OFDMA-PON with MQAM downlink for flexible allocation

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Abstract: In this paper, the 40-Gbps orthogonal frequency division multiple access (OFDMA) technology enabled by subcarrier allocation in the form of integrated architecture for the intra-cell is proposed in the downlink transmission passive broadband optical access system. The data-carrying subcarriers in the inverse fast Fourier transform/fast Fourier transform (IFFT/FFT) size of 1 024 points are successfully divided into three sub-channels, in which each sub-channel has 256 useful subcarriers, by using adaptive dynamic bandwidth allocation (DBA). Taking the inherent advantages of M-ary quadrature amplitude modulation (MQAM) modulation mechanism into account, the performance of the absolutely identical MQAM format over the different sub-channels for the downstream OFDMA-passive optical network (PON) is investigated based on the intensity modulation direct detection (IMDD) system by simulations. The results show that three parallel 4QAM or 16QAM or 64QAM OFDMA data, which are transmitted over three sub-channels, is more suitable for different sub-channel allocations, respectively. In addition, comparing with single port 4/16/64QAM OFDM over the same access system, the receiver sensitivity economizes -0.6 dBm, 0.6 dBm, 4.6 dBm at the bit error rate (BER) value of 10^{-3} respectively.

Keywords: orthogonal frequency division multiple access (OFDMA), passive optical network (PON), downlink transmission, dynamic bandwidth allocation (DBA).

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1. Introduction

Recently, the idea of connecting everything to mobile internet such as transport, education, healthcare, manufacturing, finance and enterprise, being provided by the Global Mobile Broadband (GMBB) Forum, takes account of boosting network capacity, connecting small cells,

enhancing service experience, maximizing network potential, expanding connection opportunities and creating a better world in the upcoming future [1]. Because of the inherent balance between the data rate and the communication capacity, both mobile communication carriers and Internet-service providers will bring about high effectiveness, significant promotion as well as responsibility and pave a new way to the passive optical network (PON) based on orthogonal frequency division multiple access (OFDMA), which have a large number of things on its side, for example, high spectral efficiency (SE), steel patience to fiber dispersion introduced by pulse broadening, flexible bandwidth resource allocation, and excellent cost-effectiveness [2–34]. In the traditional PON method, a project, the international telecommunication union telecommunication standardization sector Gigabit PON (ITU-T GPON) series smooth evolution from GPON in 2002 to next-generation PON (NG-PON) making up of 100-Gigabit PON1 (XG-PON1) and NG-PON2, was successfully initiated by the full service access network (FSAN). On the other hand, a scheme, IEEE 802.3 Ethernet PON (EPON) series smooth evolution from EPON in 2004 to 10G-EPON in 2009 and then to NG-EPON in the form of non-return-to-zero (NRZ), Duo-Binary and 4 pulse amplitude modulation (PAM4) in 2015, was originated by the European Federation for Medical Informatics (EFMI) workgroup. At the same time, to meet the ever increasing bandwidth demands caused by big videos, big operation, big architecture and big IT from end-users, the OFDMA technique has been considered as one of the most promising broadband candidates for the next generation PON and is much taken with researchers. However, unlike the long-haul coherent detection optical OFDMA PONs, the short reach direct detection optical OFDMA PONs, especially for the downstream transmission, has a large number of advantages, for instance, more simple transceiver, lower computational complexity, lower component cost and more stable system performance [11–15].

