Fiber- Optic Communication Systems and Techniques

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Lecture -01
Overview of fiber-optic communication systems

Hello everyone, welcome to this course called fiber optic systems and techniques, Fiber-Optic Communication Systems and Techniques. In fact, my name is Pradeep Kumar K and I am the Department of Electrical Engineering at the Indian Institute of Technology Kanpur and it is my pleasure to talk to you, take you through this particular course which I believe is very important for almost every communication engineer.

And the reason why this course is important will become of course, clear as we move along the course, but we will set a stage by showing why this particular course would be important for your future. So, if you look at what communications is today you perhaps would not require any introductions to what is communication and why communications is important I mean we are communicating all the time. So, the first thing that we would do probably every morning is to wake up and then hold our smart phone and then chat with our friends over many applications one of the popular one is What's app.

What's app provides you, instant provides you an ability to instantly communicate to your friends where ever they might be all over the world and it does provide different type of communication modes for example, you can text your friend. So, this is one type of communication you can call up using what is app whether it is an audio call or video calls. So, this is another type of communication you can even communicate multimedia for example, you can download a picture or you can you know download a gif file or another type of a movie file for example, and then send all these files across over what is app.

So, these communications seem quite instantaneous. So, the moment you click send here within very small amount of delay your recipient would have actually received this message right and again note that you do not have to know the I mean you do not have to have the person nearby you person could be located anywhere in the world and information is exchanged almost instantaneously.

But if you think a little deeper and ask how exactly is this possible we will enter into what is called as a physical layer of communications right. So, there are devices which take information and come you know convert it into a format that is suitable for transmission and then transmit across certain physical channels. So, that your friend or your recipient of the particular message that you have sent would be able to receive the message and you know make whatever the use of that particular message is.

And if you also notice that this is not the only type of communication that you will have most likely we will also on that particular day you will download movies and watch movies some of you may be very creative. So, you might actually create a skit of yourself or you create a small you know kind of a entertainment module and you want to upload this module you will do.

So, you will upload these modules on to streaming services such as YouTube. So, all this is essentially called as multimedia traffic or multimedia communication. So, you have different media communications including voice that was a traditional communication source, then you have pictures, you have videos, you have files, you have text files, you have lots of other formats or files that you are actually transmitting.

And most of this transmission is done in the real time or at least in with extremely small amounts of delay and this trend of traffic has actually you know it was contributed because of the explosive growth in internet and now because internet is available the growth is continuing. So, it is a self cycling kind of a process so, first you had the network and because you had the network there is an increase in the traffic and because there is an increase in traffic you have to keep tweaking the network.

So, that the network is now able to handle this traffic. So, it is a continuing process of cycle where traffic feeds network, network feeds traffic, the availability of network means you can communicate because you are communicating you demand certain things from the network, the network has to be continuously built and optimized.

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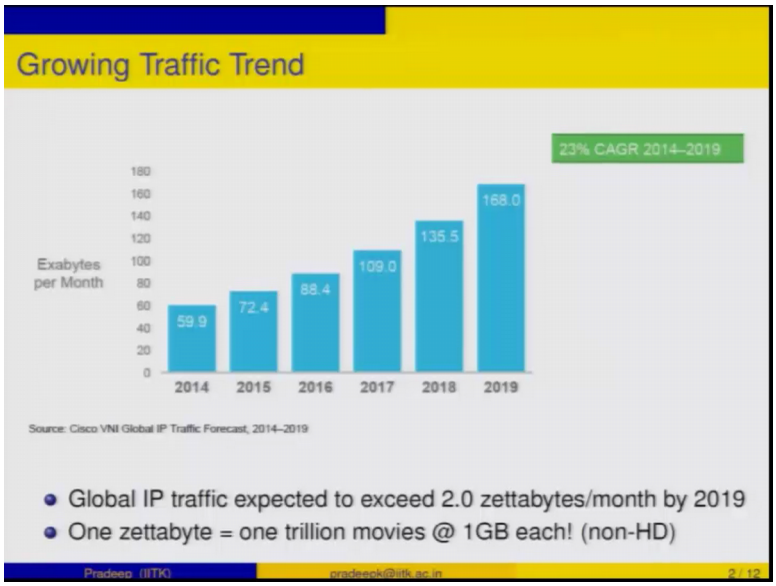

