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Discussion

Joint subcarrier channel and time slots allocation algorithm in OFDMA passive optical networks

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ABSTRACT

This paper investigates upstream resource allocation problem in Orthogonal Frequency Division Multiplexing Access Passive Optical Networks (OFDMA-PON). One assignment problem with subcarrier channel utilization and Total Grant Time (*TGT*) is analyzed and formulated. The Shortest Request First Scheduling (SRF) algorithm and Greedy Scheduling Algorithm (GSA) are demonstrated and evaluated through simulations. The results show that the proposed algorithms achieve less *TGT* and higher channel utilization compared with traditional sequence scheme.

1. Introduction

Recently, Orthogonal Frequency Division Multiplexing Access Passive Optical Networks (OFDMA-PON) technology is recognized as a promising candidate for future optical access networks due to its unique advantages, such as high spectral efficiency and flexible bandwidth granularity [1–3]. In addition, OFDMA-PON allows different optical network units (ONUs) to occupy more than one subcarrier channels at the same time, which is not supported in Wavelength Division Multiplexing PON (WDM-PON) and Time Division Multiplexing PON (TDM-PON). Therefore, some resource allocation algorithms used in conventional PON systems [4–6] cannot be simply applied to the OFDMA-PON. In upstream transmission of OFDMA-PON, multiple ONUs can transmit data through the shared channels (one or more subcarriers stand for one channel). Fig. 1 describes the resource allocation model of the OFDMA-PON system, which could be viewed as a two-dimensional allocation: one is frequency consisting of orthogonal subcarriers of different wavelengths; the other is time which is composed of time slots in the transmitting period. The data from different ONUs is transmitted over OFDMA subcarrier channels (SC) in same or different wavelengths. To avoid collision, different ONUs can occupy same subcarrier channel in different time slots.

To our best knowledge, numerous works about OFDMA-PON are focused on the physical layer, only fewer works about Dynamic bandwidth allocation (DBA) algorithms have been studied [7–12]. In [7], multiple channel scheduling algorithms for OFDMA-PON were demonstrated to achieve higher link utilization, while they did not provide the analysis about the user delay. Zhang et al. proposed an efficient Medium Access Control (MAC) protocol which utilizes the abundance of OFDMA subcarriers to dynamically allocate subcarrier channels [8], while they did not consider the realization of scheduling about subcarriers and time slots. In [9–12], authors presented the online scheduling subcarrier channels assignment algorithms without involving the fairness among ONUs.

In order to share efficiently the system resource in OFDMA-PON, we utilized the offline scheduling framework to achieve the fairness of ONUs and introduced the parameter *TGT* for the first time in [13] to analyze the transmission delay brought by the grant time for each ONU. In this text, we further demonstrate the allocation problem in OFDMA-PON, and give a detailed analysis for achieving small *TGT* and high channel utilization. Two algorithms about allocating subcarrier channels and time slots are also proposed to deal with this optimal scheduling problem.

2. Problem description, formulation and theoretical analysis

In this paper, we consider the subcarrier channels and time slots assignment problem in single scheduling cycle time for

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upstream transmission. We assume that each ONU has full access to all channels and the total number of subcarrier channels is fixed. As each subcarrier channel is considered as an independent pipe, each ONU can utilize multiple subcarrier channels simultaneously. In our scheduling model, the unit in the frequency domain is a channel which includes one or more subcarriers, but each channel has the same bandwidth which means the number of subcarriers in every channel is fully same. Therefore, the smallest unit in the model is a time slot in a channel. The parameters used in this paper are defined in Table 1.

2.1. Channel utilization

The channel utilization is an important parameter in the PON system with resource sharing [7] which is also focused by us in this paper. From [7], this parameter U is related to the optimal schedule length. U is defined as [7]

$$U=\sum_{k=1}^{K} d(k)/ML \tag{1}$$

$d(k)$ and M are fixed when optical line terminal (OLT) makes scheduling decisions in one cycle time. In order to optimize U, the minimum of L can be calculated as

$$L=\mathrm{ceil}\left(\sum_{k=1}^{K} d(k)/M\right) \tag{2}$$

where ceil(x) represents the minimum integer not smaller than x.

