Future Generation of Passive Optical Networks

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Abstract: In this paper, a WDM-OFDM-PON architecture based on quadrature-amplitude-modulation (QAM) orthogonal frequency-division-multiplexing (OFDM) for downstream and upstream channels is presented. In our simulation, we theoretically demonstrate the architecture based on centralized-light source using direct detection which is a promising solution for ever increasing demand of bandwidth. For downstream channel, 10-Gbps 16-QAM OFDM signal is successfully transmitted over the distance of 50-km single-mode-fiber.

Keywords: Passive Optical Network, Orthogonal frequency-division-multiplexing, Wavelength division multiplexing, Next generation PON, Optical access network.

Introduction

Over the last twenty years, advances in the world's network of wireless systems and fiber-optic cables have been moving at a speed close to Moore's law. Recent surge in bandwidth demand driven by fast growing video-on-demand (VOD) services and emerging applications like network gaming, peer to peer downloading, etc. has revitalized the growth of optical communication industry. To fulfill high bandwidth demand, service providers and enterprises must require newer hybrid wireless-optical fiber network. Optical access network like fiber-to-the-home (FTTH) connect computers at subscribers' home with optical line terminal (OLT) at central office (CO). Rather than placing ethernet switch at CO, passive optical network (PON) employs passive splitter for distribution of signal to multiple users. Due to lower operational expenditure, PON is a promising alternative to point-to-point (P2P) network and active ethernet network for broadband access network architecture.

Currently deployed various types of time-division-multiplexed (TDM) PON system, standardized under different version of ITU and IEEE, solely provides a downstream and upstream data rate of 622 Mbps to 10.313 Gbps [1-3]. To achieve higher throughput, Wagner proposed an idea to use wavelength-division-multiplexing (WDM)scheme along with PON [4]. For access networks, Zhang et al. [5] discussed a WDM-PON model based on single-side-band (SSB) multi-level multi-band (MM) carrier-less-amplitude/ phase- modulation (CAP). In WDM-PON, each end user or optical network terminal (ONU) distribute the signal to/from OLT by using WDM coupler. In contrast to TDM-PON where all subscribers share a same wavelength, WDM-PON supplies each ONU with dedicated wavelengths that provides better security and scalability. Due to direct connection between OLT and ONUs, the nature of link in WDM-PON is P2P. For maximum flexibility, each link can be operated at different speed and with different protocol and pay-as-you-grow upgrades [6-7]. Many approaches have been reported to reduce the expensive cost of transmitter placed at ONUs by sharing transmitters of upstream data [8-9].Advancement in processing capabilities of information and coding has contributed to increased usage of OFDM in composite optical networks. Recently, OFDM technology is widely adopted in optical networking, from long-haul, to access networks and to home networks. PON uses OFDM as the modulation scheme and exploits its advantages like superior spectral efficiency and dynamic allocation of each subcarrier in real-time, to improve the bandwidth purveying of optical access network [10-11]. OFDM uses a large number of closely-spaced orthogonal subcarriers modulated by QAM or quadrature-phase-shift-keying (QPSK) technique to carry data traffic. K. Guo et al. [12] analyzed the performance of high capacity and power efficient 10 Gbps ONU in upstream transmission with the different method of asymmetric clipping OFDM based on WDM PON. I. Kartiwa et al. [13] presented the demonstration onuse of millimeter wave signal by optical carrier suppression method for 20 Gbps in uplink transmission over the distance of 20 km optical fiber.

The use of OFDM in PON is discussed in detail in section II. Section III presents the architecture of based on WDM and OFDM techniques. The demonstrated architecture will be a promising candidate in future generation optical networks. Simulation results are discussed in Section III and conclusions are arranged in the last section.

OFDM-PON

Some of the features of OFDM are the reason of its wide acceptability in RF and optical communication. OFDM belongs to the class of multicarrier modulation (MCM), illustrated in Figure 1, in which many subcarriers are used to carry information for one user only. In frequency domain, OFDM subcarriers do not need additional guard bands and all subcarriers are orthogonal to each other for the period of an OFDM symbol.Multiple orthogonal subcarriers are responsible to carry the upstream and downstream data.

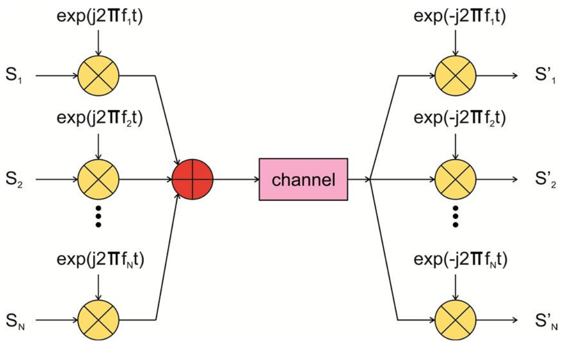

Figure 1: Concept of multicarrier modulation technique

The high-rate information stream of symbol rate R consists of large complex data symbols, which are translated into N subcarriers of low-rate substream by serial to parallel (S/P) convertor. Each subcarrier can be modulated by basic modulation schemes like QAM, QPSK. Inverse fast fourier transform (IFFT) is then taken over the substreams that convert it from frequency domain to time domain. IFFT output generates the orthogonal sinusoids, and the block of transformed symbols constitutes an OFDM symbol of N/R s. The cyclic prefix (CP) also has an importance in OFDM, since it provides robustness between each OFDM symbols and reduces inter-symbol interference (ISI). For CP, a copy from the end of same symbol is used for prefixing.

