Experimental analysis of TCP and UDP during LTE Handover

Liang Zhang, Takao Okamawari and Teruya Fujii
Softbank Mobile Corporation, Wireless System Research Center
Telecom Center Building East Tower 13F, 2-5-10 Aomi, Koto-ku, Tokyo, 135-8070 Japan
E-mail: {cho.ryo, takao.okamawari}@g.softbank.co.jp

Abstract— **Mobile IP services, including web browsing, VoIP (Voice over IP), video streaming and so on, are demanding more and more bandwidth with higher communication quality. LTE (Long Term Evolution) is one of the solutions to provide higher data throughput and lower latency. In this paper, we experimentally analyze the performance of TCP and UDP during LTE handover. The mobile users experience performance degradation due to the interference between source and target eNBs (evolved NodeB). Also the interruption during handover may affect delay sensitive service such as VoIP. We measured the TCP throughput and the delay of UDP during the handover process on our indoor and outdoor LTE testbeds. The results show that better TCP throughput performance is obtained by decreasing the A3 offset value. This also improves the delay performance during a handover.**

Keywords- LTE, handover, Communication system control, Mobile communication.

I. INTRODUCTION

The mobile network requires more and more bandwidth due to the popularity of smart phones that consume vast amounts of bandwidth. To meet this demand, mobile operators have started to deploy LTE networks to utilize radio resources more efficiently. LTE was designed by 3GPP (3rd Generation Partnership Project) to provide an all-IP network with higher throughput and lower latency [1, 2]. However, throughput performance is degraded by the interference between source and target eNBs during handover. In addition, there is a link interruption during handover because LTE supports only hard handover [3]. Although the loss or out-of-order delivery of packets can be avoided by the X2 forwarding scheme, the interruption degrades the delay performance of UDP because no data can be sent from eNB to UE during the interruption period [4].

Experimental studies on TCP and UDP performance during handover in HSPA (High Speed Packet Access) network can be found in [5]. There are several studies on LTE handover that use numerical simulation [6-10]. In this paper we experimentally analyze the TCP throughput and UDP delay during LTE handover by using indoor and outdoor testbeds. The indoor testbed consists of EPC (Evolved Packet Core), eNBs, and UEs (User Equipment) in full compliance with 3GPP release 8. Fading simulators are used to emulate the propagation environment between the eNBs and the UEs. The outdoor testbed, located in Kumagaya city in Japan, was used to evaluate both TCP and UDP performance in a real propagation environment. The experiment is conducted with various handover parameters. Then the influence of handover parameters on both TCP and UDP performance is analyzed.

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

II. INDOOR EXPERIMENT

A. TCP throughput evaluation

We used the scenario shown in Fig. 1 to evaluate TCP throughput. In this scenario, there are two eNBs and three UEs. UE1 is moving between eNB1 and eNB2. UE2 and UE3 are statically attached to eNB1 and eNB2, respectively. Note here that the scheduler in each eNB assigns all available radio resources to the UE(s) by using a proportional fair algorithm. Therefore, the interference from the neighboring cell includes not only reference and control signals, but also the user plane signal if enough user plane data is supplied from the eNBs to the UEs.

Fig. 2 shows a schematic diagram of the indoor experiment. The EPC, two eNBs and UEs comply with 3GPP LTE release 8. Table I summarizes the main system features of the LTE system used in the experiment. UE1 (moving UE) is connected to both eNB1 and eNB2. At UE1, RSRP (Reference Signal Receiving Power) for eNB1 is controlled by the programmable attenuator and it is varied periodically between -80 and -100dBm as shown in Fig. 3. The increase/decrease rate of RSRP is set at 1dBm/sec. On the other hand, RSRP for eNB2 is set constant at -90dBm. At first, UE1 is attached to eNB1 because RSRP for eNB1 is higher than eNB2. As the RSRP for eNB1 decreases and if the RSRP for eNB2 is A dB higher than eNB1 for T milliseconds, where A is A3 offset and T is TTT (Time To Trigger), handover is triggered and eNB2 becomes the serving eNB for UE1. In this way, UE1 is repeatedly handed over between eNB1 and eNB2. Note here that UE2 and UE3 remain attached to eNB1 and eNB2, respectively.

