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Performance Improvement of Packet Delay in Advanced Public Transportation System Using Multi Path UDP on Cellular Environment

***Abstract**. Mobile wireless networks are now capable of carrying tens of Mbps of data. The development of mobile wireless network has also triggered the development of many mobile applications that can support the Intelligent Transportation System (ITS). Some mobile applications require a reliable wireless communication network in order to maintain real-time communication. However, the quality of mobile wireless link is affected by its propagation channel: its propagation environment and velocity of the mobile terminal. In order to enhance the reliability of mobile wireless communication channel, the use of multipath data link is introduced. At the moment, the existing multipath internet has not yet been applied to mobile wireless network. This paper proposes a data communication protocol using multipath User Datagram Protocol (MP-UDP) in order to shorten data transaction latency between mobile terminal and its server. The measurement results show that the use of MP-UDP could significantly improve the availability performance in poor wireless communication link. The field measurement using 4G-LTE (Long Term Evolution) network in the city of Malang has shown increasing availability of a 1 second time-out packet data communication link, from a 96% availability for a single UDP path towards a 98.9% availability for MP-UDP.*

***Streszczenie.** Mobilne sieci bezprzewodowe mogą teraz przesyłać dziesiątki Mb/s danych. Rozwój mobilnej sieci bezprzewodowej przyczynił się również do powstania wielu aplikacji mobilnych, które mogą wspierać Inteligentny System Transportowy (ITS). Niektóre aplikacje mobilne wymagają niezawodnej bezprzewodowej sieci komunikacyjnej w celu utrzymania komunikacji w czasie rzeczywistym. Jednak na jakość mobilnego łącza bezprzewodowego wpływa jego kanał propagacji: środowisko propagacji i prędkość terminala mobilnego. W celu zwiększenia niezawodności mobilnego kanału komunikacji bezprzewodowej wprowadzamy zastosowanie wielościeżkowego łącza danych. W chwili obecnej istniejący wielościeżkowy internet nie został jeszcze zastosowany w mobilnej sieci bezprzewodowej. W artykule zaproponowano protokół transmisji danych wykorzystujący wielościeżkowy protokół datagramów użytkownika (MP-UDP) w celu skrócenia opóźnienia transakcji danych między terminalem mobilnym a jego serwerem. Wyniki pomiarów pokazują, że zastosowanie MP-UDP może znacząco poprawić wydajność dostępności w słabym łączu bezprzewodowym. Pomiary w terenie za pomocą sieci 4G-LTE (Long Term Evolution) w mieście Malang wykazały rosnącą dostępność jednosekundowego łącza transmisji danych pakietowych z limitem czasu, od 96% dostępności dla pojedynczej ścieżki UDP do 98,9% dostępności dla MP-UDP. (**Poprawa wydajności opóźnień pakietów w zaawansowanym systemie transportu publicznego z wykorzystaniem wielościeżkowego protokołu UDP w środowisku komórkowym**)*

Keywords: wireless mobile network, multipath Internet protocol, MP-UDP
Słowa kluczowe: bezprzewodowa sieć komórkowa, wielościeżkowy protokół internetowy, wielościeżkowy UDP.

Introduction

Recent development of cellular mobile communication technology has strengthened bulk data transmission from tens to hundreds of Mbps in mobile propagation environment [1, 2]. This condition is supported by the development of radio communication technology such as the application of multiple antennas at the transmitter and the receiver or MIMO (Multi Input Multi Output) [3], the use of the spread spectrum method [4, 5] or the application of OFDM (Orthogonal Frequency Division Multiplexing) modulation techniques [6].

Currently, the image of public transportation in Indonesia in general is still less comfortable for users. In order to support a public transportation system that will attract public interest, the application of ITS in Indonesia could be initiated in the public transportation. With increased comfort supported by ITS technology, in the Advanced Public Transportation System (APTS), it is expected that people will use the public transportation more than private vehicles [7].

