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# Experimental demonstration of IDMA-OFDM for passive optical network

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ABSTRACT

We present interleave division multiple access (IDMA) scheme combined with orthogonal frequency division multiplexing (OFDM) for passive optical network, which offers improved transmission performance and good chromatic dispersion tolerance. The interleavers are employed to separate different users and the generated chips are modulated on OFDM subcarriers. The feasibility of IDMA-OFDM-PON is experimentally verified with a bitrate of 3.3 Gb/s per user. Compared with OFDMA, IDMA-OFDM offers 8 and 6 dB gains in term of receiver sensitivity in the cases of 2 and 4 users, respectively.



## 1. Introduction

Passive optical network (PON) is considered as a very promising method to implement a fiber-to-the-home (FTTH) system [1–3]. The exponential growth of global communications nowadays demands next generation PON with high spectral efficiency and high data rates. Currently most deployed PONs are gigabit PON (GPON) and Ethernet PON (EPON), both of which suffer from high transmission impairment because of chromatic dispersion when the data rate is beyond 10 Gb/s. Owing to their high spectral efficiency, good chromatic dispersion tolerance, flexible and dynamic bandwidth allocation as well as the ability to adapt to frequency dependent channel quality with simple single-tap equalization [4–6], the orthogonal frequency division multiplexing (OFDM) based PONs including orthogonal frequency division multiple access (OFDMA), wavelength division multiplexing (WDM)-OFDM-PON, time division multiplexing (TDM)-OFDM-PON and code division multiple access (CDMA)-OFDM PON [7–11] are investigated as promising solutions for future optical access. TDM-OFDM-PON suffers from transmission impairments at higher transmission speeds caused by burst synchronization and interference between different optical network units (ONUs). WDM-OFDM PON is impressive for its high data rate but is relatively expensive and complex due to the use of high-cost optical components, such as arrayed waveguide gratings. The management of wavelengths of ONUs is a key technical challenge for OFDMA-PON [12,13]. CDMA-OFDM-PON has many attractive features, such as high power budget margins, a secure physical layer and good chromatic dispersion tolerance.

In this paper, we experimentally demonstrate interleave division multiple access (IDMA) scheme combined with OFDM for PON, in which the interleavers are employed to separate different ONUs and the generated chips are modulated on OFDM subcarriers (SCs). IDMA incorporates all the attractive features of CDMA and it also provides some excellent features such as low complexity detection for systems with large numbers of users and improved transmission performance [14,15]. The concept of IDMA-OFDM has already been widely applied in wireless communications [16], uplink PON [17], uplink visible light communication (VLC) systems [18]. The feasibility of IDMA-OFDM-PON is experimentally verified with a bitrate of 3.3 Gb/s per user. Compared with OFDMA, IDMA-OFDM offers 8 and 6 dB gains in term of receiver sensitivity in the cases of 2 and 4 users, respectively.

## 2. Technique principle

Fig. 1 shows the schematic diagram of downstream IDMA-OFDM-PON with $K$ users. In the transmitter (Tx), the source data for each user is fed into a spreader for the purpose of bandwidth expansion. The bits after spreading are usually called chips. Then a unique interleaver ($\pi_k$) is allocated to user $k$ ($k = 1, 2, \dots K$), which is used as the only means to separate different users. Moreover, burst error control can be achieved by dispersing the sequences of the chips randomly using the interleavers. After interleaving, chips from all users ($x_k$, $k = 1, 2, \dots K$) are combined and then converted to OFDM symbols with inverse discrete Fourier transform (IDFT) operation. Cyclic prefix (CP) and preamble are inserted to combat chromatic dispersion induced inter-symbol interference (ISI) and for channel estimation, respectively. The

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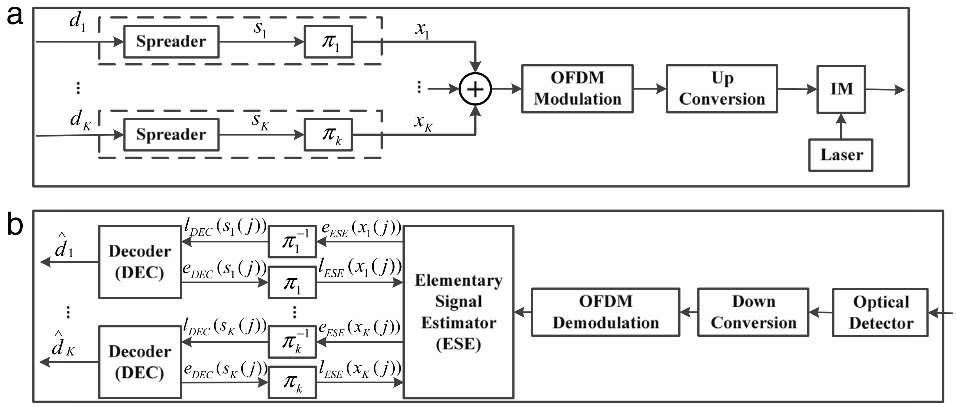


**Fig. 1.** Block diagram of (a) transmitter and (b) receiver for IDMA-OFDM-PON.

generated baseband OFDM signal is up-converted in order to generate a real-valued signal for intensity modulation (IM) of the laser. After fiber transmission, the optical IDMA-OFDM signal is detected by an optical detector at the receiver and then down-converted to baseband. After frame synchronization, the signal is sent to the OFDM demodulation module, which consists of discrete Fourier transform (DFT) operation, CP removal and channel equalization. The decoded signal is sent to the IDMA iterative decoding module, which consists of an elementary signal estimator (ESE) and $K$ posterior probability decoders (DECs). The received signal after perfect channel equalization can be written as:

$$r(j) = \sum_{k=1}^{K} x_k(j) + n(j), \tag{1}$$

where $n(j)$ is the noise term. The outputs of ESE are extrinsic logarithm likelihood ratios (ELLRs) for each user, which can be written as:

$$e_{ESE}\left(x_k(j)\right) = 2\frac{r(j) - E(r(j)) + E\left(x_k(j)\right)}{Var(r(j)) - Var\left(x_k(j)\right)} \quad (k = 1, 2 \ldots K). \tag{2}$$

