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Research Article

Performance Analysis of An Optical Fiber Communication Network

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Abstract

The introduction of optical fiber has transformed the telecommunication industry and it has played a very important and key part in the information age. Optical fiber is widely preferred for data transmission to other media of communication because of their capability to carry extensive information and its dielectric nature. However, this mode of transmission has faced an issue of high latency which later reduces the throughput as well as reducing the quality of Experience at the customer side. This paper presents how different tests of throughput and latency were carried out using Viavi test kit, analyzed and then after compared the obtained results with the standard defined by IEEE and ITU for conformity. Some of the results conformed with the defined whereas others did not because of different reasons that include congestion of the link, faulty hardware on the network, poor quality of the fiber cable and the distance covered by the optical fiber link. The mitigation measures for the above causes were discussed in this paper and they include upgrading the bandwidth of the link, ensuring the use of quality fiber cables, regular maintenance in order to sight out the faulty components on the link as well as employment of several repeaters on long distance optical fiber links.

1.0 Introduction

The advent of fiber optic communication systems has revolutionized the industry of Telecommunication (Agrawal, 2016) .When compared with other transmission media, it has shown to be the most preferred option in terms of latency, data carrying capacity, and immunity to cross-talk and noise amongst others (Agrawal, 2016). Corning Glass work developed the first optical fiber in 1970s, it had a low attenuation levels compared to the copper wires that were before its development and was mainly used for communication (Iizuka, 2019).

Optical fiber communication involves the conversion of an electrical signal to an optical (light) signal by the transmitter, transporting the signal along the cable of fiber, making sure that the signal doesn't get too distorted or get attenuated during transmission, reception of the signal (optical) and then conversion of the optical signal back to an electrical signal (Senior, n.d.). Optical fiber finds application in Telecommunications, networking, industrial/commercial, medical, broadcast, data storage and defense/Government (Addanki et al., 2018).

Amidst improved parameters in an optical communications system, fiber optic links are inundated with challenges of validating network key performance indices of throughput, latency, and packet jitter and frame loss rates. Throughput is the amount of data that is sent and received over a communication link and is measured in kilobytes per second, kbps. Higher rates of measurement include mega, Giga and terabytes per second. Latency refers to the time taken for a data transfer from source to the destination, while frame loss rate is the percentage of frames intended to be sent by a given network but was not delivered. A packet jitter is a time delay in the sending of data packets over a given network. These parameters need to be tested and confirmed during acceptance test procedures (ATP), before putting traffic on the link as a safeguard towards network performance and customer quality of experience, QoE (Hailu et al., 2020). For this research, we used the T-BERT/MTS 5800 to test both the 10G and 100G line rates in appraising and validating these parameters in a fiber optics link and compare the results with benchmark requirements set by the International Telecommunications Union (ITU) and the Institute of Electrical and Electronics Engineers (IEEE).

1.1 Fiber optic communication principles

Fiber- optic communication is a mode of transmission in which information or data is transmitted from the sender to the destination in form of light pulse through an optical fiber cable (Agrawal, 2016). Digital information is transmitted on a wave which is generated by the carrier source. Light- emitting diodes (LEDs) and laser diodes (LD) are always the light sources used, however, lasers are preferred because they transmit light far away with limited errors, are more powerful, and also operate at faster speeds compared to LEDs (Hitz et al., 2012). The source is always switched on and off quickly and accurately to ensure that the signals are properly transmitted. Optical fiber is preferred to copper wire communication because it offers a number of advantages which include extremely high band width, ability to transmit over longer distances, its resistance to electromagnetic interference, its small size, low -security risks, and its weight are light (Iizuka, 2019). Optic fiber finds application in telecommunication systems, submarine cable networks, used in traffic management systems and CCTV surveillance cameras (Addanki et al., 2018).

