Hybrid OFDM-based multi-band wireless and baseband signal transmission in PON access

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A hybrid OFDM-baseband (BB) signal and three-band OFDM wireless channels using the 2.5 GHz bandwidth directly modulated laser and 10 GHz bandwidth electroabsorption modulated laser in a passive optical network (PON) is investigated. Each 16-QAM OFDM wireless and 64-QAM OFDM-BB signals can achieve 11.2 and 15 Gbit/s traffic data rates, respectively, in 20 km fibre transmissions. Moreover, the network performance has also been analysed and discussed.

Introduction: Recently, the development of optical access networks has allowed the introduction of many broadband and multi-play services for end users [1–3]. These broadband services can be transmitted and distributed to end users using wireless and wired connections. Hence, the optical access networks supporting multi-bands including the wireless signals, such as the ultra-wideband (UWB) [2], and the baseband signals, like the Gigabit-Ethernet (GbE) and passive optical network (PON) [3, 4] are very essential.

To comply with such requirements in a cost-effective way, optical orthogonal frequency division multiplexing (OFDM) has been proposed as a promising modulation format for PONs [5]. OFDM provides the advantages of high spectral efficiency, high tolerance to multipath fading (in wireless transmission) and chromatic dispersion (in optical fibre transmission), allowing dynamic bandwidth sharing by using orthogonal frequency division multiple access (OFDMA). Moreover, the new standardised broadband wireless technologies, such as the worldwide interoperability for microwave access (WiMAX), UWB and long-term evolution (LTE) etc., also use the OFDM modulation.

In this Letter, we propose and investigate the hybrid OFDM-based three-band wireless and baseband signal generation and transmission in a PON. The OFDM wireless signals in the frequency range from 1.764 to 10.345 GHz and the OFDM-baseband (BB) signal are generated by an electroabsorption modulated laser (EML) and directly modulated laser (DML), respectively. The three-band wireless signals are upconverted at 3.164, 6.055 and 8.945 GHz with the same bandwidth of 2.8 GHz and modulated at 16-QAM format to achieve 11.2 Gbit/s traffic data, respectively. The three wireless bands are arbitrarily selected in this proof-of-concept demonstration; however, they can be easily tuned to 3.5, 5.8 and 10 GHz to support different-bands standard WiMAX simultaneously. Also, the OFDM-BB signal is modulated at 64-QAM format in 2.5 GHz bandwidth to obtain 15 Gbit/s downstream rate. The bit error rate (BER) performance of the proposed PON system is also demonstrated.

Experiment and results: Fig. 1 shows the proposed hybrid three-band wired and wireless OFDM-based PON architecture. Here, the 2.5 GHz bandwidth DML and 10 GHz bandwidth EML are used to carry the baseband (λ_1) and three-band wireless signals (λ_2), respectively, in the central office (CO). λ_1 and λ_2 are set at 1549.2 and 1550.0 nm. Furthermore, the OFDM-BB and three-band wireless signals are combined via a wavelength-multiplexer and transmit through a $1 \times N$ splitter (SP) at the remote node (RN), and then into each optical network unit (ONU), as shown in Fig. 1. The total singlemode fibre (SMF) transmission is 20 km.

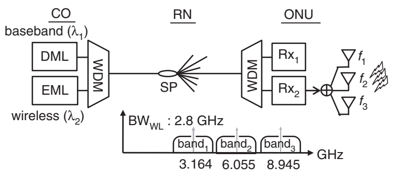

Fig. 1 *Proposed hybrid wired and wireless downstream OFDM-based PON architecture*

In this measurement, the OFDM-BB signal is modulated at 64-QAM format to produce a total traffic rate of 15 Gbit/s in a 2.5 GHz bandwidth. Fig. 1 also presents the frequency spectrum of three-band OFDM wireless signals. The channel 1 to channel 3 is upconverted in the frequency of 3.164, 6.055 and 8.945 GHz, respectively, via the I-Q modulation. Each wireless channel has the same bandwidth of 2.8 GHz. In addition each wireless channel is modulated at 16-QAM OFDM format to generate a total rate of 11.2 Gbit/s. Also, the proposed three-band OFDM channels can be used for the LTE, WiMAX and UWB applications simultaneously. At the ONU, the three-band OFDM wireless channels can be filtered for different requirements of the end users.

Fig. 2 shows the experimental setup of the proposed OFDM-BB signals and three-band OFDM wireless channels. Here, three-band OFDM signals are using the same modulation of 16-QAM with a fast-Fourier transform (FFT) size of 512 and cyclic prefix (CP) size of 8. The BB and wireless OFDM signals are generated by an arbitrary waveform generator (AWG, Tektronix® AWG7122) using the Matlab® programs. The signal processing of OFDM transmitter (Tx) consists of serial-to-parallel conversion, QAM symbol encoding, inverse fast-Fourier transform (IFFT), cyclic prefix (CP) insertion, and digital-to-analogue conversion (DAC). The sampling rate and DAC resolution of AWG are 12 GS/s and 8 bits, respectively.