APTS requires a reliable wireless communication network to be able to carry out Vehicle to Infrastructure (V2I) control center communication in real-time [8, 9, 10]. One of the applications on the APTS is the requirement of fast delivery of information is online ticket sales application. Long data delivery times in the online e-ticketing process can cause long queues. Communication through the cellular network for online ticketing applications is affected by the quality of the radio wave propagation channel. The condition of radio propagation channels in the vehicular network is not always good, because there are always changes in the relative distance between the sender and receiver as well as in the propagation environment [11]. At the previous research stage, this condition sometimes caused data packets to be sent quickly, but sometimes it took a long time: up to tens of seconds by using HTTP [12]. HTTP was chosen to carry the APTS payload, to be easy to use and supported by many platforms, because the protocol is text-based [13]. The latency of data communication using HTTP will have no effect when the transmission medium is a cable. Data communication latency will interfere when using a wireless network with uncertain propagation conditions and coverage area or heavy radio traffic conditions. The drawback of HTTP in cellular communication is the possibility of high latency when the radio propagation channel conditions are not good. The high latency condition in the HTTP protocol is due to the existence of a re-transmission mechanism if there is a packet loss in the process of sending data between the client and server.

To reduce the high RTT delay on wireless networks, the HTTP protocol was replaced by the UDP protocol to carry the APTS payload. The disadvantage of UDP is that it is not reliable because there is no automatic ACK process by the kernel. One way to improve the performance of packet delay is to use multipath Internet [14]. Based on these conditions, to increase the availability of wireless communication links for APTS data communication, a multi-path wireless link method based on UDP is proposed. The proposed MultipathUDP (MP-UDP) in this paper has the following advantages:

1. By using special software control, MP-UDP can reach lower latency compared with another protocol.
2. With the application of MP-UDP, the probability of communication breakdown due to user density and poor radio propagation link on a public operator can be reduced (higher reliability).
3. Based on the measurement results, MP-UDP can significantly improve performance, in terms of reducing packet loss and RTT delay.

This paper will be organized as follows. The second and third sections cover the protocol design and experimental plan respectively. The fourth section represents the test results and discussion. The last part is the conclusion of this research.

MP-UDP design for APTS

The wireless telecommunication system used in mobile communications is now integrated with the Internet. In this section, the system modelling for communication between on-board clients and servers located in a data centre are presented. The multipath wireless communication system on a mobile wireless network can be illustrated in Figure 1. For example, the first path is connected to operator #1 and the second path uses operator #2. At the moment, the easiest wireless communication networks to use for on-board communication are the city Wi-Fi network and the 3G/LTE cellular operator network [15,16]. Because it uses a public network, QoS on the network cannot be managed and the data packets sent must also compete with data packets from other users [17]. By using a multipath wireless network, if the condition of one network is bad, the other paths can still operate smoothly. Thus, the availability of links obtained on multipath will be higher than that of one path only.

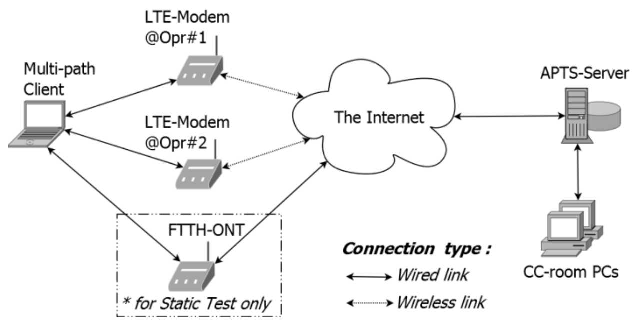

Fig. 1 Multipath Internet over 2 cellular networks

A communication design using multipath Internet is as a result of the increase of wireless communication systems capacity using multiple antennas [18, 19]. In this study, by using multiple (parallel) paths, the availability of wireless communication paths will also increase because the unavailability of the system only occurs when all paths are not available. The equation for system availability with multipath Internet is Eq. (1)

$$(1)\ a(t) = 1 - \{(1-a_1(t)) \cdot (1-a_2(t))\}$$

where: $a(t)$ = availability of the system; $a_1(t)$ = availability of path1; $a_2(t)$ = availability of path2

