

Nov 1st, 3:45 PM - 4:00 PM

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Recommended Citation

Sulejmani, Sulejman D., "Architectures Technologies and Energy Efficiency of Optical Networks" (2013). *UBT International Conference*. 56.

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Architectures Technologies and Energy Efficiency of Optical Networks

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Abstract. The Increasing of today's Internet services as are online video gaming, video games, video conferencing and video on demand in terms of multicasting has changed the concept of the classical approach to the networks because these services requires broadband frequency for data communication. The rapid expansion of the customer network, require wide bandwidth and increasing of energy expenditures. To gain energy efficiency we propose a novel architecture. The solution of these problems is solved by using of passive optical networks which are able to transmit data simultaneously in a broadband communication by using of optical multiplexers. The important parameters on the designing of an optical telecommunication network are energy consumption and energy efficiency of the network.

Keywords: Architectures, technologies, energy consumption, energy efficiency.

1 Introduction

Continuing demand for increasing of services on the Internet connection makes necessary the use of such networks which use bandwidth, high transmission speed and high capacity data access on the Internet network. Wired networks of copper conductors can't fulfill these requirements because of their rapid growth, that's why the last few years it is evident the use of optical cable communication on metropolitan networks and on Wide Area Networks in all communication space and levels. This implies designing of computer network architectures and advanced technologies which are possible to carry traffic with more speed and provide services which require broadband communication.

Constantly are in use two types of optical networking technologies passive and active technologies. On the optical network technology every user has access to the network and possibility to exploit it in the entire transmission frequency band without limitation through optical multiplexer.

To reduce the impact of electronic-optical converter equipment and optical-electronic convertors on the hybrid networks we are using Optical Add-Drop Multiplexer which provides construction of transparent network and an entirely optical signal from the source of the information to its user.

2 Architectures of Optical Networks

By using of optical fibers we may design an optical network with high data transmission speed. This network also is very safe in data transfer and is transparent in relation of the signal transmitted. This network provides unlimited frequency bandwidth for transmitting or receiving data bits for each subscriber. Optical network can be passive or active either depending of the type of consisting elements. If optical network is consisting of passive elements as optical fibers, splitters, couplers and connectors, than this is passive optical network. In order to avoid a conflict of information here a transmission medium is divided into certain frequency bands between the users. By sharing of network resources according to space, time, frequency or code domain may be realized multiple data access. Some of techniques for multiple data access approach in optical networks are [11]:

1. Wavelength Division Multiple Access (WDMA).
2. Subcarrier Multiple Access (SCMA).

3. Time Division Multiple Access (TDMA).
4. Code Division Multiple Access (CDMA).

With massive increase of data volume and challenge of new applications the existing standard network with copper wire can't stand with the fast pace of this change. Because of these requirements it is imposed the new designed network made by the optical fibers. Steadily is working such optical networks to be expanded in size and capacity but at the same time the energy efficiency and the price of upgrading of such networks to be minimal. Multifaceted optical network requires applying of system of open and innovative standard from which we will have social and industrial benefits.

Optical networks of the next generation are expected to be designed with the opportunity to be integrated into one unit the transfer of packets and actual optical data transmission. These technologies of the service providers provide fast services with lower price of maintenance of the network.

The problem is about the control of the network communication in optical networks. The question is does this control should be integrated with the level up to the IP or the IP is implemented independently on the optical network? From this point of view we have the following architectures of optical networks:

1. Network architecture where optical network has full control over its resources. However this control is realized independently from the network development strategy.
2. Network architecture in which the control is fully integrated on the optical networks through IP routers and optical switching nodes (OXC) [4].

Automatically Switched Optical Network (ASON) is a type of network which is fully controlled by an independent control in which the network communication with clients is conducted through network user interface. This network interface carries in itself all signaling information for the network control. Connections with clients in ASON networks are running over through optical channels which channels are offering the following type of service:

- permanent connection via optical channel
- soft permanent connection through the optical channel
- automatic switching connection via optical channel

In the second network architecture, optical network and control network are built into one new common integrated network where one protocol is activated for setting the connection through all elements of the network. This architecture is scalable without duplication of functions and without conflicts in network control. As long as are using the IP routers, this kind of network is a cost-effective and evocative for use. An interesting question which requires a response is:

Which telecommunication network architectures are cheaper for using, maintenance and expansion of its amount of capacity whether it is optical or electronic network architecture?

