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Generation Next Optical Infrastructure Technology 3-M's

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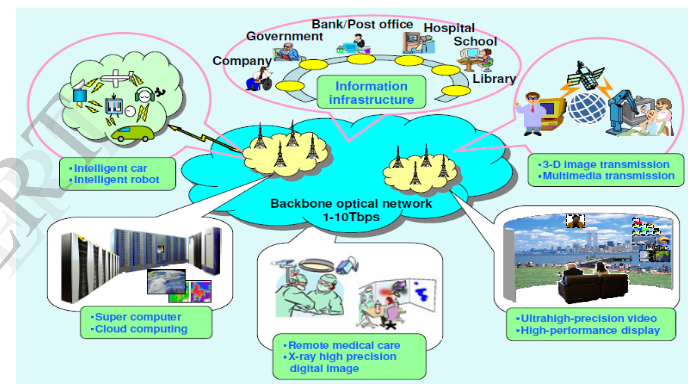
Abstract

During the past few years, the capacity of the optical communication infrastructure in back bone networks has tremendously increased as it allows fast transmission of data. Within more 10 or less years, the information capacity will grow more and more and in order to solve, this problem, giga bits transmission system, won't work, it will require network, which will work in peta bits or Exa bits. And for this very purpose, the idea of 3M technologies has been proposed. So, in this paper, the physical challenges which are creating hurdles to implement this technology completely is reviewed and recent developments in two M's i.e. multi-core and multi-mode technologies with respect to 3M technologies in order to complete the Generation Next optical Infrastructure technology is discussed.

Introduction

With the development of WDM and EDFA ,over the last few years the ,the capacity of the optical communication infrastructure in backbone networks has increased a thousand-fold and is still increasing at a fast pace. According to the analysis, there has been three times increase in transmission rate per Fiber in optical communication network, thus achieving transmission rate of the order of tera bits/transmission [1]. Although, there are vast developments taking place in the field of optical fiber communications field, the information capacity is increasing at a very fast rate approximately 40% annually [2].



New Services In Future[9]

This implies ,within near future or within a span of 10-20 years we will be in need of that core network which can support throughput in Exa bits/s and backbone transmission must support Peta bits/s per fiber instead in Giga bits as many new applications and services will come in existence as shown in figure above. However, it is widely recognized that the maximum transmission capacity of a single strand of fiber is rapidly approaching its limit at ~100 Tbit/s owing to optical power limitations imposed by the fiber fuse phenomenon and the finite transmission bandwidth determined by optical amplifiers [2]. So, in order to look for alternatives and explore new ideas to solve these kind of issues a study group called EXAT (Extremely Advanced Transmission) was launched by Japan in 2008 , where all researchers ,academicians, scientists were requested to look for this challenge collectively and the main focus of this study was to identify physical limitations, i.e., the amount of optical power (bit/s rate) that can be transmitted safely during transmission in optical fibers, the optical bandwidth for optical amplification, and the capacity of optical submarine cables systems now limited by the electrical power supplied to the optical amplifier repeaters [3].And finally , the concept of 3-M technologies came in existence. By the term 3-M technologies , it means three core technologies i.e. Multi-Level Modulation format, Multi-Core Fibers(MCF) and Mode division Multiplexing [4].This idea has already grasped attention of many world renowned scientists of the same field and many papers have been presented in conferences within these some years. Thus, in this paper, the physical factors which are hampering this future technology along with review of developments in two M'S i.e. Multi- core and Mode technology is reviewed.

The organization of paper is as follows: Section 2 deals with physical factors which are acting as inhibitor to achieve high transmission over optical fiber communication network. Section 3 is related to advancements in two M's i.e. multi-mode and multi core followed by future work and finally section 4 in which conclusion and References is given.

Section 2

3M (multi) technologies

By the term 3-M technology we simply mean the combination of three technologies i.e. "Multi-core Fiber technology" "Multi-mode Control technology" and "Multi-level Modulation technology" and together, these are known as 3-M technologies. In fig 2, the concept of 3-M technologies is given.

