Coexistence GPON, NG-PON, and CATV systems

Tomas Horváth, Lukáš Kočí, Michal Jurčík, Miloslav Filka

Department of Telecommunications
Faculty of Electrical Engineering and Communication
Brno University of Technology, Czech Republic

Abstract— **This article deals with the coexistence of two passive optical standards with video transmission using the CATV technology. The paper shows the cross coexistence of standards that are used for an analysis of critical parameters BER. The results of simulations define border parameters for data services in networks with the BER parameter. The designed model has proven that it is able to transfer 4 services via GPON, NG-PON networks (data, IPTV, voice, and analogue television signal.**

Keywords— **Passive optical networks, GPON, NG-PON, coexistence, OptSim, simulation.**

I. INTRODUCTION

Passive optical networks are of much promise for the application in the present access networks. The absence of the active units leads to immense savings the energy and maintenance. The passive technology is used in many countries. For example, the GPON (Gigabit Passive Optical Network) technology is dominant in European access networks.

GPON is standard, that offered sufficient bandwidth in the past. The GPON system offers a symmetric transmission speed of 2.5 Gbps but when Triple play services started to be used and video resolution increased, these speeds seem to be low. Today's trend is to have many TV sets at home. It is no exception when each TV (Television) set uses a different channel when the subscriber has paid for services where many channels are in HD (High Definition) resolution. Due to these facts, bandwidth started to be insufficient and so it was necessary to look for other systems which would allow easy transition between channels or their coexistence.

The next step was to approve the specification of NG-PON (Next Generation PON) networks in 2010. In practice, there are two scenarios. The first is when ISP (Internet Services Provider) has GPON included in its network with NG-PON technology [1]. In this case it is important to have coexistence in order to make use of existing ODN (Optical Distribution Network) [1]. The second choice is that the operator does not provide any technology and the NG-PON technology is the first one in this network [1]. In this case, coexistence is not important. OptSim v5.2 provided by the RSOFT company was used as the simulation software.

For current optical networks some types of migration from older to the latest standards are defined [2]. With the migration from older standard to the latest ones leads to decreased receiver sensitivity [2]. To increase sensitivity, FEC (Forward Error Correction) should be implement which is able to improve sensitivity. Another possibility is to increase the power of laser or to use an optical amplifier using.

In [3] sequential migration was defined. Current GPONs systems are intended to migrate to NG-PON1, employing identical colourless ONU [3]. This solution uses the existing optical distribution network, which enables coexistence. There are many types of coexistence, for example using WBF (Wavelength Bloch Filter), multiplexing/demultiplexing transmitted signal or using DBA (Dynamic Bandwidth Allocation) algorithm [4], [5], [6].

This paper deals with designed enables choosing the wavelength via tunable filters. The tunable filter is contained in the ONU (Optical Network Unit) units on the subscriber side. By this solution, a dynamic change of the wavelength of transmission signal is attained. Within the network the CATV (Cable Television) signal is transmitted, which makes use of the 256QAM (Quadrature Amplitude Modulation) modulation. On the subscriber side the signal is divided between the data modem and the set-top-box, using wavelength division multiplexing.

The main contribution of the paper is the determination of the maximum bit error rate value in the transfer of 4 services in the coexistence model. This is followed, by the research into effects of increased spectral width of the laser on bit error rate, and the determination of minimal wavelength spacing in the final optical spectrum of all transmitted services

The rest of the paper is structured as follows. Section 2 gives an overview of some other related works. Section 3 describes separately the technologies in the coexistence model. Section 4 shows the designed model and parameters of blocks. Section 5 discusses the results achieved and Section 6 concludes the paper.

II. RELATED WORK

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In recent years, many works related to migration between standards have been published. Works published to date are aimed at the theoretical migration between the GPON and NG- PON standards.

In [2] the possibility of decreased sensitivity to the subscriber side was published with its solutions. Further, the publication [2] presents the use of existing optical distribution networks and the wavelength selection. The article is aimed only at the theoretical possibilities of migration.

Most of the recent works deal with two possibilities of migration: greenfield and brownfield [3] [7]. These types are defined in [4].

The current trend is to focus on wavelength blocking via WBF [8]. These filters can be on the service provider OLT (Optical Line Termination) or the subscriber side ONU (Optical Network Unit). The designed solution in [8] has deficiencies in the control of these filters, if they are tuned by the manufacturing process on the explicit wavelength.

