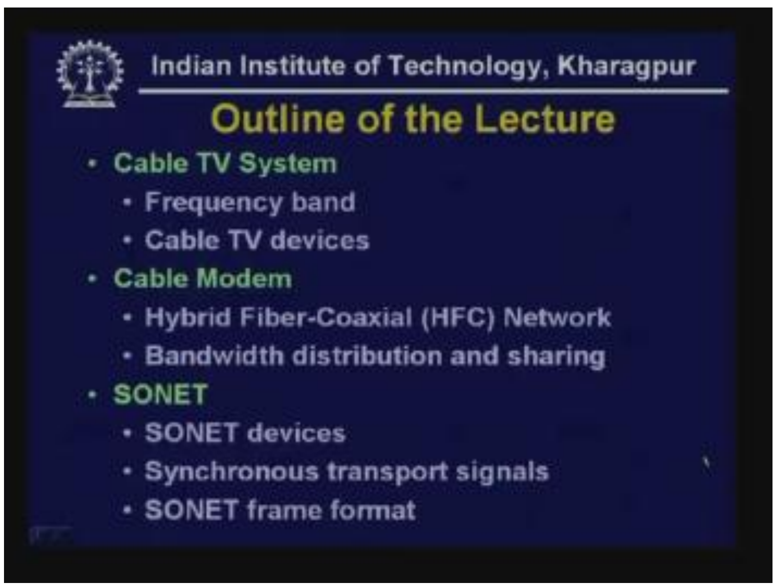
Data Communications
Prof. A. Pal
Department of Computer Science & Engineering
Indian Institute of Technology, Kharagpur
Lecture-13
Multiplexing Applications-2

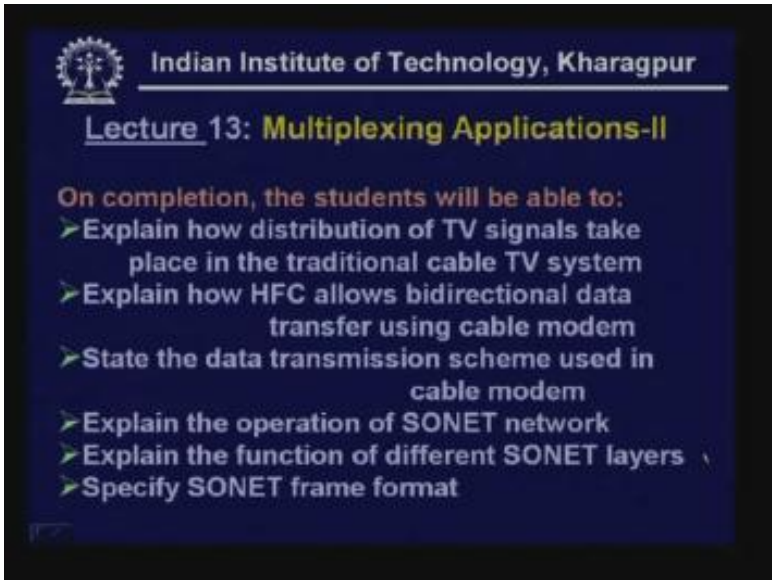
Hello viewers welcome to today's lecture on multiplexing applications. This is the second lecture on multiplexing applications. In the last lecture we have discussed about the telephone network and DSL technology which are very important applications of multiplexing. In today's lecture we shall consider two another important applications of multiplexing one in cable modem and we shall see how these conventional cable TV networks has been extended to provide internet service. And also we shall see how multiplexing is used in SONET. So here is the outline of today's lecture.

