Scientific Research Publishing

Communications and Network, 2022, 14, 200-209
https://www.scirp.org/journal/cn
ISSN Online: 1947-3826
ISSN Print: 1949-2421

Reachability-Based Packet Scheduler of Multipath QUIC for Heterogeneous Mobile Networks

Riki Okunishi[1], Rui Teng[2], Kenya Sato[1,2]

[1]Graduate School of Science and Engineering, Doshisha University, Kyoto, Japan
[2]Mobility Research Center, Doshisha University, Kyoto, Japan
Email: ksato@mail.doshisha.ac.jp

How to cite this paper: Okunishi, R., Teng, R. and Sato, K. (2022) Reachability-Based Packet Scheduler of Multipath QUIC for Heterogeneous Mobile Networks. *Communications and Network*, **14**, 200-209.
https://doi.org/10.4236/cn.2022.144011

Received: August 4, 2022
Accepted: November 27, 2022
Published: November 30, 2022

Abstract

In recent years, we need more bandwidth to enjoy entertainment contents such as video streaming, music and online gaming. To gain enough bandwidth, technologies that combine bandwidth by using multiple interfaces at same time are desired. Multipath transport protocols which combine multiple paths for packet delivery at the transport layer are a promising technology. Such protocols have a mechanism, called "packet scheduler", to select the interface to send a packet. However, existing studies of the packet scheduler have not explicitly considered the compatibility of mobility with bonding of bandwidth. Therefore, when smartphone users move out of coverage of communication networks such as wireless Local Area Network (LAN) and Long Term Evolution (LTE) by vehicle, packet loss occurs, leading to a decrease of throughput. In this study, we propose a packet scheduler that selects an appropriate communication path so that packets can reach the peer before it moves out of the coverage. Based on routes of a vehicle and the position and communication range of the access point, the time at which a communication path will be lost is predicted. In addition, we employ MPQUIC (Multipath QUIC (Quick UDP Internet Connections)), which is a multipath transport protocol proposed as the extension of QUIC protocol, to reduce the ACK packet loss in multipath communication, and to reduce the time until the starts of retransmission. We evaluated the number of packet losses, the throughput and the time until starts of retransmission using a simulator and show the superiority of proposed method.

Keywords

Mobility, Multipath Transport Protocol, Multipath QUIC

1. Introduction

The advances of smartphones support the services of video streaming, music, game, allowing user to enjoy the entertainment contents [1]. Smartphone enables these applications by connecting to heterogenous networks involving Long Term Evolution (LTE), 5G, and Wi-Fi [2]. Concurrent utilization of WLAN and LTE will increase the available bandwidth, and it is called bandwidth aggregation. Multipath transport protocol is a technology that supports bandwidth aggregation.

An example application is to shift communication ways to a low-cost Wi-Fi from LTE when a vehicle enters the zone of Wi-Fi services. Multi-path communication is a method to increase the bandwidth of wireless communication. By the combination of multiple ways of communications such as LTE and WLAN, the performance of throughput and delay are expected to be improved.

Multipath transport protocol (MP-TCP) enables the multiple TCP connections in parallel [3], as shown in **Figure 1**. MP-TCP has multiple modes. The handover mode allows multiple communication path to be seamlessly switched while avoiding the temporary disconnection due to the handover. Furthermore, the full mesh mode allows multiple communication methods to be applied concurrently to improve the bandwidth.

MP-TCP has a mechanism called "packet scheduler" to select an interface to send a packet to. On the other hand, multiple-path TCP cannot support ACK packet trans-mission on a different route of the associated data packets. This problem is caused by the fact that the middle box such as firewall may discard ACK as the unsafe packet. This problem is difficult to solve in TCP and will cause the retransmission due to the loss of ACK packet, leading to the degradation of throughput.

