Design and Evaluation on Mobile Edge Caching Testbed

Can Zhang, Mingyuan Zang, and Ying Yan

Abstract—Internet traffic is predicted to increase fast over the next years. A large portion of it will be generated by mobile video services. Such a data explosion puts higher requirements on the capacity of the mobile network. Deploying more bandwidth resources to increase the network capacity is one solution, but it also means high cost. Mobile Edge Caching (MEC) is a new solution put forward these years to deal with the drastic growth of video data by bringing the video resources close to users at the edge cache. Researches have been done on the design of MEC, and implementing it in an emulator is one of the ways to verify the design. An emulator can provide real-case protocol implementation and more credible results compared with simulator. This paper studies the LTE emulators available in the market and proposes an MEC testbed based on the OpenAirInterface platform. Two use cases of the testbed are demonstrated and their performances are evaluated separately.

Index Terms—Testbed, mobile edge caching, LTE emulation, open air interface.

I. INTRODUCTION

In the past few years, Mobile Edge Caching (MEC) technology has become a promising technology and received increasing attention from both industry and academia. The MEC is a promising solution to the case, where increasing volume of video content are streamed and exchanged with the stringent latency requirement. Compared with deploying extra resource in the backhaul network, caching in the radio access network (RAN) is effective and economical. Specifically, MEC shifts the burden of data transmission from the backhaul network to the fronthaul network in order to minimize bandwidth requirement and improve latency.

To evaluate different caching scenarios, various testing methods are adopted. Large-scale lab and field tests can be conducted by mobile network operators, which require resources on testing equipment and are usually time consuming. The most commonly adopted method for academic researchers is simulation. Network simulation tools are software-based programs and use statistical/numerical models for traffic generation and performance analysis. Popular network simulation tools are available such as Riverbed Modeler (previously known as OPNET), NS3, Omnet++, NetSim and so on. Network protocols and scenarios are implemented in a pure software environment. Testing goals are reached based on assumptions and the adjustment of simulation parameters. However, the simulation environments are not close enough to the real testing situations. Therefore, emulation tools show a better way to approach the real wireless communication system. Compared with the simulation method, the emulation system contains both hardware equipment and software protocol stacks. The emulation platform implements a full stack mobile communication system and involves a software defined radio (SDR) based radio communication environment. The LTE network emulators allow users to utilize lab equipment effectively and to test different network topologies with reduced deployment cost. Nowadays, several platforms are available to offer the emulate LTE network and to examine the transmission-level features. Common emulation platforms include OpenAirInterface (OAI), Amarisoft LTE, srsLTE, OpenEPC and OpenLTE. Details of these platforms are introduced in section II.

In this paper, an OAI-based LTE emulation testbed is set up. The testbed offers a software platform, developed based on the standardized LTE protocols. The proposed in-lab emulation platform can produce testing results closer to the real application while achieving repeatability and portability. This testbed presents an end-to-end communication system with access from multiple users. MEC functions have been implemented and tested with a steady performance.

Our contributions are summarized as follows:

• First, we conduct a survey of existing network emulators and related researches in the literature.

• Second, MEC testbed is prototyped and its design process is introduced in details with focusing on the setup procedure and modelling principles.

• Third, we present two basic tests to verify the proposed advantages of such an in-lab MEC testbed.

The remainder of this paper is organized as follows. Section II presents a survey of existing LTE network emulators. Section III provides a thorough description of testbed configurations and MEC design including the system implementation on control plane and user plane. Section IV discusses MEC performance under several testing scenarios. Section V summarizes our work and proposes the future work.

II. SURVEY OF LTE NETWORK EMULATOR

This section provides a preliminary survey on existing LTE network emulators and introduces their key. Moreover, related applications and deployment scenarios are presented based on literature study.

OpenAirInterface (OAI): OAI is an open-source emulation platform provided by OpenAirInterface Software Alliance of EURECOM. It is one of the most comprehensive and competitive open-source LTE network emulators based on Software Defined Radio (SDR) system. Its current implementation provides a complete wireless protocol stack as well as an IPv4/IPv6 network device interface under Linux system. All elements of the 4G LTE system such as user equipment (UE), evolved NodeB (eNodeB), and the Evolved Packet Core (EPC) are provided. The software program is
installed and run on the host computer with an SDR card for wireless signal processing. Regarding MEC in LTE system, some researchers have built a single user access network on OAI platform to investigate from different aspects. An MEC architecture is proposed in [1] and a prototype for data caching use case is conducted. Authors in paper [2] deploy OAI platform to implement a collaborative caching system based on service function chaining method.