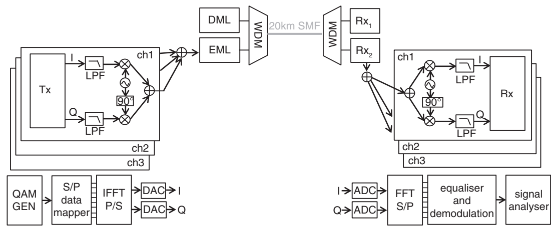

Fig. 2 *Experimental setup of proposed OFDM-BB signals and three-band OFDM wireless channels*

After 20 km transmission and direct detection, the BB and three-band OFDM signals are received and captured by a digital oscilloscope (Tektronix® DPO 71254) with 50 GS/s sampling rate and 3 dB bandwidth of 12.5 GHz. An off-line Matlab® DSP program is used to demodulate the OFDM signals and the demodulation process includes synchronisation, FFT, one-tap equalisation, and QAM symbol decoding. Lastly, according to the measured constellation diagram, the signal-to-noise ratio (SNR) can be observed and used to calculate the bit error rate (BER).

For the OFDM-BB signal, here 127 subcarriers of 64-QAM OFDM formats only occupied a 2.5 GHz bandwidth of 1.95 MHz to 2.50 GHz. 15 Gbit/s downstream signals are generated using a 2.5 GHz DML. Thus, Fig. 3 shows the BER measurements of the OFDM-BB signal at the back-to-back (B2B) and 20 km SMF transmission; the received sensitivities of −12.6 and −11.2 dBm at B2B and 20 km fibre transmission, respectively, at the forward error correction (FEC) threshold ($\text{BER} = 3.8 \times 10^{-3}$). As a result, after 20 km transmission, nearly 1.4 dB power penalty is obtained owing to the fibre chromatic dispersion. The inserts of Fig. 3 are the corresponding constellation diagrams at the B2B and 20 km fibre transmission under the FEC level. Here, in the practical OFDM system, the required sampling rate and DA/AD resolution are 5 GS/s and 7 bits. Moreover, if the output power of the DML is 7.5 dBm, the OFDM-BB signal would support 16 ONUs after passing through a 1×16 SP (12 dB) and 20 km fibre (4 dB) [total power budget is 16 dB].

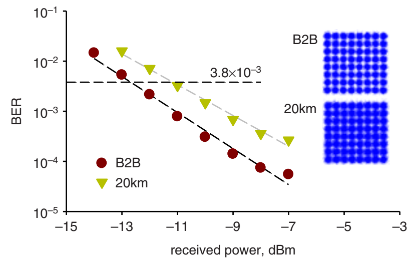

Fig. 3 *BER measurements of OFDM-BB signal at back-to-back (B2B) and 20 km SMF transmission*

For the three-band OFDM wireless signals, we can use the I-Q modulation to upconvert and downconvert the three-band channels for signal measurement. Each upconverted channel has 72 OFDM subcarriers to occupy a bandwidth of 2.8 GHz, producing the total data rate of

11.2 Gbit/s. Fig. 4 shows the BER measurements of the three-band wireless OFDM channels at the B2B and 20 km SMF transmission. The received sensitivities are −19.25, −16.65 and −16.48 dBm at B2B under the BER of 3.8×10^{-3}, respectively. The sensitivities of −18.78, −15.21 and −10.20 dBm are also measured after 20 km fibre transmission. Here, the measured power penalties are 0.47, 1.44 and 6.28 dB after 20 km fibre transmission, respectively. We can also observe the higher frequency OFDM band has higher measured power penalty owing to the power fading and fibre dispersion effects. Moreover, the inserts of Fig. 4 are the measured corresponding constellations of the three-band OFDM channels at the B2B and 20 km fibre transmission under the FEC threshold. Furthermore, in this measurement, the practical requirements of sampling rate and DA/AD resolution are 5 GS/s and 5 bits for signal processing. As mentioned before, the three-band wireless channels also can provide 16 ONUs for the broadcasting signal owing to the higher penalty of the third OFDM band.

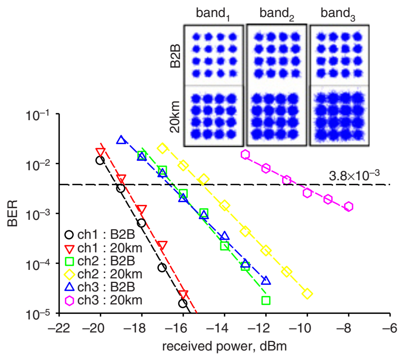

Fig. 4 *BER measurements of three-band wireless OFDM channels at B2B and 20 km SMF transmission*

Conclusion: We have proposed and experimentally demonstrated the generation and transmission of a hybrid OFDM-BB signal and three-band OFDM wireless signals for supporting PONs and standardised wireless applications simultaneously. Here, the downstream BB signal is modulated at 64-QAM OFDM format using a 2.5 GH bandwidth DML to produce 15 Gbit/s traffic rate. The three-band wireless channels are modulated at 16-QAM OFDM format simultaneously employing a 10 GHz bandwidth EML to generate 11.2 Gbit/s wireless signal. Each channel is upconverted to 3.164, 6.055 and 8.945 GHz, respectively, via the I-Q modulation technology. The three wireless bands are arbitrarily selected in this proof-of-concept demonstration; however, they can be easily tuned for supporting the LTE, WiMAX and UWB applications simultaneously in the same network. Here, the BB and three-band OFDM signals can also support 16 ONUs for traffic data link by the proposed PON system.

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One or more of the Figures in this Letter are available in colour online.

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