1.2 Future trends of optical fiber communication

Attaining a high quality of data transmission is crucial in fiber optic communication for the optical signals' distorted waveform with low or nearly to zero attenuation levels and low signal to noise ration during transmission. Improving on the optical transceiver is also a concern to embrace new and advanced modulation techniques.

Fiber optic communication network will be entirely optical; the signals will be optically processed without any electrical conversions at any stage during signal transmission. Presently signals are converted to electrical form before processing is done meaning signals switching takes place in both electrical and optical domains. After processing and routing, the signals are then converted to optical form for them to be transmitted over longer distances. The situation of conversion of signals from electrical form to optical form and verse visa gives rise to delays in communication which limits high data rate transmissions in optical fiber.

1.3 Optical transmitter/ receiver technology improvement.

It is significant in optical communication to attain high quality transmission even for signals with distorted waveform as well as a low signal to noise ratio. This can be achieved if the transmitters and receivers used in communication embrace the new and advanced modulation techniques with very good optical signal to noise ratio (OSNR) tolerance plus excellent chromatic dispersion thus fit for ultra -long haul communication system.

1.4 Optic fiber benchmark requirements

This paper considered throughput and latency as the benchmark requirements in the optical network performance.

I. Latency

Latency refers to delay in transmission time or in the time it takes for information to transfer through a fiber cable, and it is a very vital indicator of network performance. Since the information in optical fiber is transmitted through pulses of light, the delay is seen or occurs in the time taken for the light pulses to travel through a fiber cable (Seraji et al., 2019).

Latency is calculated using

$$D = T \times V \qquad 2.1$$

Where D is the distance light travels through a given fiber cable, T is the time the light pulses take to travel a given distance D and V is the velocity of light. In a vacuum light travel at a velocity of 299,792,458 m/s, however, the speed of light through an optical fiber core is quite slow compared to the speed of light in the vacuum. This is due to differences in the refractive indices of light through glass and light through air or free (Seraji et al., 2020). It is so important to know the refractive index of the glass core in the fiber optic wave guide before the speed of light(latency). Latency is not good as far as communication is concerned so it should be reduced in one way or the other to ensure a seamless optical fiber communication(Chitimalla et al., 2017). Latency can be reduced through the use of high-quality fiber cable as light tends to travel through it faster compared to low-quality fiber, carefully handling fiber during constructions and also ensuring that fiber requirements conform with the standards defined by IEEE and ITU.

II. Throughput

This is the actual amount of data that is transmitted without errors over a fiber link, and it's expressed in bits per second since it is always measured per unit time. It is an average rate that is measured depending on the available bandwidth or capacity of the link and also depends on the latency or delay in that link (Bhat & Balachandra Achar, 2019). Many factors affect throughput and some of them include limitation of the transmission media where if a given channel or link is meant to carry a given amount of data, it cannot carry an amount beyond that specific amount, latency which is the time taken for data packets to transfer from the transmitter to the destination, the network congestion, the packet losses and errors also affect the throughput of a fiber link. Theoretically, throughput is 95% of the available bandwidth for a given link. It is very important to measure or test for the throughput of a network to improve the performance of that network(Hodara, 2017). If a test or measured and found to be low than what is expected, then there is need to optimize the network. Optimization can be done by identifying the bottlenecks, increasing the bandwidth of the channel if possible, replacing faulty devices on the network, and also ensuring the quality of services so that the critical traffic is not affected by congestion in the network (Ibrahimov & Hasanov, 2021).

Table 1: Acceptable Requirements (EXFO Inc., 2011)**.**

Traffic Type	Real-Time Data	High-Priority Data	Best -Effort Data
CIR (Mbits/s) (Green traffic)	5	10	2.5
EIR (Mbits/s) (Yellow traffic)	0	5	5
Latency (ms)	< 5	5-15	< 30
Packet jitter (ms)	< 1		
Packet loss (%)	< 0.001	< 0.05	< 0.05

Committed Information rate (CIR) is the bandwidth which is supposed to be there at all times to support transmission of given service. The minimum key performance indicators (KPI) must be met at green traffic.

