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Energy Considerations Regarding Next Generation Passive Optical Networks

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The increasing demand for faster broadband access requires the development of next-generation Passive Optical Networks (PONs) operating at very high bit rates (e.g. 40 Gb/s). On the same time, energy efficiency in Information and Communication Technology (ICT) infrastructure has become a very important topic. In this paper, several proposed solutions for future high-speed PONs, such as coherent and incoherent multilevel signaling, wavelength-multiplexed On-Off Keying (OOK) and Orthogonal Frequency Division Multiplexing (OFDM), are examined with regards to the energy consumption of the system, with results indicating that the necessary bit rates can be provided without sacrificing energy efficiency.

Introduction

The emergence of new, bandwidth demanding applications like file sharing, High Definition Television and social networking, has fueled the deployment of fiber-based access networks across the world. The introduction of even more bandwidth-hungry services, such as 3D HDTV, cloud computing and telepresence, means that the demand for higher bit rates will continue unabated [1]. To cope with the demand, the PON community has developed a series of standards based on Time-Division Multiplexing (TDM), with the last ones specifying 10 Gb/s operation. Discussions are under way for Next Generation PONs, with key requirements being increased bit rate, increased splitting ratio and longer reach [2]. Some of the most promising approaches for achieving these requirements are optical multilevel modulation formats (coherent or incoherent), OFDM and Wavelength-Division Multiplexed (WDM) OOK channels.
The exponential growth of traffic over today's communication networks has greatly increased power consumption in these networks. The contribution of optical Internet Protocol (IP) networks to the total power consumption in OECD countries was estimated at around 0.4% in 2009, and as higher bit rates are required, the percentage is expected to reach 1.5-2% soon [3]. The bulk of energy over communication networks is consumed in access networks, which are responsible for almost 90% of the energy spent [3]. As energy efficiency has become an important issue for societies for environmental and economical reasons, it is critical to consider the impact of Next Generation optical access networks in power consumption.
In the following sections of the paper, the proposed solutions will be discussed and their power consumption, based on estimations on the components required for each one, will be calculated for a number of important system parameters. Then, the results are discussed and some conclusions are offered.

Next Generation Passive Optical Networks

Traditionally, the bit rate in every successive TDM-PON standard is increased by a factor of 4, and it is expected that 40 Gb/s transmission capability will be required for the next implementation. Several alternatives to achieve this bit rate, all based on 10

GHz components, have been examined. The first one is shown in Fig. 1a and is based on Phase Shift-Keying with Polarization Multiplexing (QPSK-POLMUX) with coherent detection to transmit 2 bits/symbol/polarization (a scaled version of the system in [4]). The main components needed are Balanced Photo Detectors (BPD), driver amplifiers, External Cavity Lasers (ECL) and Digital Signal Processing (DSP). Another method, proposed by the authors in [5], implements a 16 Differential Quadrature Amplitude Modulation (DQAM) signal to transmit 4 bits/symbol (Fig. 1b). This approach requires the same components as QPSK-POLMUX, but in reduced numbers. Another research direction that was gathered a lot of interest uses electrical multilevel modulation, especially in the form of directly-detected OFDM, shown in Fig. 1c. This approach also depends heavily on DSP, but it requires significantly less opto-electronic components [6]. Finally, the last proposal capable of 40 Gb/s involves multiplexing four 10 Gb/s OOK channels on different wavelengths and is shown in Fig. 1d. That way, complex photonics and DSP can be avoided, but four transceivers are necessary in every Optical Network Unit (ONU) in the user premises. In total, these four architectures represent a wide range of options and design trade-offs and the analysis of their power consumption that will follow can shed light to the energy efficiency that can be expected for future TDM-PONs.

