

A novel ECDM-OFDM-PON architecture for Next-Generation optical access network

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Abstract: This paper proposes a novel architecture for next-generation passive optical network (PON) based on electrical code division multiplexing orthogonal frequency division multiplexing (ECDM-OFDM) access. The feasibility of bidirectional transmission with the same wavelength has been experimentally demonstrated under this architecture. An error-free transmission of two PON channels has been successfully demonstrated in the experiment.

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1. Introduction

Orthogonal frequency division multiplexed passive optical network (OFDM-PON) has been regarded as a promising solution for future broadband access networks due to its high spectrum efficiency, large dispersion tolerance and the flexibility on both multiple services provisioning and dynamic bandwidth allocation [1–11]. Recently, many researches and developments focus on OFDM-PON, such as hybrid wavelength division multiplexing-orthogonal frequency division multiplexing PON (WDM-OFDM-PON) [2–5] and hybrid time division multiplexing-orthogonal frequency division multiplexing PON (TDM-OFDM-PON, also called OFDMA-PON) [8–10]. However, the WDM-OFDM-PON systems need many high speed OFDM transceivers and arrayed waveguide gratings to allocate the bandwidth among the optical network units (ONUs), which will not only increase the system cost and complexity but also lacks the flexibility to dynamically allocate the resources among different services and ONUs. The TDM-OFDM-PON systems enable dynamic bandwidth allocation among different services and ONUs, but it still needs to be improved, such as the interference between different ONUs and insecurity on the physical layer, which is caused by the broadcast downstream transmission. In addition, due to the beat noise problem, the TDM-OFDM-PON system has to allocate different wavelength for upstream traffic of each ONU, which will cause the system to use several lasers at the OLT or ONU [8–10,12]. Electrical code division multiple access (ECDMA) technologies have many attractive features such as high power budget, secure physical layer, small interference between different users and low beat noise among different channels [13,14].

In this paper, we propose and experimentally demonstrate a novel architecture based on hybrid electrical code division multiplexing-orthogonal frequency division multiplexing passive optical network (ECDM-OFDM-PON). This architecture enables different ONUs/services to occupy same subcarriers at the same time, and can eliminate the interference between different ONUs/services due to the high code-correlation. In addition, due to the high code-gain, it can combat the loss at the power splitter so as to support more ONUs, and mitigate the beating noise among different ONUs. A 5-Gb/s ECDM-OFDM signal for two ONUs is transmitted in the ECDM-OFDM-PON to validate the architecture feasibility. An error free 20-km transmission of both downstream and upstream signals is demonstrated in our experiment.

2. System model

The proposed configuration combines ECDM technology and OFDM-PON, where the OFDM subcarriers can be dynamically assigned to different ONUs or services in different code chips. The data streams are orthogonal to each other in both code chips and subcarriers, which cannot only eliminate the crosstalk between the sub-channels, but also ensure the security of the data. In ECDM-OFDM-PON, each ONU is allocated with one sub-channel including one specific code chip and one or more subcarriers. The subcarriers can be used for different services, such as voice/video signal, point to point (P2P) and WiMax signals.

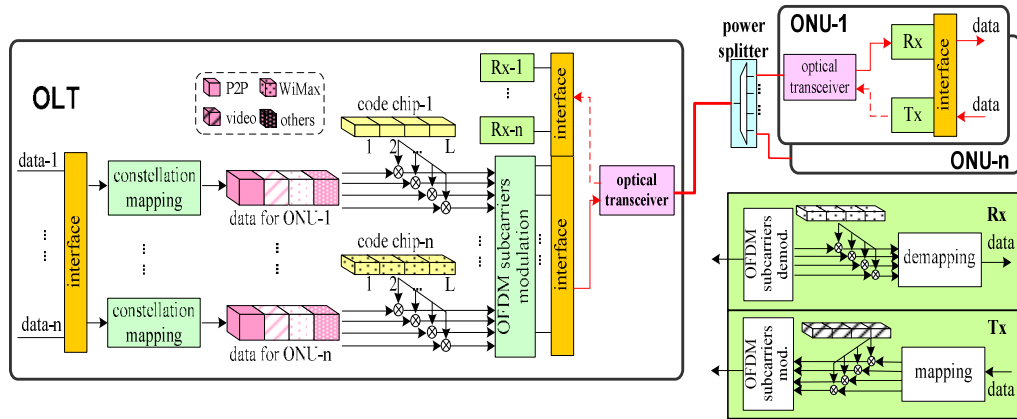


Fig. 1. The proposed architecture of ECDM-OFDM-PON.(L denotes the length of the code chip.)