(Refer Slide Time: 1:49)



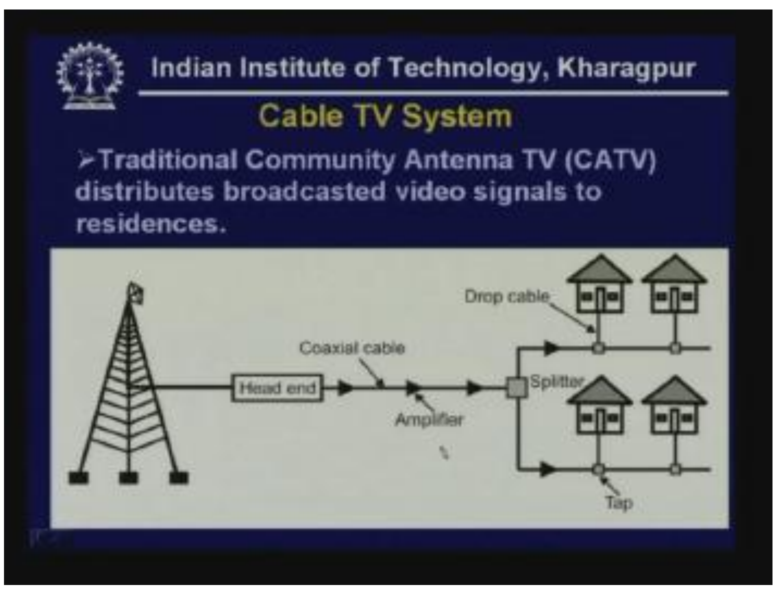
First we shall consider the standard cable TV system the frequency bands used and various devices used in cable TV system then we shall discuss about the extension of cable TV system into a new network known as Hybrid Fiber Coaxial network or in short HFC network. We shall discuss how the bandwidth is distributed and how the bandwidth is shared between upstream and downstream data so that you can have internet service. Then we shall consider SONET the Synchronous Optical Network. Here we shall see the different types of devices used in SONET network and the STS Synchronous Transport Signals the hierarchy of signal levels used in SONET network. We shall discuss about SONET frame format.

(Refer Slide Time: 3:06)



And on completion of this lecture students will be able to explain how distribution of TV signals take place in the traditional cable TV system. They will be able to explain how HFC Hybrid Fiber Coaxial cable network allows bidirectional data transfer using cable modem. They will be able to state the data transmission scheme used in cable modem. So far as the second application of multiplexing is concerned they will be able to explain the operation of SONET network, they will be able to explain the function of different SONET layers. As we shall see there are four different layers in SONET network and they will be able to explain the SONET frame format.

(Refer Slide Time: 5:14)



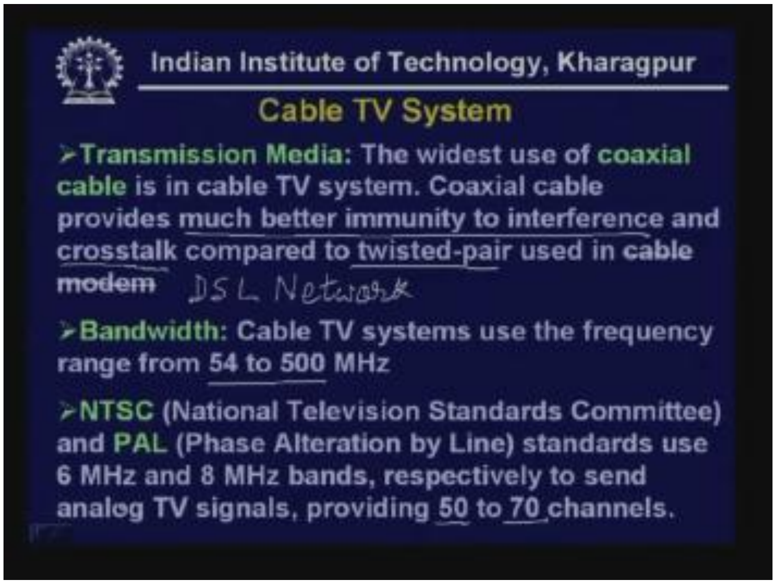
So here is the traditional Community Antenna TV or commonly known as CATV network. As you can see the basic purpose is to distribute the broadcasted video signals to residences. That means the TV signals which are received through an antenna, here is an antenna which is usually installed on the top of a roof (Refer Slide Time: 4:13) that receives the TV signal sent through satellite and then a device is used which is known as head and head end is responsible for distributing the signal on a cable network. This cable distribution system as you can see can have a number of amplifiers because the signal strength gets attenuated as the signal goes from the head end towards the residential complexes. So you can have a large number of amplifiers.

