

# A Multi-domain Network Simulator based on NS-3

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**Abstract:** With telecommunication technology development now moving to a different generation of wireless communication from 4G to 5G, user connections become faster and more reliable. However, from the view of application developers, there is still a testbed environment lacking to evaluate their systems reliability and performance. In this paper, we present an extension for the LTE module collaboration via roaming based on NS-3 simulator, which will provide an ecosystem for on-car service testing as a sample context. We also evaluate the model with specific metrics to check whether the model is adaptable to real-time processes.

## 1 INTRODUCTION

Distributed systems and computer networks are at the core of cloud computing, which contains both complex hardware and software infrastructures (Princy and Nigel, 2015). However, the high cost of building and testing real infrastructures calls for alternative solutions to give clear indications about the reliability and performance of the system before even building it. For decades simulations have been used to evaluate different aspects of software systems and test different configuration settings. In this paper, we describe our effort in designing and building a simulation environment module to support roaming services.

Followed by (Huawei, 2020), the roaming services facilitates service accessing by mobile users from outside of home network, roaming is only allowed with the visited network having similar network standards and signed roaming agreement with the home network.

In particular, we focus on building a cross-domain Long Term Evolution - Evolved Packet Core (LTE-EPC) model, which will be applied for on-car services when changing its service providers, in other words, the car crosses its country borders or gets far from its current connected Base Station (BS).

Traditionally, on-car services as multimedia or gaming will connect with the nearest Base Transceiver Station (BTS in 3G or eNodeB in 4G), the data flow will be established from a server to the running service via the core network and telecommunication infrastructure. A problem happens when the car moves far from the current BTS, the network sig-

nal will become weaker and then unstable, the current mobile network solves this problem by disconnecting with the connected BTS and then reconnect with the next nearest one. All mobile sessions from the previous BTS also move to the next, and services also need to reconnect, this behavior is called **handover** or **handoff** (HO). The handover event will be triggered when the serving cell becomes worse than a specific threshold, the value could be measured by Reference Signal Receive Power (RSRP) or Reference Signal Received Quality (RSRQ).

There are two cases for services after the handover event, the first case is to connect with the same LTE network, in other words, this is the Intra-operator handover, and other kind of handover between two independent LTE, which is called Inter-operator handover. These concepts will be explained in the background section. The first case is already implemented in the LTE-EPC module in NS-3, thus we focus on the other case and evaluate it in this paper.

The handover between two LTE raises some issues for our simulator:

- When should we trigger the handover event? Similar to intra-operator handover, we have to define a threshold-based RSRQ or RSRP to trigger the event.
- Which is a suitable route for User Equipment (UE) requests? After the handover, requests from UE could follow the roaming route to come back to the home network to access the original server or request a new server from the visited network.
- Which UE's information should be kept after han-

do over? Keeping connections with an LTE network requires session information as IP address, International Mobile Subscriber Identity (IMSI), UE session in BTS, etc. We have to decide which data should be updated for the new LTE and which one should be maintained.

The rest of the paper is organized as follows: we will start with the background to show concepts in LTE, the next is the core technologies we used to build our architecture. Section four is about related work, the architecture design and evaluation are in section five and six respectively and the last one is conclusion.

## 2 BACKGROUND

This section will present general concepts related to network communication and components. These fundamental studies will be used for our further coming implementation.

### 2.1 LTE Main Components

We introduce LTE components here to get a better understanding of our further design. 4G/LTE architecture divides into two main sets which are the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) from LTE and the EPC (Page and Dricot, 2016).

E-UTRAN is the radio access network and contains eNodeB which will handle requests from UE (user equipment) and forwards them to EPC. EPC is the core network of LTE architecture which consists of the following components:

- MME: stands for Mobility Management Entity that manages UE access network and mobility as well as establishing the bearer path for UE.
- S-GW: means Serving GateWay, the main function of S-GW is to forward or route user data packages. It also controls inter-eNodeB handover and provides mobility between LTE and other types of networks.
- P-GW: Packet GateWay provides connectivities from UE to external networks by being the point of exit and entry for UE requests.
- HSS: Home Subscriber Server that presents for a central database that contains user information.

Each component in EPC is connected by interfaces which is shown in Figure 1.

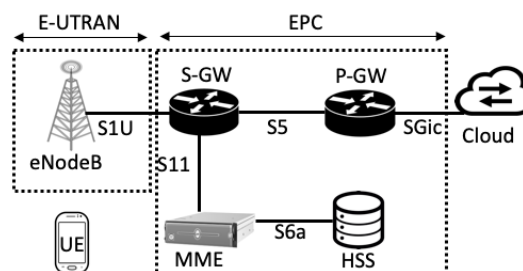


Figure 1: LTE architecture.

