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RESEARCH ARTICLE

REVIEW ON CHARACTERIZING DIGITAL OPTICAL FIBER COMMUNICATION NETWORKS: A COMPARATIVE ANALYSIS

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ABSTRACT

The general outlook that is presented below in this paper describes the model of basic communication, types of fibers, and loss mechanisms in single-mode fibers. The performance of digital fiber optic communication systems will be considered for wavelengths of 1310, 1550 nm, transmission channels: copper wires, radio frequency (RF), and optical fibers. The paper looks into attenuation causes, which are absorption, scattering, and bending losses, and the possible impact these might have on signal quality along long distances. It also states what advantages lie in using optical fibers in data transmission at large bandwidths, and their dielectric nature. Finally, it discusses the challenges in fiber optic communication and promising developments in this field, including the development of integrated optics and modern optical fibers.

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INTRODUCTION

Optical fibers were invented in the 1960s, around the same time of invention of laser. Since then, use and demand for optical fibers have seen an astronomical surge. Today, fiber-optic systems are used in myriad applications mainly fuelled by the internet and e-commerce explosion, which have resulted in a tremendous influx of information traffic. And at this point, the message has to have some medium of transmission. Indeed, a medium must be considered, which could be equally limitless in bandwidth to cope with such an enormous volume of information. A fiber-optic data link comprises three major components: a transmitter, an optical fiber, and a receiver. Moreover, it also includes any splices or connectors used to join together the individual sections of optical fiber into each other and to the transmitter and receiver. Each component of the data link acts as an integral part of its operation. It actually is quite essential in transferring the signal. Point-to-point fiber-optic links are the core elements of all fiber-optic systems. In truth, fiber-optic systems come from such unions of point-to-point fiber-optic links. The transmission distance is inherently limited because of fiber losses, which diminish signal power on the receiver. However, it should be mentioned that although the fiber itself is low-loss, the spacing of the signal between amplifiers can be considered well below the threshold power of all optical receivers due to fiber losses, which can indeed be considered as below the threshold power of all optical receivers (Govind, 2002)

Attenuation

The significant property, which determines the optimum capacity of the transmission medium in optical fibers, is the signal loss, or attenuation, and the mechanism of signal distortions. Such properties and the mechanism of signal distortion determine the maximum distance between the transmitter and the receiver (or amplifier) at which the signal power needs to be amplified to a power level that allows clear reception. The extent of attenuation may vary in terms of wavelengths and the materials used in the construction of fibers. The loss of the fiber can be expressed as the negative logarithm of the input power (Pin) divided by the output power (Pout) within the fiber. The loss is usually expressed in terms of decibels per kilometre (dB/km) for optical fibers, with a being the attenuation coefficient (Ajoy Ghatak, 2020; Shehab, 2017; Nick Massa, 2000)

$Loss(dB) = -10\log (P_{out} / P_{in})$
$\alpha = (dB/km) = -(10/L) \log (P_{out} / P_{in})$

Where,

P_{in} - input power transmitted to the fiber
P_{out} - power received at the output of the fiber
α – attenuation co- efficient

Optical fibers can either be single-mode fibers (SM) or multimode fibers (MM). In order to accommodate large core diameters, high numerical apertures are used for multimode fibers, since the larger core diameters would also need increased light collection capacity, with small core diameters and high numerical apertures for short-distance, high-reliability applications. However, the multimode fiber bandwidth times distance is quite low compared with the single-mode fiber bandwidth times distance since multimode fibers can sustain the propagation of several modes (Bahaa, 1991) Besides, the attenuation coefficient (α) of single-mode fibers is less than that of multimode fibers.

Bending and Splice loss: The fibers are carriers of light that create the world's greatest communication network. Although not entirely functional, the fibers are affected by losses which ultimately lead to degradation in the quality of the transmitted signal. The optical losses, which have been broadly classified in two groups, are intrinsic and extrinsic. Intrinsic Losses—this is loss due to the fiber itself. It shows up due to the physical characteristics inherent in the fiber material, and it has always been there since it was produced. Light emission takes place inside the fiber, and this intrinsic loss starts at the very moment that the fiber is constructed. The most common types of intrinsic loss are scattering and absorption (Sangeetha, 2015) Scattering takes place whenever light rays inside the fiber touch on small irregularities of the fiber material and are scattered. On the other hand, absorption takes place when the light energy gets absorbed by the material of the fiber, which then changes into heat. In the end, this will end up reducing the power of the light signal as it propagates through the fiber (Raghuwanshi, 2014)

Extrinsic Losses is the loss that occurs due to causes around the fiber. These may occur as soon as the fiber is put into a system, mainly due to environmental reasons or improper treatment of the fiber. One of the most common types of extrinsic loss is the bending loss, which happens whenever the fiber is bent at a large angle and the incident angle on the fiber is greater than the critical angle.(9) At that time, the light comes out of the refractive interface of the fiber, thus resulting in a loss of signal power. Usually, the loss can be classified as macro-bending or micro-bending.

