Clarification of Accommodatable Number of Functional Split Base Stations in TDM-PON Fronthaul

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Abstract: Mobile fronthaul (MFH) is the optical link between a central unit (CU) and a distributed unit (DU) in centralized radio access network (C-RAN) architecture. To suppress the cost of MFH, we have studied MFH networking based on a time division multiplexed passive optical network (TDM-PON). We have proposed low-latency uplink forwarding with a mobile dynamic bandwidth allocation (M-DBA) scheme. When the M-DBA scheme is employed, the uplink latency can be suppressed compared with fixed bandwidth allocation (FBA). In this paper, we clarify the number of ONUs that can be accommodated by the M-DBA scheme when also accommodating a novel functional split based C-RAN.

Keywords: TDM-PON, Mobile Fronthaul, Dynamic Bandwidth Allocation, 5G

Classification: Optical fiber for communications

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1 Introduction

A centralized RAN (C-RAN) architecture is employed for a mobile base station (MBS) to reduce costs and make MBSs cooperate each other. With the C-RAN architecture, a radio frequency (RF) functional block and part of the physical processing unit are located in a distributed unit (DU) at the antenna site [1]. The other upper layer processing units are consolidated in a centralized unit (CU). The transmission link between the CU and the DU is connected by an optical fiber and called mobile fronthaul (MFH). MFH networking has been widely studied to limit the MFH link cost, and we have studied MFH networking based on a time division multiplexed passive optical network (TDM-PON) [3], [4]. Specifically, we have proposed low-latency uplink forwarding with a mobile dynamic bandwidth allocation (M-DBA) scheme. When the M-DBA scheme is employed, the optical line terminal (OLT) and the DU cooperate as regards the uplink transmission through a dedicated interface defined as a cooperative interface (C-IF) [5]. Moreover, we have demonstrated experimentally that the M-DBA can reduce uplink forwarding latency compared with the conventional fixed bandwidth allocation (FBA) scheme [6]. However, the number of DUs that can be accommodated has not been estimated. In general, the cost reduction becomes greater as we increase the number of accommodatable optical network units (ONUs) connected to the DUs. In this paper, we clarify the number of ONUs that can be accommodated based on statistical information regarding the amount of MFH data, with the M-DBA or the conventional FBA when accommodating functional split based MBSs [1], [2].

2 Overview of Mobile-DBA Scheme

The bandwidth allocation scheme is detailed in [3], [5], and [6]. The CU calculates a wireless schedule for a wireless uplink transmission from user equipment (UE). The CU then allocates the wireless bandwidth to the UE.
After 4 transmission time intervals (TTIs), the UE transmits a wireless signal to the DU. With a long-term evolution (LTE) system, 1 TTI equals one millisecond. In the M-DBA scheme, the CU transmits the calculated wireless scheduling information to the OLT through the C-IF. The OLT calculates the bandwidth for each ONU based on the wireless scheduling information and allocates the bandwidth to each ONU. After 4 TTIs, when the DU forwards the MFH signal to the ONU, the ONU has already been allocated a suitable bandwidth and can forward its signal to the OLT without any transmission waiting time. Thus the transmission waiting latency is minimized.

3 Functional split-based MBS

If the MBS employs a conventional functional split point (e.g. common public radio interface (CPRI)[7]), the MFH link will have to cope with a huge amount of data in 5G era. Therefore a novel functional split point has been discussed[1], [2] to reduce the amount of MFH data. In [1], there are several candidate functional split points. Fig.1(a) shows the functional blocks with the novel functional split point. The option number in Fig. 1(a) refers to [1]. A MAC-PHY split (option 6) and an Intra-PHY split (option 7-2) are particularly suitable with TDM-PON since the MFH traffic is packetized in a layer-2 frame. For options 6 and 7-2, the amount of MFH data is following,

\[D_{mfh} = \begin{cases} N_{lay}S_{tbs} & \text{(if option 6)} \\ N_{lay}N_{iq}N_{q}N_{rb}N_{sc}N_{sym} & \text{(if option 7-2)} \end{cases}\]

where \(N_{lay}\) is the number of multiple-input and multiple-output (MIMO) layers, \(S_{tbs}\) is the transport block size, \(N_{iq}\) is the number of in- and quadrature-phase parts (=2), \(N_{q}\) is the number of quantization bits of the in- and quadrature-phase parts, \(N_{rb}\) is the number of resource blocks in a wireless system bandwidth, \(N_{sc}\) is the number of subcarriers in a resource block, and \(N_{sym}\) is the number of orthogonal frequency division multiplexed (OFDM) symbols in a physical uplink shared channel (PUSCH).