Then with the help of a splitter the coaxial cable is divided to be distributed in big residential campus and here as you can see a drop cable is used which taps from the distribution cable the coaxial cable and takes it to the residences. This is the overview or the schematic view of the standard cable TV system.

And as we have mentioned the cable TV system uses the coaxial cable compared to the DSL technology which uses the twisted-pair. So, in cable TV we find the widest use of coaxial cable. And as you know the coaxial cable provides much better immunity to interference and cross talk compared to twisted-pair so it gives you a data bandwidth compared to DSL network.

As you have seen in DSL network twisted-pair is used and the actual bandwidth is much less than the highest possible bandwidth. That means the bandwidth of the twisted-pair is not fully exploited because of the noise, interference, cross talk and so on. So the actual bandwidth available is restricted and as a consequence the available bandwidth is much less and obviously coaxial cable used in your cable TV system provides you a better alternative and it gives you higher bandwidth. and the bandwidth of the cable TV system use the frequency range from 54 to 500 MHz so this is the frequency range that is being used for cable TV system for distributing the number of large number of TV signals from different stations. There are two standards; one is your NTSC that is National Television Standards Committee and another is Phase Alteration by Line PAL standards which use a 6 MHz and 8 MHz bands respectively.

(Refer Slide Time: 7:51)

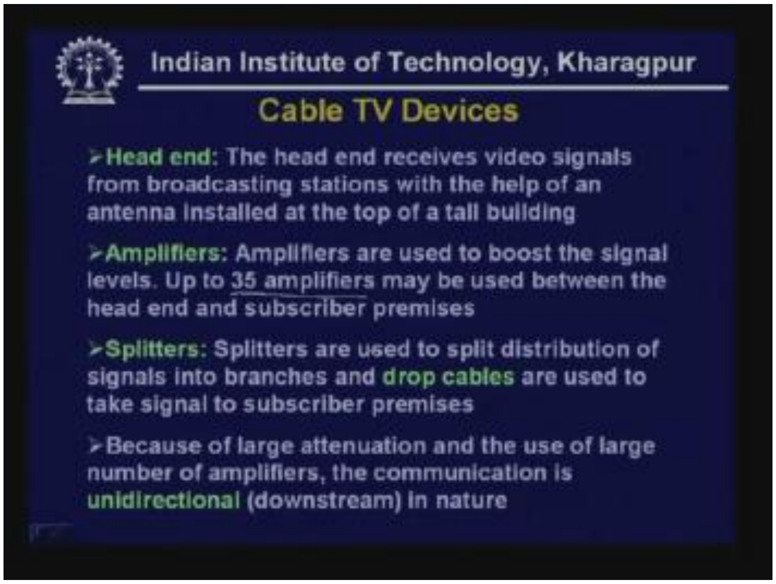


And since it uses 6 MHz and 8 MHz bandwidth this 54 to 500 MHz is distributed over a number of channels providing 50 to 70 channels depending on whether you are using NTSC or PAL standards. Depending on the standards used the number will be different. For example, if NTSC is used you will get about 70 channels and if all is used you will be getting about 50 channels because you require high bandwidth per channel. These are the popular standard.

As you have seen in the background there are three important devices used in cable TV devices. The first one was the head end. The head end receives the video signals from the broadcasting stations with the help of antenna installed at the top of a tall building.

In this diagram here I have shown a tower it need not be a separate tower but this antenna can be mounted on the roof of a building and from there the electrical signals is amplified and goes to the head end and from the head end it is distributed over the coaxial cable. So after receiving the video signal it is distributed on the coaxial cable.

