

Measurement of TCP and UDP performance over UAS relay networks

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Abstract—This paper presents a measurement setup for transport protocol of wireless relay network using an unmanned aircraft (UA). The UA can fly back and forth to ferry data from multiple ground based access points or ground stations (GSs) that are located in the distance without connection to the backbone due to the network disconnection caused by a large-scale disaster. In such disaster area, a demand of communications through the data including moving images, sounds and pieces of text increases. In this paper, we conduct the experimental measurement of the wireless relay network using UA and analyzes its behavior. In this experimental measurement, we evaluate the basic performance of TCP and UDP protocol based on usage scenes. The numerical results of its goodput and delay performance of will be shown in this paper.

I. INTRODUCTION

The use of an unmanned aircraft (UA) is a promising low-cost approach that can provide additional redundancy in the communication networks such as direct, satellite, or cellular links. In particular, redundant wireless networks play a critical role in the case of emergency when the communication networks are partially or completely interrupted due to the disaster or unexpected power failure.

A relatively small, flexible UA that flies at lower altitudes for providing relay services for ground-based access point stations or ground stations (GSs) has been introduced [1], [2]. Especially, the fixed-wing UA can fly back and forth to ferry data from multiple GSs that are located in the distance without connection to the backbone due to the network disconnection caused by a large-scale disaster. Thus, the fixed-wing UA has a potential to serve as a relay to extend the coverage and improve the connectivity [3]. We consider such an application assuming a network with a fixed-wing small UA flying over two GSs in this paper. The UA acts as a decode-and-forward relay, receiving the messages from the co-channel users (i.e., GS-a) on the ground and transmitting the collected data to other users (i.e., GS-b). In this manner, the UA can reinforce the communication infrastructure by complementing existing networks such as satellite and cellular. The UA may find itself particularly useful in case of emergency since it does not rely on the infrastructure that requires manual maintenance such as power stations that could be also damaged [4] [5]. If the some users communicate other users via the UA relay network, the quality of service to be satisfied over wireless links. However, the performance of the typical networking protocols is yet not clear sufficiently to realize the applications for emergency

disaster.

The performance evaluation of the network using UA has been shown in [6] [7] [8] [9]. TCP has its own dynamic behavior to control congestion so that it is difficult to estimate the TCP performance in the wireless network using UAV [6] [7]. In [8], the ad-hoc network using quadcopter and wireless mesh nodes has been considered and the end-to-end throughput has been shown. In this networks, the quadcopter and nodes are interconnected to each other and building an IEEE802.11s. Moreover, the throughput performance of the network using IEEE802.11a has been shown in [9]. These studies have assumed the quadcopter, not fixed-wing UA.

Therefore, we focus on the relay network using the fixed-wing UA in this paper and evaluate the wireless packet data networks based on experimental measurements. In particular, basic performances of TCP and UDP are measured in the various realistic conditions since many applications use TCP or UDP as a transport layer protocol. Then, we will show numerical results of the delay time and the throughput performance.

The rest of the paper is organized as follows: Section II describes a wireless relay network using UA, and in Section III the measurement setup and the measurement environment are presented. Section IV presents numerical results of the experimental measurement. Finally, concluding remarks with possible future work are given in Section V.

II. WIRELESS RELAY NETWORK USING UAV

Figure 1 shows an overview of the wireless relay network using UA. Figure 2 shows an example of the trajectory of UA in the experimental measurement. Each GSs and UA is equipped with a single antenna used for transmission and reception in a half duplex manner.

The wireless relay network using UA consists of UA and two GSs denoted by GS-a and GS-b. The UA is equipped with flight management system, propulsion system, energy storage, networked communication, miniaturized devices, and autonomous control. The UA circles around above the fixed area automatically.

The GS consists of a transmit/receive antenna, a transceiver for the data transmission and the measurement of the physical layer and a PC for the measurement of the transport layer.

