

Modeling and Analyzing LTE Networks with EstiNet Network Simulator and Emulator

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Abstract – LTE (Long Term Evolution) networks have been introduced in 3GPP (Third Generation Partnership Project) release 8 specifications, with an objective of high-data-rate, low-latency and packet-optimized radio access technology. This paper analyses the possibilities, capabilities and features of EstiNet Network Simulator and Emulator that can be used for modelling and analysing the behaviour of LTE networks. It also illustrates a simple scenario where one or several LTE User Equipment (UEs) are connected to Internet, and evaluates the throughput performance for TCP and UDP traffic in downlink direction. Some important LTE network parameters are also specified for this performance evaluation. Finally it will be concluded that EstiNet is a suitable simulation and emulation tool for modelling and analysing the behaviour of LTE networks.

Keywords – LTE, LTE-Advanced, EstiNet, SAE, EUTRAN, EPS, TCP, UDP.

I. INTRODUCTION

Recently, there has been an increasing demand for Internet access over the mobile devices. To address this, the wireless telecommunication industry defined a new air interface for mobile communications that provides a framework for high mobility broadband services and increase in the overall system capacity.

One emerging technology that supports this air interface is **LTE (Long Term Evolution)**, which is the current evolutionary step in the third Generation Partnership Project (3GPP) roadmap for future wireless cellular systems [1]. LTE was introduced in 3GPP Release 8, which—besides the definition of the novel physical layer—also contains many other remarkable innovations [2, 3]. Most notable are:

- Redevelopment of the system architecture, now called System Architecture Evolution (SAE);
- Self-organization, and self-optimization of the network; and
- Introduction of home base-stations.

The overall objective for LTE is to provide a significantly increased peak data rates, reduced delay (latency), scalable bandwidth capacity and more multi-user flexibility than the currently deployed networks. It also provides backwards compatibility with existing 3GPP and 3GPP2 technologies (GSM, UMTS, HSPA, CDMA 2000), as well as inter-working with other non-3GPP and non-3GPP2 technologies such as

IEEE 802.16 WiMAX (Worldwide Interoperability for Microwave Access), and IEEE 802.11 WLAN (Wireless Local Area Networks), i.e. WiFi (Wireless Fidelity) standard [4].

Since LTE is relatively new standard it is important to model and analyse the behaviour and the performances of LTE Network. This paper analyses the possibilities, capabilities and features of EstiNet Network Simulator and Emulator that can be used for modelling and analysing the behaviour of LTE networks [5]. EstiNet is chosen since it provides a suitable Graphical User Interface (GUI) and novel protocol stack. Additionally EstiNet can act as an emulator, i.e. it provides a possibility to test the simulation scenario on a real traffic. Moreover it has a good documentation.

The paper is organized as follows. Section II presents the LTE node components in EstiNet, and analyses the possibilities of EstiNet for simulating LTE Network. Section III presents a simple LTE Network simulation scenario. Section IV analyses the throughput simulation results on LTE air interface for TCP and UDP traffic in downlink direction. Finally Section V concludes the paper and provides information about future work.

II. LTE NETWORK NODES IN ESTINET

LTE is a cellular system that supports only Packet-Switched (PS) services, compared to the previous Circuit-Switched (CS) cellular systems. It provides seamless Internet Protocol (IP) connectivity between User Equipment (UE) and the Packet Data Network (PDN), without any disruption to the end users' applications during mobility. The term 'LTE' encompasses the evolution of the radio access through the Evolved-Universal Terrestrial Radio Access Network (E-UTRAN). This evolution is accompanied by an evolution of the non-radio aspects of the network under the term 'System Architecture Evolution' (SAE) which includes the Evolved Packet Core (EPC) network. Together LTE and SAE comprise the Evolved Packet System (EPS). An overview of LTE-SAE System (EPS System) architecture is given in [4].

