OPTICAL FIBER COMMUNICATION EVOLUTION, TECHNOLOGY AND FUTURE TRENDS

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Abstract: -iber optic systems are important telecommunication infrastructure for world-wide broadband networks. Wide bandwidth signal transmission with low delay is a key requirement in present day applications. Optical fibers provide enormous and unsurpassed transmission bandwidth with negligible latency, and are now the transmission medium of choice for long distance and high data rate transmission in telecommunication networks. This paper gives an overview of fiber optic communication systems including their key technologies, and also discusses their technological trend towards the next generation.

Index Terms: - Bandwidth, Broadband, Fiber optics, Latency, Telecommunication.

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I. INTRODUCTION

The major driving force behind the widespread use of fiber optics communication is the high and rapidly increasing consumer and commercial demand for more telecommunication capacity and internet services, with fiber optic technology capable of providing the required information capacity (larger than both wireless connections and copper cable). Advances in technology have enabled more data to be conveyed through a single optical fiber over long distances. The transmission capacity in optical communication networks are significantly improved using wavelength division multiplexing.

A desirable feature for future optical networks is the ability to process information entirely in the optical domain for the purpose of amplification, multiplexing, de-multiplexing, switching, filtering, and correlation, since optical signal processing is more efficient than electrical signal processing.

Several new classes of optical communication networks are presently emerging. For example, Code Division Multiple Access networks using optical signal processing techniques have recently being introduced. Despite the associated benefits of utilizing optical fiber for communication (such as its high reliability over long distances, low attenuation, low interference, high security, very high information capacity, longer life span and ease of maintenance), research is still ongoing to further improve on the present fiber optics communication system, and also to solve some of the challenges facing it. Future optical communication systems are envisioned to be more robust than the present system. This paper is organized as follows. Section II describes the basic principles of fiber optics communication. Section III looks at the history and evolution of fiber optics communication while section IV gives the technology involved. Section V presents comparison with electrical transmission and section VI showcases some envisioned future trends in fiber optics communication. In section VII discusses the limitations and in section VIII, we draw the conclusion for the paper.

II. BASIC PRINCIPLES OF FIBER OPTIC COMMUNICATION

Fiber optic communication is a communication technology that uses light pulses to transfer information from one point to another through an optical fiber. The information transmitted is essentially digital information generated by telephone systems, cable television companies, and computer systems. An optical fiber is a dielectric cylindrical waveguide made from low-loss materials, usually silicon dioxide. The core of the waveguide has a refractive index a little higher than that of the outer medium (cladding), so that light pulses is guided along the axis of the fiber by total internal reflection. Fiber optic communication systems consists of an optical transmitter to convert an electrical signal to an optical signal for transmission through the optical fiber, a cable containing several bundles of optical fibers, optical amplifiers to boost the power of the optical signal, and an optical receiver to reconvert the received optical signal back to the original transmitted electrical signal. Figure 1 gives a simplified description of a basic fiber optic communication system.

Fig.1. Basic fiber optic communication system

Optical fibers fall into two major categories, namely: step index optical fiber, which include single mode optical fiber and multimode optical fiber, and graded index optical fiber. Single mode step index optical fiber has a core diameter less than 10 micrometers and only allows one light path. Multimode step index optical fiber has a core diameter greater than or equal to 50 micrometers and allows several light paths, this leads to modal dispersion. Graded index optical fibers have their core refractive index gradually decrease farther from the centre of the core, this increased refraction at the core centre slows the speed of some light rays, thereby allowing all the light rays to reach the receiver at almost the same time, thereby reducing dispersion. Figure 2 gives a description of the various optical fiber modes.

Fig2: optical fiber modes

III. EVOLUTION OF FIBER OPTICS COMMUNICATION

Optical fiber was first developed in 1970 by Corning Glass Works. At the same time, GaAs semiconductor lasers were also developed for transmitting light through the fiber optic cables. The first-generation fiber optic system was developed in 1975, it used GaAs semiconductor lasers, operated at a wavelength of $0.8\ \mu\text{m}$, and bit rate of 45 Megabits/second with 10Km repeater spacing.

In the early 1980's, the second generation of fiber optic communication was developed, it used InGaAsP semiconductor lasers and operated at a wavelength of $1.3\ \mu\text{m}$. By 1987, these fiber optic systems were operating at bit rates of up to 1.7 Gigabits/second on single mode fiber with 50Km repeater spacing.