Reference [4] proposed a notification method for MP-TCP based on frame retransmission and the number of successful packet delivery, using mesh mode to improve the throughput. However, this study has not considered the packet

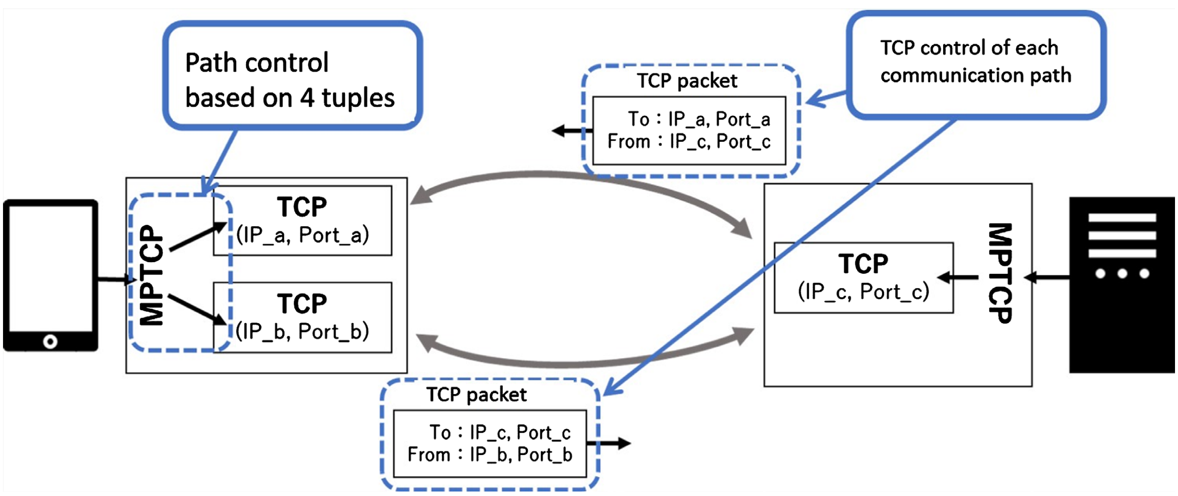

Figure 1. Control of communication route in MP-TCP.

loss due to the time out problem in packet retransmission in case of path disconnection.

Reference [5] examines the congestion window and the utilization of Wi-Fi SNR variation in mobility for MP-TCP. The proposed method alleviates the degradation of throughput and packet loss in path handoff. However, this method considers the seamless handoff instead of bandwidth aggregation.

Reference [2] has basically discussed the issue of packet loss in path disconnection in the utilization of bandwidth aggregation. However, the paper has not included the detail examination of the problem and method.

This study aims to reduce the packet losses and avoid throughput degradation in case the communication paths are broken down during the movement of vehicles that utilize the multipath transport protocol for the bandwidth aggregation in mobile environment. In this paper, we introduce and explicitly examine a method of multipath-QUIC based method to reduce the ACK packet loss in multipath communication. The basic idea is to enable the delivery of ACK packet in a different path with the transmission to overcome the "on-light" problem that causes the losses of ACK packets.

We evaluate the number of packet losses and throughput by comparing the proposed method with the conventional methods. The evaluation results reveal that the proposed method increases the throughput and decreases the packet loses.

2. Proposed Method

2.1. Overview of the Proposed Method

In the bandwidth aggregation of multipath transport protocol, mobility incurs the packet loss when a packet is on the road to the destination and the route is disconnected. We call such packets inflight packets. Furthermore, ACK packet loss incurs the delay of retransmission and degradation of throughput.

In this paper, we proposed a method that predicts the route disconnection and stops data delivery in the disconnected route in order to reduce packet losses caused by inflight packets. Moreover, the ACK packet is sent via a different route, avoiding the delay of retransmission.

The overview of proposed method is shown in **Figure 2**. The smartphone obtains the communication information from the management server based on the travelling information from the vehicle. When communication is enabled, the smartphone computes the route disconnection time and shares information with the server. On the time of predicted time of route disconnection, smartphone stops the packet delivery to the WLAN, and switches the connection to the LTE.

2.2. The Time of Path Disconnection

The proposed method decides the route-disconnection time by utilizing the travelling information, AP position and the communication range. The travelling information is obtained from the vehicle, while the AP information is got from server. As shown in **Figure 3**, smartphone estimates the position of disconnection

