Service integrated access network using highly spectral-efficient MASK-MQAM-OFDM coding

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Abstract: A highly spectral-efficient M-ary amplitude shift keying M-ary quadrature amplitude modulation orthogonal frequency division multiplexing (MASK-MQAM-OFDM) was proposed for the access network. With the highly spectral-efficient characteristic of MASK-MQAM-OFDM, seamless integration among passive-optical network (PON), wireless fiber-to-the-antenna (FTTA), and optical wireless visible light communication (VLC) can be achieved without using extra bandwidth for different services. A proof-of-concept experiment was demonstrated. The relation between the spectral efficiency of the MASK-MQAM-OFDM and the upstream signal performance was also discussed.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.4510) Optical communications.

References and links

1. C. W. Chow, F. M. Kuo, J. W. Shi, C. H. Yeh, Y. F. Wu, and C. L. Pan, "100 GHz ultra-wideband wireless system for the fiber to the antenna networks," in Proc. OFC, San Diego, USA, 2010, Paper OThF1.
2. W.-Y. Lin, C.-H. Chang, P.-C. Peng, H.-H. Lu, and C.-H. Huang, "Direct CATV modulation and phase remodulated radio-over-fiber transport system," Opt. Express **18**(10), 10301–10307 (2010).
3. C. H. Yeh, Y. F. Liu, C. W. Chow, Y. Liu, P. Y. Huang, and H. K. Tsang, "Investigation of 4-ASK modulation with digital filtering to increase 20 times of direct modulation speed of white-light LED visible light communication system," Opt. Express **20**(15), 16218–16223 (2012).
4. Y. Tian and Y. Su, "A WDM-PON system providing quadruple play service with converged optical and wireless access," in 34th European Conference on Optical Communication, (Brussels, 2008), Paper P.6.07.
5. A. Banerjee, Y. Park, F. Clarke, H. Song, S. Yang, G. Kramer, K. Kim, and B. Mukherjee, "Wavelength-division-multiplexed passive optical network (WDM-PON) technologies for broadband access: a review [Invited]," J. Opt. Netw. **4**(11), 737–758 (2005).
6. B. Zhang, Y. Lu, D. Wang, J. Zhang, and B. Yang, "A wireless access architecture based on radio over fiber technology for telemedicine system," in Proc. IEEE/ICME, Beijing, 2007, 349–352.
7. J.-S. Lee, Y.-W. Su, and C.-C. Shen, "A comparative study of wireless protocols: bluetooth, UWB, ZigBee, and Wi-Fi," in The 33rd Annual Conference of the IEEE Industrial Electronics Society (Taipei, 2007), pp. 46–51.
8. C. W. Chow, C. H. Wang, C. H. Yeh, and S. Chi, "Analysis of the carrier-suppressed single-sideband modulators used to mitigate Rayleigh backscattering in carrier-distributed PON," Opt. Express **19**(11), 10973–10978 (2011).
9. C. W. Chow, C. H. Yeh, C. H. Wang, F. Y. Shih, and S. Chi, "Signal remodulation high split-ratio hybrid WDM-TDM PONs using RSOA-based ONUs," Electron. Lett. **45**(17), 903–905 (2009).

1. Introduction

Among the fiber-optic communication technologies, passive optical network (PON) is considered as a simple and cost effective access network architecture. Therefore, integrating broadband services in a PON is highly desirable. The triple-play service, which provides the convergent Internet protocol (IP) data, voice, and video transmissions, into an optic-fiber communication is an example of service integration. Besides the wired services, the existing radio-frequency (RF) wireless systems and optical wireless visible light communication (VLC) are also capable of being integrated into the fiber-optic communication [1–3]. Hence, the integration of the triple-play service and the mobile service results in the quadruple-play

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service. Achievement of quadruple-play can highly reduce the system complexity and the cost. Thus, quadruple-play service has been extensively studied recently [4].