On a multi-path link, the Round-Trip Time (RTT) delay for sending data from the client to the server is illustrated in Figure 2. This RTT delay are affected by 1) the propagation time of data packets from the client to the server (T0=>T1), 2) the processing time of data packets on the server (T1=>T2), 3) the propagation time of sending reply data from the server back to the client. If we review the duration of the waiting time for a reply (ACK) from the server, then the time duration is:

$$(2)\ RTT_{system} = \min\ \{RTT_{path1}, RTT_{path2}\}$$

where:
RTT_{path1}: RTT communication time via Opr#1 path.
RTT_{path2}: RTT communication time via Opr#2 path.

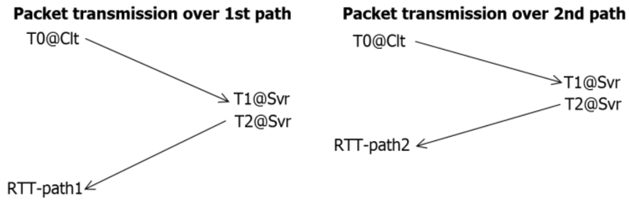

Fig. 2 MP-UDP Timing Diagram

The application of the Multipath Internet protocol can be implemented by taking a hardware or software approach. Multipath Internet implementation approach in hardware can be taken by using a multihoming router that can function for fail-safe and load balancing of several Internet gateways [20, 21]. In software approach, Multipath Internet can also use available protocols such as the MP-TCP and SCTP protocols which are supported by the kernel on the Linux operating system [22, 23]. An easy-to-use Internet multipath system is a device or system that already functions as a router. SCTP is not easy to implement because there must be a change in the interface at the application layer. In this study we have also tried a multihoming hardware router and an OpenMPTCP-Router [24]. Weaknesses in the use of existing multipath Internet routers, the more optimal path cannot be chosen from application layer.

To improve link availability in applications that require low latency, in this study MP-UDP is developed instead of using the existing MP Internet system. This is done with the advantage of being able to exercise direct control based on link quality in real-time. UDP is the transport layer protocol on the Internet. This protocol is generally applied to data communications that require high speed, such as streaming data on telephony over the Internet. The application of the UDP protocol can be done easily since the cellular network (LTE 4G) is IP-based [25]. By using the UDP, packet handling on the network can be controlled directly at the application layer according to the level of urgency of the data packet. Controls at the application layer include how long the time-out is and which dual path is the best choice for traffic to pass based on an analysis of the average ACK reception delay record.

In order to obtain the optimal results, the path selection algorithm is selected based on the type of packet and the urgency of each type of data packet. The types of traffic on the APTS could include: 1) location information and sensors if needed, 2) message traffic between cabin crew and operators at TMC, 3) information on on-board conditions with conditions at the bus stop. These different types of traffic can be used to build algorithms such as the flow-chart in Figure 3.

As a protocol implementation plan, the urgency level of data packets is classified into 3 groups. The first group of data packets is the information on position data packets and sensor data which are sent periodically. This first group of data packets may be lost on the way, however in the next period of transmission, it will also be updated. The second group of data packets is the data packets that should reach their destination but are not too urgent (delay tolerant). The last group is a group of data that are urgent/critical, namely data packets that should reach their destination immediately. For the type of data packet that is 'urgent/critical', it will be sent through two paths simultaneously. For 'regular' data packets, data packets are sent via one of the paths. For data packets that are periodic, the delivery is 'fire-and-forget'.

