First demonstration of optical-mobile cooperation interface for mobile fronthaul with TDM-PON

Hiroko Nomura¹a), Hiroshi Ou¹, Tatsuya Shimada¹, Takayuki Kobayashi², Daisuke Hisano¹, Hiroyuki Uzawa¹, Jun Terada¹, and Akihiro Otaka¹

¹ NTT Access Network Systems Laboratories, Kanagawa 239–0847, Japan
² NTT Network Innovation Laboratories, Kanagawa 239–0847, Japan

a) nomura.hiroko@lab.ntt.co.jp

Abstract: To achieve cost-effective mobile fronthaul (MFH) with a time-division-multiplexing passive optical network (TDM-PON), we present a prototype optical-mobile cooperation interface, which converts mobile upstream scheduling information to transmission request information for the mobile upstream data that will arrive at each optical network unit (ONU). By basing bandwidth allocation on the request information converted by the interface, low-latency upstream transmission can be achieved on the MFH with the TDM-PON. We demonstrate the time spent for the conversion process in the prototype interface under various and practical conditions for the first time.

Keywords: TDM-PON, DBA, mobile fronthaul, LTE, 5G

Classification: Fiber-Optic Transmission for Communications

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1 Introduction

In the next generation mobile communication system (5G), the ultra-high density deployment of small cells is being considered as a way of increasing the bandwidth of user equipment (UE) [1]. In such networks, a huge number of optical fibers will be needed to create a mobile fronthaul (MFH) that links centralized baseband units (BBUs) to remote radio heads (RRHs).

A packet-based centralized-radio access network (C-RAN) has been proposed for such a network, where part of the baseband function like MAC-PHY split and split-PHY processing (SPP) [2, 3] is executed in an RRH. Since a packet-based C-RAN transmits packet data on an MFH, it enables us to reuse common Ethernet components and has good affinity with the time-division-multiplexing passive optical networks (TDM-PON) [4]. By constructing the MFH with a TDM-PON, we can achieve a cost-effective MFH for 5G, because an optical fiber can be shared by multiple RRHs.

On the other hand, a TDM-PON suffers a large latency due to classical dynamic bandwidth allocation (DBA). Although DBA offers the advantage of high bandwidth utilization, it requires transmission request information such as report [4] for the mobile upstream data arriving at each optical network unit (ONU) every DBA cycle, and this takes much more time than the latency requirement imposed on the MFH [5].

To reduce the latency, the mobile-scheduling-information-based DBA (mobile-DBA) can be considered [5, 6]. It allocates upstream bandwidth to each ONU by using mobile upstream scheduling information (mobile-info) received from a BBU in advance instead of gathering the request information from ONUs.

However the mobile-info is generated for each UE at the BBU and is not the same as the request information for each ONU. In other words, the mobile-info needs to be converted to the request information to achieve mobile-DBA. This conversion should be executed in a short processing time in order to obtain sufficient processing time for DBA process.

To solve the issue, we present a prototype optical-mobile cooperation interface that converts mobile-info to request information for each ONU. In addition, with this prototype, we demonstrate the time spent for the conversion process at the interface under various and practical conditions based on the long-term evolution (LTE) specification for the first time.

2 Overall TDM-PON system for MFH

2.1 Mobile upstream scheduling information

In the mobile system, a BBU schedules the upstream transmission for each UE at every transmission time interval (TTI). The TTI is set at 1 ms in the LTE specification. The scheduling result is transmitted to each UE as downlink control...
information (DCI) [7]. For example, DCI has allocated resource blocks (RB) and a modulation and coding scheme (MCS). Each UE transmits uplink data on the basis of DCI. In a mobile system with a frequency division duplex (FDD), DCI is forwarded from the BBU to the UE in advance so that scheduled mobile upstream data arrive at the BBU once 4 TTIs have passed.

2.2 Mobile-DBA scheme
In the TDM-PON based MFH, BBU is connected to an OLT, and one RRH is connected to one ONU. The OLT is connected to multiple ONUs through an optical fiber and an optical splitter. For mobile-DBA, the OLT receives mobile-info from BBUs. Mobile-DBA allocates an upstream bandwidth to each ONU using the received mobile-info. Since waiting time for collecting request information from ONUs does not occur, the upstream latency caused by DBA can be reduced.

On the other hand, the mobile-info is generated for each UE by every TTI at the BBU and it is not the same as the transmission request information, which includes both the data arriving timing from the RRH and the size of the data that arrived from the RRH. To allocate bandwidth based on the mobile-info that received from BBU at every TTI, it is necessary to convert this information to request information for each ONU.

3 Prototype optical-mobile cooperation interface
3.1 Overview
Fig. 1(a) shows an overview of the prototype optical-mobile cooperation interface for converting mobile-info to request information for each ONU at the OLT. The prototype interface is mainly implemented with software (SW) in order to support any kind of notification format for mobile-info. The mobile-info is provided with an out-of-channel approach from the BBU to prevent reducing the bandwidth available for mobile downstream data on the MFH.