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Qian et al. were committed to driving the experimental demonstration of a novel OFDMA PON by offering several source-free optical network units (ONUs) and charting system framework for downstream and upstream [11]. All the same, both 40 Gb/s and 108 Gb/s OFDMA-PONs approaches with polarization multiplexing and direct detection in the form of 16 quadrature amplitude modulation (16QAM) were proposed and demonstrated to simplify receiver end hardware complexity [12]. Jin et al. experimentally investigated the real time OFDMA-PONs structure of reflective semiconductor optical amplifier (RSOA)-based in ONU1 and distributed feedback (DFB)-based in ONU2 enabled by 32-QAM in subcarriers of 1 to 7 and 64-QAM in subcarriers of 8 to 15 modulation technologies in the intensity modulation direct detection (IMDD) broadband optical access networks OANs for the uplink transmission, respectively, and the wavelength spacing between the two adjacent ONUs was studied across the C-band [13]. In addition, the OFDMA PON bidirectional transmission with coherent detection optical line terminal (OLT) and direct detection ONUs for 21.6 Gb/s QPSK and 14.5 Gb/s 32QAM was realized in [14] by using carrier-reuse, single-feeder and wavelength division multiplex (WDM) based on single fiber light wave centralization. He et al. verified a full-duplex optical access system with hybrid 64/16/4QAM-OFDM downlink and NRZ uplink, where bit error rate (BER) values lower than hardware decision forward error correction (HD-FEC) are obtained after 20 km length standard single mode fiber (SSMF) transmission [15]. Chen et al. firstly demonstrated the real-time reconfigurable 4/16/64QAM OFDM data in X-band radio over fiber (RoF) system. Moreover, after 1.5 m wireless and 2.26 km SSMF, the systems achieve the BER required by communication link, namely, HD-FEC threshold of 3.8×10^{-3} [16].

In this paper, a 40 Gbps three sub-channels OFDMA downlink architecture enabled by M-ary QAM (MQAM) technology is experimentally proposed and simulated over 20 km length SSMF transmission in IMDD PON access system, where each sub-channel has been made up of 256 successively possible sub-carriers and three sub-channels are absolutely conveyed by three identical 4QAM, 16QAM, 64QAM data streams. This project successfully employs both channel estimation (CE) and carrier phase estimation (CPE) at the receiver side to improve system performance. The best sub-channel receiving performance of 4QAM OFDMA PON is the second sub-channel, 16QAM is the first sub-channel, 64QAM is the second sub-channel. In addition, the receiver sensitivity has been obviously enhanced by -0.6 dBm, 0.6 dBm, 4.6 dBm comparing with single port 4QAM, 16QAM, 64QAM OFDMA broadband OAN.

In particular, the main advantages of this design in this paper is that three different data symbols transmitting over three sub-channels can save the spectrum resource to compare the existing model.

2. System setup

As Fig. 1 shows, the subcarrier indexes in the range of 129 to 384, 385 to 640, and 641 to 896 are defined as the first sub-channel, the second sub-channel and the third sub-channel, respectively. It is noteworthy that the maximum possible subcarrier in the inverse fast Fourier transformation (IFFT) is 1 024, in which, the total 768 location subcarriers varying from 129 to 896 are successfully implemented to convey three useful MQAM data streams. Moreover, the number of prefix points, the size of training symbols, and the averaged OFDM power are 100, 8 and 16 dBm, respectively.

Fig. 1 Three sub-channels allocation

The setup of the three sub-channels MQAM OFDMA PON system for the downlink transmission is in reported detail in Fig. 2, which is constitutive of OLT in the transmitting central office (CO), optical fiber link between OLT and ONU, and ONU in the receiving base station (BS). At the OLT, three parallel binary input data streams are generated by three pseudo random bit sequence generators (PRBSs) with the bit rate of global bit rate $\times 256/1\,024$. Each binary data stream is firstly mapped into MQAM, then OFDM modulation is executed and finally digital-to-analog converter (DAC) is performed with the sample rate of 10 Gigabit samples per second and cubic interpolation filtering to generate the MQAM OFDMA baseband electrical signal. Here, it also needs to mention that OFDM modulation will carry out a series of process, including serial/parallel conversion (S/P), IFFT, insertion cyclic prefix (CP) in the form of symbol extension in guard interval, and parallel/serial conversion (P/S). In the electrical to optical (E/O) convertor, MQAM OFDMA baseband electrical signal functioning as the electrical modulation sig-