Different approaches to integrate different services into a single optical transmission system have been investigated. Integrating all signals for different services in electrical domain into a single package and separating them at the remote node (RN) or at the receiver end is one approach accomplish service integration. However, this technology is rather complex and costly. Another approach to achieve service integration is to transmit signals for different services at different frequency bands. The optical way to accomplish this idea is the wavelength-division multiplexing (WDM) technology [5]; and the electrical way to accomplish this idea is the radio-over-fiber (RoF) technology [6]. The WDM technology is typically impractical because most of the services occupied only narrow bandwidths. This may cause a waste of the available bandwidth of the optical transmission system. RoF technology for nowadays applications is sometimes inappropriate because some wireless standards, such as Wi-Fi, use low-frequency band, which may overlap with the optical baseband signal [7].

In this work, a service-integrated network was proposed. An M-ary amplitude-shift keying M-ary quadrature amplitude modulation orthogonal frequency division multiplexing (MASK-MQAM-OFDM) coding technology was used to provide a transparent communication among different services. In the proof-of-concept experiment, 2-ASK-16-QAM-OFDM modulation in the downstream signal and OOK upstream signal were used. The spectral efficiency of the MASK-MQAM-OFDM is higher than the typical OFDM signal.

2. Principle of MASK-MQAM-OFDM

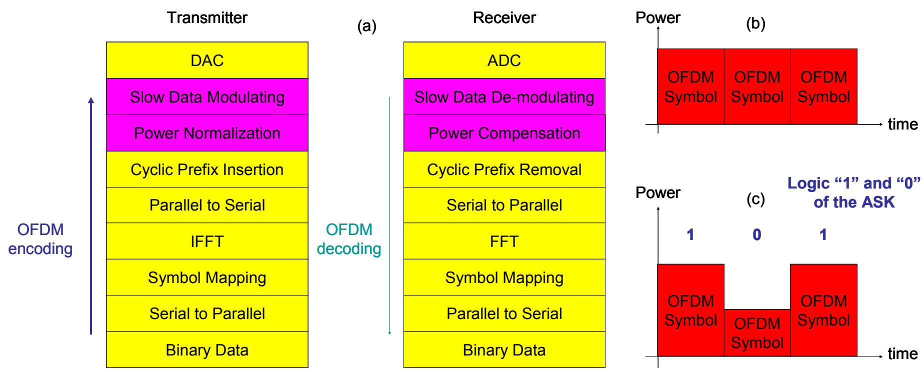

Fig. 1. (a) Modulation and de-modulation process of the MASK-MQAM-OFDM coding, (b) time trace of typical OFDM coding, (c) time trace of proposed MASK-MQAM-OFDM coding.

Figures 1(a) and 1(b) show the block diagrams of the OFDM encoding and decoding processes. The yellow part of Fig. 1(a) is the typical transmitting and receiving process for an OFDM symbol. A binary sequence is transformed from a serial stream into a parallel stream and mapped into a corresponding symbol. Then inverse fast Fourier transform (IFFT) operation is taken to generate the sequences as combinations of orthogonal-frequency sine wave in a specific time window. After transforming the signal back into the serial data stream, a cyclic prefix (CP) is added to reduce the chromatic dispersion. The electrical analog signal is generated after a digital-to-analog converter (DAC). The pink part of Fig. 1(a) is our proposed MASK-MQAM-OFDM process. Before being fed into the DAC, each digital OFDM symbol is normalized in its power. Power normalization is achieved by divided each OFDM symbol by its average power, which is the square root of the summation of the OFDM digital signals within the same OFDM symbol. Then, a lower frequency MASK signal will modulate the power of each OFDM symbol. The total power of an OFDM symbol denotes the MASK signal. Figures 1(b) and 1(c) show the schematic time traces of the typical OFDM and

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the proposed MASK-QAM-OFDM signal respectively. This illustrates the average power level of the OFDM signal is modulated by the MASK signal.