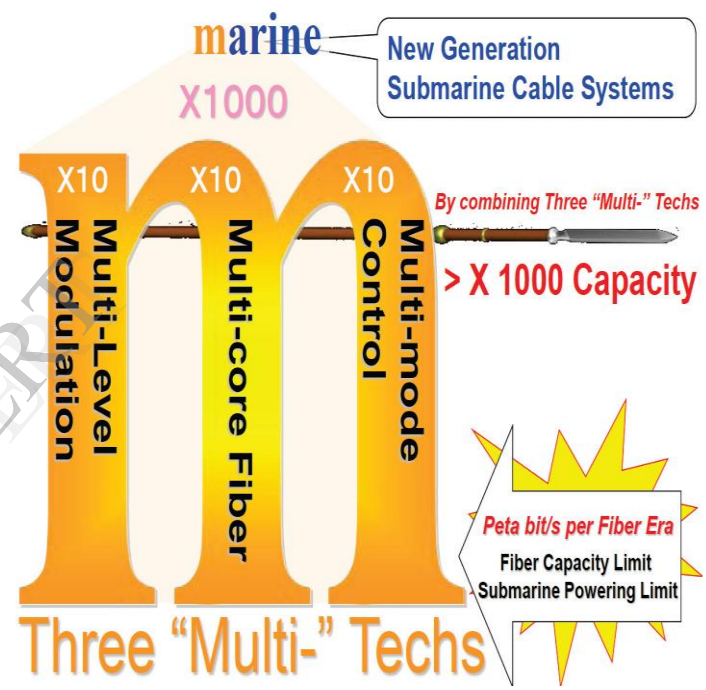


Fig. 2. Three "Multi-" (3M) Technologies to achieve >1000 x capacity and throughput[1]

To combine all these three technologies together ,tedious research is going on in EXAT and currently focus is on studying these three areas based on 3-M technology.

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Physical Limitations

There are three major limiting factors, which are hampering the future high speed optical communication infrastructure as already mentioned above. In the figure 1, technological overview of optical fiber system is given.

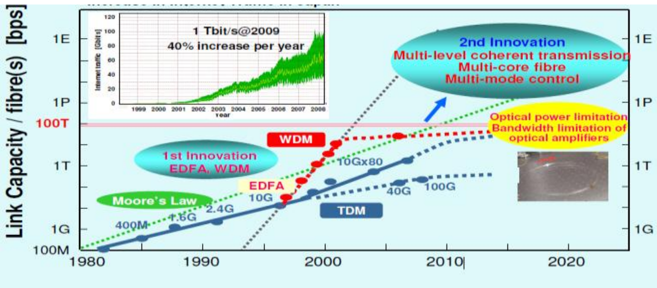
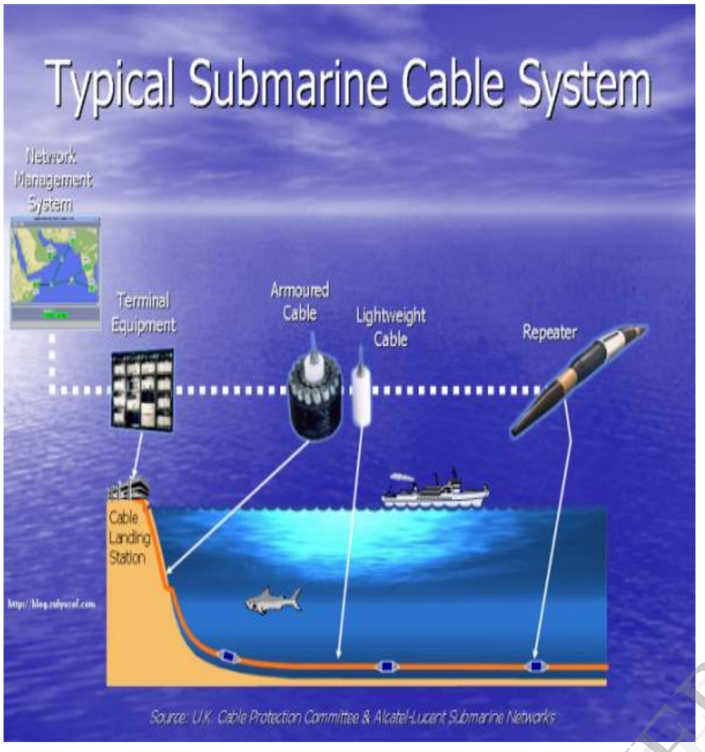


Fig. 1.Overview of Optical Fiber Transmission [1].

