PERFORMANCE OF TRANSMISSION SYSTEM TECHNOLOGY WDM IN 10 Gbps & 40 Gbps, CASE OF BACKBONE LINE PRISTINA-SKOPJE

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ABSTRACT

Transmissions systems with optical fiber nowadays are very important. Optical fibers offer the possibility of transmission speeds with higher capacities and fulfilled the needs and requirements of customers in the field of telecommunications. This trend is present in Kosovo also. The overall backbone transmission technology in Kosovo is based on fibred optic and some areas in microwave technology. Problems related to the signals losses such as attenuation, dispersion etc. are expressed also in optical fiber transmissions too. But with the development of advanced technologies, such as transmitting technology WDM / DWDM and different amplifiers make significant improvements to increased transmission performance. The main focus in this case at my paper would be aimed to achieve an improvement in performance in transmission systems with optical fiber in the transmission backbone line Pristina – Skopje, using OptiSystem 13.0, which is a simulator device. Optical cable length is ~ 107.56 km. My aim in this paper is to analyzes two cases of the transmission system 10 Gbps and 40 Gbps. The first transmission cases will be without EDFA (Erbium Doped Fiber amplifier) amplifier, and in the second case I will use EDFA amplifier. From these two cases we will see the difference between transmission line with EDFA and without EDFA amplifier in the transmission system 10 Gbps and 40 Gbps. The comparisons will clearly show the impact of amplifiers in increasing the quality of the transmitted signal by using the EDFA amplifiers.

Keywords: Optical fiber, WDM technology, EDFA amplifier.

INTRODUCTION

The use of optical fiber in communications systems is growing very quickly in the last years. However, optical networks in terms of efficiency are described in functionality that is related to routing, service protection, and are comprised from optical nodes that are interconnected in the topologies. [1] Telecommunication networks nowadays require high speeds and transmission capacity, but they are facing with continuous problems for transmitting, it is necessary to use optical networks which are based on optical technology. In this paper I will explain shortly the types of optical cables, the role of WDM/DWDM technology and the role of optical amplifiers. After this, I will explain, analyze and compare two case studies for 10 Gbps and 40 Gbps with EDFA amplifier and without EDFA amplifier.

Optical fiber

Optical fibers consist of several main parts: [1]
- Core (the light goes through)
- Internal cladding - surrounding the core with an optical material and makes the light to be reflected from the edges towards the core.
- Buffer coating - is plastic cover and protects the optical fibers from damage and humidity.

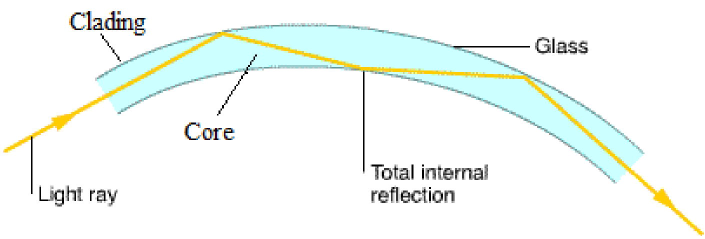

Figure 1. Optical cable

Based on the mode of transmission of the signal, optical fibers are divided in:
- single-mode fiber and
- multi-mode fibers.

Single mode fibers have small core diameter of ~ 9 µm and transmit infrared laser light in wavelength between 1.300 and 1.550 nanometers (nm). Multimode fibers usually have a diameter from 50 µm to 100 µm and transmit in wavelength from 850 nm to 1.300 nm. [2] [6]

Optical signal losses

The main factors that influence the optical signal losses are: attenuation, dispersion, scattering, absorption. Attenuation causes weakening of the signal (the optical effect of radiate energy) and the dispersion causes the expansion of the pulses that influences two effects: scattering and absorption. [4] [5]

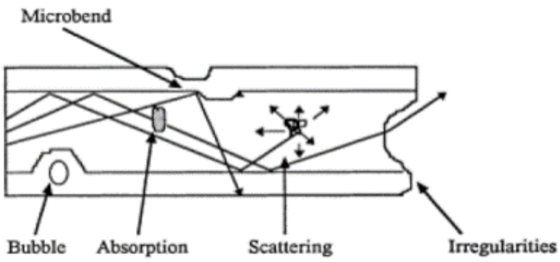

Figure 2. Factors of signal losses in optical fiber

WDM Technology

WDM (Wavelength-Division Multiplexing) is a technology that has to do with multiplexing of several information carriers of signals in an optical fiber. This technique allows communication in both directions and is based on the use of different wavelengths (or colors) arising from a light source (LED or Laser diodes) to multiplex the information without losses in the transmission carrier. [1] [2]

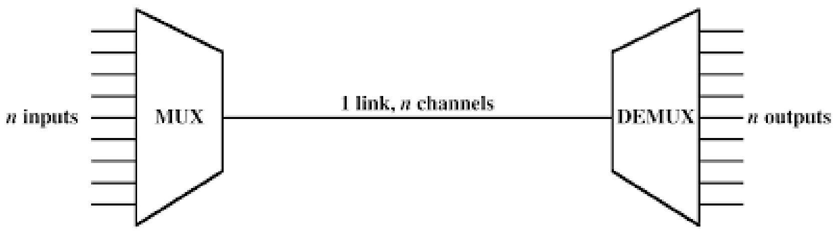

Figure 3. Multiplexer and demultiplexer

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DWDM (Dens Wavelength-Division Multiplexing) technology system is used in the fiber optic single-mode transmission in C band, it is 1.550 nm and usually use a density space of 40 channel frequency spacing to 100 GHz, but it is possible to use 80 channels in the frequency spacing of 50 GHz channels, [1] [9] so we can double the number of transmitted channels. Some technologies like ultra-dense Wavelength-Division Multiplexing have the ability to transmit more channels in the frequency channel spacing 25 GHz and 12.5 GHz. [8]

EDFA Amplifier

Rare earth elements have very good properties of amplification, and are used in the fiber optic transmission systems. Some of rare-earth elements are Er (erbium), Tm (thulium), Yb (Ytterbium), Pr (praseodymium) or combination between them (eg. Er / Yb), each of them operate in a different spectral band [3]. The element of erbium Er^{3+} is adequate for amplification in case of using DWDM's technology in the spectral range of 1.3 µm and 1.5 µm. EDFA (erbium-doped fiber amplifier) was the first optical amplifier and has revolutionized the optical communication in the early 1990s. Now days, they are widely used in all kinds of fiber communication systems. Two adequate wavelengths for optical frequency excitation of EDFA's are 980 nm and 1480 nm and producing stimulated emission at 1530 nm - 1565 nm range in C band. [3] [7] [10]

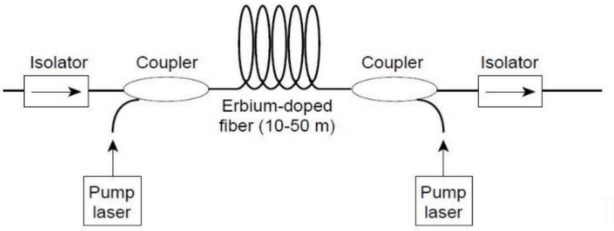

Figure 4. A schematic diagram of a doped fiber amplifier

LITERATURE REVIEW

David R. Goff (1999). *Fiber Optic Reference Guide*. Focal Press Woburn: USA

David R. Goff (1999) examines the role of equipment's interconnection. The author in this book presents the essential concepts of the fiber optics industry and gives the feeling of how the technology really works in a clear and short way, it becomes easier to predict the trends of development what the future bring in relation with the expansion of the network, cost reduction, standardization of networks, development of new materials and technologies.

