A Low-Latency DWBA Scheme for TWDM-PON Based Fronthaul Network with Non-Zero Laser Tuning Time

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Abstract: The influence of laser tuning delay is investigated for the TWDM-PON based fronthaul transmission and proposed a WT-DWBA scheme to improve the bandwidth efficiency. We realize a superior performance in wavelength reduction up to 47%.

1. Introduction

Recent advances in 5G networks have driven more stringent requirements of high bandwidth efficiency, ultra-low latency, and low system costs [1]. Centralized or cloud radio access networks (C-RANs) have emerged as the promising approach to cope with the stringent requirements and ever-increasing traffic of mass mobile devices. Time and wavelength division multiplexed (TWDM) passive optical network (PON) offer economical fronthaul solutions to realize the fronthaul network infrastructure in C-RAN. Although there have been many research efforts to efficiently accommodate the fronthaul traffic, few consider the time cost of the tunable laser wavelength tuning [2]. Meanwhile, to satisfy the stringent delay requirement for fronthaul transmission, previous works focus on fixed bandwidth allocation (FBA) [3], which only considers the worst burst case. However, FBA cannot guarantee bandwidth efficiency, and redundant resource waste will arise.

This paper investigates the influence of the tunable laser wavelength tuning delay for the TWDM-PON based fronthaul upstream transmission. To improve the fronthaul bandwidth efficiency and meet the rigorous latency requirement, for the first time, we propose a heuristic for wavelength-tuning-based dynamic wavelength and bandwidth allocation (WT-DWBA) scheme with a non-zero laser tuning time. Simulation results show that the proposed scheme can significantly reduce the number of active wavelength channels, attaining up to 47% reduction compared to the state-of-art FBA algorithm.

2. Principle and Problem Formulation

In this paper, a time-division duplex (TDD) system is assumed where the data transmission between neighboring RUs is synchronized. Due to the TDD system, the upstream data reception timings are the same for all RUs, and so does the starting timing of the transmission time interval (TTI) cycle. We focus on the upstream wavelength and time slot allocation for general TWDM-PON based fronthaul. For TWDM-PON, each optical network unit (ONU) is equipped with tunable transmitters and receivers. To guarantee the strict latency requirement, a cooperative interface scheme utilizing the scheduling information of the wireless domain for DWBA [4] is adopted. Fig. 1(a) shows the process for mobile scheduling, bandwidth allocation, and uplink data transmission. The mobile scheduling is processed before uplink data transmission of UE. Thus, there is enough time to allocate the wavelength and bandwidth and send the gate information to the optical line terminal (OLT) and ONU.

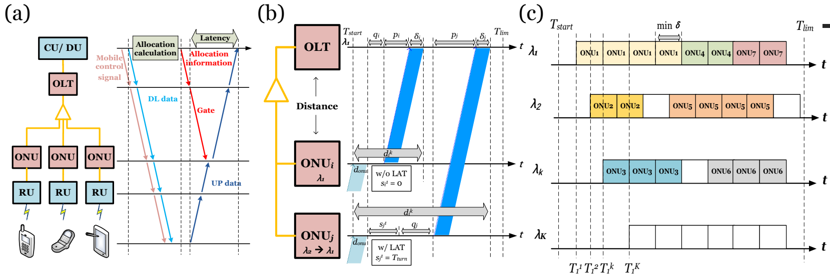

Fig. 1. (a) Upstream transmission of MFH, (b) Data transmission sequence, (c) An allocation example.

Algorithm 1: WT-DWBA Scheme

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1  Initialization: Calculate $\min d_i^k$, $T_1^k$, $N_k$
2  Preparation: Compute the available time slots for each ONU.
3  Calculate the lower bound for the number of active wavelengths $N_{low}$.
4  Allocation: Iteratively allocate the earliest available time slots for the $N_{low}$ wavelength by turns.
5  Allocate a new active wavelength channel for the unserved ONUs.
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Fig. 1(b) shows the data transmission and reception process in TWDM-PON based fronthaul. The ONU_i and ONU_j are located with a different distance from OLT and only ONU_j needs to change the wavelength from λ_2 to λ_1. In the TDD system, the data arrival timing T_{start} are the same for all ONUs. The processing delay in the ONUs is denoted as d_{onu} and the queuing delay is denoted by q_i. The propagation delay between ONU_i and the OLT is denoted as p_i, which depends on the distance and the transmission speed. Assuming the laser tuning time is T_{turn}, the laser tuning delay $s_i^k = 0$ without laser wavelength tuning (LAT) and $s_i^k = T_{tune}$ with LAT for ONU_i using wavelength k. We denote the expected final arrival time for the data from ONU_i to OLT using wavelength k as d_i^k, $d_i^k = T_{start} + d_{onu} + s_i^k + q_i + p_i + \delta_i + 2\sigma$, where δ_i is the data transmission period. σ denotes the synchronization time error value. With T_{lim} donates the latency requirements, inequation $d_i^w \leq T_{lim}$ should be satisfied when ONU_i is allocated with wavelength w. The data arrival timing T_{start} and processing delay d_{onu} are the same for all ONUs. Given a ONU_i, p_i and δ_i are also fixed. The final arrival time d_i^w is dependent on the selected wavelength w and the queuing delay q_i. Therefore, given the ONU requests, the wavelength channel needs to be allocated and the queuing delay needs to be determined for each ONU to guarantee the latency requirement and optimize the resource usage.

