Performance Evaluation of End-to-End Communication Quality of LTE

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***Abstract*— LTE (Long Term Evolution) is standardized in 3GPP (3rd Generation Partnership Project) to provide higher data throughput as well as lower latency for various IP based services including web browsing, VoIP (Voice over IP), video streaming and so on. In this paper, we conduct the performance evaluation of LTE by indoor and outdoor experiments. We evaluated both TCP throughput and UDP transmission delay. For the TCP throughput evaluation, we observed the TCP-uplink-limit problem in which the uplink performance degradation in low SNR (Signal to Noise Ratio) region affects on the downlink TCP throughput. We also analyzed the transmission delay of UDP packets. The delay distribution is affected by the traffic pattern, i.e. packet size and inter packet gap.**

Keywords- LTE, Communication quality, Throughput, Transmission delay.

I. INTRODUCTION

3GPP summarized the standardization work for LTE in its release 8 [1, 2] and the commercial service of LTE has been launched in several countries at the time of this writing. LTE is designed to provide higher throughput and lower latency than its predecessors, e.g. HSDPA (High Speed Downlink Packet Access) which is also known as 3GPP release 5 [3]. OFDMA (Orthogonal Frequency Division Multiple Access) is adopted for downlink access, AMC (Adaptive Modulation and Coding) and MIMO (Multiple Input and Multiple Output) are used for achieving higher throughput. Also, LTE adopts a flat network architecture which can effectively shorten the transmission delay compared to existing mobile networks [4].

To evaluate the end-to-end communication quality of LTE, we build indoor and outdoor LTE testbeds and evaluate both TCP throughput and UDP transmission delay. First, we evaluate the communication quality of TCP and UDP in the indoor LTE testbed. A fading simulator (FS) is used for emulating a radio propagation environment. Next, a similar measurement is conducted in a real radio propagation environment by using the outdoor LTE testbed. Based on the experimental results obtained by the indoor and outdoor testbeds, we analyze the end-to-end communication quality of LTE.

This paper is organized as follows. Section II explains the results of the performance evaluation in the indoor testbed. Both TCP throughput and downlink delay of UDP packets are measured. In Section III, the results of the outdoor experiment are presented. Finally, our concluding remarks are stated in Section IV.

II. INDOOR EXPERIMENT

In this section, we explain the results of the TCP and UDP performance evaluation over LTE in the indoor testbed.

A. TCP throughput evaluation

1) Experimantal setup

Fig.1 shows the schematic diagram of the indoor experiment. EPC (Evolved Packet Core), eNB (evolved NodeB) and UE (User Equipment) are compliant with 3GPP release 8. Table I summarizes the main system features of the LTE system used in the testbed. 5MHz bandwidth in 2.1GHz and 1.9GHz are utilized for downlink and uplink, respectively. 2x2 MIMO and 1x2 SIMO (Single Input and Multiple Output) are used for downlink and uplink, respectively. Transmit power per antenna port is 20W for downlink and 200mW for uplink. Therefore, the transmit power difference between downlink and uplink is 23dB (=20Wx2/0.2w).

FSs are inserted between the eNB and the UE to emulate a radio propagation environment. The propagation model used in the indoor experiment is ETU (Extended Typical Urban) [5] and maximum Doppler frequency is f_D=70Hz, which corresponds to velocity of 35km/h at 2.1GHz. Attenuators (ATTs) are used for adjusting pathloss for both downlink and uplink. A server PC (Server) is located at the EPC side and a client PC (Client) is located at the UE side. TCP stream is generated by the Server and sent to the Client.

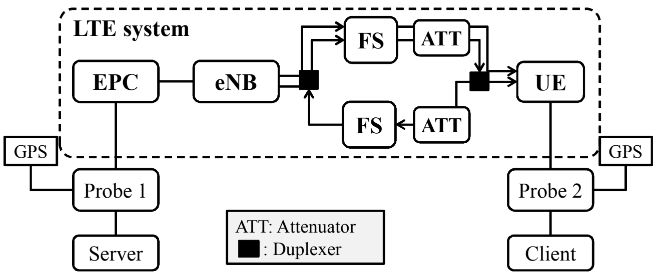


Figure 1. Indoor experiment setup.