A very important fact is also made whether this technology of the network architecture during the time is still capable to perform its functions smoothly and which is the price of it? It is obvious that over the time the price of the electronic technology falls faster than on the optical technologies for the construction of a network or architecture.

From these point of view we may conclude that the advantage of optical network is not in its price but in its huge capacity and the possibility to increase more with little equipment or replacement of components with other systemic network components. The goal is to increase the capacity of the frequency band.

The trend of the replacement of the electronic nodes, switches and gates should be expand in all spatial levels of the network, both in term of access network and global network.

If in the optical network we are installing active elements as for example optical active amplifiers than we have an active optical network. These optically active amplifiers replace the electronic access nodes of the network. Other part of the access network remains as unchanged passive optical networks.

Such amended architecture of the network access is represented in the Fig. 1. This architecture can work at up to 10 Giga bits per second with thousand of user sites in each amplifier of the passive optical networks [1,10].

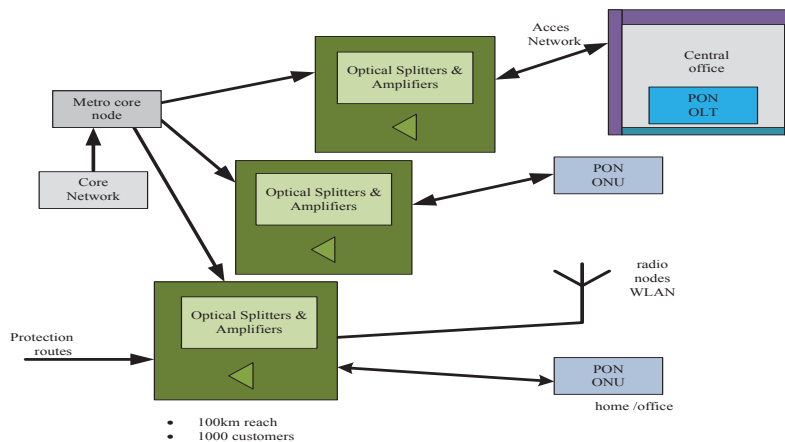


Fig.1. Optical network architecture

3 Technologies of passive optical networks

If we can say for Electronics and Computer engineering that they are on the top of their development and achievement of their technologies. The same conclusion we can't say for the Optical science and its application to build the most modern optical network communications which may resist to the present time. This means it is necessary to build one new common technology which in the best way can absorb all the challenges that comes from the electronics, optical science and software engineering and incorporate them on building a modern optical network technology.

Passive optical network represents a cheap and optimal network which is present everywhere with the Ethernet technology. The challenge of the technology is how to use optical fibers for building telecommunication networks and computer networks in all areas and levels of the network starting from end user, LAN network, WAN network and national networks and wider.

By using of optical fibers and other passive optical network components we expect to improve the network performances as are the speed of the data transfer, the data volume, increasing the number of users and data transfer for each user with the low price of labor technologies. But today's and mostly for the next time we have more need to increase the bandwidth of data transmission which request new WDM technology and applying it in two-way communication both in reception and in data transmission. Initiative for using passive optical network with WDM although dated from eighties it is not yet in its full swing due to lack of possible sufficient wide bandwidth. Also insufficiently modern technology in order for such design, lack of appropriate protocols and necessary software support for these networks architecture are some of the problems left to this network technology. Passive optical network geographically may be expand to 20 km and in a few cases with special additional equipment and up to 100 km with the transmission speed of up to 100 Giga bit per second for each wavelength of the optical fiber .

In the local communication may be use and wireless optical network technology for the transmission of data from the central office to the end users of the network. With the WAN network architecture are in a consideration also and the use of optical multiplexers which multiplies optical data bits in order to transmit data to many users simultaneously. In the national networks and other networks of the wide scope are using and so-called Dynamic Optical Circuit Switching (DOCS), which enable efficient and the dynamic dense flow of data and packages through these networks.

WDM technology can transfer a large volume of data on the range of some 10^{12} bit per second. Each dysfunction of any network component as are for example links of the optical fibers, amplifiers, transceivers and optical connectors can cause data transmission loss. On the interest of the further analysis is: how much should be the scope of the error in case this network to survive and when this

network is functioning partially? When the network is out of work for large robust errors during transmission?

