SDN Based Evolved Packet Core Architecture For Efficient User Mobility Support

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***Abstract*—In current generation LTE networks, user mobility leads to high levels of signaling traffic from the eNodeB (Evolved Node B) to the Evolved Packet Core (EPC) for maintaining the GPRS Tunneling Protocol (GTP) and Proxy Mobile IPv6 (PMIPv6) tunnel. Further, the presence of Packet Gateway (PGW) at the network edge introduces additional delay for every signaling procedure. In this paper, we propose an improved EPC architecture based on Software Defined Networking (SDN) concepts. This architecture (logically) centralizes the control plane functionality of EPC thereby eliminating the use of mobility management protocols and reducing mobility related signaling costs. The architecture utilizes the global network view feature of SDN for mobility management. The proposed architecture has been implemented in the ns-3 simulator framework. The results quantify the performance of the proposed architecture in terms of signaling cost, tunneling cost, handover latency and scalability.**

I. Introduction

The tremendous growth in mobile data traffic requires a significant re-design of the network's data and control planes. An analysis of messaging events in an existing LTE Evolved Packet Core (EPC), also called 3GPP–EPC, showed that the signaling load for mobility management was very high and mainly due to connection establishment/release, handover and tracking area update events [1]. For next generation networks, an architecture that supports low signaling cost while handling such events (like connection establishment/release, handovers, etc.) is required. The objective of this paper is to design a scalable LTE EPC architecture that incorporates efficient control signaling mechanisms to help meet the future network's requirements.

The proposed architecture is based on software defined networking (SDN) concepts [2]. SDN based systems separate the *data* and *control* planes and provide several advantages in terms of network programmability, network virtualization and others. The OpenFlow protocol [3] has emerged as an industry standard for interaction between the controller and the routing/switching hardware elements in the network.

In the proposed architecture, the control plane functionalities of the EPC's Mobility Management Entity (MME), Serving Gateway (SGW) and Packet Gateway (PGW) are moved to a logically centralized controller referred to as the EPC Controller; the SGW and PGW are replaced with an OpenFlow switch [3]. The use of GTP or PMIPv6 mobility management protocol is eliminated in the proposed EPC architecture. Instead, solutions based on SDN concepts are designed to provide IP mobility, QoS and security. The EPC Controller handles flow-based routing. When the UE moves within or outside the network (from LTE to WiFi and similar), the IP address remains unchanged. The packets are forwarded along the updated routes as specified by the EPC Controller.

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A comparison of signaling costs in the existing and proposed LTE architectures is presented. The architecture has also been implemented in the ns3 simulator and related performance results in terms of user throughput and delay are presented.

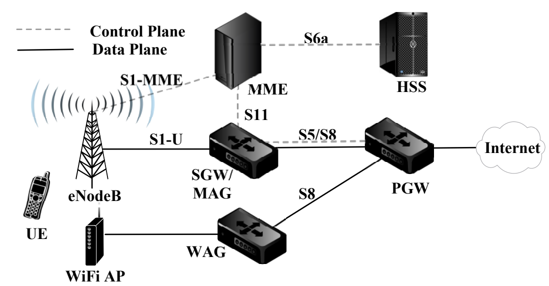


Fig. 1: 3GPP–EPC Architecture.

II. Background and Related Work

This section presents some background material on LTE networks, SDN networks, and related work.

Overview of 3GPP–EPC Architecture: The 3GPP Evolved Packet Core (EPC) architecture mainly consists of Mobility Management Entity (MME), Serving Gateway (SGW), Packet Gateway (PGW) and the Home Subscriber Server (HSS) as shown in Fig. 1. The data packets travel from the user equipment (UE) to the PGW via the enodeB and the SGW. The MME exchanges the relevant control signals with the UE and also selects the SGW and PGW that will serve a given UE. The MME is also involved in the handover process as the UE moves within the LTE network.

In order to improve performance in the LTE networks and for load balancing purposes, mobile data offloading from LTE to a non-3GPP network such as WiFi is often done. This requires a seamless handover where existing flows on the LTE network are moved to the WiFi network and vice-versa. The PMIPv6 protocol standardized by IETF and the GTP protocol are used for providing such network mobility.

