Demonstration of Cooperative Transport Interface Enabled Cooperative DBA for 5G Fronthaul over TDM-PON

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Abstract *We demonstrate the operation of an end-to-end 5G network enabled by bandwidth efficient and low latency transport of mobile fronthaul traffic over a 25GS TDM-PON system using cooperative transport interface (CTI) and Cooperative DBA (Co-DBA). ©2023 The Author(s)*

1. Introduction

The 5G Centralized Radio Access Network (C-RAN) architecture is based on the split processing of RAN functions between the Radio Unit (RU), Distributed Unit (DU) and Centralized Unit (CU) to enable flexible and cost-effective large-scale deployments of the RAN. The benefits of C-RAN architecture could be further enhanced by using a cost-efficient solution for traffic aggregation and distribution between the RAN entities. In this context, the Time Division Multiplexed - Passive Optical Network (TDM-PON) that utilizes a passive point-to-multipoint optical infrastructure to provide fixed broadband access is well positioned as a transport network for the C-RAN architecture [1].

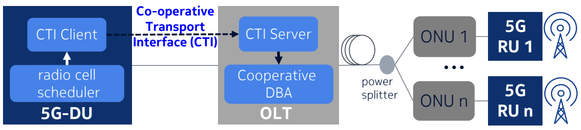

Fig.1: 5G C-RAN using fronthaul over TDM-PON

However, the challenge in using existing TDM-PON technology, specifically for the fronthaul connection between the RU and DU, is that the typical upstream latency and latency variation of the TDM-PON is an order of magnitude higher than the hundreds of microseconds tolerated by the fronthaul traffic [2]. This is due to the slow reaction time of the dynamic bandwidth assignment (DBA) process used in TDM-PON for upstream bandwidth sharing amongst multiple services. The latency of TDM-PON can be improved by increasing the upstream burst frequency for a fixed bandwidth assignment (FBA) that equals to the peak traffic requirement. This approach is suitable for a constant bit rate traffic such as the previous generation mobile fronthaul based on Common Public Radio Interface (CPRI) as demonstrated in [3]. However, the 5G fronthaul interface enables statistically random traffic proportional to the radio resource utilization of the RU as shown in [4]. Therefore, assigning a fixed bandwidth corresponding to peak traffic requirement is bandwidth inefficient for the statistically varying fronthaul traffic in 5G C-RAN.

A co-operative DBA (Co-DBA) mechanism was proposed in [5] to achieve bandwidth efficiency while still supporting low latency for mobile fronthaul. This approach provides exact bandwidth requirement and the time at which the fronthaul traffic will arrive at the ONU. With accurate synchronization between the radio system and the PON system, optical line terminal (OLT) can provision the exact amount of bandwidth at the exact time to the mobile fronthaul traffic. The Co-DBA approach is considered in the ITU-T supplementary document [6] and the interface between the radio cell scheduler and the Co-DBA is specified as cooperative transport interface (CTI) in the open RAN (ORAN) specification [7] for mobile fronthaul transport. The Co-DBA concept with a pre-standard CTI has been demonstrated in [8] on a customized TDM-PON platform and using radio system emulators.

In this paper, we report on the first demonstration of an end-to-end 5G network operation using a 25GS-PON [10] system enabled by CTI to transport fronthaul traffic. The paper describes the details of a CTI server and Co-DBA implementation for upstream burst scheduling. The implemented solution is integrated and evaluated in a 5G network testbed to evaluate bandwidth efficiency and latency performance of the TDM-PON.

2. CTI and Co-DBA implementation

The CTI specification includes a CTI client which is typically coupled with a radio cell scheduler in the DU and a CTI server which is coupled with the Co-DBA process within the OLT of the TDM-PON system, and they communicate using CTI messages as shown in Fig. 1. For a successful operation of CTI, the radio system and the PON system need to have a common time reference with the time of day (ToD) which is obtained by synchronizing to a timing grandmaster using precision time protocol (PTP) as well as by keeping a mapping of the ToD to their respective frame counters. The radio cell scheduler uses a reference of system frame number (SFN) incrementing every 10 ms and a radio slot