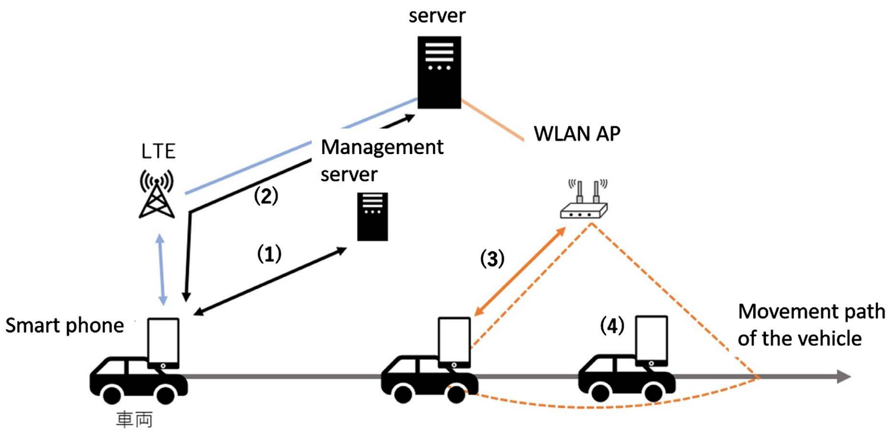

Figure 2. Overview of the proposed method.

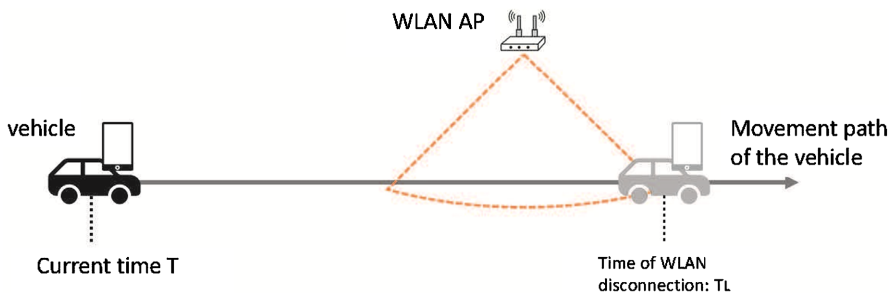

Figure 3. Time of WLAN disconnection.

with WLAN based on the cross point of movement, AP position and AP communication range.

The time of path disconnection is calculated based on Friss model. Given RX power threshold, we obtain the distance between smartphone and AP as shown by Equations (1) and (2). In the equations, L_0 is the reference path loss at reference distance of $d_0 = 1$ [m], Pt is the transmission power (dBm), T is the energy threshold (dBm) of the receiving signal, and n is the propagation loss factor.

$$L = L_0 + 10n\log_{10}\left(\frac{d}{d_0}\right)^2 \tag{1}$$

$$d = d_0 \times 10^{\left(P_t - T - L_0\right)/10n} \tag{2}$$

2.3. Downlink Delay Measurement

To measure the downlink delay from server to the client (smartphone), server generates a time stamp when sending packet to the client, which returns the RTT, called RTT_{down} here, to the server. The server and client smooth the RTT based on Equation [3], same with that stated in [6]. And α is set to 0.125 in this study.

$$SRTT_{new} = \alpha SRTT_{old} + (1-\alpha) SRTT_{down} \tag{3}$$

2.4. Delivery of ACK Using MPQUIC

The proposed method utilizes the MPQUIC, which is a multipath transport protocol based on QUIC [7]. In QUIC, the header part is encrypted, avoiding being affected by the mid-box. For this reason, MPQUIC is different with MP-TCP, and supports the ACK packet delivery in different paths, as shown in **Figure 4** [8].

In the proposed method, on the time to stop packet delivery via WLAN, the smart phone sends ACK packets through another route, so as to avoid the delay of retransmission caused by the loss of ACK packets.

2.5. The Process of the Proposed Method

We introduce the procedure of the proposed method as follows based on **Figure 5**.

1) Vehicle provides the smartphone its travelling path information.

2) Smartphone obtains the information of AP and the communication range of AP from the management server based on it's travelling path.

3) Smartphone computes the WLAN disconnection time TL from the travelling path, AP information, and shares TL information with the server.

4) Smartphone sets path connection with WLAN when entering the scope of WLAN. Then both LTE and WLAN are used for smartphone to communicate with the server.

5) On time Tp, which is derived from TL based on delay time, the scheduler of the smartphone makes the following actions.

a) Server stops the packet delivery on WLAN, and selects LTE for packet delivery;

b) Smartphone also selects LTE to delivery data packet. This allows ACK frame of receiving packets to be sent via LTE.

