ARTICLE IN PRESS

The Korean Institute of Communications and Information Sciences

Available online at www.sciencedirect.com

ScienceDirect

ICT Express ▮ (▮▮▮▮) ▮▮▮–▮▮▮

www.elsevier.com/locate/icte

Optimal dynamic subcarrier allocation for dual-band OFDMA-PON supporting integrated fronthaul and backhaul in 5G networks

Yazan M. Allawi[a,*], Geun Young Kim[a], Jungbum Cho[a], Ahmad G. Reza[b], Yongsoo Na[a], June-Koo Kevin Rhee[b]

[a] *Innovative Technology R&D Center, HFR, Inc. for Mobile Internet, Gyeonggi-do, Republic of Korea*
[b] *Electrical Engineering Department, KAIST, Daejeon, Republic of Korea*

Received 27 November 2016; received in revised form 14 August 2017; accepted 25 September 2017
Available online xxxx

Abstract

We propose a novel dynamic subcarrier allocation (DSCA) design for dual-band orthogonal frequency division multiple access passive optical network (DB-OFDMA-PON), supporting integrated fronthaul and backhaul services, given their stringent requirements in emerging 5G networks. An optimization problem is formulated to maximize both the bandwidth utilization and QoS guarantees. The simulation results show that our proposed DSCA achieves the desired statistical multiplexing gain and high performance in terms of throughput and delay.

Keywords: Backhaul; Dynamic subcarrier allocation; Fronthaul; Dual-band OFDMA; Passive optical network

1. Introduction

Recently, orthogonal frequency division multiple access (OFDMA) has been introduced as a potential candidate for future passive optical network (PON) systems, owing to its capability to provide high spectral efficiency that can suffice the 5G mobile fronthaul (FH) and backhaul (BH) requirements [1]. While this gives OFDMA-PON an upper hand in terms of aggregate data rates compared to other access technologies, it provides more flexibility for network design with finer granularity for bandwidth allocation as an additional advantage to 5G mobile network operators [2]. Moreover, the PON configuration is more efficient in terms of both capital and operational expenditures, when the remote radio heads (RRHs) of optical network units (ONUs) are connected to a single baseband unit (BBU) of the optical line terminal (OLT). Here, ONU and OLT in the context of PON correspond to remote terminal (RT) and central office terminal (COT), respectively [3,4].

On the other hand, dual-band (DB) OFDMA-PON, which consists of multiple OFDM symbols multiplexed with different carrier frequencies, has been considered as a favorable architecture as it can mitigate the implementation cost for single-band OFDMA-PON systems, such as high-speed digital-to-analog and analog-to-digital converters, expensive radio frequency (RF) components, and broadband digital signal processing [5]. The main principle of the DB-OFDMA-PON approach is to divide the entire bandwidth offered by a COT into two non-overlapping bands, and have each RT equipped with an RF local oscillator (LO) tunable to the band of interest. Different state-of-the-art designs have been proposed for cost-effective DB-OFDMA-PON [5–8]. In this paper, we present our DB-OFDMA-PON system architecture, which consists of a COT connecting a number of RTs as illustrated in Fig. 1, targeting the accommodation of heterogeneous high speed FH and BH services in a cost-effective manner.

One of the challenges for the realization of this proposal is to achieve DSCA that is capable of providing the desired

* Corresponding author.
E-mail addresses: yazanma@kaist.ac.kr (Y.M. Allawi), rhee.jk@kaist.ac.kr (J.K. Rhee).
Peer review under responsibility of The Korean Institute of Communications Information Sciences.

https://doi.org/10.1016/j.icte.2017.09.001

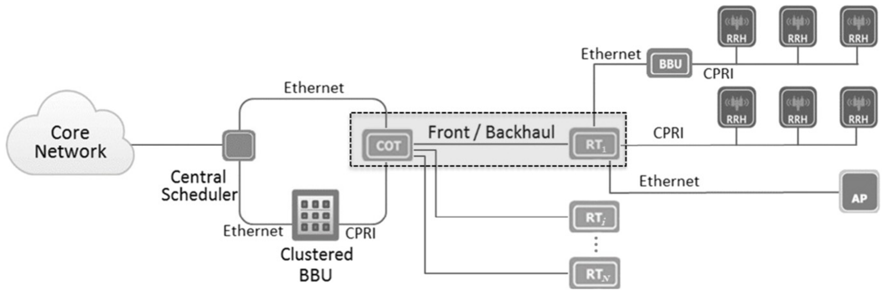

Fig. 1. Illustration of the proposed DB-OFDMA-PON system architecture.