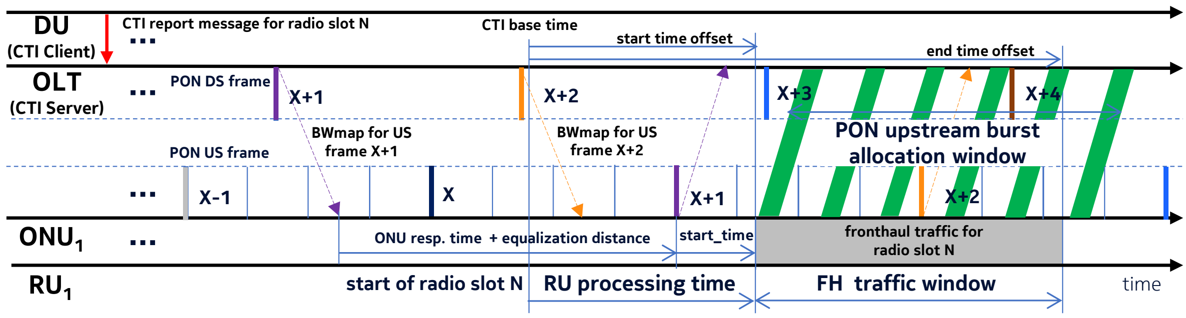

Fig. 2: Interworking of cooperative transport interface and cooperative DBA

number within the SFN. Similarly, the TDM-PON upstream scheduler works with reference to a counter of the 125 µs downstream frames.

The uplink (UL) traffic requests from the user equipment (UE) attached to a radio cell result in UL scheduling grants from the corresponding radio cell scheduler. The CTI client interprets these UL scheduling grants and sends CTI report messages containing the information about bandwidth requirement (i.e. bytes requested) and timing (i.e. base time, start time offset, end time offset) of the fronthaul (FH) traffic from the RU during a scheduled UL slot. The start time offset and end time offset establish a FH traffic window (as shown in Fig. 2) relative to the base time, in which requested number of bytes are output by the RU on the fronthaul interface. The CTI report messages are received a few radio slot durations before the actual FH traffic.

The information within a CTI report message is mapped into the TDM-PON specific timing and bandwidth maps (BWmaps) by the Co-DBA process. The Co-DBA process converts the base time + start time offset ToD value from the CTI report message to a specific upstream PON frame and a start_time within that PON frame for the corresponding ONU. The end time offset from the CTI message is used to create a PON upstream burst allocation window for the ONU as shown in Fig. 2. The bytes requested for FH traffic during the radio slot are provisioned using BWmaps that allocate a series of equal size bursts every quarter frame (QF) duration (i.e. 31.25 µs) over the PON upstream burst allocation window as described in [11].

3. Experimental Testbed

To evaluate the performance of CTI enabled TDM-PON for fronthaul traffic, we use an end-to-end 5G network testbed with a commercial 25GS-PON system as shown in Fig. 3.

Two RUs are connected to two ONUs using a 10G Ethernet switch (Eth Sw RU in Fig. 3). The ONUs are connected to the OLT using a 1x8 optical power splitter without any long distance fibre. The 10G Ethernet interface of the OLT that carries the FH traffic is connected to the DU entity using another 10G Ethernet switch (Eth Sw DU in Fig. 3). A control interface of the OLT is also connected to the DU interface that sends CTI messages via Eth Sw DU. The DU is connected to the CU over a 10GE connection carrying F1 interface traffic and the CU connects to a 5G standalone (SA) core. A test phone UE is connected to RU1 using a cable.

The RUs in our testbed use 90 MHz bandwidth with a sub-carrier spacing of 30 KHz at a centre frequency of 3.45 GHz. A proprietary L1 functional split is implemented between the RU and the DU such that the UL traffic on the fronthaul interface is proportional to the radio resource utilization in an UL radio slot. The radio system uses a 4 DL/1 UL slot TDD configuration where each radio slot is 500 µs. The fronthaul traffic for the UL radio slot is generated by the RU as a burst of eCPRI-over-Ethernet frames during the FH traffic window (as shown in Fig. 2) shorter than the radio slot duration. The OLT implements a CTI server and the Co-DBA process as described in Section 2. The DU entity implements the remaining functions of the L1 and L2 of the RAN protocol stack and the CTI client. We use the iperf utility to generate UL traffic from the UE to the server hosting the 5G SA core.

4. Measurement Setup

The experimental testbed described above is used to measure the latency and bandwidth efficiency of the TDM-PON system for FH traffic.

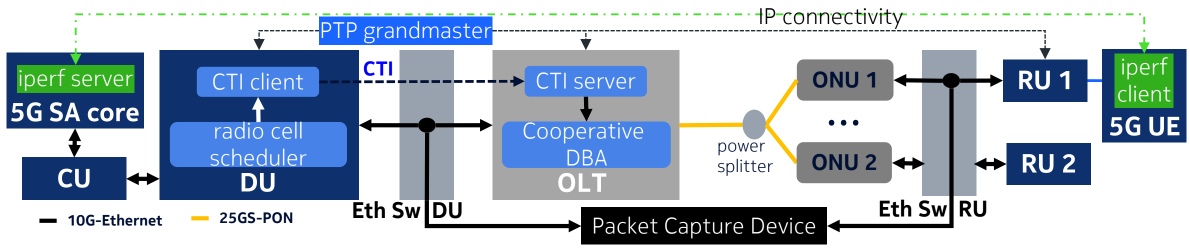

Fig. 3: 5G network testbed with fronthaul over 25GS-PON

For one-way latency measurements, the FH traffic between the RU and DU is tapped at their respective ports connected to the Eth Sw RU and Eth Sw DU and capture it using a packet capture device as shown in Fig. 3. The packet capture device uses accurate timestamping for captured packets and all ports of the device are synchronized to the same clock source. Therefore, by comparing the capture timestamps of the same FH packet on both ports of the capture device, we can determine one-way latency for FH packets through the TDM-PON system and calculate packet latency variation.