In addition, the MFH link has bursty traffic distribution characteristics. With option 6 in Fig.1, the wireless signal is demodulated and decoded with respect to each TTI. The bursty MFH traffic is periodically generated at every TTI. For option 7-2, two types of bursty traffic distribution are conceivable. First is bursty MFH traffic with a resource block interval. When a wireless signal is forwarded by every resource block, the interval of the bursty MFH traffic is 0.5 TTI. The other is the bursty MFH traffic generated by every OFDM symbol. For example, for an LTE system, 1 TTI is equivalent to 1 millisecond and 14 OFDM symbols are transmitted during 1 TTI. As a result, bursty MFH traffic with an interval of approximately 71.4 \(\mu s\) is generated.

Fig. 1 (b)-(d) summarizes the three types of bursty MFH traffic distribution.

4 Calculation method and analysis result

We estimate the probability \(P\) that all DUs generate MFH signals at the same time without exceeding the latency requirement \(T_{req}\). We assume the three
types of MFH traffic distribution shown in Fig.1(b)-(d). The estimation method is divided into two steps. First we calculate the probability mass function of the discrete probability distribution for the amount of MFH data. Then we calculate the number of accommodatable DUs taking the M-DBA into consideration.

### 4.1 Probability mass function for MFH data amount

We use the LTE module [9] of a network simulator 3 (ns-3) [10]. The LTE module generates the TBS and modulation coding scheme (MCS) information per TTI and we simulate multiple times with different UE deployment locations and different mobile traffic generation conditions. This is because the wireless throughput changes depending on the propagation environment between the DU and the UE. And, in [11], the parameter for the number of the UEs is described as 2, 5, 8, 10, and 14. Since the cell size was smaller than that in [11], in this paper we assumed 4 UEs as half of the median described in [11]. We then converted the TBS and MCS information about the LTE system into MFH data assuming a 5G system in accordance with Eq. (1). We produced a histogram of the MFH data. The class of the histogram indicates the MFH data volume $v_{\text{mfh}}$. The frequency of the histogram is equivalent to the discrete probability $p(v_{\text{mfh}})$. We assume that all the DUs generate an MFH signal according to its histogram.

### 4.2 Number of accommodatable DUs based on M-DBA

We define the DU identifier as $i$, and the number of ONUs (= DUs) as $N_{\text{onu}}$. The request size $r_i$ of the uplink transmission from the CU to the OLT through C-IF is equivalent to the MFH data volume $v_{\text{mfh}}$. We need to calculate the transmission waiting time $D_i$ for all the DUs. The allocated bandwidth $b_i$ [byte/polling cycle] is as follows,

$$b_i = \frac{r_i}{\sum_{k=1}^{N_{\text{onu}}} r_k} C_{\text{pon}},$$

where the $b_i$ unit is bytes per polling cycle and $C_{\text{pon}}$ is the PON link capacity. The polling cycle means the uplink transmission interval of the TDM-PON.
system. The number of polling cycles $N_{poll}^i$ to forward the request size $r_i$ is,

$$N_{poll}^i = ceil\left(\frac{r_i}{b_i}\right).$$

(3)

$ceil(x)$ represents a ceiling function. Therefore the transmission waiting time $D_i$ is,

$$D_i = N_{poll}^i T_{poll} - L_i + T_{fix},$$

(4)

where $T_{poll}$ is the polling cycle and $L_i$ is the original frame length. $T_{fix}$ is the fixed latency caused by processing delay and frequency/synchronization errors. Next, we calculate the probability $P$.

