Migration towards All-Optical Networks: A Case Study of Optical Access Networks in Libya

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الملخص

تشهد السنوات القليلة الأخيرة تزايدًا سريعًا ومستمرًا لاستخدام شبكة المعلومات ونقلًا لكم عظيم ومتصاعدٍ من البيانات، هذا بدوره سيجبر العالم إلى ضرورة التحول إلى تقنية اتصالات جديدة لديها القدرة على نقل كميات هائلة من البيانات بشكل فعال وبكل يسر. لذلك، تم تقديم جيل جديد من شبكة الألياف الضوئية، يُعرف باسم الألياف الضوئية بالكامل، كبنية تحتية جديدة لشبكات الاتصالات الأساسية وذلك لتلبية متطلبات النطاق الترددي المتزايدة والتي ستكون تحديًا كبيرًا خلال السنوات القادمة. هذه التقنية تبشر باتصال بصري شامل بين أطراف الشبكات، مع عدم حدوث اختناقات بسبب التحويلات الكهروضوئية.

تستعرض هذه الورقة أحدث ما توصلت إليه تكنولوجيا الشبكات الضوئية، من خلال وصف موجز للميزات المحتملة والفوائد المكتسبة مقارنة بوسائط الإرسال الأخرى المتواجدة. يدور النهج العام لهذا العمل حول استعراض خدمات توصيل الألياف على وجه التحديد في الألياف الضوئية بالكامل. وكذلك سيتم تسليط الضوء على المكونات الرئيسية الضرورية عند التحول إلى استخدام شبكة الألياف الضوئية بالكامل، بما في ذلك الوصلات المتقاطعة الضوئية الفريدة. أيضًا، سيتم مراجعة الأشكال الأكثر شيوعًا لشبكات إرسال متعدد بتقسيم طول الموجة كأسلوب تعدد إرسال يستخدم للاستفادة من عرض النطاق الترددي المتاح. في هذه الورقة يتم تخصيص اهتمام استثنائي للمفهوم العام لشبكات الألياف الضوئية الحالية والجيل القادم في ليبيا من حيث كفاءة استهلاك الطاقة الكهربائية. حيث سيتم توفير هائل في الطاقة الكهربية من خلال التحول لاستعمال الشبكة الضوئية بالكامل، والذي سيكون له تأثير ايجابي على نطاق واسع على مستوى الوطن، لا سيما خلال أزمة انقطاع الكهرباء التي تواجه الشبكة العامة للكهرباء والتي تعاني منها الدولة منذ سنوات عديدة.

Abstract

As the use of data keeps on increasing rapidly, the world soon will be forced to shift to a new technology that has the ability to carry massive amounts of data effectively without any burden. A new generation of optical fiber, known as all-optical fiber, was introduced as the new backbone telecom infrastructure to meet growing bandwidth demands which will be a big challenge in the upcoming years. This technology promises an end-to-end optical connection between the end points, with no bottlenecks occurring due to electro-optic conversions.

This paper studies the state of the art for all-optical network technology, by briefly describing the potential features and the benefits gained over other existed transmission mediums. The general approach of this work is all about specifically overviewing the fiber connection services in all-optical networks. It highlights the key components used in transition to fully optical network, including the unique all-optical cross-connects. Also, the most common forms of wave division multiplexing networks are reviewed as a multiplexing technique used to utilize the available bandwidth. However, a particular attention is devoted to the general conception of current and next-generation optical fiber networks in Libya in terms of energy efficiency. A huge power savings would be achieved via upgrading to all-optical network, which would influence positively on a countrywide level, mainly during the electricity outage crisis facing the national power system network along many years.

Keywords: All-Optical Networks; WDM; Optical Fiber Network Components; Energy Efficient

1. Introduction

With the widespread use and the increasing demand for broadband services, the need for high-bandwidth-transmission medium with high speed signals has forced researchers to seek a better technology via the transition to the use of optical fiber at the physical layer. According to ITU estimates, approximately 63 per cent of the world's population (about 4.9 billion people) used the Internet in 2021. The number of Fiber to the x (FTTx) users worldwide has also seen tremendous growth as it grew around tenfold over the past decade according to recent reports by Omdia [1]. This growth is expected to push the total number of optical fiber network users to more than 850 million users by the end of 2022 as shown in Figure 1.

In consequence, bandwidth is increasingly becoming a precious resource. Since the currently available traditional network capacity is no longer sufficient, especially with the rapid growth of bandwidth-intensive applications, such as video conferencing, video on demand, voice over IP, social networking, etc., researches are racing to come up with better solutions and enhancements.