3. Performance Evaluation

In this section, we introduce the system environment and metrics that are employed in the simulation.

3.1. Simulation Environment

Table 1 shows the simulation environment. The simulation is carried out based

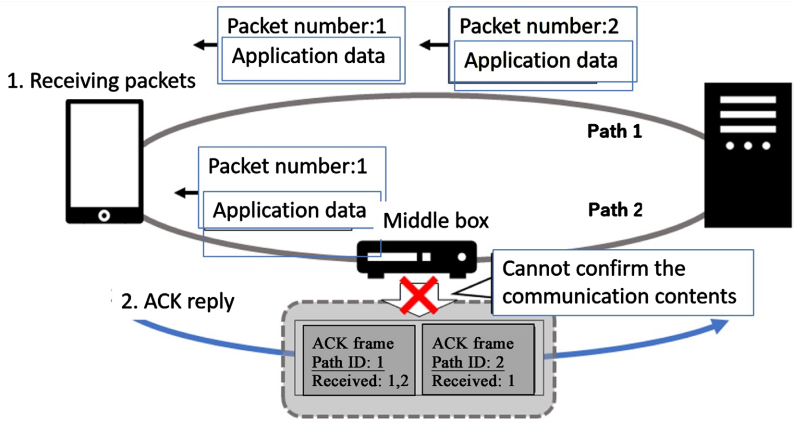

Figure 4. ACK frame delivery via different path.

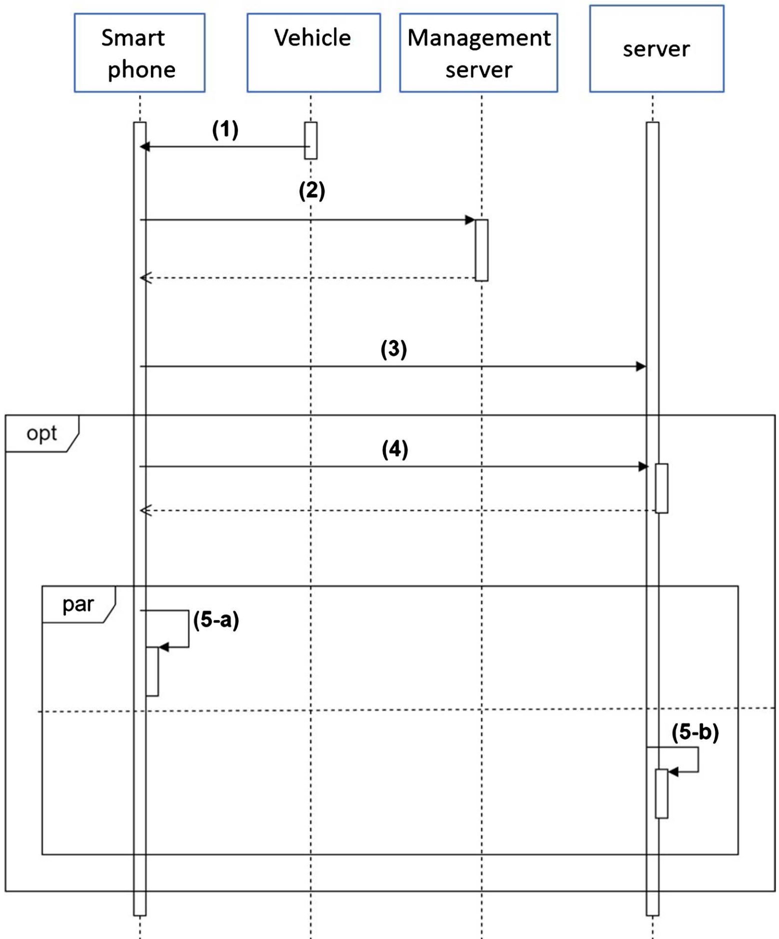

Figure 5. The operation sequence of the proposed method.

Table 1. Simulation setup.