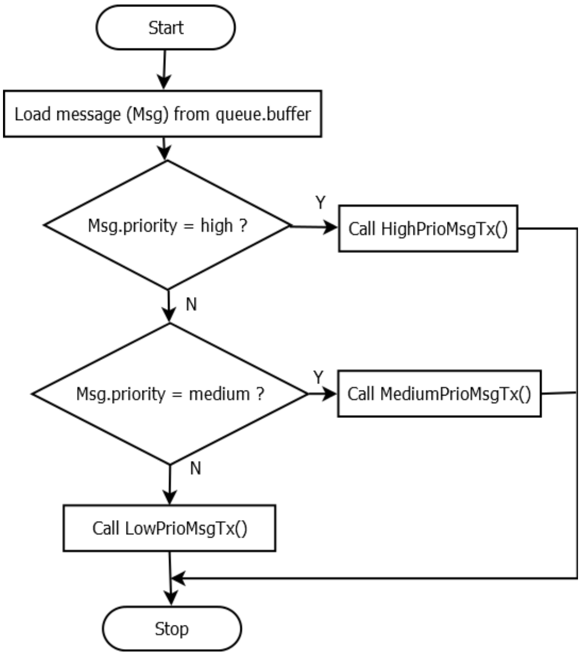

Fig. 3 Flowchart for the priority groups division of data packets

The biggest traffic on simple APTS is fleet location information. Location information is generally carried out periodically, for example every 10 seconds. The location information package can be placed in the lowest QoS class. If this location information does not arrive, it will be updated by the next periodic data transmission.

This periodic delivery of location information can also be used to detect the quality of the link being used. For messaging, sometimes it is very urgent/critical so it must be delivered to the destination immediately with a high successful rate. For example, emergency messages and messages in the electronic ticket system. In the ticket system, if you have to wait too long for a response, it can cause business process disruption, namely the emergence of long queues in the ticket inspection/validation process.

The transport layer protocol used in this multi-path internet test is a UDP. This transport protocol was chosen because it does not need to do handshaking first. Thus, the duration of time measured when sending and receiving reply data from the server is the duration of time used by only two transmission processes, namely from the client to the server and the reply from the server back to the client. This Multipath Multichannel (MP-MC) system will utilize the data from the results of quality probing of the UDP-based data communication link at the time of sending the periodic data. Data packets that are not urgent will be sent through the available links alternately. Packets with medium urgency will be sent via the link with the best quality. For urgent and critical data, packets will be sent via two links simultaneously (redundant).

Experimental Setup

Experiments in this study were carried out in both static and moving conditions. The measurements in static conditions aim to obtain the characteristics of the link through the 4G LTE network compared to the link through the optical cable access point. The use of fiber optic media from Fiber to The Home (FTTH) operator services in this measurement serves as a comparison of link quality between wired and wireless networks. Static testing was carried out in a residential area in Lawang, Malang Regency, while mobile testing of wireless communication link was carried out in the area of Batu city and Malang city. The environmental conditions for the mobile wireless link testing were along highways and roads in Malang and Batu cities. This measurement aims to get the real characteristics of MP-UDP in the field.

In this experiment, we used two LTE CPEs and a FTTH (Fiber to The Home) CPE on the client side. For the configuration of the device used, refer to Figure 1. FTTH was only used as a time comparison in measuring static conditions. The APTS server used was located in a data center in the city of Jakarta. The distance between the client and server is about 900 km (estimated shortest path of the cable network between Malang and Jakarta).