The UA receives the signal from the GSs and then the UA transmits the received signal to the other GS. In this exper-

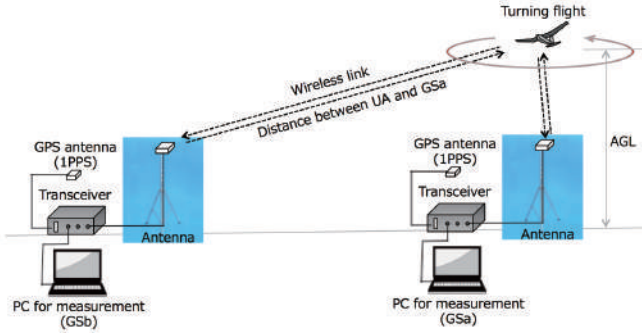


Fig. 1: The overview of wireless relay network using UA.



Fig. 2: The trajectory of UA in the non-urban area

imental measurement, the frequency band of the transmitter was chosen as 2 GHz and the transmit power was 2 W.

Table I shows the specification of UA. We use a different type of UA in this measurement. Table II shows the specification of transceiver for on-board and transceiver of GS. The wireless link supposed by the wireless relay network using UA is a narrow band link for the data transmission.

TABLE I: SPECIFICATION OF FIXED-WING UA

	TYPE 1	TYPE 2
Wing span, Weight	2.05 m, 3.7 kg	2.8 m, 5.9 kg
Payload	0.5 kg	0.5 kg
Flight time	0.5 hour	2-4 hours

TABLE II: SPECIFICATION OF TRANSCEIVER FOR ON-BOARD AND GS FOR NON-CONTROL AND COMMAND LINK

Frequency/bandwidth	2 GHz/8 MHz (Experimental)
Transmit power	2 W
Modulation	MSK
Multiple access	TDMA/TDD
Tx/Rx antenna	$\lambda/4$ whip antenna
Data rate/ throughput	6 Mbps/400 kbps
Time synchronization	1PPS by GPS

Through our initial experiment using a UA, we have succeeded in establishing wireless relay networks. A snapshot of our experimental measurement setup is shown in Fig. 3: The two GAPs (denoted by GAP_a and GS_b) separated by 0.5 km were able to exchange pictures and text messages through the UAV that is located 21 km from GSs.

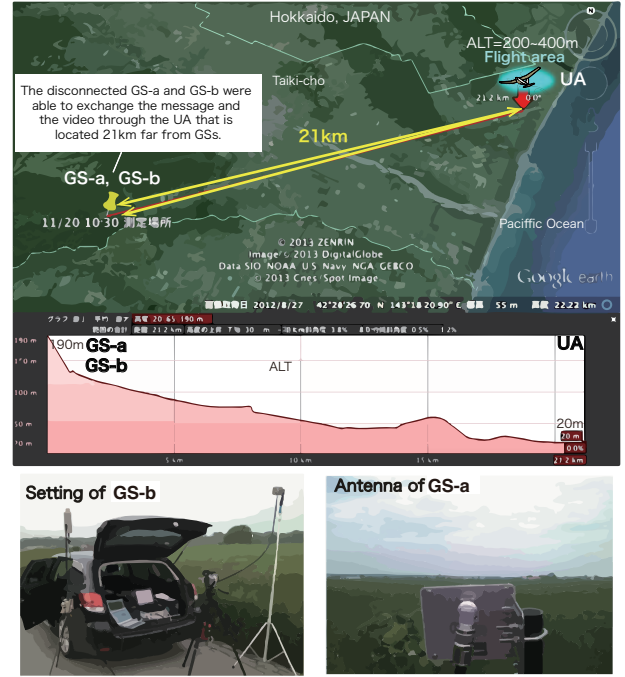


Fig. 3: Experimental measurement of wireless relay network using UA.

III. EXPERIMENTAL SETUP

A. Hardware & Software

In this experiment, we employ traffic generator such as IPERF [10] to generate TCP as well as UDP packets and we use Wireshark traffic monitor tool [11] to monitor sequence number of packets, packet types, size, arrival and departure time, and so on. We study the system parameters of the network and describe the measuring parameters as follow.

