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Proposal of Client-Server Based Vertical Handover Scheme Using Virtual Routers for Edge Computing in Local 5G Networks and WLANs

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***Abstract*— This paper proposes a client-server based vertical handover scheme for edge computing services that selects shorter RTT (Round Trip Time) routes between local 5G networks and WLANs (Wireless Local Area Networks). WLAN access points are used to cover 5G poor reception areas caused by high diffraction losses at 4.7 GHz. The key technology of the proposed scheme is dynamic routing performed by server-side and client-side virtual routers. Client IP (Internet Protocol) address is fixed to one so that the client can use TCP (Transmission Control Protocol) during vertical handover. IP addresses assigned by the local 5G networks and WLANs are used as relay node addresses. QUIC and MP (Multi-Path) TCP, standardized by IETF (Internet Engineering Task Force), are known to have client-server based vertical handover capabilities; however, these protocols have the following problems. (1) Since application programs intended for TCP cannot be used for QUIC as they are, a huge number of client-side programs must be modified to replace TCP with QUIC. (2) MPTCP is OS (Operating System) dependent and is currently not implemented in Windows. On the other hand, the proposed scheme can use widely spread TCP and TCP application programs as they are. Moreover, the proposed scheme is OS-independent since the virtual routers are implemented as application programs. We constructed a test network using 5G-SA (Stand Alone) and WLAN on a virtual machine and evaluated the performance of the proposed scheme. The evaluation results show that the handover outage time the proposed scheme is less than 20 ms.**

Keywords*— *edge computing, local 5G, WLAN, vertical handover, dynamic routing, virtual router

I. INTRODUCTION

In recent years, the need for edge computing services has increased. A short RTT (Round Trip Time) wireless network is required to provide the services such as high-performance computing capabilities in laptops and vehicle control in smart factories. Short RTT local 5G networks operated by companies and local governments are useful to provide the edge computing services. Therefore, Japan has assigned the 4.7 GHz band to the local 5G networks [1].

The local 5G networks in Japan use 5G-SA (Stand Alone) instead of 5G-NSA (Non-Stand Alone) because LTE (Long Term Evolution), which is part of 5G-NSA, is not available to non-MNOs (Mobile Network Operators). LTE uses various frequency bands. In particular, the 700MHz, 800MHz, and 900MHz bands can significantly reduce LTE poor reception areas due to low shadowing effects since a diffraction loss decreases as a radio frequency decreases [2]. On the other hand, the local 5G networks operating on higher radio frequencies such as 4.7 GHz instead of sub-GHz inevitably have more areas with poor reception due to increased shadowing effects. As a result, user satisfaction with the local 5G networks would decline as areas with poor reception increase.

Distributed deployment of RRUs (Remote Radio Units) [3] is one solution to the poor reception problem. However, 5G network equipment including RRU is expensive and not cost-effective. Another solution is a heterogeneous wireless network with vertical handover capability between the local 5G networks and cost-effective WLANs (Wireless Local Area Networks). IEEE (Institute of Electrical and Electronics Engineers) has been standardizing WLAN specifications [4]. The current standard is 802.11 ax [5] for high throughput and the next version is 802.11 be [6] for short RTT. WLAN products with short RTT will be available after the standardization process is completed.

Local 5G operators have edge servers to provide their own edge computing services to users. In this situation, vertical handover capabilities can be implemented on the server and client sides. The advantages of the client-server based vertical handover schemes are as follows. (1) The handover schemes are applicable to any air interface. (2) No additional handover capabilities are required in wireless networks. MPTCP (Multi-Path Transmission Control Protocol) [7][8] and QUIC [9][10] are known to have client-server based vertical handover capabilities. MPTCP enables simultaneous use of multiple IP (Internet Protocol) addresses and is backward compatible with TCP; however, MPTCP is OS (Operating System) dependent and is not implemented in Windows, which is a high market share OS. QUIC can also use multiple IP addresses simultaneously; however, the protocol cannot use application programs intended for TCP since it is not compatible with TCP. A huge number of client-side programs must be modified to replace TCP with QUIC. A vertical handover scheme has been proposed based on application programs that select sockets on the server and client sides [11]. However, this scheme has a problem that it is difficult to implement. This paper proposes a client-server based vertical handover scheme that is easy to implement, OS-independent and applicable to widely used TCP and TCP application programs.