3. Proposed WT-DWBA Allocation Scheme

Our objective is to minimize the number of active wavelength channels and satisfy the strict latency requirements to reduce the deployment cost and operational energy consumption. The proposed allocation algorithm is introduced in algorithm 1. We first calculate some initialization values in step 1. Let k denote the identifier for wavelength channels. K is the total number of available wavelengths channels and M is the number of ONUs. The minimal final arrival time $\min d_i^k$ is calculated with queening $q_i = 0$ for all OUN i and wavelength k. The earliest possible arrival time T_1^k is calculated for all K wavelength channels based on d_i^k. Then, based on the T_1^k, latency requirement T_{lim} and the smallest data transmission period min δ_i, we can calculate the number of time slots using $N_k = \lfloor T_{lim} - T_1^k - \sigma / \min \delta_i \rfloor$ for each wavelength channel k. In step 2 and 3, the available time slots of each ONU for all wavelength channels can be attained. After that, we can attain a lower bound for active wavelength channels N_{low} such that $\sum_k N_k \geq \sum_i b_i$. In step 4, we iteratively allocate the time slots of the N_{low} wavelength channels. As Fig. 1(c) shows, each wavelength channel is allocated with one ONU and the wavelength channels are selected by turns. Each time, we select the available ONU with the largest request demand. New wavelength channel is active when N_{low} active wavelength channels cannot satisfy all the ONU request demand. The computational complexity of the proposed WT-DBA algorithm is O(MK).

4. Simulation Results

Simulation is carried out to analyze the influence of laser tuning delay and evaluate the proposed WT-DWBA scheme. The system discussed in section 2 is assumed. The delay threshold is set at 250μs. The propagation delay is 5μs/km. The upstream link bandwidth L was 8.7 Gb/s per channel, considering the PON system's overhead. The synchronization timing error was set as 1.5μs. The transmitted data size is selected based on [5] considering the 5G parameters and the functional splitting option 6. The number of transmission blocks is set to 2, and the number of MIMO streams is chosen from 1, 2, and 4.

Fig. 2 shows the simulation result for the WT-DWBA allocation scheme to minimize the active wavelength channel. The result is compared with the wavelength and bandwidth allocation algorithm (WBAA) proposed in [3]. Fig. 2 (a) shows the performance of the proposed algorithm with different numbers of ONU and load for the 10-μs laser tuning time case. The proposed WT-DWBA algorithm can effectively reduce the number of active wavelength channels and up to 47% reduction can be achieved for a 43.75% load case. With the load increases, the performance of WT-DWBA has a degradation and approach to WBAA. The influence of laser tuning time is also investigated in Fig. 2 (b-c) for M = 20 and M = 30 number of ONUs cases respectively. Employing WT-DWBA, smaller ONU laser tuning time saves more active wavelength channels. Results also exhibit the WT-DWBA can attain a superior performance with laser tuning time smaller than 100μs compared to the state-of-art FBA algorithm WBAA.

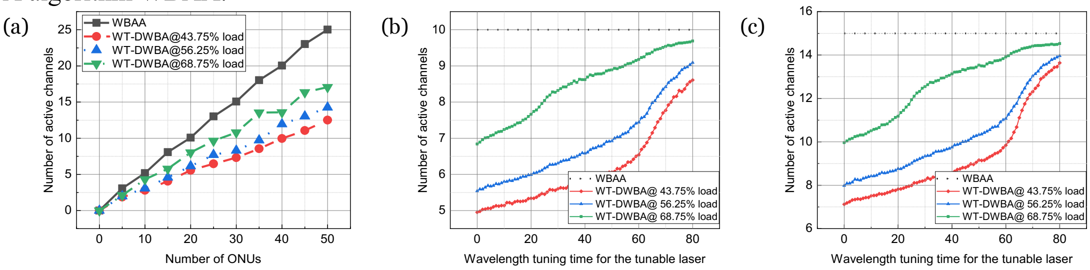

Fig. 2. Simulation results: (a) Influence of the ONU number and load, (b-c) Influence of laser tuning time: (b) $M = 20$, (c) $M = 30$

5. Summary

We investigate the influence of laser tuning delay for the TWDM-PON based fronthaul transmission. For the first time, we proposed a WT-DWBA scheme to improve bandwidth efficiency and meet the rigorous latency requirement simultaneously. Simulation results show that the proposed WT-DWBA can significantly reduce the number of active wavelength channels and attain up to 47% reduction compared to the state-of-art FBA algorithm.

6. References

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