is assigned, connecting to a PDN, and a default EPS bearer is established all at the same time. When a user who has

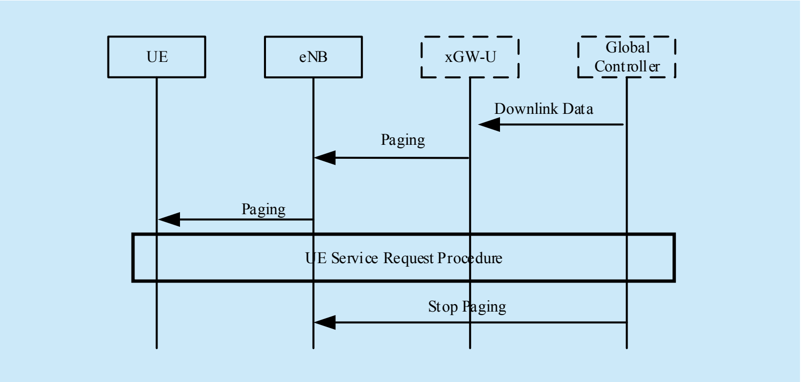

Fig. 5 *Network triggered service request procedure*

been using a service through a default bearer attempts to use a service which requires higher QoS that the current default bearer cannot provide, a dedicated bearer is established on demand. Dedicated bearer activation/deactivation procedures requested by UE are shown in Fig. 6. The most specific setups are the Policy Request and Policy Response. As described in the section 2, Orchestrator stores PCC rules to the xGW-C, then Global Control could invoked the unified RESTful API provided Orchestrator to obtain QoS and charging rules for the xGW-C. After the Global Controller has the policy rules, it notices the eNB to allocate enough air resources for UE to establish the dedicated bearer with demanded QoS. On the core network side, Global Controller configures the xGW-Us through the configuration messages. From these messages, xGW-Us build dynamically flow tables to match dedicated bearer flow from the UE or PDN.

IV. Analytical Model

The analysis of the states of the application is modeled based on queuing theory. Each application with type t has two states that the average duration of active is denoted by a_t^{-1} and the average duration of inactive is denoted by b_t^{-1}. And we assume that each application may or may not require a different QoS level offered by the dedicated bearer. Furthermore, the average arrival rate λ_t of type t application is thus:

$$\lambda_t = \frac{1}{a_t^{-1} + b_t^{-1}} \quad (1)$$

Fig. 7 describes the transitions of applications states, RRC states and dedicated bearer states.

We set θ as the average number of transitions from Connected to Idle states per unit time. Moreover, we derive its expression from the corresponding formula derivation process based on states transitions model. Among the formula, τ is inactivity timer that is set in the system and once this timer expires. RRC state changes to Idle.

