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An Optical WDM Network Concept for Tanzania

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***Abstract*—**Tanzania is a developing country, which significantly lags behind the rest of the world in information communications technology (ICT), especially for the Internet. Internet connectivity to the rest of the world is via expensive satellite links, thus leaving the majority of the population unable to access the Internet due to the high cost. This paper introduces the concept of an optical WDM network for Internet infrastructure in Tanzania, so as to reduce Internet connection costs, and provide Internet access to the majority of people who live in both urban and rural areas. We also present a proposed optical WDM network, which mitigates the effects of system impairments, and provide simulation results to show that the data is successfully transmitted over a longer distance using a WDM network.

***Keywords*—**Internet infrastructure, Internet access, Internet traffic, WDM.

I. INTRODUCTION

INTERNET services have been available in Tanzania since 1996, however until today there is no current Internet infrastructure (backbone) that uses optical fiber, as a consequence the connectivity is over satellite links to the rest of the world. At the present, the Tanzania Telecommunications Company (TTCL) [1], which is the largest government telecommunication company, provides Internet access by means of microwave links, leased lines, and optical fiber in some commercial areas of the old capital city, Dar –es-Salaam. Apart from TTCL, there are other private companies, which provide Internet access to their customers by means of microwave links and very small aperture terminal fixed satellite communication (VSAT) technology; their customers are mostly, private or government organizations.

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For example: SatCom Network Africa LTD (SCNA) [2] owns a private satellite hub in Tanzania; this covers most of the urban areas with VSAT's to provide Internet access.

However, many people who live in rural areas do not have Internet access, and those who live in urban areas depends only on the digital leased lines or microwave links. Their Internet connection to the rest of the world is through a satellite; hence they only have limited Internet access due to the high connection costs of satellite. Internet access is a key part of communications and the basis of socio-economic development [3]; therefore for a developing country like Tanzania, Internet access needs to be given a priority so that it can be accessible by the majority of the population.

At the moment, there is project to implement a national ICT backbone [4] by using optical fiber and connect it to the rest of the world through South Africa by means of East African submarine cable [5], however it remains unknown when this project will finish. The national ICT backbone goal is to reduce the Internet connection charge and provide Internet access to the majority of the people who live in both urban and rural areas.

The rest of the paper is organized as follows. In section II, we discuss the existing optical fibers in Tanzania. Section III discusses the concept of optical WDM network. Section IV describes the requirements of optical WDM network and present the network topology. In Section V, we provide techniques to reduce the system impairments. Section VI provides simulation results. Finally, we summarize the paper in section V1I.

II. THE EXISTING OPTICAL FIBER COMMUNICATION SYSTEMS

The existing optical fibers in Tanzania are separated and owned by the Tanzania Electric Supply Company (TANESCO), Tanzania-Zambia Railway Authority (TAZARA), Tanzania Railway Corporation (TRC), Tanzania Telecommunication Company Limited (TTCL), and Songo Songo Gas Supply Company in Tanzania (SONGAS) [4]. TTCL is funded by the government and donors to improve voice and Internet services by the use of optical fiber cables; Tazara and TRC link all their stations along the railway lines by means of optical fibers for signaling and monitoring of railway lines; Tanesco and Songo Songo Companies link all their electricity generation power stations, transmission and distributions control centers by using optical fibers for voices communication services between their substation centers.

These optical fiber communication systems are built using synchronous digital hierarchy systems (SDH) in the form of rings or point-to-point links in other areas, operating with a maximum bandwidth of 622 Mb/s using a single wavelength channel on a standard single mode fiber (SMF)(or G.652 according to the ITU standard).

III. Concepts of optical WDM network

Internet infrastructures in most places of the world have been supported by the advancement of optical fiber technology, most notably wavelength division multiplexing (WDM) systems. Optical technology by means of wavelength division multiplexing has revolutionized long distance data transport and has resulted in high capacity data highways, cost reductions, extremely low bit error rate, and operational simplification of the overall Internet infrastructure.

A WDM is basically a fiber optical transmission technique, which multiplexes many signals of different wavelengths and is capable of providing data capacity in excess of hundreds of gigabit per second over thousands of kilometers in a single mode fiber. In additional, the WDM system uses optical fibers for data transmission, which is more secure compared with other data transmission systems e.g., satellite, from tapping (as light does not radiate from the fiber, it is nearly impossible to tap into it secretly without detection). It is also immune to interference and crosstalk.

