Comparitive Analysis of 8-DPSK and 16-QAM Digital Modulation, using RoF for Hybrid WDM-TDM PON

Mayur Gambhir, Nayana Shenvi

Abstract— Hybrid WDM-TDM Passive optical networks (PON) combine both wavelength division multiplexing (WDM) and time division multiplexing (TDM) into a single PON, offering reduced cost, high scalability and increased data rates, hence hybrid PONs are currently effective solutions. The objective of this paper is to investigate and analyse various digital modulation schemes in conjuction with the hybrid WDM-TDM architecture, and implement a PON with efficient performance at 2.5 Gbps data rate, while trying to reduce costs. Radio-over-fiber technlogy (RoF) is used as it allows direct transmission of radio frequency (RF) through the fiber without the need of frequency conversion at the reciever. Digital modulation techniques like QPSK, M-PSK, M-QAM provide high spectral efficiency and better utilization of bandwidth. In this paper, 8-DPSK and 16-QAM are investigated for 2.5 Gbps, 4 Gbps and 5 Gbps, for a standard single mode fiber length of 25 km, and the performance is compared for hybrid PON architecture. It is shown that 16-QAM offers better performance at higher data rates. The performance analysis is based on eye diagrams, constellation diagrams, OSNR, and received optical power. OptiSystem simulation software package is used for simulation.

Index Terms— Hybrid WDM-TDM PON, digital modulation, radio over fiber, 8-PSK,16-QAM, digital RoF, DPSK, QAM, OSNR, eye diagram.

1 INTRODUCTION

There has been a steady increase in the demand for broadband services and hence the consequent increase in the volume of generated traffic in our communication networks. Hybrid WDM-TDM Passive optical networks (PON) are currently feasible effective solutions. Old generation optical access networks (e.g. TDM-PONs) are not able to meet the growing requirements.

Radio-over-fiber technlogy (RoF) is used as it allows direct transmission of radio frequency (RF) through the fiber without the need of frequency conversion at the reciever, and can be directly radiated using antennas [1]. RoF offers a combination of high capacity optical fiber and flexible wireless networks. This technology is introduced to reduce infrastructure cost and the complexity of remote antenna units (RAU). RoF technology can enhance the performance of wireless communication systems with the combination of large bandwidth (BW) and low attenuation characteristics offered by optical fiber [2].

The sharing of infrastructure and equipment between several base stations (BS) through passive optical network (PON) architecture is emerging as a low cost solution. This makes the PONs over active deployments dominant and reported worldwide, the GPON standard preferred in America, while Ethernet PON is the elected standard in Asia. [2].

The characteristics of GPON technology has been standardized by International Telecommunication Union-T (ITU-T) in Recommendation G.984 series [3]. GPON architecture has been integrated with RoF technology in [4], demonstrating a cost-efficient solution for 3G BSs.

In [2], the authors have used a Hybrid gigabit PON (GPON). A 2.5 Gbps GPON downstream link was analysed using RoF technology in GPON network architecture where differential phase-shift keying (8DPSK) modulation is used. They were able to show support for 32 to 64 users, for a range of 25 km at upto rates of 2.5 Gbps.

Advanced multilevel modulations like quadrature phase shift keying (QPSK), M-PSK (M-ary PSK) and quadrature amplitude modulation (QAM) have been proposed to increase the bitrate while keeping low the signal bandwidth.

In [5] the authors proposed and demonstrated a highly spectral efficient extended reach (ER)-PON using 4 Gb/s OFDM-QAM for both upstream and downstream signals, while achieving a high split-ratio of 256. Due to the high spectral efficiency of the M-QAM in each subcarrier of the OFDM signal, low-bandwidth optical components can still be used. This means we can directly increase the data rate of the system while using the existing optical components developed for GPONs. [5].