The third generation of fiber optic communication operating at a wavelength of $1.55\ \mu\text{m}$ was developed in 1990. These systems were operating at a bit rate of up to 2.5 Gigabits/second on a single longitudinal mode fiber with 100Km repeater spacing.

The fourth generation of fiber optic systems made use of optical amplifiers as a replacement for repeaters, and utilized wavelength division multiplexing (WDM) to increase data rates. By 1996, transmission of over 11,300Km at a data rate of 5 Gigabits/second had been demonstrated using submarine cables.

The fifth-generation fiber optic communication systems use the Dense Wave Division Multiplexing (DWDM) to further increase data rates. Also, the concept of optical solitons, which are pulses that can preserve their shape by counteracting the negative effects of dispersion, is also being explored. Figure 3 shows the evolution of fiber optic communication.

Fig3: Evolution of fiber optic communication

IV. TECHNOLOGY

Modern fiber-optic communication systems generally include an optical transmitter to convert an electric signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of Amplifiers, and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information generated by computers, telephone systems and cable television companies.

A. Transmitters:

The most commonly used optical transmitters are semiconductor devices such as light-emitting diodes(LEDs) and laser diodes. The difference between LEDs and laser diodes is that LEDs produce incoherent light, while the laser diodes produce coherent light. For use in optical communications, semiconductor optical transmitters must be designed to be compact, efficient, and reliable while operating in an optimal wavelength range and directly modulated at high frequencies. The output of a Laser is relatively directional, allowing high coupling efficiency (~50%) into single-mode fiber. The narrow spectral width also allows for high bit rates since it reduces the effect of chromatic dispersion. Furthermore, the semiconductor lasers can be modulated directly at high frequencies because of short recombination time. Commonly used classes of semiconductor laser transmitters used in fiber optics include VCSEL (Vertical Cavity Surface Emitting Laser), and DFB (Distributed Feed Back). Laser diodes are often directly modulated, that is the light output is controlled by a current applied directly to the device. For very high data rates or very long distance links, a laser source may be operated continuous wave, and the light modulated by an external device such as electro-absorption modulator eliminating laser chirp, which broadens the linewidth of directly modulated lasers, increasing the chromatic dispersion in the fiber.

B. Receivers

The main component of an optical receiver is a photo detector, which converts light into electricity using the photoelectric effect. The photodetector is typically a semiconductor-based photodiode. Several types of photodiodes include p-n photodiodes, p-i-n photodiodes, and avalanche photodiodes. Metal semiconductor-metal (MSM) photo detectors are also used due to their suitability for circuit integration in regenerators and wavelength-division multiplexers. Optical-electrical converters are typically coupled with a Transimpedance amplifier and a limiting amplifier to produce a digital signal in the electrical domain from the incoming optical signal, which may be attenuated and distorted while passing through the channel. Further signal processing such as clock recovery from data (CDR) performed by phase-locked loop may also be applied before the data is passed on.

C. Amplifiers

The transmission distance of a fiber-optic communication system has traditionally been limited by fiber attenuation and by fiber distortion. By using opto-electronic repeaters, these problems have been eliminated. These repeaters convert the signal into an electric signal, and then use a transmitter to send the signal again at a higher intensity than it was at before. Because of the high complexity with modern wavelength-division multiplexed signals (including the fact that they had to be installed about once every 20km) the cost of these repeaters is very high. An alternative approach is to use an optical amplifier, which amplifies the optical signal directly without having to convert the signal into the electrical domain. It is made by doping a length of a fiber with the rare-earth mineral erbium and pumping it with light from a laser with a shorter wavelength than the communications signal (typically 980nm). Amplifiers have largely replaced repeaters in new installations.

D. Wavelength-division-multiplexing

Wavelength-division multiplexing (WDM) is the practice of multiplying the available capacity of optical fibers through use of parallel channels, each channel on a dedicated wavelength of light. This requires a wavelength division multiplexer in the transmitting equipment and demultiplexer (essentially a spectrometer) in the receiving equipment. Arrayed waveguide gratings are commonly used for multiplexing and demultiplexing in WDM. Using WDM technology, now commercially, the bandwidth of a fiber can be divided into as many as 160 channels to support a combined bit rate in the range of 1.6 Tbit/s.

