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THE CREATION OF THE TIME AND WAVELENGTH DIVISION MULTIPLEXED (TWDM) MODEL FOR THE NEXT GENERATION PASSIVE OPTICAL NETWORK (NG-PON2)

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Abstract—**Research subject.** The article provides the experimental model of TWDM-PON. **Method.** A large number of papers, especially from international platforms IEEE and OFC, have been studied, as the result of this knowledge was built the model of TWDM-PON. For the creation of this model was used VPIphotonics™ simulation soft-ware. **Core results.** During the deep study of NG-PON2 was de-scribed the main op-tions of TWDM-PON, and characterized the principal components to build this model. Based on this knowledge was created the simulation of downstream transmission in TWDM-PON**. Practical relevance.** The resulting model provides the opportunity to test in real time the TWDM-PON. For example, by changing the distance or some other parameters while controlling the received power and bit error rate.
Keywords—Optical Fiber Communication, PON, 5G, WDM, XG-PON1, G-PON.

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Introduction

In 2011 Full-Service Access Network Group with the support of Information Telecommunication Union introduced New Generation Passive Optical Network 2[1,2]. This emergence was initiated by the several challenges:

[1] ITU-T G.989. 40-Gigabit-Capable Passive Optical Networks (NG-PON2), Series Recommendations.
[2] Full Service Access Network (FSAN). [Online]. Available: http://www.fsan.org/

1. The gradual growth of internet traffic.

Annually Internet traffic grows. Different international telecom companies predict that the global IP traffic will reach 2.3 Zettabyte per year or 194 Exabyte per month in 2020. That is almost two times more than today in 2017.

2. The 5th Generation of mobile network.

According to the latest information, the first 5G test area will be deployed in the next year at the Winter Olympic Games in South Korea. It is expected that 5G network will provide a connection to a variety of devices [1, 2], will establish billions of connections [3, 4], and will present new technologies, such as CRAN, CoMP etc. However, the existing infrastructure is not prepared for such a development. This suggests necessary changes in the current network, which TWDM-PON technology can produce, especially the possibility of the symmetrical line, providing 40 Gb/s downstream and upstream capacity.

3. The incapacity of the XG-PON1.

The first new generation PON can not coexist with previous generations of PON. This makes XG-PON1 very expensive for operators. Furthermore, XG-PON1 provides only 10 Gb/s downstream and 2.5 Gb/s. upstream capacity, what is not enough for solving upcoming challenges.

The FSAN meeting in April 2012 selected the time and wavelength division multiplexed passive optical network as a primary solution for NG-PON2.

In this paper, we summarized the TWDM-PON research by reviewing the basics of TWDM-PON and presenting the experimental model of TWDM-PON.

PON architectures

There are several choices for the next generation of PON. The three most popular architectures are described in more detail below.

1. TDM – Time-Division Multiplexing

The TDM approach is very similar to existing PON systems, using only a single wavelength for upstream and a single wavelength for downstream transmission.

For this method should be implemented a passive power splitter, which divides the incoming signal to the different ONU's (Fig. 1).

