Numerical analysis on accommodation of TDD-based fronthaul and secondary services in a TDM-PON

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Abstract: We propose a bandwidth allocation technique for accommodating a time division duplex mobile base station (TDD-BS) and a secondary system in a TDM-PON. Operating availability is confirmed with essential three types of TDD configuration taken from the seven types described by the Third Generation Partnership Project (3GPP) standardization group. We evaluate the latency of the TDD-BS and the throughput of the secondary system. We report that the TDD-BS signal is forwarded in less than about 50 μ s and is unaffected by the secondary system. The throughput of the secondary system is improved compared with that of the conventional technique.

Keywords: TDM-PON, bandwidth allocation, mobile fronthaul, 5G

Classification: Fiber-Optic Transmission for Communications

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1 Introduction

The 5th generation mobile network (5G) is attracting attention. For the 5G era, the use of a time division duplex (TDD) system has been studied in relation to flexible frequency band [1]. In addition, centralized-radio access network (C-RAN) architecture is a key technology for realizing 5G. By employing a C-RAN, it is possible to cooperate between mobile base stations (BSs) [2]. With a C-RAN, BS is divided into a baseband unit (BBU) and a remote radio head (RRH). The BBU and RRH are connected by optical fiber, and the channel is called mobile fronthaul (MFH). In recent years, there has been a plan to densely deploy RRHs to cover a lot of user equipment (UE) with a large capacity transmission. MFH must therefore be cost-effective and the application of a time division multiplexing-passive optical network (TDM-PON) has attracted attention [3, 4].

Moreover, we have focused on the characteristics of TDD-based MFH and studied unallocated periods in TDD-based MFH. We have proposed accommodating the TDD-based MFH and secondary services in a TDM-PON [5]. In [5] however, we did not sufficiently consider the TDD configuration. The standardization group, 3GPP, has a specific requirement for the TDD configuration [6]. In 3GPP, the uplink-downlink ratio has seven TDD configuration patterns and we have evaluated one of them. We report evaluations for throughput and latency with different TDD configurations by means of numerical simulation.

2 Proposed system

Fig. 1(a) shows the concept of multiple accommodation technique. This technique uses the unallocated periods in the TDD-based MFH. The TDD-based RRH switches upstream and downstream temporally. The TDM-PON uses different upstream and downstream wavelengths in the optical domain. The optical downstream period is not used when the wireless domain is uplink state. The secondary service signal is overlapped in this unused period as shown in Fig. 1(a)-1. Thus, the mobile signal is unaffected by the secondary signal. The upstream and downstream

Fig. 1. Operation principle of the proposed scheme.

are switched in rotation with respect to each sub-frame. In a long-term-evolution (LTE) mobile system, for instance, the sub-frame length is 1 ms. As a way of distinguishing uplink and downlink periods, we use the mobile and secondary signals queued in an optical line terminal (OLT). For the downstream, the mobile signal has higher priority than the secondary signal, and is forwarded to an optical network unit (ONU) and RRH without additional latency.

However, for the uplink transmission in a TDM-PON, the upstream from the ONUs is transmitted at an allocated time by an OLT. The OLT sends information about the bandwidth and transmittable time to ONUs to avoid signal collision. This scheme is called bandwidth allocation. Thus, the OLT needs to distinguish the allocated or unallocated periods and send the bandwidth allocation signal. A traffic monitor distinguishes the unallocated periods in the OLT as shown in Fig. 1(a)-2. In this paper, the traffic monitor is defined as a TDD frame monitor. Fig. 1(b) depicts the bandwidth allocation technique with or without the proposed technique. With the conventional scheme shown in Fig. 1(b)-1, the ONUs, which are connected to the secondary systems, are permanently allocated surplus bandwidth. In Fig. 1(b)-2 for the monitor period ('period A'), the ONUs, which are connected to TDD-based RRHs (P-ONUs), are permanently allocated bandwidth. The surplus bandwidth is allocated to the ONUs, which are connected to secondary systems

(S-ONUs). Periods after period A operate in the same way as period A when the wireless signal is upstream. When the wireless link is downstream, P-ONUs are unallocated and S-ONUs are allocated their bandwidths dynamically. By applying this technique, the S-ONU throughput is expanded.

3 Numerical simulation

3.1 Simulation parameters

Table I(a) shows the numerical simulation parameters. As a PON system, we assume 10 Gbit-Ethernet PON (10G-EPON) [7]. The proposed technique is applied to different types of TDM-based PONs such as wavelength division multiplexing (WDM)/TDM-PONs [8]. The processing delays in the OLT and ONU are not considered. The P-ONUs are given a fixed bandwidth allocation (FBA) and the S-ONUs are given a typical dynamic bandwidth allocation (DBA) [9]. In the MAC-PHY split, it is assumed that the signal is packetized in the Ethernet frame. The data volume V is defined as

Table I. Parameters and TDD definition.

(a). Simulation parameters.

<i>Item</i>		<i>Value</i>
Mobile	Number of RRHs(P-ONUs)	4
	Number of UE	50
	System bandwidth	20.0 MHz/carrier
	Carrier aggregation N_{CA}	5 carriers
	MIMO N_{MIMO}	2 layers
	BS model	MAC-PHY split [10]
Secondary	Number of S-ONUs	4
10G-EPON	Simulation time	0.5 s
	Monitoring time	10.0 ms
	DBA cycle	125 μ s
	FBA to P-ONU	1.0 Gbps/P-ONU
	FEC	RS(255, 223)
	Guard time for laser on T_{ON}	512 ns
	Guard time for laser off T_{OFF}	512 ns
	Synchronization time	1200 ns

(b). TD-LTE sub-frame structure [6].