So, if you look at the growing traffic trend today or may be just about 2 years ago this is a forecast done by a very famous company called Cisco you probably would have heard about that and you would actually see that, what Cisco forecasts is the amount of data that is communicated over internet network the traffic has is only growing I mean it is expected to grow by the end of next year that is 2019 to about 180 or 168 exabytes per month and this is just the type of a traffic that is over internet.

Internet is a very specific type of a network over which you are communicating and that traffic alone is going to go up to 168 exabytes per month and if you aggregate the compound aggregate data rate over the entire world the global IP traffic as we would call it, if expected to exceed about 2 zettabytes per month by the next year. Now just to give you an idea of what a zettabyte is, 1 zettabyte can actually hold 1 trillion 1 trillion movies ok.

So, it can hold one trillion movies each of those movies at about 1 GB, 1 GB is fairly good amount for a very good movie in a non h d format perhaps, but 1 GB of such 1 trillion movies is what is actually moving every month right. So, it is moving every month I mean it is expected to move every month by the next year. So, you can see that the amount of traffic that is flowing on the network is quite huge and it does not show any sign of actually slowing down.

So, which means that engineers, physicists, material scientists, all other type of you know scientists and others have to continuously innovate in order to make the network take this amount of load, because you if your network is not optimized, if your network is not up to the mark then the traffic demand exists, but you do not really have a network to support that kind of a traffic.

So, it is important that one understands that as the network traffic grows how to actually make the network be able to communicate this amount of traffic. So, that is what this course hopefully is all about and you could not learn everything, but you would get an idea of what goes on in this type of networks.

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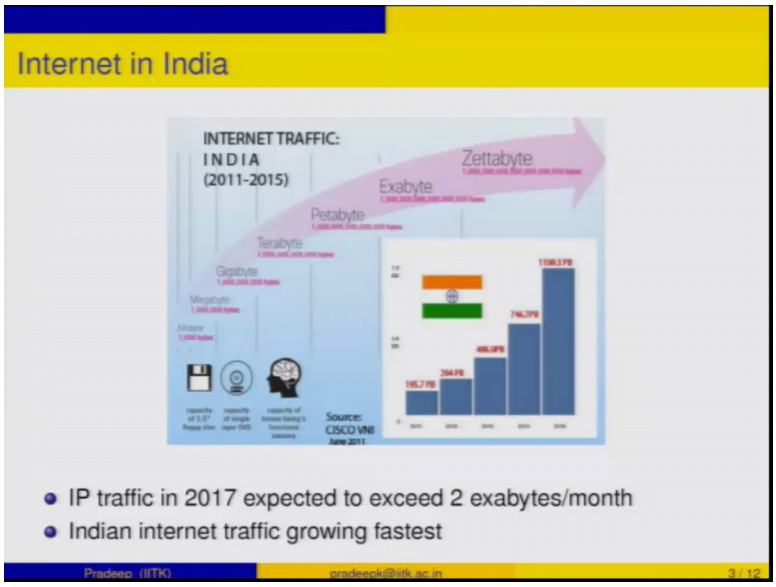

If you focus on to Indian scenario, you would see that Indian scenario started of slightly later because the availability of network was not as wide as the global networks. So, over the last 10 years or so, we have seen tremendous network penetration even in India now almost everyone holds a smart phone, it is not even just a wireless phone it is a smart phone that most of us have and we use all kinds of apps to communicate with our friends know everything that you can think of with a smart phone you can actually do that.

