

NG-PON1: technology presentation, implementation in practice and coexistence with the GPON system

Vesna Eržen, Boštjan Batagelj

*University of Ljubljana, Faculty of Electrical Engineering, Tržaška 25, 1000 Ljubljana, Slovenia
E-mail: erzenvesna@gmail.com, bostjan.batagelj@fe.uni-lj.si*

Abstract The paper presents technology of the ten-gigabit-capable Passive Optical Network – XG-PON which in two phases of its development (XG-PON1 and XG-PON2) takes the first step towards the Next-generation Passive Optical Network 1 – NG-PON1. Results of researches and analyses of the development of the fixed broadband optical network are summarized. The focus is on describing the migration process of the Gigabit-capable Passive Optical Network – GPON to NG-PON1. The migration to the new technology is sensible only if related to technological improvements that enable enhanced services and if the investments needed for migration are cost-efficient. Arrival of a new technology is always characterized by a certain range of changes in the existing system, therefore, the purpose of the paper is to answer the questions what is the scope of changes needed in the existing passive and active elements and which new elements need to be added. In relation to this, special attention is given to coexistence of GPON and NG-PON1. It is shown that for coexistence of the GPON and NG-PON1 systems using wavelength blocking filters – WBF based on the Thin Film Filter – TFF and Wavelength Division Multiplexing – WDM splitters is a cost-efficient and technologically adequate solution.

Keywords: Next-generation Passive Optical Network, optical access network, Gigabit-capable Passive Optical Network, coexistence

1 INTRODUCTION

By the Nielsen's law, the required bandwidth in different access network is constantly increasing by approx. 50% every year [1]. Lately, the increase is mainly due to cloud computing and IPTV [2]. As the optical fiber is a broadband medium, which in theory and practice achieves very high transmission speeds, more and more service providers decide to use it in building a new or upgrading the existing optical access network.

When the fiber runs from the central office to the home of the end user, the technology is called Fiber to the Home – FTTH. When building FTTH, two basic architectures of the network are possible: Point-to-point – P2P [3] or Point-to-multipoint – P2MP.

The Gigabit-capable Passive Optical Network – GPON is based on the architecture of P2MP and was selected by the majority of providers of telecommunication services in Europe and the USA. GPON is standardized by the ITU-T (International Telecommunication Union – Telecommunications) series of recommendations G.984 [4]. In accordance with the standard, it provides various combinations of transmission speeds. In practice, the most commonly realized asymmetric speed of data transfer is at the downstream speed of 2.4 Gbit/s and the upstream speed

of 1.2 Gbit/s. The other possibility is symmetric transmission speed of 2.4 Gbit/s. As the optical fiber is able to transport much higher bit rates, the Next-generations PON – NG-PON systems promise much higher transmission speeds.

In 2010, the ITU-T G.987 standard [5] was approved. It defines the first phase in the development of the Ten-gigabit-capable PON – XG-PON1 system. X in the abbreviation XG-PON stands for the Roman numeral 10 to denote 10 Gbit/s of the system transmission speed. This is true for the downstream transmission. The upstream transmission speed of XG-PON1 is 2.5 Gbit/s. The standard above contains also trends which refer to the 2nd phase in the development of the ten-gigabit PON system (XG-PON2) which anticipate the symmetric transmission speed of 10 Gbit/s in the downstream and upstream of data.

The paper defines general characteristics and physical level of the GPON, XG-PON1 and XG-PON2 systems. The emphasis is on the recently standardized XG-PON1 technology. The technology definitions are based upon standards formed or still being formed in the working group FSAN – Full Service Access Network of the international association ITU-T. In its Chapter 3, a chronological overview of the development of technologies is given and demands to be fulfilled are identified enabling achievement of the simplest possible and spontaneous migration to the Next-generation PON.

Two possible ways or scenarios of migrating from GPON to XG-PON1 and demands for their coexistence are described. Chapter 4 deals with the question which network devices are adequate to use to achieve compatibility of the NG-PON1 and GPON systems. In Chapter 5 the most important conclusions are drawn.

2 TECHNOLOGY DESCRIPTION

2.1 GPON

Compliantly with ITU-T G.984, the GPON's Optical Distribution Network – ODN connects the Optical Line Terminal – OLT with the Optical Network Terminal – ONT or Optical Network Unit – ONU via a passive optical splitter. The basic components of the PON network are shown in Fig. 1. ONT is intended for one end user. ONU is able to have more end users connected to it, with different types of connections (optics, copper pairs, wireless connection).