E. Bandwidth-distance product

The value of a product of bandwidth and distance is a criteria because there is a tradeoff between the bandwidth of the signal and the distance the signal can be carried. For example, a common multi-mode fiber with bandwidth-distance product of 500MHz signal for 1km or a 1000MHz signal for 0.5 km. IN INTENSIVE DEVELOPMENT new scientists have managed to reach speed of 101 Tbit/s by multiplexing 370 channels over single fiber, while similar Japanese effort reached 109 terabits per second, but through a difficult production of cable with seven fibers. But this is rarely matching the 50% per year exponentially increasing backbone traffic.

F. Transmission windows

Each effect that contributes to attenuation and dispersion depends on the optical wavelength. The wavelength bands (or windows) that exist where these effects are weakest are the most favorable for transmission. These windows have been standardized, and the currently defined bands are the following:

Band	Description	Wavelength Range
O band	Original	1260 to 1360 nm
E band	Extended	1360 to 1460 nm
S band	short wavelengths	1460 to 1530 nm
C band	conventional ("erbium window")	1530 to 1565 nm
L band	long wavelengths	1565 to 1625 nm
U band	ultralong wavelengths	1625 to 1675 nm

This table shows that current technology has managed to bridge the second and third windows that were originally disjoint.

V. COMPARISON WITH ELECTRICAL TRANSMISSION

The choice between optical fiber and electrical (or copper) transmission for a particular system is made based on a number of trades-offs. Optical fiber is generally chosen for systems requiring higher bandwidth or spanning longer distances than electrical cabling can accommodate. The main benefits of fiber are its exceptionally low loss (allowing long distances between amplifiers/repeaters), its absence of ground currents and other parasite signal and power issues common to long parallel electric conductor runs (due to its reliance on light rather than electricity for transmission, and the dielectric nature of fiber optic), and its inherently high data-carrying capacity.

Thousands of electrical links would be required to replace a single high bandwidth fiber cable. Another benefit of fibers is that even when run alongside each other for long distances, fiber cables experience effectively no crosstalk, in contrast to some types of electrical transmission lines. Fiber can be installed in areas with high electromagnetic interference (EMI), such as alongside utility lines, power lines, and railroad tracks. Optical fibers are more difficult and expensive to splice than electrical conductors. And at higher powers, optical fibers are susceptible to fiber fuse, resulting in catastrophic destruction of the fiber core and damage to transmission components. Nonmetallic all-dielectric cables are also ideal for areas of high lightning-strike incidence. In short distance and relatively low bandwidth applications, electrical transmission is often preferred because of its:

- Lower material cost, where large quantities are not required.
- Lower cost of transmitters and receivers.
- Capability to carry electrical power as well as signals (in specially designed cables).
- Ease of operating transducers in linear mode.

Because of these benefits of electrical transmission, optical communication is not common in short box-to-box, backplane, or chip-to-chip applications; however, optical systems on those scales have been demonstrated in the laboratory. Optical fiber cables can be installed in buildings with the same equipment that is used to install copper and coaxial cables, with some modifications due to the small size and limited pull tension and bend radius of optical cables. Optical cables can typically be installed in duct systems in spans of 6000 meters or more depending on the duct's condition, layout of the duct system, and installation technique. Longer cables can be coiled at an intermediate point and pulled farther into the duct system as necessary. In certain situations fiber may be used even for short distance or low bandwidth applications, due to other important features:

- Immunity to electromagnetic interference, including nuclear electromagnetic pulses (although fiber can be damaged by alpha and beta radiation).
- High electrical resistance, making it safe to use near high-voltage equipment or between areas with different earth potentials.
- Lighter weight—important, for example, in aircraft.

VI. FUTURE TRENDS IN FIBER OPTICS COMMUNICATION

Fiber optics communication is definitely the future of data communication. The evolution of fiber optic communication has been driven by advancement in technology and increased demand for fiber optic communication. It is expected to continue into the future, with the development of new and more advanced communication technology. Below are some of the envisioned future trends in fiber optic communication.

A. All Optical Communication Networks

An all-fiber optic communication is envisioned which will be completely in the optical domain, giving rise to an all-optical communication network. In such networks, all signals will be processed in the optical domain, without any form of electrical manipulation. Presently, processing and switching of signals take place in the electrical domain, optical signals must first be converted to electrical signal before they can be processed, and routed to their destination. After the processing and routing, the signals are then re-converted to optical signals, which are transmitted over long distances to their destination. This optical to electrical conversion, and vice versa, results in added latency on the network and thus is a limitation to achieving very high data rates.