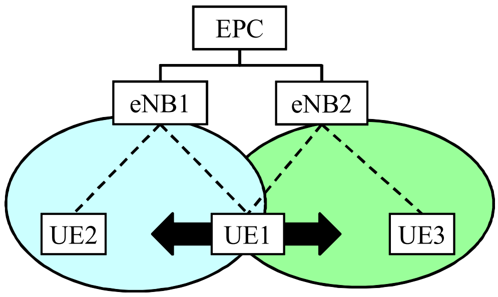


Figure 1. Experimental scenario.

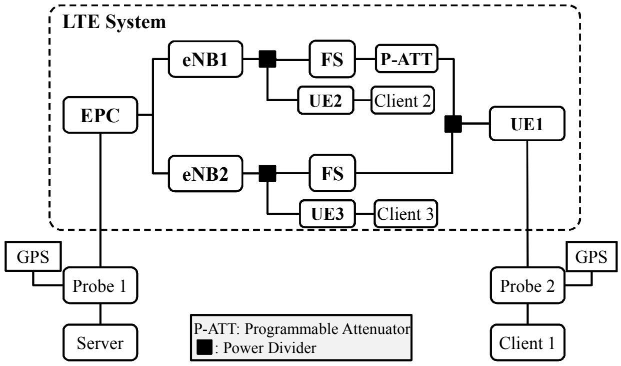


Figure 2. Schematic diagram of indoor experimental setup.

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

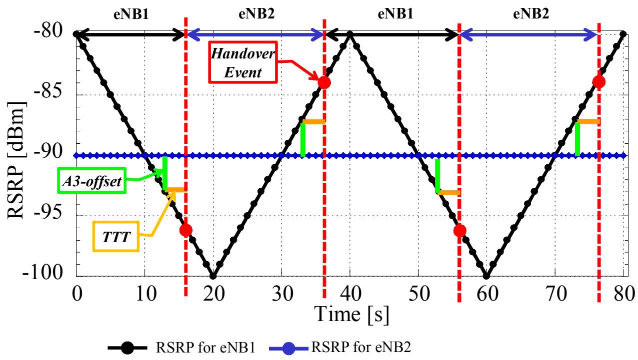


Figure 3. LTE intra-frequency handover scenario.

FSs (Fading Simulators) are inserted between the eNBs and the moving UE to emulate a radio propagation environment. The propagation model used in the indoor experiment is ETU (Extended Typical Urban) and maximum Doppler frequency f_D = 70Hz, which corresponds to the velocity of 35km/h. A server PC is located at EPC side and client PCs are located at UEs. TCP streams are generated by Server and sent to Client 1, 2 and 3. We used the TCP implementation of Linux kernel 2.6.24. The congestion avoidance algorithm is BIC (Binary Increase Congestion control) and FRTO (Forwarding Retransmission TimeOut) is employed to avoid spurious timeout [11, 12].

We measured TCP throughput at various A values to investigate how TCP throughput during handover is affected by A3 offset value. Fig. 4 shows a typical result of TCP throughput when A = 0, 2, 4 and 6dB. T is set at 320 ms in this experiment. Note that the red dotted vertical lines shown in Fig. 4 represent the time of handover events.

As you can see in the figure, TCP throughput is degraded just before and after handover because the interference from the neighboring eNB is high around this point. If you notice the TCP throughput just before handover, TCP throughput is better if A3 offset is small because large A3 offset values increase the interference.

To look more closely at the TCP throughput degradation just before handover, we filtered the TCP throughput in the following manner (See Fig. 5). We measured RSRP for eNB1 and eNB2 at the same time as the TCP throughput measurement. If the difference in RSRP of the serving cell ($RSRP_{\text{serving}}$) and RSRP of the target cell ($RSRP_{\text{target}}$) is less than a predefined filtering threshold (F), i.e.,

$$RSRP_{\text{serving}} - RSRP_{\text{target}} < F, \qquad (1)$$

the throughput samples are counted as shown in Fig. 5. Otherwise, the samples are filtered out. Fig. 6 shows the CDF (Cumulative Distribution Function) of TCP throughput obtained by the filtering method given above. The filtering threshold was set at F = 2dB. Handover was repeated 60 times to gather many samples. Fig. 6 clearly shows that small A3 offset improves TCP throughput.