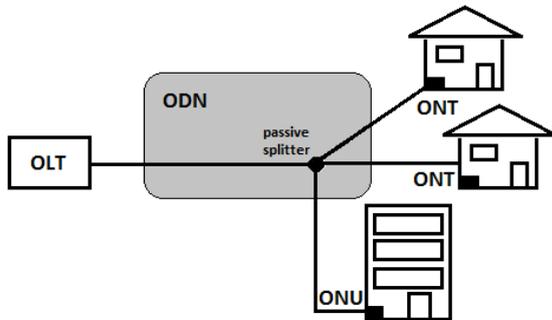


Figure 1. GPON network consists of OLT in the central office, passive optical splitter and ONT/ONU units

The ODN network is entirely passive, meaning that it contains no elements needing electric power supply for its operation.

Its downstream transmission is different from its upstream transmission. In the downstream, there is a continuous data stream, where the communication among OLT and individual ONTs runs via Time Division Multiplexing – TDM. ONT/ONU receive all frames and discard those that are not intended for them. In the upstream, there is an interrupted series of data bursts where separate ONT/ONU units communicate with OLT in the central unit via a multiple access on the basis of Time Division Multiple Access – TDMA [6].

OLT in the central office can support various split ratios (1:16, 1:32 or 1:64 or more), depending on the desired reach. A higher ratio means a lower reach and vice versa because there is a limited power budget in the network. To increase the power budget in the network, compliantly with the ITU-T G.984.6 recommendation [7], the active components of the Reach Extenders – RE can be used.

The downstream transmission in a single-fiber system operates at the wavelength of 1490 nm and the upstream transmission at the wavelength of 1310 nm. At

the wavelength of 1550 nm, a video signal is transmitted.

2.2 XG-PON1

The downstream transmission of XG-PON1 is 10 Gbit/s and the upstream transmission is 2.5 Gbit/s. Because of specific demands of the optical-transceiver market and industry, the FSAN/ITU-T group selected the bandwidth between 1575 nm and 1580 nm for the downstream and 1260 nm to 1280 nm for the upstream transmission (Fig. 2). Choosing the adequate band was not easy mainly because of the need for the guard band which prevents interference among signals of the near wavelengths.

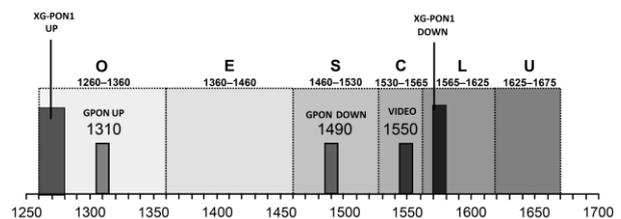


Figure 2. GPON and XG-PON wavelength allocation

The main components of the XG-PON1 network architecture are OLT in the central office, ODN and ONU/ONT units at the user end. The standard defines a simple and complex ODN as shown in Fig. 3. The simple ODN consists of a single passive Optical Distribution Segment – ODS and the complex ODN consists of a group of passive ODSs interconnected with reach extenders [8].

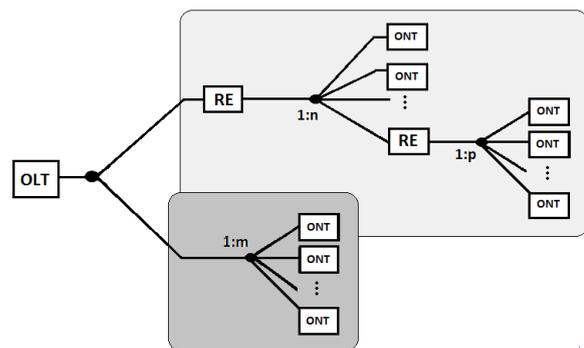


Figure 3. Example of simple and complex networks united in a single PON.

The reach extender – RE, which increases the optical link budget, consists of technologies, such as optical amplifiers and regenerators on the basis of optical-electrical-optical conversion. RE is anticipated to have an important role in the NG-PON system [9], [10]. The reach extenders are used to increase the power budget thus increasing the reach and split ratio and also merging more ODS.

On higher network levels (transmission convergence – TC layer) management and encapsulation (framing) in the XG-PON1 system takes place, as is the case with GPON [11]. This is important from the coexistence point of view.

The downstream window is only 5 nm wide. To operate normally, such a narrow band uses cooled laser sources to stabilize the wavelength. Such special sources are in the first place related to higher costs [12].