Another benefit of all optical networks is that there will not be any need to replace the electronics when data rate increases, since all signal processing and routing occurs in the optical domain. However, before this can become a reality, difficulties in optical routing, and wavelength switching has to be solved. Research is currently ongoing to find an effective solution

to these difficulties.

B. Multi – Terabit Optical Networks

Dense Wave Division Multiplexing (DWDM) paves the way for multi-terabit transmission. The world-wide need for increased bandwidth availability has led to the interest in developing multi-terabit optical networks. Presently, four terabit networks using 40Gb/s data rate combined with 100 DWDM channels exists. Researchers are looking at achieving even higher bandwidth with 100Gb/s. With the continuous reduction in the cost of fiber optic components, the availability of much greater bandwidth in the future is possible.

C. Intelligent Optical Transmission Network

Presently, traditional optical networks are not able to adapt to the rapid growth of online data services due to the unpredictability of dynamic allocation of bandwidth, traditional optical networks rely mainly on manual configuration of network connectivity, which is time consuming, and unable to fully adapt to the demands of the modern network. Intelligent optical network is a future trend in optical network development, and will have the following applications: traffic engineering, dynamic resource route allocation, special control protocols for network management, scalable signaling capabilities, bandwidth on demand, wavelength rental, wavelength wholesale, differentiated services for a variety of Quality-of-Service levels, and so on. It will take some time before the intelligent optical network can be applied to all levels of the network, it will first be applied in long-haul networks, and gradually be applied to the network edge.

D. Ultra – Long Haul Optical Transmission

In the area of ultra-long haul optical transmission, the limitations imposed due to imperfections in the transmission medium are subject for research. Cancellation of dispersion effect has prompted researchers to study the potential benefits of soliton propagation. More understanding of the interactions between the electromagnetic light wave and the transmission medium is necessary to proceed towards an infrastructure with the most favorable conditions for a light pulse to propagate.

E. Improvements in Laser Technology

Another future trend will be the extension of present semiconductor lasers to a wider variety of lasing wave lengths. Shorter wavelength lasers with very high output powers are of interest in some high-density optical applications. Presently, laser sources which are spectrally shaped through chirp managing to compensate for chromatic dispersion are available. Chirp managing means that the laser is controlled such that it undergoes a sudden change in its wavelength when firing a pulse, such that the chromatic dispersion experienced by the pulse is reduced. There is need to develop instruments to be used to characterize such lasers. Also, single mode tunable lasers are of great importance for future coherent optical systems. These tunable lasers lase in a single longitudinal mode that can be tuned to a range of different frequencies.

F. Laser Neural Network Nodes

The laser neural network is an effective option for the realization of optical network nodes. A dedicated hardware configuration working in the optical domain and the use of ultra-fast photonic sections is expected to further improve the capacity and speed of telecommunication networks. As optical networks become more complex in the future, the use of optical laser neural nodes can be an effective solution.

G. Polymer Optic Fibers

Polymer optical fibers offer many benefits when compared to other data communication solutions such as copper cables, wireless communication systems, and glass fiber. In comparison with glass optical fibers, polymer optical fibers provide an easy and less expensive processing of optical signals, and are more flexible for plug interconnections. The use of polymer optical fibers as the transmission media for aircrafts is presently under research by different Research and Development groups due to its benefits. The German Aerospace Center have concluded that “the use of Polymer Optical Fibers multimedia fibers appears to be possible for future aircraft applications. Also, in the future, polymer optical fibers will likely displace copper cables for the last mile connection from the telecommunication company’s last distribution box and the served end consumer. The future Gigabit Polymer Optical Fiber standard will be based on Tomlinson-Harashima Precoding, Multilevel PAM Modulation, and Multilevel Coset Coding Modulation.

H. High – Altitude Platforms

Presently, optical inter satellite links and orbit-to-ground links exists, the latter suffering from unfavorable weather conditions. Current research explores optical communication to and from high altitude platforms. High altitude platforms are airships situated above the clouds at heights of 16 to 25Km, where the unfavorable atmospheric impact on a laser beam is less severe than directly above the ground. As shown in figure 4, optical links between high-altitude platforms, satellites and ground stations are expected to serve as broadband back-haul communication channels, if a high-altitude platform functions as a data relay station.