In existing optical fiber communication systems as described above, only a small fraction of the fiber capacity is used, but by using WDM system is possible to exploit the huge capacity more efficiently. Therefore it can be used to meet Internet traffic demand in Tanzania by maximizing the use of existing optical fibers communication systems. The possibility using existing optical fibers more efficiently makes WDM system a very attractive commercial proposition.

Therefore, the WDM network can be considered as the right choice for constructing an Internet infrastructure in Tanzania, because of its potential limitless capability, huge bandwidth (nearly 50 terabit) per second (Tb/s), low signal loss (as low as 0.2 dB/km, low signal distortion, lower power requirement, low material usage, small space requirement, security and low cost.

Thus, it is vital to upgrade existing optical communication systems to WDM system in order to implement the Internet infrastructure to provide Internet access to the majority of people who live in both urban and rural areas, as it is often very expensive to install new fibers in the ground. The fiber network can be connected to the rest of the world by means of East African submarine cable, this would greatly reduce Internet connection charges.

IV. Optical WDM Network Requirements

A. Network Topology

Ring topology has become very popular in the telecommunication system infrastructure community [6], [7]. A ring is the simplest network that provides two separate paths between any pair of nodes that do not have any nodes or links in common except the source and destination nodes. This allows a WDM ring network to be a resilient to failures, and also impose low network requirements on the optical hardware; network protection and on the network management system.

Therefore based on the above facts, we have chosen the 4-interconnected WDM rings network to constitute an Internet infrastructure for Tanzania as shown in the block diagram in Fig. 1. The distance between 2-nodes in a ring and a total length of one WDM ring is estimated to be not more than 600 km and 3000 km respectively. The WDM network nodes represent 21 cities in Tanzania, and each one is installed with the reconfigurable add/drop multiplexer (ROADM) or an optical crossconnect switch (OXC) as shown in the block diagram.

The optical WDM network is then connected to the rest of the world via East African submarine cable through Dar-es-Salaam (DSM), Zanzibar and Coast cities. At the edge of the network, the SDH metro rings are used to add/drop the local Internet traffic to or from the WDM network respectively. Note: The ROADM and OXC are outlined with a circle and box respectively as shown in the block diagram.

B. Dynamic Traffic

Since the Internet traffic has been doubling every year especially in the commercial city, Dar-es-Salaam or in other major cities, for example Mwanza or Arusha, we have chosen the dynamic traffic to meet those demands. The traffic is dynamic if lightpath request (i.e., Internet traffic) arrive and terminate at random times. With dynamic traffic, an existing lightpath can be dropped and a new one established in response to changing traffic patterns or network component failures in the WDM network. Dynamic traffic is configured by the use of OXC or ROADM, which can add/drop any wavelength in the WDM network.

C. Traffic Protection

Protected optical links between nodes in each WDM ring can be realized by establishing a working path and a protection path [6]. From the network management perspective, we prefer four-fiber bi-directional line switched rings (BLSR/4). A BLSR/4 has two working fibers and two protection fibers. It employs two types of protection mechanisms: span switching and ring switching. In span switching, if a transmitter or receiver on a working fiber fails, or a working fiber is cut on the link between two nodes, the traffic is routed onto the protection fiber on that link between these two nodes.

In case of both working and protection fibers (4-fibers) cuts on the link between two nodes, the traffic is rerouted around the ring by the nodes adjacent to the failure on the protection fibers by using ring switching. Also a BLSR/4 can use the protection bandwidth to carry low priority or extra traffic, under normal operation, but this extra traffic is lost in the event of a failure in the WDM rings network. However this feature will requires additional signaling between the nodes in the event of a failure to indicate to the other nodes that they should operate in protection mode and throw away the low priority traffic.

D. Wavelength blocking

This kind of blocking can only occur in the WDM networks [8]-[12]. It happens when there is no capability to assign a lightpath request (i.e., Internet traffic) to an unused wavelength in the WDM network. Therefore, to avoid this, we prefer 40 wavelength channels, dynamic traffic as described above, and dynamic routing and wavelength assignment (RWA) algorithms.