In this paper we use the hybrid-WDM-TDM PON architecture combined with RoF technology, and compare the performance of network for 8-DPSK and 16-QAM digital modulation, for three data rates (2.5 Gbps, 4 Gbps and 5 Gbps), for 25 km optical fiber. The paper focuses on downstream part only.

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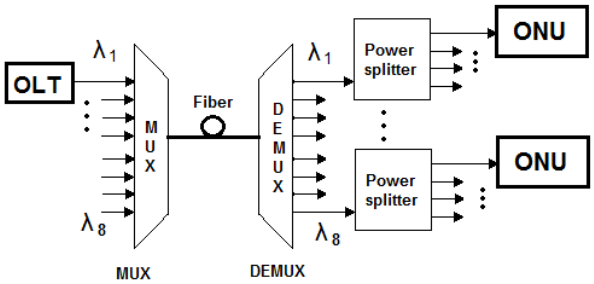

Figure 1: Hybrid WDM-TDM PON architecture

2 TRANSMISSION TECHNOLOGIES

2.1 Radio-over-fiber (RoF) Technology

An RF signal (modulated by analog or digital modulation techniques) can be transported by an analog fiber optic link. The RF signal may be baseband data, modulated IF, or the actual modulated RF signal to be distributed. The RF signal is used to modulate the optical source in transmitter. The resulting optical signal is launched into an optical fiber. At the other end of the fiber, we need an optical receiver that converts the optical signal to RF again, with the help of a demodulator.

Digitized RoF technique improves spectral efficiency, and also reduces the hardware count, while performance is limited by interchannel interference as a result of spectral aliasing of the regenerated IF signals, which limits the signal to noise ratio [6].

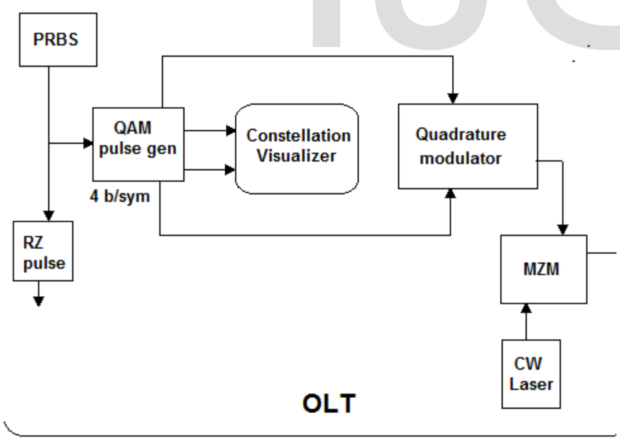

Figure 2: Schematic diagram of OLT in hybrid PON

2.2 Multilevel Digital Modulation

Digital modulation techniques like QPSK, M-PSK, M-QAM provide high spectral efficiency and better utilization of bandwidth.

The emerging of DWDM-PONs will require an increasing spectral efficiency due to channel-limited bandwidth. If an alphabet having M symbols is used, the relationship between symbol rate f_{sym} and bit rate f_b (bit/s) is ruled by the equation:

$$f_{sym} = (f_b / log_2 M) \quad [\text{sym/s}] \tag{1}$$

8-PSK is an M-PSK multilevel modulation scheme where M=8. All phasors in an 8PSK signal have the same amplitude as defined by the circle in the constellation diagram. The phase position represents the codes. 8-PSK uses eight different phase shifts 45° apart to represent 3-bit code groups from 000 to 111. Each specific phase corresponds to an assigned 3-bit code group. There are 5 levels of output amplitudes for I & Q.

M-QAM uses a combination of both amplitude and phase to represent multiple-bit words. QAM is usually square (M = 2^{2K} symbols). Most common forms are 16-QAM, 64-QAM and 256-QAM. By moving to a higher-order constellation, it is possible to transmit more bits per symbol.