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II. Proposed Vertical Handover Scheme

A. Overview of Proposed Handover Scheme

As the need for wireless data communication grows, the number of clients with two wireless network interfaces such as 5G and WLAN is increasing. These networks have different packet transmission routes from a client to the server and assign different IP addresses to the client. Since TCP cannot simultaneously use multiple IP addresses, TCP connections cannot be maintained during air interface reselection, as shown in Fig. 1(a). On the other hand, in a fiber network, it is known that a packet transmission route can be reselected while maintaining TCP connections by using a routing protocol that performs dynamic routing. In this case, relay node A on packet transmission route X and relay node B on route Y can have different IP addresses, as shown in Fig. 1(b). Comparing (a) and (b) in Fig. 1, (a) has the same network configuration as (b) when virtual routers are added to the server and client.

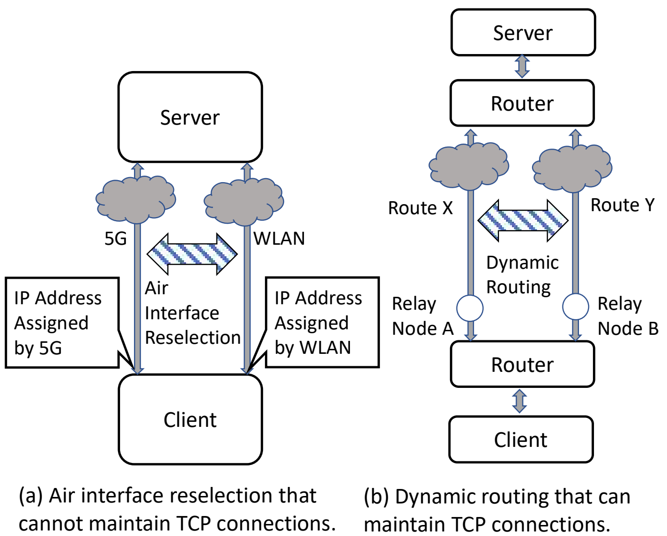

Fig. 1. Conventional network configurations.

Considering the above, we propose a vertical handover scheme based on dynamic routing as shown in Fig. 2. In the proposed scheme, a server-side virtual router and a client-side virtual router control downlink and uplink packet transmission routes, respectively. Each router has three ports. The two ports on the wireless communication side are connected to the 5G and WLAN air interfaces. The other port on the wired side is virtually connected to the server or client network interface. GRE (Generic Routing Encapsulation) tunnels [12] are used to virtually connect two routers over 5G and WLAN links, as described in the next subsection. The two IP addresses assigned to the client by 5G and WLAN are different. However, these are relay node addresses, not terminal node addresses. Note that TCP allows relay nodes to use different IP addresses, as shown in Fig. 1(b). Fig. 3(a) shows source and destination IP addresses of uplink packets. 5G and WLAN use different uplink routes. However, the client can keep the same source IP address and the server can keep the same destination IP address during vertical handover. Fig. 3(b) shows source and destination IP addresses of downlink packets. 5G and WLAN use different downlink routes. However, the server can keep the same source IP address and the client can keep the same destination IP address during vertical handover. Therefore, the proposed scheme can keep the same IP addresses and maintain the TCP connections during vertical handover.

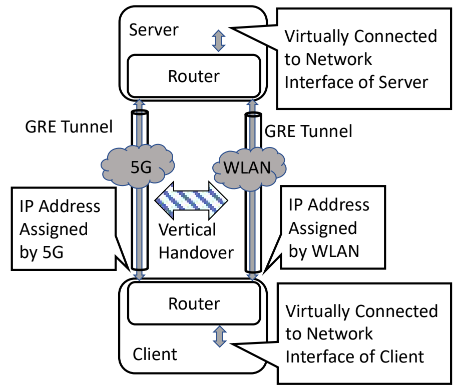

Fig. 2. Network configuration of proposed scheme.