The upstream window being 20 nm wide, uncooled laser sources can be used and the ONU optics costs decreased.

2.3 XG-PON2

The FSAN/ITU-T group has still not achieved consensus and clear cues regarding the next stage of the NG-PON1 system, marked as the XG-PON2 system. The XG-PON2 system refers to the increase in the upstream transmission speed from 2.5 Gbit/s to 10 Gbit/s, enabling the symmetrical transmission speed in the upstream and downstream direction.

Some experts see the possibility of spontaneous migration from the GPON to the XG-PON1 technology and later to the XG-PON2 technology with some adjustments on the transmission convergence layer made. It is planned to retain the downstream wavelength of the XG-PON1 system and extend the framing structures for the TC layer. That would support a higher upstream transmission speed (10 Gbit/s) and compatibility of XG-PON1, XG-PON2 and GPON.

Solutions related to the coexistence of the XG-PON1, XG-PON2 and GPON are facing some technological shortcomings. Firstly, it is not clear if fragmentation should be supported in the upstream at higher transmission speeds and what would be the impacts on the Dynamic Bandwidth Allocation – DBA. Also, a separate receiver at OLT will be needed to prepare for the reception of data at different transmission speeds in the upstream. Difficulties because of the nature of the upstream burst occur at approximately 5 Gbit/s. The key problem is principally in the receiver designed so as to enable a precise detection of the change in the high- and low-signal levels and at the same time prompt adjustment of and appropriate time for signal recovery [10].

3 OUTLINE OF THE MIGRATION PROCESS

The PON systems are well established in practice and are regarded as a very prospective access technology. After 2000, the GPON technology has become widely recognized. The ten-gigabit PON systems mark the next stage of development. These are the XG-PON1 and XG-PON2 systems which are in technical literature marked under the umbrella term NG-PON1. The Conceptual definition of NG-PON1 goes back to 2008. In 2010, XG-PON1 was standardized. Due to the ever increasing

needs for a higher bandwidth, it is expected that this technology will reach the market until the end of year 2013.

3.1 Migration to the new technology scenario

The G.987.1 recommendation for the XG-PON1 technology purposes two scenarios enabling migration from the GPON to the XG-PON1 technology. When service providers want to change the copper connection with the optical one, they can build the XG-PON1 system. This migration scenario is called the PON green-field migration scenario. The other way of migrating to the XG-PON1 system operation is upgrading the existing GPON system where upgrading or replacement of the ONU/ONT units is needed. This can be done either one after one other in a longer time period or all at once. The period of coexistence of the GPON and XG-PON1 system in a single ODN depends on this decision. This migration scenario is called the PON brown-field migration scenario.

When we talking about the NG-PON1 systems, the concept of consolidation of the network should not be ignored. The idea is to combine and reduce the number of central offices in an extended and long-reach access, which is possible due to the large power budget in the NG-PON1 systems.

The main goal of introducing NG-PON1 is the increase in the data-transfer speed, which can be achieved at a minimal cost [9]. This can be done by minor interventions on the physical level of the network. To protect investments made by the service providers for GPON, the FSAN/ITU-T group in its recommendations defined demands enabling coexistence of the NG-PON1 and the GPON system.

The demands [13] related to the process of migration to NG-PON1 and having to be considered when designing standards are:

- optimization of the new equipment costs;
- enabling coexistence of the new PON systems with the currently used ones to protect the operator investments;
- optimal exploitation of the existing resources (bandwidth) by using a dynamic bandwidth allocation to users;
- preserving and reusing the optical infrastructure;
- minimization of network interference when migrating to the new technology by precise prior planning.

For achieving coexistence, when migrating to the XG-PON1 technology, it is important, the existing both the colorless ONT units and the ODN network can be used as they are. Advantages of the XG-PON1 over the GPON technology are higher profits per user, simple network expansion and efficient network management and planning [14].

3.2 Coexistence of the NG-PON1 with the GPON system

The G.987 standard anticipates coexistence of XG-PON1 with GPON and transmission of video signals into the same ODN system. If common ODN is intended for XG-PON1, GPON and transmission of video, it is required for differentiation of the data traffic to use special wavelength blocking filters – WBF.

The most important condition to the met for the NG-PON1 and GPON system coexistence is operation in the existing optical distribution network. Because of the differences in the wavelength bands the two systems operate in, some updating ensuring simultaneous transmission of different wavelength signals should be made.

