ANALYSIS OF BER AND Q-FACTOR OF OPTICAL FIBERS IN A COMMUNICATION NETWORK

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Abstract- Optical Fiber communication has been greatly effective in the modern communication system. This paper describes the effect of Signal-to-noise Ratio, Bit-Error-Ratio and Q-factor in Optical Fiber communication network. We have analyzed the characteristics of MAC and OFM transmitter /receiver devices in a network. We propose the possibility of a network where an application of Photonic Crystal Fibers can be realized in which will have lower values of Signal-to-Noise Ratio and Bit-Error-Ratio and improved Q-factor.

Keywords: MAC; OFM; BER; SNR; Q-factor

INTRODUCTION

Optical communication is any type of communication in which instead of electrical current, light is used to carry the signal to the remote end. Optical communication depends upon optical fibers to carry signals to their respective destinations.

The components of an Optical communication system are as follows:

- Transmitter: An electronic signal is converted into a light signal by a transmitter. Semiconductors devices are the most commonly used such as light-emitting diodes (LEDs) and Laser diodes.
- Receivers: Light is converted into an electric current using a photo-detector due photoelectric effect which is installed in the receiver which is a semiconductor-based photodiode.
- Optical Fiber: It consists of a cladding, a core and a buffer. Through the buffer the cladding guides the light onwards the core. This is based upon total internal reflection

Recommender system suggest the items to user on the basis of their preferences. For this specific purpose, it uses various filtering techniques.

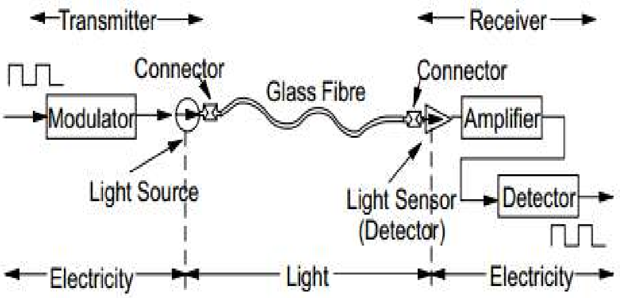

Fig. 1 Basic Components of an Optical Communication System

Advantages of Optical Communication are as follows:

1. Weight and size reduced
2. Material cost reduced
3. Information capacity increased
4. Negligible Electromagnetic Interference

This paper is divided into six sections. The first section focusses on basics of Communication in the optical fibers and its mechanism. The second section briefs about the types of noises in a Communication System which creates a random disruption in the transmission and the reception of the signals. Section three and four define Signal to Noise ratio (SNR) which is defined as is the figure of merit for evaluating the performance of the communication system [5] and Bit error Rate (BER) defined as the rate at which errors occur in a transmission system. It can be directly translated into the number of errors that occur in a string of a stated number of bits and factors affecting them. A network is considered and analyzed for various factors such as the SNR and BER calculations in the considered computer network and observed the respective results in section five and in the last section, hollow core optical fibers are explained and their advantages in computer networks over the traditional optical fibers.

- **Fiber Optic Communication:** The most modern form of broadband communication today is Fiber optic communication. The technology has gone through many revolutions through time since its commencement. It has seen an unparalleled growth and technological reform in last two decades. The modern application using information technology has been greatly benefitted during this technology. In Optical Fiber communication, light pulses are sent through an optical fiber which carries information to be transmitted from one place to another. In order to carry information, light creates an electromagnetic wave carrier. Fiber optics communication have the following basic steps: Optical signals created using transmitter, the signal is relayed along the fiber, Optical signal is received so that the signal does not become weak or distorted, and then converts optical signal into an electrical signal [2].

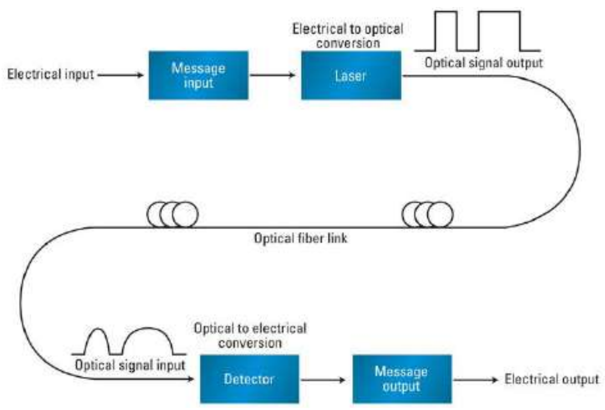

Fig. 2 Components of point-to-point Optical Fiber Communication System

- **Noise:** In a Communication System, Noise is an unwanted signal which creates a random disruption in the transmission and the reception of the signals. Occurrence of noise in a communication system is mainly due to external sources (e.g. interference generated by device next to the receiver system) or may be generated from spontaneous fluctuations internal to a circuit.External noise may be classified into the following three types [3]:
    - *Atmospheric noises*
    - *Extraterrestrial noises*
    - *Man-made noises or industrial noises.*