And in India the last year itself we have exceeded about 2 exabytes per month, it is natural that as more and more penetration network penetration happens in India this number would grow up and amongst all the other developing countries, it is the Indian internet traffic that is growing at the fastest possible rate.

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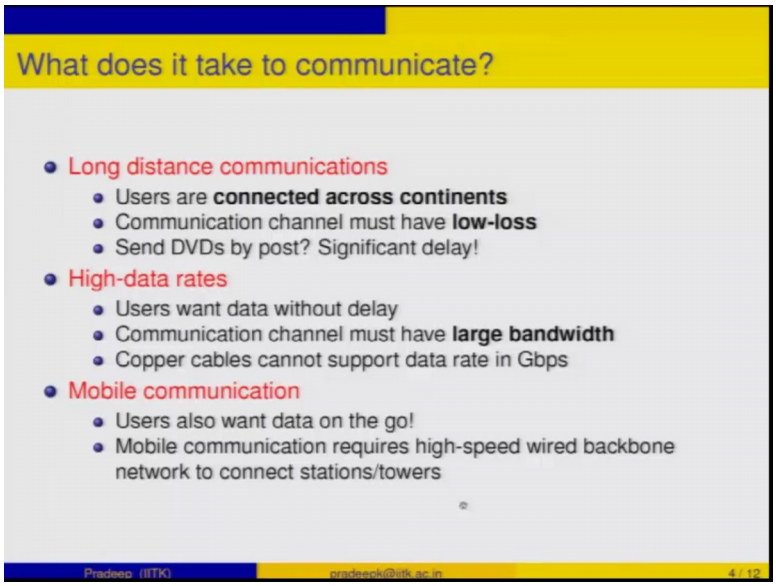

So, if you now look at what exactly it takes to communicate, I mean people are communicating people were communicating even before this devices were built for example, about 200 to or 300 years ago people would communicate either by shouting across the room because most of the recipients and the person who was communicating were stationed in the same room or if your friend happen to be there somewhere out then you would write a letter and then have someone hand deliver this particular letter right.

So, you could communicate sometimes you could write a letter or a novel and then communicate. So, you are at a say at a time communicating more words than you would communicate with the single letter. But not all these communication systems are you know are actually you know interesting in the sense that they do not satisfy certain prominent requirements of communication systems that we now expect when we say communication is happening.

So, what kind of properties do we expect when we talk about communication systems and these are the 3 main properties which I think you have to satisfy if your system is going to be called as a nice modern communication system. So, what are those properties, first of all there should not be any bound on the distance of communication. So, it should not happen that if I am communicating to a person within India I can communicate within say about a second or 2 seconds at most delay, but if I am

communicating to a person let us say in world I should not be you know made to suffer a delay of about 10-15 days so, that is clearly not acceptable.

So, what you want is, you want communication right to any part of the world we call this as long distance communication. So, you should be able to connect any person on globe to any other point on globe a person in the on the point of globe so, they are connected across continents. Clearly if you are going to demand that such communication must happen and must happen over kind of real time, you want to your communication channel to have as low loss as possible there is simply no point in communicating to your friend in United States where most of the data that you have sent is kind of lost right so, such a scenario is not acceptable.

So, you want long distance communication and if you want long distance communications you better have communication channels which have extremely low loss ok. So, a colleague of mine suggested this idea why cannot we just take about say 1000 DVDs and then send them by post. So, at the same time you will have lot of information, but because you are sending it over post there is a significant delay which gives us the second criteria which we do not want to have is that you just do not want to wait for 2 days 3 days or 10 days to get that particular information. They want the data right now right so, they want the data right now.

So, when you send the message or when you download a movie on to YouTube you want to be able to see the movie entirely now, let us say within the next 2 seconds or something the movie should start. If someone offers you a service saying that sir you will not have any interruption during the movie you know process of viewing, but please give us 2 days or 2 weeks of time to set this up, your first instinct would be to kind of reject that offer.