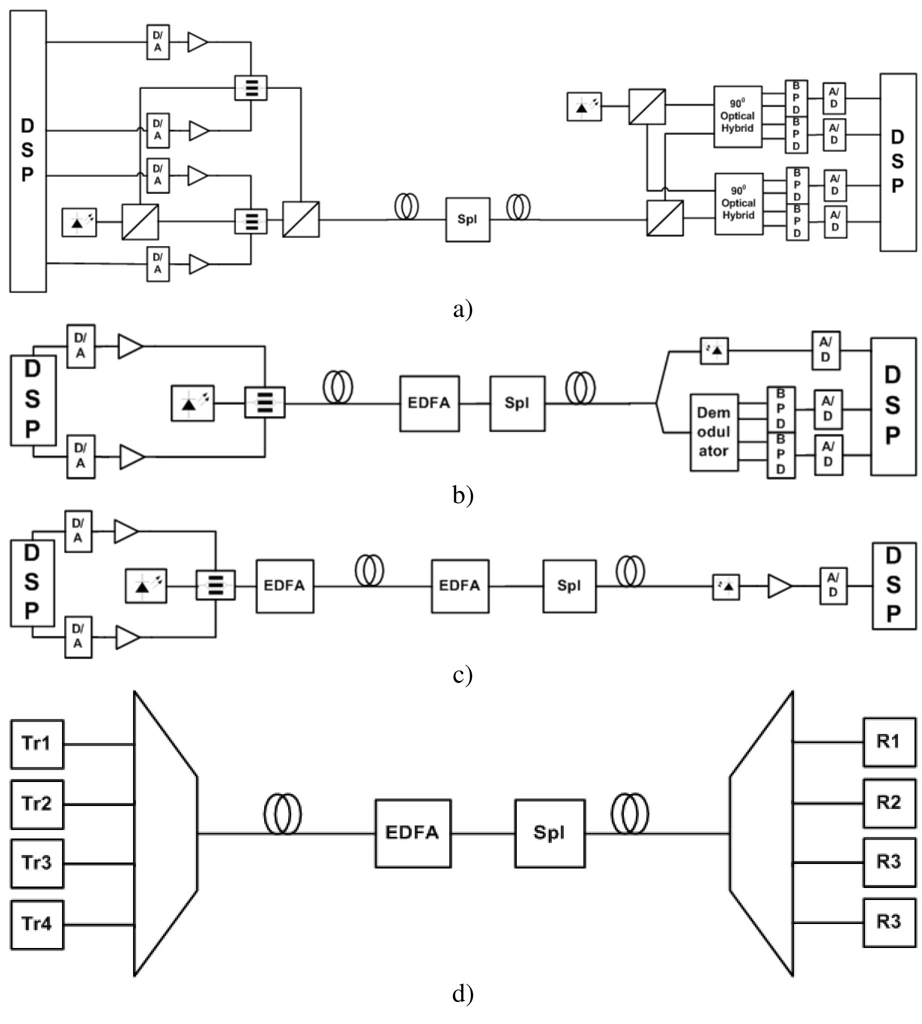

Fig. 1 a) DQSPK-POLMUX b) DQAM c) OFDM d) 4xOOK (downstream only, upstream symmetric)

Power consumption analysis and results

Calculating the power consumption of a future PON is difficult, since certain components are not commercially available yet. For those components, we use the values obtained from the extensive research performed in [8]. For the DSP chips (which include the A/D and D/A converters, as well as the ASIC), values recommended in [9] are used. The results are summarized in Table 1. Another important parameter is the sleep mode in the ONU. Since in TDN PONs users share the bandwidth in the time domain, most of the time the receiver and transmitter are idle and it is possible to shut them down to save energy. For our calculations, a conservatively optimistic value of 0.7 for this off-time is assumed (unless otherwise stated).

Table 1

Component	**Power Consumption (W)**
Photoreceiver and Balanced Photo Detectors	0.5
10 Gb/s Transceiver	2.5
ECL	1
EDFA	25
Electrical amplifier	3
DSP (OFDM, DQPSK single polarization)	5
DSP (incoherent DQAM)	4.5