At the receiver end, the OFDM part of the MASK-MQAM-OFDM signal is manipulated by inversely processing the signal described above. After the analog-to-digital converter (ADC), the received signal was normalized by power of each OFDM symbol. Then, the fast Fourier transform (FFT) is taken for each OFDM symbol after removing the CP. Each symbol modulated at the subcarriers is mapped back into the original binary sequence. The MASK signal can be directly detected by a low-bandwidth photo-diode (PD) using envelope-detection. Hence, this provides an extra modulation dimension, and the spectral efficiency of the MASK-MQAM-OFDM signal is higher than that of the typical OFDM signal.

3. Network architecture

Figure 2 is the proposed architecture. The downstream MASK-MQAM-OFDM signal is coded and launched by an arbitrary waveform generator (AWG), which is the DAC used as described in Fig. 1(a). The optical carrier can be modulated by either directly modulation techniques or external modulation techniques. An external modulation technique may give a higher data rate and control the optical power range by appropriately setting its bias point. The power range control of an optical signal is important because it relates to the performance of the re-modulated upstream signal. In the WDM time-division multiplexing (TDM) hybrid system, the modulated optical signals of different wavelengths are combined together by an arrayed waveguide grating and then are launched into the fiber. At the RN, the optical signals of different wavelengths are separated by another arrayed waveguide grating. Then the optical signals of different wavelengths are further spilt into n optical network units (ONUs) by a 1:n splitter. At each ONU, the optical signal is split into k paths, each path for different services. The upstream and downstream signals for different services will pass through different paths.

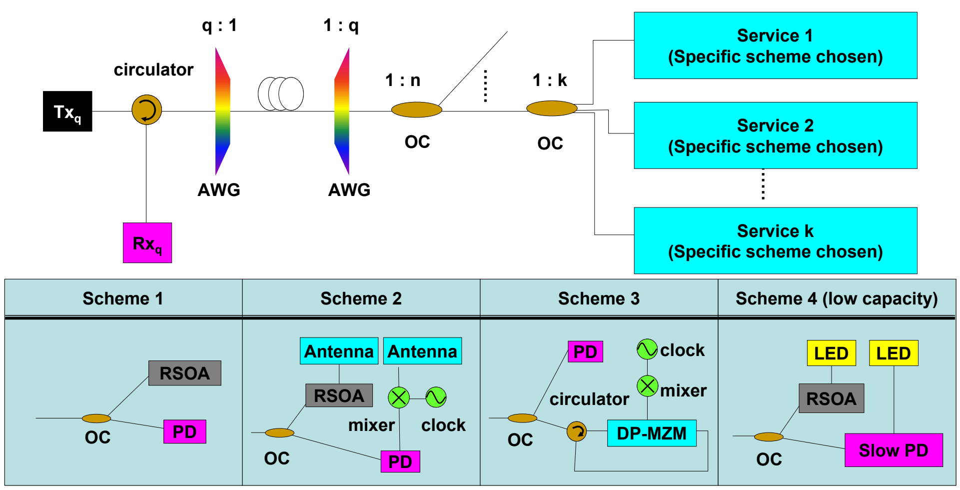

Fig. 2. Proposed service-integrated network architecture using MASK-MQAM-OFDM modulation.

Different services share the OFDM part or the MASK part of the transmitted MASK-MQAM-OFDM signal in TDM way. For the high capacity services, their data are coded in the OFDM part of the transmitted MASK-MQAM-OFDM signal. The Rxs of these high capacity services consist of a fast PD and ADC. After the ADC, the received signals are demodulated as described in Fig. 1(a). For low capacity services, such as the RF or VLC, their data are coded in the MASK part. The Rxs of these low capacity services consist of only slow PD to directly receive the MASK data by envelope-detection.