  Internal noise may be put into the following four categories.
    - *Thermal noise or white noise or Johnson noise*
    - *Shot noise.*
    - *Transit time noise*
    - *Miscellaneous internal noise*

- Thermal Noise: Noise generated in any resistance due to random motion of electrons is called thermal noise or white or Johnson noise.
  Within any resistor there exists a random motion of electrons which leads to random current. In the load resistor RL the mean square thermal noise is [4].

$$\overline{i_{NT}^2} = \frac{4k_B T \Delta f}{R_L}$$

  Here Δ f is the bandwidth of detection. The incidence of Optical Power does not affect the Thermal Noise.

- Shot Noise: Shot noise is random its average value is zero. Hence mean square short noise current is given by [4]

$$\overline{i_{NS}^2} = 2e(I + I_d)\Delta f$$

Where, e= electron charge, I= average current and Δ f= bandwidth

- Signal-to-Noise Ratio (SNR): Signal-to-Noise Ratio is the figure of merit for evaluating the performance of the communication system [5].

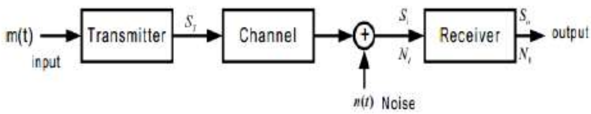

Fig. 3 Communication system with additive noise

During transmission a certain signal m(t) is transmitted with power ST. s(t) is corrupted by noise n(t). The channel may also attenuate or distort the signal. At the receiver we have mixed noise and signal. The receiver processes the signal to get desired Signal power S_o and Noise power N_o

The signal to noise ratio is given by

$$\frac{S}{N} = \frac{Signal\ Power}{Noise\ Power}$$

The total mean square noise current which actually is the sum of Shot noise and Thermal noise is directly proportional to the total noise power. Therefore [4],

$$\text{SNR} = \frac{R^2 P^2}{2e(I + I_d)\Delta f + 4k_B T/R_L \cdot \Delta f}$$

Where, R is Responsivity, P is the Optical Power

For Shot Noise limited

$$\text{SNR} = \frac{R^2 P^2}{2e(RP + I_d)\Delta f}$$

Where, I=RP

For Thermal Noise

$$\text{SNR} = \frac{R^2 P^2 R_L}{4k_B T \Delta f}$$

SNR can also be defined in terms of Ratio of Signal Power over Noise Power.

$$Signal\ TO\ Noise\ Ratio = 10\log\frac{Signal\ power}{Noise\ Power} = 10\log\frac{P_s}{P_n}$$

The signal to noise in dB is expressed by

$$\left(\frac{S}{N}\right)_{dB} = 10\log_{10}\left(\frac{S}{N}\right)$$

- Bit Error Rate (BER): BER is a key parameter that is used in assessing systems that transmit digital data from one location to another

  Bit Error Rate = Number of errors/Total number of bits sent

  Too high BER indicates that a slower data rate would improve the overall transmission time for a given amount of transmitted data since the BER might be reduced, lowering the number of packets that had to b present [6]. A Rayleigh, or fading, signal path is not "noise" in the intuitive sense of the familiar hissing sound of "white noise," but it is a random process that is analyzed in the same manner as Gaussian noise [7].
- BER and SNR: With SNR having higher values the BER would be significantly lower. BER is related to SNR through the equation [4].

$$\text{BER} = \frac{1}{2}\left[1 - \text{erf}\left(\frac{\sqrt{\text{SNR}}}{2\sqrt{2}}\right)\right]$$

Where, erf is the error function. For x>3

$$\text{erf}(x) = 1 - \frac{1}{\sqrt{\pi}x}e^{-x^2}$$

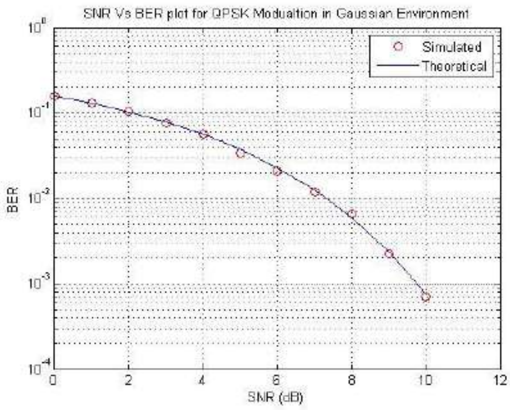

Figure 4. The graph shows the proportionality of SNR with respect to BER [9]

II. Fiber Optic Computer Networks

With the advent of application of fiber optical cables, there has been significant increase in the quality and dynamicity of modern-day computer networking.