Table I. System features

System feature	Downlink	Uplink
Frequency	2.1GHz	1.9GHz
Bandwidth	5MHz	5MHz
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM
Space Diversity	2x2 MIMO	1x2 SIMO
Tx power	43dBm	23dBm
Max Throughput	35Mbps	10Mbps

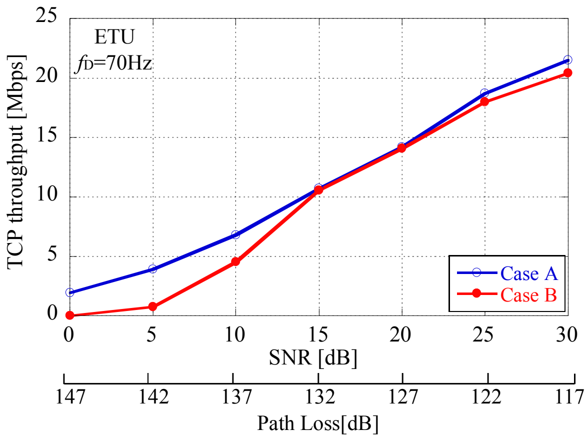


Figure 2. Downlink TCP throughput measurement.

2) Downlink TCP throughtput measurement results

First, we evaluated the characteristics of downlink TCP throughput in the case where the FS is inserted in downlink only and fading is not applied in uplink (Case A). The blue line in Fig. 2 shows the measurement result.

Next, we inserted the FS not only in downlink but also in uplink (Case B). This simulates a practical environment, in which the fading conditions of downlink and uplink are the same. The result is shown with the red line in Fig. 2. If you focus on the downlink TCP throughput in the larger pathloss region (>132dB), the TCP throughput in Case B is degraded compared to Case A.

3) Analysis of "TCP uplink limit problem"

We think that the TCP throughput in Case B is degraded due to the performance degradation of uplink by fading. An ACK packet plays a very important role for the flow control in TCP. If ACK packets are lost or delayed by the performance degradation of uplink, the downlink throughput is also degraded [6]. We call it "TCP uplink limit problem" in this paper.

To confirm the TCP uplink limit problem, we conducted additional indoor experiment with Case B. The pathloss of uplink was intentionally configured at 5dB and 10dB lower than that of downlink. The measurement results are shown in Fig. 3. The throughput performance of uplink is improved as the pathloss difference becomes larger. In the case where uplink pathloss is 10dB lower than downlink, we obtained nearly the same downlink throughput performance with the Case A.

We evaluate this asymmetric link by using the normalized bandwidth ratio k, which is defined as follows [7],

$$k = (T_{DL} / T_{UL}) / (L_{DL} / L_{UL}), \tag{1}$$

where T_{DL} and T_{UL} represent the downlink throughput and uplink throughput and L_{DL} and L_{UL} represent the packet size for downlink and uplink. In this experiment, L_{DL}=1500bytes (a TCP packet) and L_{UL}=40bytes (an ACK packet) are used. Since every downlink TCP packet is acknowledged by an ACK packet in this testbed, the uplink is get saturated if k>1 and the saturated uplink disrupts the downlink performance [6].

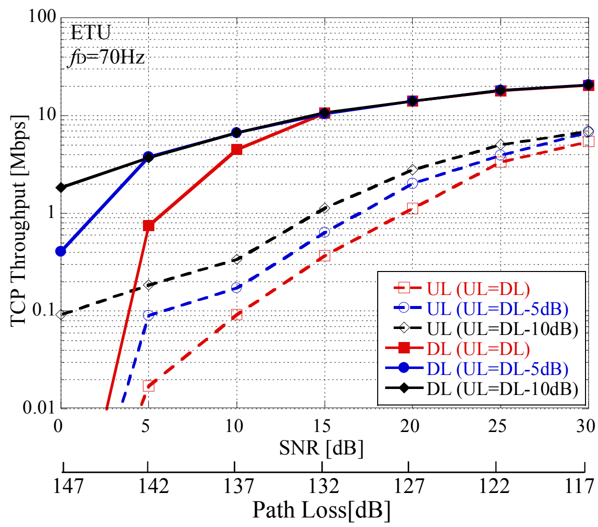


Figure 3. TCP throughput measurement for downlink and uplink.

