Bidirectional MB-OFDM Ultra-wideband WDM Access Networks Using a Time Frequency Code Scheme

Hao-Yu Chan, Heng-Te Li, Chia-Wei Chao, and Wen-Piao Lin
Department and Graduate Institute of Electrical Engineering, Chang Gung University, Taiwan, R.O.C.
E-mail: m9621005@stmail.cgu.edu.tw, wplin@mail.cgu.edu.tw

Abstract—This study proposes a novel time frequency code (TFC) scheme for a bidirectional multiband orthogonal frequency division multiplexing (MB-OFDM) ultra-wideband (UWB) wavelength division multiplexing (WDM) access network. The network can avoid the interference by using different TFCs under bidirectional transmission in the same wavelength. By the way, Fabry–Perot laser diodes and multi mode fibers are adopted in the access ring due to cost down and increase number of optical network units (ONUs). Moreover, we set up an experimental system to demonstrate that the proposed scheme can indeed provide many advantages of very low-cost, simple structure and reducing wavelength usage for practically bidirectional high-speed wireless MB-OFDM UWB WDM access networks.

Index Terms—time frequency code (TFC), bidirectional MB-OFDM, ultra-wideband (UWB), WDM access network

I. Introduction

Recently, fiber to the home (FTTH) has been popularly used to provide high speed wireless access and personal-area multimedia services to a large number of subscribers. Ultra-wideband (UWB) radio-over-fiber (RoF) is an attractive solution for broadband services. The research and development is focused on passive optical network (PON), such as time-division-multiplexing PON (TDM-PON) and wavelength division multiplexing-PON (WDM-PON). However, TDM-PON systems have to use framing technology and complex scheduling algorithms to support different applications. WDM-PON still lacks the flexibility to dynamically allocate the bandwidth among the optical network units (ONUs), which is a promising approach to meet the requirements of future access networks [1-4]. Moreover, UWB was defined by FCC that main frequency band is from 3.1 to 10.6 GHz with a maximum equivalent isotropic radiated power (EIRP) of -41.3 dBm/MHz.

Multiband orthogonal frequency division multiplexing (MB-OFDM) system is more efficient at capturing multipath energy than an equivalent single-carrier system using the same total bandwidth. MB-OFDM modulations possess additional desirable properties, such as high spectral efficiency, inherent resilience to narrow-band RF interference, and spectral flexibility. MB-OFDM is divided the UWB band to be the smaller 14 sub-bands. Each sub-band has 528MHz and contains 128 subcarriers. The MB-OFDM standard defines both an UWB physical layer (PHY) and medium access control (MAC) and supports data rates from 53.3 to 480 Mb/s [5-7]. In this study, we propose a new time frequency code (TFC) scheme for a bidirectional MB-OFDM wireless access network. We measure the actual transmission package error rate (PER) and various wireless transmission distances on an ONU cascade ring under up/downstream transmission simultaneously using only one wavelength.

II. Architecture

A bidirectional TFC-based MB-OFDM ring access network architecture is shown in Fig.1. The optical line terminal (OLT) use distributed feedback laser diode (DFB-LD) with a wavelength of 1550nm for downstream. The Wisair DV9110 development kit (DVK) is used to generate MB-OFDM signals. The operation band of the kit is band group 1 from 3.168GHz to 4.752GHz. The hopping sequence is used a regular sequence as \( f_1, f_1, f_1, \ldots (\text{TFC 5}) \) and \( f_3, f_3, f_3, \ldots (\text{TFC 7}) \). The offered data rate is from 53.3 to 480 Mbps. In this architecture, we design one ONU by one end user. Moreover, each user is allotted different TFC to up/downstream transmission. Here, two different TFCs are applied for three cases of up/downstream. Case 1 is the downstream transmitted TFC 5 and TFC 7 simultaneously, and we
surveyed the downstream PER of ONU2’s end user in TFC 5. Case 2 is the upstream transmitted from ONU1’s end user by using TFC 7 and ONU2’s end user by using TFC 5 simultaneously and then the upstream PER of TFC 5 from ONU2’s end user is measured. Case 3 is two end users operation on ONU2 simultaneously. TFC 5 is for downstream, and TFC 7 is transmitted by ONU2’s end user 2. The downstream PER is surveyed at ONU2’s end user1 node. After MB-OFDM signals directly modulated in DFB laser, erbium-doped fiber amplifier (EDFA) is used for amplifying optical signal, and then the up/downstream data was divided by first optical circulator. Arrayed-waveguide grating (AWG) is proposed as routing device to multiplex and de-multiplex the optical channels transmitted along the fiber to ONU. Figure 2 shows the ONU ring and end user block diagrams. The optical signal is demodulated by photo diode (PD) to electric MB-OFDM signal. The MB-OFDM data was separated into two parts by a splitter. One emits by UWB antennas over the indoor wireless channel environment and received signal by another received UWB antenna of end user. Another and end user’s upstream data are combined to new signals with up/downstream data, which was transmitted by FP-LD over MMF to next ONU. So we can cascade many ONU’s to become the architecture of ring. The last DFB-LD of OUN have to use temperate controller to tune the same wavelength as DFB-LD of OLT, and then transmitted total signal including up/downstream data of every ONUs in same way from OLT to second optical circulator.