The tunable receiver for GPON networks was described in [9]. By this tunable receiver stepwise migration from GPON to NG-PON with 1 Gbps transfer speed per subscriber was attained

There are also many works dealing with the migration of standard [3]-[9]. None of them contains analog television signal transfer.

One of the last designs contains migration from GPON to the hybrid passive optical network [10]. In the hybrid passive optical network wavelength and time multiplex are contained to obtain mutual coexistence.

III. GPON, NG-PON1, AND CATV

The GPON Standard was approved by ITU-T (International Telecommunication Union) in 2003 as ITU-T G.984.X. They reason for introducing of this standard was to increase bandwidth for access networks.

The previous A-PON (Asynchronous Transfer Mode PON) and B-PON (Broadband PON) standards did not have enough bandwidth for new Triple play services. Triple play is a combination of three services which are transmitted in real time. Another drawback of these standards was that they supported the ATM (Asynchronous Transfer Mode) transport protocol only

The ATM protocol was not deployed as much as expected. On the other hand, the Ethernet protocol was expanded. This standard was developed in optical networks. Therefore the GPON standard supports the two above mentioned protocols Ethernet because of its deployment and massive expansion, and the ATM protocol for backward compatibility with older types of passive optical networks

GPON specification supports the following combinations of transmission speeds

- Downstream 1244.16 Mbps, Upstream 155.52; 622.08 and 1244.16 Mbps
- Downstream 2488.32 Mbps, Upstream 155.52; 622.08; 1244.16 and 2488.32 Mbps

Standard specifications are divided into many parts. ITU-T G.984.1 gives a general specification and contains the block scheme of GPON standard (for reference model see Fig. 1, transmission speed, logical and physical reach, splitter ratios, and so on.

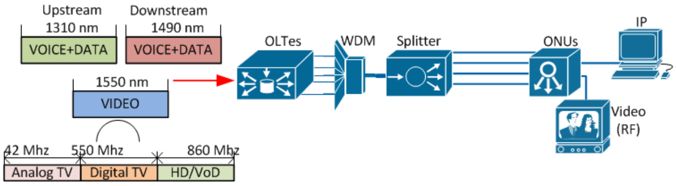

Fig. 1: General scheme of GPON network with RF video system [11]

The ITU-T G.984.2 recommendation specifies the transmitter and receiver transmission signal parameters, recovery time, forward error correction algorithm, and so on. In ITU-T G.984.3 the GPON transmission convergent layer denoted as GTC (GPON Transmission Convergence) is described. GTC is responsible for transmitted data flow on the physical layer, addressing, protocol encapsulation, frame format, and so on. ITU-T G.984.4 describes the ONT management and interface control, control frame format, and so on. ITU-T G.984.5 describes the wavelength extension of the bandwidth. ITU-T G.984.6 describes methods of increasing the system reach optical amplifier or repeater, optic–electric convertor, and so on. The last part of ITU-T G.984.7 deals with the extension of system range up to 40 km. GPON works with wavelengths of 1480–1500 nm for downstream and 1260–1360 nm for upstream. The wavelengths 1550-1560 nm are reserved for the RF overlay video system (CATV) [12].

The NG-PON Standard was approved in 2010. Next demands on bandwidth resulted from video on demand expansion and the most popular full HD video transmission. Downstream transmission speed was increased four times to 9.95328 Gbps and for upstream to 2.48832 Gbps. For the NG-PON network two attenuation plans were proposed: Nominal: 14–29 dB and Nominal2: 16–31 dB [13]. The physical reach of the NG-PON network is the same as that of GPON and it is 20 km, which can be increased up to 60 km [13]. The range of wavelengths assigned by ITU-T to NG-PON networks is 1575–1580 nm for downstream and 1290–1330 nm for upstream. The 1550–1560 nm range is reserved for RF overlay video transmission.

The CATV system in this article was solved by 256QAM modulation. The task was to demonstrate video transfer for the 1550 nm wavelength.

Video transmission could be solved in two ways.

The first choice is to transfer data via IP protocol. For this option the same wavelengths are used as for downstream, as defined in the standard. The transmission type is unicast and so only one flow is transmitted to the subscriber. In this method, the bandwidth on optical fiber is decreased. If, for example; the subscriber watches the HDTV channel, the bandwidth is decreased by about 40 Mbps. Also, the transfer will be more sensitive to errors because video will be mixed with packets for IP protocol.