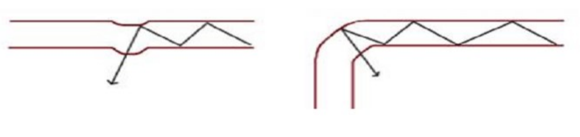

Fig.1Micro bending loss Macro bending loss

Macro-Bending Loss happens where the fiber is bent at a large angle so that the incident angle on the fiber is greater than the critical angle. At that time, light leaks out of the fiber, thereby causing loss. Generally, macro-bending is visually identifiable with the naked eye, and sometimes straightening the fiber will fix it. Micro-Bending Loss is a rather subtle but very slight type of loss induced by bending (Sandeep Singh, 2018). Most of the time, it originates from some form of defect in the surface of the fiber. It could be as a result of pressure applied to the fiber or at the interface between the fiber core and cladding through defects. Micro-bending loss is most often very small and almost imperceptible to the naked eye but has an adverse effect on the fibber's performance (Salleh, 2015)

Generally, the sensitivity of a fiber to bending-induced loss is highly dependent on the mode field diameter (MFD), which actually describes the area through which the light propagates inside a fiber. A fiber bent at a large angle will leak out much lighter when the MFD is large. In summary, splices required in fiber optic communication to perform the joining or linking of two or more fibers inside the transmission cable involve permanent or temporary methods. Fusion splicing is such a permanent method of splicing, while mechanical splices are temporary in nature. In fact, the splicing process is required for permanent connections to ensure optimum performance. It goes on to make temporary interruptions in the connection since it is either impossible or not done properly, hence causing loss in this kind of process. In general, splices can provide lower loss, greater physical strength, and lower cost compared to other fiber connecting methods, like connectors.

Bit Error Rate: One of the key metrics used in critical digital communication systems, such as those for optical fiber communications, is the Bit Error Rate (BER). The Bit Error Rate (BER) describes the relative amount of errors obtained between all the bits transmitted in a communication system. In other words, it is some way of estimating how many errors were received incorrectly from all the bits being sent. For instance, suppose you send a string of light signals through a fiber optic cable. Each light signal represents one bit of information: either '1' or '0'. When some of the light signals are lost or their state changes between '1' to '0' or vice versa, this means that bit errors have taken place. The bit error rate mainly stems from two main issues: fiber attenuation and noise. One big factor is fiber attenuation—all because of the material properties of the fiber and their extrinsic characteristics, such as temperature, pressure, or bending of the fiber. The other is noise. Just like radio static tends to be transmitted when tuning, an optical fiber can receive random interference from the environment. This is brought about by interference between the light signals and leads to the bit errors. Another factor is dispersion. Dispersion means that pulses, as being transmitted in optical fibers, reach different parts of the signal because different wavelengths travel differently through the fiber core. This helps in the possibility that some parts of the signal arrive at different times than others, which would therefore lead to the bit errors (Jahangir Alam, 2011)

Q- factor: Q-factor or Quality factor is a dimensionless parameter that indicates the quality of the signal in a fiber optic communication system. It represents the measure of separation between "0" and "1" levels in a digital signal with respect to the noise affecting the signal.

The Q-factor has a high value if there is little overlap between "0" and "1" levels, hence a low probability of errors in bits. Q-factor is proportional to the difference between the means divided by the sum of standard deviations of levels; this therefore depicts the separation between levels in units of the standard deviation. This definition may then be defined in such a way as it measures the difference between the means divided by the sum of standard deviations. This gives a measure of separation between levels.

$$Q = \frac{SNR\sqrt{2TBopt}}{1+\sqrt{1+2SNR}}$$

$$SNR = \frac{I_1 - I_0}{I_0}$$

Where,

T – Bit period
B_{opt} – Bandwidth of optical fiber

SNR – Signal to Noise ratio

I_0, I_1 – means of low pass filtered electrical current(13). The Q-factor and BER are related. As the Q-factor increases or separates between the "0" and "1" levels, BER reduces and represents fewer errors in the signal levels. On the other hand, if Q-factor decreases, BER increases and represents more errors within signal levels. This relationship may be estimated with the statistical error functions. For a binary signal that is subjected to Gaussian noise, BER can be derived from the Q-factor using the error function, which gives the probability of a random variable drawn from a Gaussian distribution having some value within a specified range. In everyday speech, this means that by improving Q-factor—for example, through increasing signal power or reducing noise—the BER reduces and, thus, improves the quality of the communication link. Conversely, factors that reduce Q-factor, such as attenuation and dispersion in the fiber, raise BER and degrade the quality of the link.(12)

$$BER = \frac{1}{2}\, erfc\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{1}{Q\sqrt{2\pi}}\exp\left(-\frac{Q}{2}\right)$$

Where,
erfc – complementary error function

DISCUSSION

A channel, in telecommunications terms, refers to the very crucial link that electrically connects the transmitter with the receiver. This could be a pair of wires, coaxial cable, free space, an optical fiber, or laser beam. This means that the channel should be properly chosen so as not to degrade the overall performance of the communication system. The optical fiber will be selected as the channel responsible for transmitting data from one point to another during this transmission process. However, during this transmission process, the signal gets distorted due to two main factors. The first one is system distortion, which is inherent in the system itself. Secondly, noise is usually random in nature and is introduced by various sources.

As the signal moves through the optical fiber, optical power loss rises linearly with the length of the fiber. This loss was found especially visible when wavelength 1310 nm is used in the transmission process. Optical losses were even found to be more prominent when using this wavelength as compared to using a wavelength of 1550 nm. Both Single Mode (SM) and Multimode (MM) fibers were used during this study, showing even more single-mode (SM) fiber loss compared to a multi-mode (MM) fiber. This was observed because single-mode fibers have smaller cores through which light travels in one path with less signalling distortion and hence minimal loss. On the other hand, multi-mode fibers have larger cores with signal distortion leading to an increase in loss. Occasionally, misplaced optical fibers may come into contact with anything else while installing them, hence these misplaced can lead to micro-bending loss. On the other hand, another type of loss that is experienced in optical fibers is macro-bending loss. It is realized that these bending losses do not remain constant but rather depend on the wavelength. There is an observation whereby as the wavelength increases, the bending losses also increase.Also increase in the number of splices between fiber optic causes an increase in BER and decreases in both SNR and Q-factor values in SM and MM fibers.

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