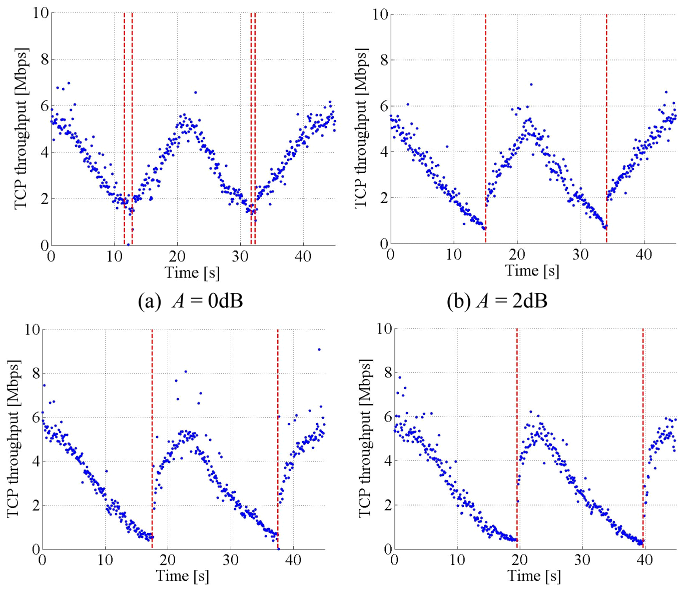


Figure 4. Indoor TCP throughput results.

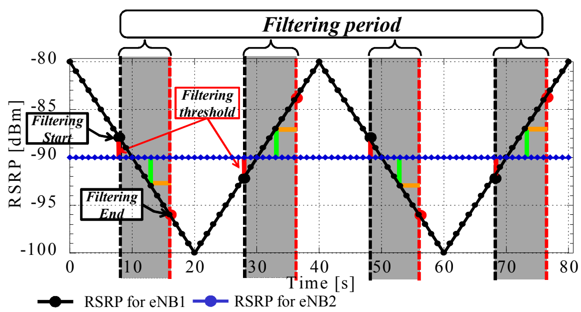


Figure 5. Filtering throughput samples just before handover events.

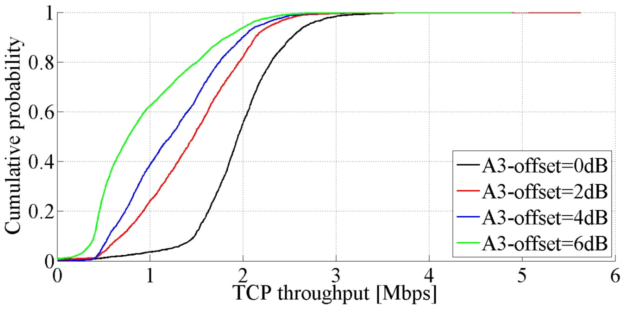


Figure 6. CDF for TCP throughput just before handover events.

B. UDP delay evaluation

We use the same scenario shown in Fig.1 except that UE2 and UE3 are eliminated. Therefore, there is only one single UE (UE1) in the UDP delay evaluation. The experimental setup is basically the same as the one shown in Fig. 2. UDP traffic is generated by Server and sent to Client1. The transmission rate is set at 1Mbps and 4Mpbs. Since we set the UDP packet size at 1250 bytes, a packet is sent to Client 1 every 10ms for 1Mbps and 2.5ms for 4Mbps. Downlink delay of UDP packets was measured by Probe1 and Probe2 in Fig. 2. When a packet goes through both probes, the transmit times are recorded. Since Probe1 and Probe2 are synchronized by GPS (Global Positioning System), it is possible to calculate the downlink delay by taking the difference of the recorded times at Probe1 and Probe2 for each packet.

Fig. 7 shows the downlink delay during LTE handover with various A3 offset values. Note that the red dotted vertical lines shown in Fig. 7 represent the time of handover events. A is set at 2, 4 and 6dB and T is set at 320ms.

First, if you look at Fig. 7 (a), (b), (c) and (d) most UDP packets exhibit a delay between 8 and 16ms. If a UDP packet is sent normally, the delay is around 8ms in this testbed. However, there are packets that experience HARQ (Hybrid Automatic Repeat reQuest) retransmission. In this case, the transmission delay is increased by an additional 8ms [13] which creates the delay distribution between 8 and 16ms. You can also observe delay spikes that exceed 70ms just after handover. When handover occurs, UDP packets are buffered in eNB because eNB cannot send packets due to the interruption caused by the handover. We think that the delay spikes are created by this buffering operation.