Index	Sub-frame number									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
5	D	S	U	D	D	D	D	D	D	D

U: Uplink, D: Downlink, S: Special Sub-frame

$$V = TBS \cdot N_{CA} \cdot N_{MIMO}. \quad (1)$$

where TBS is the transport block size [bit]. N_{CA} and N_{MIMO} are the numbers of carrier aggregations and MIMO streams. TBS is generated by an LTE module [11] in a network simulator-3 [12]. We assumed that the RRHs randomly upload data from the UE. That is, the UE intermittently sends UDP flows to each RRH. The intervals and durations of the bursts are exponentially distributed random variables. The average burst duration is 1 s and the average burst interval is 5 s. The data rates of the bursts are 2 Mbps. The packet lengths are 1024 bytes. Note that the generated data traffic is frequency division duplex (FDD). After generating the traffic, we convert it from FDD to TDD and insert the control signal into the uplink sub-frame. In this paper, we evaluate the transfer latency of P-ONUs and the S-ONUs throughput. Indexes 0, 1 and 5 of the TDD configuration are assumed as shown in Table I(b). Index 0 has the most uplink sub-frame, and the index 5 has the most downlink sub-frame. In index 1, the uplink/downlink ratio is 1:1. These three types of TDD configuration cover other configurations. Note that the special sub-frame includes both uplink and downlink signals. Thus, the special sub-frame is defined as the uplink signal in this study.

3.2 Latency for MFH and throughput for secondary system

Fig. 2(a) shows the latency results for P-ONUs. In Fig. 2(a), the TDD configuration is changed with the proposed technique. The result on the far left is the conventional FBA scheme. For all cases in Fig. 2(a), the application of the proposed bandwidth allocation technique is unaffected to TDD-based MFH. The latency of TDD-based MFH is less than about 50 μ s. In Fig. 2(a), the average latency has a different variation. This is because the transmission order of each ONU is changed with respect to each DBA cycle to achieve fair queuing latency. However, here the RRH is not phase-synchronized with the TDM-PON system. Thus, an offset is needed between the start position of the sub-frame changing period in the TDD system and the DBA cycle in the TDM-PON system. The maximum offset is about one DBA cycle. In the proposed scheme, one extra optical bandwidth is allocated to the P-ONUs for forwarding the sub-frame in time. In this simulation, the number of transmittable times and the number of accommodated ONUs are indivisible. For this reason, the transmission order of the P-ONUs is not completely fair. This leads to a variation in the average latency. Even though the proposed system has latency variation, it is possible to consider the latency as a fixed value after the MFH signal has queued in the OLT until the maximum latency.

Fig. 2(b–e) show the throughput histograms of the S-ONUs. Here, the throughput is defined as the output data [bit]/DBA cycle. Fig. 2(b) was obtained without the proposed technique, and Fig. 2(c–e) were obtained with the proposed technique. In Fig. 2(b), about 25% of the throughput is concentrated at 3.5 Gbps. This is because the remaining three S-ONUs transmit with the smaller amounts of throughput less than 0.5 Gbps when the first bandwidth allocated S-ONU transmits a large number of queuing data with about 3.5 Gbps. In the next DBA cycle, the allocation ordering is changed to guarantee fairness. Thus, about 25% of the throughputs of all the S-ONUs are concentrated at 3.5 Gbps. And the average

(a) Latency result for P-ONUs.

(b) W/o proposed technique.

(c) Index 0.

(d) Index 1.

(e) Index 5.

Fig. 2. Latency result for P-ONUs and throughput distribution for S-ONUs.

throughput with congestion is about 0.87 Gbps. In Fig. 2(c–e), the throughput histograms have a different frequency distribution because the queuing time of the S-ONUs depends on the TDD configuration. For Index0, a number of S-ONU signals are queued because the mobile uplink signals are transmitted for 4 ms (#1–#4 and #6–#9 in Table I(b)). After that, the S-ONU transmits the queued signals for the duration of 1 ms (#0 and #5 in Table I(b)) with the high throughput (>4 Gbps). The case of Index 1 differs from that of Index 0 only in that the transmittable duration time is 2 ms. For Index5, the S-ONU transmits for the duration of 8 ms while the mobile system communicates for 1 wireless frame (= 10 ms). The S-ONUs use most of the bandwidth. Thus the distribution of the throughput tends to concentrate at the input throughput.

In Fig. 2(c–e), the <0.5 Gbps rate is decreased and the >1.0 Gbps rate is increased. Therefore, the S-ONU throughput is expanded. The average throughput is close to 1.0 Gbps (= input throughput) in all cases.

4 Conclusion

We evaluated the upstream latency for TDD-based MFH and the throughput for a secondary system with essential three types of TDD configurations. From the numerical simulation result, we confirmed that the TDD-based MFH is unaffected and has a low latency performance of less than about $50\ \mu\text{s}$ through accommodation in a TDM-PON. The throughput of the secondary system is increased. As a further study, we must analyze the effect of Ethernet frame size on packetization in a TDM-PON. Moreover, in this work, 4 secondary systems were accommodated. Typically, with the DBA technique, the bandwidth can be allocated efficiently by the statistical multiplexing effect. Therefore, the increased number of P/S-ONUs must be analyzed.

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