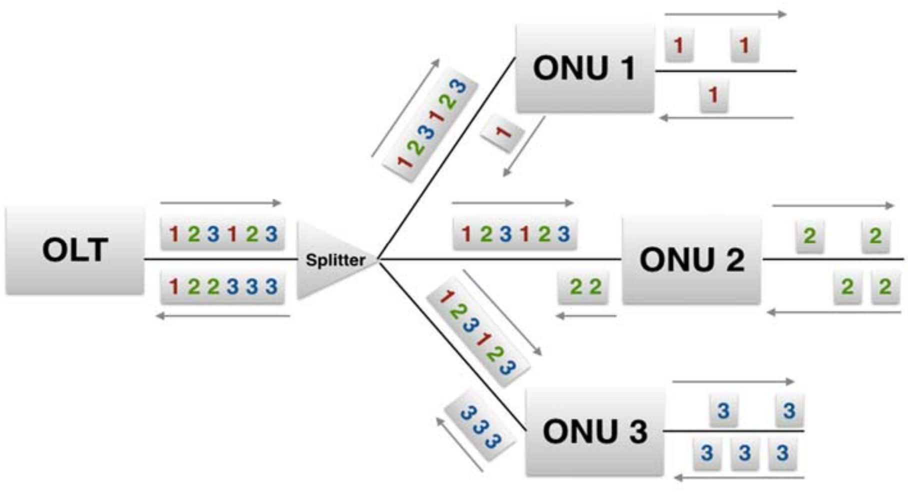

Fig. 1. TDM-PON architecture

In downstream, the signal from the OLT is multiplexed in different time slots (Fig. 1 presents 3 time slots) and transmitted to ONU's, where each ONU see their own data through the address labels embedded in the signal.

In the upstream, a mechanism to avoid collisions must be implemented.

This method is very simple in comparison with WDM technology. Nevertheless, FSAN dropped TDM-PON from consideration because of the lower bandwidth.

2. WDM – Wavelength Division Multiplexing

There are many proposals concerning how WDM-PON can be implemented. These included: externally seeded WDM-PON, Ultra-dense Coherent WDM-PON, tunable WDM-PON etc.

However, the main idea of WDM is using different wavelengths for transmission. Signals for ONUs are broadcasted on independent wavelengths and multiplexed on a shared fiber infrastructure. To ensure that each ONU will receive only its own wavelength, it is necessary to implement a tunable filter in ONU.

The WDM approach has higher bandwidth capacity than TDM. Nevertheless, WDM devices are significantly expensive and they are limited by the number of wavelengths available, hence powerful OLT are needed. The project of this architecture will require a great investment.

3. TWDM – Time and Wavelength Division Multiplexing

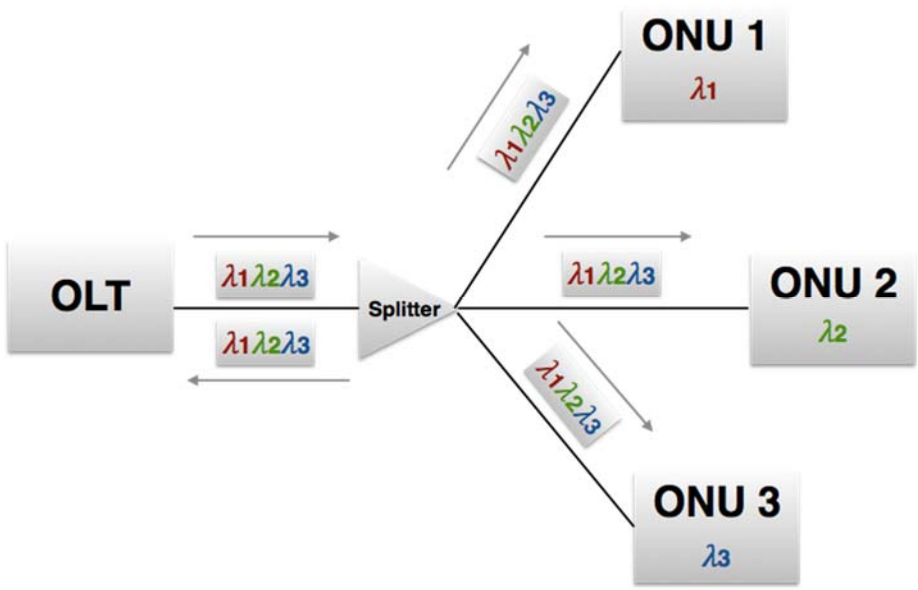

Fig. 2. TWDM-PON architecture

The TWDM technology is a hybrid of TDM-PON and WDM-PON, where all set of wavelengths that travels through the WDM feeder fiber are broadcasted to all the users using a power splitter and leaving the schedule of the time slots to the MAC layer (Fig. 2). In this case, the ONU should be colorless. To facilitate colorless ONUs, λ-tunable transmitters and receivers are necessary (variants for tunable receivers/transmitters are presented in the next chapter).

The TWDM-PON technology is the key solution for implementing the NG-PON2 architecture. The most important options of the TWDM-PON approach was described below.

Key options of the TWDM-PON

- Bit rate

The main idea of TWDM-PON is increasing the PON bit rate by stacking XG-PONs via multiple pairs of wavelengths. An XG-PON system offers the bit rate of 10 Gb/s in downstream and 2.5 Gb/s. in upstream.