- The MTU of PC is set to 2,276 bytes. The OS of PC for measurement is Windows 7.
- The fragmentation threshold at the MAC layer is set to 11,832 bytes. The size of packets greater than the fragmentation threshold are fragmented at the MAC layer.
- The frame rate at the MAC layer is 5 frame per sec.
- A small UDP packet is sent over the wireless relay network using UA from a PC connected the transceiver of GS-b. Then the PC connected the transceiver of GS-a sends back an answering message.
- A TCP packet is sent over the wireless relay network using UA from a PC connected the transceiver of GS-b. Then the PC connected the transceiver of GS-a sends back an answering message. In addition, the traffic of TCP data and acknowledgement is sent over its network.

B. Environments

Before presenting our measurement results, we briefly overview our measurement environments. We carried out our measurements in the wireless relay network using small UA, which is deployed in Sendai-city, Miyagi and Taiki-cho,

Hokkaido, JAPAN. The Sendai-city is the urban area and the Taiki-cho is categorized as the rural area (non-urban area). These characteristic of environment are as follows.

- 1) Urban area: it is difficult to ensure the wireless link of line-of-sight between UA and GAPs in the urban area. Thus, channel environment is poor through the building is closely located to the GS.
- 2) Non-urban area(Rural area): It is easy to realize the wireless link of the line-of-sight between UA and GAPs since there is no a high building in the non-urban area. The channel environment is good through the building is located far from GS.

IV. NUMERICAL RESULTS

This section describes the numerical results of ICMP, UDP, and TCP protocol. Firstly, we evaluate the basic performance of these protocols. Secondly, we compare the performance of urban area with no-urban area.

A. ICMP performance

It is necessary for various applications to estimate the delay performances such as round trip time (RTT) and delay jitter. We measured round trip times at 12 km and 21 km points in the urban area. In the case of 12 km point, the GS-a is located near the UA and the GS-b deploys at 12 km far from GS-a. On the other hand, in the case of 21 km point, the both GS-a and GS-b deploys at 21 km far from the flight area of UA. In this experimental measurement, we send packets from GS-b to GS-a during 50 sec by using a ping command.

Figure 4 shows the cumulative distribution function (CDF) of RTT for wireless relay network using UA at 12 km and 21 km. It is clear that the relay network with UA has a relatively large RTT. The RTT includes the propagation delay of PHY layer, the delay of MAC layer, and processing delay. In the case of 21 km, the minimum will estimate $RRT = 0.07 \text{ msec} + 400 \text{ msec} + \alpha$. Moreover, the delay variation of 12 km point is 128 msec and that of 21 point is 105 msec.

B. UDP performance

Figure 5 shows the UDP-goodput of the various transmission rate at 5 km, 12 km and 21 km in the non-urban area. In this measurement, the UDP packet sends and its performance is evaluated during 60 sec using iperf. Obviously, the UDP-goodput of the wireless bridge using UAS can be improved by increasing of the transmission rate as well as the typical wireless networks. The UDP-goodput can be close to 320 kbps when transmission rate is 1000 kbps.

Figure 6 shows the jitter of the various transmission rate at 5 km, 12 km and 21 km in the non-urban area. When the transmission rate is 100 kbps, the jitter is largest value in the case of this experimental measurement.

Figures 7 show an example of measurement results 25 km of UDP protocol: (a) the distance between UA and GS, (b) the received signal level of UA and GS-b, (c) the number of UDP packets, and (d) the time delta from previous displayed frame by Wireshark traffic monitor tool. The horizontal axis are