Excess Information rate is the additional bandwidth that is a beyond CIR that may be available depending on the network loading usage. When in yellow traffic, the minimum KPI may not be met.

Red traffic refers to the traffic that is beyond CIR or EIR rates and this traffic cannot be transmitted unless other services are disrupted.

2.0 Materials and Methods

Both Quantitative and qualitative data collection methods were used, the data was analyzed and then compared with the standards defined by IEEE and ITU before validation was done.

2.1 Equipment requirement

The device T-BERB/MTS 5800 presented in figure 1 was used to test for different parameters in the 10M, 10G, 25G, 40G and 100G links. For this research it was used to test the throughput and latency for both the 100G and 10G link rates.

Figure 1: Viavi test kit (Catalog)

2.2 Data collection

This was done by implementing or carrying out link tests in the field using the test equipment of VIAVI test set (T-BERT/MTS 5800).

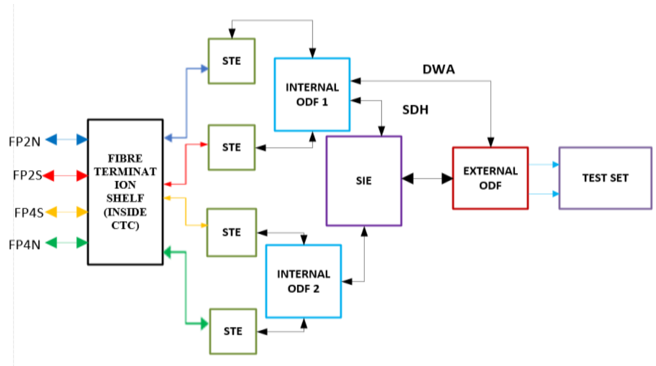

Figure 2: Four -fiber pair submarine system.

LEGEND

FIBER PAIR 2 NORTH

FIBER PAIR 2 SOUTH

FIBER PAIR 4 NORTH

FIBER PAIR 4 SOUTH

A submarine optical link is chosen as case study for analysis because of its long distance since its single mode optical fiber with zero dispersion wavelength of 1300nm plus reduced losses compared to other standards single mode optical fiber. It's a four-fiber pair submarine system as illustrated in figure 2.

The submarine fiber is connected via the fiber termination shelf from Power Feeding Equipment (PFE) at submarine cable landing station into submarine line terminal equipment, SLTE.

The SLTE products deliver large capacity, high reliability data transmission as well as high performance. The connection from SLTE is then distributed into internal optical distribution frame (ODF) through direct wavelength access (DWA) or SDH interconnection equipment.

The ODF provide end to end distribution of the backbone cable in the optical fiber communication and also handle termination and cross-connection of cables.

The internal ODF are then connected to SIE to the external ODF. Fiber patches are then connected from the E-ODF to the test equipment to undertake the test used in the analysis.

3.0 Results

The Viavi test equipment was used carried out all the tests for latency and throughput on both the 100G and 10G links, generated all the data required for the analysis including the starting time and the ending time.

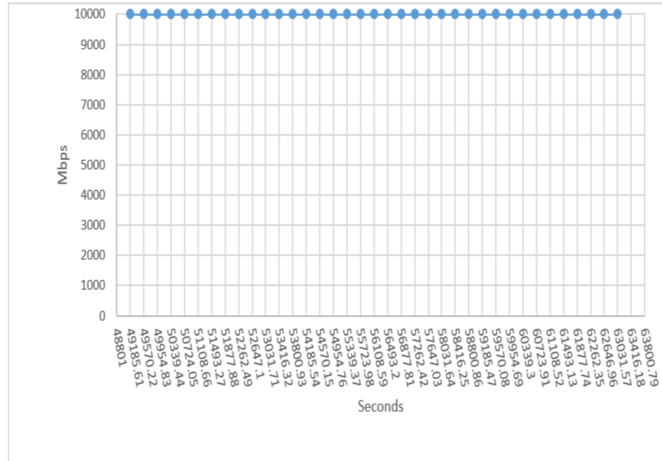

Figure 3: Throughput obtained in test 1.