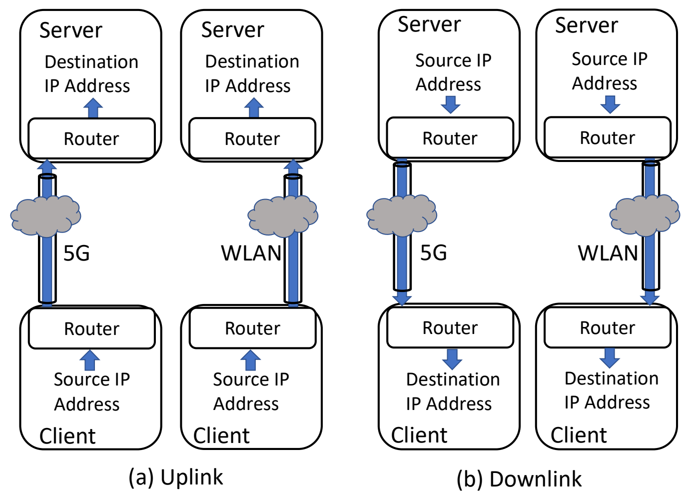

Fig. 3. Source and destination IP addresses of uplink and downlink packets.

B. Routing and Tunneling Protocols

Since the proposed vertical handover scheme is based on dynamic routing, faster routing convergence is required to perform vertical handover with shorter delay. A simpler network configuration is preferable for faster convergence in the proposed scheme. The simplest network configuration to select a shorter RTT route between two routes is two direct point-to-point connections. Therefore, a tunneling protocol is required to virtually establish two direct connections over 5G and WLAN links between the server-side router and the client-side router. Additionally, the 5G-side tunnel is required to transmit multicast packets for the routing protocol of the proposed scheme on the 5G user plane. The WLAN-side tunnel is required to isolate the routing protocol of the proposed scheme and the routing protocol in contents server networks, which often already exist. Among the tunneling protocols supported by the virtual routers [13], the proposed scheme adopts GRE tunneling due to its low overhead and ability to transmit multicast packets. The proposed scheme also adopts OSPF (Open Shortest Path First) [14] among the routing protocols supported by the virtual routers for fast convergence. The proposed scheme adopts OSPF cost settings based on RTT measurements instead of interface link rates to select a shorter RTT route.

C. OSPF Cost Setting Using RTT Measurement Results

The proposed scheme is easy to implement since the vertical handover is performed by the standardized protocols [12][14] and the developed virtual routers [13]. We developed only cost setting application. The roles of the application are to measure RTTs for the 5G and WLAN links and to set the cost for each wireless link based on the measured results. The costs determine the packet transmission route. The cost setting application is implemented on the client and operates as follows. (1) First, the cost setting application connects to OSPF daemons on the client-side and server-side virtual routers. (2) The echo request ICMP (Internet Control Message Protocol) packets are sent every 5 ms from the client to the 5G and WLAN interface addresses of the server. (3) The average RTTs of 5G and WLAN are calculated from the reception times of the echo reply ICMP packets returned within 15 ms and the transmission times of the corresponding echo request ICMP packets. (4) The average RTTs measured over the 5G and WLAN links are compared and the network interface with the shorter RTT is selected for sending and receiving data packets. (5) A cost of 1 for the selected interface and a cost of 2 for the other interface are set to the OSPF daemons. (6) (2) through (5) are repeated. To accurately detect a shorter RTT route, the echo request packets are always sent except in link-down cases. Sending packets every 5 ms can increase the power consumption of a client. Reducing power consumption is further study.

D. Network Configuration to Accommodate Multiple Clients

In the proposed scheme, the uplink packet transmission route is updated by updating the next hop address to the server network from 5G to WLAN or vice versa in the client-side routing table. On the other hand, the downlink packet transmission route is updated by updating the next hop address to each client network in the server-side routing table. Fig. 4 shows the network configuration to accommodate multiple clients. Two GRE tunnels with virtual network interfaces for 5G and WLAN are provided to each client. The server-side router sends packets to the appropriate network (5G or WLAN) depending on the next-hop address to each client. A minimum size network is assigned to each client, and the number of clients is one in the network. As a result, the numbers of 5G and WLAN networks are the same as the maximum number of simultaneously connected clients.

