Enhancing MPTCP Performance on High-Speed Trains with Predictive Handover-Aware Packet Scheduling

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***Abstract*— In the environment of a high-speed train operating at a speed of 300 km/h, TCP experiences challenges arising from the train's high mobility, such as rapidly changing channel conditions and frequent inter-cell handovers. These challenges result in significant decreases in throughput and temporary connection interruptions. The Multi-Path TCP (MPTCP) using multiple cellular carriers for high-speed train scenarios is being considered as a solution to address these issues caused by frequent inter-cell handovers. However, the default scheduler(minRTT) of MPTCP inadequately handles frequent handovers occurring in the high-speed train environment, leading to a degradation in throughput. In this paper, we propose a location-based predictive handover-aware packet scheduler designed for the high-speed train environment, considering its unique characteristics: fixed path, stationary base station locations, and constant velocity. The proposed scheduler, upon handover occurrence, demonstrated an average instantaneous throughput enhancement of 20.8% and an overall throughput improvement of 1.95%.**

Keywords*— *MPTCP, High-speed train, Handover, Transport protocols, Packet scheduler

I. Introduction

Since its initial launch in 2004, South Korea's high-speed train (KTX) has consistently seen a rise in passenger numbers. With the increasing volume of passengers, there arises a demand for enhancing the quality of wireless internet service provided within the train compartments. Furthermore, the growing usage of real-time content like online gaming and video streaming necessitates low-latency and high-speed communication.

Multi-path TCP (MPTCP) [3] can be a solution to these requirements. MPTCP is an extension of TCP that allows multiple paths to be used within an end-to-end connection. When a user device has more than two interfaces and multiple IP addresses, MPTCP enables the utilization of multiple TCP paths as subflows to transmit data through various routes. When employing MPTCP, theoretically, the available bandwidth can be increased by the sum of the bandwidths of multiple subflows. Presently, the KTX is equipped with two LTE operator networks (KT and SKT), which utilize the LTE signals received from external sources to provide internet services via Wi-Fi within the train compartments. Hence, by utilizing the two LTE operator networks simultaneously employed in the KTX, it becomes possible to enhance the quality of internet service on the train.

However, LTE performance significantly degrades in high-speed mobile environments due to issues such as multipath fading, signal attenuation based on distance, shadowing, and handovers [1]. Especially, in the high-speed train environment where trains travel at a speed of 300 km/h, handovers can occur more than 6 times per minute, significantly degrading the performance of MPTCP [2]. MPTCP employs packet schedulers to distribute packets among multiple subflows, but the currently employed schedulers were designed without considering handovers. Consequently, even when handovers occur, these schedulers fail to predict them and continue transmitting packets along the path where the handover took place. In this scenario, packets from the path where the handover occurred do not reach the recipient at the expected time, leading to the emergence of the Out-of-Order (OFO) problem [4], causing packet reordering among subflows. Therefore, when handovers take place, MPTCP can exhibit lower performance compared to a single TCP that does not experience handovers.

In this paper, we propose a location-based handover prediction scheduler that leverages pre-collected train location and handover information to address the performance degradation issue of MPTCP caused by frequent handovers in high-speed train environments. We evaluate the proposed handover prediction scheduler using NS-3, a network simulation tool.

II. Proposed Scheduler

A. Motivation

High-speed trains possess a unique environment where they have constant speed, fixed operation times, predefined routes, and established positions of base stations. This allows for the prediction of User Equipment (UE) movement paths and travel times, as well as the anticipation of when and where handovers might occur. Consequently, by collecting train and base station location information beforehand and continuously measuring train positions during operation, it becomes possible to predict handovers. By incorporating this prediction into packet scheduling, it becomes feasible to enhance overall throughput.

Furthermore, according to the measurements presented in [2], the two LTE operator networks installed on the high-speed train do not experience handovers simultaneously. Consequently, even if the path where a handover occurs is obstructed, data can continue to be transmitted through other paths, ensuring the continuity of the connection.

B. Proposed Scheduler

Figure 1 illustrates the framework of the proposed scheduler. In a high-speed train environment, it is possible to predict handovers more easily due to the ability to pre-collect

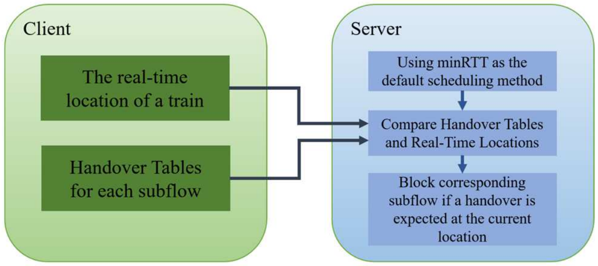

Fig. 1. Proposed Scheduler framework.