Fig. 1 also shows an LTE user who has moved to a WiFi network and communicates with the Internet through its Wireless Access Gateway (WAG). The PGW is connected to the WAG to support inter-mobility with WiFi network. In PMIPv6, the EPC's PGW acts as a Local Mobility Anchor (LMA) and the SGW acts as a Mobility Access Gateway (MAG). The LMA acts as a anchor for a UE; that is, all traffic to/from the UE go through the LMA. The LMA forwards packets to the UE via the MAG. For a given UE's connection, there is one LMA and multiple MAGs since the UE can move between different MAGs. The MAG nodes support the mobility agent functions by taking care of mobility related signaling. When the UE moves between MAGs, the network establishes a new tunnel between the new MAG and its LMA. The specific drawbacks in terms of higher signaling overhead are described later.

Software Defined Networks: One of the main objectives of software defined networking (SDN) is to expedite innovation in network architectures. The main concept of SDN is the separation of control and data planes [2]. The goal is to make switches and routers commodity items that implement basic forwarding and packet classification functions, while the network control resides in programmable software based controllers, residing outside these routers. The communication between the controller and the switches is done using the OpenFlow standard, that is part of the specifications released by the Open Networking Foundation (ONF) (www.opennetworking.org). The proposed LTE EPC architecture attempts to apply the key principles of SDN to wireless cellular networks. The specific objective is to build a scalable EPC architecture that supports efficient user mobility support between different networks.

Related work: There have been several proposals for the use of SDN in wireless networks. In [4], the current control protocols in eNB-MME and MME-SGW interfaces are replaced by OpenFlow in order to introduce flexibility and programmability. The UE's S1 and S5 data bearers (GTP tunnels) are kept in the network equipment during the application's idle period to reduce the signaling load. The work in [5] describes an integration of LTE control plane with OpenFlow and setting up GTP using OpenFlow. However, these two approaches do not completely utilize the advantages of SDN since they use GTP to provide IP mobility instead of using the *global view* property of SDN. Also, they need to extend the OpenFlow switch to include the virtual ports to allow encapsulation and decapsulation of GTP header, thus supporting flow-based routing using GTP Tunnel End Point Identifier.

The SoftCell architecture [6] provides a scalable framework for supporting fine-grained policies in LTE core network by using core switches which forwards traffic based on hierarchical addresses and policy tags. The work in [7] analyses the functionalities of PGW and SGW, and proposes four different frameworks to realize GTP function via SDN. The work described in [8] eliminates the GTP tunnel and discusses a Layer-2 approach for mobility within the network, and transport in the mobile backhaul. The SoftMoW [9] architecture proposes a hierarchy of controllers to support IP based mobility between the different LTE networks.

In our proposed architecture, we centralize the EPC control plane with the inter-mobility anchor control plane which helps in managing the IP-based flow mobility between LTE and other access networks.

III. Signaling Overhead in existing LTE framework

This section describes the key mobility related activities and the corresponding signaling processes and overhead involved.

Initial Attach and New Access Bearer: Here, the UE initiates the attach procedure to register with the network to receive services. This procedure as described in [10] consists of UE authentication, UE registration and EPS Bearer establishment processes. After authentication, the UE registers itself with the network and the network allocates IP address to the UE and establishes the first Packet Data Network (PDN) connection. The first Packet Data Network (PDN) connection is also known as *Default Bearer*. Whenever UE wants to set up a new bearer (i.e., Dedicated Bearer), it sends a NAS Service Request message to the MME that sets up a new connection.

Intra-LTE Handover: There are many types of intra-LTE handover procedures; here, we consider the X2 based handover with SGW relocation scenario as described in [10]. In this scenario the UE moves between the eNodeB's which are connected to different SGW's.

Inter-RAT Handover Procedure: In the 3GPP–EPC architecture, PMIPv6 is used for network-based inter-mobility management. This procedure as described in [11] consists of deletion of the PMIPv6 tunnel that is present between the previous MAG (SGW) and the LMA (PGW); and establishment of a PMIPv6 tunnel between the new MAG and the LMA (PGW).

The major drawbacks of the 3GPP–EPC architecture are the high volume of control signaling and event occurrence delay. This happens due to the maintenance of GTP or PMIPv6 tunnel. In all the above events, it has been observed that most of the messages are for tunnel management. The GTP or PMIPv6 tunnel is used to provide IP mobility, but at the cost of high control signaling, event occurrence delay and tunneling load.