Host OS	Windows 10 Home 64 Bits
CPU	Intel(R) Core™ i7-8550U CPU @ 1.80 GHz
Memory	8 GB
Virtual environment	VirtualBox 6.1.28
Guest OS	Ubuntu 20.04 LTS
Main memory	4096 MB
Number of processors	4
Simulator	Mininet-WiFi 2.6
Go language	go1.17

on a network simulator of Mininet-Wi-Fi. In MPQUIC implementation, the library implemented by GO language is utilized. The simulation scenario is shown in Figure 6. The client connects to the server using Wi-Fi, which has a delay of 25 ms, and 5 Mbps bandwidth.

Since Mininet-WiFi does not support LTE in the simulation, we minimize the

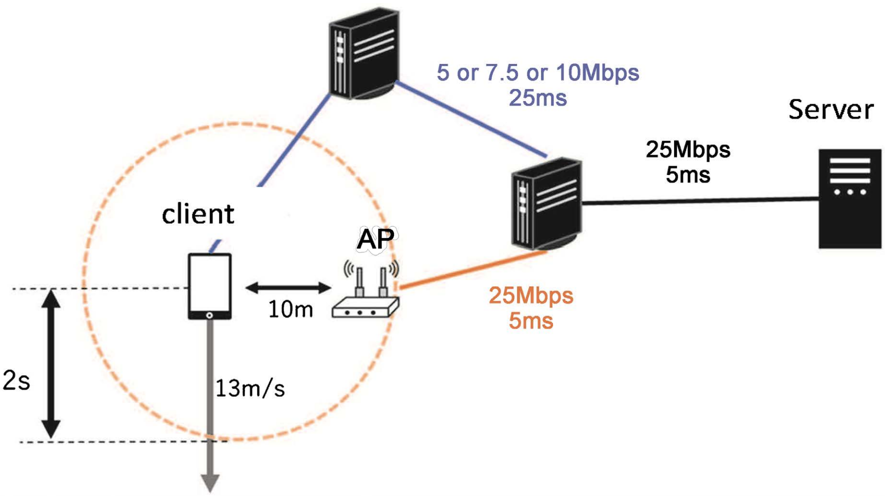

Figure 6. Simulation environment.

LTE communication by setting the wired LAN connection parameter same with [9], and we set the packet loss to be 0. IEEE 802.11ac Wi-Fi protocol is adopted and the threshold of signal receiving power is set to -91 dbm. Furthermore, data rate for packet delivery is set to 5 Mbps. The communication range of the AP is set to 70 m, based on the propagation loss factor n being set to 3.0, with the consideration of wireless propagation in the real environment.

When the simulation is started, client uses both LTE and WLAN for downloading 5 MBytes file from the server. At the same time, client moves with a speed of 1.3 m/s at a position that is 10 m away from the AP. The client moves out of the communication range after 2 s. Client predicts the time of being out of communication range, and shares the time information the server. The simulation runs are carried out 10 times. And the average result is employed.

In addition, logfile is outputted involving packet transmission and receiving process since it is difficult to analyze the packet MPQUIC internal states from the packet capture.

3.2. The Evaluation Metrics

Based on the above scenario, the proposed method is compared with the method that employs scheduler in terms of low RTT. Low RTT is the min RTT in the shortest path for which the scheduler has the highest priority in packet transmission. Furthermore, for comparison, the ACK frame will not be delivered in a different path with that the data is sent from.

The evaluation metrics include packets loss, the throughput in Wi-Fi network, and the arriving time. The throughput is the total number of bytes of QUIC packets divided by the communication duration. The Wi-Fi communication duration for the proposed method is the period from the time that the communication starts to the time that Wi-Fi is stopped to transmit packets.

The communication time for low RTT is the period from the start of the communication to the time that the path is broken down. The arriving time refers to the time that the transmission packet arrives at the client (smartphone, including the process of retransmission.

3.3. Evaluation Results

The results of packet losses of LTE are shown in Table 2, and Figure 7 shows the average throughput per path. Figure 8 shows the cumulative distribution of packet arriving time.

1) Packet loss

The results in Table 2 show that the proposed method effectively reduces the packet loss by 90 percent in any bandwidth compared with ECF and low RTT. In every case of LTE bandwidth, the proposed method enables a much smaller number of packet losses. We consider the reason is that the proposed method reduces the number of inflight packets. On the other hand, the proposed method still has packet losses. We consider that the fluctuation of signal strength causes the difference with path loss position calculated.