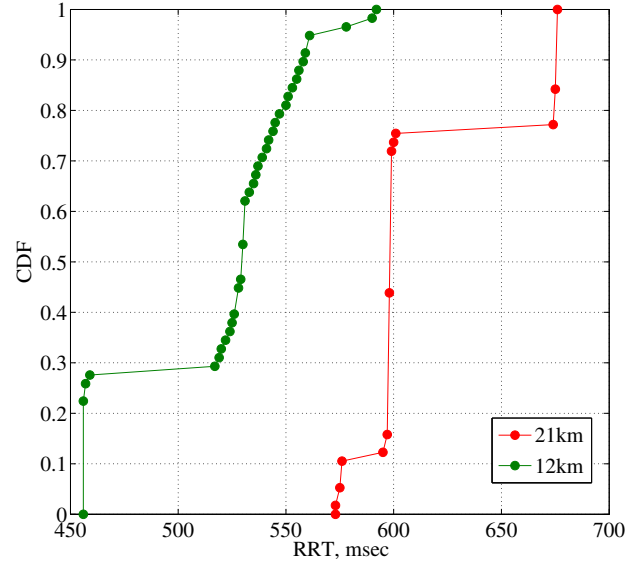


Fig. 4: CDF of RRT at 12 km and 21 km in the non-urban area

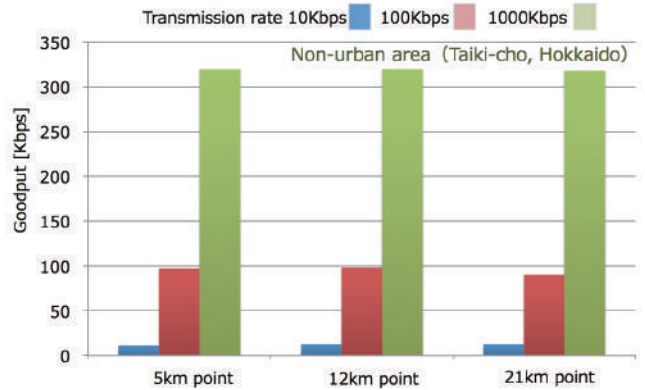


Fig. 5: The UDP-goodput of transmission rate at 5 km, 12 km and 21 km in the non-urban area

plotted in steps of 0.1 sec. In Fig. 7(a), the distance between UA and GS-b varies the according the circling of UA. It is found that the received signal level of UA and GS-b depends on the distance. However, there are some parts of low level even in the case of the shorter distance area in Fig.7(b). This is because the wireless link between UA and GS-b are shielded by the body of UA during circling. From Figs. 7(c) and (d), it would appear that the UDP packet can be received adequately.

C. TCP performance

Figure 8 shows the TCP-goodput at 5 km, 12 km and 21 km in the non-urban area. Absolutely, the TCP-goodput increases by increasing the window size wherever the measurement point. The maximum TCP-goodput is close to 400 kbps at 5 km point in the non-urban area.

Figures 9 show an example of measurement results 25 km of TCP protocol: (a) the distance between UA and GS, (b) the