Figure 1 shows the architecture of the network. After constellation mapping, the downstream channels are spread spectrum with code chips, and then allocated to the given subcarriers to generate the OFDM frame, which realized by inverse fast Fourier transform (IFFT). OLT controls the code chips and subcarriers allocation for each ONU according to different service demands. The OFDM frame is converted to optical OFDM signal in the optical transceiver. Since there is only one laser used, no optical beating noise exists. When the signals reach the ONUs, each ONU extracts its own data from the proper subcarriers with its code chip.

For upstream traffic, each ONU executes the data mapping and assigns the data to the given subcarriers and code chip. After the optical transceiver, the optical OFDM signals from ONUs will be combined and transmitted to the OLT. Due to the orthogonal nature of code chip and OFDM subcarriers, the interference from other ONUs can be minimized. In addition, the beat noise can be suppressed attributed to the code gain, so one wavelength is enough for all ONUs.

3. Experiment and results

3.1 Downstream setup

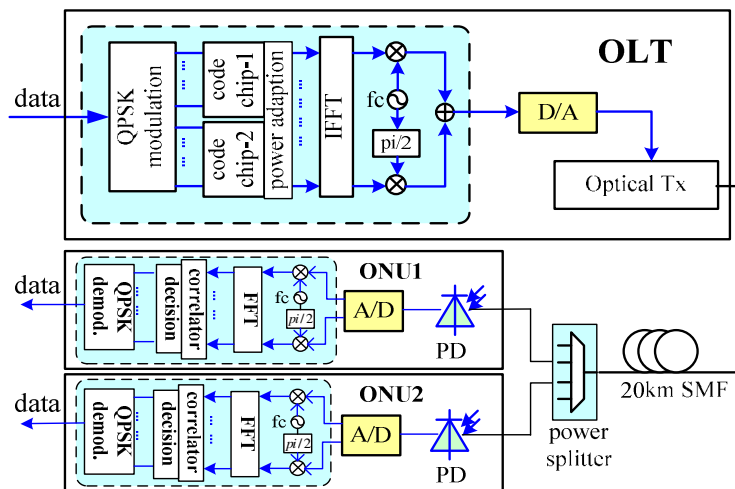


Fig. 2. Downstream experimental setup.

Figure 2 shows the experimental setup of downstream for two users to validate the above architecture. The ECDM-OFDM signal is generated by Matlab programming and uploaded into an Arbitrary Wavelength Generator (AWG) for 10-bit D/A conversion. PRBS sequence at $2^{23}-1$ is QPSK mapped and two 8-bit-length Walsh code chips are assigned to ONU1 and ONU2 for signal spreading respectively. Walsh code is defined using a Hadamard matrix of order $2L$, and the spreading Matrix is given by

$$W_{2L} = \begin{pmatrix} W_L & W_L \\ W_L & -W_L \end{pmatrix}, \quad W_1 = (1) \quad (1)$$

It is assumed that $u[k]$ and $v[k]$ are the QPSK data symbols, where k denotes the k^{th} symbol. Then the symbols are spread using Walsh code W . After power adaption, the encode signals are mapped into the OFDM subcarriers through IFFT. The k^{th} OFDM symbol can be written as

$$S_{ik} = \sum_{m=1}^M \sum_{i=1}^{N-1} \{u[k]W_m + jv[k]W_m\} \exp(j2\pi f_i k / N) \quad (2)$$