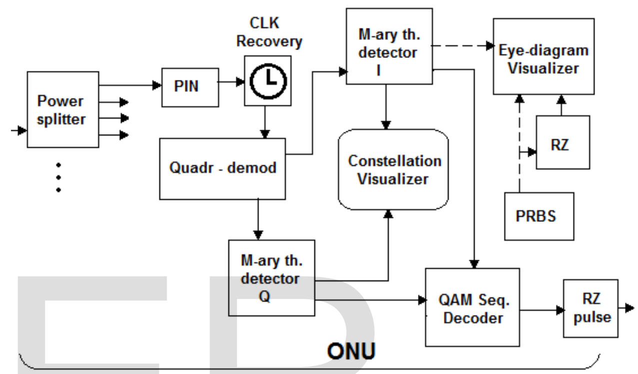

Figure 3: Schematic diagram of ONU in hybrid PON

If data-rates beyond those offered by 8-PSK are required, usually QAM is preferred since it can achieve a greater distance between adjacent points in the I-Q plane as the constellation points are more evenly distributed. But using QAM can lead to greater symbol errors [5], because of the proximity of adjacent constellation points compared to 8-PSK.

3 HYBRID ARCHITECTURE

Although TDM PON provides higher bandwidth than traditional copper-based access networks, there exists the need for further increasing the bandwidth of the PON by employing wavelength-division multiplexing (WDM) so that multiple wavelengths may be supported in either or both upstream and downstream directions. Such a PON is known as a WDM-PON. A WDM-PON solution provides scalability because it can support multiple independent wavelengths over the same fiber infrastructure, is inherently transparent to the channel bit rate, and it does not suffer power-splitting losses. [7]

PON architecture system includes three important apparatus: optical line terminals (OLT), optical network units/optical network terminals (ONU/ONT) and optical distribution network (ODN).

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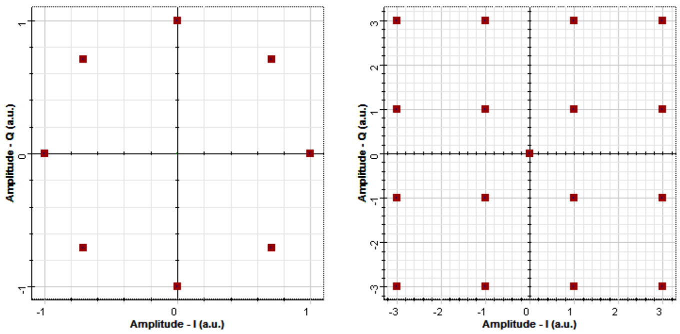

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Figure 4: Ideal constellation diagrams at transmitter, for a) 8-DPSK, and b) 16-QAM

The transmitters at the OLT generate a single wavelength carrying the data destined for a specific ONU. In the OLT, the RF signal is modulated by a DPSK sequence generator or a QAM pulse generator and combined with CW laser at wavelengths starting from 193.1 THz to 193.8 THz. These wavelengths are then coupled onto a single fiber using WDM Multiplexer (MUX), with specific insertion loss, located inside the CO. The multiplexed output is, in turn, connected to a primary single mode fiber (SMF) of length 25 km which terminates on a WDM Demultiplexer (DEMUX) as shown in Fig. 1 [8].

The WDM DEMUX separates all the wavelengths, according to the way they were combined at the OLT side, and feeds each one to a power splitter which distributes the signal to four users as shown in Fig. 2.

The hybrid WDM/TDM PON consists of 32 ONUs as shown in Fig. 6.10. They are split into eight WDM groups, sharing eight wavelengths in a WDM mode. Within each group, four ONUs share one wavelength in a TDM mode. The frequency spacing is 100 GHz, which indicates Dense-WDM (DWDM) transmission.