These questions are looking for solution because various people have different approach to network and use entirely different volume of information and data, as well as various levels and parts of the network. Commercial data transmission among optical network is using most comprehensive wavelength from 1530 nm to 1565 nm by using DWDM which is characterized with a significantly small data transmission loss [9]. In general, the use of optical cables in the world in the next decade is expected to be increased to 25% [2].

About 70% of the total real communication is used for data transmission from one node to another node. This is a reason of using multiplexers instead of switching circuits or routers. Multiplexers are in the situation to send further a part of necessary data which is required and the other part of the data to discard as unnecessary. Such a multiplexer is known as Optical Add-Drop Multiplexer (OADM) [4][9]. With such a selective approach of the data and with the help of the optical add-drop multiplexer it is possible to release desirable channel with a certain wavelength in a given node of the network where we want to set a communication. The other channels that are not in use are returned back at the network for next use.

This provides a low price data communication but does not allow the reconfiguration of the architecture of the network. If we want to reconfigure the network we set a switcher in optical add-drop multiplexer. These multiplexer will not let unused bandwidth to fail but under certain condition or questionnaire will bring it back into network and so it will be active. This way of networking with reconfigurable multiplexers is used in Wide Area Networks.

The advantage of optical network technology in data transmission is that is offering services with higher quality. The facilities are on using the less number of network devices under condition that we have data transfer in wider band without using of boxes and the port counter. Network operators require optical networks to be in a position to link and manage with the prerequisites of the optical - electronic architectures without any problems.

The opportunity of optical communications through the switcher is cheaper and will replace transponders which are out number. Transponders are placed in each end of each channel with a certain wavelength in the electronic or combined electronic and optical networks. Technology of passive optical network has its advantages and disadvantages. Advantages of using passive optical network technology against the other network technologies are:

- Unused resources and resources which are in the frequency band are distributed to the users in the dynamic manner depending on their requirements and not equally to all users.
- This technology has the possibility to transfer various types of data for different purposes simultaneous.
- The network structure is formed in such kind that the price should be minimal either in the installation and maintenance of optical cables.
- Optical network technology supports any kind of service to all its customers either in a symmetric or asymmetric compatible manner.

As the shortcomings of the passive optical network are:

- Network protocols of this optical network are more complex than in other networks in order to avoid collision during the data transmission.
- Network components should have a higher working technologic performances but this is going to increase the price of this network.

By using of optical networks until year 2015 is intended to improve the Energy Efficiency up to 1.000 times from the current situation. One of optical networking architecture that enables the use of broadband transmission with low price and high efficiency for all customers is Gigabit Passive Optical Network (GPON). By using of GPON network we can use advanced applications such as high definition television, cloud computing, video conferences, online video gaming [5]. This network has different

bandwidth of upstream transmission of 1.244 Giga bits per second and downstream transmission bandwidth of 2.488 Giga bits per second. This makes this network to be asymmetrical [10].

Because of the above mentioned characteristics this network can be used in all geographic and spatial reliefs for different distances. We can say that the use of this network in the oncoming years will be dominant.

This network is built from an Optical Line Terminal (OLT) located in the central side and the Optical Network Units (ONUs) located on the users side which are working in multipoint principle. GPON is easy to install and it is low price and high level of integration. This network has a small module cards for ONUs, easy maintenance and reduces power consumption [11].

GPON component devices consist of an optical module of the transceiver, a GPON chip, optical amplifier, interfaces and optical controlling circuits. Participation of the energy consumption of the access networks like PON, GPON on the entire energy consumption of the network is approximately 80 percent [1].

This means that ONUs with a minimum value in energy cost maximally reduce energy cost on the entire network. Therefore the Power Management unit (PMU) is flexible and combined in hardware and software manner enabling maximum energy savings throughout the network system. This causes the activation of only those network elements which currently serve to carry out certain applications, while modules respectively the other network elements which are not in use are not active.

In this way PMU enables maximum energy savings. It is a downstream communication when data are transferred from one OLT to the ONUs units while we have upstream communication when the data is transferred in the opposite direction namely from ONUs units to the OLT unit of the GPON. On the GPON there is an error in transmission as a result of the submission of the so-called rogue ONUs which may be a software or hardware errors. This implies interference in transmission and greater optical power transmission signal from the ONUs. In these case ONU behave abnormally into the network. In this case the OLT makes isolation of each rogue ONU from network activity which behaves in abnormal manner and appears as an error in the optical network [3].