$$P = \sum_{s_1=0}^{M} \sum_{s_2=0}^{M} \cdots \sum_{s_{N_{onu}}=0}^{M} (p_1(r_{s_1})p_2(r_{s_2})\cdots p_{N_{onu}}(r_{s_{N_{onu}}})),$$

(5)

where the identifier $s_i$ is the class of the histogram and $M$ is the maximum value of its class. The number of summations depends on the number of ONUs $N_{onu}$. When the element $p_1(r_{s_1})p_2(r_{s_2})\cdots p_{N_{onu}}(r_{s_{N_{onu}}})$ is not under the following condition, the calculation result is excluded from $P$ in Eq. (6).

$$\sum_{i=1}^{N_{onu}} D_i < T_{req}.$$  

(6)

We calculate the probability $P$ for different $N_{onu}$ values according to Eq. (3)-(7).

**Table I:** (a) Calculation parameters for mobile system.

| Item                          | Value                                      |
|-------------------------------|--------------------------------------------|
| Traffic model                 | Exponential distribution                   |
| Number of UEs                 | 2 UEs/DU                                   |
| Wireless data rate from UE    | 100 Mbps                                   |
| UE deployment                 | Uniform distribution                       |
| Transmission power from UE   | 23.0 dBm                                   |
| Noise figure from UE          | 7.0 dB                                     |
| $N_{rb}$                      | 100                                        |
| System bandwidth              | 20 MHz/CA                                  |
| Number of carrier aggregations| 5 CAs                                      |
| $N_{tay}$                     | 2                                          |
| Radius of small cell          | 10.0 m                                     |
| Minimum distance between UE and DU | 1.0 m                                   |
| Simulation time               | 30.0 s                                     |
| Number of iterations          | 1000                                       |
| Fading model                  | Extended typical urban (ETU) model         |
| Path loss model               | Urban Micro (UMi)                          |
(b) Calculation parameters for TDM-PON.

| Item                        | Value          |
|------------------------------|----------------|
| $C_{pon}$                    | 10.0 Gbps      |
| $T_{poll}$                   | 31.25 $\mu$s  |
| Minimum allocated bandwidth  | 320 byte/$T_{poll}$ |
| Burst overhead               | 1024 byte/$T_{poll}$ |
| FEC                         | RS(248,216)    |

Fig. 2: Calculation result. (a) Probability $P$ and (b) histogram for option 6, (c) and (d) for option 7-2 with OFDM symbol interval, and (e) and (f) for option 7-2 with resource block interval.

4.3 Calculation result and discussion
The calculation parameters are shown in Tab. I. The exponential distribution model is defined in [11]. For the exponential distribution model, the average burst duration was 1.0 s and the average burst interval was 5.0 s. The latency requirement $T_{req}$ was set at 150 $\mu$s. To compare the performance, we undertook the calculation when employing an FBA scheme. For the FBA, the bandwidth $b_i$ is,

$$b_i = \frac{1}{N_{onu}}C_{pon}.$$  \hspace{1cm} (7)

We show the calculation result and the histogram in Fig. 2(a)-(f). From Fig. 2(a),(b), the functional split point is assumed to be option 6. For example, the $P$ value is improved more than 20% when 8 DUs are accommodated. For option 7-2, Fig.2(e),(f) show the bursty MFH traffic distribution with a resource block interval. Fig. 2(c),(d) show the bursty MFH traffic distribution with an OFDM symbol interval. Since we expect statistical multiplexing effects, we assumed that it was not necessary for the result to be 100%.
probability threshold value \( P_{th} \) for determining the number of accommodatable ONUs is set at 90%. Then, from Fig. 2(e),(d), the number of ONUs that can be accommodated is improved from 2 to 4. Moreover, for Fig. 2(c),(d), the number is improved from 4 to 6.

5 Conclusion

We calculated the number of accommodatable ONUs when our proposed M-DBA is applied. We evaluated the number of ONUs based on the mobile traffic generated by the LTE module of the network simulator 3. For option 6, the probability is improved by more than 20% when 8 DUs are accommodated. For option 7-2, the accommodation efficiency is improved 1.5 and 2.0 times in the cases of a bursty MFH traffic distribution with OFDM symbol and resource block intervals, respectively when the probability threshold value \( P_{th} \) is set at 90%. 