The figure 3 shows the throughput measured in Mbps and each data transmitted over the 10G link. Each data packet was transmitted after every 384.61 seconds and the cumulative time in seconds was noted. This test was carried out from starting from 13:33:21pm and ended at 17:43:21 pm. The time was converted to seconds since throughput is always expressed in megabits per seconds. The test set recorded a new time after an interval of 5000 seconds and in 5000 second around 13 data points were transmitted over link. To get the time taken for which each data point to be transmitted,

$$\frac{5000}{13} = 384.61 \; seconds$$

Where 5000 is the time in seconds to transmit 13 data points.

The test gave 100% throughput meaning the available bandwidth was put to use and the data expected to be transmitted per second was transferred over the 10G link. This throughput from the test conformed to the defined because above it was 95% of the available bandwidth.

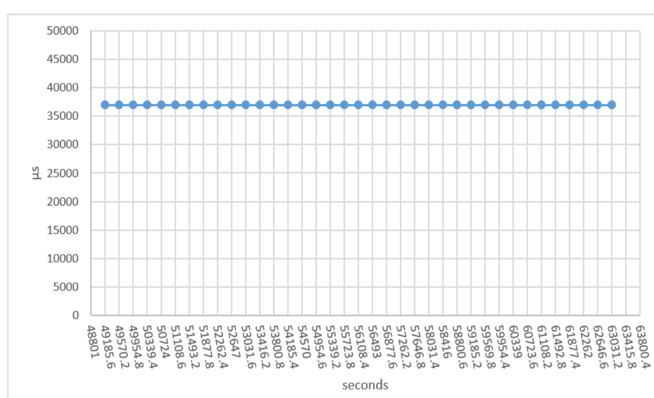

Figure 4: Latency obtained in test 1.

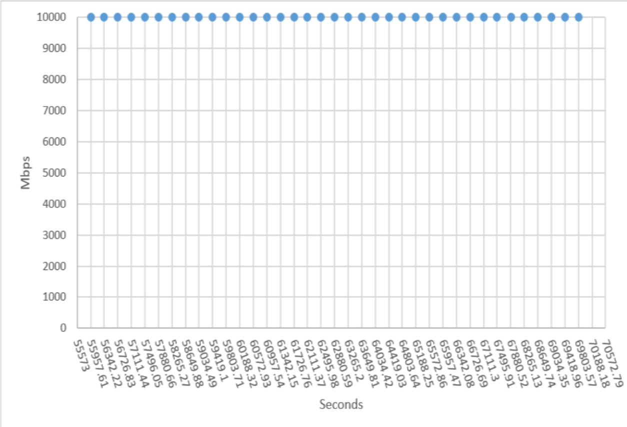

Figure 5: Throughput obtained in Test 2.

As presented in figure 4, the latency value in this test was 37000 µs and this was constant from the beginning of the test up to its end. It’s so difficult to eliminate latency completely in communication links but at least it can be reduced to low levels as it decreases the amount of data transmitted per second which is the throughput. Throughput of a given link is dependent to latency or delay encountered during transmission of data over that link.

As shown in figure 5 the test shows 100% throughput meaning the available bandwidth was put to use. Throughput is the best measure of performance of a network, if 100% of it is achieved it implies that all the data sent via that optical fiber link successfully reached their destination.

Similarly, figure 6 shows the latency value computed as 20000 µs and this was constant from the beginning of the test up to its end. This value conforms to the defined one by IEEE and ITU. Test 3 was carried out on the 100G optical link as shown in figure 7 and figure 8.