(Refer Slide Time: 9:26)

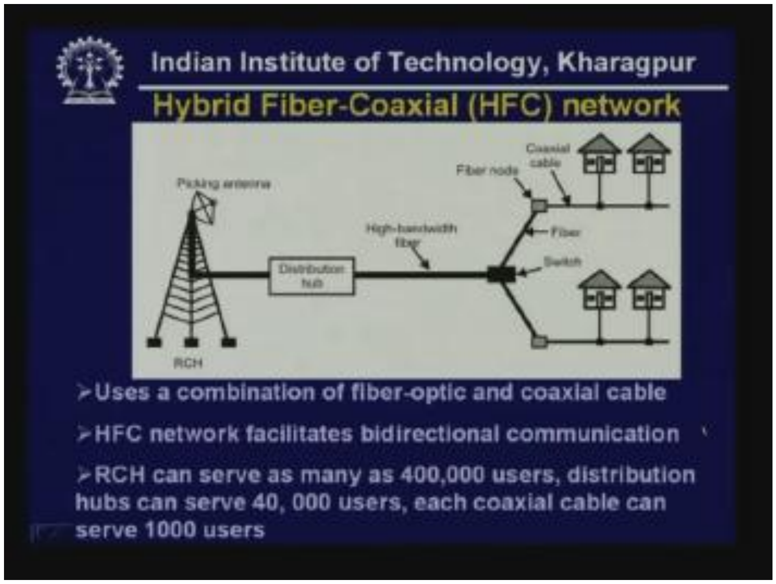


Then as I have mentioned you require amplifier to boost the signal because the coaxial cable has high attenuation so as the signal goes from the head end towards residential buildings it gets attenuated. So to improve or to boost up the signal levels you have to use amplifiers and you have to use up to 35 amplifiers in cascade between the head end and the subscriber premises. So a large number of amplifiers may be required to provide service to large number of buildings and to large number of users.

Then you have got splitters. Splitters are used to split distribution of signals into branches. So with the help of splitters from a single coaxial cable you can have two coaxial cables and so on. So you can have branches with the help of splitters. Then from the drop table you can make some kind of tap and from that tap the drop cable goes to the residential buildings that is the subscriber premises. This is how the cable TV system works with the help of three devices.

And as I mentioned because of large attenuation you will require large number of amplifiers and this restricts the communication and it is unidirectional. That means only the downstream signal goes from the head end to the residential premises so the signal transmission in standard cable TV system is unidirectional so only the downstream signal is present. Essentially the TV signals are distributed over the residential buildings with the help of this cable TV system. To overcome this limitation the cable TV system has been extended which is known as Hybrid Fiber Coaxial network.

(Refer Slide Time: 11:18)

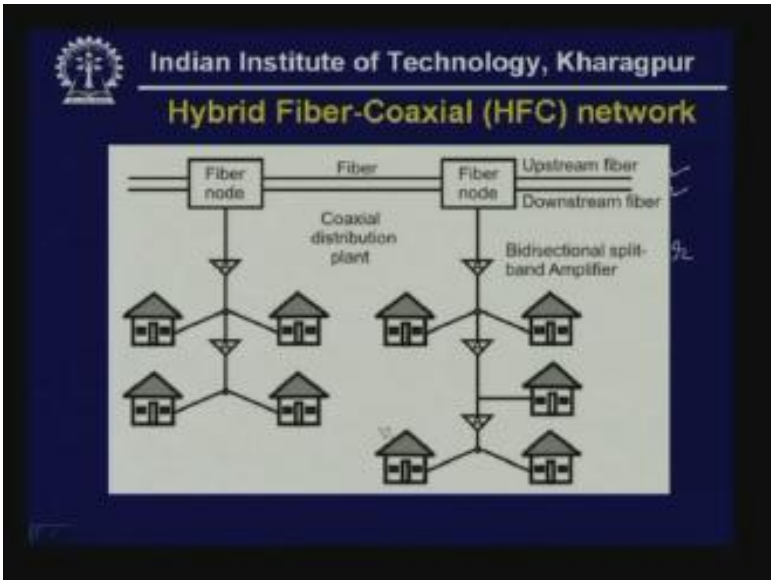


Here as you can see a combination of fiber optic and coaxial cable has been used. Here there is a Regional Cable Head RCH where the signal is picked up with the help of picking antenna and again with the help of tower the antenna is put on the top of a tall building and from there the signal goes to the distribution hubs. Thus from the distribution hubs to the fiber node it is essentially optical fiber. So you can see here in between there are switches and from the fiber node it is essentially coaxial cable. So we find that ultimately to the user premises that it is coaxial cable but in between from the distribution hub to the fiber node it is the optical fiber.