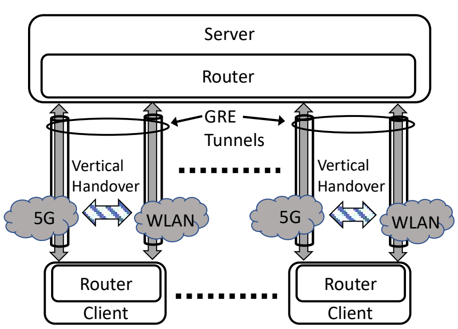

Fig. 4. Network configuration to accommodate multiple clients.

E. Handover Procedure

We discuss the vertical handover procedure of the proposed scheme under the condition that a client moving within the 5G service area moves to the 5G unreceivable area within the WLAN service area as shown in Fig. 5. The white, light gray, dark gray, and black ovals show the 5G service area, the WLAN service area, the 5G poor reception area, the 5G unreceivable area, respectively. The white diamond shows the moving client. The discussion assumes the following five points. (1) There is an obstacle in the 5G service area blocking the line-of-sight path between the 5G base-station antenna and the client. (2) There are no reflective objects around the client. (3) Due to the shadowing effect of the obstacle, there are areas with no or poor 5G reception. (4) The local 5G network has shorter RTT than WLAN in the 5G service area, excluding the 5G poor reception area. (5) The WLAN access point covers the areas with no or poor 5G reception.

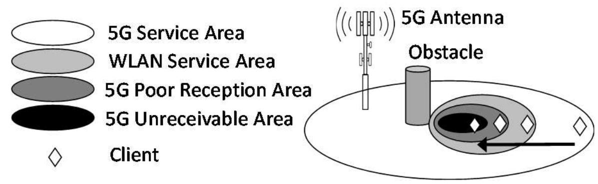

Fig. 5. Moving client and reception conditions.

Fig. 6 (a) shows the packet transmission routes when the client is in the 5G service area. The dotted and dashed lines show transmission routes of echo request and echo reply ICMP packets, respectively. The solid line shows a transmission route of packets carrying data. The client establishes the 5G link to the server after authentication using SIM (Subscriber Identity Module) card information. The WLAN link is down since the client is out of the WLAN service area. After OSPF detects 5G link up and WLAN link down, the client-side virtual router sets the next hop address to the server network to the 5G address B. The server-side virtual router also sets the next hop address to the client network to the 5G address A. Uplink and downlink data packets are sent over the 5G link by setting the next hop addresses as described above. The echo request and echo reply ICMP packets are sent over the 5G link. The echo request packets keep trying transmission over the WLAN link to detect from link down to link up status transitions for RTT measurement.

Fig. 6 (b) shows the packet transmission routes when the client is at the edge of the WLAN service area. The client establishes the WLAN link after authentication such as EAP-AKA (improved Extensible Authentication Protocol method for 3GPP Mobile network Authentication and Key Agreement) [17] using SIM card information to confirm the same client uses the 5G and WLAN links. The client sends echo requests and receives echo replies over the 5G and WLAN links to measure RTTs. The link costs of 5G and WLAN are determined by the measured 5G and WLAN RTTs, respectively. However, the client still uses the 5G link with a shorter RTT than the WLAN link for sending and receiving data packets since the next hop addresses are the same as in Fig. 6 (a).

Fig. 6 (c) shows the packet transmission routes when the client is at the edge of the 5G poor reception area. The measured

5G and WLAN RTTs update the link costs of 5G and WLAN, respectively. The shadowing effect of the obstacle reduces the RSRP (Reference Signal Received Power) level and the SINR (Signal to Interference and Noise Ratio) value of the 5G signal, which reduce the modulation level and increase the number of the L2 (Layer 2) retransmissions. As a result, the measured 5G RTT and 5G link cost increase. Due to a higher cost of 5G than WLAN, the routing tables are updated in server-side and client-side virtual routers. The client-side virtual router sets the next hop to the server network to the WLAN address D. The server-side virtual router sets the next hop to the client network to the WLAN address C. The uplink and downlink data packets are sent over the WLAN link by setting the next hop addresses as described above.

Fig. 6 (d) shows the packet transmission routes when the client is in the 5G unreceivable area. The client can use the only WLAN link since the 5G link is down. All packets are sent over the WLAN link. The echo request packets keep trying transmission over the 5G link to detect from link down to link up status transitions for RTT measurement.