### 2.2 Handover Techniques

In cellular networks, handover techniques perform an essential role for the user seamless connection while moving. An efficient handover scheme will enhance the quality of service and provide flawless mobility. (Tayyab et al., 2019) have classified handover types:

- Inter-/Intra-frequency handover: an intra-frequency neighbour is referred to a target eNodeB which operates on the same carrier frequency, in another case, the eNodeB operates different frequency which is called an inter-frequency neighbour, respectively, we also have inter-/intra-frequency handover.
- Inter-/Intra-cell layer handover: HetNets (Heterogeneous network, includes macro, micro, and picocell layers) provide a multiplicity of cellular layers to handle the capacity demand of users if handover requests come from the same layer, it is called Intra-cell layer handover, otherwise, it is Inter-cell layer handover.
- Inter-/Intra-RAT handover: RAT stands for Radio Access Technology, similar to other kinds of handover, a handover event happens in the same RAT will be Intra-RAT handover, with different RAT, this is Inter-RAT handover.
- Inter-/Intra-operator handover: This can occur between systems controlled by an administrator or an operator called Intra-operator handover, Inter-operator one is another case. Roaming is an example of Inter-operator handover.

(Tayyab et al., 2019) showed measurement concepts with RSRQ and RSRP, and steps by steps for Intra-handover. RSRP is the average received power without interference and noise components, RSRQ is calculated as the ratio of RSRP and RSSI (Received Signal Strength Indicator) while RSSI is the total received power including noise and interference. In this paper, we focus mainly on Inter-operator handover with MME change, or in other words, the case of roaming that we will investigate hereafter.

### 2.3 Roaming Procedure

According to technical paper (Huawei, 2020) (GSM, 1997) and the handover process in (Tayyab et al., 2019), the handover procedure in the roaming case generally is described following steps:

1. The UE sends an initial request to access the LTE home network (HPMN - Home Public Mobile Network) for the first time, eNodeB forwards the request to SGW and then MME, MME checks the validity of UE via HSS before responding.
2. The UE is accepted to send another request for services.
3. The UE measurement procedure is configured by the serving eNodeB according to access restriction and roaming information.
4. The UE sends an Measurement Report (MR) to the serving eNodeB.
5. Based on the MR, the serving eNodeB could make a handover decision for Intra-neighbor but the next eNodeB is not in the same LTE network so the current eNodeB keeps responding.
6. From UE, the next eNodeB signal is stronger than a specific threshold with the current connected eNodeB.
7. The UE detaches from the old cell in-home network and requests to connect with the target cell (new cell) in the visited network (VPMN - Visited Public Mobile Network).
8. In the visited network, eNodeB receives an initial request to connect, it is forwards to SGW and then MME.
9. MME fails to verify the identity of HSS, it requests to the HSS of the home network via  $S6a$  interface.
10. HSS from the home network confirms the UE identity, from now, UE can access the visited network with two cases of service requests. Its IP address will be updated followed by the network while its IMSI is still maintained.
  - (a) Requested service is available in the visited network: service data flow will be sent to PGW of visited network and then its server as normal (Visited server requests).
  - (b) Requested service is not available in the visited network: the service request follows  $S8$  interface to come back the home PGW and then home core network (Roaming server requests).

Figure 2 illustrated the roaming flow in LTE architecture between two adjacent network. Besides

described components, we also have PCRF (Policy and Charging Rules Function) for both visited and home network (vPCRF and hPCRF), which take care of managing quality of service, it communicates with PGW via Gx interface.

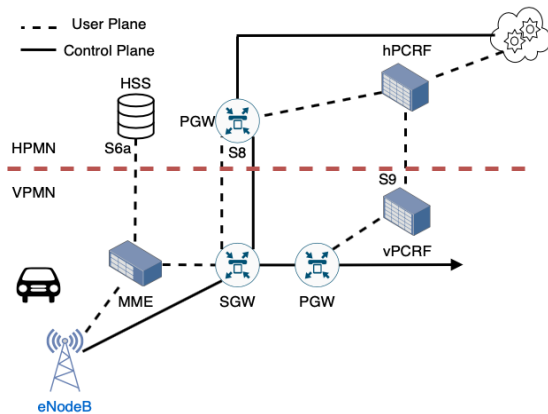


Figure 2: LTE roaming architecture.