And because of the use of the optical fiber you can have lesser attenuation and as a consequence you will require a small number of repeaters or amplifiers. And as a consequence you can use bidirectional communication. So now you can have bidirectional communication and not only that because of very high bandwidth of optical fiber it is possible to serve a large number of users. As you can see a single regional cable head can serve as many as 400,000 users. So, from here the RCH can go to several distribution hubs and altogether 400,000 users can be served and from each distribution hub 40,000 users can be provided service.

On the other hand each coaxial cable coming out from the fiber node can be used to serve about 1000 users. So you can see there is a hierarchy of the optical fiber cable distribution and this is how it is done as shown in this diagram.

(Refer Slide Time: 14:34)



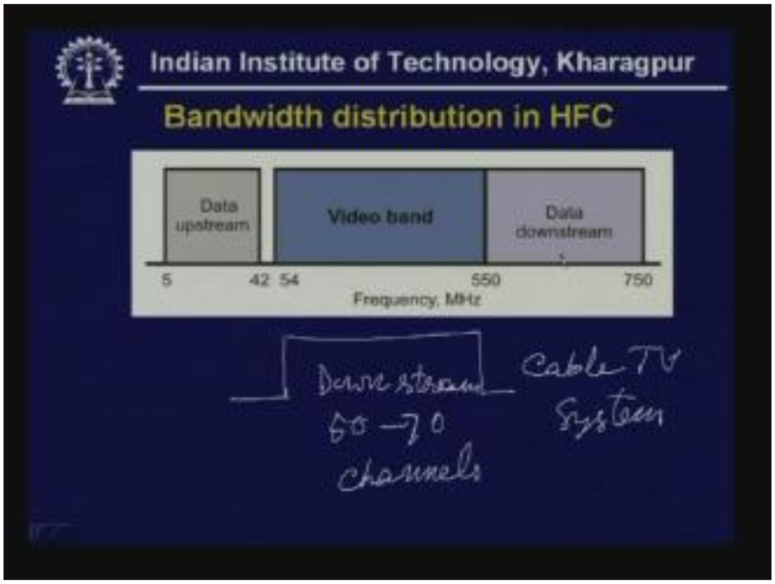
Here as you can see this is the optical fiber cable. There are two cables; one is upstream fiber another is downstream fiber so you require a pair of optical fiber cable for bidirectional communication so you have upstream and downstream fiber cable. Of course when the length is long you will require some amplifier but the number of amplifiers required will be much smaller. There we have seen the number of amplifiers required is 35 but here it is restricted to 5 or 6 or 7 and not more than that.

Then from the fiber node the signal is distributed using coaxial cable and whenever necessary to amplify you will require it will be bidirectional split band amplifier. So you can see that with the help of several bidirectional split band amplifiers the signal is distributed in the residential premises. So each such coaxial cable can serve as many as 1000 users as you have seen in the last slide so thousand users can be served.

This is the coaxial distribution plant ultimately going to the residential premises. Here is the taps taken from the coaxial cable (Refer Slide Time: 14:55) and these are the bidirectional split band amplifiers. This is the overall network for HFC system.

Now let us look at the bandwidth distribution of HFC Hybrid Fiber Coaxial cable system. In case of standard cable TV network you have got only downstream band that is from 54 MHz so from 54 to 550 MHz was the bandwidth used in cable TV system. So it was only downstream which can support about 50 to 70 channels. But here we find we have got three distinct frequency bands.