The second option is to use the RF video overlay system. The difference between transmission using IP protocol and RF video overlay is that the RF video overlay is transmitted via broadcast, rather than unicast. There is no interference between the video and IP signal. The video signal is therefore distributed to each unit of the ONU, and it is up to the customer whether to monitor the video or not.

The transfer itself is ongoing. The advantage of this distribution is the signal transmission in dedicated wavelengths of 1550–1560 nm. The effect of transfer separation is that the data do not interact. Therefore, the wavelengths are not used by any of the standard passive optical networks. They are reserved for the RF video overlay system.

IV. SIMULATION MODELS

For the GPON standard passive optical network, a simulation model was proposed in the OptSim v5.2 application. The proposed model is shown in Fig. 2. The GPON network contains an OLT unit, WDM (Wavelength Division Multiplex) combiner, optical fiber, splitter and ONU unit on the subscriber side. In the ONU unit an LED (Light Emitting Diode) diode is used as a photodetector. Tab.1 contains details of the setting parameters. The minimal sensitivity for attenuation classes A and B must be –25 dBm and for class C –26 dBm on the ONU side [14]. On the OLT side the minimal power level are divided into three attenuation classes A, B and C, which should be at least –4, 1 and 5 dBm [14]. The maximum power level is at least 1, 6 and 9 dBm for A, B and C attenuation classes [14]. In terms of distribution networks in the GPON network three attenuation classes are defined: 5-20 dB for Class A, 10–25 dB for class B and 15–30 dB for class C [14].

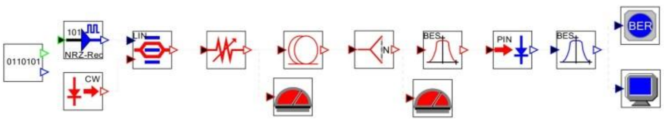

Fig. 2: Proposed scheme of GPON system

TABLE 1: GPON network parameters

Datasource	
Bit Rate	2.48832 Gbps
Sequence	Random
Modulator driver	
REC NRZ	LOW - 0 V HIGH - 5 V
CW Lor. laser	
CW Power	1.5–6 dBm
λ	1490 nm
WDM combiner	
Attenuation	3 dB/per slot
Splitter 1:32	
Attenuation	17 dB
Photodetector	
PIN	1490 nm

The GPON network in coexistence with the NG-PON network always exhibited a bit error rate of $1{\cdot}10^{-40}$. This value is considered the ideal – zero – value in the OptSim application [15]. The maximum value of bit error rate given in ITU-T is $1{\cdot}10^{-10}$ [14].

Tab. 2 contains details of setting parameters for the NG-PON network.

TABLE 2: NG-PON network parameters

Datasource	
Bit Rate	9.95328 Gbps
Sequence	Random
Modulator driver	
REC NRZ	LOW - 0 V HIGH - 5 V
CW Lor. laser	
CW Power	2–7 dBm
λ	1577 nm
WDM combiner	
Attenuation	3 dB/per slot
Splitter 1:32	
Attenuation	17 dB
Photodetector	
APD	1577 nm

The bit error rate must not be worse than $1{\cdot}10^{-12}$ for the NG-PON network [16].

V. SIMULATION RESULTS DISCUSSION

As mentioned previously, the results for the GPON network were not different when increasing the performance or even when changing the splitter attenuation within the attenuation classes. The dependence was always constant. On the other hand, the NGPON network exhibited changed parameters, which are given below in the graphs. The first simulation tested the effect of increasing splitter attenuation on the result and bit error rate.

Bit error rate is defined as the ratio of incorrectly received bits to the total number of bits received over time [15].The bit error rate is the main indicator of the overall quality of the optical system. The calculation of BER is proceeded from known Q factor value. The Q factor describes the analog quality of digital signal with respect SNR (Signal to Noise Ratio). These values are represented by the following equation [15]:

$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0},$$

where I_1 – logic level ”1”, I_0 – logic level ”0”, σ_1 – standard deviation of the logic level ”1”, σ_0 – standard deviation of the logic level ”0” [3]. When we know Q-factor, we can define BER with the following equation [15]:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{\exp\left(\frac{-Q^2}{2}\right)}{Q\sqrt{2}} \, [-].$$

The aim of this simulation was to approach and go beyond the maximum value of bit error rate. The values of splitter attenuation were increased from 17 to 26 dB (see in Fig. 3). Further increase was not possible, as this would exceed the maximum attenuation plan for the NG- PON network. The maximum value of attenuation was 33 dB, namely 26 dB for the splitter, 4 dB in the optical fiber and 3 dB with the WDM combiner. This value was only sense a test value.