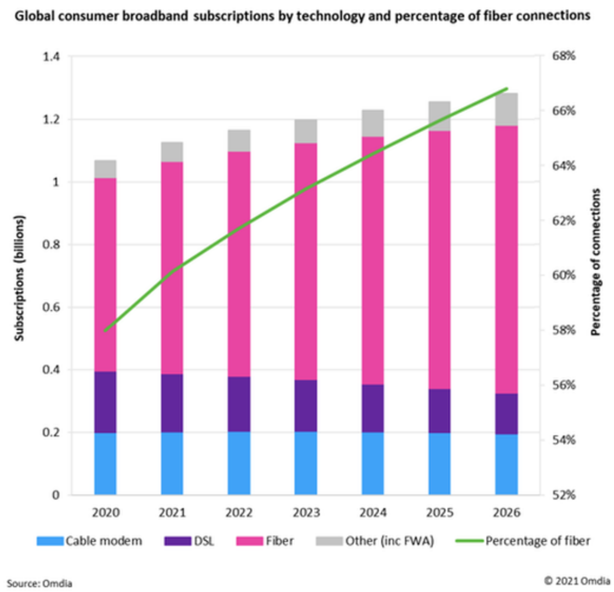

Figure 1. Global Gigabit Broadband Users

As is known, nothing in the universe travels faster than light. The optic fiber technology exploited light to convey data signals over distance making it capable to eliminate bandwidth constraints faced by other last-mile technologies that are doomed to fail to satisfy neither the bandwidth greed of future bandwidth-intensive applications nor ease fast network scalability necessary. The superiority and potential of optic fiber technology is easily comprehended if we simply compare the overall bandwidth of radio in the globe, which is merely 25GHz, to the staggering 25,000 GHz capacity of a single fiber hair. Infrared signals can be transmitted over silica fiber for many miles with extremely low loss [2]. Optical fiber has, also, been the only reliable transmission medium for modern backbone network infrastructures.

"Photonics will be in the 21st century what electronics was in the 20th century" said John S. Mayo, the previous president of AT&T Bell Labs. Hence, it comes with no surprise that optical fibers have predominantly replaced copper wire communications in backbone networks.

1.1 Generations of Optical Networks

Two main generations of optical fiber communication along with their features are discussed in this section. First-generation optical network is the earliest of those forms [3] and is still used today. This type of networks employs sets of optical fibers interconnected with electronic switches which necessitate converting the transmitted optic signal, processed or routed, into an electrical form and then converting it back into an optic form, Optic-Electric-Optic (OEO). Two examples of first-generation optical networks are SONET (Synchronous Optical Network) which forms the core of the telecommunications infrastructure in North America and the similar SDH (Synchronous Digital Hierarchy) Network which is used in both Europe and Asia [4].

In this earlier generation, having to handle data influx in the electrical domain, and bearing with the slower electronic data processing, causes serious bottlenecks in the overall transmission capacity. The result is much lower data rate than the optical transmission rate along with a large optical-electronic bandwidth mismatch which hinders the potential performance and benefits of optical communication [5].

The above limitations gave rise to the second generation of optical networks, also known as All-optical Networks or AON. In all-optical networks, most of the basic networking functions, such as routing, switching, and multiplexing are performed in the optical domain. Hence, optical signals can be transported thousands of kilometers without conversion to the electrical domain at every network element interface. The signal is only converted from electrical to optic and from optic to electrical when entering and leaving the network with total absence of regenerating devices that act in the electrical domain. This allows for the utilization of the vast bandwidth available in fiber without electronic devices subject to the electronic bottlenecks. This also allows for reduction in the overall electrical power needed for operating and cooling [6].

In this network, client signal is transported in the photonic domain between end points' pieces of equipment and all processing and control of optical switches harness, in part or in whole, the use of optical technology. In some cases, electrical signals are limited to the control associated with optical switches and other transport components.

Optic Signals on the AONs can have different data rates and formats, as they are never terminated inside the core network. A notable term in AON we must refer to here is transparency. Transparency is a property that allows the light to flow through the fiber waveguide entirely in the optical domain without any processing or interpreting by switches or routers [7]. Transparent networks are attractive due to this measurement which also provides additional benefits, such as reduced delay through the elimination of bottleneck caused by optical-electrical conversion, reduced cost due to a need for fewer system components, and great flexibility. On the other hand, transparency might bring about physical-layer impairments (PLIs) (both Linear and non-linear impairments) and security attacks experienced along the transmission path. These impairments impose penalties to the transported optical signal in the form of deterioration of signal quality accumulated as it travels a light path. Hence, signal regeneration functionality at intermediate nodes such as re-amplify, re-shape and re-time is significantly beneficial to improve the optical signal quality. In such network, we can distinguish a lightpath representing a temporary end-to-end optical connection between the end nodes, which behaves like a high-speed transparent pipe between them [5].

In all-optical networks, the capacity is enormous, reaching 10s to 100s Gigabit/s. This availability of high capacity promises to address the future needs and have the potential to bring AON technology from research test bed to the market and practical realization. The considerable progress in device implementation technologies makes it possible to design AON.

Thanks to the emergence and the advancement of all-optical device technologies that have the capability of processing the optical signals and relieving the system from congestion, such as tunable lasers (transmitters), tunable filters (receivers), wide-band amplifiers, optical couplers, and all-optical cross-connects.