QoS and efficiently utilizing system bandwidth in the framework of multiple frequency bands. The DSCA problem in a DB-OFDMA-PON system is an optimization model to find the optimal frequency band and size of subcarrier (SC) allocations for each RT, and their grouping for each band in order to maximize both bandwidth utilization and QoS guarantees. We propose a novel DSCA algorithm to perform the *Initial Allocation* and *Allocation Adjustment* of SC in real time, in compliance with the strict requirements of the targeted services. This paper provides brief reviews on the existing DSCA schemes and our proposed DSCA algorithm, followed by numerical results.

Table 1
FH and BH service types and requirements.

Service type	S_k	Non-compressed	Compressed	Rate (Mbps)	N^k_{SC}
FH	S_1	CPRI-2	CPRI-3	1114.112	11
	S_2	CPRI-3	CPRI-5	2228.224	22
	S_3	CPRI-5	CPRI-7	4456.448	43
	S_4	CPRI-7	–	8912.900	86
BH	S_5	GbE	–	1114.112	11
	S_6	10GbE	–	11141.12	107

2. Background

Bandwidth allocation in OFDMA-PON systems, which is referred to in literature as subcarrier allocation (SCA) problem, has received considerable attention in recent years. One of the earliest research efforts in this field [9] proposed two SCA algorithms. The first is the dynamic circuit transmission (DCT) algorithm, which involves frequency-domain-only bandwidth allocation and employs three-way signaling with connection admission control (CAC) for effective bandwidth estimation. While DCT has simple signaling requirements, it is suitable only for non-bursty traffic scenarios. The second algorithm presented in [9] is the fixed burst transmission (FBT) in which simple round-robin scheduling and interleaved polling with adaptive cycle time (IPACT) algorithms are used to realize time-slot granularity of hybrid OFDMA/TDMA. However, FBT has a limited performance in terms of satisfying the QoS requirements. The work in [10] proposed an asynchronous dynamic SCA (A-DSCA), which dedicates a fixed number of SCs to be exclusively used for control and management signaling to achieve statistical multiplexing gain among the RTs, eliminating the need for synchronization. However, this scheme requires frequent exchange of report messages (every 10.5 µs), which increases computation complexity at the COT and results in non-negligible overhead in the upstream.

In another DSCA, which was proposed in [11], status reporting from RTs is not required, as it monitors their queue status with respect to the quality of service (QoS) and service level agreement (SLA). This provides a simpler MAC design with QoS-awareness. However, low priority RTs may suffer from long end-to-end delay. To alleviate these shortcomings, the same authors proposed two hybrid OFDMA/TDMA based algorithms in [12]; a monitoring-based sequential DSCA (S-DSCA) in which the COT allocates bandwidth by monitoring the utilized time slots, and a reporting-based S-DSCA where each RT is polled periodically to report the utilization of bandwidth. Both the algorithms are capable of providing fine granularity and enhanced QoS compliance, at the cost of monitoring or reporting. Fixed SCA (FSCA) should be considered as an option when only FH services are considered or when the provisioned BH services are always allocated sufficient resources. For instance, FSCA has been employed alongside different DSCA to operate in an alternative mode [11,12].

The DSCA design considerations in our DB-OFDMA-PON system emphasize the objective of a DSCA algorithm to efficiently distribute the available system capacity among the competing RTs so that better QoS performance is achieved under the physical layer constraints of our proposed DB-OFDMA-PON shown in Fig. 1. Specifically, having two non-overlapped frequency bands, on which SC-blocks can be allocated based on service demands by RTs, introduces a new challenge that has not been addressed in existing single-band OFDMA-PON SCA algorithms [9–13]. Fig. 2 depicts in detail, an example with four RTs, each of which has a different set of services randomly selected from Table 1. In this example, the system is assumed to have 128 SCs in each band with a 104.448 Mbps throughput per SC.

Using any of the methods discussed earlier (i.e., monitoring, reporting, or dedicated control subcarriers), a COT can determine the number of SCs that need to be allocated to each of its associated RTs. Fig. 2(b) shows how 256 SCs, which are available on both high and low frequency bands, can be utilized when the provisioned SC-blocks of each RT are allocated in the order of the RT ID. While this sequential (SEQ) allocation would yield high utilization in conventional single-band OFDMA-PONs, as in [11] and [12], it is not so in the case

Please cite this article in press as: Y.M. Allawi, et al., Optimal dynamic subcarrier allocation for dual-band OFDMA-PON supporting integrated fronthaul and backhaul in 5G networks, ICT Express (2017), https://doi.org/10.1016/j.icte.2017.09.001.