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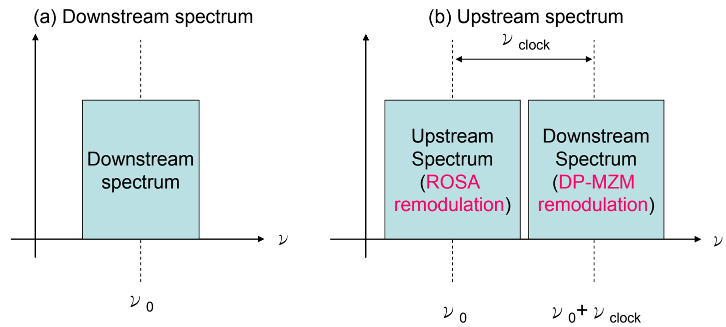

Fig. 3. Schematic diagrams of (a) downstream and (a) upstream (generated by RSOA and DP-MZM) signals.

The upstream signals are generated by re-modulating the downstream signals. Several techniques could be taken for the re-modulation process. The combination of a reflective semiconductor optical amplifier (RSOA) and a dual parallel Mach-Zehnder modulator (DP-MZM) may be a good choice [8, 9]. For producing the upstream signal using the DP-MZM similar to ref [8], the spectrum of the upstream signal is shifted away from the distributed optical source frequency (ν_0). The frequency-shifting is determined by the applied electrical clock signal to the DP-MZM (ν_{clock}). For producing the upstream signal using the RSOA similar to ref [9], the ROSA can erase the downstream signal by gain-saturation and generate the upstream signal by re-modulating the downstream signal. Both the upstream and downstream signals are at the same frequency. As shown in the schematic diagrams in Fig. 3, the upstream signals are separated to different frequency bands, and can be transmitted to the head-end office simultaneously.

4. Experiment

Figure 4 shows the proof-of-concept experiment. The modulation levels for the MASK and the MQAM are 2 and 16 respectively in this demonstration. The 2-ASK-16-QAM-OFDM signals were coded as described in Section 2 and was generated by the AWG. First, the generated 16-QAM-OFDM code was normalized in power and modulated by the 2-ASK signals. The logic "zero" were chosen among 0.6 ~0.8 (60% ~80%) of the maximum power of each OFDM symbol. The sample rate of the AWG is 8 Gs/s with 3.2 GHz 3-dB bandwidth. For the OFDM part of the signal, two kinds of FFT sizes, 128 and 64, were chosen for comparing 2-ASK signal performance. For FFT size of 128, the net data rate of the OFDM part was about 4.18 Gb/s, while for FFT size of 64, the net data rate was about 3.08 Gb/s (after removing the CP). The data rate differences were mainly resulted from the differences between subcarriers used (respectively 19 and 7 for FFT size of 128 and 64), the CP size, and the training symbol size. The CP was set to be 1/32 of the FFT size. 10 OFDM training symbols were taken every 100 OFDM data symbols.

The electrical signals generated by the AWG were input into a 2 GHz 3-dB bandwidth direct-modulated-laser (DML) (with input power of −3 dBm). At the ONU, the downstream signals were divided into two paths by an optical coupler (OC). In one of the paths, the downstream signals were received by a PD and demodulated through digital signal process (DSP). For simplifying the experimental complexity, the slow PD was not used. The 2-ASK signals were simultaneously demodulated with the OFDM signals using DSP.

The other path of the output of the OC was used for the upstream signal. For demonstration, the upstream signals were generated by re-modulated the downstream signal using only RSOAs. The upstream signal was 2 Gb/s on-off-keying (OOK) signal. Bias current of 50~80 mA were set to compare the performance of the upstream signals.

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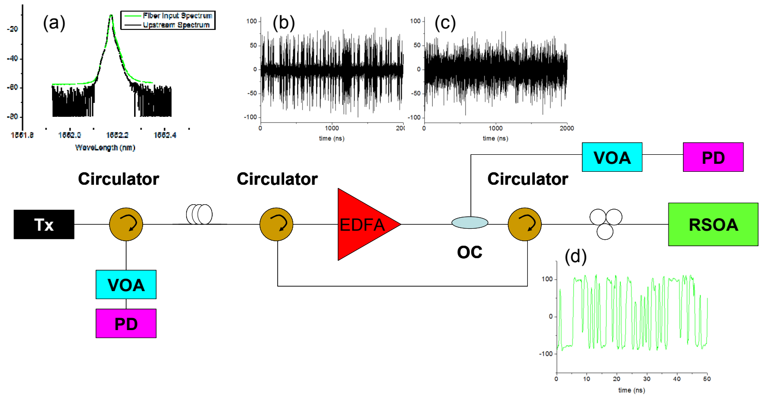