(Refer Slide Time: 16:04)

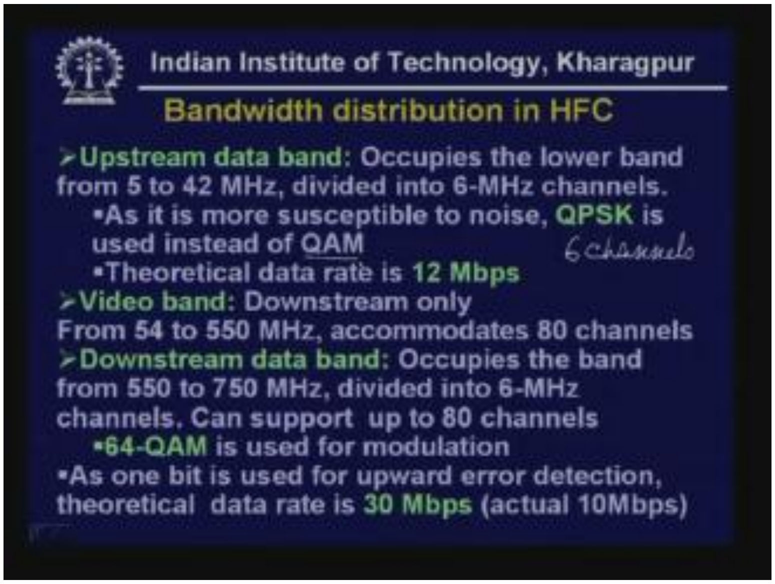


We have retained the video band that is downstream frequency band used for video distribution and in addition to that there are two data bands one is data upstream and another is data downstream. Data upstream band is from 5 to 42 and data downstream is from 550 to 750. We observe that the upstream bandwidth is much smaller than the downstream bandwidth. You may be asking why the upstream bandwidth is smaller than the downstream bandwidth.

Usually it is used for internet service. Now it is used for providing internet service to the residential users. So in such cases usually the data which is going from the users to the internet is small on the other hand the large volume of data flows from the internet to the users. So as a consequence you require higher bandwidth for downstream data compared to upstream bandwidth that’s why we will see that the upstream bandwidth is smaller compared to downstream bandwidth and the similar situation we have seen in DSL technology also.

Now we see how the bandwidth distribution takes place and how it is being utilized. First we consider the upstream data band that occupies the lower band 5 to 42 MHz which is divided into 6 MHz channels so since it is 5 to 42 we will have only 6 channels and each of these 6 channels will have 6 MHz bandwidth and as it is more susceptible to noise QPSK is used for modulation purpose instead of QAM because amplitude modulation as you know it is prone to error whenever there is noise.

(Refer Slide Time: 18:04)



Thus since it uses QPSK you can have only 12 mega bits per bandwidth. That is, the theoretical data rate that is possible is 12 Mbps because whenever we use 6 MHz bandwidth channel our data rate will be 12 Mbps multiplied by 2. That means per signal element you can send two bits of data that’s how you get this 12 Mbps.

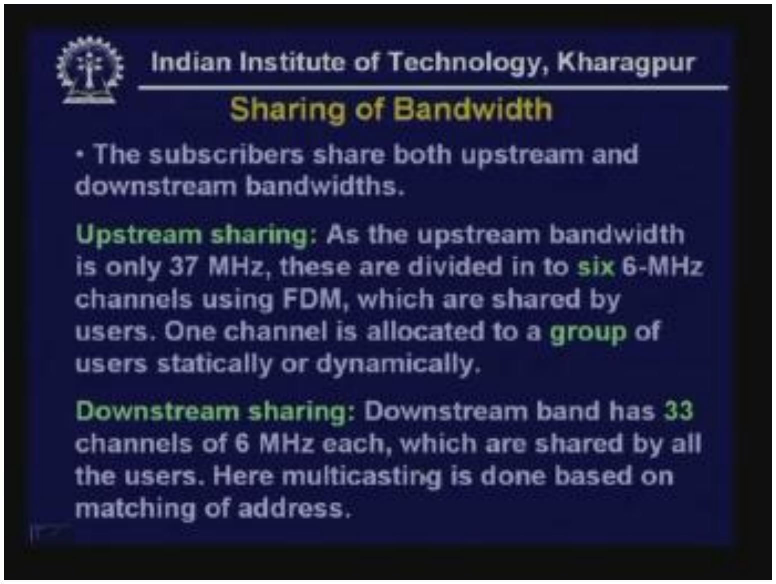
Although this is the theoretical maximum data rate the actual data rate in the upstream direction will be much smaller because you cannot really achieve this 12 Mbps bandwidth. Then the video band that is downstream only is used for 54 to 550 MHz it can accommodate up to 80 channels. Since each channel requires six MHz you can have at most eighty channels that is about 80 channels can be transmitted is for video band.