Now you do not want that kind of a delay you want the data to be exchanged or communicated right now and to do so, you want no delay in the system, which means that you are communicating at very high data rates and to communicate at very high data rates which makes delay kind of negligible you need to have your communication channels to have large bandwidth.

So, communication channels must have large bandwidth and because your communication channel must connect persons across continents you need to have

communication channels which are very low loss right. So, you need to have these 2 requirements side by side so, you have a low loss channel to enable long distance communication and you have a large bandwidth channel so, that the data rate can actually go.

About 70 or may be 50 years ago most of the communication was actually happening using copper cable. So, everywhere you had this telephone lines of course, in India you could see them even in the late 80s and these telephone lines were actually connected across all over India using this copper cables. Today we do not use this copper cables because our primary communication is not just voice no one likes to just talk to another person you want to be able to communicate in different modes as I said.

And unfortunately copper cables cannot support data rate at the rates you require which is in a few tones of Gbps so, in you cannot communicate using copper cables with high data rate. The third and important type of communication that we have now grown a custom to is mobile communication, you do not want to sit in front of a computer or you be fixed in a particular position and then you connect to the network and then look at whatever that you are doing right.

So, you do not want to commit yourself to a particular location may be you are travelling to you visit your friend and you want the travel to be enjoyable experience. So, you turn on the network on your smart phone and then you start viewing some websites if you are interested in reading or you know download some kind of a movie or some kind of a streaming service and then start looking at it. So, you want data on the go as you are going you need to have data.

Again this particular communication is wireless communication as we would call it because there is no physical channel involved, there is no physical wire for example, you are carrying you are not carrying any wire attached to something as you travel. So, the communication is happening from the communication base station to your cell phone in a no wire condition.

So, this is a wireless condition and this is one type of communication which is very prominent wireless communications, but it would so, just connecting the world with base stations and having everyone carry smart phones would not create the mobile

communications or the wireless communications as we know today, because communication between base stations cannot rely on wireless communications alone.

The data rate, aggregate data rate that the wireless channel that is just your air around will not support the kind of required data rates in 100s of Gbps. So, your mobile towers themselves are actually connected by wired communication. So, this wired communication would it be copper cables not really, because each base station has a large amount of data to communicate to other base stations and clearly you cannot do. So, if you were go back and connect a copper cable so, what sort of communication channel is the one that is connecting not only the base station to base station, but other type of network.

So, if you actually dig a little deeper into this, you will see that the world is communicating by a single technology except for the last access point. So, that is from the base station to cell phone that is wireless communication, you do not want normally you do not want provided you live with the current communication standards and the speeds, but if you demand much more from it then you would have to even replace at wireless communication in the last mile by a wired communication. So, if it is not copper cable what is the world connected to? How are we actually communicating the data?

The world is connected to communication a network or the communication network is made out of a single element not a single element, but the major transmission media called as an optical fiber. This is an optical fiber right so, of course, this optical fiber is to be used in practice therefore, it actually does not I mean, this is not the exact fiber that is used in practice, but these are the fibers that we use in laboratories to carry out experiments.

In practice you cannot just lay one type of I mean one single fiber you will actually have to package these fibers into cables and lay them. Today the world is laid with millions of such optical fiber, millions of kilometers of such optical cables, each cable carrying a bundle of optical fibers. So, what is an optical fiber, if you look very closely I am not sure whether you will be able to see this, but if you look very closely you will actually see you know a transparent a kind of a wire you might say, but this is not a wire of course, you see this transparent region or a semitransparent region and then you will see this orange colored thing. Of course, the color orange is just coincidental it does not have

to be this particular color you there are they are color coded, but they are do not necessarily have to be this particular color.

So, you have this transparent thing which is an optical fiber of course, there is you might not be able to see this will not be able to see this, but there are 2 layers in this particular fiber ok. So, this transparent region itself is made of 2 concentric layers, one inner layer is what we call as the core layer and outer layer is what we call as the cladding layer. So, you have an inner layer which is core and an outer layer which is cladding and core and cladding are covered by a optical coating. So, this is called as a coating or rather this after a small amount of coating this is called as a jacket so, this is a jacketed optical fiber.