**Amarisoft LTE:** Amarisoft LTE is a commercial software product for LTE network emulation [3]. Similar to OAI in terms of complete implementation and emulation capabilities, Amarisoft LTE supports full stack LTE protocol in software. In [4] the authors conduct a detailed security analysis on different mobile networks including Global System for Mobiles (GSM), General Packet Radio Service (GPRS) and System Architecture Evolution/Long Term Evolution (SAE/LTE). An end-to-end mobile communication security testbed using open source components on a virtualized platform is set up. To implement the SAE/LTE network, LTE Amarisoft 100 is used as the EPC in the testbed. Authors in [5] propose a mobile relay architecture for public transport system. They evaluate the architecture with Amarisoft software suite.

**srsLTE:** srsLTE is a free and open-source software developed by Software Radio Systems (SRS) company [6]. It contains a complete SDR LTE eNodeB application (srsENB), a UE application featuring all layers (srsUE), a light-weight LTE core network implementation with MME, HSS and S/P-GW (srsEPC). The comparison between two open-source tools, OAI and srsLTE, has been conducted in research. In [7], testbeds using OAI and srsLTE are set up respectively, comprising one eNodeB and one UE. The authors measure the downlink throughput under different bandwidth configurations. CPU execution time and memory usage for key modules in OAI and srsLTE are tested and compared. The paper [8] reports performance assessments of srsLTE and OAI. The differences in throughput and resource consumption are investigated and quantified. Based on the results, the authors provide guidelines for deploying 5G testbeds with these tools. A testbed using the srsLTE library is designed in [9]. Investigations focus on the performance assessment of enhanced smart meter traffic in the grid over LTE network.

**OpenEPC:** OpenEPC project has been developed by Fraunhofer Institute FOKUS since 2008. It covers all functional elements in 3GPP EPC specifications and offers advanced IP mobility and QoS control. In [10], a flexible and extensible Diameter based testing system for next generation mobile network is designed. A novel architecture for mobile video surveillance system over EPC is proposed in [11], which allows the delivery of videos streams with different QoS and video quality profiles. [12] demonstrates a distributed network architecture using a custom off the shelf LTE small cell and OpenEPC. In [13], OpenEPC is added to an existing LTE based network as virtual core network. The Nokia small cells are deployed for the LTE radio. OpenEPC as a virtual LTE core network could be deployed as Network Function Virtualization (NFV) based EPC. However, this platform only focuses on the implementation of EPC. For a complete LTE system, eNodeB and UE functions are required from other partners.

**OpenLTE:** OpenLTE project is also an open source implementation of 3GPP LTE specifications and focuses on transmission and reception of the downlink. OpenLTE is limited with lack of a UE software and many features are still under development. [14] presents a data offloading solution using a coexistent LTE and WiFi testbed based on OpenLTE. No performance has been conducted from this paper since the OpenLTE package is not stable enough.

To a summary, various options are available with pros and cons. Due to the high compliance to 3GPP LTE standards, the support for all system elements, the reputation for stability and sufficient technical guidance from OAI community, we have chosen the OAI platform in this work.

### III. System Implementation

#### A. Testbed Layout and Setup

The experimental environment of our in-lab MEC network platform is shown in Fig. 1. The testbed is set up according to the recommendations provided by OAI community.

For the software configuration, OAI software stacks are installed in eNodeB as openairinterface5g (v0.6.1) [15] and EPC as openair-cn (v0.4.0) [16]. Detailed configurations are listed as follows:

1. **eNodeB configurations** Configuration file `enb.band7.tm1.usrp210.conf` defines all the parameters for eNodeB. Identification parameters and network interfaces in the configuration file are modified for the testbed.
2. **EPC configurations** The EPC implementation in OAI includes the functions of MME, HSS, SGW and PGW. MME performs mobility management and authentication; HSS offers a database with UEs’ information; SGW handles data forwarding and switching on the user plane and PGW assigns IP address to UEs and serves as
implementation on control plane and data plane are provided in the remainder of this section.