The wavelength band for the upstream transmission in GPON extends from 1260 nm to 1360 nm and for the downstream transmission from 1480 nm to 1500 nm. The function of the neighboring bands is to assure safety by separating the GPON bands the bands of the XG-PON1 system. In this way, interference among the signals of the nearby wavelengths is prevented. G.984.5 recommends installation of low price bracket WBFs to ensure isolation outside the guard band and to reduce in this way the cost of migrating from GPON to XG-PON1.

Fig. 4 shows the basic elements enabling coexistence between the GPON and XG-PON1 system. In the downstream transmission, the signal runs from the central office where two separate OLT units for GPON and XG-PON1 transmit. To allow for coexistence, a splitter (made on the basis of Wavelength Division Multiplexing – WDM) is used for its combining signals of different wavelengths (GPON, XG-PON1, video) in the downstream transmission to the common optical fiber and for splitting these signals in a reverse route. The WDM splitter can be placed in the central office [8].

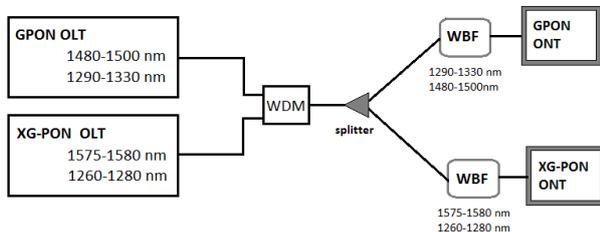


Figure 4. Basic network architecture enabling coexistence of the GPON and XG-PON1 system.

For the signal to operate and be processed properly in a separate ONT unit (for GPON and XG-PON1), it is preliminary passed through WBFs to assure isolation outside the guard bands as required. This makes the wider band of the wavelength to remain at our disposal for the next generation of the PON systems [14].

When extending the reach or increasing the power budget in the network by migrating to XG-PON1, the G.987.1 standard foresees two possible architectures. One proposes installation of RE containing technologies for simultaneous amplification of the GPON and XG-PON1 signals (Fig. 5). The other uses RE only for strengthening XG-PON1 (Fig. 6). The existing PON elements (OLT, ONT) despite being retained, coexistence is achieved and, at the same time, the power budget in the network is increased to the extent defined by the standard.

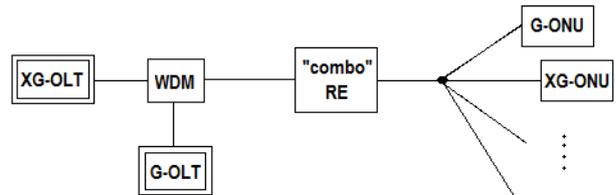


Figure 5. Combined RE reinforces the GPON and XG-PON1 signals simultaneously

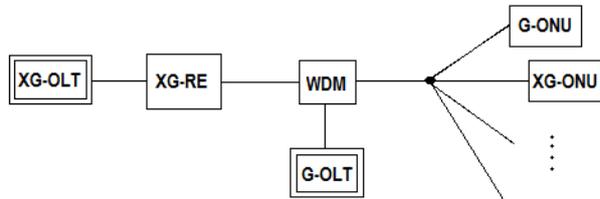


Figure 6. By using XG-PON1 RE, a sufficient power budget in ODN is ensured.

4 NEW DEVICES OF THE XG-PON1 SYSTEM

Implementation of NG-PON1 into practice is designed in the way optimally protecting investments of operators in the existing system. It is for this purpose that XG-PON1 operates in the same ODN as GPON. Despite that when migrating to a new technology there are still some investments that cannot be avoided.

As shown in Table 1, when migrating to the NG-PON1 system, there are some elements that should be changed, some that can be used in their unchanged form and some that need to be upgraded. The unmarked cells in Table 1 are devices needing to be substituted, added or upgraded when migration to the new technology.

Table 1. Adequacy of the network elements in different examples of the PON systems.

Devices	GPON	XG-PON1	XG-PON2
OLT			
ONU			
SPLITTERS			
CABLES			
FILTERS			
WDM SPLITTERS			

As already mentioned, to allow for coexistence, wavelengths of different signals transmitted via the common fiber need to be separated. This can be done by using special adjustable lasers or WBFs.

Speaking in terms of cost efficiency, using the WBFs, manufactured on the basis of the Thin Film Filter – TFF technology, is more appropriate than using adjustable expensive lasers. Besides WBFs have longer been present on the market and are a more developed technology. Development of adjustable lasers is still in progress and their use is to some extent technologically limited. An example of such a limitation is a system for laser temperature stabilization. Its implementation being quite demanding, the cost of the final product is high.

