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OPTICAL AMPLIFIERS FOR REACH EXTENSION OF PASSIVE OPTICAL NETWORK FOR RURAL SETTLEMENTS

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ABSTRACT

This article is devoted to reach extended PON and optical amplifier technologies to extend physical limitation of PON from 20km to 60 km. with analysis of optical amplifiers, like EDFA, Raman, SOA amplifier, quantum-well and quantum-dot semiconductor optical amplifier for reach extension and the corresponding requirements of PON.

Keywords: *FTTH, PON, OA, PON, SOA, EDFA, QD-SOA.*

1. INTRODUCTION

The Fiber-to-the-Home (FTTH), Fibre-to-the-Building (FTTB), Fibre-to-the-Curb (FTTC), Fibre-to-the-Cabinet (FTTCab), Fibre-to-the-Office (FTTO) and Fibre-to-the-Cell-site (FTTCell) technologies are main attractive technologies to replace copper based access technology, due to it offers the high bandwidth of its optical infrastructure. A promising technology for fiber access systems is the Passive Optical Network (PON). PON is mature technology for broadband access. In Kazakhstan first commercial deployments of Gigabit PON (GPON) in Almaty was started in 2010 [1] and in Nur-Sultan in 2011 [2].By state statistic agency, the number of fixed Internet subscribers in Kazakhstan for 2018 was 2462.4 thousand units [3]. In 2018 was begun the construction of fiber-optic communication lines to provide broadband access to rural settlements. Within two years, it is planned to build more than 15 thousand km of fiber-optic communication lines and connect almost 2.5 thousand state and budget organizations (schools, hospitals, boarding schools, rescue services, police, akimats), in 828 rural settlements to the broadband access [4][5].At the end of 2018, the installed capacity of broadband access amounted to 2 420 855 ports, of which the port capacity using FTTH technology is 41%. The number of fixed lines in the Kazakhtelecom JSC network as of January 1, 2019 amounted to 2 978 472 units, including 2 123 977 units in the city telecommunication network and 854 495 units in the rural network. With regard to the installation of telephones in villages, 98.8% of the 6,534 rural settlements have telephones and 81% of rural settlements have access to the Internet using broadband access technology [6].

Thus Gouvernement initiatives addressing the digital divide between urban and rural areas, expanding infocommunication infrastructure to increase demand for more bandwidth and services for example broadband Internet access and mobile communication 4G (in the future 5G) [7], public services eGov, electronic commerce, e-learning, telemedicine, Smart cities, IoT, video on demand, HDTV, 4 or 8K UHDTV, HD video gaming, Machine to Machine (M2M), cloud computing, etc. [8].

The rural settlements needs high speed for Internet access, from the Figure 1 we see that, thus extended reach PON solution most suitable cost-effective technology[9].

The first-mile bottleneck problem can be analysed through open web-platforms like broadbandspeedchecker [10], speedtest[11] which has a free software tool for users to measures internet speed of their Internet Service Providers. Internet access speed for main Kazakhstan cities Nur-Sultan and Almaty and nearby settlements are illustrated in Figure 1. In Figure 1 a) internet access speed rate for Nur-Sultan city centre is average 24.79Mbit/s, for suburb ~7Mbit/sec. which is 3.5 times lower. If we compare with an internet speed rate in the settlements close to Nur-Sultan for ~60km (Figure 1 b), we can see average speed rate

1.2Mbit/sec in Shortandy village, which is 20 times lower than in the city Nur-Sultan. Almaty city, which is most populated city in Kazakhstan, Figure 1 c shows average internet speed 29.65Mbit/s in specific districts, and in the settlements like Talgar town average speed is 9.86Mbit/s and near Kaskelen town 3.93 Mbit/s, thus 3 and7.5 times lower compare to Almaty, respectively.

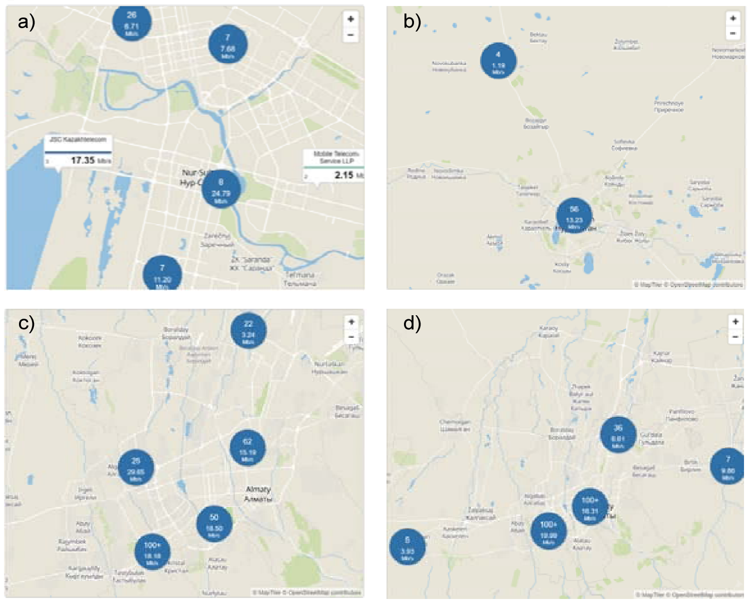

Figure 1: Www.Broadbandspeedchecker.Co.Uk Web-Site Results For Internet Speed In Main Kazakhstan Cities A)Nur-Sultan; B) Shortandy Village In Aqmola Region, ~60 Km From Nur-Sultan; C) Almaty D) Almaty Region Settlements In The Distance ~40 Km From Almaty [10]