However, to utilize the vast bandwidth of optical fiber and avoid electronic bottlenecks, multiplexing among multiple user transmissions is the key solution to apply the concurrency. In AON, concurrency can be introduced through time slots (OTDM-optical time division multiplexing), wave shape (CDM-code division multiplexing) or wavelength (WDM-wavelength division multiplexing). This paper will present WDM optical network which can be classified into two classes: broadcast and select, and wavelength-routed networks.

One more great benefit of all-optical connectivity network is the very low energy consumption compared to other networks achieved by saving millions kWh of electricity and thousands of tons of carbon emissions, paving the road to green all-optical network [8].

2. The Basic Components of All-Optical Network Technology

With the purpose to enable the realization of all-optical network architecture, optic components should be used to support such networks. These key components are responsible for end-to-end transmission of optical signals, ensuring the signal remains optical throughout. Some of these components are certainly based on electronics to operate, but the transmitted data signal itself is not converted to an electrical signal as in the traditional SONET/SDH based systems. Optic equipment include Amplifiers, multiplexers, dense wavelength division multiplexers (DWDM), optical add-drop multiplexers (ADM), and optical cross-connects, tunable Lasers, fast tuning receivers frequency converters, splitters, and combiners [5].

2.1 All-Optical Amplifiers

Optical signal power is vulnerable to degradation due to attenuation and some other signal losses. Optical signals need to be at a minimum optical input power to operate properly so the signal can be correctly decoded at the receiver's far end. An optical signal travels as long as possible before its power falls below a predetermined threshold. Optical amplifiers are used to boost the optical power by amplifying the total WDM signal directly without converting it to an electrical signal (versus using electrical amplifiers that mandated converting optical signal to electrical, amplifying it, and then converting it back to an optical signal, which has proven to be a very complicated and expensive process). Those amplifiers are serially located along the signal path and their implementation allows creation of long optical lightpaths [5].

Optical amplifiers are critical and necessary components of all-optic networks, whether electrically powered or totally optical amplifiers. It is worth mentioning here that electrically-powered optical amplifiers use electricity to operate but do not intercept the optic signal and they do provide complete data transparency. The main concept used for operation in optical amplifiers is the concept of stimulated emission. Various optical amplifier types are widely used but only two popular types of optical amplifiers are presented in this paper: Semi-conductor optical amplifiers and rare-earth doped fiber amplifiers.

2.1.1 Semiconductor Optical Amplifier (SOA)

This type of optical amplifiers uses a semiconductor as a gain medium to amplify the power of the incident optical signal in order to compensate for the power loss incurred before reaching this point. Once photons enter the active region from outside, stimulated emission occurs. The incoming photons with a specific energy interact with semiconductor excited electrons forcing them to get back to the ground state which causes them to lose energy in the form of photons with the same wavelength as the incident optical signal, resulting in amplification to the incident optical signal as shown in Figure 2.

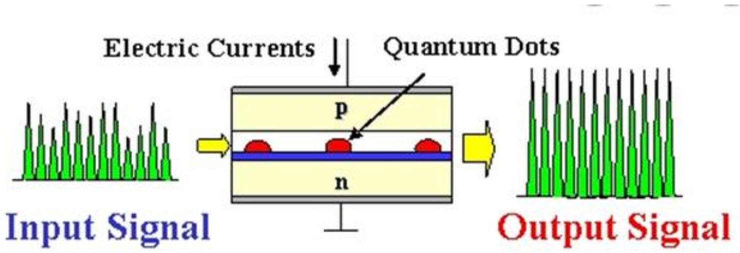

Figure 2. Principle of Operation of Semiconductor Optical Amplifier

The semiconductor optical amplifier is of small size and electrically pumped. Such amplifiers are operating at signal wavelengths between 0.85µm and 1.6µm, and generate gains of up to 30dB. These amplifiers are often used in telecommunication systems available in the form of fiber-pigtailed components [9].

2.1.2 Erbium Doped Fiber Amplifier (EDFA)

Erbium is a rare-earth element that, when excited, emits light with wavelength of around 1.54µm. EDFA, shown in figure 3, is the most deployed fiber amplifier used to achieve signal amplification over long-haul optical communication. In this type of amplifiers, optical fiber glass is doped with trivalent erbium ions ($Er3+$) and injected at fiber end with a laser known as pump light with a wavelength of/around 0.98µm or of/around 1.45µm. The pump light stimulates the erbium ions into certain metastable levels so when the optical signal light passes through theses exited atoms stimulation emission takes place and hence light is amplified [10].

Optical signal power can be boosted as needed in this type of amplifiers by adding certain dopants concentrations at different intervals of the fiber core. The EDFA amplification region varies from application to application; it usually operates with signals of wavelengths of 980nm and 1480nm with the capability to amplify optical signals in the 1.55µm band or 1.58µm band.