Fig. 4. Proof-of-concept experiment. Inset: (a) optical spectra of downstream and upstream signals; (b) time trace of 0.2 of maximum power for 2-ASK "zero" level; (c) 0.6 of maximum power for 2-ASK "zero" level; (d) time trace of the re-modulated upstream OOK signal.

5. Results and discussions

Different logic "zero" levels (or the extinction ratio (ER)) of the 2-ASK will affect the total performance of the 2-ASK-16-QAM-OFDM signal. For higher logic "zero" level (lower ER of the 2-ASK), the 2-ASK modulation will perform worse. On the contrary, for lower logic "zero" level (higher ER of the 2-ASK), the 16-QAM-OFDM will perform worse. To test the performance of different 2-ASK logic "zero" levels, we choose 0.6 of the maximum power 16-QAM-OFDM symbol as the 2-ASK logic "zero" level. Figures 5(a) and 5(b) show the signal performance differences of the downstream signals for different 2-ASK logic "zero" levels chosen.

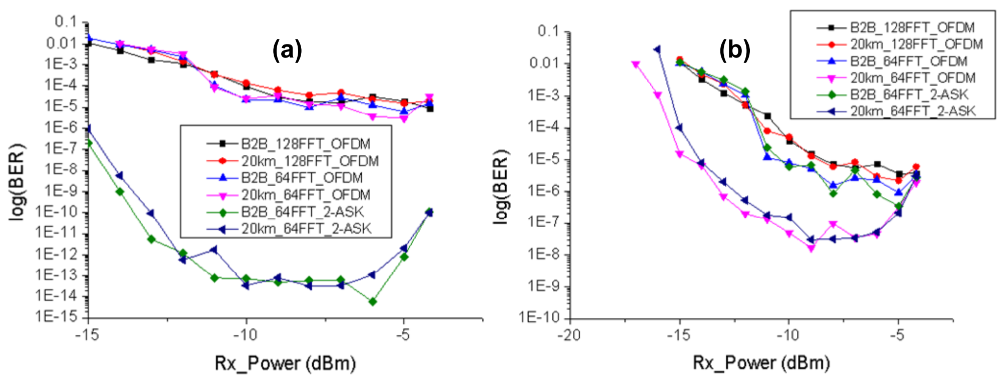

Fig. 5. BER performances of the downstream signals using (a) 0.6 of maximum power for 2-ASK "zero" level, (b) 0.7 of maximum power for 2-ASK "zero" level.

The choice for 2-ASK logic "zero" level also affects the performance of the upstream signal. Typical OFDM signal can be viewed as a source of high frequency pulse train, and the slow signals can modulate the pulse train directly. However, the peak of an arbitrary OFDM symbol is not constant. This may reduce the performance of the resulted slow signals. To choose a good 2-ASK logic "zero" level to reduce the peak level oscillation of the OFDM signal is also important in our propose architecture. Moreover, the bias current of the RSOA is also an important parameter. Sufficient bias current is required for the re-modulation. Extremely high bias current may saturate the re-modulated signal and also reduce the signal performance. Figures 6(a)-6(d) are the upstream signal performance under different RSOA bias currents and different 2-ASK logic "zero" levels. The upstream signals at 50 mA and 60 mA biased re-modulation can both reach bit error rate (BER) of 10^{-9} (error-free) after 20 km

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transmission. While RSOA was biased over 60 mA, the signal performance started to decrease. After 20 km transmission, BER of 10^{-9} was not achievable for 70 mA and 80 mA biased re-modulation. Since the downstream signal and the upstream re-modulated signal shared the same fiber path, the power penalty between the B2B and the 20 km SMF transmission is mainly caused by Rayleigh backscattering.