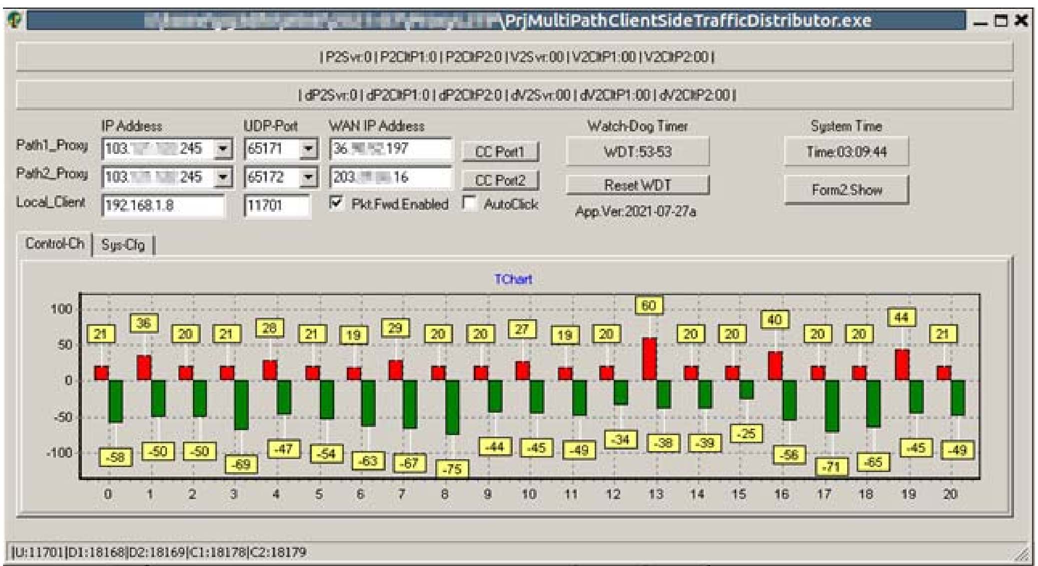

Fig. 4 GUI for MP-UDP measurement software

The software used is OS MS-Windows 10 on the client side and Linux OS on the server side. In application layer software, the program for the client is designed to send data packets simultaneously through two different paths to the server periodically every five seconds. Figure 4 shows a software graphical user interface (GUI) specifically designed for MP-UDP dual channel monitoring. This software is used to split and manage the flow of data packets through two different Internet gateways. This software is also responsible for recording Internet Control Message Protocol (ICMP) data packets.

(ICMP) 'pings' from the client to the MP-UDP proxy for further analysis. The software is also equipped for the process of detecting IP WAN (Wide Area Network) addresses to monitor and ensure that data packets have been passed on two different Internet link paths by operators. The chart contained in the software serves to visually observe the difference in RTT delay directly. The data packet that is sent is equipped with a sequential-ID and timestamp which can be used as the basis for calculating the RTT delay in a packet.

On the server side, the received packet will be opened and replied back by attaching the server timestamp. With the timestamp on the client and server, when the reply data is received by the client, it is possible to calculate the RTT time, the time duration from the client to the server and the time duration from the server back to the client.

Result and Discussion

Measurements in this research are divided into 2 stages, namely measurements in static conditions and measurements in moving conditions. Measurements in static conditions are used to determine the condition of the RTT delay on the cellular network based on the time of day. Measurements in mobile conditions, to obtain the characteristics of the cellular network.

A. Measurement results in static conditions

The results of the measurements under static conditions are shown in Table 1 and Figure 5. In this condition, the 4G LTE CPE terminal is in the same place as the FTTH CPE. It appears that the lowest latency is achieved by FTTH where the average result is 34.3 msec. While the quality of the LTE wireless network link has an average latency of 138.5 msec for Operator 1 and 215.1 msec for Operator 2. From Figure 5, the Cumulative Distribution Function (CDF) graph of the RTT between the On-Board Unit (OBU) and the Traffic Management Center server (TMC) can be concluded that more than 90% data latency via FTTH only takes about 30 msec. For data packets sent via LTE, the latency is spread with a minimum value of 47 msec and has an average value of about 3-4 times the minimum value. In OBUs that use FTTH links, RTT delays generally accumulate at almost the same speed because the delay is only affected by the propagation delay of data packets on fiber optics and processing delays when data packets transit on several routers and L2-switches. While on the LTE operator network link, because on the wired back-bone network (TMC server to BTS provider) the distance is almost the same, then the propagation time of data packets to the server is of course also almost the same. The possible cause of the large distribution of RTT delay on LTE operators is due to the MAC (scheduling) mechanism so that it can serve multiple access proportionally to all wireless cell users at the BTS provider. One way to limit the rate of data traffic is by using the delay method in the data packet queue buffer on a router. As a result, there is an additional delay on the LTE networks when there are a lot of wireless cell users. Thus, when the queue is loose, the RTT delay can be 47 msec. However, when the network is congested, the RTT delay can be in the range of 100 to 700 msec.