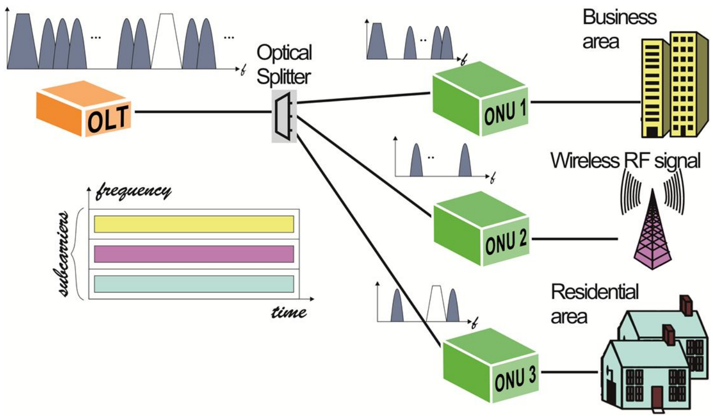

Figure 2: General view of OFDM-PON

In optical communication, OFDM symbols are generated electrically and then modulated on light signal. OFDM is suitable for support of heterogeneous services that means any arbitrary information can be communicated over an optical channel. Figure 2 shows the general architecture of OFDM-PON system. Here, OLT is used for time and frequency-domain partitioning of an OFDM frame. The preconfigured time slots and non-reserved OFDM subcarriers are broadcasted to all ONU's. According to time and frequency-domain scheduling, some of the information can be reserved for particular users in form of packets and are delivered only to intended recipient. As shown in Figure 2, filled-square block is transferred only to business area on specific time and frequency.

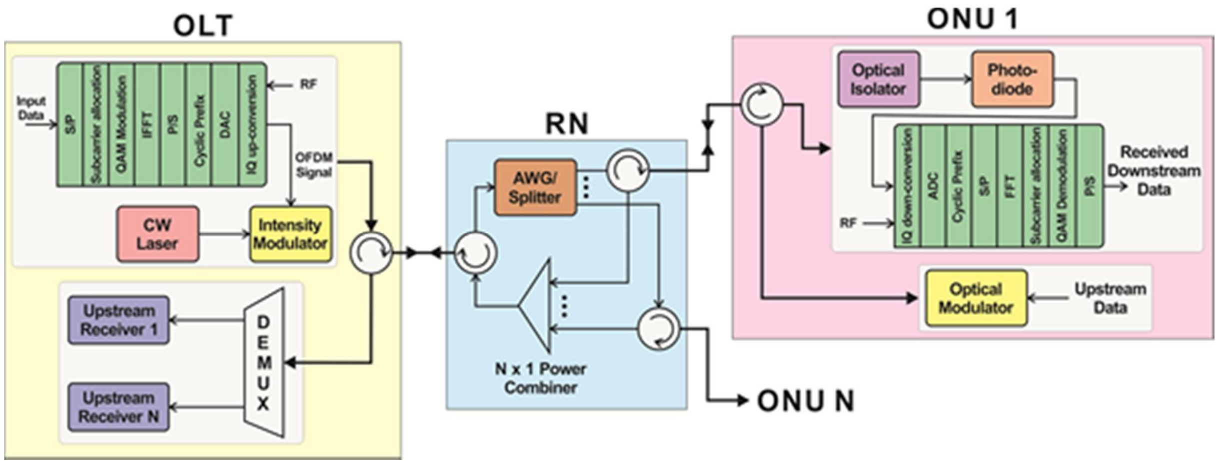

Figure 4:Architecture of WDM-OFDM-PON system

For bandwidth efficiency, 128 number of subcarriers are used thereby spectrum of subcarriers is overlapped. RF signal of 10 GHz is also exerted to provide up-conversion of OFDM symbol.Erbium doped fiber amplifier (EDFA) amplifies the light signal to 3 dBm before transmitting into optical fiber. In remote node (RN), arrayed waveguide grating or WDM-multiplexer/ de-multiplexer are employed to distribute the signal to each ONU.Optical isolator provides isolation to the downstream signal before demodulating it to recover the information. Some of the parameters during simulations' are listed in Table 1.

Table 1. Various system parameters observed during simulation

Parameters	Description
Number of Channels	8
Channel Spacing	100 GHz
Center Emission Wavelength	1537.2 nm
Fiber Length	50 km (SSMF)
Excess Loss	3 dB
QAM bit number	4
CP	25%

Same RF frequency is required for down-conversion of OFDM symbol. As the system is based on centralized light wave direct modulation technique that results no need of light source at ONU side, the light is directly processed by an optical modulator for upstream i.e. carrier reuse scheme is implemented. Similarly, the upstream information is recovered at receiver side at OLT.