nal directly drives the dual port Mach-Zehnder modulator (DP-MZM), in which, the extinction ratio (ER), switching bias voltage, switching radio frequency (RF) voltage, insertion loss, bias voltage1, bias voltage2 are 30 dB, 4 V, 4 V, 2 dB, 0 V, 2 V, respectively. A continuous wavelength (CW) optical signal generated by the external cavity laser (ECL1), functioning as the optical carrier signal, is modulated by an intensity modulator in terms of DP-MZM, the other continuous wave optical signal generated by ECL2, without data modulation, is recombined with the MQAM OFDMA modulated baseband optical signal with the help of a 3 dB optical coupler (OC) after modulation. Both ECL1 and ECL2 have the exactly same value in power, line-width and initial phase, which are 4 dBm, 0.1 MHz, and 0° , but only different in the frequency value. Then, the erbium-doped fiber amplifier (EDFA) with both 10 dB gain and 4 dB noise figure is exploited to enhance the transmission optical power and eliminate the greater additional insertion loss caused by passive optical splitter (OS) before 20 km long span transmission of SSMF that possesses features of the attenuation factor of 0.2 dB/km, the chromatic dispersion (CD) coefficient of 16.75 ps/nm/km and the polarization mode dispersion (PMD) coefficient of 0.05 ps/ $\sqrt{\text{km}}$. Subsequently, the OS is used to split the received optical signal into two branches: one is used for downlink direct detection and another uplink seamless connection. At the ONU, the received optical MQAM

OFDMA modulated optical baseband signal is firstly filtered by Bessel optical filter (BOF1) to limit the signal bandwidth and select the center frequency, then attenuated by a variable optical attenuator (VOA) to make the received optical power (ROP) preferably meet the signal noise ratio (SNR), and finally detected by a positive intrinsic negative photodiode (PIN PD) to convert the optical signal into the electrical signal. As such, after analog to digital converter (ADC) and down-sampling, OFDM demodulation is of great importance at the receiver side, which consists of S/P, removing CP, fast Fourier transform (FFT), CE by means of training symbols, CPE by dint of pilot symbols, P/S. Without loss of generality, the generated M-ary symbol sequences will be de-mapped into binary signals as a function of the QAM sequence decoder principle. In order to perspicuously achieve the relationship between BER and ROP, BER testers are carried out to compare the transmitted binary sequence signal with the received ones. In the same BER, the single port used for transmitting the MQAM data symbol needs the lower ROP to compare the three sub-channels, in which the former occupies the sub-channel index from 129 to 896, and the latter either occupies the subcarrier from 129 to 384 (first sub-channel set), or from 385 to 640 (the second sub-channel set), or from 641 to 896 (the third sub-channel set), i.e., the three sub-channel set is used to transmit the data symbol for the 4QAM, 16QAM, 64QAM in a time slot, respectively.

Fig. 2 System simulation for three sub-channels MQAM OFDMA in PON downlink

3. Simulation results

Without loss of generality, we consider OFDMA PON with MQAM downlink transmission to carry out the flexible allocation. In order to achieve the numerical results, Table 1 presents the parameter settings in our paper in detail. In addition, we adapt the Optisystem 7.0 to simulate the practical model.

It can be achieved some information that the research specialist staff are interested in from Fig. 3. As it is known that the lower level modulation format occupies more broadband frequencies while the lower level modulation with the lower constellation value, the higher bit rate and the better BER performance. Three 4QAM data, three 16QAM data and three 64QAM data make up the frequency bandwidths of 1.8 GHz, 1.0 GHz and 0.6 GHz at

the power changing from -35 dBm to 0 dBm, respectively. In order to further investigate the relationship between the BER and the ROP in the OFDMA optical access network for the downstream data, the plots of the 4QAM, 16QAM, 64QAM optical OFDMA signal composed by three sub-channels after 20-km-long SSMF propagation are shown in Figs. 4–6, respectively.

Table 1 Parameter settings in the simulation

Description	Value
Bit rate/(Gb/s)	40
IFFT size	1 024
Three subchannels	129–384, 385–640, 641–896
Cyclic prefix	100
Training symbol	8
Fiber length/km	20
Averaged power/dBm	16
Attenuation factor/(dB/km)	0.2
CD coefficient/(ps/nm/km)	16.75
PMD coefficient/(ps/sqrt(km))	0.05

Fig. 3 Power spectral density for different sub-channels

Fig. 4 BER performance versus ROP for 4QAM OFDMA downlink transmission

Fig. 5 BER performance versus ROP for 16QAM OFDMA downlink transmission

Fig. 6 BER performance versus ROP for 64QAM OFDMA downlink transmission

It is worth explaining that the subcarrier index of the single port MQAM OFDMA transmission situation is distributed in the range of 129 to 896. In this paper, we adapt the time-division multiplexing PON (TDM-PON) to realize the dynamic resource allocation. Therefore, the three users enabled by the ONU can use the three sub-channels in a time slot to transmit the data symbol.