Second, Fig. 7 (e) exhibits a different delay pattern. The delay of UDP packets increases before handover. The distribution is shifted to 16ms and 24ms. Since the interference is severe with A=6dB, the number of HARQ retransmissions is increased. (Sometimes, a second retransmission is required.) As a result, the delay performance is degraded before handover as shown in Fig. 7 (e).

Third, if you look at Fig. 7 (f), the delay of UDP packets quickly increases up to 110ms before handover and the delay spike reaches nearly 200ms. We think that the wireless link capacity just before handover is degraded due to the interference. The link capacity becomes lower than the UDP transfer rate, which is 4Mbps in this case. Therefore, the downlink UDP packets that exceed the link capacity are buffered at the serving eNB until the link capacity recovers after handover. This effect greatly degrades the delay performance as shown in Fig. 7 (f).

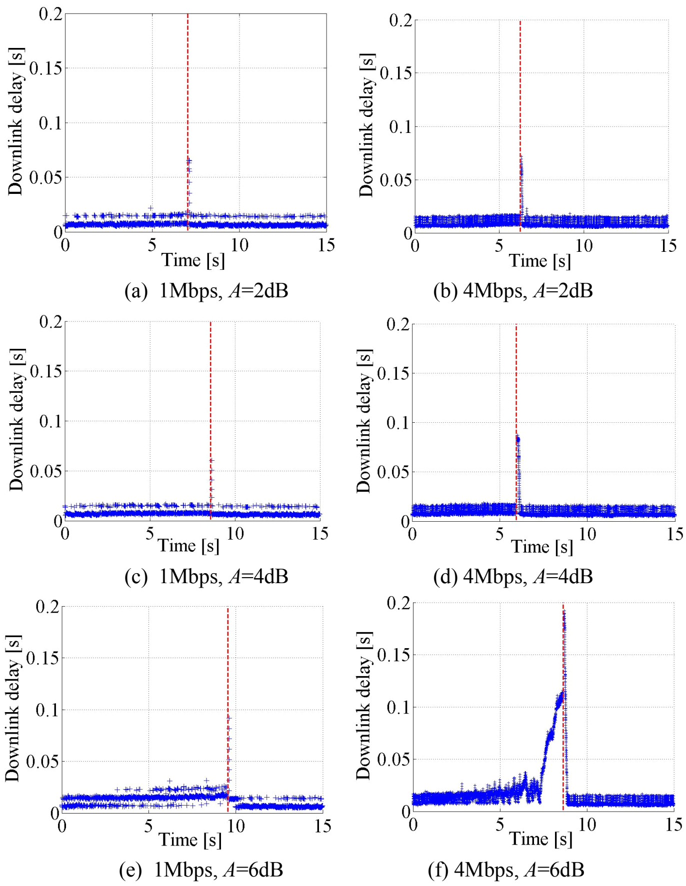


Figure 7. Indoor downlink UDP delay results.

The result of the indoor experiment shows that handover creates a delay spike of 70ms or higher. However, if the transfer rate of UDP packets is higher than the degraded link capacity before handover, the delay spike becomes 200ms or more. This suggests that the users of a high data rate real time service, such as high quality video conference, may experience performance degradation during LTE handover [14].

III. OUTDOOR EXPERIMENT

We built an LTE testbed in Kumagaya city, Japan. Both TCP throughput and UDP delay during handover were evaluated in a real fading environment.

A. Outdoor experiment configuration

The outdoor experiment replicates the scenario shown in Fig. 1. Fig. 8 shows the experimental setup. The EPC is placed in our laboratory located in Tokyo. BSs (Base Stations) are located in Kumagaya nearly 70km from Tokyo laboratory. BSs are connected to EPC by an IP network. RTT (Round Trip Time) between EPC and BS is around 6ms. BSs are also connected by an IP network. RTT between BSs is less than 1ms. Each BS uses an eNB with a polarization-diversity antenna. The antenna heights for BS1 and BS2 are 20m and 50m, respectively. UE1 (moving 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 (corresponds to 3wavelengths at 2.1GHz). UE2 and UE3 are placed nearby BS1 and BS2, respectively.

Fig. 9 illustrates the location of the BSs and the measurement courses used in the outdoor experiment. The area is located in a typical sub-urban area. The distance between A and B is about 250m and the distance between C and D is about 150m. AB is used for TCP throughput evaluation and CD is used for UDP delay evaluation. The van drove along these courses at around 30 km/h. The radio propagation condition over the measurement course is regarded as non-line-of-site (NLOS).