where m is the m^{th} user and f_i denotes the i^{th} subcarriers of OFDM signal. In our experiment, the IFFT size is 256, and 48 subcarriers unfilled for over sampling, 8 pilots for phase estimation. The length of cyclic prefix is 1/16 of symbol time, and the signal is up-converted by digital I-Q modulation to 2GHz. The information for all ONUs are mapped into the OFDM symbols, and then a training sequence is inserted every 60 OFDM symbols for time synchronization and channel estimation. The training sequence is an OFDM symbol with the same parameters as data symbol, which can estimate every subcarrier more accurately. In our experiment, the subcarriers allocated to ONU1 and ONU2 are the same. The 5-Gb/s downstream signals are fed into the optical transmitter, which consisting of an intensity modulator plus a DFB laser at 1551.9nm. The Tx power is set to be 5dBm.

After 20-km transmission, the downstream signal is divided by a power splitter and delivered to ONU1 and ONU2 respectively. At the ONU, the signal is fed into a 10GHz PIN PD for O/E conversion, and then sampled by a 20-GS/s real-time scope for Matlab processing to recover the bit stream. For the down-converted signal, we adopt 4-Tap Butterworth filter, and the LMMSE is employed for estimation. The received signal is picked out from subcarriers through FFT, and then correlated with its dedicated code chip. Thanks to the orthogonal nature of the Walsh code, the right data can be extracted from the downstream signal and the interference of the two ONU can be eliminated.

3.2 Upstream setup

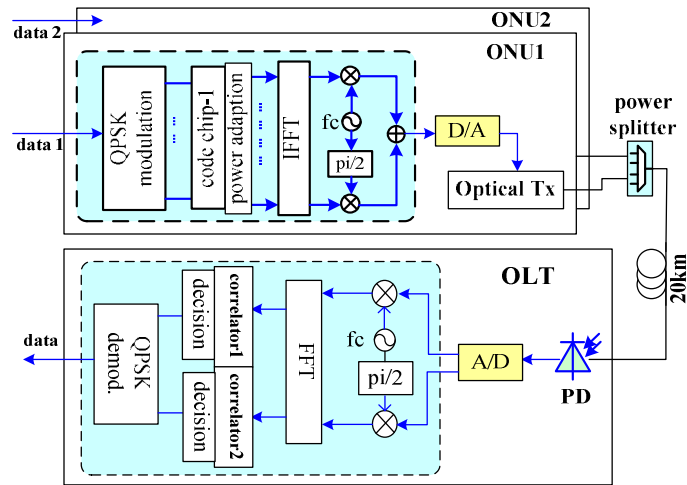


Fig. 3. Upstream experimental setup.

The experimental setup of upstream traffic is illuminated in Fig. 3. Two 2.5-Gb/s ECDCM-OFDM signals are generated offline and up-converted to 1GHz using digital I-Q modulation. Then the waveforms are produced through the AWG at 10-bit DAC. QPSK is used to map bit stream, and the total upstream rate of ECDCM-OFDM-PON is 5-Gb/s. Two directly modulated lasers at 1551.9nm are used as the transmitter at ONUs, and the output power of the lasers are 2dBm.

At OLT, the upstream signal is detected by a 2.5GHz APD photodiode, and then demodulated with the same mechanism as the downstream signal.

3.3 Results

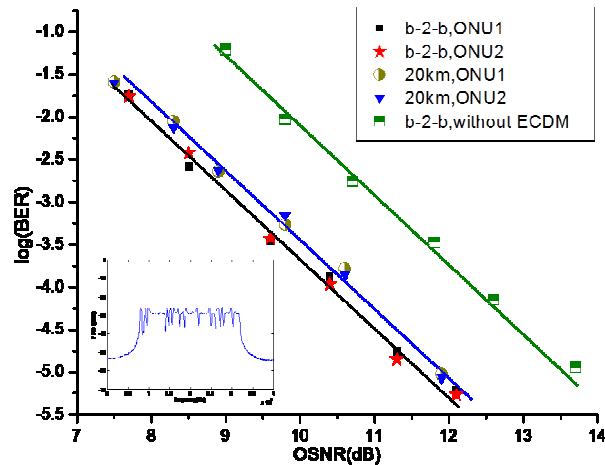


Fig. 4. BER curves at different ONU and electrical spectrum of ECDCM-OFDM downstream signal (inset).