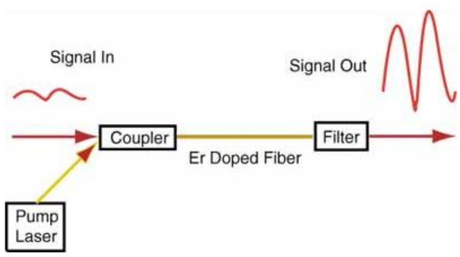

Figure 3. Erbium Doped Fiber Amplifier

2.2 Optical Multiplexers in AONs

Efficient utilization of bandwidth provided by a single wavelength is one of the most challenging issue in optical networks. Usually, such available bandwidth is much higher than a typical requested connection. If the whole optical channel is dedicated to a single connection, a considerable part of the capacity will be wasted and the number of source–destination data connections would be much more than the number of available wavelengths in a typical network.

Hence, multiplexing is used to combine multiple optical signals in a single fiber and in return parallel fibers can be replaced by wavelength channels on a single fiber. Multiplexing is used to fully use the inherent immense capacity of optical fibers [9]. There are many multiplexing techniques. The most popular and commonly used one in the optical domain is wavelength division multiplexing (WDM). Its popularity is due to its commercially availability over CDMA and OTDMA, and for its less complicated requirements of hardware and synchronization. It converges a set of optical carrier signals into one beam in a single optical fiber using different wavelengths of laser light as shown in Figure 4. The devices mounted on the receiving end must have the ability to separate out the combined components of the light beam so that they can be discretely detected.

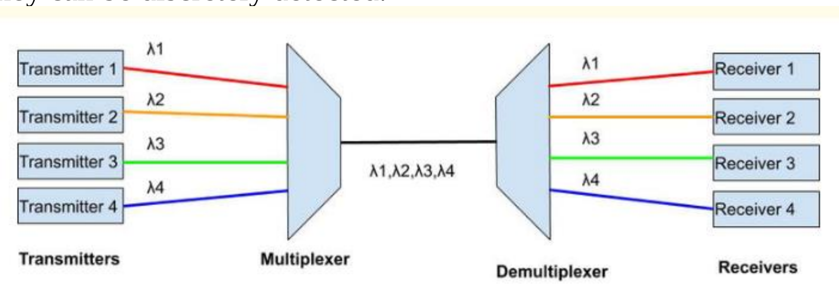

Figure 4. Lightpaths in WDM Networks

In long haul WDM links, amplification is essentially needed where all channels are amplified together by a single wideband optical amplifier, without the need of separate amplifiers for each channel. This is superior to 1G network, in which each channel requires a separate amplifier. Hence, WDM links offer high cost-effectiveness to the system in addition to better exploitation of the existing fibers. WDM networks have the ability of conveying a massive amount of data. Thus, even a single failure in an optic fiber link may obstruct a tremendous number of services and cause enormous data losses. Consequently, survivability of the network is a crucial concern for network operators.

Various techniques used for multiplexing and demultiplexing. A simple way of multiplexing or demultiplexing of light can be done using a prism as shown in Figure 5. Other techniques include waveguide grating diffraction, arrayed waveguide grating, and using multilayer interference filters [11].

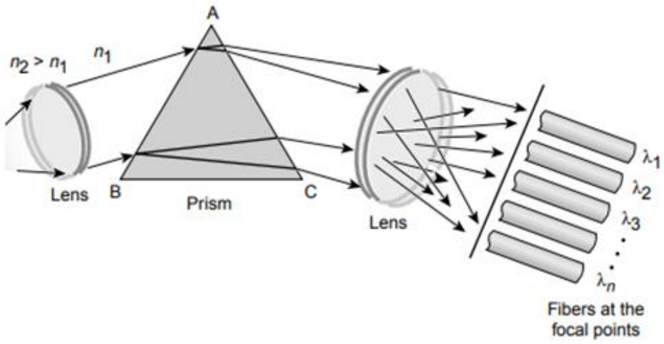

Figure 5. Prism refraction demultiplexing

2.2.1 Channel Separation

In WDM optical networks, the usable range of the spectrum of light (1300–1550 nm) is divided into multiple channels, each channel represents a wavelength (also referred to as a "color"). For a better resource utilization, the WDM channel spacing has to be reduced and closely packed to fit more wavelengths within a certain wavelength domain on a single fiber as seen in Figure 5. However, the minimum wavelength spacing is restricted and actually dependent on many significant factors such as inter-channel crosstalk, the channel data rate, the modulation format, filter quality, laser wavelength stability, transmission length and more [12].

In fact, the narrower the WDM channel spacing, the higher laser performance is required. Thence, tunable transmitters and receivers are essentially required in optical network system and their designs are significantly more sophisticated than a single wavelength link. For that, transmitters should have narrow line widths to avoid inter-channel interference besides having very high degree of thermal stability to prevent drifting. Further, narrow bandwidth filters (receivers) should be able to separate each channel individually.