### 3 CORE TECHNOLOGIES

NS-3 (Riley and Henderson, 2010) is a discrete-event network simulator that is free and open-source software. The goal of NS-3 is to develop a simulation environment suitable for networking research. NS-3 is maintained by a worldwide volunteer team and releases a new stable version for every three months with a new model developed.

Besides network simulator supports, NS-3 also provides real-time scheduler to facilitate a number of simulation-in-the-loop use cases for interacting with real systems. NS-3 can receive or send packages from a real network or serve as an interconnection framework between virtual machines. Here, we developed our model based on the NS-3 simulator functions.

There are two main components of EPC-LTE in NS-3 as LTE module and EPC module. The **LTE module** (Piro et al., 2011) provides a basic implementation of LTE devices, including propagation models and PHY and MAC layers. It focuses on modeling the E-UTRAN part of a system that contains eNodeB and UE with their channel connections as Radio Resource Management, Packet Scheduling, and Dynamic Spectrum Access. The **EPC module** (Baldo et al., 2012) includes core network interfaces, protocols, and entities as PGW, SGW and MME. Interfaces connecting components also presented there. The **EPC-LTE** structure and component details are online<sup>1</sup>

<sup>1</sup><https://www.nsnam.org/docs/models/html/lte-design.html>

## 4 RELATED WORK

Besides concepts with paper referred to in Section 2, we would investigate paperwork about roaming architecture based NS-3, but we found no simulators working that way.

Another point we would like to focus on is about the NS-3 interaction with the real world application. (Quinlan et al., 2016) propose a platform based NS-3 to simulate Dynamic Adaptive Streaming over HTTP (DASH), their work also inherit the LTE module from LENA project to build an LTE environment which is set up in an independent computer. Tap bridge is installed to connect interfaces from the computer with Raspberry Pi machines. They provide their configuration with source code<sup>2</sup>, which is useful for our extension. (Sabbah et al., 2018) extend the LTE-EPC module with CORE (Common Open Research Emulator) to facilitate large-scale real-time network traffic, they built a topology with several LTE-EPC, each eNodeB in LTE will make a local controller for UEs. They experiment with 32 EPCs, 2 eNodeBs per each EPC and 5 UEs for each eNodeB. Their result is comprehensive with a large-scale model that can support our work to scale up, however, to overcome the problem of the EPC communication, remote hosts of each EPC connects to each others to form a ring topology, so UEs always can connect to its original host.

Moreover, Docker container enables us to build a flexible environment, we also want a combination of Docker and NS-3, J.A.Alvarez Aldana explains his work<sup>3</sup> with port connection and traffic flows between Docker and NS-3, configuration and environment setup are presented in detail. (Portabales and Nores, 2018) also extend from the work of Aldana to make the simulator adaptable with IoT simulations, they even pack their NS-3 work into a Docker container to make the flexible deployment. We could follow their work to extend our model.

Our previous work (Le et al., 2019), (?) built a Mobile Edge Cloud management based on blockchain (?), (?), the LTE simulator inherits from SimuLTE (Virdis et al., 2014) which runs on OMNetpp environment (Varga and Hornig, 2008) and INET (Varga, 2020), and the mobility simulator is controlled by Veins (Sommer et al., 2008) and Sumo (Behrisch et al., 2011). However the work does not present fully the concept of changing domain in the LTE network, eNodeBs are still connected to share user session while higher network layers as PGW or MME does not collaborate to exchange the user data. So

<sup>2</sup><https://www.ucc.ie/en/misl/research/software/lanman2016/>

<sup>3</sup><https://chepeftw.github.io/NS3DockerEmulator>

we decide to build an architecture based on NS-3 which attracts more attention and contributions from the community, so the upgrade and improvement for our architecture will be more easier.

## 5 ARCHITECTURE DESIGN

In this section, we propose an architecture for the multi-domain LTE simulator, we will start with a general design and then go in detail later.

### 5.1 General Design

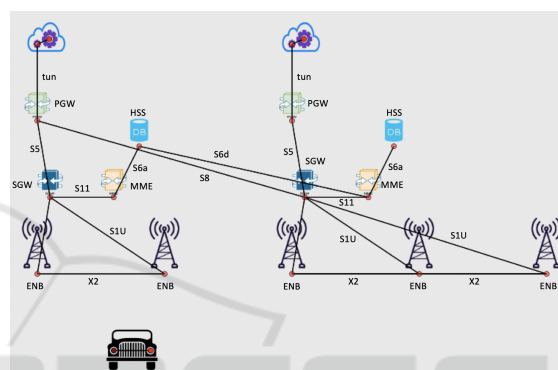


Figure 3: General design.

