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Trend of Optical Fibre in the Next Generation

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Abstract— According to the requirements of high bandwidth capacity, low-latency cellular capability, gigabit high speeds, and more available spectrum for communications in both uplink and downlink bands, the ever-present 4G cellular network is poised to be restructured by 5G networks. The paper first considers the principles of optical fibre communications, and then focuses on the characteristics of different types of optical fibres. Finally, the paper considers key technologies in ever-more dramatic advances in the next generation of 5G wireless network. The ultimate objective of this paper is to highlight how optical fibre will be deployed in 5G systems as it plays a vital role in the transition toward the next mobile cellular network, supporting the exponential increase in both Internet of Things (IoT) devices and personal smart devices in the 5G network infrastructures.

Index Terms— Optical fibre communications, 5G networks, Wireless technology, Fibre-based next-generation, Wired communications.

1 Introduction

Communication can be defined as the process of conveying information, data, signal, or an image from one position, i.e. information sink, to another position, i.e. destination point, over the transmission medium. A communication system typically occurs when an information is intended to be transmitted or transferred over arbitrary distances. It is achieved by modulating the transmitted signal onto a form of an electromagnetic carrier wave to carry information. This modulated carrier is then transmitted through the optical fibre to the destination point. Then, the modulated signal is converted into an electrical signal in order to obtain an original information.

2 Principles of Optical Fibre Communication Systems

2.1 Transmission inside Optical Fibre

The basic principles of communication systems are shown schematically in Figure 1. The transmitter receives the input electric signal transmitted from the optical source. The information source provides an electrical signal, for example, a sound, to a transmitter which comprises of electrical and electronic components [1]. At this stage, the information signal is converted into a suitable form that is ready to be transmitted over the transmission medium. This process can be accomplished by modulating the optical carrier. The transmission medium can be a pair of twisted wires, a coaxial cable, a radio link, or an optical fibre. Here in this paper we put emphasis on data transmission over an optical fibre.

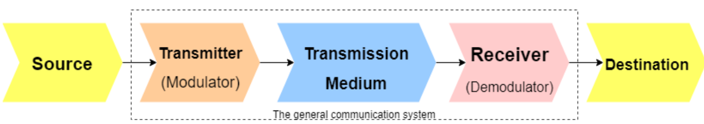

Fig. 1. Block diagram of general communication systems.

The schematic diagram of the optical fibre communication system is shown in Figure 2. The information from the source provides an electrical signal which drives an optical source to modulate the lightwave carrier. The optical source, e.g. a semiconductor laser or LED, provides the electrical-optical (e-o) conversion. Then, the optical signal is transmitted over the transmission medium (i.e. an optical fibre). Once the signal arrived at a receiver side, the transmitted signal (in a form of an optical signal) is converted back into the original information signal (i.e. in a form of an electrical signal) by demodulating the signal before through the optical detector. Moreover, the photodiodes, phototransistors, and photoconductors can be used as an optical detector so as to perceive the received optical signal and perform the optical-electrical (o-e) conversion.

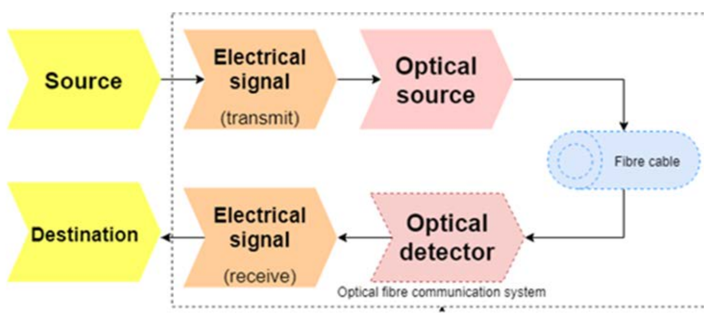

Fig. 2. Configuration of optical communication systems [2].

The modulation of lightwave can be utilised using either an analog or digital information signal. Analog modulation gives a continuous variation of lightwave emitted from the optical source, whereas discrete changing (ON-OFF keying) of light pulse intensity can be obtained from digital modulation [2]. Analog modulation is less efficient with an optical fibre communication since it requires a higher signal-to-noise ratio than digital modulation. Such that analog optical fibre communication links are limited to short haul applications, operated at lower frequency band with lower bandwidth than a digital link.