In this paper, we consider the ratio of bandwidth required to bandwidth assigned for the FH traffic as a metric of bandwidth efficiency which is agnostic of the absolute bandwidth values and highlights the performance of the DBA scheme. The bandwidth efficiency of 100% means the bandwidth required by the FH traffic is exactly assigned by the upstream scheduling of the TDM-PON system. To measure the required bandwidth for the FH connection, we tap the CTI report messages at Eth Sw DU and capture them on the packet capture device. The instantaneous bandwidth required for the FH traffic is calculated using the time difference between the base time and bytes requested from the consecutive CTI report messages. The bandwidth assigned for the FH traffic is obtained from the PON system.

5. Results

The measurements for FH packet latency and FH bandwidth efficiency are obtained during an UL traffic test from the UE to the 5G SA core. The measurements are for a duration of 3 seconds, which corresponds to ~1200 UL radio slots and over 100k FH packets. Since Co-DBA is a technique for upstream bandwidth management in TDM-PON, we only report the performance in the upstream direction. We compare the FH bandwidth efficiency and latency performance of our Co-DBA implementation described in section 2 (called as CTI + Co-DBA + QF) with the fixed bandwidth assignment for peak traffic requirement and continuous quarter frame burst allocation (called as Fixed BW (peak) + QF) scheme described in [11].

As shown in Fig. 4, the bandwidth efficiency for the CTI + Co-DBA + QF is 90.9%, as our Co-DBA implementation always assigns 10% higher bandwidth than requested within the CTI report message to account for experimental margin in timing synchronization. However, the average bandwidth efficiency for the FBA (peak) + QF scheme is only ~ 6% which is 15x lower than the CTI + Co-DBA + QF. Since the timing of the FH traffic window is not used in the FBA (peak) + QF scheme, the peak bandwidth calculated using bytes requested by the largest UL radio slot and the duration of FH traffic window is continuously allocated even when there is lower or no UL FH traffic which results in significantly low bandwidth efficiency.

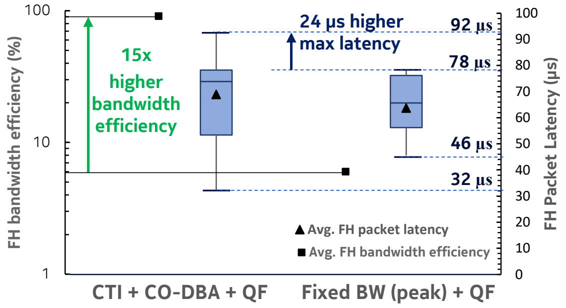

Fig. 4: Performance of different bandwidth allocation schemes for FH traffic over TDM-PON

The FH packet latency statistics for the two bandwidth assignment schemes are shown using box plots on the secondary Y axis in Fig. 4. The FBA (peak) + QF scheme provides upstream FH packet latency between 46 µs and 78 µs with a maximum latency variation of 32 µs whereas the CTI + Co-DBA + QF results in the upstream FH packet latency between 32 µs and 92 µs with a maximum latency variation of 60 µs. The average latency is very similar in both cases at 63 µs and 68 µs respectively. The latency values would be higher by ~5 µs/km for the fibre deployed in the PON. The maximum latency and the maximum packet latency variation is higher in case of CTI + CO-DBA + QF scheme than FBA (peak) + QF scheme by 24 µs and 28 µs respectively. This is due to a different timing alignment between the start of FH traffic window and the start of PON upstream burst allocation window in CTI + CO-DBA + QF scheme compared to the timing alignment between the start of FH traffic window and the start of next upstream burst in the FBA (peak) + QF scheme. The results from Fig. 4 show that CTI + Co-DBA + QF scheme is highly bandwidth efficient while keeping the FH packet latencies within the thresholds specified in ORAN specification [2].

6. Conclusion

We demonstrated the operation of an end-to-end 5G radio system using CTI and Co-DBA enabled 25GS-PON for fronthaul transport. Using CTI and Co-DBA is significantly bandwidth efficient for FH traffic with a marginal increase in latency compared to the fixed bandwidth assignment.

Acknowledgements

This work was partially funded by the Federal Ministry of Education and Research (BMBF), Germany. (AI-NET ANTILLAS: 16KIS1305, 6G-ANNA: 16KIS077K).

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