When both downlink and uplink pathloss are the same (the red solid line and the red dotted line in Fig. 3), k=1.18 is obtained at SNR=5dB (T_{DL}=750kbps and T_{UL}=17kbps) and the uplink is saturated as k>1. Therefore, we can observe the throughput degradation in downlink as shown in the red solid line in Fig. 3. However, when the uplink pathloss is 10 dB lower than the downlink pathloss (the black solid line and the black dotted line in Fig. 3), k=0.53 is obtained at SNR=5dB (T_{DL}=3.7Mbps and T_{UL}=185kbps) and the uplink is not saturated as k<1. In this case, there is no downlink throughput degradation as shown in the black solid line in Fig. 3.

This result suggests that one has to take care of the balance between the downlink throughput and the uplink throughput. In the case of TCP, T_{UL} > (40/1500)T_{DL} is required to efficiently use the available bandwidth in downlink.

B. UDP delay evaluation

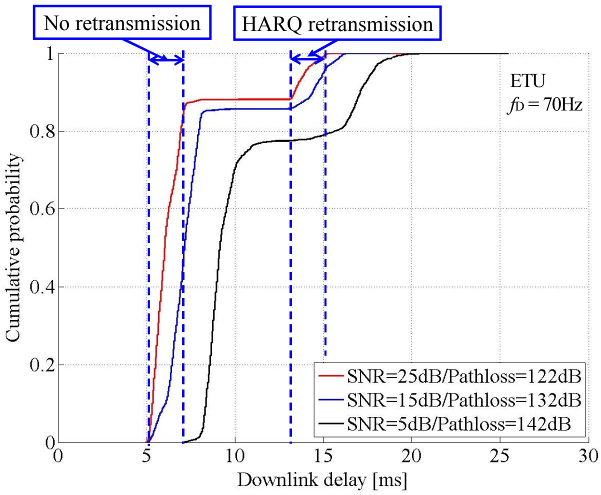
1) Experimental setup

The experimental setup for the UDP delay measurement is similar to that for the TCP throughput measurement shown in Fig. 1. FSs and ATTs are used for emulating the radio propagation environment. UDP packets are sent from the Server to the Client to measure the end-to-end transmission delay. Probe1 and Probe2 are located on the EPC side and the UE side, respectively. When UDP packets pass through the probes, the passing times are recorded respectively. Since GPS (Global Positioning System) is used for synchronizing the clocks on the separated probes, the transmission delay of downlink can be obtained from the difference of the recorded times at the Probe1 and the Probe2.

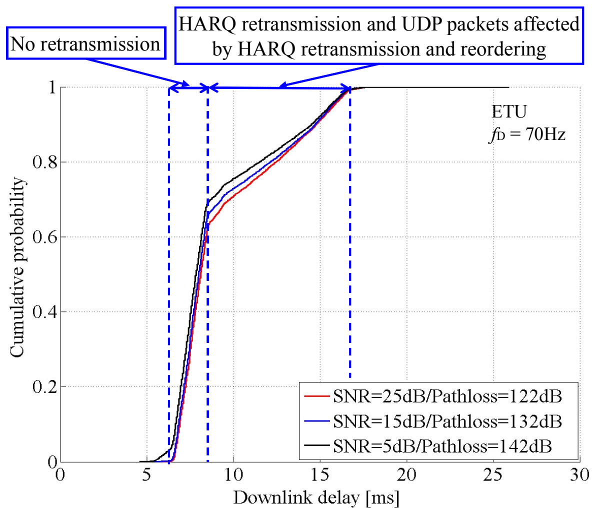
2) Downlink UDP delay measurement results

UDP packets are sent at 1Mbps from the Server to the Client. Two kinds of traffic patterns are used, long packet and short packet. In the former case, the packet size is 1250 bytes and the inter packet gap is 10ms. In the latter case, the packet size is 125 bytes and the inter packet gap is 1ms.