A TWDM-PON system uses four pairs of wavelengths, which is able to provide 40 Gb/s. and 10 Gb/s. in downstream and upstream, respectively. Each TWDM-PON ONU can provide peak rates up to 10 Gb/s downstream and 2.5 Gbit/s. upstream [5].

- Wavelength plan

The wavelength plan for NG-PON2 has been selected as the best compromise for coexistence with G-PON, XG-PON1, and RF Video. There are two wavelength plans that would be selected based on the presence, or not, of RF Video. In our paper was chosen the wavelength plan without RF video (Fig. 3).

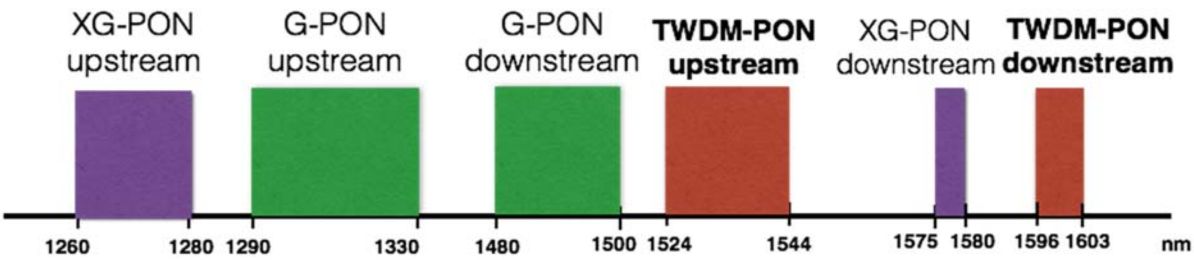

Fig. 3. C-minus/L-minus band wavelength plan for NG-PON2

In this case, the upstream wavelength bands for TWDM are located in the C-band (1524–1544 nm) where components are already shipping in high volume so this should facilitate lower costs in the Optical Network Units. The downstream TWDM transceiver components will be lower volume, and costs are shared across multiple subscribers, so L-band wavelengths are allocated (1596–1603 nm) [6, 13].

- Coexistence

Wavelength plan for NG-PON system must guarantee compatibility TWDM-PON with legacy PON systems G-PON and XG-PON [9].

Fig.4 shows, how these three networks (NG-PON2, G-PON, XG-PON1) can use one line for signal transmission. The NG-PON2 consists of three parts: Optical Network Unit, Optical Distribution Network and Optical Line Terminal. This concept corresponds to all previous generations of PON. However, for guarantee the coexistence with previous generations, the ODN part has the special coexistence element. As this element is used a wavelength multiplexing/demultiplexing devices.

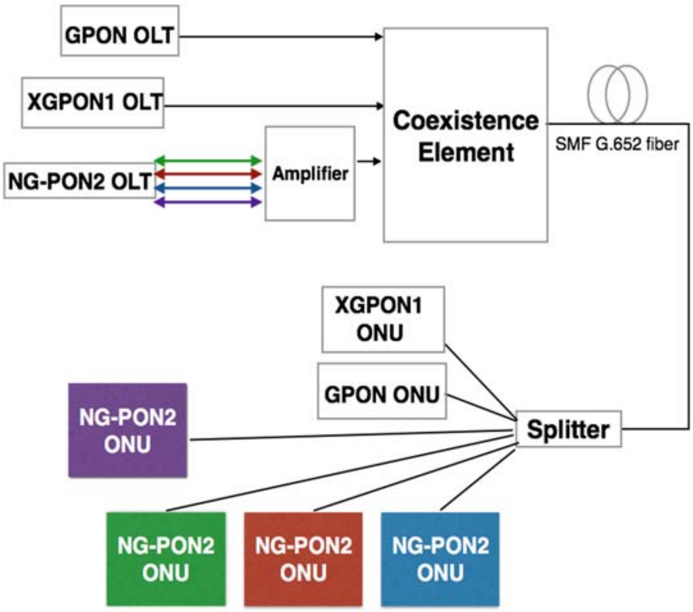

Fig. 4. The coexistence TWDM-PON with G-PON and XG-PON

- A tunable receiver and a tunable transmitter

Each ONU should be equipped with a tunable transmitter able to adjust to any of the allocated upstream wavelengths and a tunable receiver able to tune any of the allocated downstream wavelength channels received. In other words, in the OLT to ONU downstream direction, a tunable ONU receiver is required to select the proper wavelength channel. In the ONU to OLT upstream direction, the ONU transmitter is tuned to suitable wavelength channel.