Table 1. RTT-delay (in msec) using UDP from OBU to TMC

Netw. Operator	Min	Max	Mean	Std.Dev
Cellular Opr-1	47.0	625.0	215.1	45.0
Cellular Opr-2	47.0	734.0	138.5	30.2
Wired - FTTH	31.0	94.0	34.3	8.5

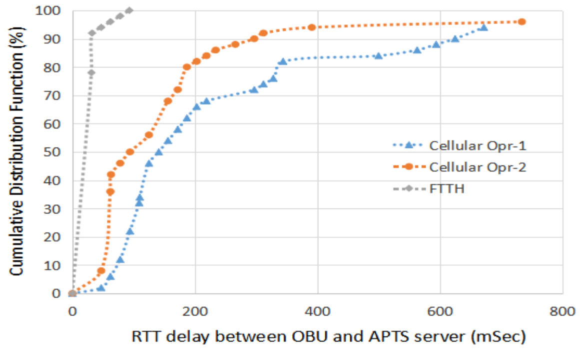

Fig. 5 CCDF RTT-UDP latency from OBU to TMC via LTE and FTTH

From table 1 and Figure 5 it can be concluded that the RTT delay in FTTH tends to accumulate at a value of about 30 msec. While on the wireless network link, the RTT delay is spread out with a fairly large jitter value. According to the calculations, if the distance between the OBU client and the TMC server is about 900 km, then the round-trip distance is around 1800 km. If the speed of light is about 2/3 speed of light on an optical cable, then the data packet propagation time is about 1800/200 or about 9 msec. The measurement results show a significant time difference to the calculation of the propagation delay (30ms:9ms). The time difference may be caused by the transit time period of data packets on the Router or Ethernet-Switch equipment. In addition, sometimes there is a routing process through alternative routes which can cause the RTT delay to be greater.

The measurement of the link quality in the second static condition is carried out to observe the number of packet loss that occurs on the link through the 4G LTE channel. The purpose of this measurement is to obtain information about the packet-loss and RTT delay based on the time span of every 1 hour in 1 day. Figure 6 shows the percentage of the average packet loss measurement in the hourly time frame for 1 day. From the graph, it can be seen that packet loss on the 4G LTE link occurs during lunch breaks and in the afternoon during relaxing hours before bed. Lunch breaks in Indonesia are typically between 12 pm to 1 pm. Afternoon leisure hours are between 7 pm to 9 pm. On single-lane wireless links, the packet loss rates can reach more than 5% during peak hours. By using dual path (Opr#1 and Opr#2), the packet loss can be reduced to close to 0%. Improved availability of this link refers to Eq. (1), which will increase when using dual path. In standard TCP-based data communication, in the event of packet loss there will be data retransmission after reaching a time-out of 3 seconds [26].

