Optical Networks Overview

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Optical Networks have revolutionized telecommunications and the world's communication need as we know it today, increasing the speed and capacity of communication. Today most of the core network consist of optical networks and there exist a large effort in taking this technology all the way to the home. In this paper we discuss an over view of the physical layer and some of the most recognized Standards Development Organization in the telecommunications industry. We give a general understanding of what component are mainly used in this type of systems and how to understand their physical function.

Index Terms: Light Wave theory, Optical Networks, Fiber, Interferometry, SDO

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I. INTRODUCTION

Networking is the back bone of the internet as we know it, giving us a way to connect and access all the computer of the network or giving us a map on what really is the internet. A network is divide in three parts the core the aggregations and the access networks. The technology's implemented threw different stages of a network have changed threw the years, the core network was first constructed using the old telephones lines, and it has been gradually improved using old infrastructure for cost effective solutions. The most costly part of the network is always the core, this being the part where the cost can be divide with the largest amount of users, thus the most exotic and high speed systems are implemented here.

In 1975 the most advance coaxial network had a bit rate of 275 Mbits/s, at around this same time the first optical networks that use Wave division multiplaxing were being developed, they could operate 640 channels and gave of a bit rate of 107 Gbits/s. This bit rate difference makes it clear why there are such powerful tools for really high traffic network, and the high cost for this technology can be spreed out with many users. Now days most of the network consists of optical fibre except the most costly part to deploy which is the Access network or the last mile. The direct link form the user to the aggregation network. The deployment of fibre changes in different regions of the world but the links that are for high data transfer are usually implemented with optical fiber.

In this paper we are going to give an overview at what are the main physical aspects of the network and how its components work, we'll cover the main protocols and Multiplexing techniques and the entities that standardize most of this technology's.

II. PHYSICAL LAYER

A critical part of any network is understanding how physical phenomenon can be exploited to create a useful technology. This is specially true for fiber networks since most of its advantages relay on the use of the physical phenomena to create passive solutions for problems that in the electrical domain may be solved in a higher layer. We are going to cover the main physical principal and components implemented in the filed.

An overview of the physics that are need to describe the main components in a optical network is shown in this section. Almost all components are described using two fundamental physical concepts absorption/emission and phase modulation, with this two concepts we can construct amplifiers, detectors, absorbed, lasers and interferometers which are the bases of all commercial components used. Everything covered in this section can be furthered researched in the Ref[1][2][3]

A. Fiber

Confining light to travel inside a fix system is a crucial part of optical networks and research in general, a physically reflection in a boundary is described by the Snell's law as shown in Eq.1 from this we can determine the total internal reflection angle θ_{crit}. Any light with and incident angle equal or large than the critical $\theta_{crit} \leq \theta$ is completely confined inside the system.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow \theta_{crit} = \arcsin\frac{n_2}{n_1} \qquad (1)$$

with this understanding the physics of a fiber becomes spacial case of reflection since its just a combination of the light getting transferred between to medium at the right angle which keeps it trapped inside the core. As

can bee seen in Fig.1 where the light in this model is traced as in ray optics, in this frame work we lose any interpretation of how light propagates threw the core or how losses work inside the fiber this is studied threw the electromagnetic optics frame work. Understanding the

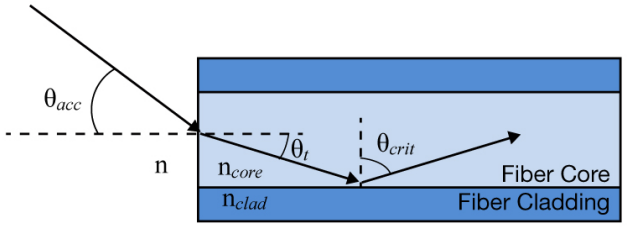


FIG. 1. Cross section of an fibre with a single core. Showing the different angles to take into account when trying to insert light in the core and trapping it.

losses inside of a medium requires us to describe light on the frame work of electromagnetic optics where we understand a wave pulse as a a superposition of waves with different frequencies, that when combined under Fourier theory produce a single traveling pulse. Thus, we can use what exploit Fourier theory to understand how shorter pulses contains a large set of frequencies which can be modulated by the cavity constriction in the laser.

In general the losses in our system are produced by the two main factors dispersion and absorption inside the core and detection system. This losses are frequency dependent this effect causes chromatic aberration, which is when a pulse loses definition because of the different speeds that frequencies are traveling at. All this losses are describe by the loss factor D of a material that is dependent of the refractive index and its higher order nonlinear components. Dispersion plays an important part for this types of system since it sets constraints on how a technology can be implemented before the system is to unreliable to use.