2) Throughput

As shown in Figure 7, compared with low RTT, ECF, the proposed method for Wi-Fi allows 77% increase of the throughput in either case of bandwidth setup. As for the combination of LTE and Wi-Fi, the throughput has the largest

Table 2. Packet loss in terms of LTE bandwidth.

	Proposal	ECF	LowRTT
5 Mbps	3.1 (±2.13)	41.0 (±1.40)	39.5 (±2.27)
7.5 Mbps	0.2 (±0.63)	38.4 (±0.96)	39.3 (±2.87)
10 Mbps	0.8 (±1.68)	39.6 (±0.97)	39.0 (±2.0)

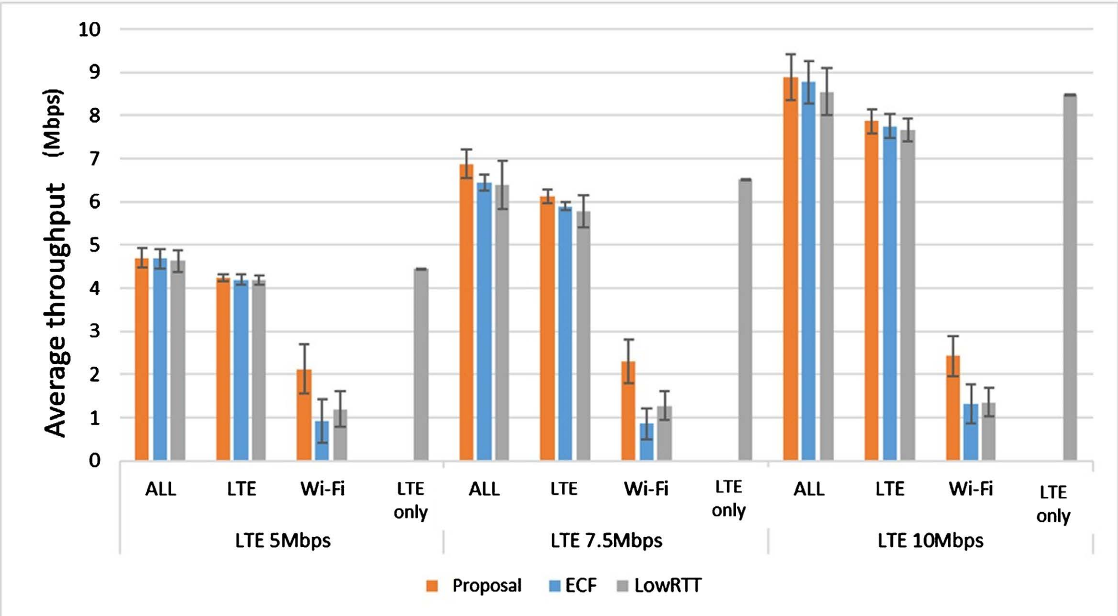

Figure 7. The average throughput in terms of communication paths.