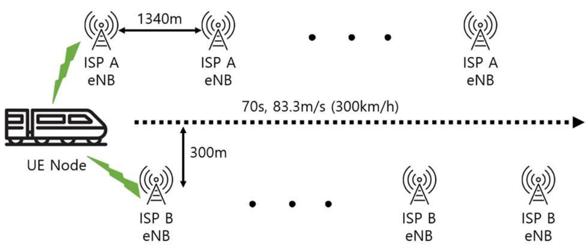

Fig. 2. The high-speed train LTE handover environment used in the experiment.

TABLE I. EXPERIMENTAL SETUP

UE speed	83.3 m/s
Distance between eNodeBs	1340m
Distance between track and eNodeB	300m
Experimental time	70 s
Number of Resource Blocks per eNodeB	25
Congestion control algorithm	LIA
Packet Scheduler	minRTT

train movement paths and locations where handovers occur. Therefore, trains utilizing the proposed scheduler collect real-time train location information through GPS installed on the train during operation. Simultaneously, they gather handover information for each subflow and create a table storing handover processing status based on the location. Once sufficient data is collected, the handover table along with the train's real-time location information collected during operation are transmitted to a server. The server dynamically compares the observed train location with the handover table. If the server predicts that a handover is in progress at the current location, it temporarily blocks the corresponding subflow until the handover processing is complete. If no handover processing is predicted, the server employs the default MPTCP scheduler, such as minRTT [5], for scheduling.

III. EVALUATION

A. Experiment Setup

To evaluate the proposed scheduler, we simulated the high-speed train environment using the Network Simulator 3.19 (NS-3) extended with MPTCP [6]. The high-speed train environment used in experiment is illustrated in Figure 2, and the configured experimental setup are presented in Table 1. To configure the environment of high-speed train, UE node, which plays the role of mobile routers on the high-speed train, was equipped with two LTE interfaces. These interfaces were connected to different ISPs, establishing the MPTCP. Each eNodeB was positioned at intervals of 1340m, considering the real-world base station locations in rural environments as available in [7]. The distance between the railway track and the base station was also set to a value similar to the actual separation between base stations and tracks, which is around 300 meters. The number of Resource Blocks for ISPs A and B was set to 25 each, providing each LTE interface with a bandwidth of 25 Mbps. Throughput was chosen as the performance metric, and to measure throughput over time, bulk data transmission was conducted for a total of 70 seconds. The utilized congestion control algorithm was LIA [8], and the minRTT scheduler was used for comparison purposes. To collect real-time positions of the UE node, modifications were made to the structure of MPTCP. Since NS-3 does not provide direct GPS functionality, cartesian coordinates were used to determine the positions of the UE node. In order to construct the handover table, a total of 50 preliminary simulations were conducted.

B. Experiment Results

Figure 3 illustrates the throughput of individual TCP connections using ISP A and ISP B within the configured experimental environment. The average throughput for each individual TCP connection over a 70-second interval is shown to be around 2.40 Mbps and 2.17 Mbps, respectively, which falls significantly short of the actual link bandwidth. This reduction in throughput is attributed to the high-speed mobility effect. Furthermore, from the graph, it can be observed that handovers occur for ISP A at 8, 27, and 51 seconds, while for ISP B, handovers occur at 15, 39, and 63 seconds. During handover events, the throughput of individual TCP connections drops by approximately 20% from the average throughput, as indicated in the graph.

Figure 4 depicts the graph representing the throughput of each subflow when conducting experiments with MPTCP utilizing the minRTT scheduler within the configured experimental environment. When using MPTCP in a high-speed train environment and experiencing handovers within a subflow, packets destined for the subflow where the handover occurred arrive later than expected. This results in OFO packets at the MPTCP level. As a consequence, the throughput of subflows without handovers also decreases, ultimately resulting in a reduction in the overall MPTCP throughput.

Figure 5 illustrates the throughput of each subflow when conducting experiments with MPTCP utilizing the proposed scheduler within the configured experimental environment. The proposed scheduler proactively blocks subflows that are anticipated to experience handovers as the train's position approaches the location of the expected handover. This strategy helps mitigate the reduction in throughput caused by OFO packets. Consequently, even when a handover occurs within one subflow, it can be observed that the throughput of other subflows is not significantly impacted.