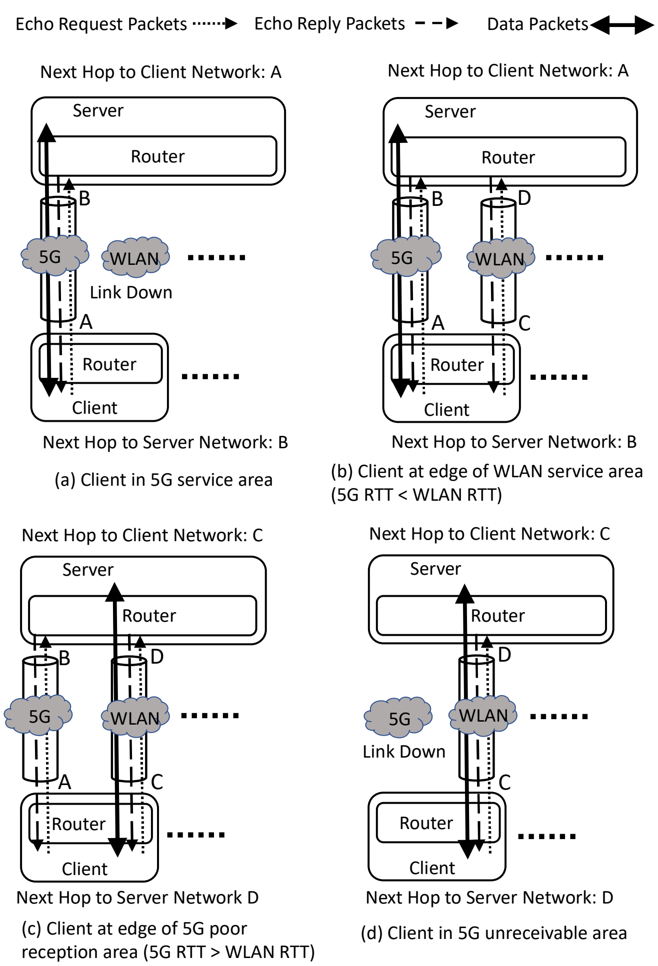

Fig. 6. Packet transmission routes.

III. Performance Evaluation

This section describes the performance evaluation of the proposed vertical handover scheme using experimentally constructed 5G network and WLAN. Assuming edge computing services such as deep learning-based object detection with uplink real-time video streaming, the performance of the proposed scheme was evaluated under the condition of uplink packet transmission. The client generates data packets and sends them to the server. The server captures the packets it receives and extracts the sequence numbers of the captured packets. To measure RTT between the server and client over the selected wireless link, the server sends the echo request packets to the client, and the client returns the echo reply packets to the server.

A. Experimental Network for Performance Evaluation

Fig. 7 shows the experimental network configuration to clarify the performance of the proposed scheme. We constructed the experimental network using network namespaces [16] on VM (Virtual Machine) of VirtualBox. The network type of 5G is SA. The numbers of servers and clients are one and one, respectively. The client has two interfaces: 5G and WLAN. The numbers of gNodeBs and 5G Cores are one and one, respectively. The number of APs is one. Table I shows functional blocks of the experimental network. VM uses Linux with Ubuntu 20.04 LTS (Long Term Support). Free5GC [17] is used for 5G Core. 5G UE (User Equipment) and gNodeB use UERANSIM [18]. WLAN UE and AP use mac80211 hwsim [19]. Quagga [13] is used as a router with OSPF.

B. Evaluation Conditions

Table II summarizes the evaluation conditions. Uplink data packets at 50 Mbit/s are generated and sent to the server. Channel conditions such as RSRP and SINR are not considered. Additional WLAN RTT is fixed to 3 ms. Additional 5G RTT variations are 1 ms to 5 ms for 5G to WLAN handover and 5 ms to 1ms for WLAN to 5G handover. Table III shows the measurement tools used for the performance evaluation. iPerf3 [20] is used to generate data packets. Wireshark [21] is used for packet capture. TC (Traffic Control) [22] is used for RTT settings.

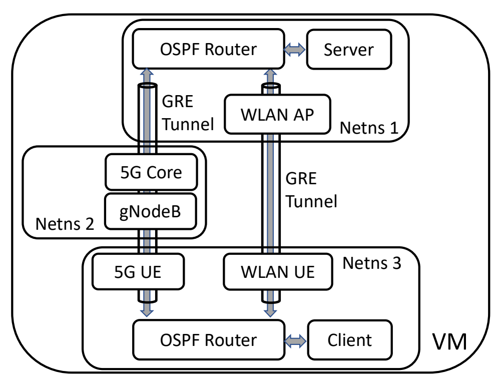

Fig. 7. Experimental network configuration.