3.2 Detail
The prototype of the optical-mobile cooperation interface has the three functions.
(i) Receiving function: receives and temporarily stores mobile-info received from the BBU.
(ii) Parameter extraction function: extracts calculation parameters such as RB and MCS from the received mobile-info.
(iii) Converting function: calculates the size of each RRH data that arrives. In detail, it calculates the data size of each UE by converting from RB information to transport block size (TBS) using MCS and the TBS table, as described in 3GPP 36.213 [7]. Then it obtains the RRH data size by summing the data sizes of the UEs connected to the RRH. The obtained RRH data size is treated as the data size arriving at the ONU.

Only the receiving function is implemented with hardware (HW) and other functions are implemented with SW.

When the mobile-info is input into the prototype, it is stored in the receiving function and an interrupt signal is input into the SW. Once the interrupt signal has
been received, the SW reads the stored information from the receiving function and executes the parameter extraction and converting functions in order. The converted result is output to the DBA function.

Fig. 1(b) shows the whole processing sequence. First, the BBU transmits the mobile-info to each UE by using DCI. At the same time, the BBU transmits them to the OLT. At the OLT, the prototype optical-mobile cooperation interface performs the above-mentioned functions and outputs the converted result. The TDM-PON interface obtains the bandwidth allocation results that is calculated on the basis of the converted result and transmits them to each ONU as grant information. After receiving upstream data from the RRH, the ONU transmits it to the BBU through the OLT according to the grant information.

3.3 Notification format of mobile-info

Since the BBU schedules the upstream transmission for each UE by every TTI, the interval for receiving the mobile-info from BBU is 1 TTI. Thus, it is important that the processing time for conversion is less than 1 TTI, as described in Fig. 1(c). For this reason we devised the notification format (cooperation frame), which includes only the information for specifying the RRH data size described in section 3.2 and assembles the multiple mobile-info as described in Fig. 2(a). Their terms are shown in Fig. 2(b). It is based on the Ethernet frame format, and the mobile-info is placed in a payload field.

The mobile-info of each UE is assembled at every RRH as a “container” because it is easy for the OLT to calculate the total data size that arrives at each ONU (RRH) by summing the data sizes of the UEs. The notified mobile-info is limited to only essential information for conversion and the multiple mobile-info is
assembled in a frame. Therefore, the conversion can be collectively done and the conversion process can be completed in a short processing time.

4 Experimental results

4.1 Experimental setup

In the prototype, the HW is implemented with FPGA and the SW is implemented with ARM CORTEX-A9. The HW and SW are connected via PCIe Gen2. The cooperation frames are generated by a traffic generator and transferred over a 10 Gbit/s Ethernet line. To verify whether all process in the prototype interface can be completed within 1 TTI or not, we measured the time spent for forwarding the cooperation frame from HW to SW as $T_{\text{forwarding}}$ and the processing time of (ii)∼(iii) as $T_{\text{converting}}$.

In this measurement, we changed the number and UEs per container in a frame (UEs/cont.) is changed from 4 to 212 that contain maximum UEs in the payload in Ethernet frame. In addition, the number of RRH is changed from 1 to 8.

4.2 Measurement results

Fig. 3 shows the measured processing times. The term “total processing time” is the sum of $T_{\text{forwarding}}$ and $T_{\text{converting}}$. Fig. 3(a) shows the total processing times when only the number of UEs/cont. is changed. From Fig. 3(a), the total processing time increases as the number of UEs/cont. increases. $T_{\text{forwarding}}$ increases with payload size. $T_{\text{converting}}$ is impacted by increases in UEs/cont. since the amount of calculation increases. The ratio of $T_{\text{forwarding}}$ to $T_{\text{converting}}$ is plotted in Fig. 3(a).

$T_{\text{forwarding}}$ and $T_{\text{converting}}$ increase but the proportion of $T_{\text{forwarding}}$ and $T_{\text{converting}}$ changes. The maximum processing time is 80 µs with 212 UEs/cont. Fig. 3(b) shows the total processing time performance results where both the number of RRHs and UEs/cont. are changed. The total processing time with 1 RRHs in Fig. 3(b) is equal to that in Fig. 3(a). With the small cell scenario defined in the
In this paper, we presented a prototype optical-mobile cooperation interface designed to efficiently convert upstream mobile-info to transmission request information. With this prototype, we measured the processing time of the conversion process at the prototype interface. The measured results show that the total processing time is 93 µs under practical conditions where the numbers of RRHs and UEs/cont. are 4 and 64, respectively. This processing time is much shorter than the TTI of 1 ms defined in the LTE specification. With our presented optical-mobile cooperation interface, a low-latency TDM-PON can be achieved for MFH application.

LTE specification [8], there are 60 UEs and 4 RRHs. From Fig. 3(b), under this practical condition, the total processing time is 93 µs and much shorter than a TTI. Although the TTI length will be shortened for low latency in 5G networks, this result shows that all of the functions in the prototype interface can be completed within the length of a TTI.

5 Conclusion

In this paper, we presented a prototype optical-mobile cooperation interface designed to efficiently convert upstream mobile-info to transmission request information. With this prototype, we measured the processing time of the conversion process at the prototype interface. The measured results show that the total processing time is 93 µs under practical conditions where the numbers of RRHs and UEs/cont. are 4 and 64, respectively. This processing time is much shorter than the TTI of 1 ms defined in the LTE specification. With our presented optical-mobile cooperation interface, a low-latency TDM-PON can be achieved for MFH application.