3.1 Three sub-channels 4QAM OFDMA data

To vary VOA values not only dynamically changes the ROP but also achieves appropriate BER, in which the other parameters maintain stable all the time. It can be clearly seen from Fig. 4 that the performance of the first sub-channel 4QAM transmission is worse than both the second and the third sub-channels in the same simulation environment. Except for the first sub-channel, at the BER value of 10^{-3} the receiver sensitivities of the second sub-channel,

the third sub-channel and the single port 4QAM OFDMA used for the direct detection system are -6.8 dBm, -5.3 dBm, and -7.4 dBm, respectively. At the same time, the constellation diagrams are estimated at the BER values of -3.25×10^{-3} , -3.12×10^{-3} , and -3.15×10^{-3} , namely, the ROPs are -6.8 dBm, -4.8 dBm, and -7.2 dBm. Under the circumstances, the lower level 4QAM transmission is more suitable for the intermediate frequency (IF) band and substantially economizes the receiver sensitivity of 1.5 dBm compared with the third sub-channel.

3.2 Three sub-channels 16QAM OFDMA data

Similarly, the three ports 16QAM OFDMA transmission quality is successfully depicted in Fig. 5, where the ROP ranging from -3.6 dBm to -2.2 dBm for both the first, second sub-channels and the single port maintains the BER less than the threshold value of 3.0×10^{-3} . On this occasion, the third sub-channel located in high frequency (HF) band must increase the transmitted optical power (TOP) to keep normal communication, namely, the BER is inferior to the threshold value. However, the higher TOP not only raises the component cost, but also increases the power penalty. Besides the third sub-channel, the receiver sensitivities of the first, second sub-channels, and the single port are -3.6 dBm, -2.4 dBm, and -2.8 dBm, respectively. Meanwhile, the constellation diagrams are scaled at the BER values of -3.2×10^{-3} , -3.3×10^{-3} , and -3.3×10^{-3} , namely, the ROPs are -2.8 dBm, -2.1 dBm, and -2.1 dBm.

3.3 Three sub-channels 64QAM OFDMA data

The case of 64QAM OFDMA downlink performance in the form of three ports is illustrated in Fig. 6. It is clear that the BER of the downstream data after 20 km SSMF transmission linearly decreases from -2.44 to -4.12 by increasing the TOP and adjusting the VOA to make ROP range from -1.7 dBm to 1.1 dBm, and the corresponding single port and the third sub-channel are also significantly improved from 2.8 dBm to 8.9 dBm, and from 5.4 dBm to 13.4 dBm, respectively. Furthermore, the higher level 64QAM OFDMA transmitted over the low and medium frequency (LMF) band shows great potential. And for the single port situation, its performance falls in between the LMF and HF. It is observed in Fig. 6 that the receiver sensitivities are -0.8 dBm, -0.6 dBm, 11 dBm, and 4 dBm, respectively. In the meantime, the constellation diagrams are estimated at the BER values of -3.3×10^{-3} , -3.2×10^{-3} , -3.1×10^{-3} and -3.3×10^{-3} , namely, the ROPs are -0.1 dBm, -0.1 dBm, 12.4 dBm and 6.9 dBm.

4. Conclusions

In this paper, we systematically design and demonstrate the OFDMA downlink for intra-cell in the PON enabled by three parallel MQAM ports, namely, three sub-channels MQAM. The 4-QAM, 16-QAM, and 64-QAM modulation schemes after 20 km SSMF transmission are simulated and the results of these three modulation schemes are compared. It is found that single 4-QAM gives the best performance (the lowest BER) compared to single 16-QAM and single 64-QAM when it comes to the same ROP. In simulation of each three ports MQAM, the results show that the best transmission sub-channels of 4QAM, 16QAM and 64QAM are the second, the first and the second sub-channel, respectively. Compared with the traditional single port, results also show that the receiver sensitivities of the proposed 4QAM, 16QAM and 64QAM formats have been enhanced by -0.6 dBm, 0.6 dBm, and 4.6 dBm, respectively.

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