IV. Proposed EPC Architecture

This section presents the proposed EPC architecture.

A. Architectural Model

The proposed EPC architecture consists of a *logically centralized* EPC Controller and OpenFlow Switches (OF-Switches) as shown in Fig. 2. The EPC Controller is connected to eNBs and OF-Switches via TCP links. The use of GTP or PMIPv6 tunnels for IP mobility is eliminated. OF-Switches provides the feature of IP mobility by forwarding the packets based on tuples as specified by EPC Controller. The components of the proposed EPC architecture are described in detail below.

EPC Controller: This is the main component of the proposed EPC architecture. It performs the tasks of UE Authentication, Mobility Management, IP Address Allocation and Charging Support. It receives the UE authentication and mobility information via TCP interfaces connected to the eNB. It routes the flows of an UE, based on the UEs location, thus providing the facility of IP mobility. It has the global view of the complete network consisting of OF-Switches, eNBs and UEs.

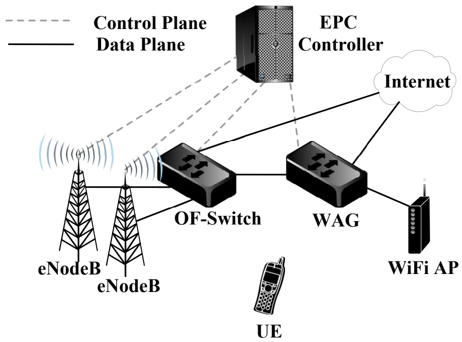
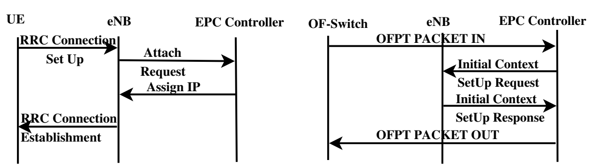


Fig. 2: Proposed EPC Architecture.

OpenFlow Switch: The OpenFlow switch, on receiving a new flow request, forwards it to the EPC Controller. The latter, based on information from the flow, identifies the corresponding UE and then routes the flow according to the UE's location, and also by updating the flow table entries of the corresponding OpenFlow switches.

eNodeB: The eNodeB functions are as in 3GPP–EPC. Each eNodeB is connected to one OF-Switch. The eNodeB, after receiving the uplink flow, directly forwards it to the OF-Switch through which it is connected. The OF-Switch, after receiving the new flow, forwards it to the EPC Controller; the latter handles it according to its flow information. The eNodeB maintains a table consisting of two fields *Flow Match Header* (*ofp_match*) and *E-UTRAN Radio Access Bearer Identifier* (*E-RAB ID*). The table is updated by the EPC Controller whenever a new flow arrives. When the downlink flow arrives, it is mapped to the corresponding radio bearer using *E-RAB ID* and then delivered to the corresponding UE.



(a) Initial Attach Procedure (b) New Flow Entry Procedure

Fig. 3: Procedures in proposed architecture.

B. Events Call Flow

The call flow for the important mobility events are described below.

1) Initial Attach Procedure: This is shown in Fig. 3a. The EPC Controller, after receiving the *Attach Request* message, authenticates the UE and allocates the IP address by sending *Assign IP* message. The *Assign IP* message consist of *IMSI*, *IP Address*, *UE Security Capabilities* and *Security Key* information elements.

2) New Flow Entry Procedure: This is shown in Fig. 3b. When a new flow arrives, the OF-Switch sends the $OFPT\_PACKET\_IN$ message to the EPC Controller. This sends the *Initial Context Set Up Request* message to the eNB that updates the table with the ofp_match and *E-RAB ID* entry corresponding to the new flow. The EPC Controller sends the $OFPT\_PACKET\_OUT$ message to the OF-Switches after receiving the *Initial Context Set Up Response* message.

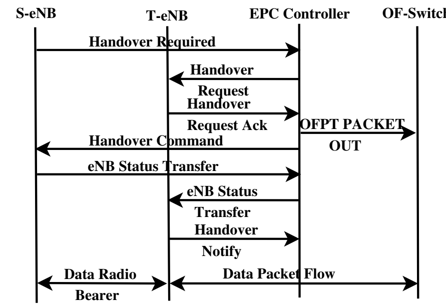


Fig. 4: Intra-LTE handover procedure in the proposed architecture.