E. Data transmission

Important components of a WDM network are: transmitter, receiver, optical fiber, optical amplifier, multiplexers/demultiple-xers (MUX/DEMUX), optical crossconnect switch (OXC) and reconfigurable add/drop multiplex switch (ROADM) [13]. These components allow a WDM network to transmit data to any other network, e.g. IP, SONET or ATM networks. Data are converted into electrical signals and coded to the non-return-to-zero (NRZ) modulation format, then converted into light signal, and assigned a wavelength channel for transmission by means of a transmitter.

The transmitter consists of tunable laser along with an external modulator. The signals from the different wavelengths channels are combined into a single mode fiber by an optical multiplexer and depending on transmission distance, amplified using erbium-doped fiber amplifiers (EDFAs) along the link. A post amplifier is used to increase the output power, a line amplifier is used typically in the middle of the link to compensate for link loss, which is normally about 0.2 dB/km on a single mode fiber. A preamplifier amplifier is used just in front of a receiver to improve the bit error ratio (BER).

The EDFAs for the C-band normally operate over the range of 1530 nm to 1560 nm, about 30 nm width. This spectral range supports 40 WDM signal channels with a separation of 0.8nm line width (corresponding to 100 GHz, ITU standard). The optical demultiplexer separates out the WDM signal channels with minimum system impairments and directs them to the individual channel receiver, which converts an optical signal into an electrical signal. The receiver comprises of a photodetector to generate an electrical current, it has a front-end amplifier to increase the power of the generated electrical signal, a filter to minimize noise of the amplified electrical current, and a decision circuit to determine whether the transmitted bit was 1 or 0 in each bit interval.

A ROADM allows single or multiple wavelengths dependent upon Internet traffic to be dropped and added to a multi-wavelength fiber. A ROADM has two line ports and a number of local ports where individual wavelength channel are dropped and added. An OXC essentially performs a similar function to ROADM but at much larger sizes. OXC have a larger number of ports and are able to switch wavelengths from one input port to another. Normally they are installed in a heavy Internet traffic node, e.g. in Dar –es-Salaam (DSM) city or to connect two

WDM rings as shown in the block diagram in Fig. 1.

V. Mitigation of System Impairments

A. Attenuation

This leads to a loss of signal power as the signal propagates over a prescribed distance. Since most of the optical fibers deployed in Tanzania are standard single mode fibers. These optical fibers have attenuation loss of 0.2 dB/km in the 1.55-micron band in which a WDM system operates. To overcome attenuation, optical amplifiers (EDFAs) are used to amplify the signal power as explained above**,** and are spaced 120 km distance apart.

B. Chromatic Dispersion

This type of dispersion occurs in single mode fibers [14], and is the widening of pulse duration as it travels through an optical fiber. As a pulse widens, it can broaden enough to interfere with neighboring pulses on the fiber, leading to a bit error at the receiver. Standard single mode fiber has a total dispersion of 17 ps/nm-km in the lower loss wavelength region of 1550 nm. To overcome this, we have used a laser source with a narrow spectral width, the distributed-feedback (DFB) laser along with a external modulator to transmit a data rate of 2.5 Gb/s per wavelength channel up to a distance of 3000 km in one WDM ring without any chromatic dispersion effects on the optical link [15] as shown in the signal eye diagram in Fig. 2.

C. Polarization mode dispersion

This is caused by the difference of propagation velocities of light in the orthogonal polarization states of the transmission medium [16]. Like fiber dispersion, PMD causes the transmitted optical pulse to spread out due to the polarization modes traveling at different speeds, this can scramble the signal. This is often occurs at high data rates, from 10 Gb/s or more per wavelength channel [15]. So we don't need to worry for transmission of the 2.5 Gb/s data rate per wavelength channel

D. Non-Linear effects

As the optical data rates, transmission length, number of wavelengths or optical power levels increase, non-linear effects arise [17]. Non-linear effects are controlled by the choice of a relatively low data rate of 2.5 Gb/s per wavelength channel, lower channel power and at least 0.8 nm wavelength spacing (corresponding to 100 GHZ frequency, ITU standard) [15].