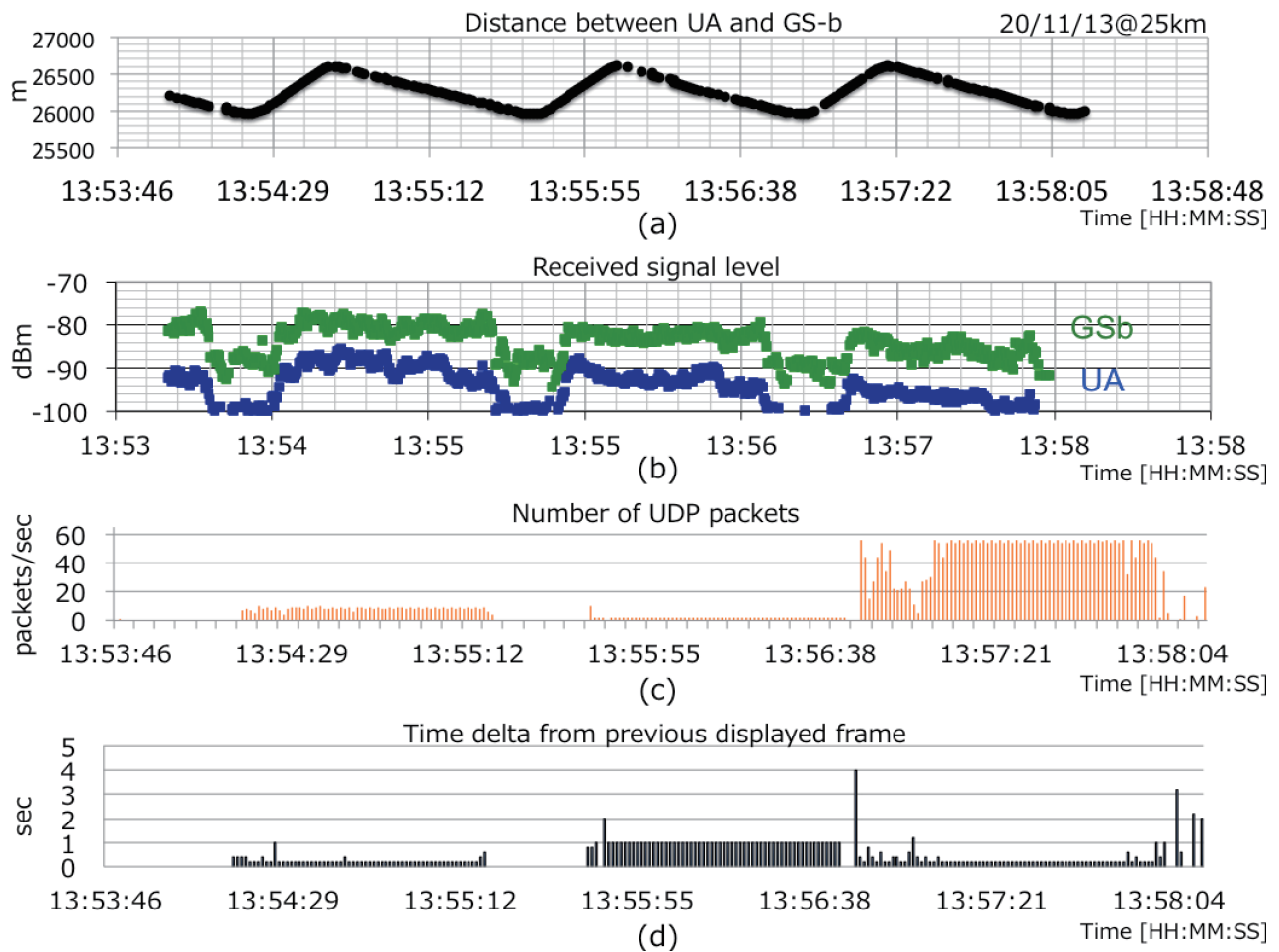


Fig. 7: An example of measurement results for UDP performance at 25 km point: (a) the distance between UA and GS, (b) the received signal level, (c) the number of UDP packets, and (d) the time delta from previous displayed frame by Wireshark traffic monitor tool

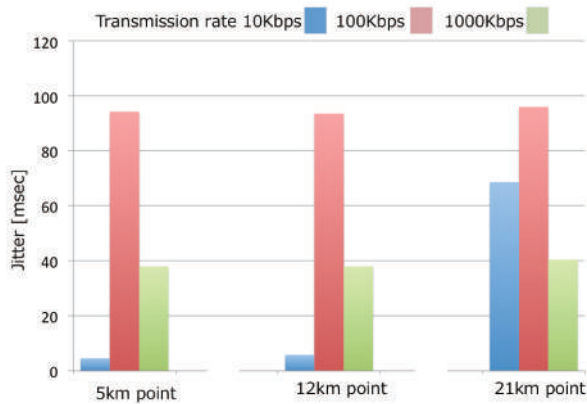


Fig. 6: The jitter of UDP for transmission rate at 5 km, 12 km and 21 km in the non-urban area

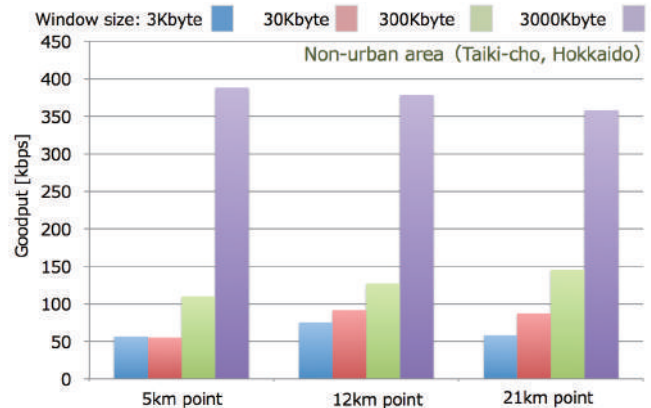


Fig. 8: The TCP-goodput of various window size at 5 km, 12 km and 21 km in the non-urban area

received signal level of UA and GS-b, (c) the received signal level of UA and GS-a, (d) the round trip time of ACK, and (e) the number of re-transmission, (f) the number of lost segments, (g) the size of window, and (h) the number of duplicate ACKs.