In EstiNet, the LTE network consists of the following types of nodes: the Packet Data Network GateWay (PDN GW), Serving GateWay/Mobility Management Entity (SGW/MME), eNodeB and User Equipment (UE) [6]. These nodes are illustrated in Fig 1.

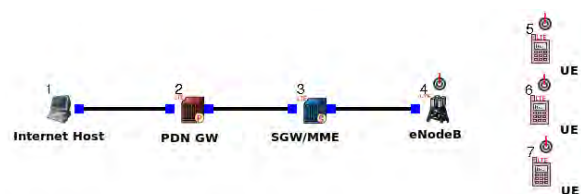


Fig. 1. LTE Network Connected to Internet Server with three User Equipments (UEs)

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The PDN GW provides connectivity to the UE to external packet data network (i.e., backhaul network) by being the point of exit and entry of traffic for the UE. It also takes care of an UE's connection establishment when an UE joins the network.

The SGW/MME routes and forwards user data packets through the GTP-U protocol. It also acts as the mobility anchor for the user plane during handovers by communicating with PDN GW. Additionally, it manages the mobility of UEs.

An eNodeB has a similar role as the base station in the conventional Point to Multi Point (PMP) network. The major eNodeB functionalities are:

- Radio Resource Management (RRM);
- Selection of SGW/MME upon UE's connection establishment; and
- Routing of packets from SGW/MME to UEs and vice versa.

The UE is identical to a mobile station and it is connected to only one eNodeB at a time. However, it scans every nearby eNodeBs every 2 seconds. If it finds that the SNR for another nearby eNodeB is higher than its current serving eNodeB, it will send a measurement report to its serving eNodeB and request for handover. EstiNet software supports the following types of LTE handover, namely handover across eNodeBs, handover across SGWs, and handover across PDN GWs.

The Default LTE-related protocol modules, i.e. the LTE Network Protocol Stack for each node can be viewed and specified via "Node Editor" button [6]. They are illustrated on Fig 2. A brief description of the protocol stack modules for the eNodeB and the UE is given below.

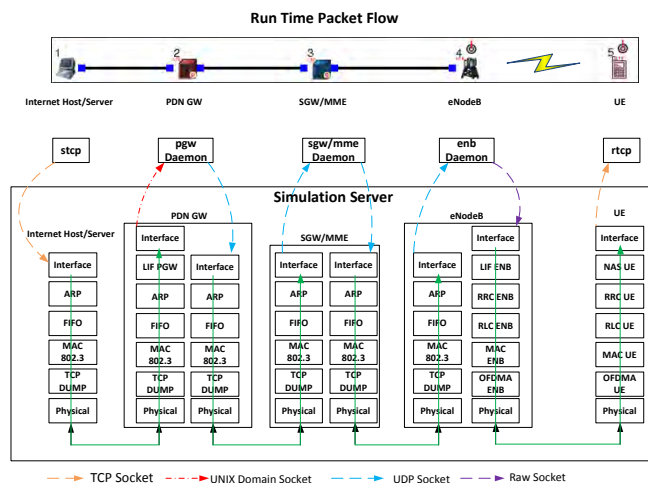


Fig. 2. LTE Network Protocol Stack Modules and TCP Run Time Packet Flow in the LTE Network

When an eNodeB, SGW, or PDN GW are added to the network topology, a daemon programs named "enb", "sgw_mme", and "pgw" are be automatically added in each node. The daemon programs are application layer programs that are responsible to carry all the necessary tasks and functions for the LTE Nodes such as routing of data packets, radio resource management, etc. EstiNet provides the

possibility to enable/disable the channel encoding/decoding. In order automatically to generate the IP addresses for the wireless nodes in a LTE network, the subnet must be explicitly specified using the "form subnet" tool on the tool bar.