In the world perspective top 10 countries with best internet speed are listed in Figure 2 a) with best speed for mobile 83.52Mbit/s and fixed broadband 197.26 Mbit/s [11] and Kazakhstan is ranked in 65th place with average speed for mobile 17.69Mbit/s and fixed broadband 41.15 Mbit/s [12], illustrated in Figure 2 b).

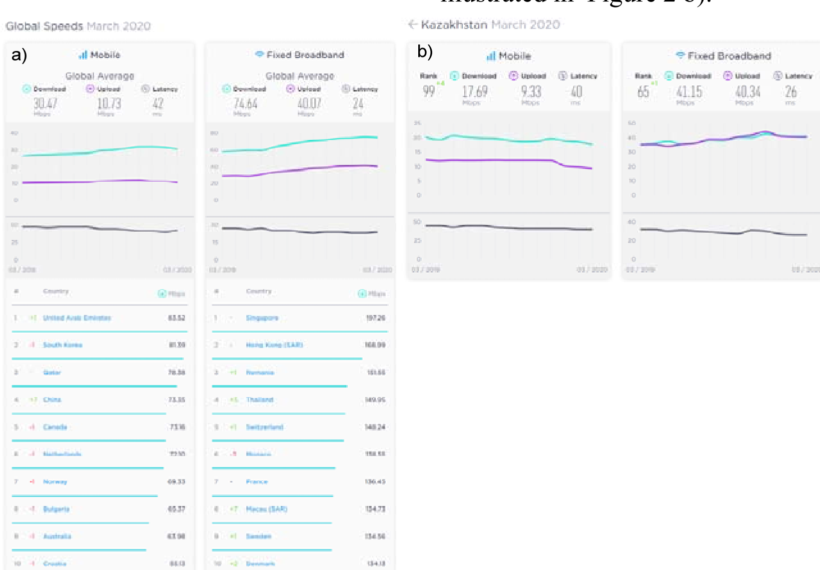

Figure 2 Www.Speedtest.Net Web-Site Information For Internet Speed Results For Mobile And Fixed Broadband Access A) For Top 10 Countries Of The World And B) For Kazakhstan Which Is Ranked 65 Place. The Graph Shows Interned Speed For The Period From March 2019 To March 2020 [11]

Today's architecture for PON has a limited physical reach of 20 km due to the high loss budget. This reach limitation makes it difficult to provide service to the customers located far from the central office. Therefore, several central offices are required to serve a huge amount of costumers. On the other hand an optical amplifier can be used to extend the reach of a PON network up to 60 km which is the limit of the logical reach in today's protocols. PON has become popular due to its utilization of low-cost passive devices in the intermediate nodes and the provision of large user bandwidth. The usage of optical fibers and high-speed processors not only allows this architecture to serve the residential users, but large corporates like the mobile operators can also use its services for backhaul support [13].

In this article, we will focus on current situation to extend the reach of PON and focus on optical amplifiers to reach rural settlements with cost efficiency.

2. PASSIVE OPTICAL NETWORK STANDARDS

PON is a point-to-multipoint (P2MP) fiber access network architecture and uses passive (unpowered) optical splitters to enable a single optical fiber to serve multiple end-users. A PON consists of an Optical Line Terminal (OLT) at the service provider's central office (CO), passive optical splitters, and a number of Optical Network Units (ONU) at end-users, illustrated in Figure . It offers a physical reach of 20 km between the central office and the customer and passive optical splitter serves 32 end-users. The path from OLT (central office) to ONU (end-user) is termed downstream (DS), and the path from ONU (end-user) to OLT (central office) is termed upstream (US).

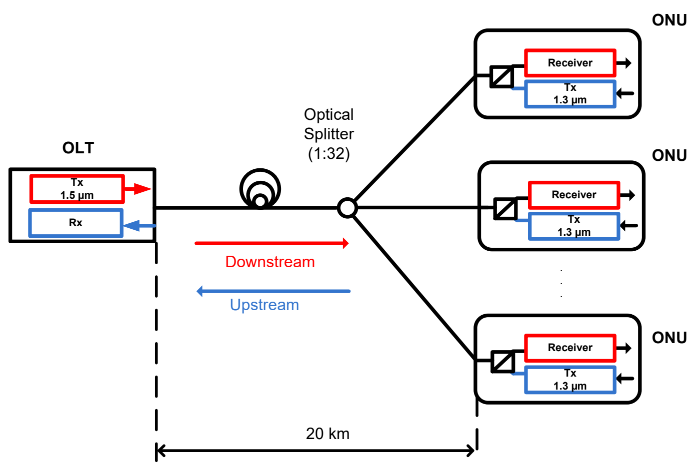

Figure 3: Passive Optical Network Architecture. PON Consists Of OLT At The Central Office Side, Passive Optical Splitter Which Serves 32 End-Users And Onus At End-Users Side. The Distance Between CO And End-Users Is 20 Km. Direction Of Downstream And Upstream Is Indicated By The Arrows