A transmission of digital information over an optical fibre is described in Figure 3. First of all, the digital information source is encoded for the optical transmission purpose. Then, the intensity of semiconductor laser with digital encoded signal is modulated directly in process of laser drive circuit. After that, a digital optical signal is launched into the optical fibre link. To provide a gain as well as reduce the noise, the avalanche photodiode (APD) or any kind of detector is commonly introduced after receiving information form the transmission medium with the help of amplifier and equaliser to boost the dropped signal. At the last stage, the received signal is decoded to recover the original digital information.

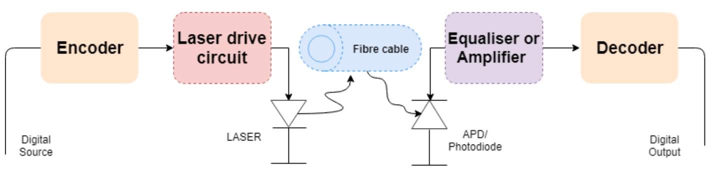

Fig.3. Block diagram of digital optical fibre communication link, having a laser source and detector at the transmission end and receiving end, respectively.

2.2 Signal Detreiorations in Optical Fibre

It should be noted that the transmitted light power propagating in a fibre decays exponentially over distances of a few meters to hundreds of kilometers due to absorption of light rays and scattering of parts of the light during the propagation process. Additionally, the transmitted pulse tends to overlap with neighboring pulses as they propagate along the length of the fibre. As a result of pulse broadening, the neighboring pulses can no longer be recovered at the receiver after travelling along optical fibre for a certain time. This effect is known as dispersion of the transmitted signal [3]. It is suggested that signal deteriorations need to be minimised in optical communications, specifically in long haul applications. The effects of attenuation and dispersion of the optical pulses are revealed in Figure 4.

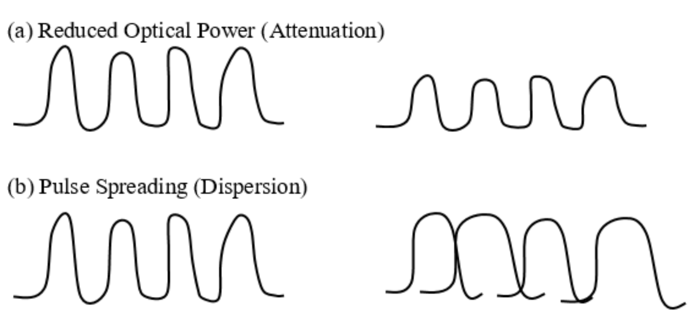

Fig. 4. The major two signal deteriorations occur in fibre optics. In (a) attenuation of light rays caused a reduction of optical power and (b) dispersion causes the optical signal spreading along the fibre.

3 Transmission Characteristics of Lightwave in Optical Fibre

3.1 Structure of Fibre Optic

Optical fibre is made from thin strands of either glass or plastic. They are typically made of silica with index-modifying dopants of Germanium dioxide (GeO_2) with a refractive index of about 1.60. There are three main components of the optical fibre; fibre core, fibre cladding, and an external protective jacket. The fibre core is located in the central region, having a higher refractive index. It is surrounded by the cladding, that is made of material of lower refractive index.

3.2 Light propagation insides the cylindrical fibre

As soon as the light ray is injected into an optical fibre, it enters the denser medium, corresponding to the inner core of the fibre. When the light ray travels from the higher refractive index to lower refractive index (i.e. from the core to cladding). The phenomenon of total internal reflection describes the propagation of light. All light rays bounces back and forth in an optical fibre displaying the phenomenon known as the total internal reflection (TIR) when it is injected into an optical fibre at an optimal angle [4].

The light is totally reflected back into the core and continues bouncing along the length of the fibre. Consequently, light can travel large distances through an optical fiber with a few optical losses. It should be noted that the light ray guides from the denser medium to the lower refractive index medium so that the angles of the total internal reflection remain the same at every position in the optical fibre.

The cladding should be thick enough in order to support the waveguide structure and reduce the radiation loss into the surrounding air. Typically, the lightwave travels in both the core and the cladding parts allowing the fields to exponentially decaying at the interface between the core and cladding. This is because the effect of the leaky modes that are continuously taking the optical power away from the direction of transmission as they propagate along the fibre. Some lights are partially guided to the core region and are eventually lost by radiating their power out of the core and so leak out of the fibre. Thus the total internal reflection will no longer take place along the direction of propagation.