An optical fiber depending on the diameter of the core has an upper limit which dictates what is the largest wavelength that can be held in the core before you cant fit any other wavelength, this is known as the cut off wavelength and usually fibers are classified by these parameter. The broadest calcification for fibers are as single mode or multi-mode which in general have a core of $50\ \mu m - 80\ \mu m$ and a single mode fibre has a core of $8\ \mu m - 10\ \mu m$ but you always have to take into account the cut off frequencies. There also are multiple types of fibres that in contrast to the one showed in Fig.1 have multiple cores in them which can be used to send multiple channels threw a single physical fibre.

B. Laser

A laser is a technology that revolutionized the world and the human understanding of how light interacts with matter. Laser stands for light amplification by stimulated emission of radiation, the main difference between light produce by a laser and any other source is coherence (all photons are the same, overall structure), all classical light sources produce chaotic light and has no over all structure. To understand why there is coherence in laser light we first have to understand what light is, from the frame work of wave optics, which is enough for our purpose, light has an amplitude, a frequency, a direction of propagation and a phase.

A good way to picture this is as a sine function which in general has an amplitude, a frequency and a phases which if you change it by a multiple of π you can get a cosine or get the opposite sing of sine, this change in phase is very important when talking about light. Now light coherence implies that all the photons have the same properties threw out all transverse mode (spatial slices of the beam) and time giving a very steady well defined light source.

A laser has three main components a optical resonator or cavity, a gain medium and a pump. The cavity has such a length that only a single mode (frequency, direction of propagation and phase) is selected, the gain medium has an emission band which is resonant with the cavity mode. The pump is used to create what is known as population inversion in the gain medium making it such that there is more electrons in an exited state than in the ground state thus letting us get amplification threw stimulated emission (it requires energy to produce light amplification which is given off by exited electrons).

When a resonant photon passes threw the resonant gain medium it starts producing a chain reaction of stimulated emission, thus, amplifying the incoming photon creating more power inside the cavity. The photons produced by means of stimulated emission are exactly the same as the incoming photon, this makes them interfere constructively building up inside the cavity and reaching what is known as steady state where the losses inside that cavity including the out going beam are the same as the gain in one round trip this is when we have a *Continues Wave laser or CW laser*. A laser can have a very narrow band as a continues wave by setting inside the cavity small etalnos (smaller resonators) which have a very large free spectral range (distance between allowed frequencies inside the resonator) it reduces the amount of frequencies inside the cavity thus producing a very close to single wavelength laser.

Since for telecommunication it is needed to send zeros and ones, light or no light a CW laser dose not really do the job, if we don't find a way to modulated. One

way to modulate can be achieved by changing the type of laser from a CW to a pulsed laser. A pulsed lasers is modulated inside the cavity using a technique known as Q-switching, the down side is that to have a very fast modulated laser induces a lot of dispersion and it is also costly to produce this type of lasers in a small standardized packet. The method that is most commonly used is modulation by a fast modulating absorption system, whose absorption band gap can be modulated at high frequencies, this would then absorbed light when a zero is needed and let the light threw when a one is needed also known as *On-Off keying OOK*.

C. Detection

The detection of light can be done using a photodiode, there exist a large type of photodiode in the market but there inner working is basically the same they all relay in the absorption of light to create free electron in a material an thus producing a measurable current change in the active region of the diode. In telecommunications you need a very fast responding diode and this is all measured threw the quality parameters used to standardized the response and sensitivity of this devices.

The two parameters are the Quantum efficiency which can be found as EQ_λ or η in the literature, the other relevant parameter is the photon resposivity R_λ. The quantum efficiency gives a measurement of how many photons are being converted threw absorption process on this diode, and the resposivity gives us insight to how much current can be expected per a unit of photon flux. For our requirements we need a photon with high η which would give off a high R_λ, this is actually standardized by an *Standards Development Organization SDO*. Since there is always going to be noise in the detector, a decision has to be made electronically if a zero or a one was detected for any specific period of time.

D. Main Components

All the components in an optical Network are designed exploiting physical phenomenon to produce an over all desired action of a system, there are two main components that are implemented in a wide range of application in optical networks, interferometers and brag grating mirrors. Both of these exploit the same physical phenomena, interference, but both are two different clever implementation of it. We are going to give a brief description on how this systems work but we will not go into to much detail on how they are mathematically described for this you can have a look at an optics book, a good reference is Ref[1].

1. *Interferometer*

There exist many types of interferometers, where they all use the phase of the light wave to produce constructive or destructive interference. In general interferometer requires two photons that are the same or indistinguishable, and it creates a phase difference between them by some process. When one acquires a phase difference equal to a multiple of $\lambda/4$ or $\pi/2$ in optical terms the pair will interfere destructively, when they acquirer a phase difference of $\lambda/2$ or π they will interfere constructively, this can be done in a number of ways. A Mach-Zender interferometer creates a optical path difference between indistinguishable photons, again one can get creative in how to accomplish this path difference. One experimental setup is shown in Fig.2. This setup would be seen when trying to measure very fine differences in optical paths but in telecommunications we are only interested in the effect of interference when we can control light intensity coming out of one of the outputs in the system.