We observe here a Star Topology network where we employed optical fibers as the medium of communication, also adding to it two different transmitter and receiver devices at the end junctions of the optical fiber media. For one node we used Media Access Converter (MAC) and for the others we used an Optical Fiber Module (OFM).

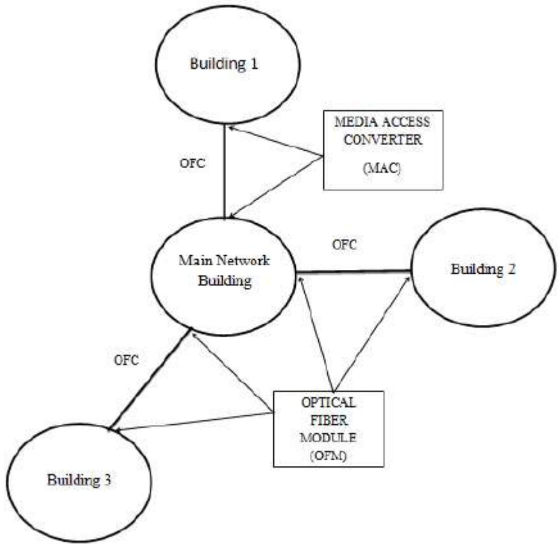

Figure 5. Optical Fiber Network in Star Topology

We observe here a Star Topology network where we employed optical fibers as the medium of communication, also adding to it two different transmitter and receiver devices at the end junctions of the optical fiber media. For one node we used Media Access Converter (MAC) and for the others we used an Optical Fiber Module (OFM). We then calculated the Signal-to-Noise Ratio (SNR), Bit Error Rate (BER) and the Q-factor values resulted in the network for both the devices i.e. MAC and OFM.

The sample network has a bit-rate of 100 Mbps.

Calculation of Signal-to-Noise Ratio (SNR), Bit Error-Rate (BER) and Q-factor in a silicon PIN photodiode. Necessary terms to be used for calculation: -

Δf = Bandwidth

b = Bit-rate

c = Capacitance

Load Resistor (R_L) = $1/\pi*c*b$

R = Responsivity

$P_{min} = (2*q*\Delta f) / R$

T = Temperature

SNR = -32.12dbm

BER =1/2 (1-0.995)

BER = 0.00224

Q-Factor = 2.84

Now let us consider an Optical Fiber Module (OFM) having a germanium PIN photodiode Model no. DEM311GT

Δf = b =100 Mbps = 1,000,000,000 bps

c = 2pm = 2×10^{-12}

$R_L = 1/\pi*c*b = 965.06\ \Omega$

R= 0.65 A/W

$P_{min} = (2*q*\Delta f) / R = 4.923 \times 10^{-11}$ W

T=22 degree Celsius = 295.15 K

SNR = 10.008 X 10-7 W = - 29.996527033 dbm

BER = 1/2 (1-0.993922571)
= 1/2 (0.006077429)
=0.0030387145
BER = 0.0030

erfc (Q/√2)= 0.0030387145 *2
Q/√2 = 1.94
Q-Factor = 2.74

We find that the SNR values are less and the BER values are subsequently greater in terms of OFM as compared to the values of MAC. So, that the higher the SNR, the lower would be corresponding BER. Moreover after the calculation of Q-factor it is observed that the OFM has less Q-factor than MAC

These values of SNR, BER and Q-factor suggest that the employment of a complete Optical communication network has many advantages such as reduction of attenuation and improved quality in the signal transmission.

However these standards set up by Optical Fibers can also be improved by the application of Photonic Crystal Fibers.

III. Photonic Crystal Fibers

Photonic crystal fibers, also known as micro structured or holey fibers, have recently generated great interest in the scientific community. Photonic crystal fibers have driven an exciting and irrepressible research activity all over the World, starting in the telecommunication field and then touching metrology, spectroscopy, microscopy, astronomy, micromachining, biology and sensing.

Figure 6: A frequently used solid-core photonic crystal fiber design [10].