The PON standards offers high bit rate, high service capability and greater service integration [14**Error! Reference source not found.**]. PON major ITU-T Recommendation are

ITU-T G.984 Gigabit-capable passive optical networks (GPON);

ITU-T G.987 10-Gigabit-capable passive optical network (XG-PON);

ITU-T G.9807 10-Gigabit-capable symmetric passive optical network (XGS-PON;

ITU-T G.989 XG-PON 40-Gigabit-capable passive optical networks (NG-PON2).

GPON is ITU-T G.984 Recommendation [15].In a GPON all signals are distributed through the optical distribution network (ODN) from the optical line terminal (OLT) to every end user's optical network termination unit (ONT) connected on the same PON branch. Great interest is given to the future development expecting increasing traffic and higher bandwidth demands and extended reach [22] The bit rates are 2488 Mbit/s for downstream and 1244 Mbit/s for upstream. The physical reach is 20 km, with a splitting ratio of 1:32 or 1:64. Logical reach is the maximum distance between ONU/ONT and OLT except for the limitation of the physical layer. In GPON, the maximum logical reach is defined as 60 km.

The GPON ITU-T Recommendation G.984 is illustrated in Figure . It operates at data rates of 2.5 Gbit/s – 1.2 Gbit/s for downstream and 2.5 Gbit/s – 622 Mbit/s for upstream. Downstream and upstream use NRZ coding. The operating wavelength range for the downstream direction on a single fiber system is around 1500 nm and for upstream around 1300 nm wavelength region. For the downstream, the mean launched power of OLT transmitter shall be between 0 and +9 dBm and the minimum receiver sensitivity of ONU receiver shall be between -21 and -28 dBm. For the upstream, the mean launched power of ONU transmitter shall be between -3 and +7 dBm and the minimum receiver sensitivity of OLT receiver shall be between -24 and -29 dBm. The maximum and minimum mean launched power and receiver sensitivity depend on the recommendation ODN class types.

GPON supports a link power budget of 28 dB, which practically limits the splitting factor to 1:32 at 20 km length and would support logical reach of 60 km and a logical split of 128, if the limitations of the physical layer could be overcome.

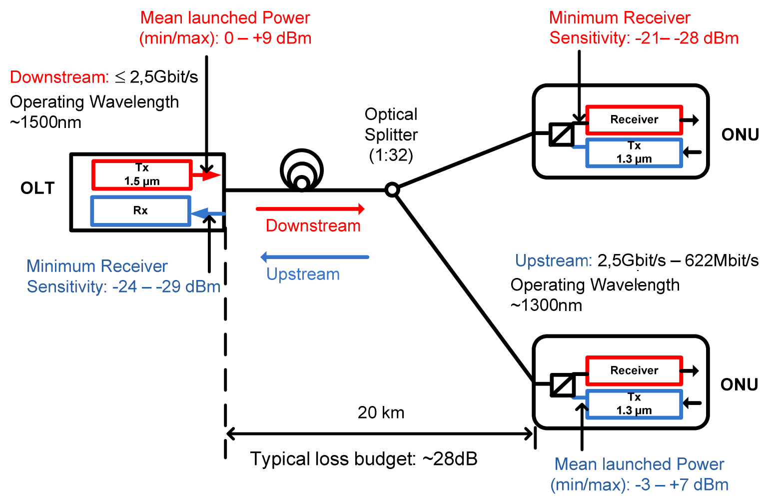

Figure 4: General Recommendations Of GPON ITU-T Standard G. 984. The Recommendations For Down- And Upstream Paths Like Operating Wavelength Regions, Bit Rates, And Launch Powers Of The Transmitters And Minimum Receiver Sensitivities Of The Receivers Are Shown

XG-PON is standardized by ITU-T G.987 [17]. XG-PON (X=10 G=Gigabit PON) offers 10 Gbit/s in downstream and 2.5 Gbit/s in upstream using a single fixed wavelength in each direction and based by next-generation passive optical network stage 1 (NG-PON1).

XG-PON1: A variant of XG-PON system that operates at a nominal line rate of 10 Gbit/s downstream and 2.5 Gbit/s upstream. XG-PON2: A variant of XG-PON system that operates at a nominal line rate of 10 Gbit/s downstream and upstream.

The wavelength range of the XG-PON1 downstream signal on a single-fibre system is from 1575-1580 nm, and the range of upstream signal for XG-PON1 is from 1260-1280 nm.

