Rerouting technique for layer-2 network using time aware shaper to accommodate TDD-based mobile front-haul

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Abstract: A rerouting technique using a time aware shaper is proposed for Internet of Things traffic in a Layer-2 network to accommodate time division duplex (TDD) based mobile front-haul. Experimental results showed that a low latency of 40 us and a high throughput near line rate could be attained at any time by avoiding the route with the reserved transfer window.

Keywords: mobile front-haul, TDD, Layer-2 network, rerouting

Classification: Network System

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1 Introduction

With the launch of 5G cellular services, Beyond 5G is needed to meet the rise in traffic [1]. A large number of remote units (RUs) will be connected to central units (CUs) through optical fiber links known as mobile front-hauls (MFHs). The networking of MFHs with Layer-2 switches (L2SWs) is compatible with 5G MFH traffic since it is packetized into Ethernet frames [2]. A Layer-2 network (L2NW) efficiently accommodates multiple RUs by significantly decreasing the number of optical fibers. This is made possible by statistical multiplexing. Meanwhile, massive Machine Type Communication (mMTC) is one application of 5G that is expected to cause a dramatic increase in Internet of Things (IoT) devices. IoT devices also use non-cellular wireless systems such as low power wide area (LPWA) for wireless connections between IoT devices and IoT gateways (IoT GWs) in accordance with various requirements specific to IoT applications [3]. IoT GWs aggregate IoT traffic in their own coverage areas and send it to the IoT cloud server via optical networks. The service-converged L2NW architecture, in which MFH and IoT traffic share an optical link, shows promise for capital and operational expenditures (CAPEX/OPEX).

To develop such architecture, it is necessary to avoid the delay in MFHs caused by IoT traffic because MFHs require extremely low latency [4]. A time aware shaper (TAS) technique in IEEE 802.1Qbv [5] avoids the delay in latency-sensitive traffic by reserving transfer windows in which non-latency-sensitive traffic cannot be transmitted. The TAS technique is particularly effective when latency-sensitive traffic is generated periodically. The MFH traffic is fully periodic since 5G cellular systems are based on time division duplex (TDD), in which downlink and uplink traffic are transmitted in turns during each TDD cycle [6].

The TAS technique reserves a fixed-length transfer window for the MFH and limits the period available for transferring IoT traffic. However, certain IoT applications, such as real-time video surveillance and closed-loop control, require a high throughput and a low latency, respectively [3]. That is, the TAS technique limits the number of IoT applications accommodated in the converged L2NW. The TAS technique was previously revised [7] to improve IoT performance by releasing the reserved transfer window only when MFH traffic is low. When the traffic is high, almost all of the reserved transfer window is used, so the performance cannot be improved with the TAS technique. Therefore, a new method is necessary to enhance the number of IoT applications that can be accommodated in the converged L2NW.

We propose a rerouting technique to improve IoT performance for any amount of MFH traffic by utilizing TDD. In our experiments, we investigated performance improvements using a practical TDD cycle of 10 ms. In previous work [8], proof-of-concept demonstrations were conducted using a TDD cycle of 1 s due to the limitations of the software-based L2SW performance.

2 Proposed TDD-based rerouting

Figure 1(a) shows a Layer-2 ring network accommodating both MFH and IoT traffic. The MFH traffic corresponds to TDD, so uplink and downlink traffic are alternately transmitted in each TDD cycle. The network controller (NWC) knows the TDD
configuration and sets the reserved transfer window for MFH to L2SWs on the basis of the configuration. This setting for L2SWs is only performed at the beginning of MFH deployment since the TDD configuration is generally static once service operation starts. The TAS technique ensures low latency for MFH downlink and uplink transmissions by stopping IoT transmission during the reserved transfer windows. In the ring network, the traffic is transmitted in either the clockwise (CW) or counterclockwise (CCW) direction. Normally, the same physical route is used between up/down link for a simple operation; if all the MFH downlink traffic is transmitted CW, then all the MFH uplink traffic is transmitted CCW. The switching of transfer routes is only conducted in certain cases, e.g., for protection against optical link disconnection or in the case of L2SW failure.

