A TCP Enhancement for Millimeter Wave Links

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***Abstract*—This paper proposes a TCP enhancement for mm-wave communications to shorten the time to resume communication after a mm-wave link is reconnected. The proposed TCP enhancement distinguishes that a retransmission timeout occurs due to a mm-wave disconnection or a network congestion. If a TCP sender detects that the timeout comes from a mm-wave disconnection, the sender keeps its retransmission timer to prevent that the retransmission timer increases exponentially. By means of some computer simulations, we show that the proposed TCP enhancement is effective to reduce the time to resume communication after mm-wave link is reconnected.**

I. INTRODUCTION

In recent years, millimeter wave (mm-wave) technology has been paid much attention. The mm-wave technology has a great potential to realize future high-speed wireless access. However, since the mm-wave technology has the following unique physical characteristics: strong straightness and diffraction, data communication is disturbed easily by obstacles [1]. In TCP, when detecting a retransmission timeout, the sender doubles the timeout value of its retransmission timer exponentially to mitigate network congestions. When a wireless-link disconnection occurs in mm-wave communications, multiple TCP segments are lost and some consecutive retransmission timeouts occur. In this case, even if the mm-wave link is reconnected, the sender should wait for a long retransmission timeouts. Thus, the time to resume communication after mm-wave link is reconnected becomes long [2]. There are some existing wireless TCPs mainly focusing on Wi-Fi or cellular systems [3], which use lower frequency band than mm-wave communications. However, the characteristics of mm-wave communications is different from that of these wireless systems.

In this paper, we propose a TCP enhancement for mm-wave communications to shorten the time to resume communication after a mm-wave link is reconnected. Via computer simulations, we show that the proposed TCP enhancement is effective to reduce the time to resume communication after mm-wave link is reconnected.

II. PROPOSED TCP ENHANCEMENT

The proposed TCP enhancement consists of two phases: Recording RTTs phase and Setting retransmission timeout value phase.

In recording RTTs phase, when receiving an ACK, a TCP sender records the RTT value rtt. When a sender receives a new ACK, the rtt is overwritten. Therefore, rtt keeps the last recorded RTT. In addition, when a TCP sender receives Dup-ACKs, the sender checks the RTT. Only if the RTT is the minimum value among RTTs of all the received Dup-ACKs, the sender records (overwrites) the RTT as $rttbase$. $rttbase$ keeps the minimum RTT of all the received Dup-ACKs.

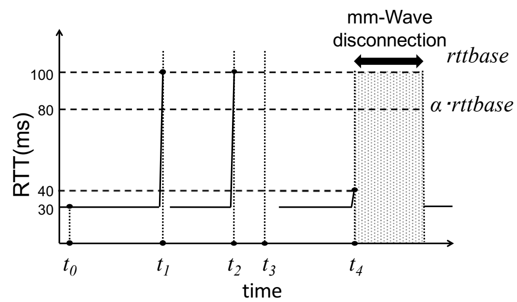


Fig. 1. Variation of RTT in proposed TCP enhancement.

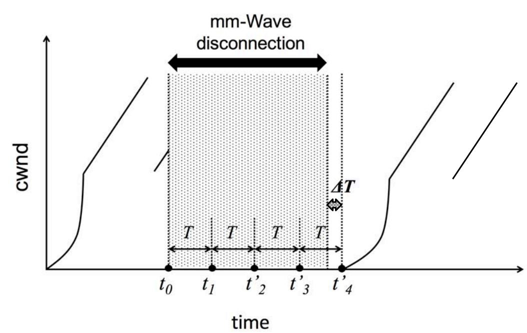


Fig. 2. Variation of congestion window in proposed TCP enhancement.

In setting retransmission timeout value phase, when a retransmission timeout occurs, a data sender distinguishes that the timeout occurs due to a mm-wave link disconnection or a network congestion, by means of the recorded RTTs. When a retransmission timeout occurs, a data sender compares the rtt and $\alpha \cdot rttbase$. α is a constant margin ($0 \leq \alpha \leq 1$).

- If $rtt < \alpha \cdot rttbase$, the data sender determines that the cause of the retransmission timeout is a disconnection of the mm-wave link. The data sender holds the value of the retransmission timer in order to reduce the time to resume communication after the mm-wave link is reconnected.
- If $rtt \geq \alpha \cdot rttbase$, the data sender determines that the cause of the retransmission timeout is a network congestion. The data sender doubles the value of the retransmission timer exponentially in order to mitigate network congestions, which is the normal operation of the TCP.

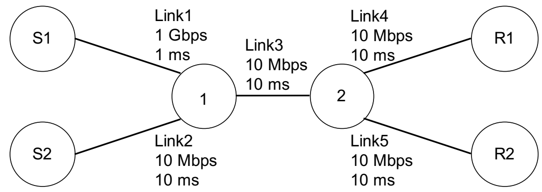


Fig. 3. Simulation topology.