Downstream and upstream use NRZ coding. For the downstream, the mean launched power of OLT transmitter shall be between +2 (+14.5) and +6 (+16.5) dBm and the minimum receiver sensitivity of ONU receiver shall be between -28 (-21.5) and -8 (-3.5) dBm. For the upstream, the mean launched power of ONU transmitter shall be between +2 and +7 dBm and the minimum receiver sensitivity of OLT receiver shall be between -27.5 (-33.5) and -7 (-13) dBm. The maximum and minimum mean launched power and receiver sensitivity depend on the recommendation ODN class types.

Split ratio: 1:64 split shall be the minimum requirement for XG-PON.

XG-PON1 must support the maximum fibre distance of at least 20 km. In addition, XG-PON1 support the maximum fibre distance of 60 km. XG-PON1.

The first candidate based on evolutionary growth is 10-Gigabit-capable passive optical network (XG-PON) based on minimal equipment investments. Coexistence of GPON and XG-PON in the same infrastructure is a most discussed issue concerning passive optical networks nowadays. Coexistence means the migration in the same ODN. Current GPON systems are intended to coexist with XG-PONs applying identical colorless ONTs. This scenario expects not only cost savings but also easier planning and maintaining the network. Coexisting GPONs and XG-PONs should be deployed on the same network infrastructure. However, some protective measures should be taken to avoid interferences between GPON and XG-PON signals. [22].

XGS-PON is standardized by ITU-T G.9807 [18]. XGS-PON (X=10, G=Gigabit, S=symmetrical PON) nominal data rate of 10 Gbit/s both in the downstream and the upstream direction. XGS-PON must be able to operate on nominally 28/29 dB loss optical distribution network (ODNs), depending on the wavelength set plan used.

XGS-PON systems are able to operate on the same ODN as XG-PON systems. The XGS-PON systems are capable of operating at the same wavelengths as an existing XG-PON system or operating at the gigabit-capable passive optical network (G-PON) wavelengths. Co-existence of XGS-PON with G-PON, 10-gigabit passive optical network (XG-PON) and next generation passive optical network 2 (NG-PON2) is supported. Maximal reuse of existing ITU-T PON Recommendations is made. The XGS-PON transmission convergence (TC) layer is based on the NG-PON2 and XG-PON TC layers. No hardware-affecting modifications to the TC-layers are needed. It is expected that TC layer devices designed for time and wavelength division multiplexing (TWDM) PON will be able to operate as XGS-PON TC layer devices. The downstream optical physical medium dependent (PMD) specifications are derived from the XG-PON PMD[23].

NG-PON2 is standardized by ITU-T G.989. XG-PON 40-Gigabit-capable passive optical networks (NG-PON2) The next-generation passive optical network stage 2 (NG-PON2) project was initiated by the full-service access network (FSAN) [24] community in 2011. The 40 Gbit/s, the time- and wavelength-division multiplexed PON (TWDM-PON) proposal which stacks multiple XG-PONs using WDM []

Time and Wavelength Division Multiplexed (TWDM) PON technology, based on dense WDM-stacked 10G PONs, was selected. Named “NG-PON2”, this was ultimately standardized in ITU-T G.989 [25]. Downstream and upstream use NRZ coding. Downstream operating wavelength band 1596-1603 nm; Upstream wideband option 1524-1544 nm. Split ratio of 1:64 or higher with optimized for TWDM 4-channel and 20 km

TWDM-PON is the most advanced and sophisticated of all NG-PON technologies. It adds more wavelengths on the fiber (initially 4 in upstream and 4 in downstream, with more possible in the future). TWDM-PON supports flexible bitrate configurations (2.5/2.5G, 10/2.5G, and 10/10G) and uses tunable lasers that allow operators to dynamically assign and change the wavelength on which a customer is connected. As with any new technology, the cost of tunable lasers is still high. But as innovations improve the technology and volumes increase, the cost of TWDM-PON will come down, in time for mass deployments predicted in 2018 and beyond. []

PON ITU-T standard summary for GPON, XG-PON, XGS-PON and TWDM-PON is listed in Table 1 and summary of wavelength distribution is illustrated in Figure 5.

Table 1: PON Major Standards And Key Features
**) Note: The physical reach is defined by split, optical module size, and fiber quality*
***) Note: the actual split ratio depends on the optical module model and fiber distance*

Characteristics	GPON	XG-PON	XGS-PON	NG-PON2 TWDM-PON
Standard	ITU-T G.984 (2003) [15]	ITU-T G.987 (2010) [17]	ITU-T G.9807 (2016) [18]	ITU-T G.989 (2015) [21]
Protocol				
Rates	DS: 2.5 Gbit/s US: 1.25 Gbit/s	DS: 10 Gbit/s US: 2.5 / 10 Gbit/s	DS: 10 Gbit/s US: 10 Gbit/s	DS: 40 Gbit/s US: 10 Gbit/s
Span (km)	20	20	20	20
Split-ratio	1:128**)	1:256**)	1:256**)	1:256**)
Co-existence	-	with GPON [23]		
Wavelength (nm)	DS: 1480 – 1500 US: 1290 – 1330	DS: 1575 – 1580 US: 1290 – 1280	DS: 1575 – 1580 US: 1290 – 1280	DS: 1596 – 1603 US: 1524 – 1544
Optical Path Loss class	B+ max loss 28 dB	C+ max loss 30 dB		