3.3 Capability of Light Gathering in Optical Fibre

The refractive index difference between the fibre core and cladding will cause any arriving ray to be reflected along the core of an optical fibre. Figure 5 presents the maximum acceptance amount of light incident into an optical fibre. A key

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parameter to determine the maximum amount of light entering into a fibre core is known as numerical aperture (NA) of the fibre. It can be found from the following equation:

$$\mathrm{NA} = n_0 \sin\theta_{\max} = \sqrt{n_1^{\,2} - n_2^{\,2}} = n_1\sqrt{2\Delta} \qquad (1)$$

where n_0 is the refractive index of air, n_1 is the refractive index of the core, n_2 is the refractive index of the cladding, and Δ is the relative refractive index difference between the core and cladding. Thus relative refractive index difference is defined by [4]:

$$\Delta = \frac{n_1^{\,2} - n_2^{\,2}}{2n_1^{\,2}} \approx \frac{n_1 - n_2}{n_1} \qquad (2)$$

On the other hand, when the light is injected at an angle greater than the maximum acceptance angle, then some fraction of the light travels into the cladding region and will be guided for a short distance only and be lost, as illustrated in Figure 5.

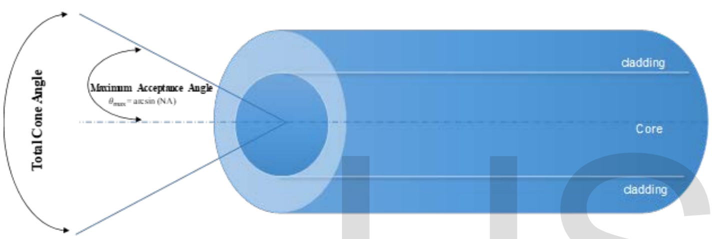

Fig. 5. Maximum acceptance amount of light incident in an optical fibre.

There is a trade-off between increasing the efficiency of optical fibre with less errors and a decrease in data rate of the signal. It is clear that the higher the value of NA the more lights can be propagated throughout out the optical fibre as compared with the smaller NA and hence increasing the efficiency of an optical fibre since more light reaches the receiver end. Conversely, a larger amount of lights propagating in a fibre with high value of NA can lead to greater dispersion, causing light pulses broadening.

3.4 Classification of Optical Fibres

Capable of a large carrying capacity and operating at longer distances are key challenges exist in the design of optical transmission systems. The use of optical fibres as a transmission medium is being increasingly improved for deployment in ever wider applications. The performance of optical fibre systems required to meet the higher bandwidth requirements and the greater transmission distances of a particular optical fibre depend on the refractive index profiles and the core size of the fibre for future communications.

A typical glass fibre can classified into two classes, identified by their size of the core, i.e. single mode fibre and multimode fibre. The core diameter of a single mode fibre core is about 5 μm to 10 μm with a cladding diameter of 125 μm whereas the core diameter of the multimode fibre has a typical size of 50 μm or 62.5 μm with the same size of the cladding [4].

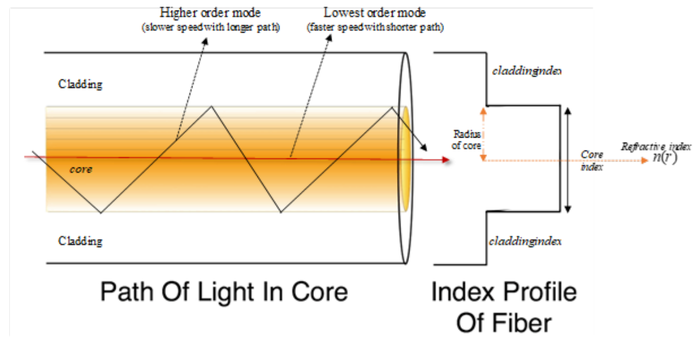

Fig. 6. Characteristics of light propagation in an optical fibre with a step index profile.

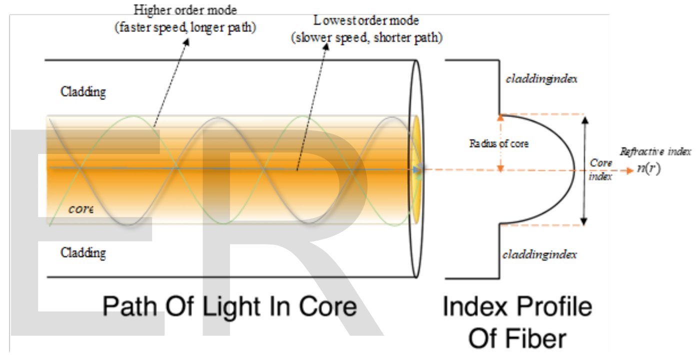

Fig. 7. Characteristics of light propagation in an optical fibre with a graded index profile.