Then the ELLR for $k$-th user is fed into its unique de-interleaver to get a priori logarithm likelihood ratio (PLLR) $l_{DEC}(s_k(j))$ for the DEC. After the DEC, the transmitted data bits and the ELLR of DEC $e_{DEC}(s_k(j))$ for $k$-th user can be obtained. $e_{DEC}(s_k(j))$ is interleaved again to obtain $l_{ESE}(x_k(j))$. $l_{ESE}(x_k(j))$ is regarded as the PLLR to update the ELLR $e_{ESE}(x_k(j))$ for the next iterative decoding process. The mean values and variances in (2) can be calculated as:

$$E\left(x_k(j)\right) = \tanh\left[\left(l_{ESE}\left(x_k(j)\right)\right)/2\right], \tag{3}$$

$$Var\left(x_k(j)\right) = 1 - \left(E\left(x_k(j)\right)\right)^2, \tag{4}$$

$$E(r(j)) = \sum_{k=1}^{K} E\left(x_k(j)\right), \tag{5}$$

$$Var(r(j)) = \sigma^2 + \sum_{k=1}^{K} Var\left(x_k(j)\right). \tag{6}$$

When the maximum iterative number we set is achieved, DEC output the final decoded data bits for all the users.

In the OFDM demodulation module, the channel equalization and DFT cost $1+\ \log_2 N/2$ multiplications per symbol, where $N$ is the number of employed subcarriers. The operation in (5) and (6) are shared by all users, costing two additions per coded bit. Overall, the ESE operations in (2)-(6) cost one tanh operation, four multiplications and six additions per coded bit per user. The cost per information bit per user is independent of the number of users $K$. Since iterative operation is required to obtain better performance, the increased cost per user are $L$ tanh operations, $4 \times L$ multiplications and $6 \times L$ additions for IDMA-OFDM compared with the OFDMA scheme, where $L$ is the number of iterations.

## 3. Experiment setup and results

Fig. 2 shows the experimental setup for IDMA-OFDM-PON. For each user, the generated data bits are spreaded before interleaving. The bitrate of each user is 3.3 Gb/s. The IDMA signals are combined and then modulated on OFDM SCs. The IDMA-OFDM signal is three times up-sampled and up-converted to 2.5 GHz by means of digital I-Q modulation and then uploaded into an arbitrary waveform generator (AWG) operating at 10 GS/s. This ensures the generated signal is real value, which can be used for IM of the laser. Note that the frequency of the RF carrier is $f_s/4$, where $f_s$ is the sampling rate of the AWG. The DFT and CP sizes are 256 and 8, respectively. The output of the AWG is used for IM of the laser. The wavelength of the laser is set to 1550 nm and the transmitted optical power is about 10 dBm. The optical network is emulated with 20 km single mode fiber (SMF), a variable optical attenuator (VOA) and a 50/50 coupler. At the receiver, the optical signal is detected by a photo-diode, the output of which is captured by a scope operating at 25 GS/s. The sampled IDMA-OFDM signals are decoded offline as shown in Fig. 1(b). All the key system parameter is provided in Table 1.

Fig. 3 shows the average bit error rate (BER) for downstream IDMA-OFDM-PON with 2 users after 20 km SMF. Note that, the BER performance improves with the increasing number of iterations. The optimum iteration is 5 beyond which there is no further improvement, e.g. at a BER of $10^{-3}$ the optical power penalties are very high and $\sim 0.3$ dB for the 1 iteration and 3 iterations, respectively when compared to 5 and 10 iterations. The bitrate per user is 3.3 Gb/s and the total bitrate is 6.6 Gb/s.

For comparison, we have also investigated an OFDMA-based downstream PON. In order to achieve the same bitrate while using the same bandwidth, QPSK and 16QAM are employed for the cases of 2 users and 4 users, respectively. All the key system parameters for OFDMA-PON are provided in Table 1. The only difference between IDMA-OFDM and OFDMA is the incoming data stream for IDFT operation. The incoming data stream is IDMA signals for IDMA-OFDM, while it is QPSK or 16QAM symbols for OFDMA. Fig. 4 shows the average BER performance for IDMA-OFDM and OFDMA based PON with 2 users. Comparing the back to back (BTB) and 20 km SMF transmission curves, we can see that the chromatic dispersion induced power penalties are negligible for both IDMA-OFDM and OFDMA. The received sensitivities are about −19 and −27 dBm for OFDMA and IDMA-OFDM, respectively. The receiver sensitivity is the required received powers to obtain a BER of 1e-3. Therefore, IDMA-OFDM offers 8 dB gain in term of receiver sensitivity compared with OFDMA in the case of 2 users. Fig. 5 shows the average BER performance for IDMA-OFDM and OFDMA based PON with 4 users after 20 km SMF. 16QAM is employed for data mapping for OFDMA. The total bitrate is $3.3G \times 4 = 13.2$ Gb/s for both IDMA-OFDM and OFDMA. As shown in Fig. 5, IDMA-OFDM offers more than 6 dB gain in term