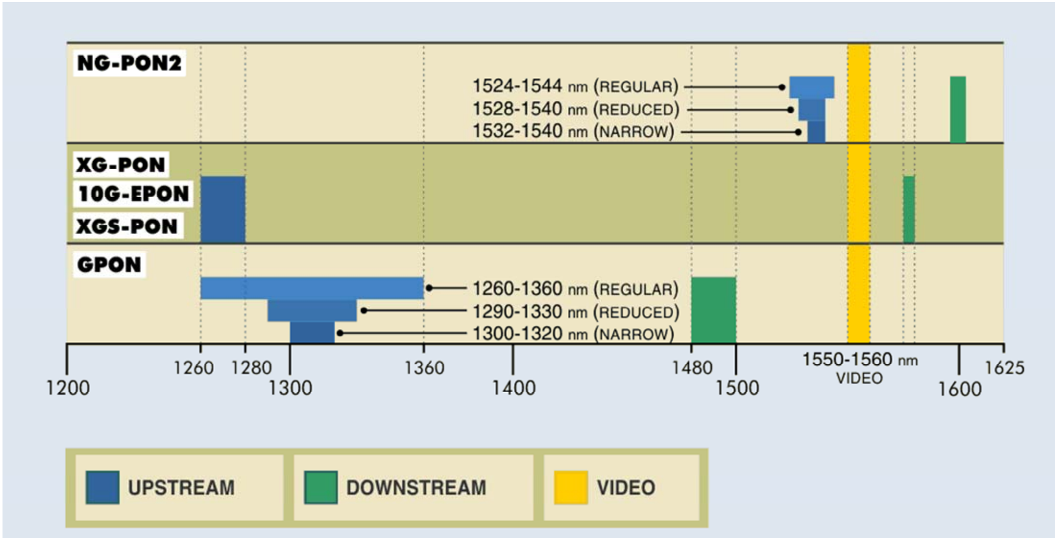

Figure 5: Wavelength Distribution For GPON, XG-PON, XGS-PON And NG-PON2 [26]

3. EXTENDED REACH PON

PON architecture with a loss budget of 28 dB has a limited physical reach of 20 km. Due to this reach limitation it is difficult to provide service to the customers located far from the central office. The power budget of the network can be extended by adding an in-line optical amplifier. The logical reach of the extended reach PON can exceed 60 km.

Extended-reach PON is a promising solution to consolidate optical metro and access into a single integrated system with significant reduction of CapEx and OpEx from lower numbers of network interfaces and elements, reduced power consumption, operation and management cost [27]

There are two general classes of extenders. The first is an optical amplifier (OA), which provides gain in optical power. The second is an optical-electrical-optical (OEO) regenerator, which receives an optical signal, reshapes and retimes it in the electrical domain and retransmits in the optical domain. [15].

ITU-T Recommendation for reach extension
G.984.6 Gigabit-capable passive optical networks (GPON): Reach extension [16]
G.987.4 10-Gigabit-capable passive optical networks (XG-PON): Reach extension [19]
G.9807.2 10 Gigabit-capable passive optical networks (XG(S)-PON): Reach extension [20]

Extended Reach Hybrid WDM/TDM GPON network with a logical reach higher than 60 km using an in-line optical amplifier illustrated in Figure . Time and wavelength division multiplexed passive optical network one of the most promising candidates of the next generation optical access system beyond 10Gb/s.[]

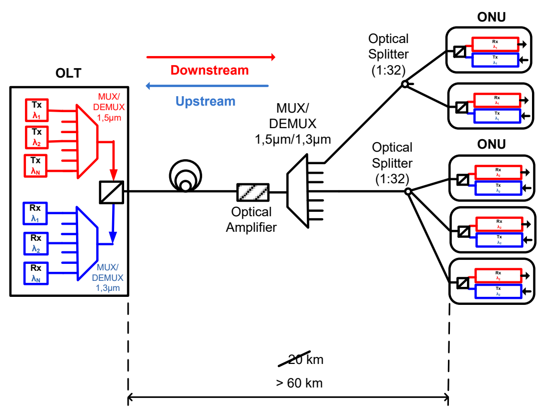

Figure 6: Extended Reach Hybrid WDM/TDM GPON With A Logical Reach Of More Than 60 Km, Using An In-Line Optical Amplifier

The advantages of the WDM/TDM PON technology:
1. Long Reach. a) consolidate thousands of central offices to a few metro nodes; b) reaches customers which are located at long distance from central office and sparsely distributed over a geographical area; c) the infrastructure of reduced local and regional central offices can be used to mount optical amplifiers; d) significantly cost saving in capital expenditure (CAPEX) and in operating expenditure (OPEX) [28].
2. High number of users, hybrid WDM/TDM GPON architecture can excess of 1000 users per OLT port [29].