So, this orange color is a jacket there are 3 layers here you might not be able to see one is the coating and or may be in this we have removed the coating. So, there is no coating, but you will see a cladding ok. So, you I can just try and pull this out may be it is difficult to do. So, because one of the properties of this optical fibers is that they are mechanically very resilient see I am trying to pull this, but I am unable to do.

But if you look closely you will see that there is a cladding and inside this cladding there is a core ok. So, this is an optical fiber which people use to communicate as I told you not exactly in this form, but these fibers are not even the current communication fibers. These are very old fibers in the sense that they were very popular in 80s they are still popular in some specialized short distance application such as Ethernet ok.

Even there other type of fibers have come in, but these are the main stay of the fibers that you know in the early 80s up to about 80s, let us say 70 to 80 is where these type of fibers were used majorly and the reason is that the core which is inside this transparent region has a diameter of about 50 micron roughly 50 micron ok. That is slightly more than your hair, but those are the early fibers and these fibers you will later see are called as multimode fibers we will come to what is a multimode fiber later on.

What we use today is not exactly this multimode fibers, but these fibers which are though are mechanically slightly not very resilient because they are very thin and you should see that this layer that I am showing you which may be very difficult for you to see this layer itself will have 2 regions or it has 2 regions, the core inside this particular layer and then there is a covering of the core by what is called as a cladding ok.

So, this core has a diameter of about 8 micron somewhere around 8 to 9 micron and the cladding is kind of standardized to have a diameter of about 125 micron. Then you put a coating that brings this up to about 250 micron and then you put a jacket if you are selling this fiber in a single piece like this. So, you actually put a jacket out there, if you do not put a jacket you actually put this you know core cladding and a coating into a loose tube and you package many many such loose tubes into a optical cable.

I will show you some pictures of an optical cable actual optical cable later on as we go through the course, but you should be amazed I mean look at this thing this is actually just one very thin strand wire this is solid it is it looks like a wire of course, it is actually made out of silica it is made out of fused silica with some amount of dopants added into it, in order to give it a particular property that you know that we will see later on, but information in the rates of 100s of gigabytes per second can be carried by this optical fiber ok.

So, each optical fiber operated can carry 100s of gigabytes per second data per channel ok. So, the aggregate data rate that an optical communication network supports today is more than a few terra bytes per second and these is possible and no this is the reason why you are actually able to communicate all over the world. So, as we go through the course you will see more of these physical pictures and we will also try to show you some experiments that are that are conducted on this optical fibers and optical networks so, that you better appreciate what goes into today's communication system

So, today's communication system is mainly about this optic using this optical fibers, now why should optical fibers be considered I mean of course, as I told you copper cables do not have enough bandwidth and of course, copper cables are also tremendously expensive not that optical fibers are not expensive, but optical fibers overcome that expense part or compensate for that expense part by being extremely you know having channels having extremely large bandwidths not even a simple comparison to copper cables. You can see that in addition to large bandwidth the optical fiber itself in the operating region that we consider has extremely small loss. So, this picture shows on the y axis loss plotted in dB per kilometer.