We prepare two independent LTE models and enable them to interact with others via the roaming channel and with UE (see Figure 3). The roaming channel is built with two main interfaces as S6d and S8.

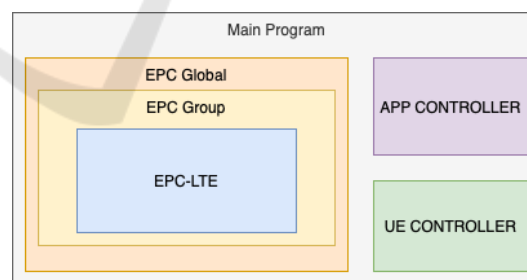


Figure 4: Additional modules.

The default LTE-EPC module of NS-3 as described above only supports a single LTE channel, components as PGW, SGW are set as fixed IP address, so we try to extend the model by adding external components as following:

- **EPC Group:** It separates PGW, EnB, SGW, Server, with the main program, we suppose that a region will keep an EPC group. Each EPC group has its right to update the IP address of components as long as the subnet mask.

- **EPC Global:** EPC Global keep a list of EPC-Group, controls roaming and other activities outside Epc groups,

EPC Global also control LTE channel, in the original code, we have some issues when the UE leaves the connected LTE and connect with the next, they are not in the same channel so it can not connect, EPC will build a common channel for all LTE-EPC and UE.

Tap devices are managed in EPC Global, it will follow configurations to pair simulated nodes with the real devices.

- **APP Controller:** Control and setup NS-3 applications, it separates common applications as UDP echo, TCP Streaming or ping from the main program.
- **UE Controller:** Setup and control UE, it will notify when finishing UE setup, UE needs change LTE, and reports UE status to the main program.

We pack all works with NS-3 into a Docker container based Ubuntu:16.04 in order to build a flexible environment, so we can deploy the system anywhere which does not depend on the host environment. NS-3 runs in Linux environment more efficiently, we also add all suitable dependencies and libraries, even with Docker tools inside, the Docker image is published in <sup>4</sup>.

## 5.2 Implementation in Detail

### 5.2.1 Supporting Technologies

**NS-3 PyViz** is based on python and enables a better view for simulation, we upgraded the core of PyViz <sup>5</sup> to add more icons as seen in Figure 3.

**NS-3 Tap interface** <sup>6</sup> is a virtual Ethernet interface that enables user programs to read and write packages to and from the interface. This interface is used for a Linux machine to build traffic channels.

**NS-3 Tap bridge** <sup>7</sup> builds a software channel between a tap interface and a node inside NS-3 simulator, so the node can acts as a real device by exchanging information via the tap interface. When a packet is sent to a tap interface, it is received by the tap bridge and then transforms the real packet to a simulated packet by converting operation inside the NS-3.

<sup>4</sup><https://hub.docker.com/repository/docker/levanthanh3005/ns3>

<sup>5</sup><https://www.nsnam.org/wiki/PyViz>

<sup>6</sup><https://hechao.li/2018/05/21/Tun-Tap-Interface/>

<sup>7</sup>[https://www.nsnam.org/doxygen/group\\_\\_tap-bridge.html](https://www.nsnam.org/doxygen/group__tap-bridge.html)

**Docker** <sup>8</sup> is a lightweight alternative for a full machine virtualization, it encapsulates applications in a container isolated from the host. Containers allow users to pack an application with all essential parts as libraries and other dependencies and deploy them in a package. Each container built its own environment with a unique network IP, resource management for CPU and memory. We also try to build our system in a container and simulate a real environment for multi-domain LTE.

### 5.2.2 IP Address Routing

The LTE default routing in NS-3 only supports the default route from UE to the server via PGW and eNodeB, now we add tap devices into the simulator, we need to update the route from the tap node to the tap server (tap node is the tap device for the UE and tap server is the tap device of the server in the topology). The work on (Quinlan et al., 2016) modifies the class of IP list routing to change the input and output of incoming route which will redirect the request from tap node to server node and from tap server to UE node. However, their work still keeps the default IP address of nodes so we upgrade with a genetic and flexible solution that enables EPC Group to control the IP routing.