- Properties Achievable by Design: Photonic crystal fibers with different designs of the hole pattern (concerning the basic geometry of the lattice, the relative size of the holes, and possibly small displacements) can have very remarkable properties, strongly depending on the design details:
  - It is possible to obtain a very high numerical aperture of e.g. 0.6 or 0.7 of multimode fibers(also for the pump cladding of a double-clad fiber) [11].
  - Single-mode guidance over very wide wavelength regions (endlessly single-mode fiber) is obtained for small ratios of hole size and hole spacing [12].
  - Extremely small or extremely large mode areas (possibly with a lower NA than possible with a conventional fiber) are possible. These lead to very strong or very

weak optical nonlinearities. PCFs can be made with a low sensitivity to bend losses even for large mode areas [13].

- Certain hole arrangements result in a photonic bandgap (→ photonic bandgap fibers), where guidance is possible even in a hollow core, as a higher refractive index in the inner part is no longer required. Such air-guiding hollow-core fibers are interesting e.g. for dispersive pulse compression at high pulse energy levels.
- Particularly for larger holes, there is the possibility to fill gases or liquids into the holes. This can be exploited for fiber-optic sensors, or for variable power attenuators.
- Asymmetric hole patterns can lead to extremely strong birefringence for polarization-maintaining fibers [8]. This can also be combined with large mode areas.
- Strongly polarization-dependent attenuation (polarizing fibers) [14, 15] can be obtained in different ways. For example, there can be a polarization-dependent fundamental mode cut-off, so that the fiber guides only light with one polarization in a certain wavelength range.
- Similarly, it is possible to suppress Raman scattering [16] by strongly attenuating longer-wavelength light.
- Very unusual chromatic dispersion properties, e.g. anomalous dispersion in the visible wavelength region [17], result particularly for PCFs with small mode areas. There is substantial design freedom, allowing for different combinations of desirable parameters.

Types of Photonic Crystal Fibers

1. Index-Guiding Fibers
2. Photonic Bandgap (Air Guiding) Fibers

Table 1. Difference between Solid and Hollow core photonic crystal fiber

Feature	Solid core Photonic Crystal Fiber	Hollow Photonic Crystal Fiber
Guidance Mechanism	Total internal reflection at boundary between high index solid core and lower "average" index between air and glass index photonic crystal cladding.	Photonic bandgap cladding confines light to an evacuated or gas filled core.
Possible Design Features	• Endlessly single mode at all wavelength • Large mode area at short wavelengths • High non-linearity Multiple cores in one fiber	• Operating bandwidth ±10% of design wavelength • Zero dispersion close to design wavelength • Near Gaussian shaped fundamental mode M2 value • Modal index ≈1. Virtually no Fresnel reflection
Applications	• Power delivery (endlessly single mode fiber) • Sensors (PM fiber)	• Power delivery (short pulses and CW) • Pulse shaping and compression • Spectroscopy

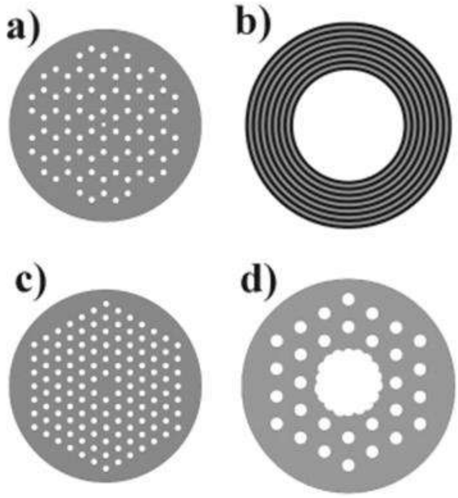

Fig.7 Different types of photonic bandgap PCFs
((a) Honeycomb photonic bandgap fiber [23], (b) Bragg hollow core fiber[24], (c) Hexagonal lattice solid-core photonic bandgap fiber, (d) Large hollow core hexagonal lattice fiber)

IV. CONCLUSION

It is to be concluded that a network system which employs an optical communication system has revolutionized the traditional network scenario as its application has increased the SNR, decreased the BER and improved the Q-factor values of the communication media which would be beneficial in low loss optical transmission. We need to have a system where the application of photonic crystal fibers can significantly increase the data transmission rate in a network.

V. FUTURE SCOPE

An application of Photonic Crystal fibers on any network can be observed and its characteristics such as data transmission rate signal strength with respect to distance, Calculation of the Signal-to-noise ratio (SNR) and Bit-Error-Rate can be performed. This may give us an insight of the advantages and disadvantages of employing a network system using Photonic Crystal fibers.

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