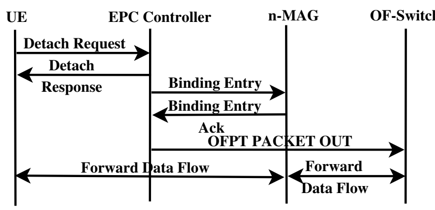


Fig. 5: Inter-RAT handover procedure in the proposed architecture.

3) Intra-LTE Handover Procedure: This is shown in Fig. 4. The source eNB (S-eNB) sends the *Handover Required* message to the EPC Controller. The EPC Controller sends the *Handover Request* message to the target eNB (T-eNB) for enquiring about the availability of resources. The target eNB sends the *Handover Request Acknowledge* message to the EPC Controller. If the resources are available at the target eNB, the EPC Controller sends the $OFPT\_PACKET\_OUT$ message to the OF-Switches for re-routing the data flow towards the target eNB. The EPC Controller informs the status of handover process to the source eNB by sending *Handover Command* message. The source eNB sends the status of the UE to the EPC Controller; the status is forwarded to target eNB. The target eNB will send the *Handover Notify* message to the EPC Controller when the UE has been identified in the target eNB and the handover has been successfully completed.

4) Inter-RAT handover Procedure: This is shown in Fig. 5. When the UE moves from one access network (e.g. LTE) to the new access network (e.g. WiFi), it will send the *Detach Request* message to the EPC Controller. The EPC Controller, based on the location information of the UE, makes the binding entry of the UE at the new access network by sending the message *Binding Entry*. The binding entry provides the same IP address to the UE at the new access network. After receiving the *Binding Entry Response*, the EPC Controller sends the $OFPT\_PACKET\_OUT$ message to the OF-Switches to re-route the flow towards the new access network.

V. Performance Analysis

In this section we analyze the proposed architecture in terms of signaling load, and compare it to 3GPP–EPC.

TABLE I: Message Sizes (Bytes) in 3GPP–EPC.

Messages	Notation	Src-Dst	Size
Tunnel Management Messages			
Create Session Request	M_{csr}	MME-SGW	335
Create Session Response	M_{csp}	SGW-MME	241
Create Session Request	$M_{csr'}$	SGW-PGW	335
Create Session Response	$M_{csp'}$	PGW-SGW	224
Modify Bearer Request	M_{mbr}	MME-SGW	101
Modify Bearer Response	M_{mbp}	SGW-MME	81
Modify Bearer Request	$M_{mbr'}$	SGW-PGW	67
Modify Bearer Response	$M_{mbp'}$	PGW-SGW	81
Delete Session Request	M_{dsr}	MME-SGW	90
Delete Session Response	M_{dsp}	SGW-MME	18
Delete Session Request	$M_{dsr'}$	SGW-PGW	90
Delete Session Response	$M_{dsp'}$	PGW-SGW	18
Context Management Messages			
Initial Context Set Up Request	M_{icsr}	MME-eNB	145
Initial Context Set Up Response	M_{icsp}	eNB-MME	86
Handover Messages			
Path Switch Request	M_{psr}	eNB-MME	~48
Path Switch Request Ack	M_{pack}	MME-eNB	~54
Handover Request	M_{hr}	MME-eNB	~84
Handover Request Ack	M_{hack}	eNB-MME	~34
eNB Status Transfer	M_{est}	eNB-MME	22
Proxy Binding Update	M_{pbu}	PGW-MAG	38
Proxy Binding Ack	M_{pba}	MAG-PGW	38

TABLE II: Message Size (Bytes) in Proposed EPC Arch.