LTE adopts HARQ (Hybrid Automatic Repeat reQuest) as a retransmission mechanism in MAC (Medium Access Control) layer. When a MAC PDU (Protocol Data Unit) cannot



(a) CDF for the long packet case



(b) CDF for the short packet case

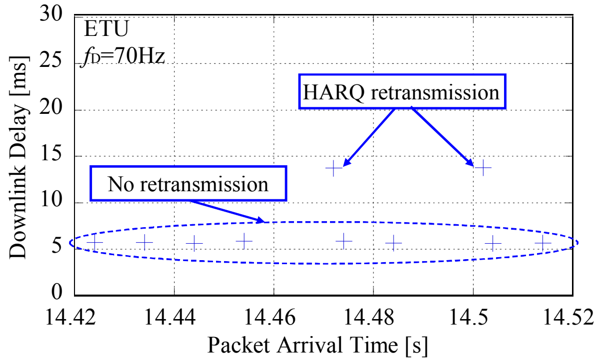
Figure 4. CDF for UDP transmission delay.

be received by UE, HARQ is triggered and the lost or erroneous PDU is retransmitted. In LTE, retransmission takes eight TTI (Transmit Time Interval). Therefore 8ms of transmission delay is added once HARQ retransmission is triggered. If the PDU still cannot be received successfully, HARQ operation is repeated until it reaches max retry. If the PDU cannot be received correctly even after the max retry, ARQ (Automatic Repeat reQuest), which is a higher layer retransmission scheme in RLC (Radio Link Control), is triggered. This retransmission may require several tens of milliseconds. Thus the additional delay with tens of milliseconds is observed once ARQ is triggered.

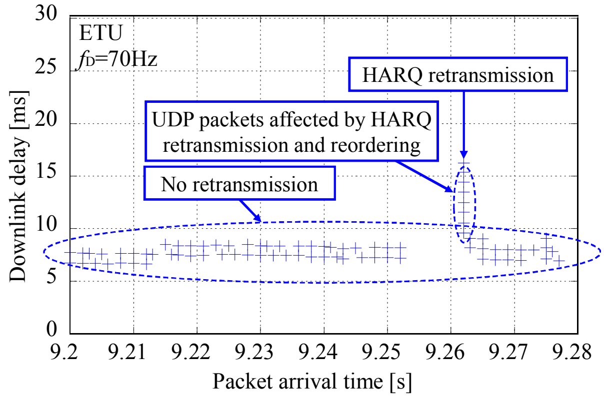
Fig. 4 shows the measurement results of UDP downlink delay in the case of ETU with f_D=70Hz. Three kinds of pathloss values, 122dB, 132dB and 142dB, are used.

3) Analysis of UDP delay distribution

Here we analyze how the two traffic patterns, the long packet case and the short packet case, affect on the delay distribution of UDP packets. There are two major differences between the long packet and the short packet cases. The first one is the delay distribution pattern and the second one is the impact of pathloss value.



(a) Typical downlink delay for the long packet case



(b) Typical downlink delay for the short packet case

Figure 5. Typical downlink delay when pathloss equals 122dB.

First, we explain the difference in the delay distribution pattern. Two separate distributions are observed in the long packet case. For example, when pathloss is 122dB, nearly 90% of packets are distributed between 5 and 7ms and the rest of packets are distributed between 13 and 15ms. On the other hand, for the short packet case, most of the samples are broadly distributed in the range between 6ms and 17ms. The difference is caused by the combined effect of inter packet gap, HARQ retransmission and subsequent reordering process.

Fig. 5 shows a typical example of the observed downlink delay, when pathloss is set at 122dB. The horizontal axis denotes the packet arrival time and the vertical axis denotes the downlink delay. In the short packet case, when a UDP packet is lost in the wireless link, the lost packet is retransmitted 8ms later by HARQ. During this period, seven following UDP packets are sent to the Client because the inter packet gap is set at 1ms. Even if the following seven packets are successfully received by the UE, they have to be buffered at the UE for reordering until the lost packet is correctly retransmitted. Therefore, the buffering delay ranging from 1ms to 7ms is added to the seven buffered packets as shown in Fig. 5 (b). In this way, the distribution between 8ms and 17ms shown in Fig. 4 (b) is created. In comparison, for the long packet case, a UDP packet is sent every 10ms which is longer than one HARQ cycle. Even if HARQ retransmission occurs, the retransmission is completed before the following UDP packet arrives at the eNB. Therefore, there is nearly no samples whose delay fall in the range between 7ms and 13ms as shown in Fig. 4 (a) and Fig. 5 (a). Therefore, two separate distributions, one for no retransmission and the other for single HARQ retransmission, are observed in the long packet case.