Figure 6 displays a graph comparing the overall MPTCP throughput between the minRTT scheduler and the proposed scheduler. When no handovers occur, both schedulers exhibit similar performance since they adopt the same operational logic. However, during handover events, the proposed scheduler shows an average instant throughput improvement of 20.8% compared to minRTT. However, over the entire duration of the experiment, the proposed scheduler

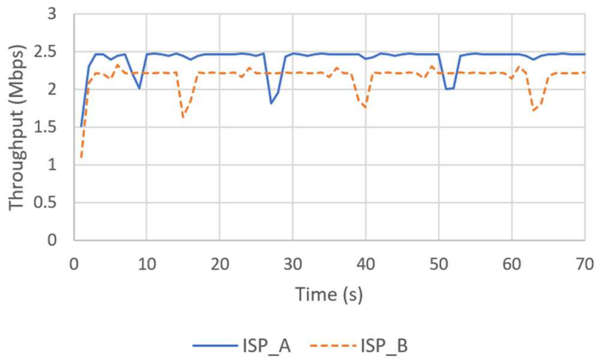

Fig. 3. Throughput of single TCP on ISP A and ISP B.

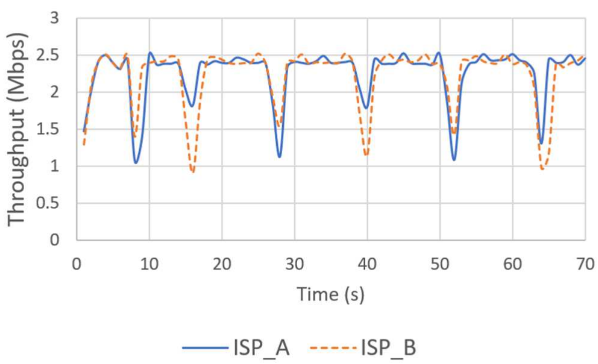

Fig. 4. Throughput of each subflow of MPTCP with minRTT.

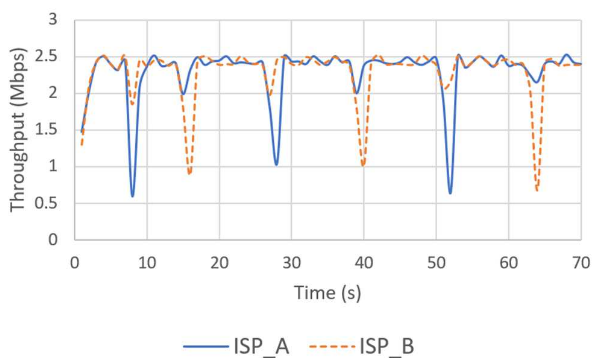

Fig. 5. Throughput of each subflow of MPTCP with proposed scheduler.

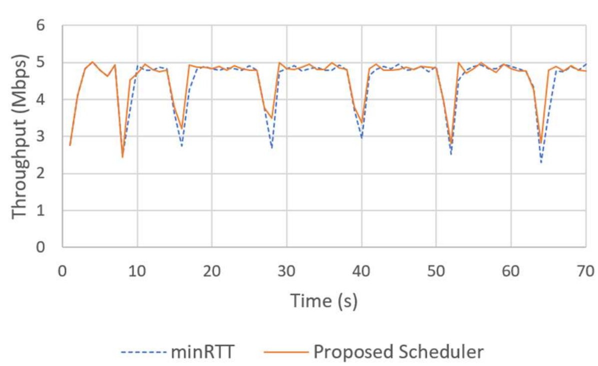

Fig. 6. Comparison of throughput between minRTT and proposed scheduler.

demonstrates an average throughput enhancement of 1.95%. As handover processing times typically take only a few milliseconds on average, the benefits gained from subflow blocking are applicable for only a short duration.

IV. Conclusion

In this paper, a location-based predictive handover-aware packet scheduler utilizing the characteristics of high-speed train was proposed to address the throughput reduction issue in MPTCP caused by frequent handovers in high-speed train environments. The proposed scheduler effectively enhances instantaneous throughput during handover events by blocking subflows experiencing handovers. However, since handover processing times typically take only a few milliseconds on average, the overall throughput gain achieved through the proposed scheduler was relatively modest. Future research aims to enhance throughput reduction caused by high-speed mobility, thereby improving overall MPTCP throughput in high-speed train environments. Additionally, there are plans to implement the proposed scheduler in the Linux kernel and evaluate its performance in real-world settings.

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