The LTE_OFDMA module icon of the protocol stack of an LTE eNodeB, provides the possibility to specify the physical-layer parameters, such as the channel ID, operating frequency, transmission power, bandwidth and the sensitivity for received signals. Additionally one can modify the SIB1 periodicity to be used by an eNodeB at the LTE_RRC module. The GUI user can log the number of CRC error packets by checking the options in "LTE_MAC_ENB_LTE" module. The throughput information incoming or outgoing packets, as well as the number of incoming and outgoing packets can be logged by checking the options in "LTE_LIF_ENB_LTE" module.

The LTE UE protocol stack provides a possibility to specify the physical-layer parameters, such as the channel ID, operating frequency, transmission power, and the sensitivity for received signals, at the LTE_OFDMA module icon. In addition, one can set the minimum sensitivity difference to trigger eNodeB handover of an UE, at the LTE_RRC module icon. With this value being set, when the UE finds another nearby eNodeB with higher sensitivity, the UE will trigger a handover procedure by sending a measurement report to its current serving eNodeB. The GUI user can log the number of CRC error packets by checking the options in "LTE_MAC_UE_LTE" module. The throughput information incoming or outgoing packets, as well as the number of incoming and outgoing packets can be logged by checking the options in "LTE_LIF_UE_LTE" module.

More information about the LTE nodes component can be found in [16].

III. SIMULATION SCENARIO

A typical example of an LTE network is already illustrated in Fig 1, where PDN gateway is connected to the internet (Internet Host or Server) via fixed link. Usually the PDN GW can be connected to the internet by a router. However for simplicity the router is not included in Fig 1. In this scenario the UEs may receive TCP packets or UDP packets from the internet server, or vice versa the UEs may transmit TCP, or UDP packets to the Internet Server. Below is described the transmission of TCP and UDP packets in downlink direction.

The network topology is defined in Draw topology mode. In "Edit Property" mode it is necessary to specify which application programs (traffic generators) should run on which nodes during simulation to generate network traffic. Application programs can run on any hosts, routers, mobile nodes LTE PDN GW, SGW, eNodeB, UE, etc. Actually, as long as a node has a layer-3 interface (i.e. it has an IP address assigned to it), any application program can run on it. In such devices' dialog boxes, there is an "Application" tab in which a user can specify the commands for launching the desired application programs.

For simplicity let a single UE is present in the LTE network. Let the internet host wants to set up a greedy TCP

traffic to the LTE UE in downlink direction. In order to achieve this the command "*rtcp -p 8000*" must be specified on the receiving node's (LTE UE) Application tab and the command "*stcp -p 8000 1.0.4.2*" on the sending node's (Internet Host) Application tab. The specified commands are exactly the same as what a user would type into a UNIX terminal to launch (run up) these application programs. Here, *stcp* and *rtcp* are the pre-installed real-life application programs that will greedily send and receive TCP data, respectively. Also, it is assumed that the receiving node (LTE UE) has an assigned IP address of 1.0.4.2 and the *rtcp* program binds its receiving socket to port 8000.

Similarly, if the internet host wants to set up greedy UDP traffic, the command "*stg -u 1000 78 -p 9000 1.0.4.2*" must be specified in the internet host, while the command "*rtg -u -p 9000*" must be specified in the receiver. Alternatively the following commands can be used: "*ttcp -t -u -s 1.0.4.2*" command in the internet host, and the "*ttcp -r*" command in the receiver.

Additionally in Edit property mode must be specified the remaining LTE Network parameters, such as eNodeB transmission power, eNodeB channel bandwidth, carrier sense power threshold of the UE. Also the parameters of the fixed links such as delay, bandwidth, and Bit Error Rate (BER), as well as the type of wireless channel must be specified. This can be performed by using the node editor button for each node, on the protocol stack level. Table I gives a summary of the parameters, traffic applications and channel type used in the simulation scenario given in Fig 1.