P.C. Becker, Olson, & Simpson (1999). *Erbium-Doped Fiber Amplifiers*. London: UK

Becker, Olson, & Simpson (1999) present research and development relating to rare earth elements especially Erbium Doped Fiber amplifiers. Describes the Physical characteristics of materials used in the production of optical fibers and equipment's and signal - pump interaction methods. Then the author explained BER's calculations, the effects of nonlinearity, the importance of ion density of the rare earth elements and basic measurement amplifier technics. This book shows the advantages of using EDFA amplifier compared with other amplifiers and is adequate for all those who wish to develop amplified equipment's, systems and components.

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Gerd Keiser (2011) *Optical Fiber Communication*. New York: USA

Author Gerd Keiser (2011) has made a comprehensive presentation regarding communications with fiber optic, elaboration of the structure, systems, fabrication and transmission components as detectors, photodetectors, digital and analog lines, concepts of WDM technology, optical networks with optical fiber. It has addressed the attenuation and dispersion phenomena that weaken the signal with examples and mathematical formulas.

Dieter Eberlein & drei Mitautoren (2013) *Lichtwellenleiter-Technik.* Dresden: Germany

Dieter Eberlein and three co-authors (2013) in their book have made a deep theoretical presentation and concretized with practical examples about optical fibers types, fiber-to-the-Home, their standards and techniques of connection with connectors, highlighting the importance of the losses to be lower and they have specified the importance of the discovery and development of new methods of connectors in order to have much less losses of optical signals in connection points.

Shiva Kumar & M. Jamal Deen 2014. *Fiber optic communication.* John Wiley&Sohn: UK

Shiva Kumar & M. Jamal Deen (2014) have treated in professional way many fundamental aspects and applications in the field of optical fiber communications. They have treated the laws of the intensity of the electric field and magnetic mathematically with many examples, the spread of radiation in optical fibers, propagation of pulses in optical fiber, schemes modulation, the design of the transmission system, the analysis of system performance, multiplexing techniques, optical amplifiers, nonlinear effects and digital signal processing system with fiber optic communications.

METHODOLOGY

The methodology that I will use in my case study will be presentation of a case stady based on theory and simulators, this case study is sketched in simulator OptiSystem 13.0 and is shown in the figure, in this sketch I will present optical network line between the two capitals Pristina-Skopje with a distance length ~ 107.56 km.

RESULTS

In this case study I will present ideal case based in theory and in the simulator. This case presented in figure 5 is designed on the simulator OptiSystem 13.0, in this sketch I present optical network line between the two capitals of Pristina - Skopje with length ~ 107.56 km. The case is simulated so that the optical cable does not have losses, as if it were only a complete cable without extensions, and with active elements such as WDM transmission, WDM multiplexer, WDM demultiplexer etc. have the minimum loss, these losses are eliminated for the purpose of presenting as the ideal of the optical signal in a network with such length. The design of the network simulator is designed based on the real network backbone line implemented Pristina-Skopje.

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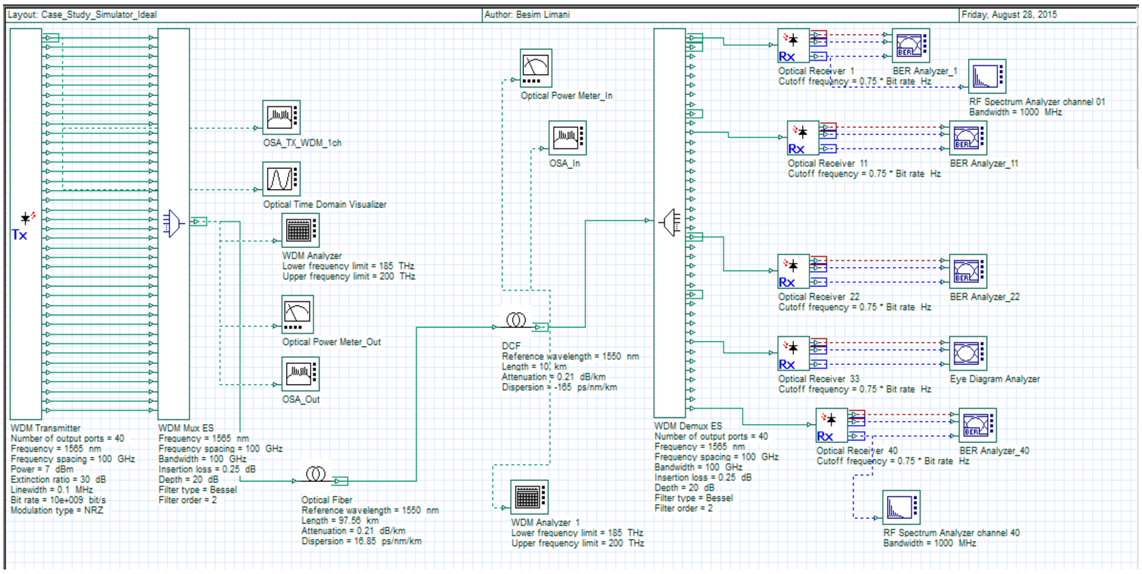

Figure 5. Optical network simulator scheme

Technical data of the optical cable and active devices used in the simulator

Optical cable which is presented in the simulator belongs to the category G.652 and technical data of this cable are shown in Table 1.

Table 1. Date of the optical cable G.652 category

Optical Cable Parameters	Fiber 1 (97.56 km)	DCF (10 km)
Reference wavelength	1550	1550
Length (km)	97.56	10
Attenuation	0.21	0.21
Dispersion	16.85	-165
Dispersion slope	0.075	-0.075
Beta 2	-20	-20
Beta 3	0	0
Differential group delay	0.2	0.2
PMD coefficient	0.5	0.5
Mean scattering section length	500	500
Scattering section dispersion	100	100
Self-phase modulation	NO	NO
Effective area	80	80
Max. nonlinear phase shift	3	3
Boundary conditions	Periodic	Periodic
Filter steppness	0.05	0.05
Lower calculation limit	1200	1200
Upper calculation limit	1700	1700
Calculate graphs	NO	NO
Number of distance steps	200	200
Number of wavelength/time steps	200	200

Technical data of the WDM / DWDM transmitter are presented in the following table:

Table 2. Technical data of the WDM / DWDM transmitter.