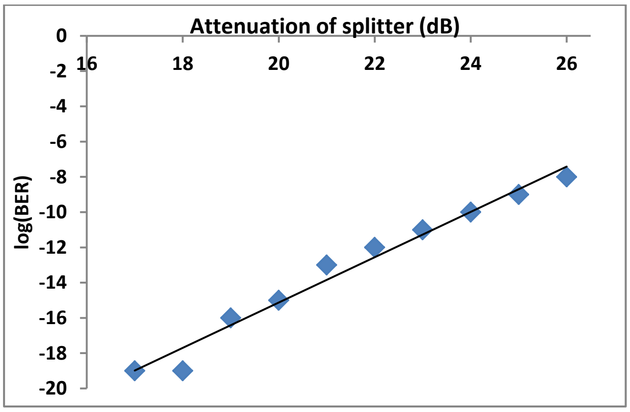

Fig. 3: Dependence of bit error rate on the value of splitter attenuation

The maximum bit error rate was reached for an attenuation value of 24 dB at the splitter. The maximum bit error rate was the same here as the maximum value given in [16]. The final results were made logarithmic for the sake of clarity.

Another simulation scenario was the effect of spectral width on final bit error rate. Initially, the first values were used as default values in OptSim application set up by OptSim application. The default value was 10 MHz. In another simulation, the spectral width of the laser with 10 MHz step was increased to 100 MHz, where the resulting value was 150 MHz. Beginning with 100 MHz the step was increased to 25 MHz. The aim was to achieve, the same as in the previous simulation, the boundary values of bit error rate, BER. The simulated results show that these values were achieved for the 150 MHz spectral width of the laser. The resulting graph of the simulation is shown in Fig. 4.

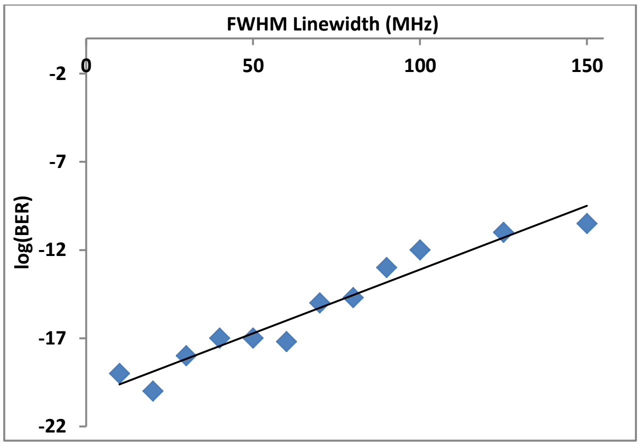

Fig. 4: Dependence of bit error rate on the spectral width of the laser

Dependence of bit error rate on the spectral width of the laser

The last dependence explored was the effect of changes in transmitting power on bit error rate. According to the ITU-T G.987.2 recommendation power values from 2 to 7 dBm were determined on the NG-PON network side [11]. As mentioned above, the final results were made logarithmic for the sake of clarity in Fig. 5. For comparison, both types of photodetector APD and PIN diodes were included. The APD diode was set to 5 nA dark current.