For the TWDM-PON ONU receiver this function can be implemented by using technologies, such as thermally tuned Fabry–Perot filter [7, 11]; angle-tuned FP filter; injection-tuned silicon ring resonator; liquid crystal tunable filter [12]; and thermally tunable FP detector.

For the TWDM-PON ONU transmitter this function can be implemented by using distributed feedback laser with temperature control; laser with partial temperature control; multisection distributed Bragg reflector laser without cooling; external cavity laser with mechanical control without cooling; ECL with thermo/electro/piezo/magneto-optic control without cooling.

The description of the created TWDM-PON model

Based on the knowledge about NG-PON2 and TWDM technologies, we created an experimental model of the TWDM-PON [8, 14].

For creating this simulation used a VPIphotonics™ software.

A. Optical Line Terminal (Fig. 5) [10]

The OLT block consists of the Pseudo-Random Bit Rate (PRBS) sequence and Non-Return to Zero (NRZ) coding; a laser; an Amplitude Modulator and a Wavelength Multiplexer.

- The PRBS block generates the 2^{10}-1 sequence.
- The Non-Return to Zero module generates an electrical signal for driving la-

sers and modulators. The NRZ line code is a binary code in which 1s are represented by a positive voltage, while 0s are represented by a negative voltage.

- The Continuous Wave Laser module models a Distributed Feedback Laser producing a continuous wave optical signal.
- In the result, both signals are received on AM.
- The AM generates the modulated signal.
- Finally, the wavelength multiplexer combines all incoming wavelengths into the feeder fiber.

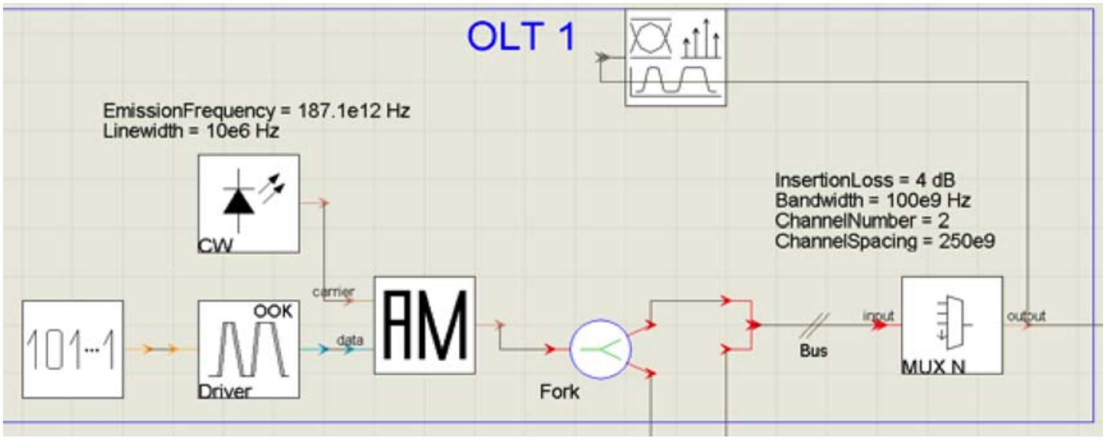

Fig. 5. TWDM-PON Optical Line Terminal

B. *Optical Distribution Network* (Fig. 6)

The ODN block consists of Single Mode Fibers (SMF), a power splitter and an attenuator.