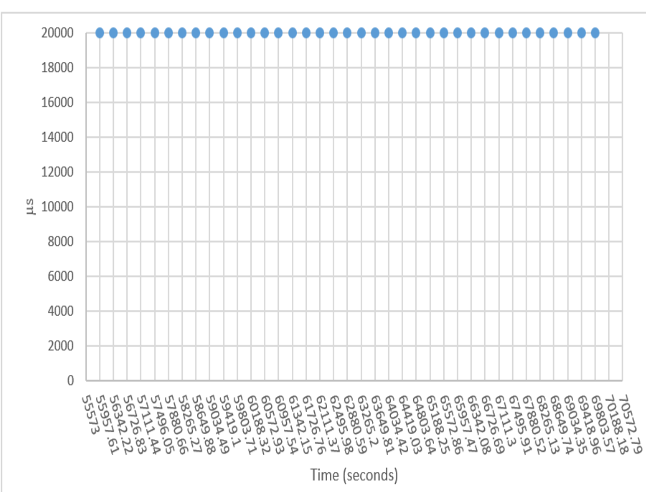

Figure 6: Latency obtained in test 2.

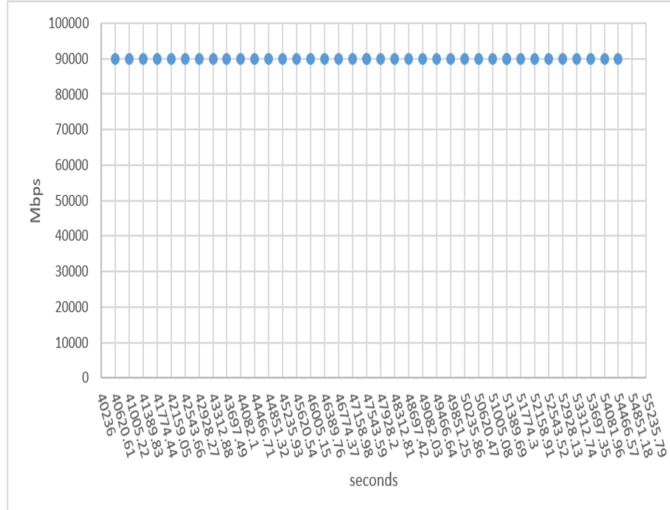

Figure 7: Throughput obtained in Test 3.

The throughput test in figure 7 above did not conform to the standards defined by IEEE and ITU because for a throughput test to be valid or be good, it should be at least 95% of the available bandwidth. The above throughput test was carried out on 100G optical fiber link, the 90000 Mbps in figure 7 shows that the actual amount of data transmitted per second is low.

Figure 8 shows that the latency obtained was 92000 µs, this value implies there was a longer delay and this really affected the throughput of the link. This bigger value of the delay is what lowered the throughput value in this test. Test 3 did not conform to standards defined by ITU and IEEE.

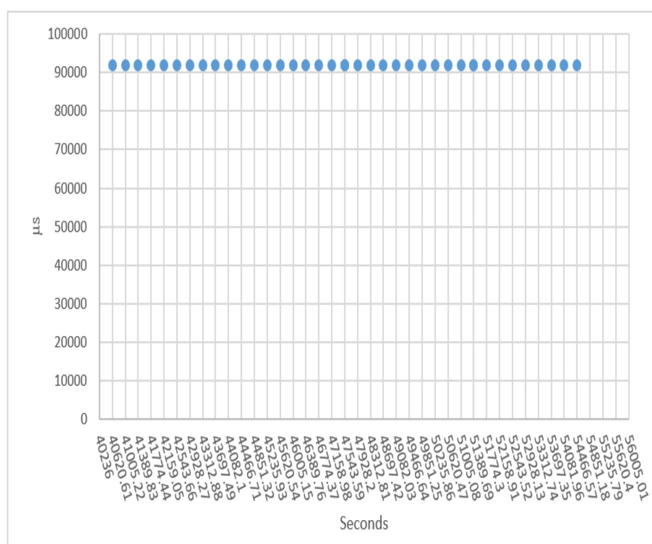

Figure 8: Latency obtained in Test 3.