B. TCP Throughput Evaluation

Fig. 10 shows the measured TCP throughput for various A values. T is set at 320ms. The red dotted vertical lines represent LTE handover events.

First, we created the CDF shown in Fig. 11 by using the filtering method explained in Section II-A to analyze the TCP throughput just before handover events. Fig. 11 shows a trend which is similar to the one recorded in the indoor experiment (Fig. 6). Decreasing A is effective in improving TCP throughput just before a handover.

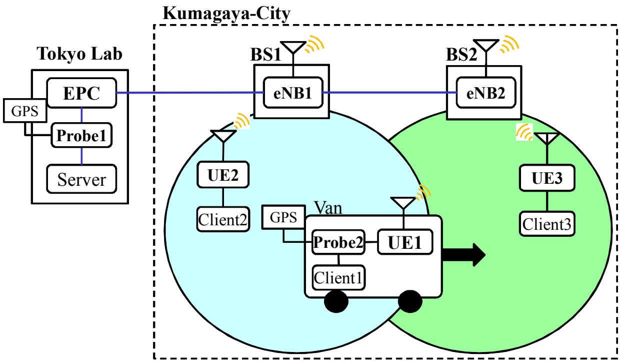


Figure 8. System configuration for outdoor experiment.

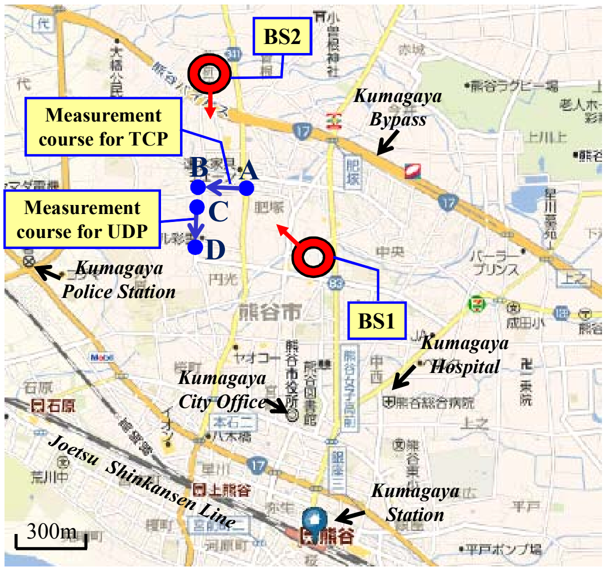
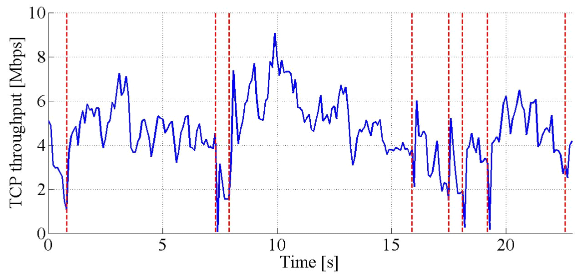
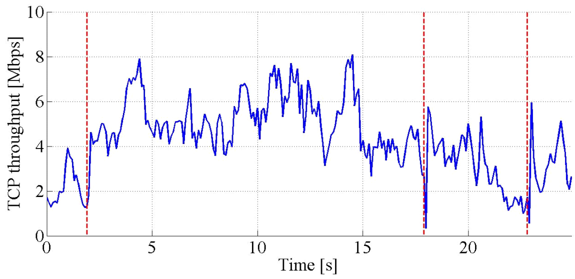


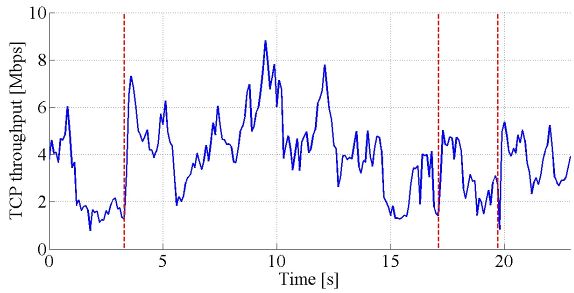
Figure 9. Outdoor experiment area and measurement courses.



(a) A = 2dB



(b) A = 4dB



(c) A = 6dB

Figure 10. Outdoor TCP throughput results.