The results of (b) and (c) are measured by transceiver of UA and GS, and the results (d), (e), (f), (g), and (h) are evaluated by Wireshark monitor tool. Similarly, the distance between UA and GS-b varies according to the circling of UA and the

received signal level of UA and GS depends on the distance.

From Fig. 9(h), it is regarded that the network congestions occur due to the segment loss and time over of window size since the number of duplicate ACKs increase as increasing the distance between UA and GS. The probability that the segment loss occurs when the duplicate ACKs is observed is 5%, and the probability that the window size is lower than 14 sec when the duplicate ACKs is observed is 36%.

From Fig. 9(d), the average of RTT is about 4.3 sec and the standard deviation of RTT is about 2.5 sec. Thus, it might be a reasonable value that the re-transmission time is set to 14 ($= 4.3 + 2.5 \times 4$) sec in the relay network using UA.

From Fig. 9(g), it is found that the window size increases by small increments after starting connection. However, for the congestion control, the window size reduces by half when the segment lost occurs as shown in Fig. 9(f). It seems that the typical congestion control is also suitable for the wireless relay network using UA.

D. Urban area vs. Non-Urban area

Figure 10a and 10b show the UDP-goodput performance at the various points in the non-urban area and the urban area. The measurement points of the non-urban area is 5 km, 12 km, and 21 km and the points of the urban area is 3.5 km, 7.4 km, 10 km and 11.6 km. In the both cases of the non-urban area and urban-area, GS-a is located near the flight area of UA and GS-b deploys the each measurement point. In the non-urban area, the UDP-goodput achieves more than 90 kbps whereas the UDP-goodput is 90 kbps at just 3.5 km in the urban area due to the poor channel environment.

V. CONCLUSIONS

We have presented a measurement setup of wireless relay network using a UA and evaluated its behavior. The numerical results of the experimental measurement of TCP and UDP performance based on usage scenes have been shown. The network layer protocol of the wireless relay network using UA depends on the marginal environment such as the urban or non-urban area. The UDP protocol has good performance in the throughput terms over the wireless relay network using UA compared with the TCP protocol. The design of the network protocol for various applications, extension to multiple-antenna UA/GS systems will be left as our future works.

ACKNOWLEDGEMENT

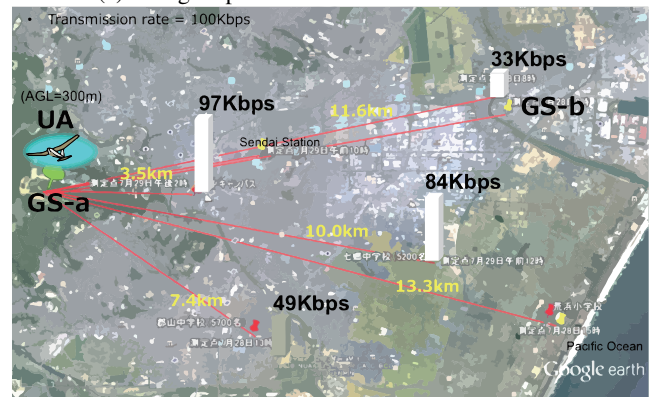
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(a) The goodput of UDP in the non-urban area