Two main types of WDM technologies are used today. Channel spacing of 20nm is known as Coarse Wavelength Division Multiplexing (CWDM) and channel spacing of 0.4 or 0.8nm is known as Dense Wavelength Division Multiplexing (DWDM). The latter allows much higher number of signals than in CWDM to be combined in the same optical bandwidth.

2.3 Optical Switching

In all-optic network, the optical switching devices do not implement any OEO conversion as in the conventional current switching techniques used in optical networks. An arriving optical signal on input port with any wavelength can be switched to an output fiber of the same wavelength without conversion to the electrical domain. This implies that the optical signal is transparent to the switch and the switch cannot sense the traversed signal format and its data rate. Optical switching devices, however, still perform control functions associated with optical switching in electric domain while the data signals remain optical along the transmission path.

Optical switches can be broadly categorized into different types depending on the switching method. Optical cross-connects (OXC) switch is one of the commonly used relational switches and is the key element of the all-optical network as discussed below.

2.3.1 Optical Cross-Connects

An optical cross-connect switch (OXC) is an optical switch device that can exchange incident optical signals between different optical paths from input to the output [9]. This switch is wavelength independent because it is oblivious to the wavelengths of the transported signal. OXC comprises an optical cross-connect matrix, input and output interfaces, management control unit and other modules. The core of OXC is essentially based on the cross-connect matrix, which uses integrated interconnections to build an all-optical switching resource pool. The OXC system consists of all-optical backplane, optical tributary board and optical line board, achieving all-optical cross-connections and remarkably advances in switching efficiency of large-granularity services. The use of all-optical cross-connects allows space and power savings and more simple deployment for ROADM sites. The OXC occupy just 10% of the room taken by other counterpart technologies and consume only 40% of their energy.

2 x 2 cross-connect is one of the very basic optical cross connects as shown in Figure 6. It routes two input signals to two output signals and has two states: cross state and bar state. When the state is bar, both inputs continue onwards to the output; the signal from the upper input port is routed to the upper output port, and the signal from the lower input port is routed to the lower output port. When the state is cross, the signal from the upper input port is routed to the lower output port, and the signal from the lower input port is routed to the upper output port [13].

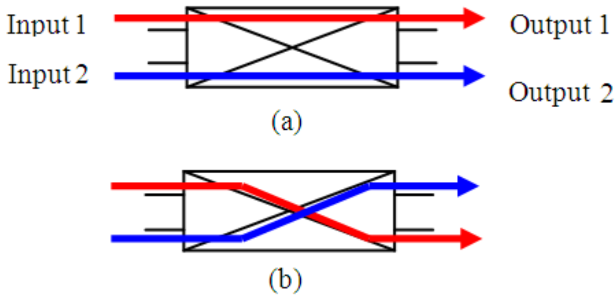

Figure 6. 2 x 2 optical cross-connect (a) bar and (b) cross state

3. Architectural Designs of WDM Networks

Different architectural forms of WDM networks and each has its own advantages and disadvantages. In this section we briefly present three of the most commonly used types of WDM networks: *Passive Optical Network (PON), Broadcast and Select Networks,* and *Wavelength Routing Networks*.

3.1 Passive Optical Network (PON)

The word "passive" denotes the use of equipment in the network that doesn't require electrical input. These include optical fiber cable, passive routers, couplers, and filters. This type of network is generally designed and preferred for LANs or MANs, where small distance communications is set. In these networks, optic signal does not require amplification since it does not travel long distances and it is not affected by attenuation. For more detailed discussion, see [14].

3.2 Broadcast and Select Networks

This model of all-optical WDM networks makes use of couplers. Various nodes transmit distinct wavelengths over optic channels [15]. All of these transmissions are combined in a passive star coupler or onto a bus. A star coupler is a piece of glass that combines and then splits the received signal on any of its ports to all the ports. Thus, a copy of aggregated signal is distributed to each receiver.

Each end-node's receiver filters out the intended wavelength by having tunable receivers over multiple channels to get the wavelength indented for it. The transmitter end-node, on the other hand, should have narrow line-width tunable transmitter in order to avoid inter-channel interference and have the ability to access to multiple wavelengths for proper network operation.

All-optical WDM broadcast and select network has different physical topologies. The most popular and the simplest one is based on a passive star coupler, where an NxN star coupler is placed on the center of the network. It connects, through input and output ports, each end-node via pair of optic fibers as shown in Figure 7. When the input signal reaches this start coupler with input power P_{in}, it will be distributed to all ports of this coupler. Therefore, the output power on each output fiber is $P_{out} = P_{in}/N$. However, in a bus topology, different power levels are received by different stations and the signal power gets split among all nodes maintaining a certain minimal strength. In result, there is limited number of users that can be hooked to this type of network which makes it inadequate for use for long distance communication.