Results and Discussion

At central office/ OLT, lorrentzian laser tuned at 1537.2 nm is used with single polarization representation to generate continuous light wave. Out of 128 subcarriers comprised for an OFDM signal, 100 and 28 subcarriers are used for data transmission and guard band respectively. Both upstream and downstream channel are set to a bit rate of 10-Gbps.

In this work, we have simulated the architecture of Figure 3 for 8 downlink and uplink OFDM channels as per mentioned parameters in Table 1. Figure 4 and 5 shows the electrical nature of signal at the output of QAM modulator at CO or OLT and PIN detector at ONU each for one channel respectively.Figure 6 and 7 depicts the constellation diagram of transmitted and received QAM of downstream under direct detection for OFDM signal at OLT and ONU respectively. We can analyze that due to various impairments of the fiber channel, noise affects the constellation diagram at ONU. Also the bit error rate is evaluated for centralized light wave direct detection system.

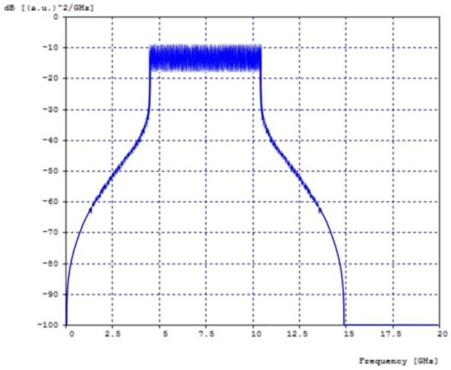

Figure 4: Output of QAM-modulator at OLT for one channel

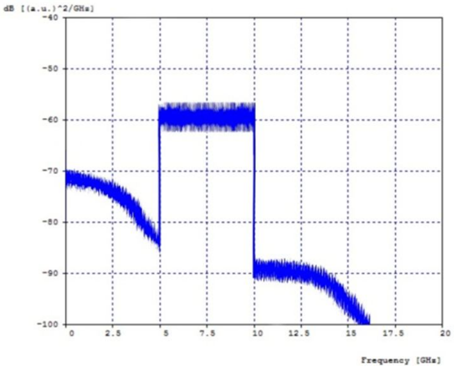

Figure 5: Output of downstream OFDM signal at photo-diode at ONU for one channel

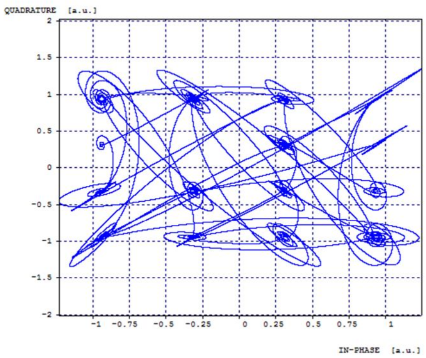

Figure 6: QAM constellation diagram of downstream data at OLT

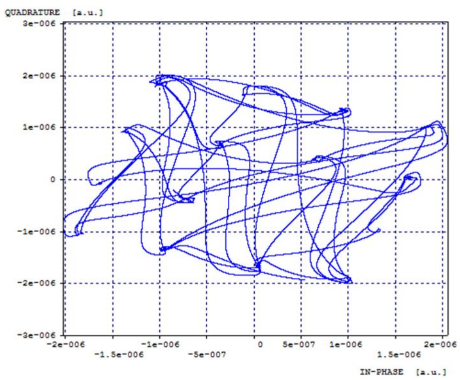

Figure 7: QAM constellation diagram of downstream data at ONU

Figure 8 shows the performance of receiver sensitivity for BER versus received power of OFDM 16-QAM. It is obvious that more power must be collected under back-to-back (B2B) condition. Under B2B, the power received is about 20.1 dBm at 10^{-11} BER. About 1.7 dBm power penalty of 16-QAM OFDM downlink is observed after 50 km distance at BER of 10^{-11}.

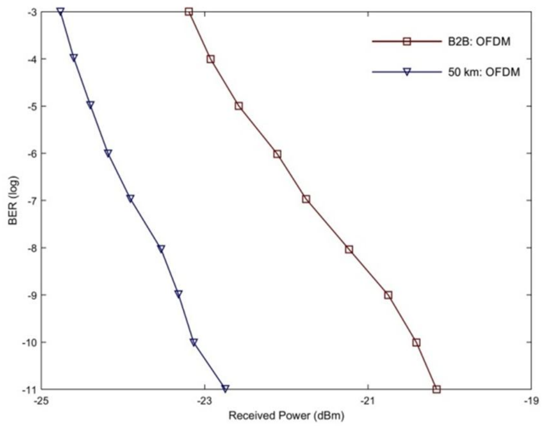

Figure 8: BER measurements of downlink signals with 16-QAM OFDM

Conclusion

This work shows the future generation architecture of PON based on combination of WDM-OFDM-PON system. We have calculated the receiver sensitivity at different BERs of downstream OFDM signal. Results demonstrate that 10-Gbps 16-QAM OFDM downstream signal is successfully transmitted over the distance of 50 km SMF.

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