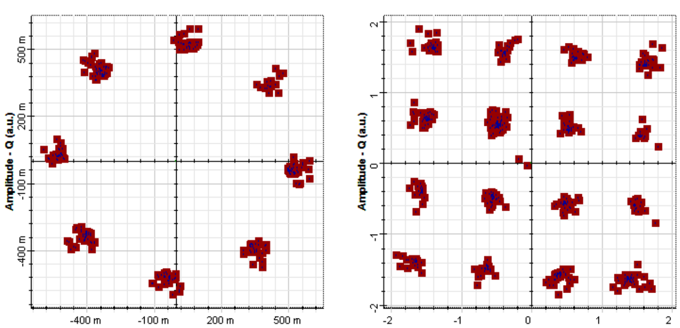

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Figure 5: Constellation diagrams at receiver, for a) 8-DPSK, and b) 16-QAM

4 SIMULATION DESIGN & SETUP

In this section we briefly describe the simulation setup in OptiSystem 13. All necessary parameters are based on the GPON standardized properties [3]. The architecture shown in schematic Fig. 6.11 is used to simulate the hybrid PON architecture, using 16-QAM over RoF. The simulation focuses only on the downstream part. 8-DPSK modulation technique is discussed in [2]. Here we describe the generation, transmission and reception of 16-QAM signals.

TABLE 1: General parameters for simulation

Parameters	Value (8DPSK)	Value (16-QAM)
RoF Operation frequency	2.4 GHz	2.4 GHz
Type of encoding	DPSK	none
Bitrate (Gbps)	2.5	2.5
Symbol rate (Gbps)	$Bitrate/3$	$Bitrate/4$
Sequence length	256	512
Samples per bit	64	64
Fiber length (km)	25	25
Reference wavelength (nm)	1550	1550

In the CO downlink, a QAM signal is generated. The downlink channels are multiplexed by a 1xN MUX and demultiplexed by a DEMUX. The multiplexed downlink DPSK signals are sent through the fiber and demultiplexed at receiver, which connects each wavelength to a 1x4 power splitter (split ratio=4). Each splitter finally connects to four base stations (BS). At the OLT, the electrical data signal is generated by the pseudo-random bit sequence (PRBS) generator, at 2.5 Gbps. The data is modulated by a QAM pulse generator, using 4 bits/symbol to generate a 16-QAM signal. The QAM signal is fed into a quadrature modulator (QM) at 2.4 GHz. A CW laser diode is modulated at a frequency 193.1 THz by a Mach-Zehnder Modulator (MZM) to convert the electrical signal to an optical signal which is transmitted through a 25 km single mode fiber (SMF).

At the ONU in receiver, the signal is detected by a photodiode, amplified, and fed to clock recovery in order to recover the data stream before it is passed to a quadrature demodulator (QD). The output of the QD is fed to two M-ary threshold detectors (for I and Q signals respectively). The signal is quantized based on suitable value of threshold amplitudes. The constellation diagram of the signal is displayed by using an electrical constellation visualiser.

An eye-diagram visualiser tool is used to plot the M-ary signal at the QM output of the receiver. A combination of PRBS generator, RZ generator and eye diagram analyzer are used to generate the eye-diagrams. Eye diagram is displayed in a window frame of 1.5 bit duration. The demodulated 16-QAM signal has four distinct amplitude levels corresponding to A, $3A$, $-A$ and $-3A$, which can be seen in a clearly open eye diagram.

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5 RESULTS AND DISCUSSION

A Hybrid WDM-TDM model has been simulated and analyzed by the optical system simulator, OptiSystem.

The model has been constructed using the general parameters in Table 1. Eye diagrams are a good indicator of performance of the system. In Fig. 6, the eye opening clearly indicates that the system performance is good.