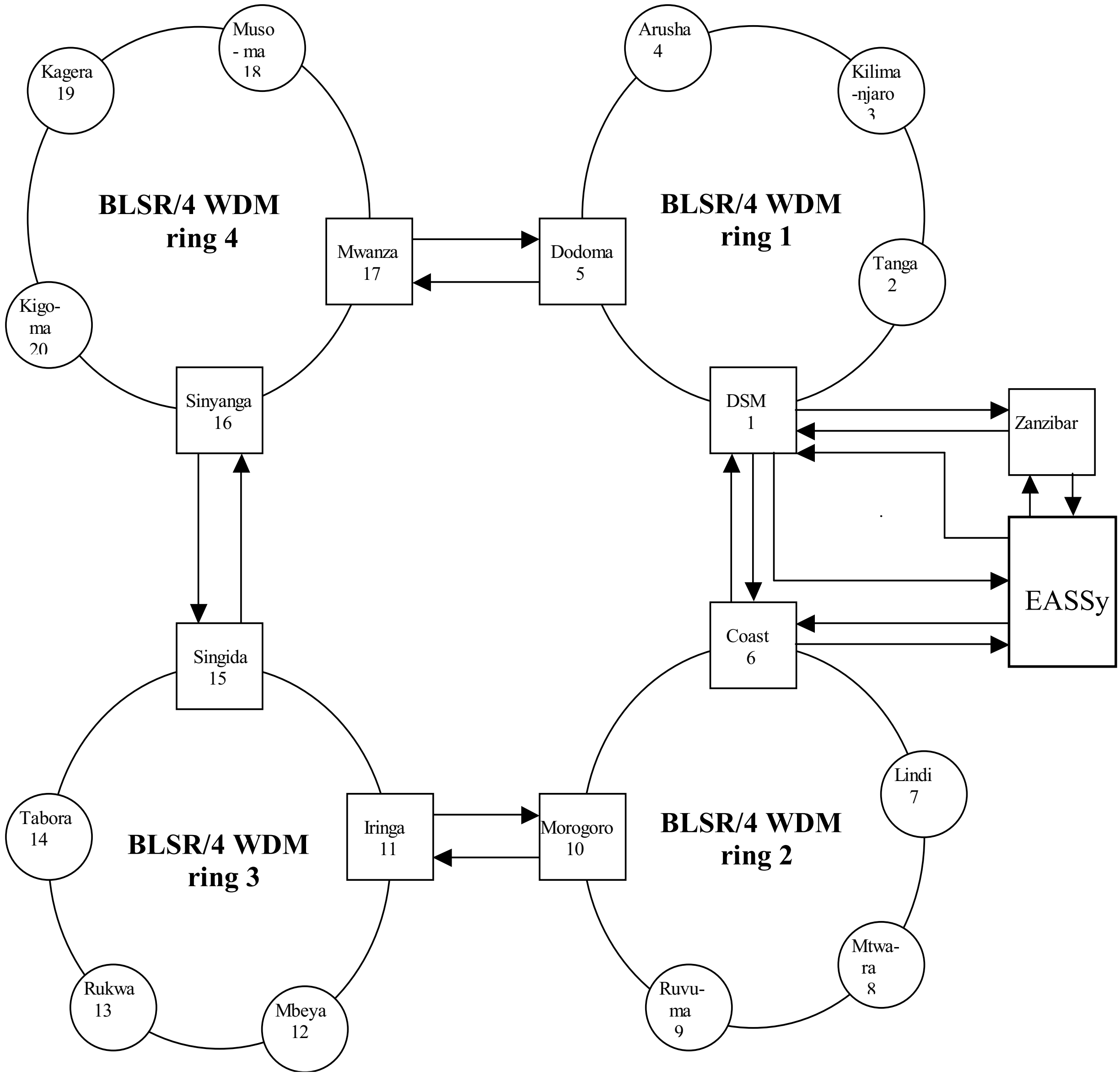

Fig. 1. Block diagram of optical WDM network for Tanzania

VI. Simulation Results

The Eye diagram is used in the simulation of WDM system to determine the quality of the electrical signal at the receiver. The measurements of signal quality in the WDM system are bit error rate (BER), signal to noise ratio (OSNR) or receiver sensitivity at the receiver

A. The Bit error rate

It is the number of errors that occur between the transmitter and the receiver. The required BER for high-speed optical data communications is in the range of 10^{-9} to 10^{-15}, a typical value is 10^{-12}, the BER of 10^{-12} corresponds to one allowed bit error for every terabit of data transmitted on average.

B. Receiver sensitivity

This is the average optical power required to achieve a certain bit error rate at a particular data rate, it is usually measured at a BER of 10^{-12} for a good WDM system performance. Fig.3 shows that, when a data rate of 2.5 Gb/s per wavelength channel is transmitted to a maximum distance of 3000 km between 2-nodes in the WDM ring, the BER of 10^{-12} corresponds to the receiver sensitivity of -30.5 dBm, which is adequate for system performance and results in an open eye diagram for the signal as shown in the signal eye diagram in Fig. 2.