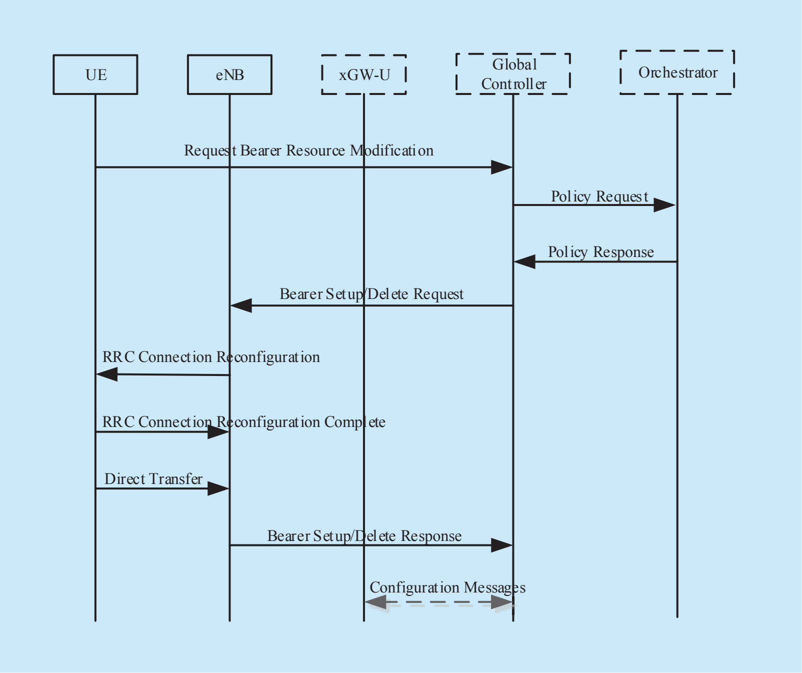

Fig. 6 *Dedicated bearer activation/deactivation*

$$\theta = \sum_{t=1}^{N} b_t \cdot \prod_{t=1}^{N} \frac{a_t}{a_t + b_t} \cdot e^{-(\sum_{t=1}^{N} b_t)\cdot\tau} \quad (2)$$

We assume that P_{ue} be the probability that any session of application with type t is originated by the UE where χ_t denotes the probability that a type t session is originated by a UE. It may be estimated as:

$$P_{ue} = \frac{\sum_{t=1}^{N} \lambda_t \chi_t}{\sum_{t=1}^{N} \lambda_t} \quad (3)$$

In contrast, the probability that session is originated by PDN can also be$(1 - P_{ue})$.

A bearer inactivity timer ϕ is set for each dedicated bearer and is managed by P-GW or Global Controller. Once the timer expires, the dedicated bearer deactivation procedure is triggered. As a result of this, we have:

$$\beta_t = \frac{a_t \cdot b_t}{a_t + b_t} \cdot e^{-b_t \cdot \phi} \quad (4)$$

We define N_u and N_p representing the number of signaling messages when the application request procedure triggered by the UE and by the Network respectively. T_{ue} is the total number of UE served by the system. In general, $T_{ue} = \rho C_s$ when ρ represents user density and C_s is the service area of the system. Consequently, the total number of signaling messages processed by the system per unit time related to Service Request procedure triggered by applications using the default bearer may be expressed as

$$S_{default} = \theta \cdot T_{ue} \cdot [N_u \cdot P_{ue} + N_p \cdot (1 - P_{ue})] \quad (5)$$

When a type t application requires a specific QoS guarantee and the default bearer can't sufficient to support it, a dedicated bear-