Next, we explain the impact of pathloss value. In the long packet case, the distribution is shifted to larger delay as the pathloss increases. On the other hand, the distribution is not changed by the pathloss value in the short packet case. This is explained by the AMC mechanism adopted in LTE. When the pathloss value is large, the radio propagation environment becomes worse. In this case, a lower MCS (Modulation and Coding Scheme) tends to be chosen and a long packet (1250 bytes) cannot be sent in one TTI because a UDP packet must be segmented into multiple MAC PDUs at the eNB. They are concatenated to the original packet at the UE. This process creates additional delay and makes the distribution shifted as shown in Fig. 4 (a). However, in the short packet case, even if MCS is getting smaller due to the large pathloss value, the segmentation can be prevented because the short packet fits in a small MCS. Therefore there is no difference in the distributions depending on pathloss as shown in Fig. 4 (b).

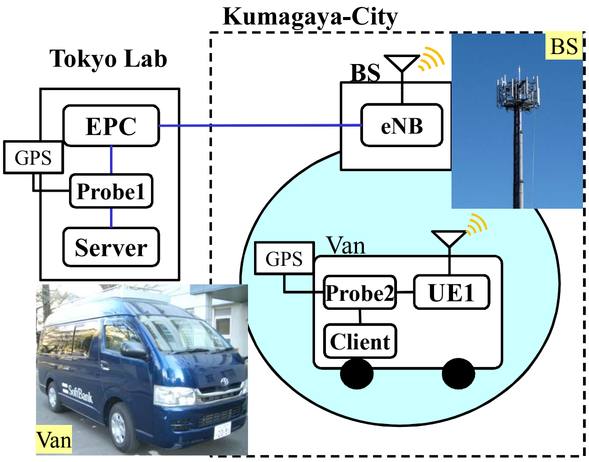


Figure 6. Outdoor experiment setup.

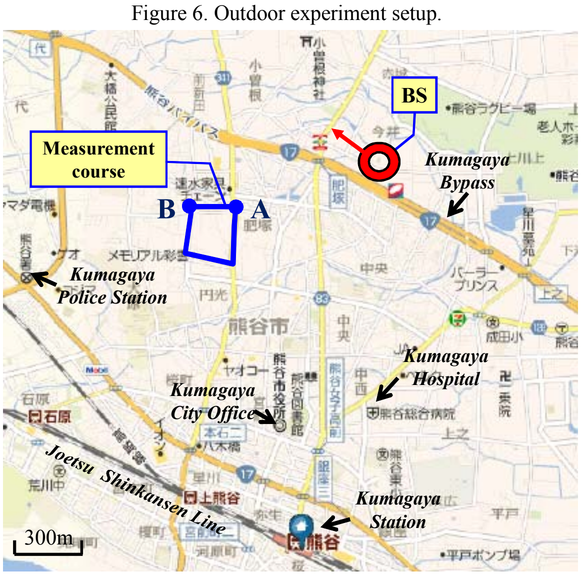


Figure 7. Outdoor experiment area and measurement course.

III. OUTDOOR EXPERIMENT

We built an LTE testbed in Kumagaya city, Japan. TCP throughput and UDP transmission delay were evaluated in the real radio propagation environment.

A. *Experimental setup*

Fig. 6 shows the experimental setup used in the outdoor experiment. The EPC is placed in our laboratory located in Tokyo. The base station (BS) is located in Kumagaya that is nearly 70km away from Tokyo laboratory. The BS is connected to the EPC by a wide area IP network. RTT (Round Trip Time) between the EPC and the BS is about 6ms. At the BS, eNB is installed with a polarization-diversity antenna and the antenna height is 30m. UE is installed in a van. Two V-V SD (vertically-polarized 2-branch space-diversity) antennas are mounted on the rooftop of the van with 40cm separation (corresponding to 3wavelengths at 2.1GHz).