The proposed TCP enhancement sets an appropriate value of retransmission timer to reduce the time to resume the communication after a mm-wave link is reconnected.

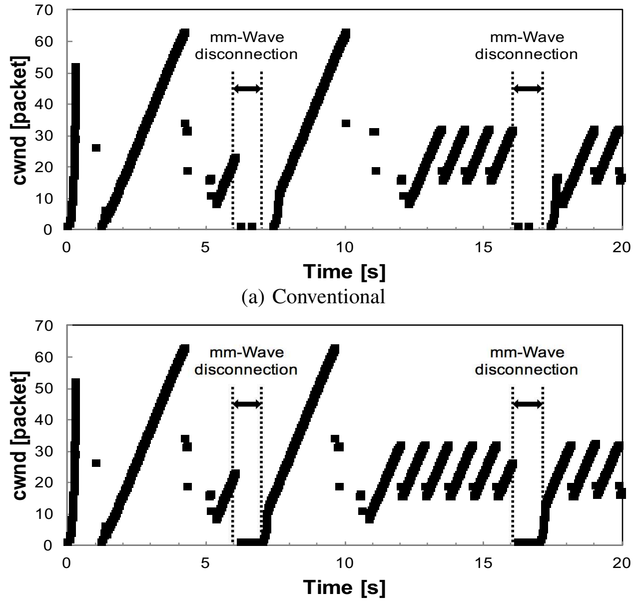
Fig. 1 illustrates the variation of RTT in the proposed TCP enhancement. We assume $\alpha = 0.8$. When a retransmission timeout occurs, a data sender distinguishes that the timeout occurs due to a mm-wave link disconnection or a network congestion, by means of the recorded RTTs. At time t_0, we assume that a TCP sender receives an ACK whose RTT is 30 ms. Therefore, rtt is 30 ms at time t_0. At time t_1, a data sender receives Dup-ACKs, and renews $rttbase$. We assume that the RTT of the received Dup-ACKs is 100 ms. At time t_2, rtt is 100 ms At time t_3, we assume that a retransmission timeout occurs due to a network congestion. In the proposed TCP enhancement, when the data sender detects the retransmission timeout, the data sender compares rtt and $\alpha \cdot rttbase$. In this case, $rtt = 100$ ms and $\alpha \cdot rttbase = 80$ ms. The data sender determines that the retransmission timeout is caused by a network congestion because $rtt > \alpha \cdot rttbase$. Then, the data sender doubles its retransmission timer. At time t_4, we assume that a retransmission timeout occurs due to a mm-wave link disconnection. In this case, we assume that $rtt = 40$ ms and $\alpha \cdot rttbase = 80$ ms. Since $rtt < \alpha \cdot rttbase$, the data sender determines that the cause of the retransmission timeout is a mm-wave link disconnection. Then, the data sender holds its retransmission timer.

Fig. 2 illustrates the variation of the congestion window of the proposed TCP enhancement. In this figure, at t_0, the mm-wave link is disconnected. In the shaded duration, a mm-wave link continues to be disconnected. At time t_1, we assume that a retransmission timeout occurs due to a mm-wave link disconnection. At that time, the data sender holds its retransmission timer. At time t'_2, a retransmission timeout occurs due to a mm-wave link disconnection again. At that time, the data sender holds its retransmission timer again. At time t'_3 and t'_4, the data sender also holds its retransmission timer. As a result, it takes ΔT to resume the communication after the mm-wave link is reconnected.

III. Performance Evaluation

We evaluate the performance of the proposed TCP enhancement for mm-wave link disconnections. We implement the proposed TCP enhancement on network simulator ns-3 (version 3.19) [4]. We use TCP Reno as the conventional method for comparison.

Fig. 3 shows the network topology in the simulation. All links are wired. We simulate mm-wave link (Link1) disconnections by means of setting hundred percent of the frame error rate in Link1. Simulation time is 20 seconds. A data sender S1 transmits data to a data receiver R1. We generate μ Mb/s background traffic from S2 to R2 in Fig. 3 after 10 second from the simulation starts. In addition, two mm-wave disconnections occur at time 6 and 16 second, respectively. The duration of each mm-wave disconnection is one second. The maximum segment size (MSS) is 1,000 Byte. The queue length of router 1 and 2 is 10 packets. We set the value of α to 0.99.



(a) Conventional

(b) Proposed

Fig. 4. Variation of congestion window.

Fig. 4 shows the variation of congestion window when $\mu = 5$ Mb/s. From Fig. 4a, we observe that TCP Reno resumes the communication at time about 7.4 second and at time about 17.4 second, respectively. On the other hand, from Fig. 4b, the proposed TCP enhancement resumes the communication at time about 7 second and at time about 17 second, respectively. In both mm-wave disconnections, the proposed TCP enhancement can reduce the time to resume communication after the mm-wave link is reconnected.

From these results, we confirm that the proposed TCP enhancement is effective to reduce the time to resume communication after the mm-wave link is reconnected in dynamic network conditions.

Acknowledgment

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