4 Optical Access Network Topology

We are using three types of optical access network topologies [11]:

- Point to point topology
- The active star topology
- The passive star topology

Point to point topology extends at the local level between two points in the network of one house or building with a high price on the initial installation. The topology of the active star is needed to realize the full optical communication between an active node and the end user. In the passive star topology which is known as passive optical network an active node is replaced with a passive splitter of power. This passive network topology does not have the active nodes and it is not necessary of power supply and maintenance of those power supplies of every node. This is an argument more why these networks are cheaper comparing with the networks with active star topology.

5 Energy Efficiency

A very important parameter in designing of optical networks architecture is energy efficiency. It affect on the economic sustainability of the network as well as in environmental parameters on the same network which obviously should be taken into account. Energy efficiency of a network is calculated as the energy consumption of all the elements connected in a network or which are in the structure of the network. For example as are transponders, optical amplifiers, optical cross connectors. Logically in general the energy consumption is lower for those networks where are active only those elements of the network which are necessary for data communication.

If the overall equipment of the network is active even when some of its elements are not necessary for optical network data communication than the energy consumption is higher and the network architecture does not have energy efficiency. The network communication every year is increasing in large scale and these leads in increasing of the energy consumption which is purpose for each network to work properly.

Electronic network communications are requesting more energy for simple reason because they are containing more network elements. Optical networks significantly are reducing energy consumption due to reduction of integral elements and devices of the network. According to the international scientific analysis is presumed that for one operation with floating point is needed 0.1 PJ/b power consumption. For every spent bit during one year in electronic network telecommunication we need one dollar in world frame [4].

Bit interleaving protocols are providing communication in passive optical networks. The use of interleaving protocols also reduces power consumption for 10 times by reducing the value from 2W to value of 200mW compared with the usual conventional protocols.

Reduction of energy consumption in an optical network unit (ONU) is implemented through clock speed, data processing, voltage values and memory chip. Parallel processing and clock high speed increases energy consumption on the optical network unit. To reach the lower value of energy consumption we need to have lower clock speed and to avoid parallel processing.

Interleaving protocol consists of header and payload bit frame. Header consists of codes for synchronization and unique identifier that identifies each ONU in passive optical network and enables ONU to read only information of the header. Header bits also contain the fields for operations, management and maintenance of the PON, and also contain information about the payload in the frame. Bit interleaving protocol uses on itself dynamic bandwidth which is very important because it allows different users of passive optical networks to exploit the different requirements of broadcasting band with various capacity of bit transmission. By reducing of energy consumption in all optical network units we can enable the reduction of energy in entire optical network.

The role of energy efficiency in the utilization of the optical network communications is evident. In today's optical communication the energy consumption is about $25 \times 10^{-3} W$ for every 10^9 b/s. For each 10^{12} b/s transmission are spending about 1000\$. In the next decade is presumed to be spent only $1 \times 10^{-3} W$ energy consumption for every 10^9 b/s. For each 10^{12} b/s transmission we have to pay 25\$. Energy efficiency on the metropolitan optical network is calculated with the following equation (1) [6].

$$E_{ef} = \eta_{pr} \eta_{ec} \left(\frac{P_{node}}{Capacity} + \frac{P_{links}}{Capacity} \right) \left[\frac{W}{Gbps} \right] \quad (1)$$

- η_{pr} , represent a factor of energy consumption for cooling and supplying of the operator.
- η_{ec} , represents a factor of providing and protection of connections which are using in the network.

The member $\eta_{ec} \left(\frac{P_{node}}{Capacity} \right)$ represents energy contribution of the network nodes as are optic cross connectors and transponders. Member $\frac{P_{links}}{Capacity}$ represents energy contribution of the network connections as are optical link amplifiers.

For lines less than $100 \times 10^3 m$ of length is not necessary to reinforce the signal by amplifier. Hence the energy efficiency is calculated with the following equation (2) [6].

$$E_{ef} = \eta_{pr} \eta_{ec} \frac{P_{node}}{Capacity} \quad (2)$$

One optical network to work properly has to satisfy the following condition: The sensitivity of the receiver has to be higher than the power of the optical signal which is received through the receiver of the optical communication link. This is expressed with the following equation (3).

$$P_{otl} - P_{lsw} - P_{lwg} \geq S_r \quad (3)$$

- P_{otl} , output power of the optical transmitter on the link
- P_{lsw} , optical power loss due to the switching elements
- P_{lwg} , optical power loss due to the waveguides
- S_r , sensitivity of the receiver

In optical network communication system with high performance the energy consumption should be less because of reducing the cost of construction and package of the network chip and because of problems with cooling and integration.