### 5.2.3 Passing Domain

This section discusses about the situation when the UE gets far from the current LTE and gets closer to the next. We need to do three main tasks, the first one is to set up the environment with network configuration, next we have to reconfigure routes of UE and servers to be adaptable with the required network, and the last one is to decide when the domain changing need to be triggered.

#### (a) Configuration

The default LTE-EPC components merge MME and HSS into a class of MME, so we separate them into two objects for a better view. This part will answer the third research question about which information we need to keep after changing domain.

Followed by an ETSI technical document about HSS (ETSI, 2013), HSS stores user-related and subscription-related information, for example, user identity, service information, supported features. To simplify the complexity, we only enable the HSS to store the user identity by keeping only IMSI and the user original zone, HSS will be a mapping of IMSI with user details.

<sup>8</sup><https://www.docker.com>

*S6d* is the interface of verification, it is the channel between HSS of the home network and MME of the visited network, once MME can not verify the UE request, it will ask the HSS of the home network via *S6d*. Therefore, only IMSI of UE is maintained in HSS, other UE data could be updated for the new network suitability.

*S8* is the interface between PGW of the home network and SGW of the visited network. After verification, if the UE request needs to use the home network service, it will be routed to this *S8* channel, in other words, this behavior is roaming as we discussed in the Background section.

#### (b) Rerouting

After setting up components and channels for the reconnection, we restart the request process. Each server has different IP addresses and since the table of available services belongs to the main cloud, we can not check in the scope of NS-3 simulator so currently, we suppose that UE has a right to choose the server to route requests.

In case of visited server requests, requests just follow the default route, but before reconnecting, UE has to detach its connection from the home LTE network by removing all requests and sessions with eNodeB, stopping all running applications. After UE accesses to the new LTE network, a new IP address will be assigned and new sessions will be established. In another case, requests will reach SGW and then come back to the home network via *S8* interface. We still have to detach the UE from the home network, but applications can still keep running, its IP address has to update to access the visited network.

#### (c) Passing Domain Trigger

Similar to the handover mechanism, we set a threshold value for RSRQ from eNodeBs, but to avoid the request overlap with handover, this threshold value has to bigger than the threshold of handover, otherwise, UE will assume that the Intra-operator handover will be the Inter-one.

## 6 EVALUATION

In this section, we configure our simulator based on the experiment settings to evaluate the model with real applications.

### 6.1 Experiment Setting

Table 1: Experiment setting.

Metrics	Values
Number of LTE-EPC network	2
Distance between eNodeBs	200 m
Number of eNodeB	5
eNodeB Transmission Power	43 dBm
UE Transmission Power	23 dBm
UE speed	10.8 m/s

As seen the topology in Figure 3, we prepare three tap devices corresponding with server 1 (the LTE on the left), server 2 (on the right), and UE. Each tap device connects to Docker containers which run applications for testing. The simulator environment is shown in Table 1 in the host environment in Table 2. Table 1, we set the UE speed is 10.8m/s as 39km/h followed by the survey (Research department, 2012).

By choosing randomly two eNodeBs in <sup>9</sup>, we set the distance between eNodeBs as 200m, five eNodeBs are setup in the same road, the distance between the first and second one is 200m and with the last one is 800m. Followed by technical slide in <sup>10</sup>, the total delay of LTE is smaller than 100ms, so we will set delay interface as default configuration of NS-3, only *s8* interface delay is calculated by propagation delay which is performed the effect of distance to the flow transmission.

Table 2: Host environment.

OS	macOS Mojave
Processor	2.3 GHz Intel Core i5
Memory	8 GB
Docker version	18.09.2

### 6.2 Measurement

We will examine latency and response time in two cases of domain changing with two applications, one is a simple ping and another is video streaming.

#### 6.2.1 Ping

We evaluate the model with two cases of requests in Figure 5 and Figure 6, the X axis shows the current timestamp receiving values as current distance which is mapped to Y2-axis, RSRP and the latency of response in Y1-axis. For the local server case, the average value of ping is around 18ms, the maximum

<sup>9</sup>[www.cellmapper.net](http://www.cellmapper.net)

<sup>10</sup>[https://www.cisco.com/c/dam/global/en\\_ae/assets/expo2011/saudi-arabia/pdfs/lte-design-and-deployment-strategies-zeljko-savic.pdf](https://www.cisco.com/c/dam/global/en_ae/assets/expo2011/saudi-arabia/pdfs/lte-design-and-deployment-strategies-zeljko-savic.pdf)

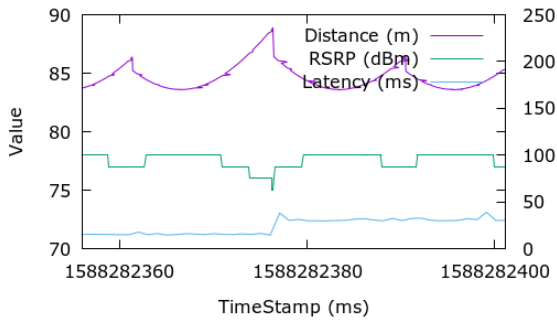


Figure 5: Roaming server requests.