WDM transmitter parameters	Values	Unit
Number of output ports	40	channel
Frequency	1565	nm
Frequency spacing	100	GHz
Power	7	dBm
Extinction ratio	30	dB
Linewidth	0.1	MHz
Initial phase	0	deg
Bit rate	10.00E+9	bits/s
Modulation type	NRZ	
Duty cycle	0.5	bit
Position	0	bit
Rise time	1/(Bit rate) *0.05	s
Fall time	1/(Bit rate) *0.06	s
Transmitter type	EML	
Noise bandwidth	6.40E+11	Hz
Noise bins spacing	6.40E+11	Hz

Technical data of the WDM / DWDM multiplexer are presented in the following table:

Table 3. Technical data of the WDM / DWDM multiplexer

WDM multiplexer parameters	Values	Units
Number of output ports	40	channel
Frequency	1565	nm
Frequency spacing	100	GHz
Bandwidth	100	GHz
Insertion loss	0.25	dB
Depth	20	dB
Filter type	Bessel	
Filter order	2	
Sample rate	128	GHz
Noise threshold	-100	dB
Noise dynamic	3	dB

Technical data of the WDM / DWDM demultiplexer are presented in the following table:

Table 4. Technical data of the WDM / DWDM demultiplexer

WDM demultiplexer parameters	Values	Units
Number of output ports	40	channel
Frequency	1565	nm
Frequency spacing	100	GHz
Bandwidth	100	GHz
Insertion loss	0.25	dB
Depth	20	dB
Filter type	Bessel	
Filter order	2	
Sample rate	128	GHz
Noise threshold	-100	dB
Noise dynamic	3	dB

Data transfer with 10 Gbps capacity in the simulator

To illustrate the simulated optical network, I will generate 10 Gbps traffic to benefit the reference value, which will be used as comparative values in other case study. The wavelength band in which operate with the simulations is C band 1530 nm - 1565 nm. The total loss in the fiber-optic cable will be 22.587 dBm, the value of the power transmission laser device is 7 dB, based on the real value of optical transmitter manufacturer Cisco SFP-10G-ZR-S dedicated to transmit in 80 km distance with capacity 10 Gbps in optical cable type G.652. The DCF (Dispersion Compensated Fiber) will be used for chromatic dispersion compensation, caused along the wayfaring of the optical signal.

Transmitting power in WDM transmission is 7dB, in the output of WDM multiplexer will be 19.698dBm, and the input in WDM Demultiplexer will be – 2.889dBm as shown in Figure 6.

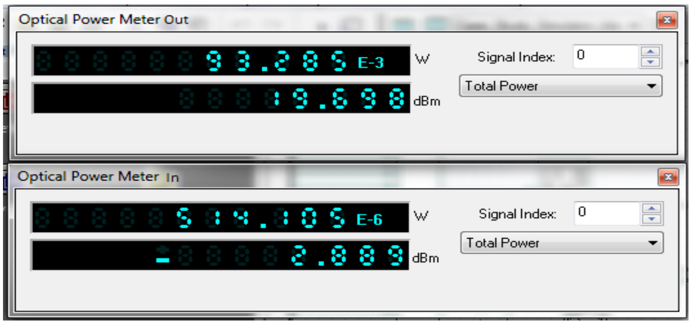

Figure 6. The power of the transmitter output signal to the multiplexer and the input of the demultiplexer.

This loss or weakening of the signal is calculated according to the formula as follows:

$P_{in} = P_{out} - \alpha$

Transmission power: $P_{out} = 19.562$ dBm,

the total losses along the optical cable: $\alpha = 22.587$ dBm

than input power is:

$P_{in} = P_{out} - \alpha = 19.698 \text{ dBm} - 22.587 \text{ dBm} = -2.889 \text{ dBm}.$

In output of demultiplexer will be connect the receiver of the optical signal and in this receiver we can measure the signal losses in the value of bits, BER (Bit Error Rate) is a key indicator parameter to estimate the value of signal transmission at 10 Gbps after passing along the optical network. To know the exact value of BER for each λ wavelength should connect a BER analyzer device at the exit of each optical receiver as shown in Figure 7. BER values for channels 01, 11, 22, and 40 are presented in tables 5, 6, 7 and 8.

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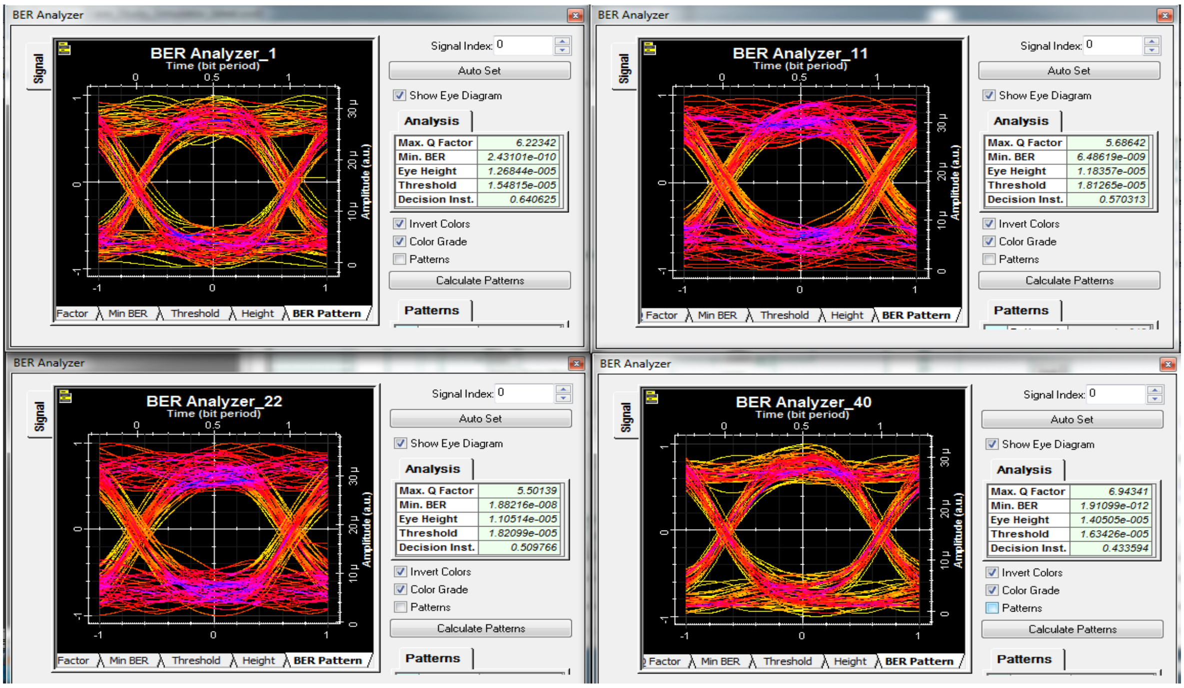

Figure 7. The value of the BER measured from BER analyzer device.