In addition to the packet loss parameters, measurements are also made on the RTT delay of the data packets. In Figure 7 it can be seen that the average RTT delay is about 200 msec on the Operator-1 link and 400 msec on the Operator-2 link. From the figure, it can be seen that the increase in latency is quite noticeable during the heavy traffic hours. The variation of the average RTT delay performance on dual path (MP-UDP) is not very significant, thus indicating good performance stability. When viewed from the RTT delay data, many RTT delays are below 200 msec. However, the combined data average delay throughout the day is still around 200 msec. The average RTT delay only drops slightly below the average RTT delay on a link through the fastest carrier network. Theoretically, the performance increase in the RTT delay follows Eq. (2). If the average value is calculated, the increase in the performance of the RTT delay is not as large as the increase in the instantaneous RTT delay. This condition is most likely caused by the large distribution of the RTT delay on the LTE/4G network. Thus, even though the minimum RTT delay on an LTE network is 47 msec, if the RTT delay on the next packet is much slower, the average RTT delay will also not increase significantly. Thus, MP-UDP is more appropriate for use in incidental wireless data communications. MP-UDP with dual-path data transmission mode is not suitable for continuous data such as live-streaming multimedia because there are many duplications of the data packets sent via dual-path.

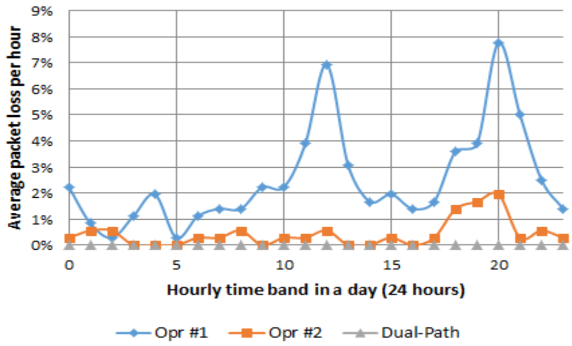

Fig. . 6 Packet Loss on the link via LTE channel

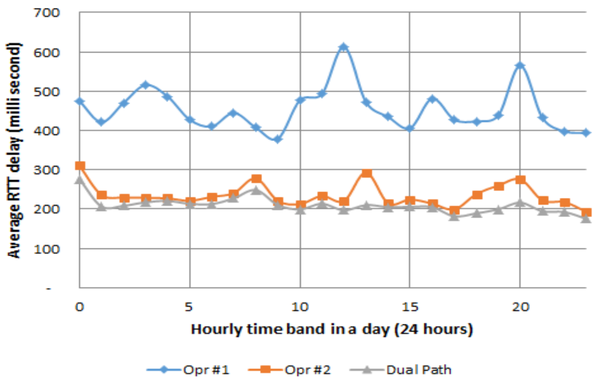

Fig. 7 Average RTT delay on the link via LTE channel

B. Measurement results in moving conditions

The experiments in this moving condition were carried out during the day. Mobile users during Covid-19 pandemic may not be as crowded as before the pandemic. Cellular traffic may also be a bit congested because the 'work from home' process uses an LTE network. This first stage of mobile measurement was carried out in a sub-urban area (between Batu city and Malang city), aimed at observing RTT behavior on LTE wireless networks. In this test, the time-out wait time is set at 10 second intervals. The test results with a time-out of 10 seconds are shown in Table 2. In the first row of the table, it can be seen that multipath networks can increase the availability of links for data transmission within 100 msec from around 70% to around 90%. In the 4th row in the table, it is also seen that the increase in the availability of data transmission within 1 second from single path to multi-path increased from around 97.5% and 95.7% to 98.9%. From the measurement results in moving conditions, it turns out that the RTT delay is more extreme than the measurement in static conditions.

From the table it can also be seen that on LTE there are many data packets that require RTT time of more than 3 seconds. In moving conditions, the RTT delay of more than 3 seconds on both operators is still at an average value of around 98%. An RTT of 3 seconds is the time-out limit for TCP/IP-based communications. This condition causes MP-UDP-based communication to be more superior in terms of speed when compared to TCP/IP-based communication. In HTTP-based communication that works over TCP/IP, if it enters the wireless network area, the packet loss is quite high. If there is a packet loss, then the RTT delay can immediately be 3 seconds or more. Even in previous studies, it is also often found that the RTT delay is more than 20 seconds when using a cellular wireless network. These conditions make MP-UDP a candidate for data communication protocols for APTS transactions that require low latency.