TABLE I. Functional Blocks of Experimental Network

Functional blocks	Packages
VM	Ubuntu 20.04 LTS
5G Core	free5GC
5G UE and gNodeB	UERANSIM
WLAN UE and AP	mac80211_hwsim
Routers	Quagga

TABLE II. EVALUATION CONDITIONS

Parameters	Descriptions
Data Traffic	Uplink only, 50 Mbit/s
Channel Conditions	Not Considered
Additional WLAN RTT	3 ms
Additional 5G RTT Variations	1 ms to 5 ms and 5 ms to 1 ms

TABLE III. MEASUREMENT TOOLS

Tools	Purposes
iPerf3	Data Packets Generation
Wireshark	Packet Capture
TC	RTT Settings

C. Evaluation Results

Fig. 8 shows the sequence numbers and RTTs in the vertical handover from 5G to WLAN. The additional WLAN RTT is 3 ms, and the additional 5G RTT is increased from 1 ms to 5 ms. The horizontal axis shows elapsed time in seconds. The left and right vertical axes show sequence number in bytes and RTT in ms, respectively. The blue and red circles indicate sequence numbers and RTTs, respectively. This figure shows that the sequence numbers linearly increase with increasing the elapsed time. The measured RTT plots can be categorized into three regions: (1) When the elapsed time is less than 2 seconds, the measured RTT is about 1.5 ms with the 5G RTT of 0.5 ms and the additional RTT of 1 ms. (2) When the elapsed time is more than 2 seconds, the measured RTT is about 3.2 ms with the WLAN RTT of 0.2 ms and the additional RTT of 3 ms. (3) When the elapsed time is around 2 seconds, the measured RTT is about 5.5 ms with the 5G RTT of 0.5 ms and the additional RTT of 5 ms. It is considered that the 5.5ms RTT region is caused by the handover delay as the packet transmission route remains to be over 5G even though WLAN RTT is shorter compared to 5G. In this figure, the sequence numbers do not start from 0. This is because the packets within 2 seconds before and after the handover timing were extracted from all captured packets. Fig. 9 shows the enlarged view of Fig. 8 from 1.95 seconds to 2.15 seconds. This figure shows that the vertical handover is performed at 2.06 seconds with the handover delay of 80 ms since the vertical handover is triggered at 1.98 seconds. No outage time is observed under the condition that the burst packet transmission interval is about 20 ms. The result suggests that the handover outage time of the proposed scheme is less than 20 ms.

Fig. 10 shows the sequence numbers and RTTs in the vertical handover from WLAN to 5G. The additional WLAN RTT is 3 ms, and the additional 5G RTT is reduced from 5 ms to 1 ms. This figure shows that the sequence numbers increase linearly as the elapsed time increases. No handover outage time is observed. The measured RTT plots can be categorized into only two regions. Long RTT region around 2 seconds is not observed. The reasons are as follows. (1) The WLAN RTT of the handover source is a constant value of 3.2 ms. (2) The 5G RTT of the handover destination is reduced from 5.5 ms to 1.5 ms. (3) The WLAN link is still used after the vertical handover is triggered. (4) The 5G link is used after the handover delay time has passed. Fig. 11 shows the enlarged view of Fig. 10 from 1.9 seconds to 2.1 seconds. The vertical handover is performed at the elapsed time of 2 seconds. It is considered that the vertical handover is triggered at the elapsed time of 1.92 seconds including 80 ms handover delay. This figure shows that the vertical handover of the proposed scheme causes the out-of-order packets observed at the elapsed time of 2.007 seconds.