Whereas in the form of tabulating are presented in the following tables:

Table 5. The measured values of the BER analyzer of ch_1 at 10 Gbps

The 1st data channel	Value	Unit
Wavelength	1565	nm
Max. Q Factor	6.22	
Min. BER	2.43 *10-10	bps
Eye Height	1.27*10-5	
Threshold	1.55*10-5	
Decision Instant	0.64	bit period

Table 6. The measured values of the BER analyzer of ch_11 at 10 Gbps

The 11th data channel	Value	Unit
Wavelength	1556.87	nm
Max. Q Factor	5.68	
Min. BER	6.48 *10-9	bps
Eye Height	1.18*10-5	
Threshold	1.81*10-5	
Decision Instant	0.57	bit period

Table 7. The measured values of the BER analyzer of ch_22 at 10 Gbps

The 22th data channel	Value	Unit
Wavelength	1548.03	nm
Max. Q Factor	5.50	
Min. BER	1.88 *10-8	bps
Eye Height	1.10*10-5	
Threshold	1.82*10-5	
Decision Instant	0.51	bit period

Table 8. The values measured by the BER analyzer of ch_40 at 10 Gbps

The 40th data channel	Value	Unit
Wavelength	1533.77	nm
Max. Q Factor	6.94	
Min. BER	1.91 *10-12	bps
Eye Height	1.40*10-5	
Threshold	1.63*10-5	
Decision Instant	0.43	bit period

Value of signal and losses can also see from the measurements with the RF Spectrum Analyzer, these values are presented graphically in the following figure:

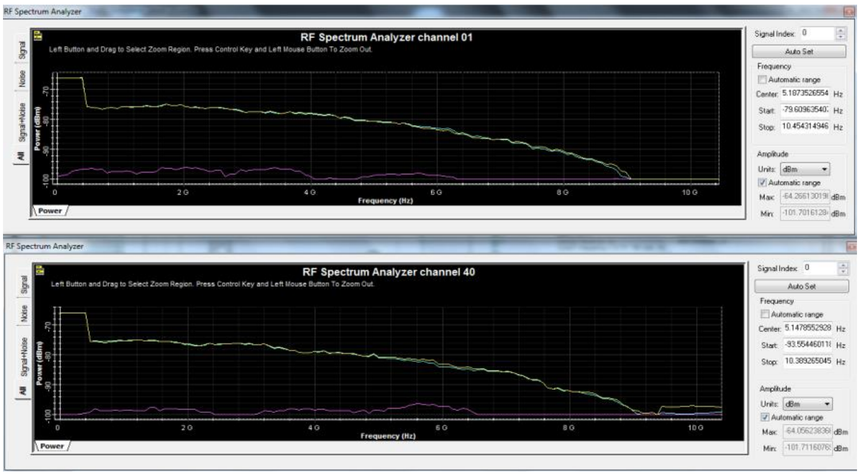

Figure 8. Radiofrequency Spectrum Analyzer

In this figure we see that the noise signal in ch_1 is approaching approximately the value ~ 9.2 GHz, but in the ch_40 channel with wavelength λ = 1533.77 nm does not lose but goes over 10 GHz. While the channel first point worth approximately ~ 9.2 GHz signal is degraded or lost.

Data transfer with 10 Gbps capacity in the simulator using EDFA amplifier

In the presented scheme of simulator network, I will connect EDFA amplifier to boost the optical signal and to achieve better results in the transfer data's. In figure 9 is shown the scheme of EDFA amplifier.

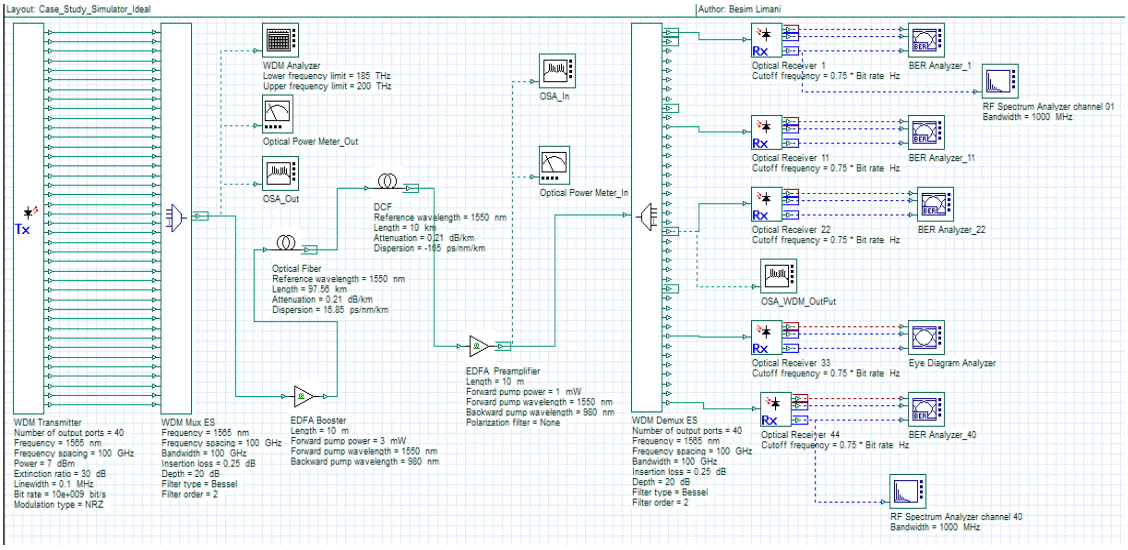

Figure 9. Optical network simulator scheme 10 Gbps with EDFA

Table 9. Values of the EDFA Booster

Description	Value	Unit
Core radius	2.2	µm
Er doping radius	2.2	µm
Er Metastable lifetime	10	ms
Numerical aperture	0.24	
Er ion density	1 e + 024	m^3
Loss at 1550 nm	0.1	dB/m
Loss at 980 nm	0.15	dB/m
Length	10	m
Forward pump power	3	mW
Backward pump power	150	mW
Forward pump wavelength	1550	nm
Backward pump wavelength	980	nm
Noise center frequency	1550	nm
Noise bandwidth	5	THz
Noise bins spcing	125	GHz
Noise threshold	-100	dB
Noise dynamic	3	dB

Table 10. Values of the EDFA preamplifier

Description	Value	Unit
Core radius	2.2	µm
Er doping radius	2.2	µm
Er Metastable lifetime	10	ms
Numerical aperture	0.24	
Er ion density	1 e + 024	m3
Loss at 1550 nm	0.1	dB/m
Loss at 980 nm	0.15	dB/m
Length	10	m
Forward pump power	1	mW
Backward pump power	150	mW

Forward pump wavelength	1550	nm
Backward pump wavelength	980	nm
Noise center frequency	1550	nm
Noise bandwidth	5	THz
Noise bins spcing	125	GHz
Noise threshold	-100	dB
Noise dynamic	3	dB

The difference between the EDFA booster and preamplifier is just on the value of the power of the forward pump where EDFA booster increase the power to greater levels than possible from the source is 3 mW, whereas EDFA preamplifier which increase the received power sensitivity is lower respectively 1 mW, because at these power values are achieved the best results of the amplified signal. After connecting the amplifiers, we became optical signal values as presented in figures 10 and 11 and tables 11,12,13 and 14.