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3. High speed for downstream and upstream traffic and possibilities to easily increase to near future bit rates up to 10 Gbit/s.
4. High bandwidth per user.
5. Single fiber interface.
6. Simple scalability and upgradeability.
7. Easy migration.
8. Multi-operability (fiber infrastructure shared by several operators).
9. Centralized management and monitoring.
10. Resiliency and traffic balancing.
11. Robustness [30].

4. OPTICAL AMPLIFIERS FOR EXTENDED REACH PON

Typical extended reach PON architecture requires optical amplification. There are different types of optical amplifiers which show high potential as linear amplifiers:

- Rare-earth-doped fiber amplifiers as: Erbium (Er); Neodymium (Nd); Ytterbium (Yb); Thulium (Tm); Praseodymium (Pr) – doped fiber amplifiers.
- Semiconductor Optical Amplifiers (SOA) as: bulk-SOA; Quantum Well – SOA (QW-SOA); Quantum Dots – SOA (QD-SOA).
- Raman Amplifiers.

To select the best optical amplifier to reach extension in PON network, these amplifiers should fulfill the PON network requirements and match the PON ITU-T standards. The amplifiers should be cheap in a price, as the cost of optical amplifier is shared among all customers in the PON network. Optical amplifiers should be flexible and functional with future applications.

The requirements for downstream (

Table ***Error! No text of specified style in document.***) amplifiers are:

- Operate at 1.5 µm wavelength region,
- transmit data rates up to 2.5 Gbit/s,
- amplify all multiplexed WDM channels equally low inter-channel cross-talk.

The transmission of the upstream signal is much more critical. The losses before the amplifier are much higher than for the downstream path, mainly due to the splitter. The end-users in the network are geographically distributed, so the distance to the amplifier varies strongly. The requirements for upstream (

Table ***Error! No text of specified style in document.***) optical amplifiers are:

- Operate at 1.3 µm wavelength region,
- high gain to compensate high losses,
- a high IPDR is needed to cover the power and distance variations of the users,
- high burst-mode tolerance is required due to the burst nature of upstream traffic.

The main amplifier requirements for extended reach PON are listed for comparison in

Table ***Error! No text of specified style in document.***.

Table ***Error! No text of specified style in document.****: Requirements For GPON Reach Extender (Amplifier), Separated For Upstream And Downstream direction*

Downstream	Upstream
Bit rate: 2.5 Gbit/s; – 40 Gbit/s	Large input power dynamic range (IPDR)
CWDM/DWDM technology	High burst mode tolerance
Flat gain to amplify several channels	High gain
	Low inter-channel cross-talk

5. PROJECTS OF EXTENDED REACH PON

Currently, reach extension for passive optical networks is a very active research field. Several studies investigate the performance of different amplifier technologies

5.1 EDFA amplifier (PIEMAN Project)

The Photonic Integrated Extended Metro and Access Network (PIEMAN) project of future broadband optical access and metro system. It is a project of the European Union (EU) and the total cost of a project is €3.9 mil. [31].

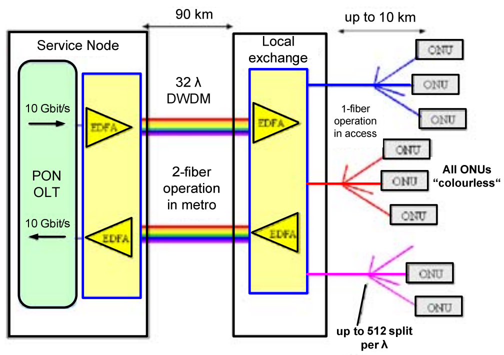

Figure 7: PIEMAN System Architecture [31]

PIEMAN will perform physical layer research aimed at a new generation of PON with use of DWDM technology up to 32 wavelength channels, each carrying a bandwidth per customer of 10 Gbit/s for the down- and upstream. Each wavelength channel is shared by up to 512 customers. This project will take a hybrid WDM/TDM approach, with a length of 100 km using EDFA amplifiers for down- and upstream parts. Network architecture of PIEMAN project is illustrated in Figure .

The upstream part of this project is beyond a scope of the PON ITU-T Recommendation. The fiber optical amplifiers especially for the 1.3 µm wavelength region are an expensive an immature technology. The upstream traffic is in burst mode, which requires additional measures in order to employ fiber amplifiers. Due to imperfect interburst suppression, in-band crosstalk arises and can therefore impose significant limitations on the split factor [32].

5.2 Raman Amplifiers

Iannone *et.al.* [33] demonstrated four conventional TDM PONs with symmetric 2.5 Gbit/s line rate. Using hybrid SOA-Raman amplifiers, an extended reach of 60 km with a common infrastructure serving 128 customers, was shown.. The experimental setup is illustrated in Figure .