4.0 Discussions

After the analysis, some of the test carried out conformed to the standards defined by ITU and IEEE when analysis was done while others data did not. There are different reasons as to why some test conformed to the defined standards and other did not as discussed below. Throughput and latency are interwoven in a way that if the latency on a given link is high leads to low throughput(Animura et al., 2020). The goal of every service provider is to ensure that the optical fiber link is used for transmission without issues for better Quality of Service as well as better Quality of Experience. Performance analysis is too important because it enables service providers to know how well the established link is running. If at all there are issues, they can be worked upon to ensure seamless communication. A given test was validated if all the parameters tested meet the defined standard. Tests were carried out at different time intervals in a given day and the variation of the different parameters was noted depending on the time the test was carried.

Quality of service in optical fiber communication is measured by the speed and reliability of that given network. If the speed is low, it means there will be delays in data transmission and this will lead to low throughput and high rates of frame losses. For service providers to promise their customers good quality of services, the network should be able to deliver or transfer data stably and it should be accessible. To ensure a stable and accessible network, the performance indices of throughput and latency should meet the defined standards. There are reasons why some of the tests did not conform with the standard defined ITU and IEEE as discussed below;

Congestion of the link. This occurs as a result of high traffic due to insufficient bandwidth and this affects network performance as its increase the delay in transmission thus reducing the throughput. Quality of Services is also affected as the link carries more data than it can handle thus leading to blockage of new connection. Congestion is time dependent, that's why there is always a reduction in the speed of a given optical fiber communication link between 7pm and 11pm. Through use of congestion avoidance techniques and congestion control technique this issue can be mitigated. Bandwidth upgrade is one of the most important mitigation measures of congestion in optical fiber communication. In case there is a bandwidth limitation on a 10G optical link, it can be replaced by 100G optical fiber link as it is a higher capacity compared to the 10G optical fiber link. The capacity of the optical fiber that is installed can be maximized via wideband transmission(Fischer et al., 2018).

Distance. Since data that is transmitted over submarine optical fiber cables travel over long distances before reaching their final destination, this greatly increases the latency in the optical fiber communication network. This is because the long distance makes the signal weaker as well as its signal strength. This greatly reduces the throughput of the given optical fiber as data takes a longer period of time to reach the intended destination. Several repeaters should be employed in order to increase the range of the transmitted signal thus enabling transmission of the optical signal over long distance with relatively limited delays.

Faulty hardware on the network. Dirty or poorly functioning hardware on an optical fiber link such as connectors and the fiber cable itself consume a lot of power and this greatly weaken the signal. When the signal strength is reduced, there are high attenuation levels which lead to delay thus low throughput.

The quality of optical fiber cable is also a very important factor in increasing delays in transmission when poor quality cable is used. Poor quality optical fiber cables lead too much delay values as latency is associated with the time it takes for light to be transmitted through the core and cladding in the optical fiber cable thus leading to low throughput. Poor quality cables are associated with chromatic dispersion which greatly increases the latency (Faramarz E. , 2020).

5.0 Conclusions

Different tests were carried out, some conformed with the defined standards by ITU and IEEE and others did not. Causes of latency that later reduces the throughput of the network were reported in this paper for those that did not conform with the standards. Latency is a very big issue as far as optical fiber communication is concerned and it should be worked upon in order to improve on both the Quality of service and Quality of Experience. It is shown that is can be reduced through ensuring that quality of optical fiber cable that is used for transmission is good, bandwidth upgrade to reduce congestion or maximizing the capacity via wideband transmission for the already installed optical fiber infrastructure, regular maintenance by service providers to sight out faulty components on the network and also employment of several repeaters for fiber that cover long distances.

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Declaration of conflict of interest

There was no conflict of interest

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