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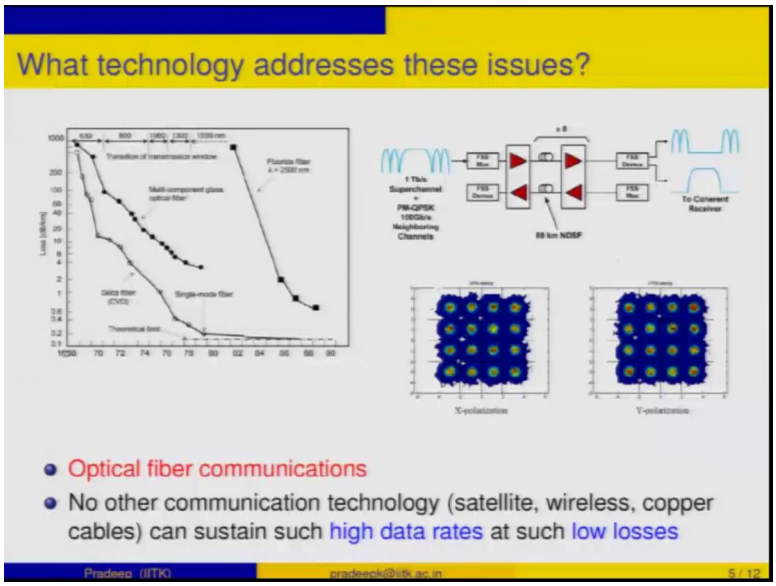

And then on the x axis is the year around 1968 to 70s when we actually had this first low loss optical fibers even at that point this particular line at around 70 where there is a circle with less than 20 dB per kilometer was a major breakthrough this is about heralded optical fiber communication and the loss from there which was slightly less than 20 dB per kilometer has only grown lower and lower and has now approached the theoretical limit.

So, if you actually see from the 84 - 85 onwards the loss that you see in this fused silica fibers by the process called as CVD chemical vapor deposition process in the so, called single mode fibers has reach the theoretical limit. So, optical fiber communications can give you very high data rates and very low losses ok. You can see an example of high data rate over here on the right hand side of this picture, you will see that there are 1 terabyte per second I mean just imagine on a mobile communication system we are talking about a few megabytes per second in the earlier generation to few gigabytes per second in the next 5 g standard, but optical communications today can offer one terabyte per second super channel.

So, where super channel means that multiple channels are aggregated into one and each channel actually I mean this super channel is surrounded by 100 gigabyte per second PM- QPSK channels.

So, you see that the channel which is kind of flat which occupies a little bit of a bandwidth is carrying data at one terabyte per second and it is coexisting with the current 100 Gbps standard. So, gone or the days of optical fibers where it could support 10 Gbps, 2.5 Gbps, 10 Gbps, today the Ethernet is actually ratified at hundred gigabyte per second. So, it is it is not even just to a 10 gigabyte per second Ethernet that you knew of about 10 years ago today the speeds have reached 100 gigabyte per second per channel and you can imagine what would be the total amount of data rate that is being carried.

Of course, this is not a practical very recently this has become practical in the sense that it now you can by this one terabyte per second transponders, but at the time where this was proposed this was just a laboratory experiment and they achieved a higher data rate by going to what is called as an advanced digital modulation format. So, this is an example of 16 quam, quam corresponds to quadrature amplitude modulation.

And you can see that instead of sending just one type of quam system you can actually send 2 such quams at the same time on the same channel exploiting what is called as polarization as a multiplexing technology. So, these type of high data rate systems have made possible by these high advanced modulation format system. So, no other technology can give you any data rate higher than current optical fiber technology at least that is what seems to be the case over the last 30 - 40 years no one knows what would be the future technology.

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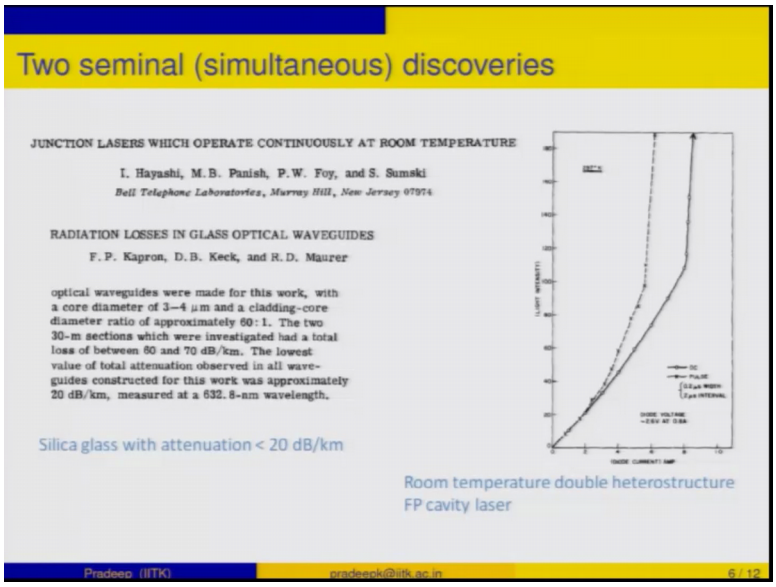