Besides the WBFs and adjustable lasers there are some other devices that can be used for wavelengths selection, but the majority of them are still being in their development and testing phase. One such example are devices based on nanowire technology. Currently, this technology is still in its early development stage and in many points of view it is not yet suitable for practical applications in the NG-PON1 systems; however, technological improvements are anticipated [15].

4.1 WDM splitters

The WDM splitter is an optical device required at central office under NG-PON1 deployment. It combines and splits signals of different wavelengths [15]. The WDM splitter increases the system performance without changing the distribution network. It provides signals of different wavelengths in the downstream transmission to merge to a common optical fiber. In the upstream transmission, it classifies signals from the common fiber in to the corresponding optical fiber.

The basic characteristics of the WDM splitters are defined in the appendix of the ITU-T G.984.5 recommendation [16]. There are different reference options of the version of the WDM splitters listed, depending on specific demands of individual systems. Fig. 7 shows a scheme of the WDM splitter which enables merging of the XG-PON1 and GPON system and transmission of video signals.

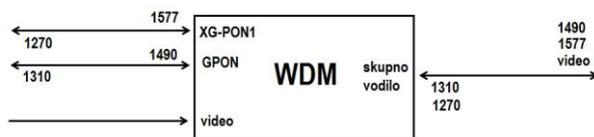


Figure 7. WDM splitter for coexistence of XG-PON1, GPON and video signals.

From the technological point of view, the fiber and the planar type of the WDM splitters are available. The first one is based on the TFF technology or on Fiber Bragg grating and usually consists of different (discrete) components for a particular wavelength. The second type is based on the use of Planar Lightwave Circuits –

PLC which are mainly made on the basis of the Photonic Integrated Circuits – PIC technology. These WDM splitters in most cases contain arrayed waveguide gratings – AWG structure. Such multiplexers can manage a great number of channels and enable parallel processing. The advantage of these devices is possible integration with other passive or active components of the network.

In the past decade, PLC components fundamentally influenced the improvement of performance of the core network. As expected, such trend should continue in next generations of access networks.

4.2 Structure of WBF

As already mentioned above, TFF can be used in manufacture of low-cost WBF which is based on simple operations of filtration. The advantage of such WBFs is in its independence from the ONT unit. Usually it is formed by a sequence of very thin layers with low-absorption of light. Their thickness can be compared to the wavelength of light. The layers are usually made of a sequence of materials of a high and low refractive index [14].

Interference of the light entering into the multilayer structure constructed by certain number of altering thin layers has a spectrally-dependent response which is the characteristics of the filter (transmittance or reflectance of optical signals). Parameters, such as the number of layers, their thickness and consistence as well as optical features crucially affect the TFF permeability. This permits the TFF filter to be adjusted to certain needs or various applications. In other words, the filter can be designed so as to meet the required spectral transmittance or reflectance.

According to the FSAN/ITU-T recommendation G.984.2, the WBF insertion loss should minimally be 32 dB outside the required passband width and maximally 5 dB within the required passband width. It should qualitatively be the highest possible contrast factor (dB/nm).

5 SUMMARY

Further generations of the PON systems increase the network capacity mostly by increasing the bit rate transmission, split ratio and reach. The NG-PON1s already used the standardized XG-PON1 system but not yet the standardized XG-PON2 system. Compared to the well-established GPON system, they increase the bit rate to 10 Gbit/s, the split ratio from 1:64 to 1:128 and the reach from 20 km to 60 km. Despite these undisputable obvious advantages, implementation of the next generation PON systems into practice should in the first place be cost-effective.

In Slovenia, the question of the PON systems remains open. A couple of years ago, when the PON systems were not yet as firmly established as they are

today, two operators, offering services via the optical link, decided to choose the point-to-point (P2P) architecture. Building a network based on the P2P architecture is compared to the PON systems often associated with higher costs resulting from higher consumption of the fiber, energy, active equipment, etc. The question still left open is what will be the interest of these providers in modernizing and transforming the existing optical architectures in accordance with the NG-PON technology and how it will be achieved.

Constructing a new PON network as well as optimizing the existing one is a most demanding task. It is important that migrating to the new technology is made in the simplest possible way preventing users from experiencing any difficulties. To achieve this, the standard regulating the new technology has to anticipate coexistence with the prior technology.