1.Optical fibers have been installed around the globe in late 70's ,so it has been more than 30 years now and noone has imagined that time how much optical power(photons per second ,i.e bits) can be transmitted safely without any fiber damage for a long distance and nonlinear interactions[1].It was during 90's ,when new technologies arised like wave division multiplexing ,optical fiber amplifiers and so on that non linear interactions i.e. noise which arised due to various optical non linear effects and a more destructive phenomenon of fiber fuse arised which caused permanent thermo-chemical damage to the fiber cores propagating for a long distance [5].In addition, recently developed distributed Raman amplifier systems requiring pumping powers of several hundred mW up to W pause a big challenge on how to further increase the capacity where its total input optical powers are approaching the fiber fuse propagation threshold power of around 1.2~1.5 W [6]. It should be anticipated that the maximum capacity of practical systems limited by the fiber fuse phenomenon would be around 100 Tbit/s per fiber assuming a substantial improvement in optical amplifier NFs (noise figures) and more power-efficient modulation schemes, which is only 1.5 orders of magnitudes larger than those of the present Tbit/s systems.

2. The optical bandwidth for optical amplification would also be a major limiting factor for long-haul transmission systems and networks. Presently, low-loss 1.5 µm bands of C-band (1530 nm-1565 nm) or L-band (1565 nm-1625 nm) with each amplifier bandwidth of about 40 nm (5 THz) are currently being used for long haul transmission. Since the total amplifier bandwidth including S-band (1460 nm-1530 nm) should be estimated to be around 120 nm (15 THz), the maximum long-haul capacity would amount to around 150 Tbit/s, assuming 10 bit/s/Hz frequency utilization efficiency. Although this value could further be increased by utilizing broadband Raman amplification and/or 1.3 µm bands, the optical power limitation from the fiber fuse should limit the ultimate capacity in the present systems[1].

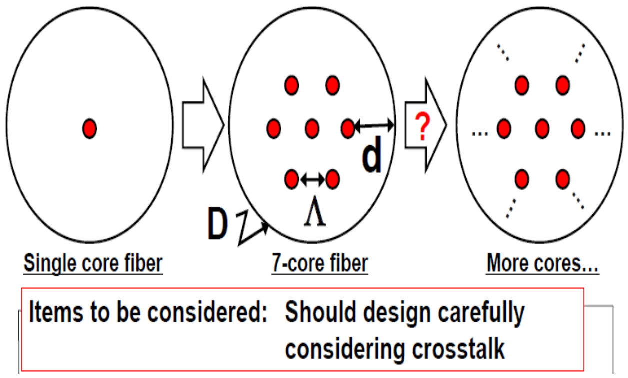
3. The base of global broadband connection is Optical submarine cable systems and there is a limitation on its cable capacity due to high pressure-proof cable design and electrical powers supplied to the optical repeaters from lands, the present maximum capacity per cable remains to be about 10 Tbit/s (10 Gbit/s, 128 WDM, eight fiber pairs) [1].



SECTION 3

Advancements in 2M's(Multi-core and Mode)

1. Space division multiplexing in multi-core fibers



Till today, the basic parameters for optical fibers have remained unchanged and in order to overcome the power limitation, we have to shift from single core to multi core. And one of the basic parameters for optical fibers have in multi-core design is to minimize the crosstalk between any pair of cores [2]. It has been found that the crosstalk in MCF is described by coupled-power theory more accurately than coupled-mode theory [14]. This indicates that the dominant factor as regards the crosstalk is stochastic mode coupling along the MCF due to longitudinal perturbations. The crosstalk is also found to be significantly affected by fiber bending [15]. Recently, a novel technique for measuring the mode coupling along an MCF using synchronous multi-channel optical time domain reflectometry (OTDR) was proposed [16]. The OTDR technique has been found to be very useful for evaluating the polarization mode coupling that occurs locally along a polarization-maintaining fiber. A schematic diagram of the MCF mode coupling measurement and the experimental results are shown in Fig. 4. As shown in Fig. 4(a), the backscattered light passing through each core of the MCF, *Pbsn*, is detected by multichannel synchronous OTDR, which is shown in Fig. 4(b). The mode coupling along the fiber can be obtained from the power ratio between the backscattered signals coming through each mode as shown in Fig. 4(c). It is important to note that this technique also clarifies the non-uniformity of the mode coupling coefficient along the fiber caused by the structural irregularity of the fiber. Furthermore, the power ratio is proportional to the fiber length, with the slope we can therefore obtain the mode coupling coefficient by taking the derivative of the

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power ratio, which is shown in Fig. 4(d). These results indicate that the mode-coupling coefficient varies with the position, and there is a structural irregularity that must be eliminated. As an attempt to suppress crosstalk without adversely affecting core density, trench-assisted MCF has been proposed, which is composed of cores[2] with depressed cladding [2, 17].