In addition to optical fibers another important invention that made it possible for us to actually use this optical fiber some income on how do I use this optical fibers, I can take a signal generator and rap a wire to this optical fibers right I just cannot do that because there are no wires to connect out there.

So, information must be launched in a very different manner I cannot take you know what I have to do is to essentially shine light into it because these fibers carry information in the form of light waves and I cannot just shine light from any other source, I cannot shine light from a tube light or a bulb I have to shine light with a very specific device known as a laser. So, we will study some aspects of laser later on. So, simultaneously having junction lasers together with the optical fibers is what made fiber optic communications possible and today you can communicate with such high data rates right.

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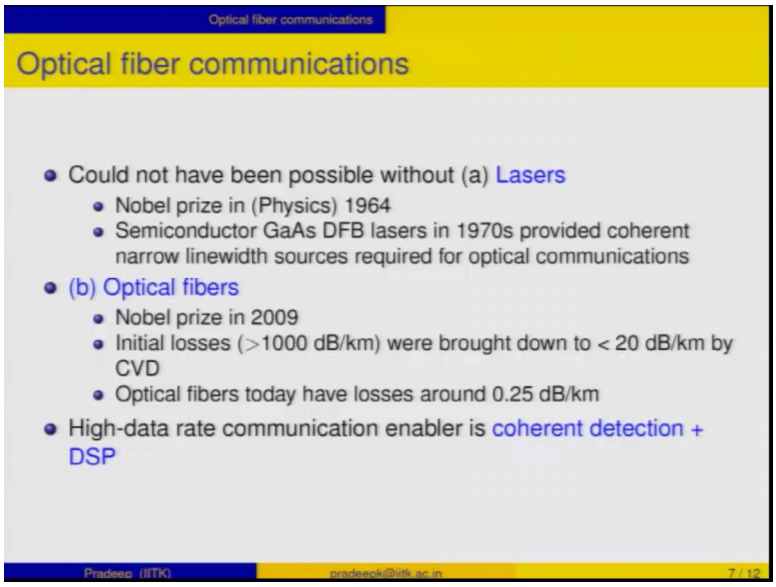

Invention of optical fibers lasers of course, has won many noble prizes, but optical fibers not (Refer Time: 26:22) the invention, but when this was suggested there were lot of skepticism, but one person you know kind of all the times said optical fibers are good please use it and demonstrated why the losses can be brought down theoretically.

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And this person actually won a noble prize in 2009 and today optical fiber communication if it has grown such a large to such a large extent is thanks to this person called Charles Kao who won this noble prize in 2009 for optical fiber communication. Of course, today optical fiber communication is not just this simple ideas that were prevalent in the 1970s today the enabler is what is called as coherent detection ok. I will come to coherent detection as when go to the course and then with some algorithms called as digital signal processing algorithm. So, combining these two is what makes very high data rate optical communication possible.