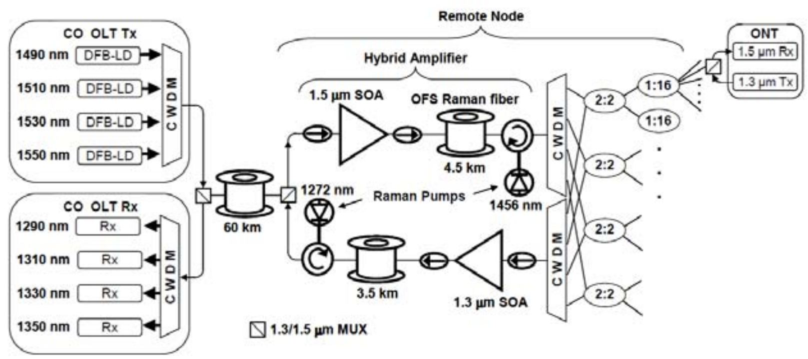

Figure 8: Experimental Setup Of Extended PON Using A Hybrid SOA-Raman Amplifier [33].

A hybrid SOA-Raman amplifier provides a large gain bandwidth of 150 nm but is a very expensive technology. The Raman amplifier is inefficient (requires strong pump laser), and shows low input dynamic range (IPDR) for the upstream.

K. L. Lee *et.al.* [34] proposed and demonstrated extended-reach GPON for rural areas using distributed Raman amplifiers. Symmetric 2.5-Gb/s bidirectional transmission was achieved for 32 subscribers over 60-km reach, without using any active extender. Proof of concept experiment illustrated in Figure .

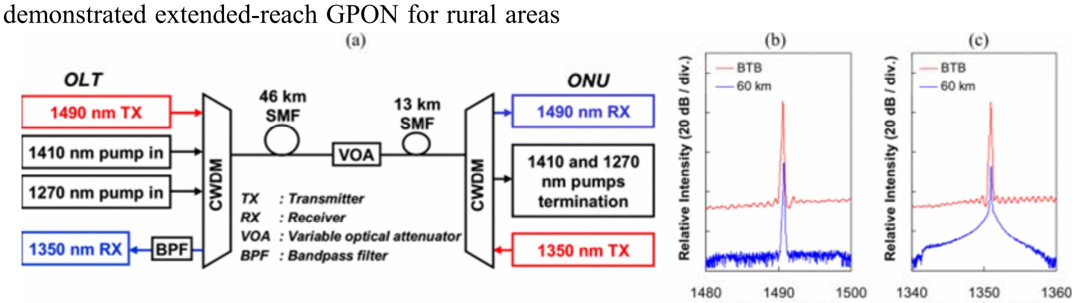

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Figure 9: (A) Proof Of Concept Experimental Setup, (B) Optical Spectra Of DS Traffic, And (C) Optical Spectra Of US Traffic [34]

5.3 SEMICONDUCTOR OPTICAL AMPLIFIER

Nesset *et.al.* [35] developed SOA at 1.3 µm wavelength region for GPON reach extension. The SOA shows high gain (30 dB) and moderate NF (7 dB). They have experimentally demonstrated extended reach GPON with one wavelength channel for up- and downstream, with a 1:32 split ratio and for a length of 60 km. The developed SOA has slow gain effects which limit the IPDR.

R. Bonk *et.al.* [36] demonstrated for the first time the advantageous performance of QD-SOAs in an extended reach *WDM/TDM* GPON. Four downstream channels with a data rate of 2.5 *Gb/s* each are amplified in a 1.5 µm QDSOA providing gain at low power consumption. In the upstream direction, two channels at a data rate of 622 Mb/s each are amplified using a 1.3 µm QD-SOA. Demonstrated a large dynamic range exceeding 40 dB and a high burst mode capability, which is needed to handle user length and user power variations. Each channel serves a reach of 60 km and is branched out with a 1:32 splitter. A total loss budget in the order of 45 dB is supported.

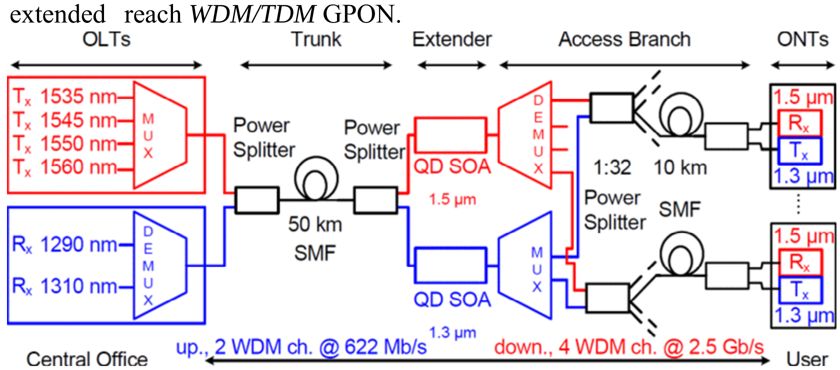

Figure 10: Extended WDM/TDM GPON Testbed With 4 Downstream And 2 Upstream Channels, Each Serving 32 Subscribers With 60 Km Reach Using QD-SOA Technology For Bi-Directional Amplification [36]

5.4 COMPARISON OF OPTICAL AMPLIFIERS

Optical amplifiers for further implementation in the extended reach PON was studied. These amplifiers have technological principle and physical property differences.

In

Table 2 listed typical specification of optical amplifiers for EDFA, bulk- and QD-SOA.