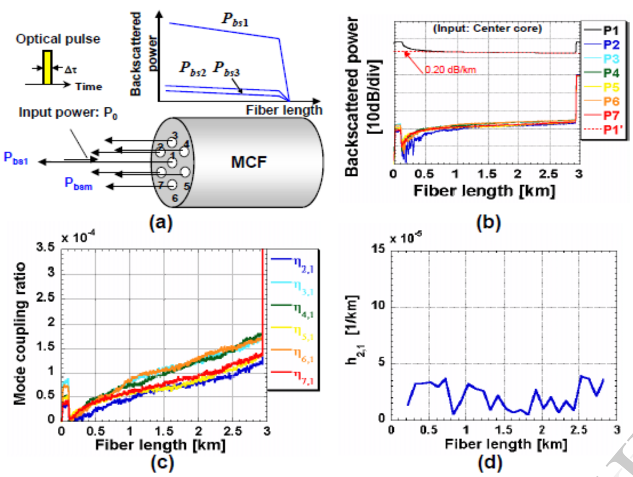

Fig. 4. Measurement of mode-coupling along MCF using multi-channel OTDR. (a) Measurement principle, (b) Backscattered OTDR signals, (c) Mode coupling ratio from center to outer cores, (d) Mode coupling coefficient.

2. Mode division multiplexing with MIMO

The other way of overcoming the capacity limitation is use of multiple modes using MIMO technology. Particularly, In MIMO technology, which was originally developed in wireless communications to cope with multi-path interference, is expected to be a key element for realizing mode multiplexing and demultiplexing capable of handling inter-modal crosstalk and differential group delay. MIMO-based multi-mode transmission is in Fig.5 above.

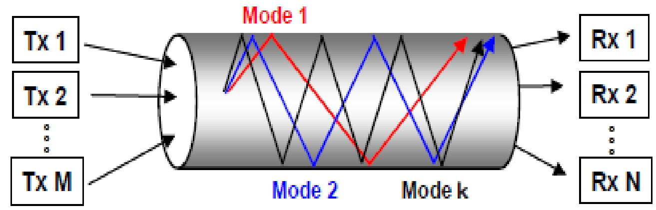

Fig. 5. Mode-division-multiplexed optical transmission using MIMO

In MIMO processing, the channel matrix H representing the mode coupling and delay is estimated from the input and received training symbols, and the transmitted signal x(t) = (x1, x2, …, xM)t is recovered by multiplying the conjugate matrix H+ by the received signal y(t) = (y1, y2, …, yN)t: x(t) = H+ y(t). MIMO-based multi-mode transmission over a few-mode fiber has been realized[2].

Future Trends

1. New generation optical fiber technology:-

New transmission optical fibers capable of transmitting well over Pbit/s information per fiber along with optical connectors, splicing, and cabling technologies are being studied. These include power-proof multi-core optical fibers, multi-mode fibers, PCF (Photonic Crystal Fiber), and PBGF (Photonic Band gap Fiber) for SDM (Space-division Multiplexing) and MDM (Mode-division Multiplexing) [1] Remote detection and halting schemes of fiber fuse phenomenon have also been developed [7].

2. Novel transmission and optical node technologies :-

Novel multiplexing/transmission schemes and node architecture beyond TDM (Time-division Multiplexing) and WDM utilizing spatial (transverse) modes and spatial coherence of light are being studied. These include super multi-level modulation, SDM/MDM and MIMO (Multi-input Multi-output) processing with multi-core/multi-mode fibers along with corresponding optical amplifiers, MUX/DEMUXs, and optical signal processing technologies. Ebit/s class multi-granularity optical node architecture has also been proposed [8].

3. Optical submarine cable system technology:-

Novel transmitters/receivers, transmission line technologies (ultra-low loss, low nonlinearity optical fibers, low-noise optical amplifiers) to achieve a capacity-distance product of Ebit/s km (100 Tbit/s per fiber, 10,000 km) are being studied[1].

Section 4

Conclusion

Thus, the physical limits were discussed and reviewed in this paper alongwith recent progress in the field of multi-core fibers and multi-mode technologies . The "multi" technologies have been applied in various physical dimensions, and the integration of these three innovative technologies will ultimately lead to a thousand-fold leap in the optical communication infrastructure in the coming future.Still it needs time and money to implement the concept of multi technologies in a single technology and get the desired result.There is still lot of literature review and experiments to be done in terms of modulation technology formats,multi mode technolgies and so on. Future focus can be on New transmission optical fibers capable of transmitting well over Pbit/s information per fiber along with optical connectors, splicing, and cabling technologies.

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