Table I
LTE Network Parameters and Traffic Applications

Name of Device	Parameters and Traffic Applications
Internet Host (Traffic Generator)	Traffic application: TCP or UDP
eNodeB	Transmission power: 43 dBm Channel Bandwidth: 10, or 20 MHz
UE (Traffic Receiver)	Traffic application: TCP or UDP Carrier Sense Power Threshold (CSPT): -100dBm
Fixed Links	Delay: 1000 μ s Bandwidth: 100 Mbps BER: 0.0
Wireless Channel	Model: Two-way ground theoretical channel model without fading PathLoss Exponent: 2.0

The measuring performance results that are of particular interest for a particular simulation network scenario can be selected in Edit Property mode in order to be logged during the simulation. For example it could be the throughput of incoming, or outgoing packets, the number of incoming or outgoing packets, the number of CRC error packets, etc.

The TCP Run – Time Packet Flow for a single UE is in Fig 2 in Section II. The protocol stack modules in the Simulation Server are all modules which simulate the MAC layer and PHY layer of the nodes on the LTE networks. On the other

hand *pgw* Daemon, *sgw_mme* Daemon, and *enb* Daemon are all user layer applications that are responsible for data routing or resource managing, and other necessary tasks to carry for LTE Nodes. By using the kernel re-entering simulation methodology, a real-life application such as *stcp*, or a real-life Linux protocol stack is directly used, and information of the packets above MAC layer will be saved to the virtual interface called "tunnel". The simulation engine will capture the packet information from tunnel interface. Then the information packets will re-enter to the protocol module designed in the Simulation Server. The simulation engine captures the TCP packet information in the "Interface" and re-enters these TCP packets into the modules from ARP to PHY. Next, the TCP packets are transmitted to PHY modules of PDN GW and the path of the packet flow now are sent from PHY to LTE_PGW. Similarly the packets are passed from PDN GW to SGW, from SGW to eNodeB and from eNodeB to UE. As such, the activity of the packet flow in the Simulation Server is a simulation of the link between Host and UE. Similarly is the UDP Run – Time Packet Flow, since the applications *stcp* and *rtcp* need to be replaced by *stg* and *rtg*, respectively.

The next section presents some simulation results of the throughput of TCP and UDP packets on LTE air interface in downlink direction for three UEs given on Fig 1. During the simulation the following channel bandwidth were evaluated: 10 MHz and 20 MHz. The simulation lasts 30 seconds and the internet host transmits the tcp, or udp packets between 5 and 30 seconds.

IV. ANALYSIS OF SIMULATION RESULTS

The simulation results in EstiNet can be analysed by using several tools: packet animation player, packet trace viewer and performance monitor [16]. Here will be presented the usage of performance monitor.

The performance monitor dynamically displays the plots of the performance curves of some logged performance metrics (such as throughput, number of dropped or packets) as the time is progressing. The throughput of LTE air interface (Uu interface) in downlink direction for both TCP and UDP packets is shown in Fig 3 and Fig 4, respectively. In particular, it displays the throughput of outgoing packets at the eNodeB and the throughput of incoming packets at the UE.

It can be noticed that as the channel bandwidth is increased from 10 MHz to 20 MHz, the throughput also increases. This is very logical since the increase in channel bandwidth leads to throughput increase. Also the throughput values of outgoing packets at the eNodeB are higher than the sum of the throughput values of incoming packets for all UEs. This is due to the distance which causes some of the packets to be dropped.

Additionally it can be observed a different behaviour in the throughputs for both TCP and UDP traffic. Because UDP is unreliable and best effort protocol, there are no ACK packages which respond from the clients (UEs) [7]. Therefore server (internet host) will greedily generates UDP packets and sends to client. However, the bandwidth of the air interface and the queue number of the eNodeB is not infinite. Due to

the queue of the eNodeB there is always full loading during the UDP connection, and a large number of the packets will be discarded from the eNodeB. This is why the total incoming UDP throughput for all UEs drastically is decreased compared to the outgoing UDP throughput at the eNodeB.