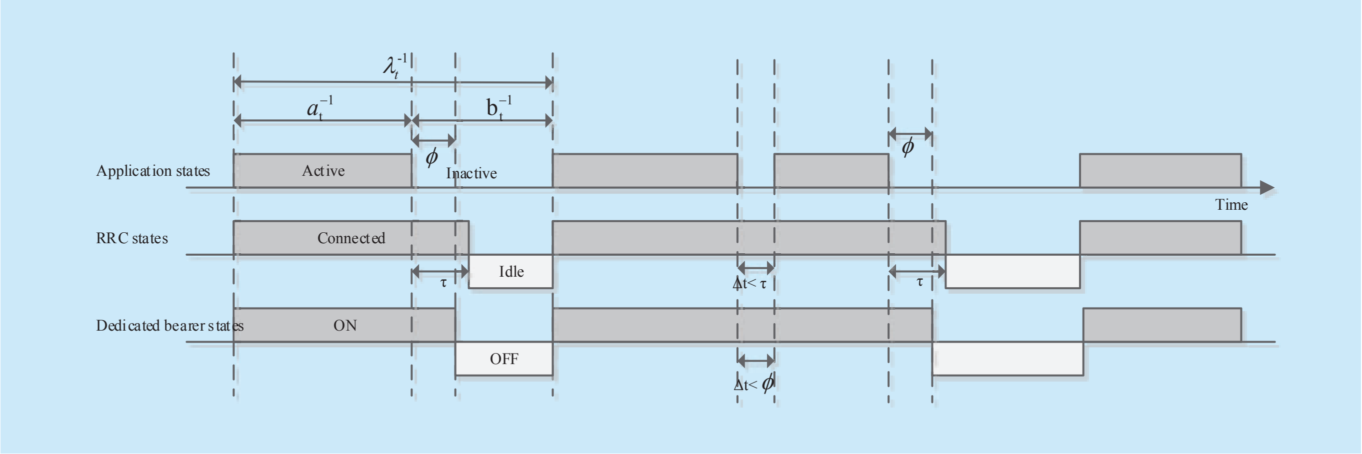

Fig. 7 *States transitions model*

er should be activated. We assume that once the data transmission through this dedicated bearer is finished. The inactivity timer is immediately triggered. We also use N_u^{db} and N_p^{db} representing the number of signaling related to activation/deactivation of dedicated bearer requested by UE and network respectively. Therefore, the total number of signaling per unit time due to dedicated bearer activation and deactivation can be computed as follow:

$$S_{dedicated}(t) = \beta_t \cdot T_{ue} \cdot [N_u^{db} \cdot \chi_t + N_p^{db} \cdot (1-\chi_t)] \quad (6)$$

Finally, we set N as the total number of applications running on a UE and ms the number of applications that do not use the dedicated bearer to fulfill additional QoS requirement. The total Processing Load S can be computed as follows:

$$S = S_{default} + \sum_{t=m+1}^{N} S_{dedicated}(t) \quad (7)$$

V. Simulation Results and Analysis

In this section, we evaluate and analyze the performance of the above system model as well as compare numerical results of signaling load related to different application scenarios in NO Stack architecture and in traditional LTE architecture, respectively. About our physical scenarios parameter setting, the value of user density ρ is set to 2300 UE per square kilometer and the scope of Service Area of the System including NO Stack and LTE is set to 1300 square kilometer.

We analyze three types of application and detail settings are shown in the table I.

Furthermore, we propose four application scenarios: the first one is an 'All Default Bearer' scenario, which only uses default bearer to support all types of application. The last three scenarios need multi-level QoS guarantee. The second scenario assumes the voice is supported by dedicated bearer, while media streaming and background applications still are supported by default bearer. In the third scenario, 10% of streaming and voice traffic are supported by dedicated bearers, while 90% of streaming traffic and background are supported by default bearer. In the fourth scenario, total voice and media streaming are supported by dedicated bearer, while Background is supported by default bearer.

Table I *Application and Detail Settings*

Type t	a_t^{-1}	b_t^{-1}	χ_t
Voice	180	5000	0.5
Media streaming	180	530	1
Background	10	80	0.8

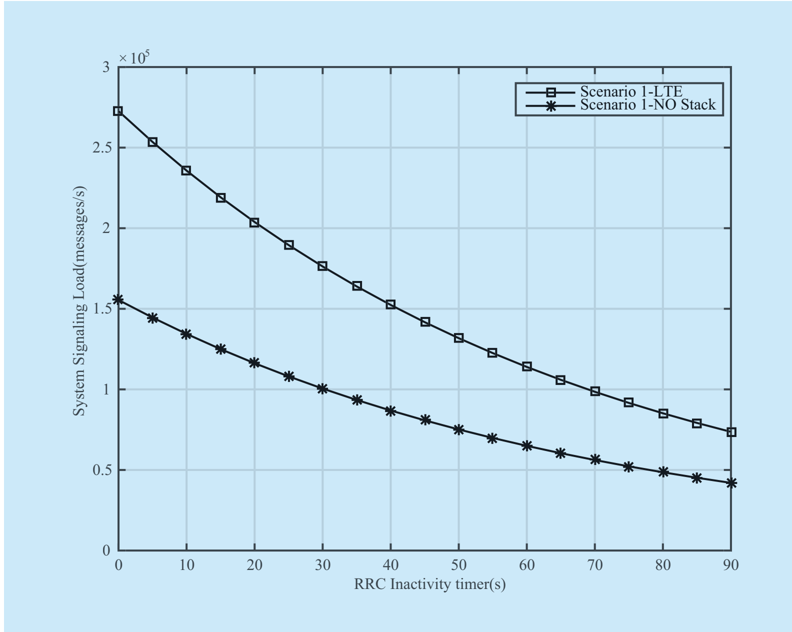

Fig. 8 *NO stack and LTE signaling loads depending on inactivity timer*

The bearer-inactivity ϕ timer is usually set to 20 seconds [12]. And we also vary the RRC inactivity timer τ from 0 to 90 seconds so as to observe the influences on the signaling load [13].