C. Control Plane Setup

4) SCTP setup in eNodeB: In LTE, the communication between eNodeB and EPC is through the SI interface. The signaling transport between eNodeB and MME on SI control plane is based on Stream Control Transmission Protocol (SCTP). In the OAI platform, a SCTP association is established between eNodeB and MME when starting the eNodeB. The SI Application Protocol (S1AP) handles all the signaling in this process. A new struct called \textit{slap\_eNodeB\_instance\_t} is firstly created, carrying all the information about eNodeB and the network information where the eNodeB is located. By calling the function \textit{slap\_eNB\_register\_mme}, eNodeB attempts to establish the connection with MME. This is initialized by assigning a set of parameters including the local and remote IP address, Application default port number for S1AP, SCTP Protocol Payload Identifier (PPID) for S1AP, and the number of inbound and outbound streams.

The SCTP association with the cache follows a similar way as described above. A new SCTP association request is prepared in which the remote address is assigned to the cache’s address instead of the SGW’s address. The corresponding association ID is increased by one compared to the original association ID to MME.

1) SCTP setup in cache: In the cache entity, a SCTP module in the Linux kernel is loaded at first. Then a SCTP server is set up, which listens to the specified port and receives SCTP packets from eNodeB.

2) GTP tunnel setup preparation: When a UE attempts to attach the network, eNodeB sends an initial UE message to initialize the process. After several message exchange in EPC, MME responds with a S1AP Initial Context Setup Request message, containing the assigned UE IP address, the uplink TEID and the UE S1AP ID provided by EPC. These identifiers are stored in a predefined globally accessible struct and processed in the function \textit{slap\_eNB\_handle\_initial\_context\_request} in eNodeB. To respond to the request from MME, eNodeB sends an S1AP Initial Context Setup Response message from the function \textit{slap\_eNB\_initial\_ctx\_resp}. A downlink TEID is generated and included in this response message. The obtained UE IP, uplink and downlink TEIDs are later used to build the GTP tunnel in the cache. In order to forward these identifiers to cache via the control plane, a SCTP message is generated and sent to cache. The message is constructed by 4 fields with a total length of 16 bytes, namely message type, TEID Downlink, TEID Uplink and UE IP address.

D. User Plane Setup

1) Enabling GTP kernel in cache: the role of S1 user plan is to transport user data packets between eNodeB and the SGW. The interface is built by using GPRS Tunneling Protocol (GTP) tunnels. To implement the MEC function, a new GTP device is added with the support of libgtpnl tool. When a SCTP message is received from eNodeB, the cache entity parses the SCTP message and obtains UE IP address, downlink TEID and uplink TEID. The GTP
tunnel connected to this device is then configured with these identifiers. The UE IP address is added into the routing table of GTP device. The cache entity can now communicate with eNodeB on user plane. It is able to handle the request encapsulated in GTP packet, access to the resource stored in cached server and respond back via GTP tunnel. A virtual interface is built in cache by setting up Linux namespaces to bind the cached server offering resource.

| Source files               | Function name                          | Function Descriptions                                           |
|----------------------------|----------------------------------------|-----------------------------------------------------------------|
| S1ap_eNB.c                 | s1ap_eNB_register_mme                  | eNodeB registers MME by setting up the SCTP association         |
|                            | s1ap_eNB_handle_sctp_association_resp  | eNodeB handles the SCTP association response from MME           |
| S1ap_eNB_handlers.c        | s1ap_eNB_handle_initial_context_request| Process the bearer parameters to set up UE context             |
| S1ap_eNB_nas_procedures.c  | s1ap_eNB_initial_ctxt_resp             | Respond to MME to indicate the successful setup of E-RAB       |
| gtpv1u_eNB.c               | gtpv1u_eNB_task                        | Send and receive GTP packets                                   |

TABLE I: OVERVIEW OF S1AP AND GTPV1-U FUNCTIONS IN OAI

2) Caching scheme implementation: Having the SCTP and GTP-U tunnels paved for the control plane and user plane respectively, the cache is prepared and ready to offer its local resources to users. In the GTPv1-U codes of OAI, the function gtpv1u_eNB_task runs a loop to handle the GTP tasks received over ITTI interface. The handling process is illustrated by a flowchart in Fig. 3.