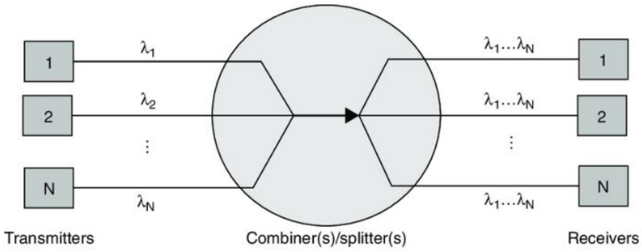

Figure 7. WDM network with combiner and splitter

3.3 Wavelength Routing Networks

Wavelength-routed optical network, also called WRN, was designed to overcome the drawbacks of broadcast-and-select network [15]. Those limitations are overcome in WRN by sending the specific signal in a particular link instead of broadcasting resulting in signal power saving. A wavelength routed network consists of wavelength selective routers and the fibers connecting them in an arbitrary topology. Each end-node is connected to one of wavelength selective routers via a fiber link as shown in figure 8. This combination of end-node and its corresponding wavelength router is referred to as a network node. It is interesting to note that these wavelength routers are totally made up of glass material (i.e., no electro-optical conversions is required), which means routers are all-optical.

An important feature of WRN is wavelength re-use. In WRN, lightpaths can use the same wavelength if they use disjoint sets of links. It should be kept in mind that in WRN no signals should be assigned the same wavelength going through the same link. Hence, signals routed to the same fiber should be on distinct wavelengths to avoid the mixing of different signals. This property is known as the wavelength continuity constraint. WRN also allows for the spatial reuse of wavelengths, which can be achieved by placing two lightpaths that do not share a fiber on their routes on the same wavelength, resulting in further efficient resource utilization.

In some networks, wavelength conversions at some or all nodes are allowed. Such networks are referred to as wavelength-convertible networks. Any lightpath that passes through these wavelength converter nodes may change its wavelength. Therefore, the lightpath may be assigned to more than single wavelength over its route. The data arriving on one wavelength along a hop, and if the same wavelength is not available in the next hop, can be transferred onto a possibly different wavelength at an intermediate node that forwards it along the next hop.

Hence, performing wavelength conversion in wavelength routing networks will make it possible to establish a lightpath with idle channels by probably having different wavelengths along a route. In consequence, using wavelength converters will benefit the system efficiency by improving the utilization of the fiber cables.

Wavelength router architectures are classified into many types: Fiber Cross-Connects, Add-Drop Multiplexers, Static Wavelength Routers, and Reconfigurable Wavelength Routers, more detailed discussion is found in [15].

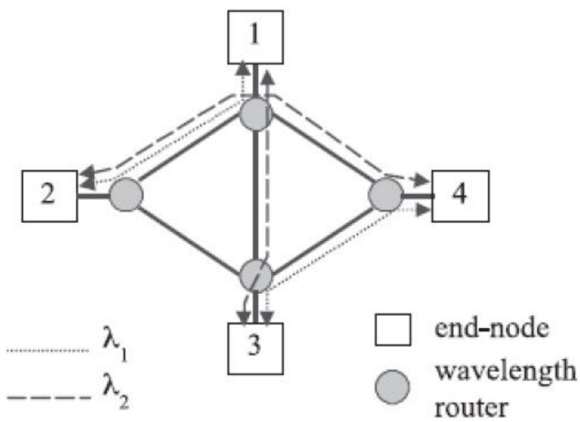

Figure 8. Wavelength routing network

4. Operational Power Consumption

The compound annual growth rate (CAGR) for Global internet traffic for the period of 2016-2021 was estimated at 26% according to Cisco [16]. The whole number of Internet users, also, was predicted to grow from 3.9 billion users in 2018 to around 5.3 billion users by 2023 at a CAGR of 6%. Consequently, massive streams of data will be generated, driven predominately by bandwidth-intensive applications.

As stated in recent reports by KTH Royal Institute of Technology in Sweden [17], in 2020 the internet has been burning 10% of the global electricity supply and that rate may grow up to 20% by 2025. Hence, and at such growth rates, the amount of electricity supply that will be needed to power the Internet could be simply unattainable in the years to come. Access networks, including fiber-to-the-home (FTTH) technologies, consume about 60% to 80% of the total Internet power consumption, which will cause devastating growth in overall energy footprint around the globe. Furthermore, higher power consumption will lead to increased energy costs and greater need for heat dissipation techniques in order to ensure the stable and safe operation of power electronic devices. With this rising electricity consumption, significant energy savings opportunities can be attained by upgrading from the first generation optical network to the second generation, thanks to the continuous improvement of less power-hungry optical technologies, particularly, OXC switches. This new technology for network sites can meet the requirements of low latency, large broadband and low-energy consumption networks.