The power of the optical signal which is generated in the optical source is calculated by the following equation (4).

$$P_{source} = P_{dest} + P_{link} \quad (4)$$

- P_{source} , is a source power of the optical signal in the optical transmission
- P_{dest} , is a minimal destination optical power in the optical transmission
- P_{link} , is a power loss along optical communication link from the source to the destination

If the network has hybrid structure, it means if in the network are involved electronic components or electronic / optical interfaces, or contrary optical / electronic interfaces than should be calculated and power of these interfaces. This means that the energy consumption for electronic / optical and optical / electronic conversions in optical communication represents a cumulative energy consumption of all constituent elements of these conversions.

Power loss in the optical communication in a similar manner is calculated as the sum of the losses due to communication lines and power loss of the elements in the lines. Energy consumption in all communication lines may not be the same, and thus the power loss in those lines is different. This is as a result because the same lines are not symmetrically loaded in one optical communication. Because of this attitude is used one device for adaptive control of power, which plays a major role in the reduction of energy consumption.

6 Reasons of the Spectral Loss

The optical cable loss is mostly dependent on its internal essential energy loss of the optical fibers. Installed optical cables also have its additional loss because of several reasons as for example temperature, the collision on optical fibers, humidity and other atmospheric conditions. Internal attenuation of the optical fibers is caused by spectral loss in the lighting of the light rays in the end with lower wavelength. Attenuation is also caused by the loss during the absorption of the hydroxyl ions and loss in infrared absorption in a higher wavelength. The appearance of hydroxyl ions comes from technological process of the optical fibers manufacturing which its maximum value achieves at the value of 1385 nanometers [9].

Optical fiber banding also causes the loss in the optical cable which loss is increasing by increasing of wavelength. Optical cables with metal protection are causing signal loss to the cable due to the corrosion of the metal protection. Hydrogen molecules will diffuse in internal of the optical cables and optical fibers are also a reason for energy loss. As the result of it the attenuation of the signal is increasing. To prevent these between metal protection and optical fibers we put a hydrogen hermetic obstacle. Hence the overall loss of an optical communication connection may be calculated by adding the loss due to the splicing of the optical fibers and attenuation.

Splice on the optical fiber can be a maximum of about 6 kilometers distance, and it depends on the type of the cable and method of its installation. The spectral loss of the optical cable which is composed from optical fibers is calculated with equation (5)[12].

$$\alpha = \alpha_{rls} + \alpha_{ha} + \alpha_{ira} + \alpha_{ma} + \alpha_{uva} + \alpha_{ec} \quad (5)$$

The members of the last equation are defined as follows:

- α_{rls} , ray light scattering loss
- α_{ha} , hydrogen absorption loss
- α_{ira} , infrared absorption loss
- α_{ma} , metal armoring loss
- α_{uva} , ultraviolet absorption loss
- α_{ec} , environment conditions loss

The ray light scattering loss is defined with the equation (6).

$$\alpha_{rls} = \frac{const}{\lambda^4} \quad (6)$$

The infrared absorption loss is defined with the equation (7)[12].

$$\alpha_{ira} = const \times e^{-\frac{const}{\lambda}} \quad (7)$$

The term α_{uva} represents a formula member which has very little value of the germanium doping and it is not taken in consideration. To avoid a loss on the metal protection this type of cable is less used that is why this kind of loss is not calculated. Loss due to the external conditions on the environment are increasing proportionally with the increase of wavelength and is very hard to separate from other losses in optical fibers of the optical cables.

7 Conclusion

Passive optical network architecture ensures progress in comparison with all other networks because it does not require voltage supply. Thus we reduce organization and maintenance of the network and also reduce the price of the operational services in the network. Low price of the network, broadband transmission and energy efficiency are some of the characteristics of those optical network architectures and technologies. As an opportunity for future study analysis may be the incorporation of WDM in wired and wireless passive optical networks with broadband transmission.

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