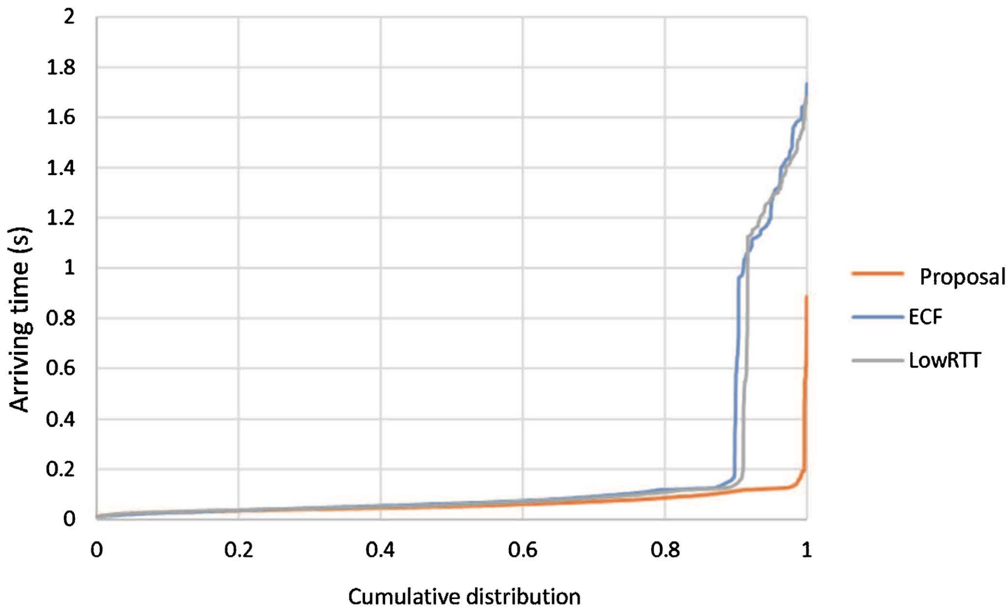

Figure 8. The cumulative distribution of the arriving time of Wi-Fi packets.

improvement when the bandwidth is set to 7.5 mbps.

3) Packet arriving time

Figure 8 shows that the proposed method has an earlier packet arriving time compared with ECF and low RTT. This difference is caused by the fact that the packet retransmission time is managed based on the communication paths. By prediction of disconnection of Wi-Fi path and employing the ACK delivery in an alternative path, the packet arriving time is improved by reducing the time taken in packet retransmission.

4. Conclusion

The loss of inflight packets causes the loss of data packets. The throughput decreases due to the delay of packet retransmission when the ACK packets cannot be successfully delivered. This research proposed a packet scheduler method that predicts the time of path loss and packet arrival features. The proposed method predicts the path loss of WLAN based on the mobility information and AP position, estimates the packet arrival time based on the downlink delay of WLAN, and selects the communication path. By using this method, the inflight packet losses caused by path loss are decreased, avoiding the decrease of the throughput and reducing packet losses.

Acknowledgements

This work is partially supported by JSPS KAKENHI grant number JP20H00589.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tran, T.X., Hajisami, A., Pandey, P. and Pompili, D. (2017) Collaborative Mobile Edge Computing in 5G Networks: New Paradigms, Scenarios, and Challenges. *IEEE Communications Magazine*, **55**, 54-61. https://doi.org/10.1109/MCOM.2017.1600863

[2] Okunishi, R., Teng, R. and Sato, K. (2021) Packet Loss Reduction Due to Loss of Path during Movement Using Multipath QUIC. IPSJ SIG Technical Report, 2021.

[3] Ford, A., Raiciu, C., Handley, M.J., Bonaventure, O. and Paasch, C. (2020) TCP Extensions for Multipath Operation with Multiple Addresses. RFC 8684, March 2020. https://doi.org/10.17487/RFC8684

[4] Lim, Y.S., Chen, Y.C., Nahum, E.M., Towsley, D. and Lee, K.W. (2014) Cross-Layer Path Management in Multi-Path Transport Protocol for Mobile Devices. *IEEE INFOCOM* 2014—*IEEE Conference on Computer Communications*, Toronto, 27 April - 02 May 2014, 1815-1823. https://doi.org/10.1109/INFOCOM.2014.6848120

[5] Sinky, H., Hamdaoui, B. and Guizani, M. (2015) Handoff-Aware Cross-Layer Assisted Multi-Path Tcp for Proactive Congestion Control in Mobile Heterogeneous Wireless Networks. 2015 *IEEE Global Communications Conference* (*GLOBECOM*), San Diego, 6-10 December 2015, 1-7. https://doi.org/10.1109/GLOCOM.2015.7417490

[6] Transmission Control Protocol (1981) RFC 793. https://datatracker.ietf.org/doc/html/rfc793

[7] Iyengar, J. and Thomson, M. (2021) QUIC: A UDP-Based Multiplexed and Secure Transport. RFC 9000, May 2021. https://doi.org/10.17487/RFC9000

[8] Coninck, Q.D. and Bonaventure, O. (2017) Multipath Quic: Design and Evaluation. *Proceedings of the* 13*th International Conference on Emerging Networking Experiments and Technologies*, New York, 2017, 160-166.

[9] Du, P., Zhao, Q. and Gerla, M. (2019) A Software Defined Multi-Path Traffic Offloading System for Heterogeneous LTE-WiFi Networks. 2019 *IEEE* 20*th International Symposium on* "*A World of Wireless*, *Mobile and Multimedia Networks*" (*WoWMoM*), Washington, 10-12 June 2019, 1-9. https://doi.org/10.1109/WoWMoM.2019.8793045