Referring to the benefits of the eco-friendly all-optical network technology, the optical cube bearer network can conserve 250,000 kWh per year which is equivalent to planting more than 2,000 trees. An example of building all-optic network is what China intends to do in some cities, it has begun to build whole all-optical cities to offer high-quality services everywhere including homes with enterprises, and it will provide high-quality 5G connections as well for everyone. As what is on progress in its local regions such as “Shudao” and the “Greater Bay Area” for instance. Since, the former is a Chinese big area that connects many provinces; this prologue transformation will save 8 million kWh of power per year, which is equivalent of planting more than 64,000 trees per year. This technology will also assist the communications industry to cut carbon emissions in the future and attain sustainable development goals for energy conservation [18]. Optic fiber networks can potentially reduce worldwide carbon dioxide emissions by 1.6 giga tons per year, which will have a direct impact on the environment, and consequently this considerably will help to reduce the growth of the global warming.

We are moving towards an intelligent era and the world is becoming fully connected. The rapid growth of energy efficient all-optical network trends has initiated claims across the globe to start building a future and ecosystem of all-optical networks immediately. All-optical networks’ ability to provide enhanced levels of functionalities while reducing the need of energy by folds will certainly make this technology play a pivotal role in building a better future for the human race.

5. Optical Fiber Networks in Libya

Libya is a developing country and the telecommunication industry has experienced rapid growth over the past two decades, being only hindered by recent events of civil unrest. Optical fiber networks are not yet deployed across the country, particularly in remote areas. Fiber optic cabling is not available yet due to management and infrastructure deployment challenges. Various local utility management organizations governing oil & gas, water, and electricity have deployed fiber-optic infrastructures for their own operations that could be leveraged for broadband connectivity. Fiber-optic cables in Libya will be the backbone of the information and data highways forming the Internet in the years to come. Fiber-optic cables allow broadband connectivity to fulfill the need of the rising data and traffic demands for current and emerging technologies. Libyan Post Telecommunications & Information Technology Company (LPTIC) have adopted the Libyan fiber optic network (LFON) via Hatif Libya subsidiary company in order to provide a modern telecom infrastructure that supports high data speed across the country through high quality transmission optical fiber network using IP protocol [18]. In the hope of covering 214 villages and cities that extends to mostly 1200 km and provide its services to all of Libya, together with the sea cables connections. Hatif Libya intends to grasp the latest FTTX technologies to satisfy customers’ increasing bandwidth demands. Optical Transport Networking (OTN) is already deployed and the deploying Automatically Switched Optical Network (ASON) technology is currently under progress. ASON is an optical transport network (OTN) that provides broadband services to carriers and their clients with dynamic connection capabilities. This dynamic connection feature is fulfilled by using a control plane that performs the call and connection control functions. ASON encompasses SONET/SDH and potentially fiber connection services in both OEO and all-optical networks. However, the greatest expectations for ASONs are related to their support for all-optical networks. ASON makes use of intelligent optical cross-connects switches which allows for it to be used to create all-optical end-to-end transparent transmissions. The current specifications of ASON control plane, however, do not support an all-optical transport plane. The ASON architecture based on transport, control, and management planes which in the future will eventually be able to support 200G/400G and can be expanded and developed to reach 9 terabytes. However, currently used wireless solutions are not adequate to deliver the incremental services that customers are looking for.

Another important motivation for building all-optical network in Libya is the massive reduction in power consumption by the local ICT infrastructure. This is viewed to be of great importance due to the power outage crisis experienced by the Libyan power grid since a decade, and on daily basis. The Libyan power grid suffers immensely because of constant failures and shortfalls either in power plants, distribution stations, transmission lines, or transformers across the country. The huge power savings mentioned in section 4 will enhance the operation of the power system network across the country through conserving hundreds of megawatts that could be used elsewhere.

The aim to upgrade to all-optic network is not as easy as it seems, never be a one night process. Several aspects should be taken into consideration for replacing the legacy national transport network, either copper cabling or first generation optic fiber, with all-optical network, in order to be equipped with the latest technologies and provides alternative paths for traffic. It necessitates to retire and replace all energy-intensive and outdated equipment installed, such as old SDH equipment and DDFs, and replacing it with the next-generation optic fiber equipment. Those legacy equipment occupy large space cabinets and have high total power consumption. However, this upgrading will offer beneficial features for the system such as: congestion-free, huge power and space saving, and significant reduction in the annual electricity fees. Certainly, that imposes to have a transition period for both, electrical and optical networks, to coexist, with planning for developing and utilizing the existing resources. All parties within industry chain must collaborate to build of an all-optical network. Furthermore, upgrading optical fiber projects should be set as national strategies, and considering these projects as foundation to build the digital economy and will drive huge investment,

6. Conclusion

This paper focused on many aspects of all-optical networks (AONs). It is clear that significant driver for this promising optical communication technology is the necessity to acquiring larger bandwidth transmission media, and for reducing the network energy consumption. The work has briefly explored the key technologies that must be used to support such networks. And the introducing of OXC switches was the beginning of a complete new chapter. However, the upgrading from current optical network to all-optical network will involve transition periods. Regarding this matter, the work is showing the status of the existing and the future options for the Libyan Optical Access Network and the confronted challenges. Pointing out to the benefits of this changeover in a number of ways, focusing mostly on energy consumption side. Most conveniently, an all-optic network does allow many services to share the same network, achieved through the visible light and infrared beams having the ability to rapidly pass through each other without interchanging. All-optic fiber network continues to gain momentum across the globe as an eco-friendly network and a green communications, and ensuring that technology and nature coexist in harmony. The balance between civilization and nature has been thrown off. We are certain that technology should not harm nature, but instead the two should coexist in healthy interacting.