Messages	Notation	Src-Dst	Size
OF Assign IP	OF_{aip}	eNB-Ctr	44
OF Initial Context Set Up Request	OF_{icsr}	Ctr-eNB	82
OF Initial Context Set Up Response	OF_{icsp}	eNB-Ctr	42
Handover Required	OF_{hrq}	eNB-Ctr	~20
Handover Request	OF_{hr}	Ctr-eNB	~62
Handover Request Ack	OF_{hack}	eNB-Ctr	~42
Handover Command	OF_{hc}	Ctr-eNB	~46
Handover Notify	OF_{hn}	eNB-Ctr	30
eNB Status Transfer	OF_{est}	eNB-Ctr	22
Proxy Binding Update	OF_{pbu}	Ctr-MAG	38
Proxy Binding Ack	OF_{pba}	MAG-Ctr	38
OFP_PACKET_IN	OF_{in}	OF_Switch-Ctr	32
OFP_PACKET_OUT	OF_{out}	Ctr-OF_Switch	24

A. *Signaling Cost*

The signaling cost is defined as the total size of all the control messages required for the completion of an event. Let λ_n be the session arrival rate for each UE. The UE arrival process follows a Poisson distribution with rate λ_u. For the 3GPP EPC architecture, the message size determined from 3GPP specifications [12], [13], [14], [4] are shown in Table I. For the proposed EPC architecture, the messages *OFPT_PACKET_IN* and *OFPT_PACKET_OUT* are determined from [3]; the rest of the messages are obtained from [12], [13], [14] by removing the information element *MME UE S1AP ID* and replacing *E-RAB ID List* with *ofp_match List* in messages. The size of the proposed EPC messages are shown in Table II. The signaling cost for the architecture is evaluated below:

1) 3GPP–EPC Architecture: The signaling costs of the various scenarios are as follows:

a. Initial Attach signaling cost is: $C_1 = M_{csr} + M_{csp} + M_{csr'} + M_{csp'} + M_{icsr} + M_{icsp} + M_{mbr} + M_{mbp} + M_{mbr'} + M_{mbp'}$

b. New Access Bearer Set Up signaling cost is: $C_2 = M_{icsr} + M_{icsp} + M_{mbr} + M_{mbp} + M_{mbr'} + M_{mbp'}$

c. Intra-LTE Handover signaling cost is: $C_3 = M_{hr} + M_{hack} + M_{est} + M_{psr} + M_{csr} + M_{csp} + M_{mbr'} + M_{mbp'} + M_{dsr} + M_{dsp} + M_{pack}$

d. Inter-RAT Handover signaling cost is: $C_4 = M_{dsr} + M_{pbu} + M_{pba} + M_{dsp} + M_{pbu} + M_{pba}$

2) Proposed Architecture: The signaling costs of the various scenarios are as follows:

a. Initial Attach signaling cost is: $C_1 = OF_{aip}$

b. New Flow Entry signaling cost is: $C_2 = OF_{in} + OF_{icsr} + OF_{icsp} + OF_{out}$

c. Intra-LTE Handover signaling cost is: $C_3 = OF_{hrq} + OF_{hr} + OF_{hack} + OF_{hc} + OF_{out}$

d. Inter-RAT Handover signaling cost is: $C_4 = OF_{pbu} + OF_{pba} + OF_{out}$

The total signaling cost for each UE of the architecture is given by:

$$TSC_{ue} = P_1.C_1 + P_2.C_2 + P_3.C_3 + P_4.C_4 \quad (1)$$

The total signaling cost for N UEs in the network is given by:

$$TSC = N \times TSC_{ue} \quad (2)$$

Here, P_1 is the probability of occurrence of scenario 1; $P_1 = 1$ since consider a UE only if it is attached to the network. P_2 is the probability of occurrence of scenario 2. We assume the session arrival rate for each UE follows Poisson distribution with rate λ_n. Thus $P_2 = \lambda_n e^{-\lambda_n}$. P_3 and P_4 are the probability of occurrence of scenario 3 and 4 respectively. P_3 and P_4 are given by [15]: $P_3 = \dfrac{\mu_c}{\mu_c + \lambda_u}$, $P_4 = \dfrac{\mu_d}{\mu_d + \lambda_u}$

Here, the variables μ_c and μ_d represent the border crossing rate of a UE out of a subnet and an access network respectively and are given by: $\mu_c = 2\dfrac{v}{\sqrt{\pi\alpha_R}}$, $\mu_d = \dfrac{\mu_c}{\sqrt{\beta}}$

Here, v is the average velocity of the UE. The access network consist of β number of eNB having the coverage area of $\alpha_R = \pi R^2$ with radius of R.