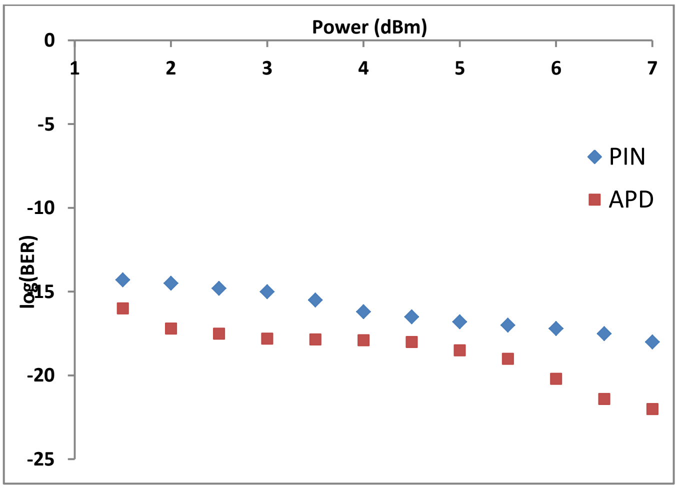

Fig. 5: Dependence of bit error rate on transmission power

Dependence of bit error rate on transmission power

To analyze the transferred services an optical analyzer was connected at the end of coexisting network model (after the splitter). The final spectrum of transmitted services is in Fig. 6. The first level is for the network, the second level is for the RF overlay system, and the last one is for the GPON network

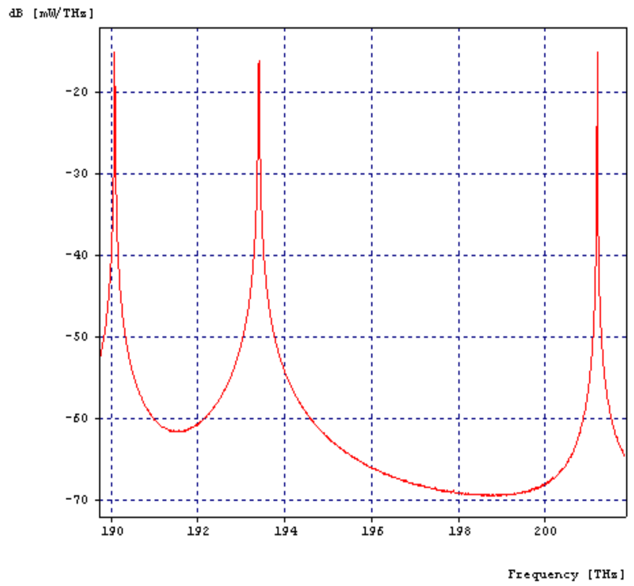

Fig. 6: Optical spectrum of transmitted route

The coexistence of both standards of passive optical network was expanded to include the CATV system. This system is designed according to Fig. 3, where the 256QAM modulation was used. The wavelength was selected from a reserved range of 1550 nm. The bit rate was set to 0.8 Gbps and 8 samples per bit. The resulting constellation diagram of the proposed model can be seen in Fig. 7. From Fig. 7 can be seen 16 states for each part I and Q in QAM modulation.

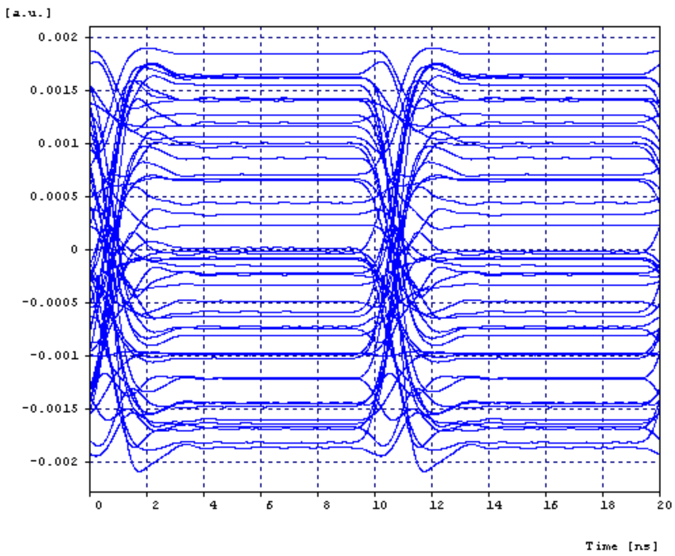

Fig. 7: Eye diagram for CATV system

VI. CONCLUSION

This paper proposed the coexistence scheme with three ITU-T standards: GPON, NG-PON and RF video overlay (CATV) system. When CATV model was added into the final simulation, final spacing between services was reduced.

The results show the possibility of coexistences between networks. Among independent services the differences between wavelengths are 20 nm. Due to this fact, interference between services does not appear. Individual attenuation classes of standards have similar attenuation values and the standards are able to use the same infrastructure.

The implementation of new line codes and addition next technology, namely the involvement of the Next Generation Passive Optical Network 2 (NG-PON2), are seen as further improvements.

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