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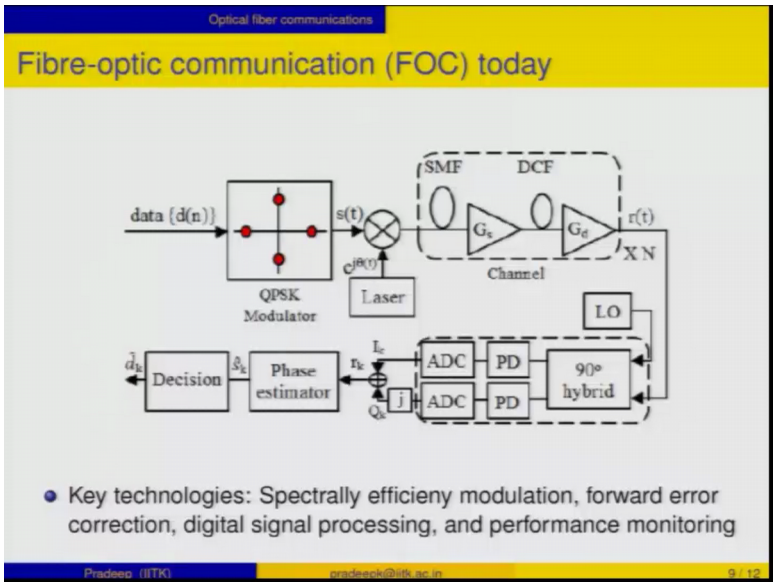

So, just to give you an example of what an optical fiber communication system would look today this is an example of a single carrier communication system. So, you have your data put into a format here the format is QPSK because this is the 100 gig standard that we are considering.

And whatever the data that comes out of this modulator or you know the mapping is actually modulated on to the optical wave or generated by the laser. So, until this portion this is all electrical, but once laser is involved this becomes optical transmit and at the receiver you mix it with a local oscillator local oscillator is also the same thing as a laser.

So, it is also another laser and then use the down converted optical signals now convert those optical signals pack into electrical signals using photo diodes and from the photo diodes you sample them apply lot of digital signal processing algorithms and then you will be able to recover your data and this course will teach you almost all aspects of this particular system.

So, this studying of optical communication I will end with this last slide involves 3 different layers, one is functional, physical realization and performance assessment. Functional means what is the input, what is the output, how do we describe this in a abstract way. Physical realization means how do I actually create a modulator, how do I make a light source, how do I create a photo detection process I mean photo detector, how do I implement a filter amplifier and so, on right.

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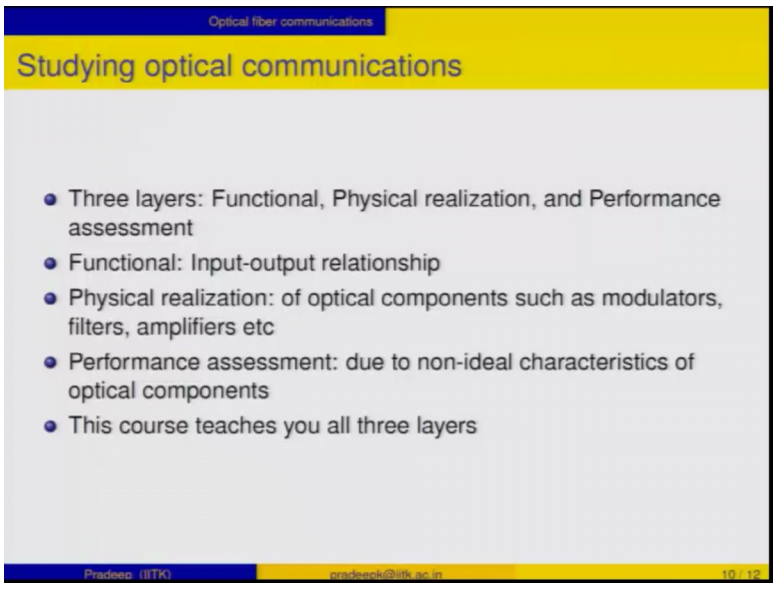

And performance assessment means these blocks are not going to be ideal. So, you need to consider those non ideal characteristics and you need to study how these non ideal characteristics affect the performance of your system and this course will teach you all 3 layers.

Thank you very much.