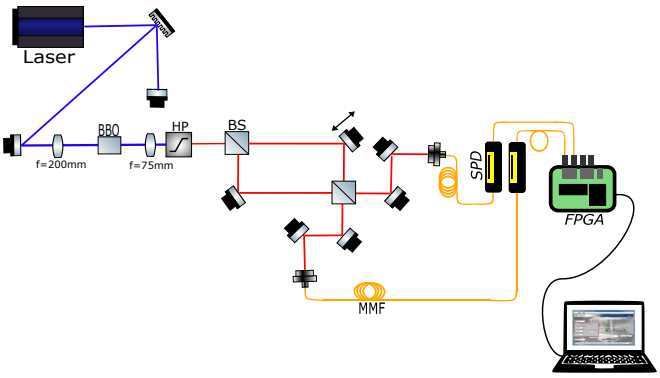


FIG. 2. Experimental setup of a Interferometer where one mirror changes position to create a difference in optical path length.

2. *Fiber Brag gratings*

A *Fiber Brag Grating FBG* is a system that acts as a mirror that reflects the total power for only a single wave length with a small band width. This mirror also exploit interference my setting a periodic variation in the refractive index of the fiber core, which generates a wavelength-specific dielectric mirror. T fundamental principle behind the operation of an FBG is Fresnel reflection,where light traveling between media of different refractive indices may both reflect and refract at the interface. The refractive index will typically alternate over a defined length, the reflected wavelength is called the Bragg wavelength. This is a very common reflector or filter in research and in the industry since it has the advantage that can be set in the optical path and not disturbing all incoming light.

III. NETWORKING & PROTOCOLS

With the physical understanding of the components one can now proceed to build a network, for this we need two things a physical medium that can send/receive information to multiple locations and a protocol that lets us encode information in the physical transport signal.The components of an optical network can be summarized in a transmitter, a receiver, a transport medium, Add-Drop modules, filters , routers, and amplifiers all this systems use the physical principals that were discussed above to achieve there over all objective.

Now we need an protocol that lets us encode information into a OOK detection system, in general today's networks run using TCP/IP stack then by extension we need a protocol that for optical networks that can be integrated to this high layer stack. The main used protocols for Optical networks are discussed in what follows.

A. SONET/SDH

One of the most commonly implemented protocols for optical networks is the *Synchronous optical networking, SONET* and *Synchronous Digital Hierarchy, SDH*, where SDH is used by most of the world while North America uses SONET. Both systems are designed to aggregate a large set of clients. The higher rate data streams are set on top of lower rate streams, this gives some advantages for high performance. The aggregation is performed using *time division multiplexing TDM* which require precise clocks. Most commonly atomic clock's can provide such a synchronisation. This protocol main concern is offer high aggregation rate by implementing time division solutions but in the optical domain we can also use other types of aggregation.

Optical transport network, OTN is a complementing protocol for SONET and SDH, since it looks to improve the transmission by implementing forward error correction and end-to-end monitoring but most importantly it exploits the optical capability of *Wave Division Multiplexing, WDM.*

IV. STANDARDS DEVELOPMENT ORGANIZATION

An *Standards Development Organization, SDO* makes sure to set an agreement in how a technology works and with what standards all the manufactures most follow to be able to use and implement these systems. In this section we'll cover some of the most meaningful and with a large impact SDO in the filed of telecommunications, making it the system that we know and depend on today.

A. Institute of Electrical and Electronics Engineers (IEEE)

Today this organization is considered as one of the largest for the development of standards and protocols for a large range of fields. This organization has created and pushed standards that are now part of are everyday life specially in our case for telecommunication. Where some of the most well known standard's are IEEE 802.11 which defines Wireless Networking also known as WiFi and one more relevant for our course is IEEE 802.3 which is the standard use for Fiber-optic connection. This are just two examples of the main protocols hat they have pushed forward that have revolutionized telecommunications.

B. International Telecommunication Union(ITU)

This organization is an agency that belongs to the United Nation this agency is the one that controls telecommunication issues. Being part of an United nations gives it special relevance since it is part of a large set of intergovernmental discussions and decisions making it one of the most relevant SDO in the world. One of the most well known and important standardization's of this SDO which has great relevance for tbs course are the set used in the previews problem, known as passive optical networks (PON) reefed to as G.983, G.984 and an other important protocol would be the Optical network transport (OTN) that we also discussed briefly and are referred to by G.709 and GG.798.

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