Based on the values above, the power consumption per user for each PON variant is estimated for a number of important system parameters. Firstly, the impact of the splitting ratio of the PON, which determines how many users are served by the PON, is examined. This affects the contribution of the shared components in the Central Office (CO) and in the Remote Node (RN) to the total power consumption. The results are shown in Fig. 2a. For low splitting ratios, incoherent DQAM and WDM OOK are the most power efficient approaches. When the splitting ratio increases, the power consumption of OFDM becomes comparable with incoherent and WDM OOK. The consumption of the coherent QPSK-POLMUX approach, however, remains steadily higher. This is caused by the high DSP-related power that is not affected by the increase in the splitting ratio. Next, the power consumption as a function of the duration of the off-time of the ONU was calculated (Fig. 2b). Again, WDM OOK has the lowest power consumption for most of the off-time values. Incoherent DQAM and OFDM have similar consumption that, for an off-time of around 0.6, approaches the WDM OOK case. Coherent QPSK-POLMUX has significantly higher power consumption that approaches the other three for an off-time of around 0.75. Finally, on Fig. 2c the results for different power consumption values of the DSP component of the system are shown. The power consumption of WDM OOK, although it is independent of the DSP value, is also included for comparison. OFDM and incoherent DQAM exhibit similar power consumption trends, whereas QPSK-POLMUX is considerably more sensitive to the DSP power consumption. The reason for this difference is the fact that QPSK-POLMUX requires double the number of A/D and D/A converters, which consume the bulk of the energy in the DSP chip, than incoherent DQAM and OFDM. It can be observed that the required values for the coherent, OFDM and incoherent approaches to have comparable consumption with the WDM OOK case are 3.5, 4 and 4.5 W respectively.

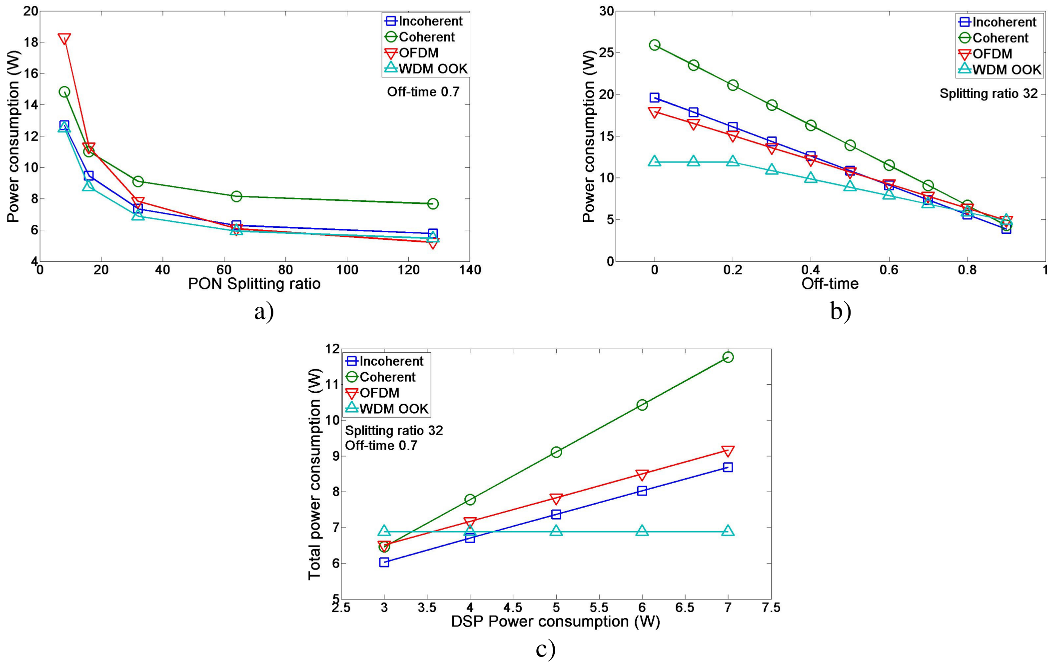

Fig. 2 Power consumption per user vs. a) Splitting ratio b) Off-time c) DSP power consumption

Conclusions

The power consumption of four different approaches for future TDM-PONs has been estimated for a number of system parameters. Results indicate that protocols that allow a high off-time in the ONU can significantly lower power consumption in the PON. In addition, research on low-power DSP is crucial for the deployment of DSP-based PON systems in access networks. In general, with careful optimization of the system parameters, it is shown that it is possible to implement 40 Gb/s TDM-PONs without sacrificing energy efficiency.

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