I. Improvements in Optical Transmitter/Receiver Technology

In fiber optics communication, it is important to achieve high quality transmission even for optical signals with distorted

waveform and low signal to noise ratio during transmission. Research is ongoing to develop optical transceivers adopting new and advanced modulation technology, with excellent chromatic dispersion and Optical Signal to Noise Ratio (OSNR) tolerance, which will be suitable for ultra-long haul communication systems. Also, better error correction codes, which are more efficient than the present BCH concatenated codes are envisioned to be available in the nearest future.

J. Improvement in Optical Amplification Technology

Erbium Doped Fiber Amplifier (EDFA) is one of the critical technologies used in optical fiber communication systems. In the future, better technologies to enhance EDFA performance will be developed. In order to increase the gain bandwidth of EDFA, better gain equalization technology for high accuracy optical amplification will be developed. Also, in order to achieve a higher output power, and a lower noise figure, high power pumping lasers that possess excellent optical amplification characteristics with outputs of more than +20dBm, and very low noise figure are envisioned to exist in the nearest future.

K. Advancement in Network Configuration of Optical Submarine Systems

In order to improve the flexibility of network configuration in optical submarine communication systems, it is expected that the development of a technology for configuring the mesh network will be a step in the right direction. As shown in figure 5, while a ring network joins stations along a single ring, a mesh network connects stations directly. Presently, most large scale optical submarine systems adopt the ring configuration. By adopting the optical add/drop multiplexing technology that branches signals in the wavelength domain, it is possible to realize mesh network configuration that directly inter-connects the stations. Research is ongoing, and in the future such network configuration will be common.

L. Improvement in WDM Technology

Research is ongoing on how to extend the wavelength range over which wave division multiplexing systems can operate. Presently, the wavelength window (C band) ranges from 1.53-1.57 μ m. Dry fiber which has a low loss window promises an extension of the range to 1.30 – 1.65 μ m. Also, developments in optical filtering technology for wave division multiplexing are envisioned in the future.

M. Improvements in Glass Fiber Design and Component Miniaturization

Presently, various impurities are added or removed from the glass fiber to change its light transmitting characteristics. The result is that the speed with which light passes along a glass fiber can be controlled, thus allowing for the production of customized glass fibers to meet the specific traffic engineering requirement of a given route. This trend is anticipated to continue in the future, in order to produce more reliable and effective glass fibers. Also, the miniaturization of optical fiber communication components is another trend that is most likely to continue in the future.

VII. OPTICAL FIBER LIMITATIONS

- Optical Fiber cables have limited bend radius (about 30 mm). So, if they are bent more, it might lead to some signal loss. But recently, bend resistant fibers have been introduced which have higher tolerance to bending.
- Unlike Copper UTP cables which have standard Rj-45 Jacks and connectors (mostly), optical fiber cables have many types of connectors and this lack of standardization adds confusion.
- By bending the normal optical fiber cables, some leakage of signal could be induced and that can be used for hacking the information in them. So, even though doing that might be difficult, they are not totally tamper proof.
- Single mode cables and their associated optics (active components) are very expensive. Even though multi-mode cables/ optics are less expensive, they are not even close to the costs of copper UTP cables/ ports. Moreover, multi-mode cables have restrictions in distance for supporting higher bandwidth (like 1 Gbps and 10 Gbps).
- There are outdoor fiber cables but they need to be shielded well. This shielding makes them less agile/ flexible to run in all the places and it increases the cost of cables as well.
- Fiber cables cannot be directly terminated on to the network/ optical switches. They need a whole array of active/ passive components like SFP Modules, Fiber Patch Cords, and appropriate connectors and Couplers. All these components add the cost of fiber network implementation at each location.

VIII. CONCLUSION

The fiber optics communications industry is an ever evolving one, the growth experienced by the industry has been enormous this past decade. There is still much work to be done to support the need for faster data rates, advanced switching techniques and more intelligent network architectures that can automatically change dynamically in response to traffic patterns and at the same time be cost efficient. The trend is expected to continue in the future as breakthroughs already attained in the laboratory will be extended to practical deployment thereby leading to a new generation in fiber optics communications.

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