![Fig.2. Block diagrams of (a) ONU ring and (b) end user.](image)

III. Measurement Results and Discussion

To generate MB-OFDM signal, we used a Wisair DV9110 DVK which just supported band group 1. Fig. 1 and Fig. 2 show the experimental setup to demonstrate our proposed system. The band group has three sub-bands. Each sub-band has 528MHz and contains 128 subcarriers. Each sub-band center frequency $f_1$, $f_2$, $f_3$ is 3432, 3960 and 4488 MHz, respectively. The band group provided seven kinds of TFCs. Agilent E4446A spectrum analyzer is operated to observe the spectrum of TFC 5 ($f_1$, $f_1$, $f_1$,....) and TFC 7 ($f_3$, $f_3$, $f_3$,....) in Fig.3.

![Fig.3. The spectrum of TFC 5 and TFC 7.](image)

In case 1 we measured the downstream PER of ONU2’s end user in TFC, when the downstream transmitted TFC 5 and TFC 7 simultaneously. In other words, TFC 7 signal be the noise of TFC 5 and measured PER of the downstream for ONU2’s end user. Fixed data rate 200 Mbps for TFC 7 from OLT. Besides, set four various data rates (53, 106, 200 and 480 Mbps) for TFC 7. Set up the end user of ONU2 in general indoor environment with different wireless transmission distances from 1 to 3 m.

![Fig.4. PER versus wireless transmission distance of ONU2’s end user from OUN2 in case 1.](image)
By measurement result was shown as Fig.4. When the downstream data rate was 480 Mbps, the wireless transmission could arrive 2 m. The packet error rate (PER) can tallied with IEEE TG3a technical requirement (PER<8%) [8]. Moreover, when the data rates were set for 106 Mbps and 53 Mbps, the wireless distance could get beyond 3 m. So we obtained that TFC 7 and TFC 5 can transmit in fiber and radiate in air with low interference. The SMF and MMF were set a short length.

In case 2 the upstream transmitted from ONU2’s end user by using TFC 5 and ONU1’s end user by using TFC 7 simultaneously. The upstream PER of TFC 5 from ONU2’s end user is surveyed. That is to say, the TFC 7 was to be noise of TFC5. Set the TFC 7 of upstream data rate to 200 Mbps and wireless distance 1 m between end user of ONU1 and end user 2. In Fig. 5, we observe that change the wireless distance of 0-1 m and data rate of 200-480 Mbps. The PER increases very rapid and the low speed as 53 Mbps and 106 Mbps is still kept stable. About PER increasing very rapid the reason could be that MB-OFDM signal was distorted by interference and attenuation in wireless channel.

In case 3 ONU2 has two end users. TFC 5 was for downstream and TFC7 was transmitted by ONU2’s end user 2. The downstream PER is measured at ONU2’s end user 1 node. The data rate of 200 Mbps was set for TFC 7 and fixed the distance between OUN2 and each end user. Moreover observe PER varying with the wireless distance 1 m between end user1 and end user 2 in Fig.6. Experimental results can be seen that the link quality would be impacted by TFC 7 when the wireless distance between end user1 and end user 2 was to be shorter than 30 cm at 200 Mbps. The link quality of 106 Mbps would be influenced by TFC 7 when the wireless distance was to be shorter than 5 cm. Finally, when 53 Mbps link quality would interfere, the wireless distance between end user 1 and end user 2 was to be shorter than 3 cm.

IV. Conclusion

We have successfully demonstrated optical and wireless transmission in a bidirectional MB-OFDM UWB WDM access network. The use of ring architecture increases number of ONUs by cascading ONUs. In addition, we utilized FD-LD and MMF in ring structure to effectively reduce the system cost. In order to reduce the wavelength usage, the different TFCs for up/downstream can avoid the interference in the same wavelength. Finally, according to the experimental results we found that the signal interference of the wireless transmission was more serious than that of the optical transmission under same noise.

V. References