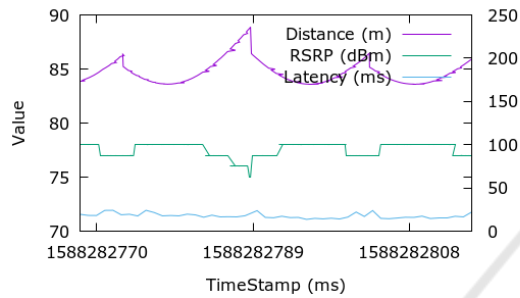


Figure 6: Local server requests.

value is 24ms which is suitable for any common service gaming or video watching. However, with roaming, the ping gets a bit higher, around 30ms and the maximum value is 54ms, it is acceptable for most of games but there is a bit lag for a timing-critical game and also live streaming video. Moreover, as our experiment, the propagation delay in s8 will have a noticeable effect only when the distance between SGW from visited network and PGW from home network is far enough since the delay is calculated by  $distance/speed\_of\_light$ <sup>11</sup>. In our model, we modify the distance is 5000km, causing 0.016ms delay.

And after changing LTE network, in the case of local server requests, the IP address of server is fixed from the calls of UE, so we have to update the server IP manually, in reality, it could affect user experience and make them incontinence because the service is not continuous.

### 6.2.2 Video Streaming

The video streaming application run on Firefox which is packed in a Docker Image<sup>12</sup> and presents for a UE screen. The video server comes from mist server<sup>13</sup>. Mist server is lightweight, only 309MB in Docker Image<sup>14</sup>, but really powerful to build a local video

<sup>11</sup><https://www.space.com/15830-light-speed.html>

<sup>12</sup><https://hub.docker.com/r/jlesage/firefox>

<sup>13</sup><https://www.mistserver.org>

<sup>14</sup><https://hub.docker.com/r/r0gger/mistserver>

streaming service, we stream a video via HTTP protocol.

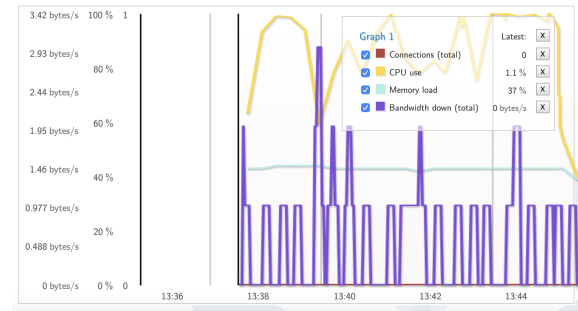


Figure 7: Metric statistic in Mist server.

The mist server only supports basic statistics as the CPU, memory usage, bandwidth up and down metrics, so we can not evaluate the latency (see Figure 7). The graph shows that the simulator connection is not stable when handover events occur both for Inter and Intra, the CPU gets lower since the requests are suspended for a while.

## 7 CONCLUSIONS

In this paper, we presented an extension of the LTE-EPC module of the NS-3 simulator for a multi-domain concept. Our work is based on technical documents about handover and roaming. All components are encapsulated in Docker containers, which facilitates a flexible simulation system so it can be deployed in any host without limitations (?), (?), (?). Besides that, connecting the simulator with real applications as ping and video streaming shows a possibility of application extension and scalability with multiple servers and UEs.

However, there are concerns we could extend for our future work. The passing domain will change the server IP, and UE by itself can not update easily, so we need to extend our model with the concept of service continuity to meet the needs of user experiments for live services. Tested applications are still limited since they do not support in-depth analysis. Thus, we have to apply more application models and use a statistic tool to investigate further.

Moreover, the 5G generation requires our system to be upgradable and adaptable. Currently, we only support to 4G network. With 5G, we could have a wider space to improve but also challenges. In the next version, we will try to add mmWave and gNB (Noll and Chowdhury, 2011) into our model as the starting point for 5G.

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