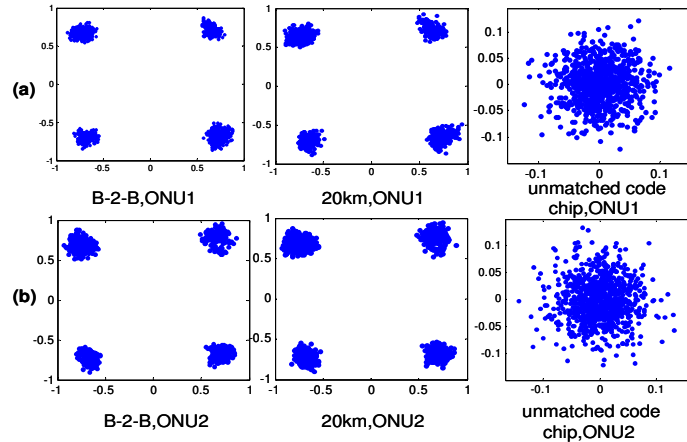


Fig. 5. Constellation maps of downstream signal.

Figure 4–6 show the 5-Gb/s ECDM-OFDM-PON signals performance. The electrical spectrum of downstream signal is shown in Fig. 4 as inset, where we can see the total bandwidth is 2.5-GHz. Figure 4 shows the downstream BER performance at ONU1 and ONU2, and there is about 0.2dB OSNR penalty with and without transmission, which almost can be ignored. Figure 4 also depicts the BER curve of OFDM signal without ECDM at the B-to-B scenario, which also operates at 5-Gb/s. There is about 2dB OSNR improvement when we adopt ECDM coding in the same scenario, which is mainly due to the code gain. However, we just demonstrate two ONUs in our experiment, so the useful data in one OFDM symbol is just 1/4 comparing with the ordinary OFDM signal in this condition, while the nominal transmitted rate is 5-Gb/s. As the ONUs increasing, the useful transmitted data would be equivalent to the ordinary OFDM because the ONUs can share the same bandwidth due to ECDM coding. Figure 5 shows the constellation maps of received signal at different ONU. When the code chip does not match the one allocated at the OLT, it cannot get the correct signal.

Figure 6 depicts the BER performance of the upstream signals, and the dispersion penalty also can be ignored. BER of 10^{-9} or less can be obtained with the help of FEC. Error free transmission has achieved for two users.

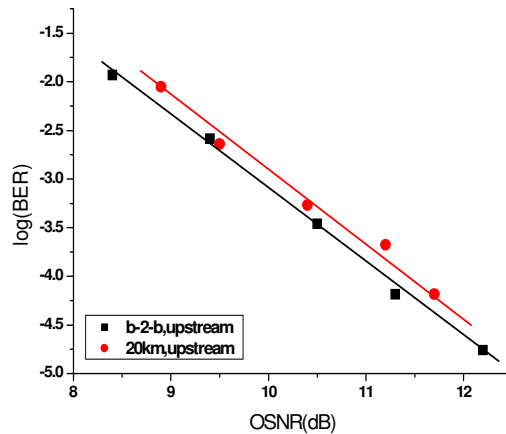


Fig. 6. Measured BER of upstream signal.

In the ideal synchronization condition, there can be eight ONU channels with the code length of 8 bit in our experiment. In the ECDM-OFDM-PON architecture, the ONUs can

share the same bandwidth or OFDM subcarriers due to ECDM coding, so the spectral efficiency will increase when we increase the number of ONUs.

4. Conclusion

We have proposed a novel ECDM-OFDM-PON architecture for different services with higher security physical layer and power budget. We also experimentally demonstrate a 5-Gb/s ECDM-OFDM-PON architecture with two PON channels. The OSNR penalty is about 0.2dB for both downstream and upstream traffic after 20-km SMF fiber. There is 2dB OSNR improvement comparing with the scenario without ECDM coding.

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