2.2. Total grant time

The *TGT* is used to measure the consumed time by ONU between start and finishing transmission in each cycle time in OFDMA-PON demonstrated in [13], which represents the transmission delay cost by each user. This metric is the sum of all ONUs' grant time which is the distance between the first transmitting time slot to the last time slot of one ONU. The *TGT* can be

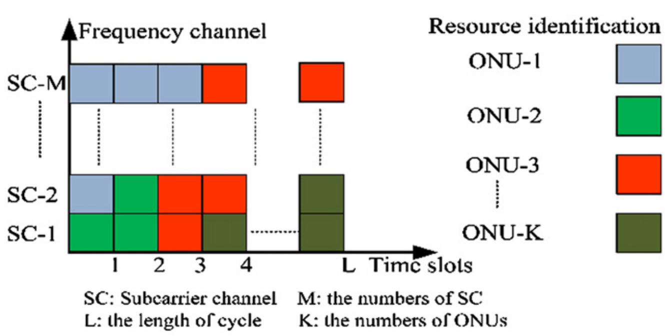

Fig. 1. Resource allocation model in OFDMA-PON.

expressed as

$$\begin{cases} TGT=\sum_{k=1}^{K}\Delta t^k \\ \Delta t^k=t^k_{end}-t^k_{start}+1 \\ t^k_{end}=\max\limits_{m}(t^k_{end,m}) \\ t^k_{start}=\min\limits_{m}(t^k_{start,m}) \end{cases} \tag{3}$$

where Δt^k is the granted time of ONU-k; $t^k_{start,m}$ and $t^k_{end,m}$ represent the first time slot and last time slot in subcarrier channel-m for ONU-k respectively, while t^k_{start} is the minimum of $t^k_{start,m}$ and t^k_{end} is the maximum of $t^k_{end,m}$ among M subcarrier channels. To achieve minimum *TGT*, we establish a mathematical model as follows:

$$\min\left(\sum_{k=1}^{K}\Delta t^k\right) \tag{4}$$

$$\text{Subject to}: \quad \sum_{m=1}^{M}\sum_{l=1}^{L}\delta^k_{m,l}=d(k), \quad k=1,2,\ldots,K, \tag{5}$$

$$\sum_{l=1}^{L}\delta^k_{m,l}\le 1, \delta^k_{m,l}\in 0,1, \quad m=1,\ldots,L,\ k=1,2,\ldots,K \tag{6}$$

$$\Delta t^k,\ t^k_{start},\ t^k_{end}\ \in[0,L] \tag{7}$$

where l is the time slot index ranging from 1 to L, $\delta^k_{m,l}$ are binary variables representing whether the time slot l on subcarrier channel m is selected for ONU-k. Objective (4) is to minimize the *TGT*. Equalization (5) guarantees that the total resources allocated for ONU-k equals to its requirements. In Eq. (6), it is guaranteed that each subcarrier is assigned to only one ONU in same time slot. The constraint conditions of *TGT*, t^k_{start} and t^k_{end} for each ONU in one subcarrier channel are shown in Eq. (7).

2.3. The theoretical minimum total grant time

From the definition of *TGT*, if each ONU is assigned multiple subcarrier channels to transmit simultaneously, *TGT* will become small. In other words, the minimum *TGT* can be achieved when all ONUs occupy as many subcarrier channels as possible for transmission. Therefore, we can derive the theoretical minimum of *TGT* in the OFDM-PONA system, which is denoted as

$$TGT_{min}=\sum_{k=1}^{K}\mathrm{ceil}(d(k)/M) \tag{8}$$

It is noted that the theoretical minimum *TGT* is independent of U. In fact, from Eq. (8), each ONU can get the minimum grant time when all subcarrier channels are assigned to one single ONU. For example, in Fig. 2, there are three subcarrier channels and four ONUs. The requirement of each ONU is 1, 4, 2, and 4 respectively. The minimum *TGT* can be calculated is 1+2+1+2=6. The blank spaces in Fig. 2 would reduce U. After calculating TGT_{min}, we can

Table 1
Symbol definitions.

Symbol	Definition
K, k	K ($K>1$) is the total number of ONUs; k is ONU-ID
L	L is the optimal schedule length per scheduling cycle
$d(k)$	Time slots requested by the $ONU-k$ in one scheduling cycle time
U, TGT	U is channel utilization; TGT is the total grant time
M, m	M ($M>1$) is the total number of subcarrier channels; m is the index of subcarrier channel
D_{min} D_{max}	D_{max} and D_{min} respectively are the evenly distributed upper bound and lower bound
TGT_{min}	The theoretical minimum of TGT