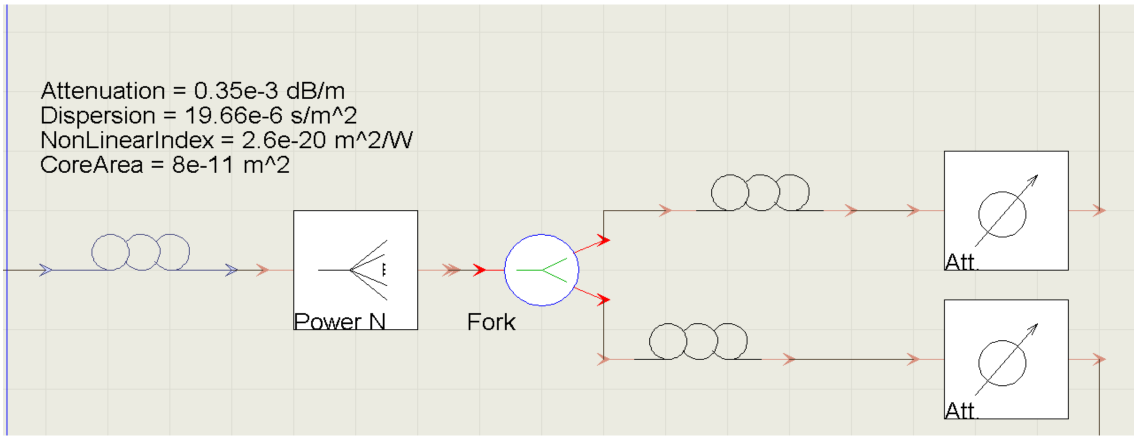

Fig. 6. TWDM-PON Optical Distribution Network

- The TWDM standard uses Single-Mode Fibers. This module solves the nonlinear Schroedinger (NLS) equation describing the propagation of linearity-polarized optical waves in fibers using the split-step Fourier method
- One of the innovations of the TWDM-PON is the use of the Power Splitter, which permits to operators deploy Fiber To The Home systems with long-lived infrastructure investments.
- Thereafter the signal splits into remote nodes.

- Additionally, before the ONU block was used the attenuator. A fiber an optical attenuator is a device used to reduce the power level of an optical signal.

C. *Optical Network Unit* (Fig. 7)

The received part is more complicated for simulation. The ONT consists of a tunable transmitter and a tunable receiver, a photodiode, the Low Pass Filter (LPF).

This paper introduces only downstream transmission model.

- At the beginning, a signal from ODN goes to a tunable optical filter, that selects specific wavelength. As this filter was used, available in the library VPIphotonics™, universal optical filter.
- Thereafter the photodiode converts the optical signal back into electrical form and recovers the data transmitted. The principal requirements for a photodiode are high sensibility, fast response, low noise, low cost and high reliability. For creation, this model has used PIN photodiode.
- Finally, the Low-Pass Filter is used to reduce noise.