Fig. 7 illustrates the location of the BS and the measurement course used in the outdoor experiment. The course is located in a typical sub-urban area. The van drove along the course around 30 km/h. The radio propagation condition of the course is regarded as non-line-of-sight (NLOS).

B. *TCP Throughput Evaluation*

When the van drove along the course, downlink TCP throughput was recorded every one second. At the same time, RSRP (Reference Signal Received Power) was also measured

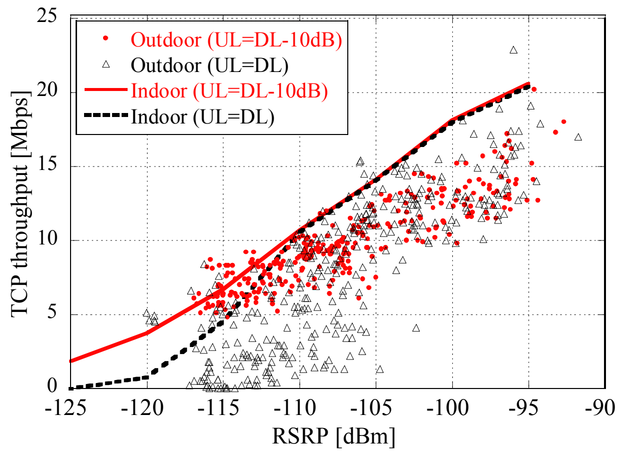


Figure 8. Outdoor TCP throughput measurement.

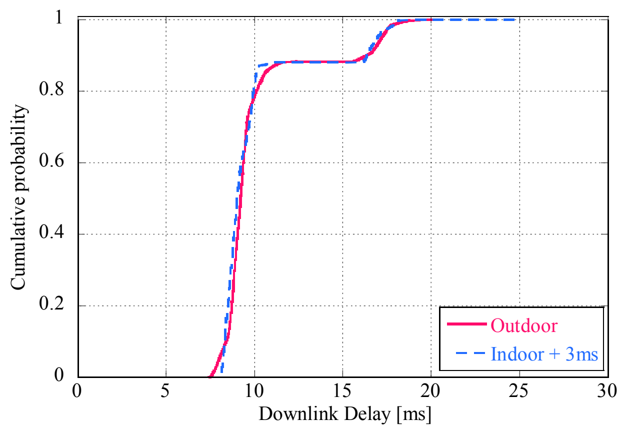


Figure 9. Outdoor UDP delay measurement.

and recorded at the UE. Fig. 8 depicts the relationship between the RSRP and the TCP throughput. Here, the black triangles denote the measurement result for the case in which pathloss values of downlink and uplink are the same. The red circles denote the measurement result for the case in which the uplink pathloss is 10dB lower than downlink. (The difference is created by an ATT at the UE side.) In the region where the RSRP is small (RSRP<-105dBm), the TCP throughput in the latter case is better than the former case. This shows that the TCP uplink limit problem is observed in the real propagation condition. For reference, the corresponding results of the indoor experiments obtained in Fig. 3 are also drawn as the red line and the black dotted line in Fig. 8. The trends of both indoor and outdoor experiments are similar.

C. UDP Delay Evaluation

UDP transmission delay was also measured in the outdoor experiment for the long packet case. The measurement course starts from point A and ends at point B. CDF of the measured downlink delay in the outdoor experiment is shown as the red line in Fig. 9. For reference, the result of the long packet case in the indoor experiment is shown as the blue dotted line. Note that 3ms is added to the indoor result to take into account the transmission delay of the IP network between the EPC and the eNB in the outdoor experiment. The results of the indoor and outdoor experiments match very well.

IV. CONCLUSION

In this paper, we evaluated the performance of TCP throughput and UDP transmission delay by using a 3GPP Release 8 compliant LTE system. In the TCP throughput experiment, it was confirmed that the performance degradation of uplink affects the downlink TCP throughput. In an asymmetric transmission channel of mobile communication environment, such as LTE, the design of uplink channel is very important. To achieve higher TCP throughput in downlink, the performance of the uplink must be designed carefully. UDP delay performance of LTE was also analyzed. Several delay patterns were observed depending on packet size and inter packet gap.

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