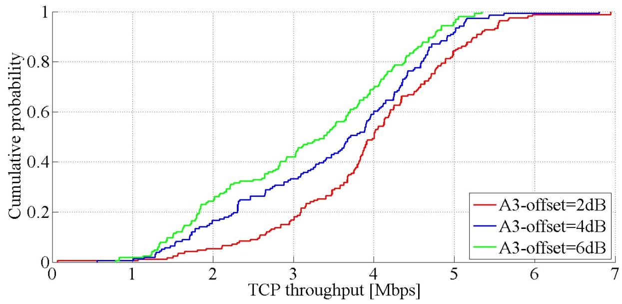
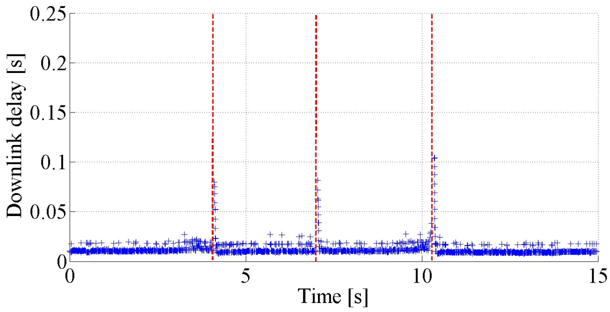


Figure 11. CDF of TCP throughput just before handover events.

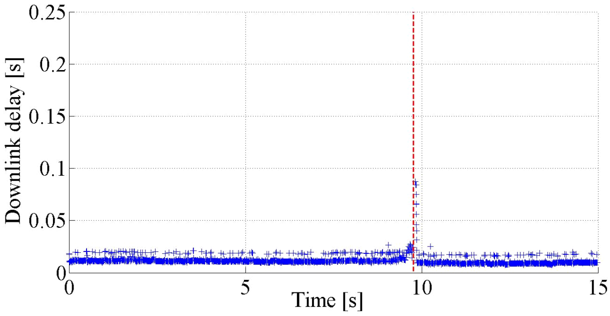
Second, if you look at the number of handover events, 9 handovers occurred when A = 2dB. In comparison, only 3 handovers occurred when A = 4 and 6dB. We think that the actual radio propagation environment triggered more handover events than the laboratory environment. Despite this fact, we obtained better TCP performance at A = 2dB and we confirmed in the field that ping-pong handover does not significantly impact TCP performance.

C. UDP Delay Evaluation

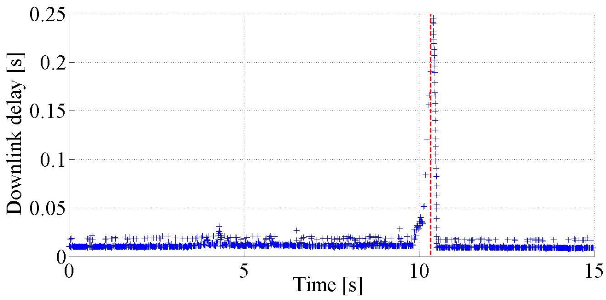
Fig. 12 shows the measured UDP delay for various A values. T is set at 320ms. UDP stream with 1Mbps transfer rate is used in the outdoor experiment. The measurement method is the same as the indoor experiment as explained in Section II-B.



(a) $A = 2$dB



(b) $A = 4$dB



(c) $A = 6$dB

Figure 12. Outdoor downlink UDP delay results.

Fig. 12 shows a similar trend with the indoor experiment. The delay increases just before handover. The rate of increase is higher at larger A3 offset value. The delay spike caused by a link interruption during handover lies around 80ms in the case of smaller A3 offset value (A = 2 and 4dB). However, the spike becomes 250ms at larger A3 offset value (A=6dB). We think that the severe interference is induced by the large A3 offset value and the buffering delay is generated by the same cause seen in the indoor experiment. (See Fig. 7 (f).) We therefore conclude that A3 offset value should be small to improve the delay performance during handover.

IV. CONCLUSION

In this paper, we evaluated TCP and UDP performance during LTE handover by using both indoor and outdoor experiments. A3 offset is a key parameter determining performance during LTE handover. So several A3 offset values were examined. TCP throughput performance can be improved by using a small A3 offset value because it can suppress interference from neighboring cells. The smaller A3 offset value may induce more ping-pong handovers, but this does not affect TCP throughput significantly. Using a small A3 offset value improves UDP delay performance as well because larger A3 offset values worsen the interference which creates large delay spikes during LTE handover.

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