On the other hand, TCP is reliable and acknowledged protocol [7]. Therefore if there are any packets discarded by receivers, the receivers (UEs) will send ACK messages to notify the server (internet host) to resend the dropped packets again. Additionally the receivers (UEs) will request the server (internet host) to speed down the packets the frequency of sending packets in order to mitigate the queue loading of the eNodeB. Therefore, it can be observed a similar throughput between the eNodeB and the total throughput for all UEs on TCP connection.

Similar results can be observed for the throughput in uplink direction. If the throughputs in downlink and uplink direction are compared it can be noticed that the throughput in UL direction (at the internet host, i.e. internet server) has lower values than the throughput in downlink direction (at the UE).

From the analysis performed above it can be concluded that EstiNet is a powerful tool for modelling and analysing LTE Networks.

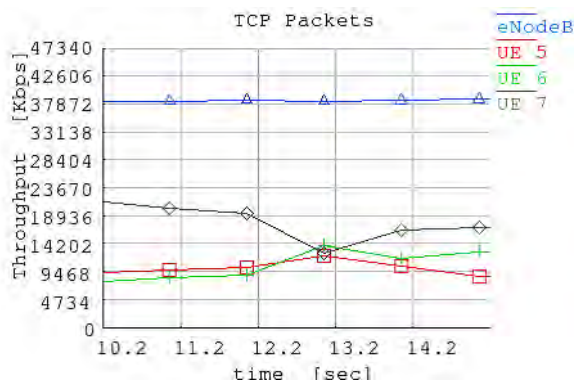


Fig. 3. Outgoing eNodeB and Incoming UEs TCP Throughput in Kbit/s in Downlink Direction for a 20 MHz Channel

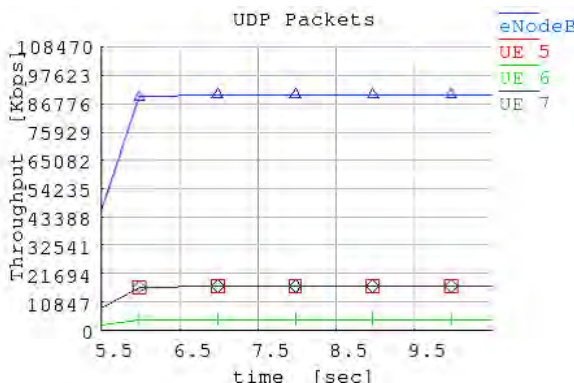


Fig. 4. Outgoing eNodeB and Incoming UEs UDP Throughput in Kbit/s in Downlink Direction for a 20 MHz Channel

V. CONCLUSION AND FUTURE WORK

This paper conceptually introduced how to model and analyse the behaviour of LTE networks with EstiNet Network simulator and emulator. EstiNet was chosen as the best choice because of its GUI interface, emulator capabilities, as well as other capabilities and features that EstiNet possess. Then the LTE node components that are implemented in EstiNet were discussed. After that a simple LTE Network scenario with three UEs, where LTE network was connected to Internet Server was discussed. It was considered a case when each UE can receive TCP or UDP packets, with particular network parameters. Also the steps required to configure this scenario were discussed. Finally the throughput simulation results for TCP and UDP traffic in downlink direction on LTE air interface by using the performance monitor were discussed. It was noticed that TCP is reliable and acknowledged protocol the outgoing throughput at the eNodeB is nearly equal to the sum of the throughputs of all UEs. On the other hand UDP is unreliable and best effort protocol and therefore the total incoming throughput of all UEs is much lower than the outgoing throughput of the eNodeB. It was concluded that EstiNet is a powerful tool for modelling and analysing LTE Networks.

In future more complex simulation scenarios will be analysed regarding the throughput on LTE air interface for the UEs in motion with different speeds, considering the Doppler effect will be analysed. Additionally different handover scenarios between eNodeBs, between SGWs and between PDN GWs will be analysed. Finally the performances of LTE-Advanced Network will be analysed by using the existing and the new protocol stack modules.

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