A circular dielectric waveguide can be characterised based on the refractive index profile of the fibre into two major types; step index profile and graded index profile. The schematic diagrams showing light wave propagation in step index fibre and graded index fibre are shown in Figure 6 and Figure 7, respectively.

The refractive index in that of the step index fibre has a uniform profile throughout the core of the fibre with a step index changes at the boundary between the core and cladding. On the other hand, the refractive index of the fibre core with a graded index type changes slowly as the light rays tends to propagate out of the central core. This means that the light rays propagating further away from the optical axis propagates faster than that propagating near the core axis. It can be understood that the light rays traveling close to the central core of fibre takes a shorter path to reach the destination at a slower speed than that traveling near the core-cladding boundary [3, 4].

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4 Fibre Optic as a Key to 5G Network Infrastuuctures

The launch of the fifth generation (5G) allows user equipment (UE) to communicate with each other or access through an online world with an ultra-low latency, high bandwidth carrying capacity, faster speed from short communication range (i.e. device-to-device) to long distance communications (i.e. access point-to-device). A lot of fibre optics will be needed to support unlimited bandwidth potential, real-time communication with faster exchange speed of a growing number of communicating devices in 5G networks [5, 6].

Indeed, a number of small cells must be installed to meet expected requirements of 5G networks so as to reduce existing dead spot areas. However, small cells will be critical at higher frequency bandwidths since 5G will need to operate above 24 GHz and into the millimeter waves frequency range. In contrast, it needs to operate below 6 GHz for lower frequencies [7].

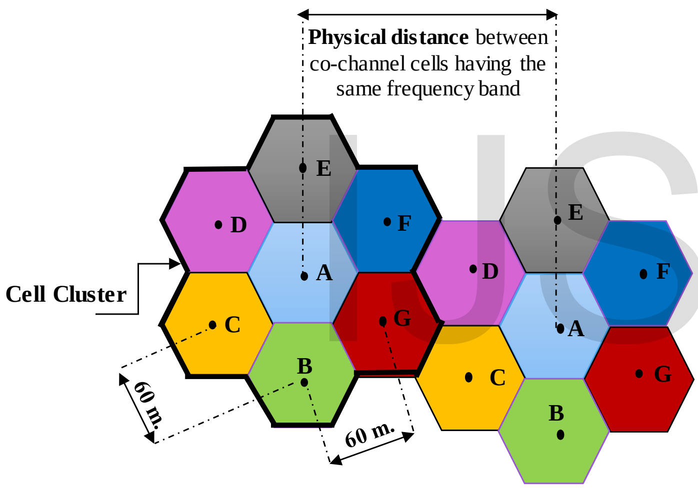

Fig. 8. Conceptual of cellular frequency of 5G networks with a spaced distance between neighboring small cells of 60 meters.

From the current perspective of 5G networks, it is suggested that a neighboring small cells should be kept apart from each other by approximately 60 meters (about 200 foots) for maximum data rates [8]. As a result, the user equipment or Internet of Things (IoT) devices obviously can look for a good connection to the surrounding base station. Figure 8 shows the frequencies reuse model enabling cellular systems to handle a large number of services simultaneously and efficiently within limited distances between the neighboring cells. There are two cell clusters showing in Figure 8. A cluster is defined as a complete set of available frequencies in which the same group of channels (i.e. the same labelling alphabet letter) can be found in another cell cluster further distance away without interference.

It can be seen that fibre optic is one of the important player for the backhaul portion of 5G network due to its key features. Fibre optic has ability to handle the massive data being generated and exchanged. Moreover, it can handle an increased speed with lower attenuation of 5G network. Also, it is immune to electromagnetic inferences with high security.

5 Conclusion

For the 5G network development, it is therefore necessary to make the technological correlation between the wired infrastructure (i.e. in the focus of the fibre optic connection) and wireless networks in which the connection between mobile radio stations and optical fibres need to be established at certain points. In addition, the need to build up many small cells and connect them to the fiber optic network also depends directly on the services and their 5G requirements. However, challenges remain in the focus of the 5G networks deployed in various applications such as Industry 4.0, the Internet of Things (IoT), the Internet of Vehicles (IoV), and vehicle-to-vehicle (V2V) connections. Further activities would reveal the extent to which types of optical fibres as well as index profile would be suitable for the 5G network infrastructure.

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