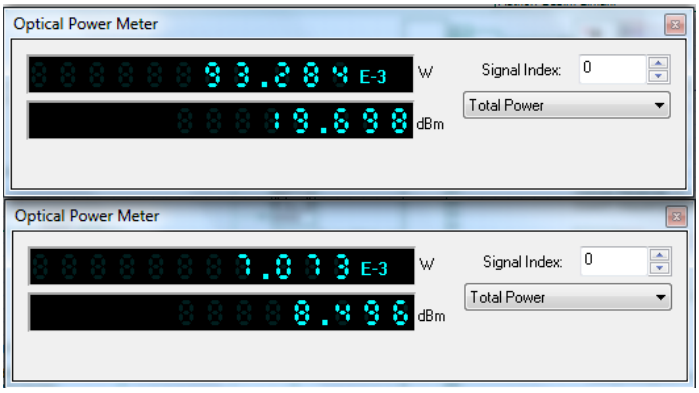

Figure 10. The power of the transmitter output signal to multiplexer and the input to demultiplexer using EDFA amplifier.

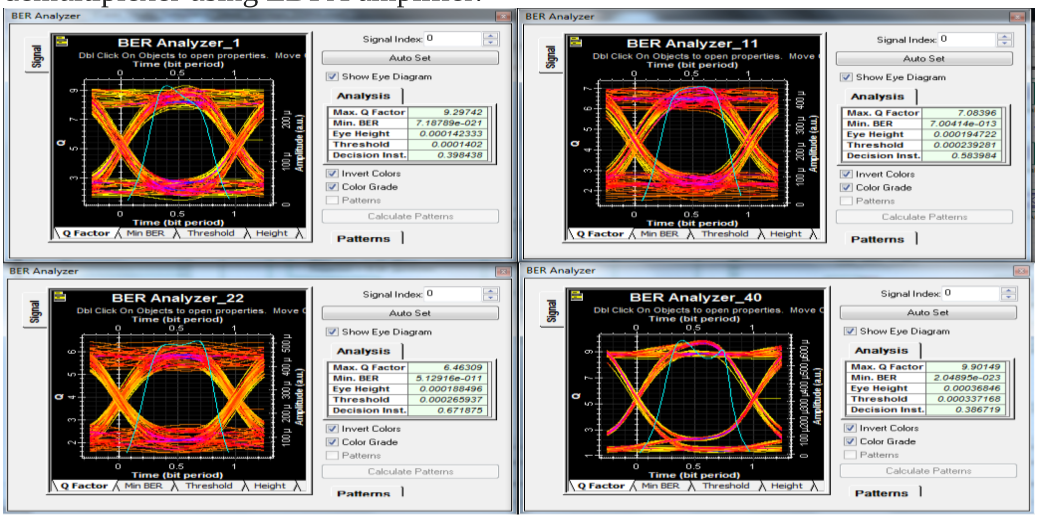

Figure 11. The value of the BER measured from BER Analyzer with EDFA

Table 11. BER values of 10 Gbps with EDFA ch_1

The 1st data channel	Value	Unit
Wavelength	1565	nm
Max. Q Factor	9.29	
Min. BER	7.18 *10-21	bps
Eye Height	0.00014	
Threshold	0.00014	
Decision Instant	0.39	bit period

Table 12. BER values of 10 Gbps with EDFA ch_11

The 11th data channel	Value	Unit
Wavelength	1556.87	nm
Max. Q Factor	7.08	
Min. BER	7.004*10-13	bps
Eye Height	0.00019	
Threshold	0.0002	
Decision Instant	0.56	bit period

Table 13. BER values of 10 Gbps with EDFA ch_22

The 22th data channel		Value	Unit
Wavelength		1548.03	nm
Max. Q Factor		6.46	
Min. BER		5.12 *10-11	bps
Eye Height		0.00018	
Threshold		0.00026	
Decision Instant		0.67	bit period

Table 14. BER values of 10 Gbps with EDFA ch_40

The 40th data channel	Value	Unit
Wavelength	1533.77	nm
Max. Q Factor	9.90	
Min. BER	2.047*10-23	bps
Eye Height	0.00036	
Threshold	0.00033	
Decision Instant	0.38	bit period

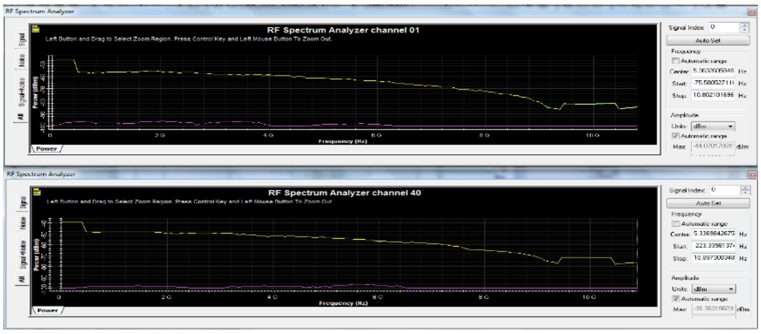

Figure 12. Radiofrequency Spectrum Analyzer

In the figure 12 we see that by using the EDFA amplifier the signal in ch_1 and in the ch_40 does not lose and transmission exceeding 10 GHz.

Data transfer with 40 Gbps capacity in the simulator

In the presented scheme of simulator network shown in figure 13 I will try to transmit data at 40 Gbps capacity. In this scheme the values of the transmitter WDM from 10 Gbps to 40 Gbps changed, the signal value of depth in WDM multiplexer and WDM demultiplexer now is 100 dB due to better performance of signal, as are presented in tables 15,16,17.