![Converged network accommodating MFH and IoT.](image)

Figure 1(b) shows an example of the time available for transmitting IoT traffic. IoT traffic consists of a sequence of Ethernet frames. The length of the traffic depends on the IoT application. As illustrated in Fig. 1(b), the length of the traffic is assumed to be longer than the reserved transfer window for MFH downlink and uplink since a large volume of traffic is required by applications such as real-time video surveillance. When the IoT traffic is transmitted CCW, it is transmitted only after the end of the uplink duration in the TDD cycle as shown in Fig. 1(b-1). Our rerouting technique for IoT traffic is designed to utilize the unused transfer windows caused by TDD configuration. In the proposed scheme, the IoT traffic is transmitted CW during the uplink duration and CCW during the downlink duration in the TDD cycle, as shown in Fig. 1(b-2), which extends the time available for IoT.

Out of the various methods for changing the used route, we selected service virtual local area network identifiers (S-VIDs) in Ethernet frames because of its simplicity compared with the other methods. The L2SW, which is connected to the IoT GWs and the entrance into the Layer-2 ring network for the IoT traffic, sets VIDs into the IoT frame. The L2SW transfers frames to the corresponding output ports on the basis of the VIDs. Thus, the changing of the VID at the input to the Layer-2 ring network is equivalent to the switching of the route.
The IoT traffic in Fig. 1(b) is assumed to be generated by one IoT GW which requires high throughput. Our rerouting is performed during the transmission of IoT traffic, so it is necessary to deal with the frame order reversal that may occur at the switching of transfer routes. The reversal can be corrected at the higher-layer protocol of the IoT server. Alternatively, the reversal can also be avoided by buffering IoT frames at the L2SW, which is connected to the IoT GWs before rerouting from the longer route to the shorter one. Even when the difference in distance between the two routes is 10 km, the buffered time which is about 50 us, is quite low compared with the low-latency requirement of a few milliseconds in IoT [3]. Even when there are multiple IoT GWs connecting to the same L2SW, by tagging their traffic with the same VID, our rerouting technique is applied as in the case of one IoT GW.

We examine the applicability of our proposed technique to other networks. As mentioned above, MFH up/down link each use a different direction in the same physical route for simple operations. As long as IoT traffic can be transmitted in both directions, it is possible to improve IoT performance by rerouting. Therefore, the proposed technique can be applied to networks such as ring, mesh, and honeycomb networks in which more than one route is provided with source-destination pairs.

3 Performance evaluation

We experimentally evaluated our scheme using the setup shown in Fig. 2. We constructed a ring-type L2NW by using four L2SWs equipped with 10 Gbps SFP+ modules. We implemented the TAS technique with FPGA-based L2SWs to work in accordance with the practical TDD cycle of 10 ms. Transfer windows were reserved for MFH at the downlink duration for CW transmission and uplink duration for CCW transmission. To set the transfer route of IoT traffic, IoT frames were tagged with VIDs corresponding to the TDD configuration. We set the transfer route of IoT frames with VID#101 to CCW(L2SW#2 -> #3 -> #4) during the downlink duration; the route of frames with VID#100 was CW(L2SW#2 -> #1 -> #4) during the special and uplink duration of the TDD cycle. MFH and IoT traffic were generated by the traffic generator.

Figures 3(a) and (b) show the results when the IoT traffic uses only one route. The throughput was defined as the number of bits successfully transmitted every 1 ms. High latency occurred for the IoT traffic, while low latency was attained for the MFH downlink and uplink by using the TAS technique. The maximum latency of 6 ms CW and 3 ms CCW were equivalent to the length of the downlink and uplink
in the TDD configuration used because the IoT needed to wait until the end of the reserved transfer window. Moreover, the average throughput CW and CCW was 4.0 Gbps and 7.0 Gbps, respectively, since IoT traffic was not transmitted at all in the reserved transfer window.

Figure 3(c) shows the performance with our rerouting technique. A low latency of 40 us was attained at all times for IoT by using the route with no MFH traffic as determined by the TDD configuration. The route conditions for MFH and IoT were the same, consisting of three L2SWs with back-to-back connections. Thus, the latency was equivalent to that in MFH. Moreover, no additional latency was observed at the timing of route switching (6 ms, 10 ms, 16 ms, 20 ms, etc.). Similarly, the IoT traffic reached a throughput of 9.8 Gbps at all times by avoiding the reserved transfer windows. We verified that our rerouting technique consistently provided low latency and high throughput. This technique can increase the potential candidates accommodated in the converged L2NW such as low-latency IoT applications requiring a few milliseconds and high data rate applications [3].

Fig. 3. Experimental results.
4 Conclusion

We proposed and experimentally evaluated a rerouting technique in order to attain low latency and high throughput for IoT traffic. Experiments showed that a low latency of 40 us and a throughput near line rate could be attained for IoT traffic at any time by avoiding the reserved transfer window, showing the feasibility of our proposed technique.

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