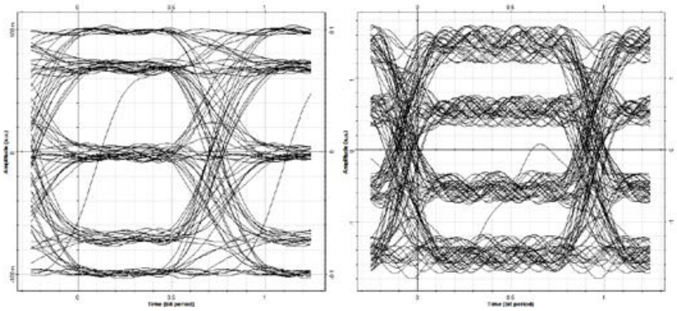

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Figure 6: Eye diagrams at receiver for 2.5 Gbps data rate, for a) 8-DPSK, and b) 16-QAM

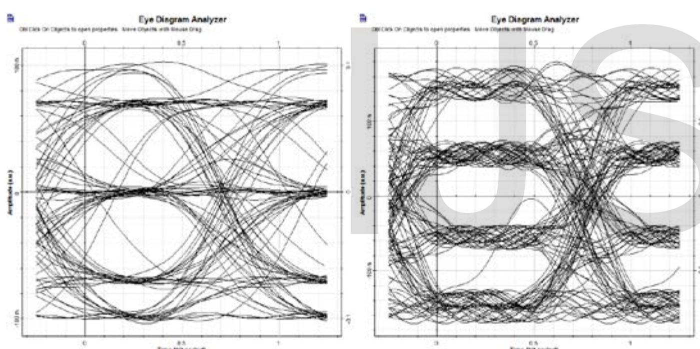

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Figure 7: Eye diagrams at receiver for 4 Gbps data rate, for a) 8-DPSK, and b) 16-QAM

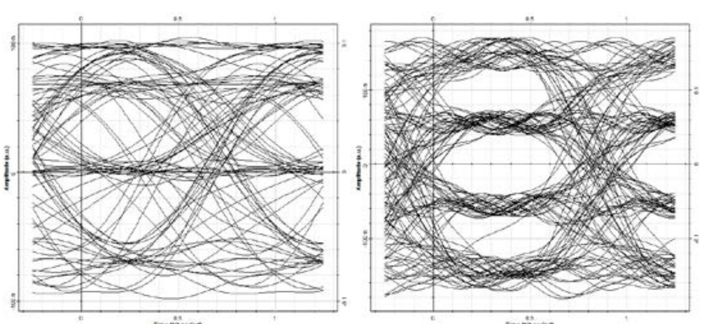

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Figure 8: Eye diagrams at receiver for 5 Gbps data rate, for a) 8-DPSK, and b) 16-QAM

A constellation diagram is a representation of a signal modulated by a digital modulation scheme. It shows the phase and amplitude values for each symbol. For 8-DPSK signal, the number of bits per symbol is 3, while for 16-QAM it is 4. The constellation diagrams of the tramsmitted signals (for 8-DPSK and 16-QAM) are shown in Fig. 4 (a) and (b) respectively.

The received signal at the receiver is shown in Fig. 5 (a) and 5(b). It is seen that the constellation of the output signal is similar to the input signal with some amplitude and phase errors.

The performance of 8-DPSK and 16-QAM have been compared at three different data rates: 2.5, 4 and 5 Gbps.

At 2.5 Gbps, it is seen that the eye openings for both modulation techniques are wide, so performance is good (Fig. 6).

At 4 Gbps (Fig. 7), the eye pattern for 8-DPSK starts to close, i.e. performance starts to degrade. But eye opening for 16-QAM is still good. At 5 Gbps (Fig. 8), the eye opening for 8-DPSK is degraded at 5 Gbps, but that for 16-QAM is still acceptable. Constellation diagrams show symbol errors at 4 and 5 Gbps, indicated by moving of constellation points from ideal position.

For 8-DPSK and 16-QAM, the optical SNR (OSNR) performance for the varying fiber lengths, at 2.5 Gbps is shown in Fig. 9 It can be seen that the OSNR at 0.1 nm bandwidth displays a decreasing pattern as the length of the fiber increases. The graph for both techniques is almost the same. Value of OSNR is sightly higher for 16-QAM.