The EDFA amplifier has higher gain and lower noise figure than SOA amplifiers. The operating wavelength of EDFA is around 1.55 µm, with a 3 dB bandwidth of 20 to 70 nm. SOA can be built to operate at 1.3 µm or 1.5 µm wavelength region, with 3 dB wavelength bandwidth of 40 to 80 nm.

Table 2: Typical Specifications And Possible Advantages And Disadvantages Of The Optical Amplifiers

	EDFA	Bulk SOA	QD - SOA
Gain [dB]	~40	~ 25	~ 25
NF [dB]	~ 5	~ 7	~ 7
Wavelength [nm]	1530 – 1610	1310 / 1550 regions	1310 / 1550 regions
Bandwidth (3dB) [nm]	20-70	40-80	40-80
Gain dynamics	Very slow (~ ms)	Fast (~ ns)	Very fast (~1 ps) Fast (~ ns)

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Polarization	independent	independent (0.2 dB)	sensitive (10 dB)
Advantages	Low channel crosstalk No patterning at high bit-rate	Burst mode tolerance Cheap	Uncooled operation Large IPDR Burst mode tolerance
Disadvantages	No burst mode Cost Power consumption inefficient	Patterning Effect	Patterning Effect
Size	Rack module	Compact	Compact
Cost Factor	Medium	Competitive	Competitive

In an EDFA, a silica fiber is randomly doped with the trivalent erbium ions and has relatively long distances between each ions, is illustrated in Figure . Each doped erbium ion has a possibility of independent amplification. The gain relaxation time is slow, in the order of milliseconds. Therefore EDFA show low crosstalk and no patterning effects at high bit rates. The crosstalk and patterning effect appears only if the incoming signal has a bit rate less than a few kbit/s.

EDFA are not burst mode capable, the power consumption is high and they are much more expensive than semiconductor optical amplifiers.

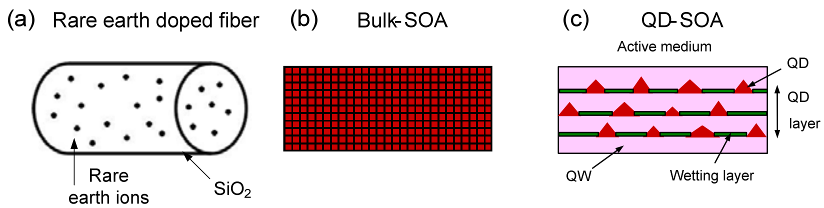

Figure 11: The Amplification Medium Of Different Optical Amplifiers: (A) Xdfa With Randomly Doped Rare Earth Ions In A Silica Based Optical Fiber. Relatively Long Distance Between Each Ions; (B) Bulk-SOA With A Combined Medium For The Amplification And Refilling; And (C) QD-SOA With Independent QD Islands In The Active Medium. WL Acts As A Carrier Reservoir For Dots Refilling

The bulk-SOA has a single medium for the amplification and refilling which is illustrated in Figure . The gain relaxation time is in the order of nanoseconds. However, gain saturation leads to patterning effects at high bitrates (>10 Gbit/s). The fact that just one medium for amplification and refilling is present leads to a coupling between the states. In a multi-wavelength operation the different wavelength channels cause strong cross-talk if the saturation input power of the SOA is reached. However, due to the fast refilling processes in a SOA compared to EDFA, the devices generally are burst mode tolerant. Today, the technological manufacturing of semiconductor devices is possible in mass-production which makes SOA cheap.

Theoretically QD-SOA amplification principles are close to EDFA amplifiers, with independent amplification of QD islands and refilling the dots from independent wetting layer reservoirs. Recently studies shows that QD-SOAs are most promising amplifiers. They have better performances in term of very fast (~1 ps) and fast (~ ns) gain dynamics; less channel crosstalk compare to bulk-SOA and that this devices operates at higher bit rates. QD-SOA have the ability to operate semi-cooled, offer a large IPDR, are cheap and show high burst mode tolerance.

6. CONCLUSION

In introduction chapter was provided studies for fiber optical broadband access FTTx technology PON and importance of deployment PON in rural areas for broadband services, which is currently first-mile bottleneck problem. The comparison of internet speed of the two main cities of Kazakhstan and nearby rural areas was provided. Additionally, ranking mobile and fixed broadband speeds of top 10 countries and ranking of Kazakhstan was illustrated.

In the main chapter PON standard and its ITU-T Recommendations are described and summary of PON standards with characteristics is listed. Advantages of the reach extended WDM/TDM PON to increase broadband access of subscribers in rural settlements was provided. Optical amplifier technologies proposed to extend physical limitation of PON from 20km to 60 km. and successful researches was provided with analysis of optical amplifiers, like EDFA, Raman, SOA amplifier, and quantum-dot semiconductor optical amplifier for reach extension and the corresponding requirements of PON. And finally was summarized comparison of Optical Amplifiers.

In conclusion QD-SOA is suitable reach extended WDM/TDM PON to increase broadband access of subscribers in rural settlements up to 60 km, due to better performances and technological manufacturing of semiconductor devices is possible in mass-production which makes SOA cheap.

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