Commercial all-optical networks are still not in place and mostly exist in research arena. Only restricted all-optical networks functions are being deployed in ASON networks. AON is still considered a technology of the future, due to a realization to a greater extent to the unlimited bandwidth dreams of this era.

References

[1] https://www.lightreading.com/optical-ip/fttx/gigabit-subscriptions-set-for-big-increase-next-year—omdia/a/d-id/774291
[2] Green, P.E., Optical networking update. IEEE Journal on Selected Areas in Communications 14, 5 (June 1996).
[3] AltanKocygit, Demeter Gokisik, SemihBilgen "All-Optical Networking", Electrical and Electronics Engineering Department, Middle East Technical University, 06531 Ankara, TURKEY, Turk J ElecEngin, VOL.9, NO.2 2001, C TU¨BI_TAK
[4] Heinz A. Willebrand and Gerald R. Clark "Free space optics: a viable last-mile alternative", Proc. SPIE 4586, Wireless and Mobile Communications, (18 October 2001); https://doi.org/10.1117/12.445229
[5] Y. Yin, R Proietti, X.Ye, C.J. Nitta, V. Akella, and S.J.B. Yoo. 2013 LIONS: An AWGR-Based Low-Latency Optical Switch for High-Performance Computing and Data Centers. IEEE Journal of Selected Topics In Quantum Electronics, 19, 2(March/April 2013), 272--280.
[6] A. A. M. Saleh and J. M. Simmons, "All-Optical Networking—Evolution, Benefits, Challenges, and Future Vision," in *Proceedings of the IEEE*, vol. 100, no. 5, pp. 1105-1117, May 2012, doi: 10.1109/JPROC.2011.2182589.
[7] J. Berthold, A. A. M. Saleh, L. Blair, and J. M. Simmons, "Optical Networking: past present and future", IEEE/OSA Journal of Lightwave Technology, vol. 26, no. 9, pp. 1104-1118, May 2008.
[8] A. Deylamsalehi, D. A. P. Davis and V. M. Vokkarane, "Electricity cost and emissions reduction in optical networks," *2017 International Conference on Computing, Networking and Communications (ICNC)*, 2017, pp. 381-386, doi: 10.1109/ICCNC.2017.7876158.
[9] 9.M.S. Borella, J.P. Jue, D. Banerjee, B. Ramamurthy, B. Mukherjee, "Optical Components for WDM Lightwave Networks," Proceedings of the IEEE, vol. 85, no. 8, pp. 1274-1307, August 1997.
[10] A. E. Willner, "Mining the optical bandwidth for a terabit per second," in *IEEE Spectrum*, vol. 34, no. 4, pp. 32-41, April 1997, doi: 10.1109/6.583444.
[11] Takashi Matsumoto, Shinji Fujita, and Toshihiko Baba, "Wavelength demultiplexer consisting of Photonic crystal superprism and superlens," Opt. Express 13, 10768-10776 (2005).
[12] Large, D., & Farmer, J. (2009). Broadband cable access networks: The HFC plant. Amsterdam: Morgan Kaufmann/Elsevier.
[13] E. Karasan and E. Ayanoglu, "Performance of WDM transport networks," in *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 7, pp. 1081-1096, Sept. 1998, doi: 10.1109/49.725180.

[14] J.M. Senior, M.R. Handley, M.S. Leeson, “Developments in Wavelength Division Multiple Access Networking," IEEE Communications Magazine, pp. 28-36, December 1998.

[15] R. Ramaswami, “MultiwavelengthLightwave Networks for Computer Communication," IEEE Communications Magazine, pp. 78-88, February 1993.

[16] “Global - 2021 forecast highlights,” CISCO, 2016. [Online]. Available: https://www.cisco.com/c/dam/m/en_us/solutions/service-provider/vni-forecast-highlights/pdf/Global_2021_Forecast_Highlights.pdf

[17] Malmodin, J., &Lundén, D. (2018). The electricity consumption and operational carbon emissions of ICT network operators 2010-2015. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-221740

[18] https://blog.huawei.com/2020/07/01/connecting-to-a-green-future-with-optical-networks/

[19] http://www.lptic.net/projects/LibyanTelecommunication holding company projects.Fachinger, J., 2006. Behavior of HTR Fuel Elements in Aquatic Phases of Repository Host Rock Formations. Nuclear Engineering & Design 236, p. 54.