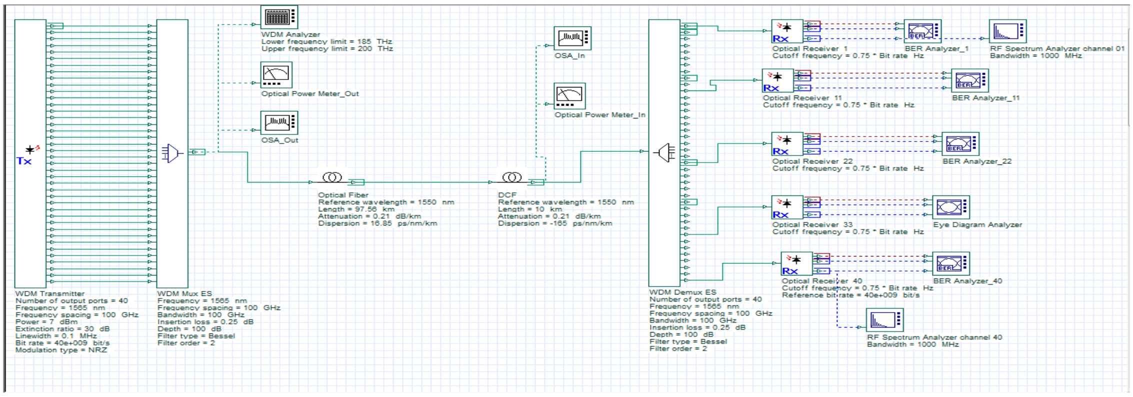

Figure 13. Optical network simulator scheme with 40 Gbps.

Whereas the values of the optical signal obtained after the measurements are shown in Figures 14, 15, 16 and in the following tables.

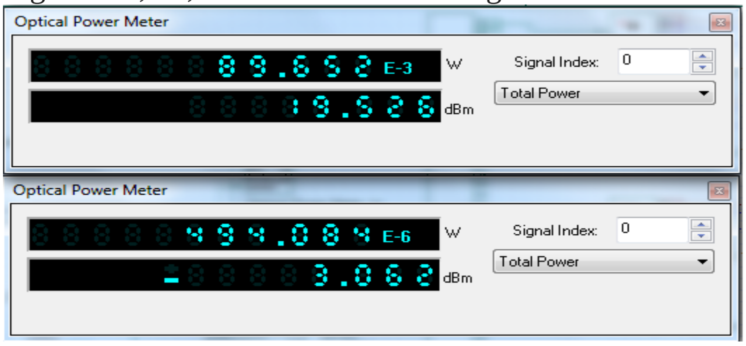

Figure 14. The power of the transmitter output signal to multiplexer and the input to demultiplexer

From this measurement is shown that the total optical signal losses are 22,588 dB.

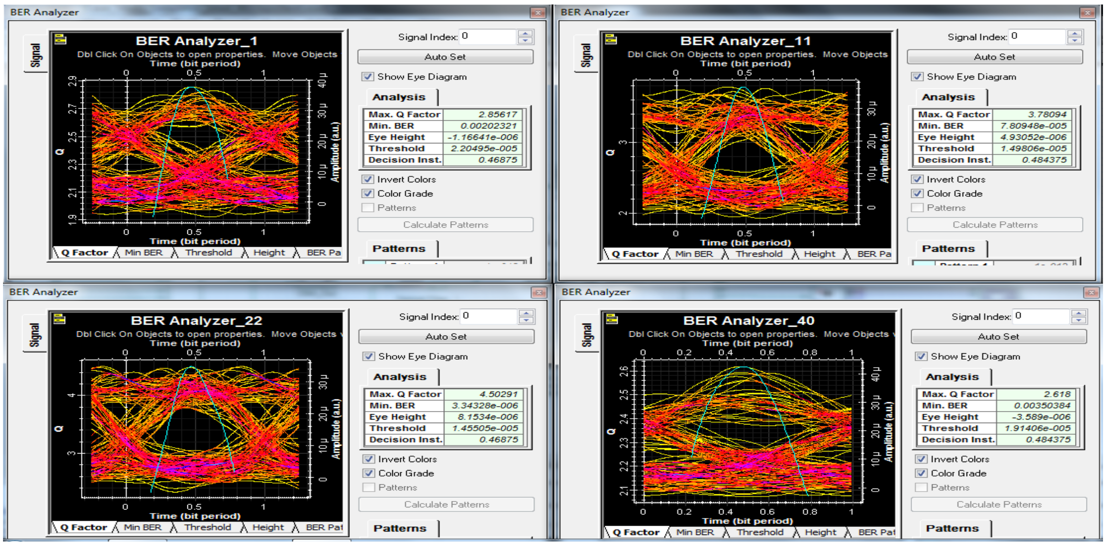

Figure 15. The value of the BER measured from BER Analyzer by 40 Gbps

Table 15. BER values of 40 Gbps ch_1

The 1st data channel	Value	Unit
Wavelength	1565	nm
Max. Q Factor	2.85	
Min. BER	0.002	bps
Eye Height	-1.16 *10-6	
Threshold	2.20*10-5	
Decision Instant	0.46	bit period

Table 16. BER values of 40 Gbps ch_11

The 11th data channel	Value	Unit
Wavelength	1556.87	nm
Max. Q Factor	3.78	
Min. BER	7.80 *10-5	bps
Eye Height	4.93 *10-6	
Threshold	1.49 *10-5	
Decision Instant	0.48	bit period

Table 17. BER values of 40 Gbps ch_22

The 22th data channel	Value	Unit
Wavelength	1548.03	nm
Max. Q Factor	4.50	
Min. BER	3.34 *10-6	bps
Eye Height	8.15 *10-6	
Threshold	1.45 *10-5	
Decision Instant	0.46	bit period

Table 18. BER values of 40 Gbps ch_40

The 40th data channel	Value	Unit
Wavelength	1533.77	nm
Max. Q Factor	2.61	
Min. BER	0.003	bps
Eye Height	-3.58 *10-6	
Threshold	1.91 *10-5	
Decision Instant	0.48	bit period

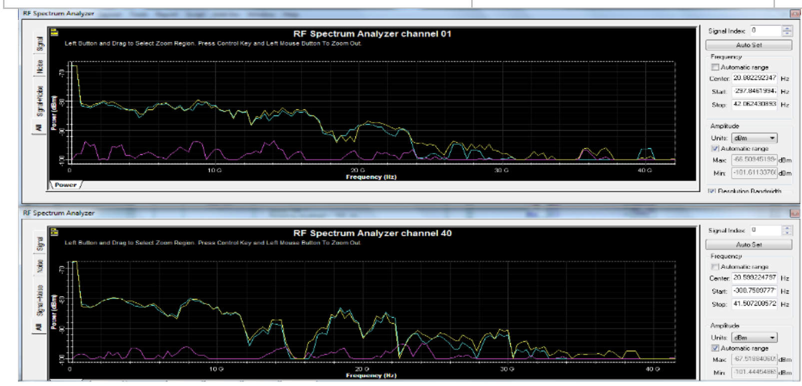

Figure 16. Radiofrequency Spectrum Analyzer.