From the results shown in Fig. 6, we can observe that 64 FFT sized re-modulation performs better under low RSOA bias current of 50 mA. When the bias current increases, the performance differences between the re-modulated upstream signals using 128 FFT sized and 64 FFT sized downstream 2-ASK-16-QAM-OFDM signal is not significant.

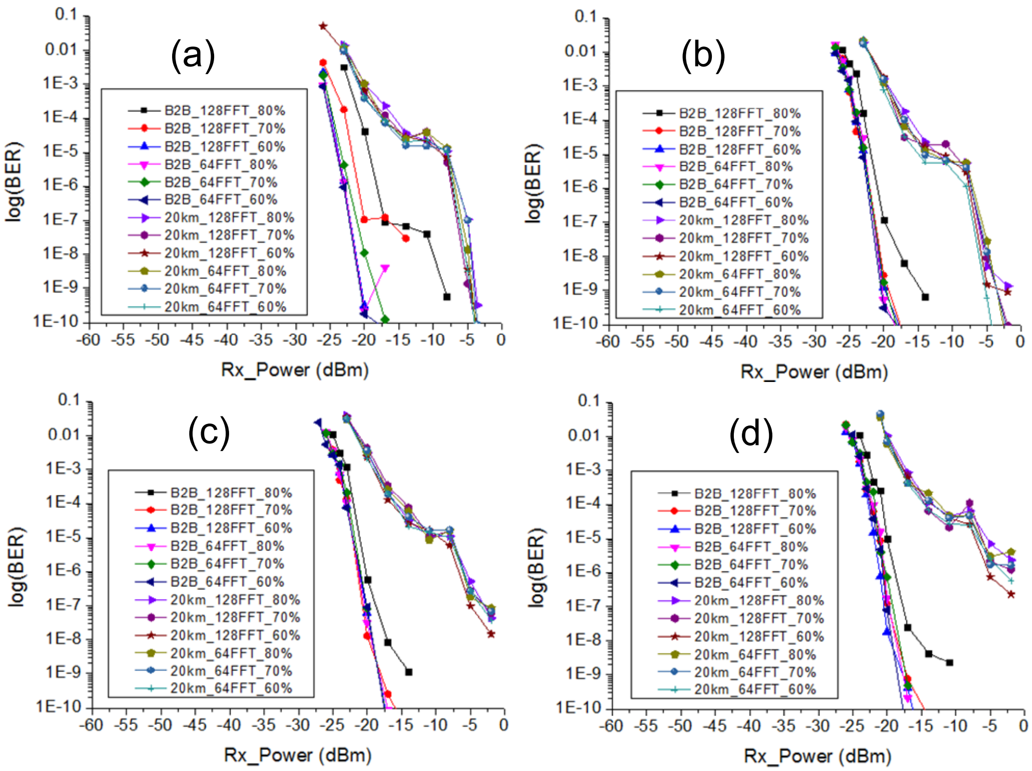

Fig. 6. BER performances of upstream signals under different RSOA bias currents of (a) 50 mA, (b) 60 mA, (c) 70mA, and (d)80mA.

6. Conclusion

In this work, a high spectral efficient MASK-MQAM-OFDM coding and a service-integrated network were proposed. In our proposed scheme, different services can be integrated transparently while the high capacity and low capacity system were all included. For the OFDM part of the signal, two kinds of FFT sizes, 128 and 64, were chosen for comparing 2-ASK signal performance. For FFT size of 128, the net data rate of the OFDM part was about 4.18 Gb/s, while for FFT size of 64, the net data rate was about 3.08 Gb/s. The 0.12 Gb/s additional capacity was achieved using 128 FFT size, while 60.61 Mb/s additional capacity was achieved using 64 FFT size. Moreover, 2 Gb/s upstream OOK signal can be achieved by re-modulating the 2-ASK-16-QAM-OFDM using commercial available RSOA.

Acknowledgments

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