Preparation of the NG-PON2 standard is in progress. It should be based on a combination of the technology of time and wavelength division multiplexing – TWDM, to protect the interest of operators wishing to minimize their investing in upgrading the network. This is contrary to previous predictions that NG-PON2 will not coexist with the existing PON systems (GPON, NG-PON1).

To achieve the GPON and NG-PON1 system to be compatible, the best solution seems to be the use of WBFs on the basis of the TFF technology at users and the WDM device to split signals of different sources in the central office [14]. To reach coexistence on the physical level it is important that operation is in the same ODN, and that management and encapsulation on transmission convergence layer are in NG-PON1 similar to that in GPON.

REFERENCES

- [1] Nielsen, "Nielsen's Law of Internet Bandwidth". <http://www.useit.com/alertbox/980405.html>, Retrieved 2008-02-27
- [2] VOLK, Mojca, GUNA, Jože, KOS, Andrej, BEŠTER, Janez. Quality-assured provisioning of IPTV services within the NGN environment. *IEEE commun. mag.*, May 2008, vol. 46, no. 5, pp. 118-126,
- [3] B. Batagelj, "Implementation concepts of an optical access network by point-to-point architecture," *Electrotechnical Review*, Ljubljana, Slovenija, pp. 259–266, 2010.
- [4] ITU-T Rec. G.984 series: "Gigabit-capable passive optical networks (G-PON)".
- [5] ITU-T Rec. G.987 series: "10-Gigabit-capable passive optical networks (XG-PON)".
- [6] B. Batagelj, "Pasivno optično dostopovno omrežje s časovnim razvrščanjem", FE in FRI, Ljubljana, 2011.
- [7] ITU-T Recommendation G.984.6, »Gigabit-capable Passive Optical Networks (GPON): Reach extension«, 2008
- [8] ITU-T Recommendation. G.987.1: "10-Gigabit-capable passive optical networks (XG-PON)".
- [9] J.-I. Kani, F. Bourgart, A. Cui, A. Rafel, M. Campbell, R. Davey, and S. Rodrigues, "Next-generation PON part I—Technology roadmap and general requirements," *IEEE Commun. Mag.*, vol. 47, no. 11, pp. 43–49, Nov. 2009.
- [10] F. J. Effenberger, H. Mukai, S. Park, and T. Pfeiffer, "Next-generation PON part II—Candidate systems for next generation PON," *IEEE Commun. Mag.*, vol. 47, no. 11, pp. 50–57, Nov. 2009.
- [11] Frank J. Effenberger, "The XG-PON System: Cost Effective 10 Gbit/s Access", *Journal of Lightwave Technology*, Vol. 29, Issue 4, pp. 403-409, 2011.
- [12] F. J. Effenberger, H. Mukai, J.-I. Kani, and M. Rasztoivits-Wiech, "Next-generation PON part III—System specifications for XG-PON," *IEEE Commun. Mag.*, vol. 47, no. 11, pp. 58–64, Nov. 2009.
- [13] M.D. Andrade, G. Kramer, L. Wosinska, Jiajia Chen, S. Sallent, B. Mukherjee, "Evaluating strategies for evolution of passive optical networks", *IEEE Communications Magazine*, V. 49, I. 7, 2011.
- [14] J. Mullerova and D. Korcek, "Super-separation thin film filtering for coexistence-type colorless WDM-PON networks," 13th International Conference on Transparent Optical Networks (ICTON), pp. 1-4, 26-30 June 2011.
- [15] L. Wosinski, Ning Zhu, Zhechao Wang, "Wavelength selective devices for WDM communication systems", 2009 IEEE 3rd International Symposium on Advanced Networks and Telecommunication Systems (ANTS), New Delhi, 14-16 Dec. 2009.
- [16] ITU-T Rec. G.984.5, Amendment 1; "Gigabit-capable passive optical networks (G-PON): Enhancement band", Oct. 2009.

Boštjan Batagelj received his Ph.D. from the University of Ljubljana for work on optical-fiber nonlinearity measurements in 2003. Currently, he is an assistant professor at the Faculty of electrical engineering. His current research interests are in areas of next-generation optical access networks and optical-technology-based timing systems. He has authored or co-authored over 150 technical and scientific publications and is named as an inventor on four patents.

Vesna Eržen obtained her B.Sc. degree in Electrical Engineering in 2012 at the University of Ljubljana, Slovenia. Her current research work is orientated towards extending the reach of communication link and increasing the number of users in a passive optical access network.