Data transfer with 40 Gbps capacity in the simulator using EDFA amplifier

Noting that the topology at approximately same value, the same as it was presented in figures 5 and 9 have achieved to transmit 10 Gbps at full capacity and I have not yet transmitted 40 Gbps at full capacity, then I will connect EDFA amplifier to improve optical signal values. Optical amplifier values are presented in the tables 23 and 24, while the scheme or the amplifier topology is shown in Figure 17.

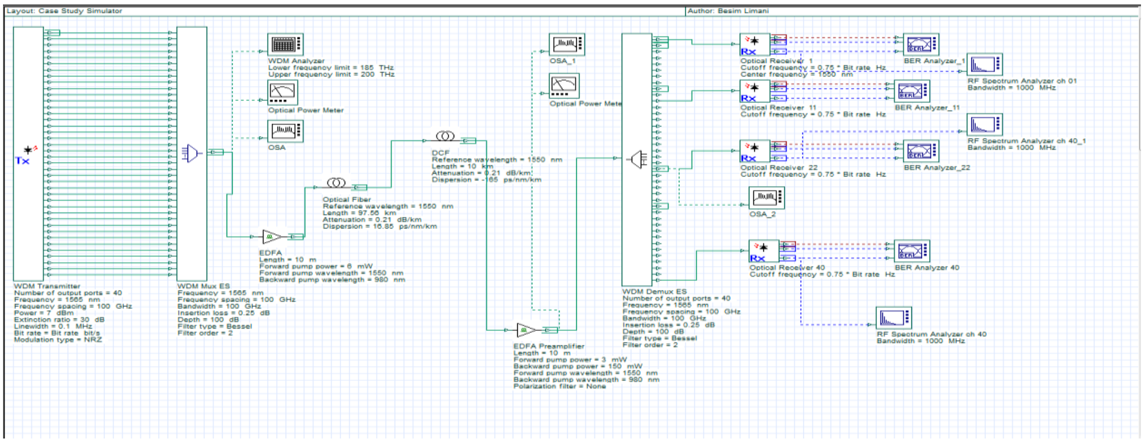

Figure 17. Optical network simulator scheme 40 Gbps with EDFA

If we now examine the values of amplifiers in tables above note that the value of the signal amplifier in the first amplifier (booster) is 6 dB respectively 7.78 mW, while in the second amplifier signal we have in the pre-amplifier value 3 dB respectively 4.77 mW. Improvement of the total value of the optical signal is considerably better as shown in figure 18 from the measurements of Optical Power Meter.

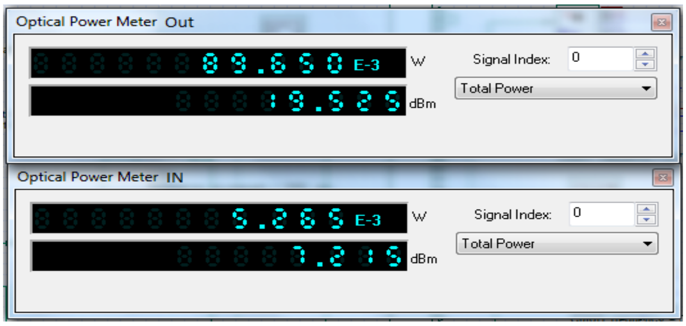

Figure 18. Optical Power Meter

The difference output signal from the multiplexer and input signal from the demultiplexer value is 12.31 dB, this mean that the optical signal during its travel along the optical cable length ~ 107 km has incurred losses of only 12.31 dB. This change improves the loss of optical signal quality which have noticed with measurements made on the simulator as they are presented in figures 19 and 20 below.

While in figure 19 we find the eye height form for channels 01, 11, 22 and 40.

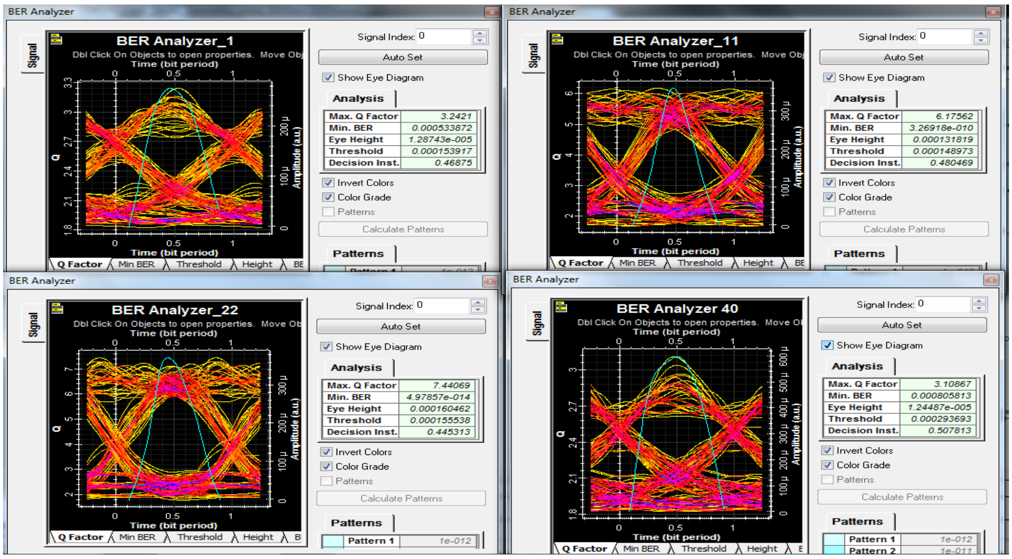

Figure 19. BER Analyzer 40 Gbps with EDFA

The measured values with the BER analyzer are presented in the following tables:

Table 19. BER values of 40 Gbps with EDFA ch_1

The 1st data channel	Value	Unit
Wavelength	1565	nm
Max. Q Factor	3.24	
Min. BER	0.00053	bps
Eye Height	1.28 *10-5	
Threshold	0.00015	
Decision Instant	0.46	bit period

Table 20. BER values of 40 Gbps with EDFA ch_11

The 11th data channel	Value	Unit
Wavelength	1556.87	nm
Max. Q Factor	6.17	
Min. BER	3.26 *10-10	bps
Eye Height	0.00013	
Threshold	0.00014	
Decision Instant	0.48	bit period

Table 21. BER values of 40 Gbps with EDFA ch_22

The 22th data channel	Value	Unit
Wavelength	1548.03	nm
Max. Q Factor	7.44	
Min. BER	4.97 *10-14	bps
Eye Height	0.00016	
Threshold	0.00015	
Decision Instant	0.44	bit period

Table 22. BER values of 40 Gbps with EDFA ch_40

The 40th data channel	Value	Unit
Wavelength	1533.77	nm
Max. Q Factor	3.10	
Min. BER	0.0008	bps
Eye Height	1.24*10-5	
Threshold	0.00029	
Decision Instant	0.50	bit period

This improvement of the signal is shown from measurements made with RF Spectrum Analyzer in figure 20.

