Thesis Overview

Performance of Long Term Evolution for Wireless Networks

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Long Term Evolution (LTE) is a standard for high speed communication in wireless networks. It is developed by 3rd Generation Partnership Project (3GPP). One of the goals of LTE was to increase the capacity of wireless networks so that communication can be performed at high speeds. The second goal was to redesign and simplify the architecture of the network so as to conform to an Internet Protocol (IP) based system so that there is significant reduction in the communication delays.

Before deploying a technology, it is advisable to evaluate its performance. In this thesis, our objective was to evaluate the performance of LTE for wireless networks. There are many issues related to a wireless network that are more complicated as compared to a wired network. For example, a protocol that is performing adequately for wired network might be compromised for wireless networks due to characteristics of wireless links such as bit error rate, mobility, multipath propagation, and hidden and exposed terminal problems. Evaluating a *medium access control* (MAC) protocol for wireless networks such as LTE is not an easy task. Moreover, there are different types of traffics at the transport layer depending on the application. It also makes the task of evaluating the performance little more complicated. In this thesis, we evaluated the performance of LTE under different types of traffics. A chapter wise summary of the contributions made in the thesis is as follows.

In *Chapter* 1, we presented an introduction to the work carried out in the thesis. The introduction contained the motivation behind evaluating the performance of LTE and the problem formulation. Besides it, we described a survey of the state-of-the-art research carried out by different researchers from different perspectives pertaining to LTE. We identified the issues related to performance evaluation of LTE. Further, the chapter contained a summary of the organization of the thesis.

Before evaluating the performance, it is utmost important to understand the LTE standard. In *Chapter* 2, we described an overview of LTE. We described the evolution, requirements and performance goals of LTE. We described the schemes used at the physical layer of LTE such as Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple Input Multiple Output (MIMO). Also, it contains the description about the architecture of LTE including its basic building blocks, which are Evolved Radio Access Network (RAN) or eNodeB, Service Gateway (SG), Mobility Management Entity (MME), Packet Data Network Gateway. Further, we described the network model of LTE and how the Quality of Service (QoS) is provided in LTE.

There are some applications that are delay tolerant; however, reliability of the data transfer is to be maintained. Such applications include Web, email, file transfer, etc. These applications run over Transmission Control Protocol (TCP) that provides a reliable transport service. If these applications are to be run over a network that is using LTE at the data link layer, it is necessary to evaluate the performance of LTE for the TCP traffic generated by these applications.

In *Chapter* 3, we tried to answer the following research question: How does LTE perform for TCP traffic? In other words, we evaluated the performance of LTE for a network running TCP at the transport layer. We carried out simulations using *Network Simulator* (NS2). While evaluating the performance, we focused on the following parameters: average *end-to-end delay*, delay *jitter*, and *throughput*. We studied the effect of the bandwidth, the number of subscribers, and the packet size on these parameters. We observed that the average end-to-end delay decreases with an increase in the link bandwidth. Specifically, if the link bandwidth is increased from 20 Mbps to 40 Mbps, the amount of decrease in the average end-to-end delay is 61%. We observed that average end-to-end delay increases with an increase in the number of subscribers. For example, if the number of subscribers is increased from 5 to 30, the increase in the delay is 110%. Further, the average throughput decreases with an increase in the number of subscribers.

On the other hand, there are some applications that are delay-sensitive and loss tolerant such as Voice over IP (VoIP), video streaming, IP television (IPTV), etc. For these applications, one requires that the packets should be sent from the source to the destination as quickly as possible. A loss in packets will degrade the quality of the application; however, it can be tolerated if the quality degradation is not too much to be accepted. These applications often use User Datagram Protocol (UDP) because it is faster as compared to TCP. The reason for UDP being fast is absence of mechanisms for handshaking, congestion control, and flow control. If one has to run these applications that are delay-sensitive and loss tolerant over a network running UDP as a transport layer protocol and LTE as a data link layer protocol, it is necessary that one should evaluate the performance of LTE for UDP traffic.

In *Chapter* 4, we tried to answer the following research question: How does LTE perform for a network running multimedia applications using UDP at the transport layer and LTE at the data link layer? While evaluating the performance, we focused on the parameters similar those used for the TCP traffic. We studied the performance of LTE for two types of traffic: *constant bit rate* (CBR), and *video* traffic. We evaluated LTE for the traffic in both the directions, uplink as well as down link. For video traffic, we observed that the average end-to-end delay increases with an increase in the number of subscribers up to a threshold value, and then remains almost constant. Also, we observed that the average end-to-end delay decreases with an increase in the link bandwidth. When the link bandwidth is changed from 20 Mbps to 40 Mbps, the amount of decrease in the delay is 41%. This is in contrast to the CBR traffic, where the amount of decrease in delay is 99% when the link bandwidth is changed from 20 Mbps to 40 Mbps.

The last chapter contains conclusion and future work. There are many directions for future work. For example, we evaluated the performance of LTE using simulations in NS2, one may propose an analytical model for the performance of LTE. During our performance evaluation, we assumed that each mobile device in the network is equipped with an omni-directional antenna. One may evaluate the performance if the mobile devices in the network are equipped with directional antennas. Further, one may devise one's own scheduling technique and may evaluate its impact on the performance of LTE.

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