The analysis is done for 50% pedestrian (speed of 1 Km/h) and 50% vehicular (30 Km/h) users in the network. The values considered are: $R = 500\ m$, $\beta = 5$, $\lambda_n = 0.03$, and $\lambda_u = 1.66$. The total signaling cost is calculated using Equation 2 and shown in Fig. 6. It is seen that the total signaling for 3GPP–EPC increases at a higher rate as compared to proposed architecture, with increasing number of users. For 10,000 users the signaling cost of 3GPP EPC architecture is 18 MBytes; the corresponding cost in the proposed architecture is around 1 MByte. If the number of UEs is very high (of the order of millions), then the signaling costs will also proportionally increase. This can become a critical bottleneck for the existing 3GPP EPC architecture.

B. *Simulation Based Analysis*

The proposed architecture was implemented in the ns-3 simulator. Here, the EPC Controller is implemented on top of the ns-3 OpenFlow controller and then connected to 100 eNBs, 11 OF-Switches. The topology also consists of 100 WiFi APs.

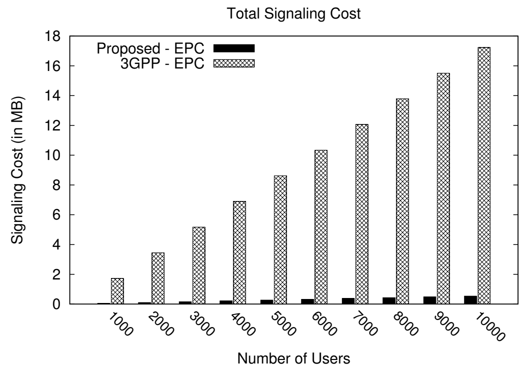


Fig. 6: Total signaling cost.

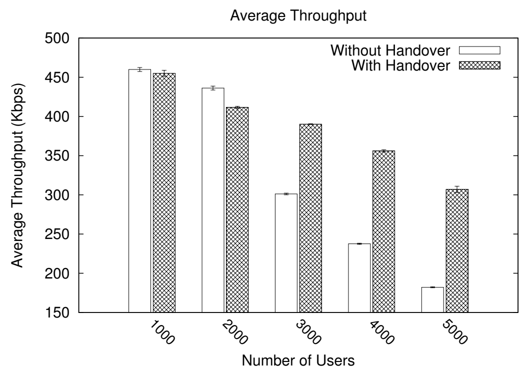


Fig. 7: Average per-user throughput.

TABLE III: Delay in the occurrence of various events

Event	3GPP–EPC	Proposed–EPC
Initial Attach	6.044 ms	2 ms
New Access Bearer Set Up / New Flow Entry	6.044 ms	2 ms
Intra-LTE Handover	177.21 ms	26 ms
Inter-RAT Handover	565 ms	26 ms

Each UE generates traffic at the rate of 500 Kbps. To test the scalability of the EPC Controller, 50% of the users send handover requests each second to the EPC Controller. It can be seen in Fig. 7 that the average per-user throughput for the different users is equivalent or higher in case of the handover scenario than from the without handover scenario. Thus, we can say that the EPC Controller is able to handle the handover requests from these users, thereby increasing the throughput of the network.

The delay for the four different events are presented in Table III. The delay for 3GPP EPC architecture is determined from ns-3 simulations by constructing a topology consisting of PGW/SGW, MME and 100 eNBs. It can be seen that the proposed architecture reduces the delay for the various procedures; from 6.044 to 2 *ms* for initial attach and new access bearer set up. Similar reduction is seen in the case of the handover procedures.

VI. Conclusions

The existing LTE network architecture has serious limitations due to high control signaling, delay and protocol stack overhead. In this paper, we have presented a new architecture to overcome the limitations of 3GPP–EPC architecture by using the concepts of SDN. The proposed architecture centralizes the functionality of EPC control plane and inter-mobility anchor at the logical controller and replaces the SGW and PGW with the OF Switch. Centralization of functionality reduces the high control signaling and delay. The evaluation results shows that the proposed architecture reduces the signaling cost, delay in the occurrence of the various events and eliminates the tunneling costs.

Acknowledgments: This work was supported in part by DST-EPSRC funded India-UK Advanced Technology Centre of Excellence in Next Generation Networks, Systems and Services (IU-ATC).

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