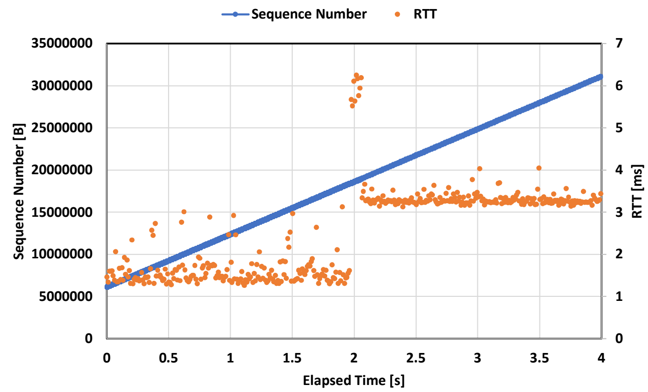

Fig. 8. Sequence numbers and RTTs in vertical handover from 5G to WLAN.

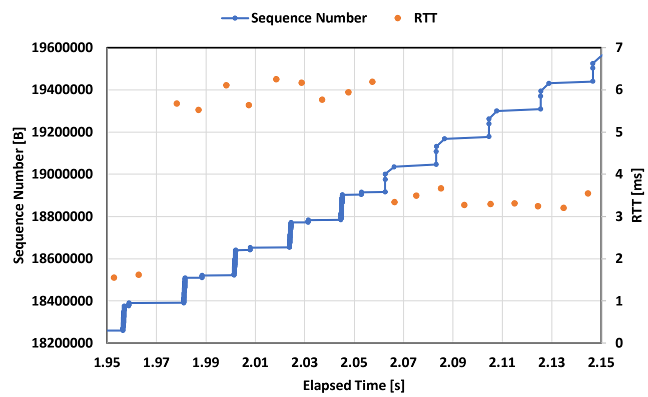

Fig. 9. Enlarged view of Fig. 8.

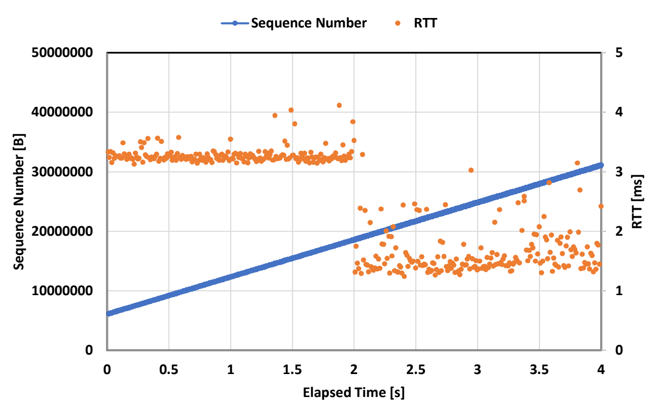

Fig. 10. Sequence numbers and RTTs in vertical handover from WLAN to 5G.

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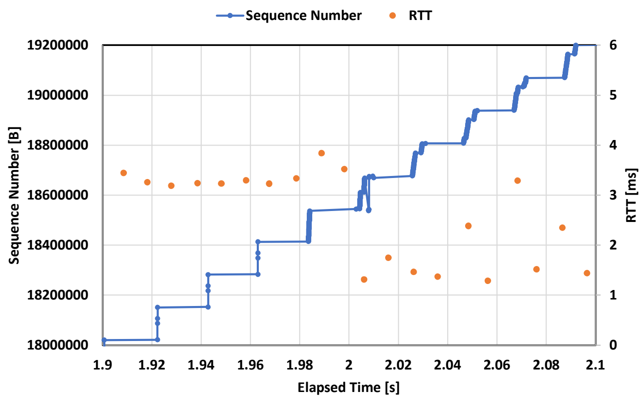

Fig. 11. Enlarged view of Fig. 10.

IV. Conclusion

In this paper, we proposed a client-server based vertical handover scheme for edge computing services using local 5G networks and WLANs. Areas with no or poor 5G reception due to high diffraction losses at 4.7 GHz are covered by WLAN access points. The advantages of the client-server based schemes are as follows. (1) No additional handover capabilities are required in wireless networks. (2) Any air interface can be applied to the schemes. Moreover, the proposed handover scheme is OS-independent and can be used with widely spread TCP and TCP application programs without modification, which are different from the conventional schemes. We have constructed an experimental network to clarify the proposed scheme performance. The results show that no outage time due to vertical handover is observed. The handover outage time of the proposed scheme is less than 20 ms since the measured burst packet transmission interval is 20 ms. The proposed scheme would be useful for cost-effective provision of the edge computing services using the local 5G networks and WLANs.

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