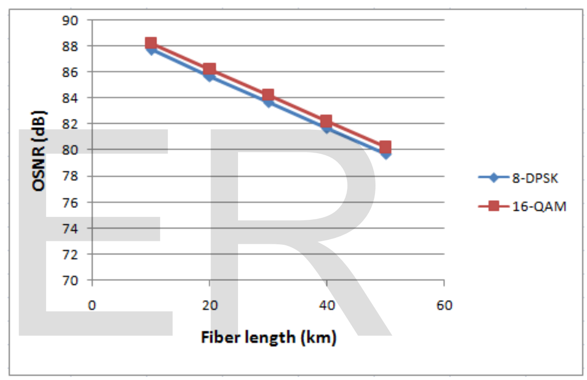

Figure 9: OSNR vs fiber length at 2.5 Gbps

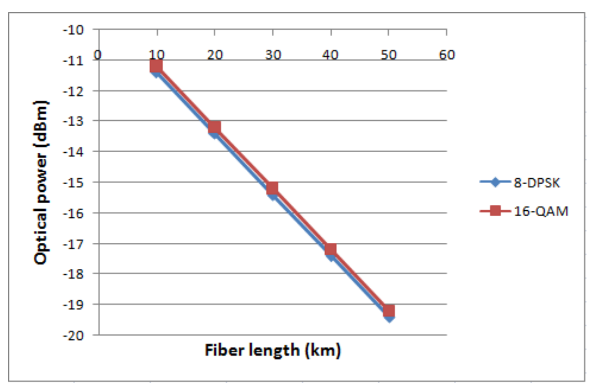

Figure 10: Received power vs fiber length at 2.5 Gbps

Fig. 10 illustrates the received optical versus the fiber length. The power (dBm) is found to reduce linearly with increasing fiber length due to attenuation. The optical power at the transmitter is 5 dBm. It can be seen from Fig. 10, that, the received optical power is around −14.2 dBm along 25 km fiber, for both 8-DPSK and 16 QAM. The number of ONUs for each splitter can be increased to eight, to give 64 ONUs in all. We can also extend the length of fiber. The power is reduced due to attenuation, dispersion, and losses which are contributed to by all devices of the network.

6 CONCLUSION

The Hybrid WDM-TDM PON using RoF, with 8-DPSK and 16-QAM techniques were analysed. The performance of the two methods were compared. In 16-QAM, as we have seen the symbol rate obtained at the output of the quadrature modulator is 1/4 of the data rate, compared to 1/3 of data rate for 8-DPSK. Thus the spectral efficiency is improved. However, it is likely that 16-QAM will suffer from more symbol errors because of signal impairments, as there are a greater number of phase shifts, which is shown by shift in constellation points from their ideal positions. The OSNR and received optical power graphs are similar for both modulation schemes. 16-QAM offers a better performance, indicated by eye-diagrams, which is noticable at higher data rates.

It is seen that just acceptable performance is obtained at 4 Gbps, with a good opening of the eye, but still with constellation point shifts. Thus, a passive optical network model with high spectral efficiency and relatively lower cost than traditional PONs can been realized. Hence it is shown that digital modulation techniques using RoF technology are suitable schemes for hybrid WDM-TDM PONs.

The 16-QAM modulation scheme, athough leading to better performance, suffers from symbol errors at high data rates. It is necessary to find a method to reduce the symbol errors. Measurement of phase and amplitude errors using error vector magnitude (EVM) ([3], [11]) has not been done in this paper, which can be carried out in future work.

Also differnt other modulation techniques like 32-QAM, 64-QAM offer promising solutions but can lead to high bit / symbol error rates in conventional designs [11]. So effective receiver design for these techniques is needed. Also design of hybrid PON systems for long reach PONs or LR-PONs, (≥ 100 km) has to be investigated.

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