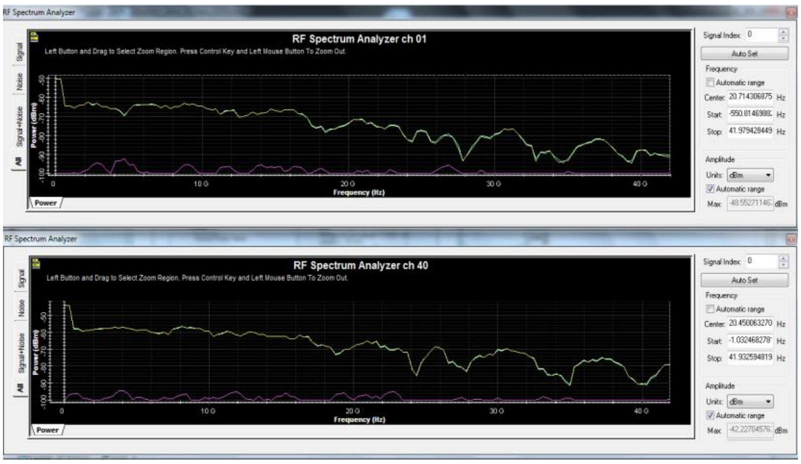

Figure 20. Measurements made in the simulator with RF Spectrum Analyzer.

DISCUSSION

In the tables 23 and 24 with 10 Gbps transmission, note that I have used the EDFA amplifier, which has significantly improved the performance of the transmission system. If we focus on channel 1 without EDFA amplifier which has minimum BER value 2.43 $*10^{-10}$, and channel 1 with EDFA amplifier has a value of 7.18 $*10^{-21}$, then appear that the error rate of bits is much lower in each channel in which is used EDFA amplifier. Also Q - Factor of ch_1 without EDFA amplifier is 6.22, and ch_1 with EDFA amplifier value of Q-Factor is 9.29, so in channels with EDFA amplifier the value of Q-Factor is higher than in channels without EDFA. This confirms the theory of the relationship between Q-Factor and BER's that: the signal has better values if Q-factor value is higher and the BER value is lower.

Analysis	**Channel 1**	**Channel 11**	**Channel 22**	**Channel 40**
Maximum Q Factor	6.22	5.68	5.50	6.94
Minimum BER	2.43 $*10^{-10}$	6.48 $*10^{-9}$	1.88 $*10^{-8}$	1.91 $*10^{-12}$
Eye Patern Height	$1.27*10^{-5}$	$1.18*10^{-5}$	$1.10*10^{-5}$	$1.40*10^{-5}$
Threshold	$1.55*10^{-5}$	$1.81*10^{-5}$	$1.82*10^{-5}$	$1.63*10^{-5}$
Decision Inst.	0.64	0.57	0.51	0.43

Table 23. Comparison of measurement channels 1, 11, 22 and 40 WDM with BER Analyzer in backbone networks on 10 Gbps.

Analysis	**Channel 1**	**Channel 11**	**Channel 22**	**Channel 40**
Maximum Q Factor	9.29	7.08	6.46	9.90
Minimum BER	7.18 $*10^{-21}$	$7.004*10^{-13}$	5.12 $*10^{-11}$	$2.047*10^{-23}$
Eye Patern Height	0.00014	0.00019	0.00018	0.00036
Threshold	0.00014	0.0002	0.00026	0.00033
Decision Inst.	0.39	0.56	0.67	0.38

Table 24. Comparison of measurement channels 1, 11, 22 and 40 WDM with BER Analyzer in backbone networks on 10 Gbps with EDFA.

In the tables 25 and 26 with 40 Gbps capacity transmission, note that the use of EDFA amplifier has significantly improved the performance of the transmission system in each

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channel. Channel 11 without EDFA amplifier has the minimum BER value 7.80 $*10^{-5}$, while channel 11 with EDFA amplifier has value 3.26 $*10^{-10}$, then appear that the error rate of bits is much lower in each channel in which EDFA amplifier is used. Also Q - Factor of ch_11 without EDFA amplifier is 3.78, and ch_11 with EDFA amplifier value of Q-Factor is 6.17, so in channels with EDFA amplifier the value of Q-Factor is higher than in channels without EDFA. This confirms the theory of the relationship between Q-Factor and BER' which I quoted above.

Analysis	**Channel 1**	**Channel 11**	**Channel 22**	**Channel 40**
Maximum Q Factor	2.85	3.78	4.50	2.61
Minimum BER	0.002	7.80 $*10^{-5}$	3.34 $*10^{-6}$	0.003
Eye Patern Height	-1.16 $*10^{-6}$	4.93 $*10^{-6}$	8.15 $*10^{-6}$	-3.58 $*10^{-6}$
Threshold	2.20$*10^{-5}$	1.49 $*10^{-5}$	1.45 $*10^{-5}$	1.91 $*10^{-5}$
Decision Inst.	0.46	0.48	0.46	0.48

Table 24. Comparison of measurement channels 1, 11, 22 and 40 WDM with BER Analyzer in backbone networks on 40 Gbps.

Analysis	**Channel 1**	**Channel 11**	**Channel 22**	**Channel 40**
Maximum Q Factor	3.24	6.17	7.44	3.10
Minimum BER	0.00053	3.26 $*10^{-10}$	4.97 $*10^{-14}$	0.0008
Eye Patern Height	1.28 $*10^{-5}$	0.00013	0.00016	1.24$*10^{-5}$
Threshold	0.00015	0.00014	0.00015	0.00029
Decision Inst.	0.46	0.48	0.44	0.50

Table 25. Comparison of measurement channels 1, 11, 22 and 40 WDM with BER Analyzer in backbone networks on 10 Gbps with EDFA.

CONCLUSIONS

In this case study I have analyzed the performance of transmission on the transmission backbone line Pristina - Skopje with optical fiber, which is based on simulation of software application (OptiSystem 13.0). Based on WDM transmission technology analysis of 10 Gbps and 40 Gbps, I have analyzed each transmission in two cases, the first case study with EDFA amplifier and the second case study without EDFA amplifier, and I have presented results in graphical and tabular form.

In each exposed figure, appears that the optical signal in the case of using EDFA amplifiers have better form and value, than in cases where we do not use signal amplifier. Without EDFA amplifier it is difficult to transmit and to achieve target of data values, and the transmitted signal will be often degraded before reaching its target. That means we have a losses of signal. Therefore, from the realized results, it appears that the role and importance of using WDM / DWDM technologies and EDFA amplifier in transmission systems with fiber optics, will help for achieving a long distances transmission and high capacity, without needing to add additional optical cables, in such way will maintain low cost of transmission systems.

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