C. Signal to noise ratio (OSNR)

This is the ratio of the average received signal power to the average optical noise power. Increasing the amplifier output power, or decreasing the noise figure, or reducing the span loss will increase the OSNR in the WDM system. Fig. 4, shows that when the data rate of 2.5 Gb/s per wavelength channel is transmitted along the optical link over a distance of 3000 km, the OSNR is approximately to 30 dB, which is high and sufficient for system performance, and also results in an open eye diagram for the signal, as shown in the signal eye diagram in Fig. 2.

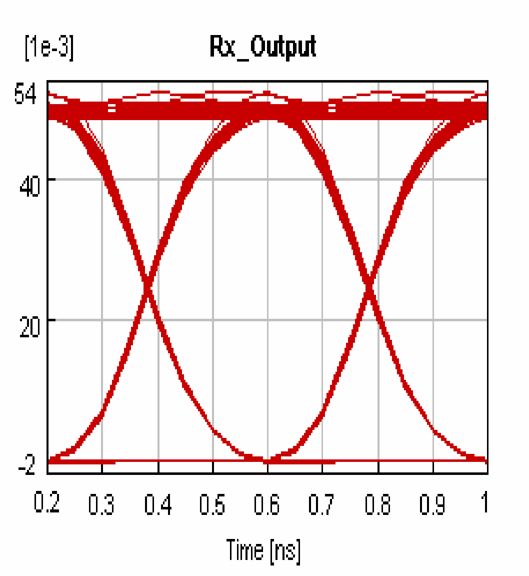

Fig. 2. Eye diagram

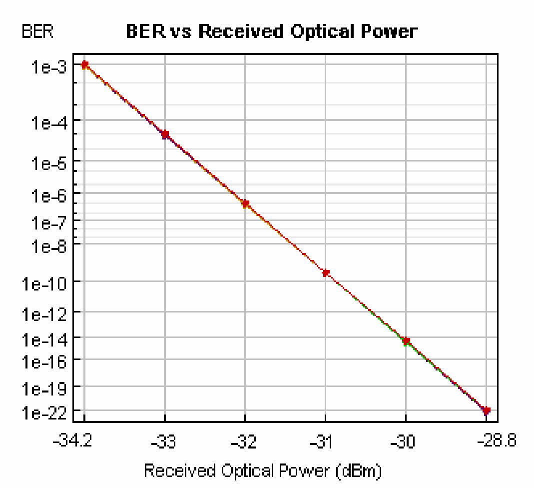

Fig. 3. Receiver sensitivity

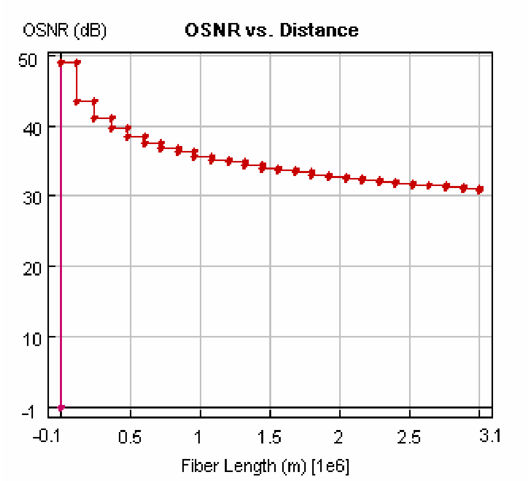

Fig. 4. OSNR. Vs. 3000 km Distance

VII. Conclusion

Tanzania is currently improving the Internet infrastructure by the use of optical fiber in order to reduce Internet costs and provide Internet access for the majority of the people. We have presented the concept of an optical WDM network for Internet infrastructure in Tanzania, and also shown that it can be implemented easily, to provide Internet access to both urban and rural areas. Our proposed WDM network yields enough capacity to cope with the increasing traffic demand in Tanzania.

Also it can be an effective solution for reduction of the Internet connection charge, since it will be connected by means of East African submarine cable to the rest of the world. This is a more cost effective solution than the existing Internet infrastructure, which connects Internet users by means of Satellite links to the rest of the world

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