IV. TESTING AND PERFORMANCE EVALUATION

A. Testing Scenarios

The proposed in-lab MEC testbed can be used to evaluate network performances. With the usage of OAI platform, the mobile transmission features are taken into account in the end-to-end communication system. In this section, we show two basic test cases to investigate the network performance.

Case A: Coding rate

The coding rate can affect the size of a video and also the quality perceived by users. High coding rate can offer better visual experience. However, the large size of the video will also burden the link. In this case, we focus on whether introducing the cache into the network can improve the video transmission under different coding rates. The test scenarios include transmission of a video with coding rate of 100 kbps and 500 kbps from either the remote server or the local cache. We inspected on the frame loss rate and delay to evaluate the quality of video perceived by users.

Case B: multiple UEs access

The number of UEs access to video server has an impact on the quality of video service. To investigate if adding edge cache could offload the traffic, we analyze the test case in which two UEs attached with two eNodeBs respectively and two eNodeBs connect to the same EPC (as shown in Figure 1). There are three scenarios designed to compare the results:

1) Scenario 1: only remote server available.
2) Scenario 2: local cache 1 is available for UE 1.
3) Scenario 3: both local cache 1 and 2 are available.

The video clip offered in this case has 2400 frames and has a coding rate of 1 Mbps. It is streamed over the emulated LTE network using Real Time Streaming Protocol (RTSP). Since the testbed is built in lab, there is little geographical distance in the backhaul network. Thus, 1% jitters and 10ms delay are added at EPC network interface on purpose to simulate the real-world network transmission.

B. Results Analysis

Case A Coding rate: Fig. 4 (a) and (b) show the results of coding rate tests. In general, caching the video clip locally can improve the Quality of Experience by reducing the jitters and delay. Considering the coding rates, the larger coding rate results in a better improvement from using the local
cache. When the coding rate is 100 kbps, introducing the cache helps to reduce the delay by 0.8%. While for the video clip with 500 kbps, the cache successfully reduces the delay by 1.5%. The results of jitter variants demonstrate also an improvement of adopting the local cache in the system. When the video clip has 100 kbps coding rate, around 2.3% jitters happens during the transmission from the remote server. This number is cut down to 1% when the cache offers the service. In the case of the video with 500 kbps rate, jitter is reduced from 2.7% to 1%.

Case B Connected UEs: Fig. 4 (c) illustrates the comparison of delay under three scenarios. When both UEs are served directly by cache, the execution time presents a decreasing trend. While this trend is not obvious for UE 1, UE 2 receives a better service with the introduction of the cache. When both UEs are served by the cache, UE 2 plays the video with a reduced delay to 2%. Even when only the UE 1 is served by cache and UE 2 is still kept served by remote server, the delay can be reduced by about 1%. This is also the case for jitters. Fig. 4 (d) demonstrates the comparison of jitters. When UE 1s request is redirected to the cache, the traffic on the backhaul link is offloaded and UE 2 gains a better service with jitters reduced from about 3% to 2.5%. When both UEs are served by the cache, UE 2 receives a decreasing number of loss frames, which is reduced to 0.5% compared with 3%.

V. CONCLUSION

This paper has provided a flexible testbed that is capable of determining performance measurements on LTE-based MEC technology. This work also gives a detailed description of its design structure and test configurations. This testbed aims to discover MEC capabilities with multiple connected users under three different test scenarios. However, the configuration possibilities are not limited to our conducted experiments. Taking into account the functional design and setup that has been verified, the proposed in-lab testbed can be used by researchers to further develop advanced MEC algorithms and to integrate with other innovative technologies, such as Software Defined Network (SDN).

Some notable observations can be made based on the test results. Firstly, network performances in terms of delay and jitter are improved by offloading the traffic from the backhaul network to the caches at eNodeB. When users request video streaming service from the local cache, they tend to experience a shorter delay, compared with that from the remote server. Furthermore, it is noticed that the improvement is more distinctive when higher bit rate video is used. Secondly, in the multiple users test scenario, the caching scheme can reduce the burden of the network bandwidth and meantime improve users experience by reducing the loss rate.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Can Zhang, Mingyuan Zang and Ying Yan conducted the research; Can Zhang and Mingyuan analyzed the data; Can Zhang, Mingyuan and Ying Yan wrote the paper; all authors had approved the final version.
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