Fig. 8 shows that impact of QoS depending on the inactivity timer τ in two different system architecture. In general, the trend of signaling load decreases exponentially when τ increase. Furthermore, the signaling load of NO Stack is obviously lower than signaling load of LTE with supporting same application scenario 'All Default Bearer', and this gap is getting smaller with the inactivity timer is getting longer due to reduction of the number of state transitions and corresponding triggered signaling. Thus, the influence of NO Stack on heavy signaling load is weak and this archi-

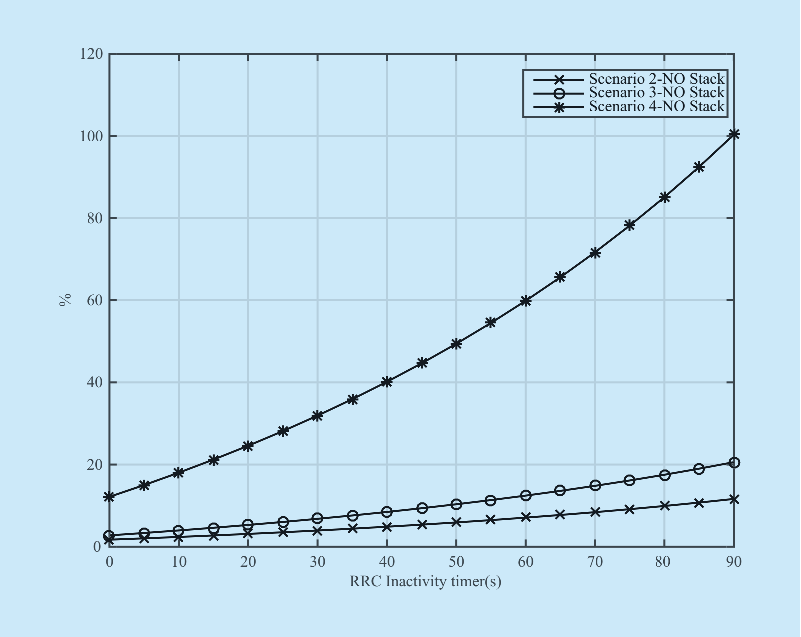

Fig. 9 *Signaling load compared all default bearer scenario*

tecture is more suitable for complex signaling interaction situation.

Fig. 9 shows the percentage increase in signaling load of three application scenarios(2, 3 and 4) requesting different QoS level compared to the 'All Default Bearer' scenario 1 in NO Stack architecture.

We can observe that each scenario requesting QoS guarantee has always higher signaling load than 'All Default Bearer' scenario, and signaling load is also higher when requested QoS level is higher. This is because that dedicated bearer is used to meet the QoS requirement in addition to default bearer. Once a session with QoS level is coming, the complete signaling procedure for dedicated bearer deployment is triggered. The results show that the increasing of signaling load is faster with inactivity timer increasing when QoS level is higher such as scenario 4, where increasing of scenario 2 and scenario 3 is moderate relative.

VI. Conclusions

In this paper, we present an analytical model to evaluate the comparison between NO Stack architecture proposed in our previous study and standard LTE architecture model in terms of signaling load. NO stack redefined the system architecture especially in core network so as to simplify the complex signaling procedure provided in LTE standard. Although the simulation result shows that signaling load decreases obviously in NO Stack regardless the value of inactivity timer, the deployment of application scenario with high QoS level using dedicated bearers could have a significant impact on the performances of core network processing signaling. Therefore, NO Stack is more suitable for multi-bearer deployment. In future work, we will further analyze the performance of NO Stack on system level platform using advanced simulator NS3.

Acknowledgement

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