(b) The goodput of UDP in the urban area

Fig. 10: The UDP-goodput performance:(a) the non-urban area (b) the urban area

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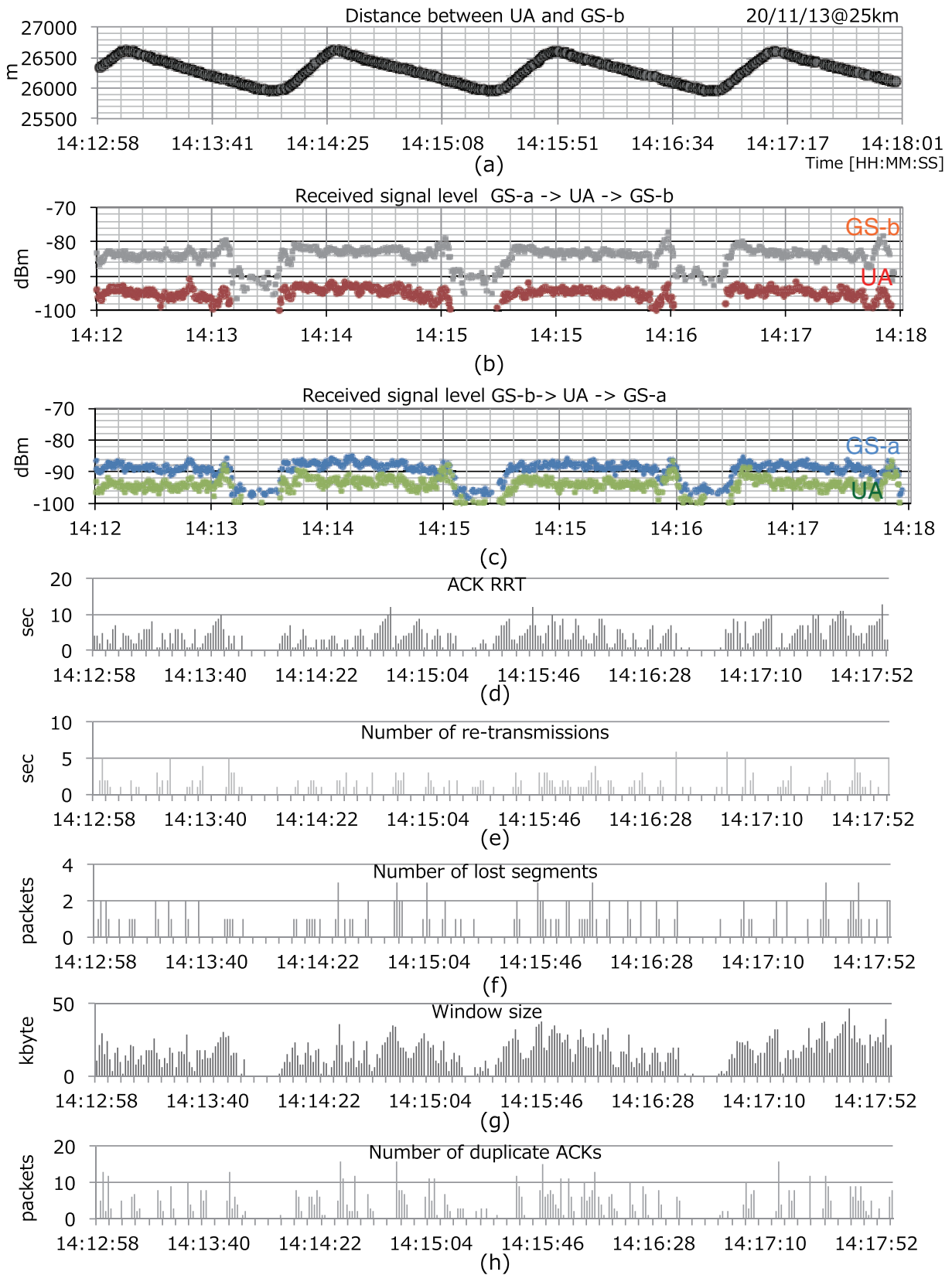


Fig. 9: An example of measurement results for UDP performance at 25 km point: (a) the distance between UA and GS, (b) the received signal level of UA and GS-b, (c) the received signal level of UA and GS-a, (d) the round trip time of ACK, and (e) the number of re-transmission, (f) the number of lost segments, (g) the size of window, and (h) the number of duplicate ACKs. The results of (d), (e), (f), (g), and (h) are evaluated by Wireshark monitor tool.