Table 2. CDF RTT delay at a timeout interval of 10 seconds

RTT-Delay Time-Out(msec)	Dual Path (Opr1+Opr2)	Single Path (Opr1)	Single Path (Opr2)
100	89.05%	71.71%	68.67%
200	96.96%	92.02%	89.51%
500	98.48%	96.65%	93.92%
1000	98.94%	97.49%	95.74%
2000	99.47%	98.17%	97.41%
3000	99.77%	98.40%	98.10%
5000	99.85%	98.40%	98.33%
9000	99.92%	98.40%	98.48%

The second step of moving measurements was carried out to obtain MP-UDP performance for RTT transmission less than 1 second. The purpose of this mobile measurement is to ensure that the MP-UDP protocol is able to support the performance of APTS data transactions (mobile data transactions) that require low latency. The location of the measurements was carried out in the northern part of the city of Malang, which has a relatively dense population. Complementary CDF (CCDF) profile information obtained from the measurement results can be seen in Figure 8. This CCDF profile is obtained from the moving measurement data that is carried out for one hour. This graph shows that the performance of MP-UDP (dual-path) on the 4G LTE network shows a significant increase in RTT delay performance. At the limit of RTT delay less than 200 msec, CCDF is 0.6% or availability is 99.4%. Also, from the graph it can be seen that the availability of more than 99.9% (3 nine) with MP-UDP protocol can be guaranteed for RTT delay less than 600ms. If the data transmission uses a single path (operator) for the RTT delay limit of less than 600 msec, the availability of 98.5% (Opr-1) and 96.8% (Opr-2), numbers are still below 99% (2 nine). From the comparison of the application of the UDP protocol between single path and multipath, it can be observed that for multiple paths it can significantly improve the performance of UDP data communication availability.

The MP-UDP protocol is applied to APTS for the process of sending data packets with low latency requirements (e.g. e-ticketing when on-board) and one second time-out. When there is a data transmission failure in the first second, it is possible that the next message can be received in the second second. When compared with the application of the TCP protocol, the retransmission of data packets will be carried out after waiting for an ACK for three seconds. This is obtained from several measurements with Wireshark, standard TCP takes about 3 seconds to wait for time-out before retransmission.

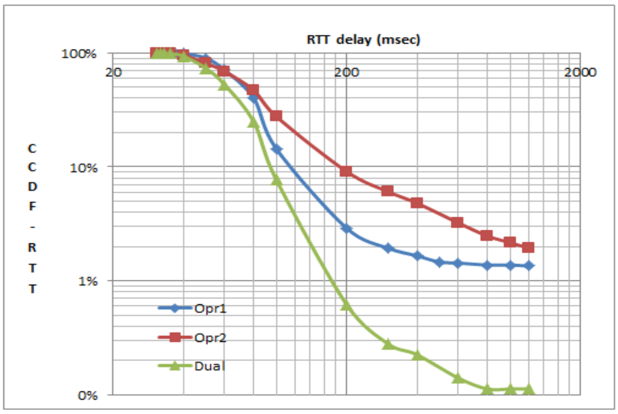

Fig.. 8 Complement of CDF (CCDF) RTT delay on moving condition measurement in the city of Malang

Conclusion

The proposed MP-UDP scheme can improve the performance of communications that need low latency such as e-ticketing. Improved availability from about 98% to 99.77% at a time out of 3 seconds. The increase in RTT delay was not significant. For applications that require low latency, with a time-out of 1 second, MP-UDP can significantly increase link availability from around 96.5% to 98.9%. Due to the quite large distribution of RTT delay on a wireless network, the performance improvement on the average RTT delay via MP-UDP is not significant. Based on the re-transmission process due to ACK time-out, the increase in RTT delay performance will be felt when there are a lot of retransmissions on the network.

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