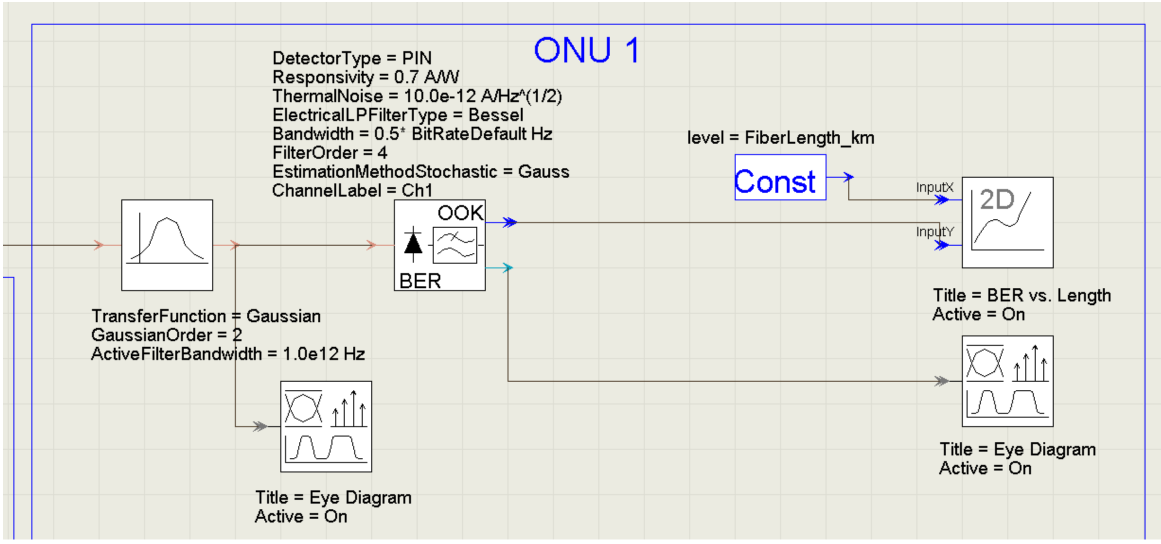

Fig. 7. TWDM-PON Optical Network Unit

The demonstration of TWDM-PON experimental model

This paper provides the experimental model of TWDM-PON, however only in downstream transmission (Fig. 8). The upstream transmission model will describe in the future research.

In our case, there are two OLT. According to wavelength plan (Fig. 3) from downstream range 1596–1603 nm was selected two frequencies 1601.46 nm (OLT1) and 1602.31 (OLT2) nm, equal 187.1 THz and 187.2 THz respectively. These two modulated signals are combined together in the Wavelength Multiplexer.

In the ODN, signals pass through SMF with the length of 40 kilometers. After power splitter, fiber divided into two remote nodes, the length of this nodes is 3 kilometers.

Finally, after tunable receiver and PIN photodiode, must be measured parameters of the signal. In our case, the basis of the measurements is the dependence received power/Bit Error Rate, and distance/Bit Error Rate.

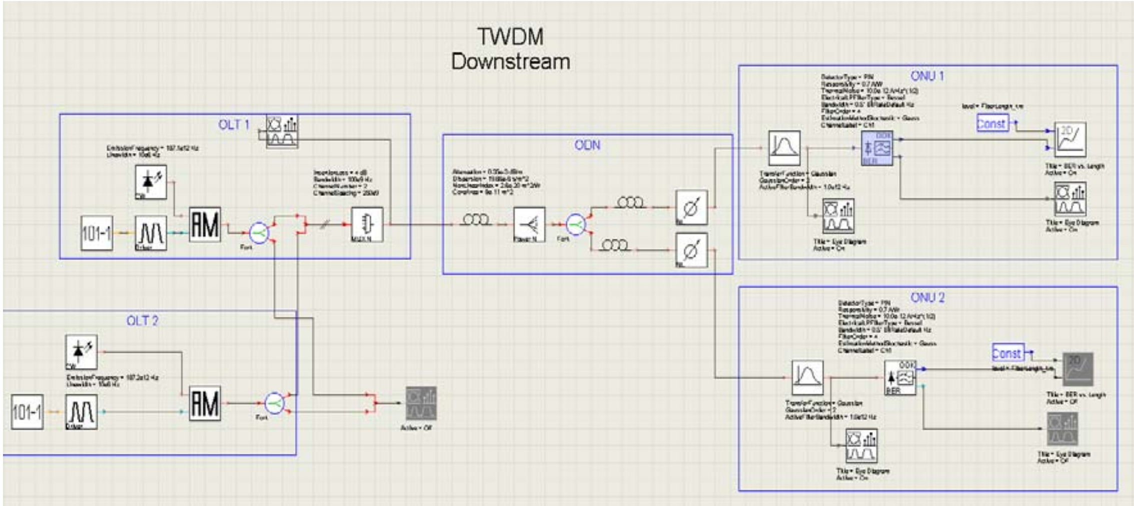

Fig. 8. TWDM-PON experimental model

Conclusion

In this paper, we have investigated the TWDM-PON and have presented its key points. As the primary solution of NG-PON2, TWDM-PON, with the ability to manage wavelength, has reason to become the core technology of the next decade. Moreover, this paper introduces the scheme of TWDM-PON. The creation of such model will allow the next generation of developers to easily design various deployment scenarios of TWDM-PON technology, based on this scheme.

Our future research on TWDM-PON would be divided into two directions. First, is the attempt to increase the distance of the feeder fiber. Second, is the creation model, which can clearly demonstrate the possibility of coexistence NG-PON2, XG-PON1 and G-PON networks.

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