On the other hand the downstream data band occupies the bandwidth from 550 to 750 MHz which is divided into 6 MHz channels and it will have about 33 channels. It will have about thirty three channels and by using that 64 QAM modulation and since you are using 64 QAM in the downstream data you can transmit six bit per signal element that gives you 6 into 6 = 36 Mbps. However, one bit is used for upward error detection and that’s how the theoretical data is 30 Mbps. However, in practice the actual will be 12 Mbps.

So you may be asking why the actual data rate is 12 Mbps?

The reason for that is the cable that is being used for this downstream data is essentially that 10 base t twisted-pair cable and with the help of that you can support only 10 Mbps. As a consequence the actual data rate will be much smaller. So we have seen how the three bands are used and how they are modulated by using QPSK and QAM.

(Refer Slide Time: 21:09)

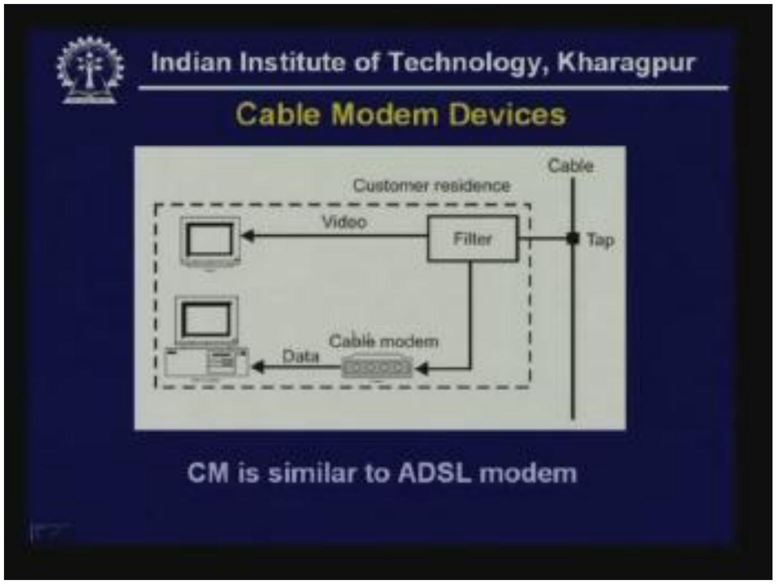


And obviously the data that is being sent either in the upstream or downstream direction is shared. The subscriber shares both the upstream and the downstream bands. As we have seen the HFC can support a large number of subscribers 400,000 from a single regional cable head. So obviously the bands have to be shared. So the upstream bandwidth is only 37 MHz these are divided into 6 MHz bands as I have already mentioned and that is done by frequency division multiplexing and these 6 MHz bandwidth can be shared by a number of users. Actually one channel is allocated to a group of users either statistically or dynamically.

We shall see how this upstream band is shared, how a particular channel can be used by a particular subscriber at a particular instant of time. That means you have to use some kind of time division multiplexing. This is actually called TDM Time Division Multiplexing and essentially it uses medium access kind of technique. We shall see how this can be done later on.

Then the downstream sharing is also done because you have got only 33 channels each of 6MHz bandwidth and these are shared by all the users. Of course here the contention is not required. There it is essentially multicasting. The signal is coming from the network may be through optical fiber cable then it is distributed through a large number of users and based on the address the signal is diverted and multicasting is used. That means here multicasting is done based on matching of address. So the different signals different channels goes to different users based on the address because each user is provided with an address whenever they get the HFC service. So here are the different devices that are used in cable modem systems.

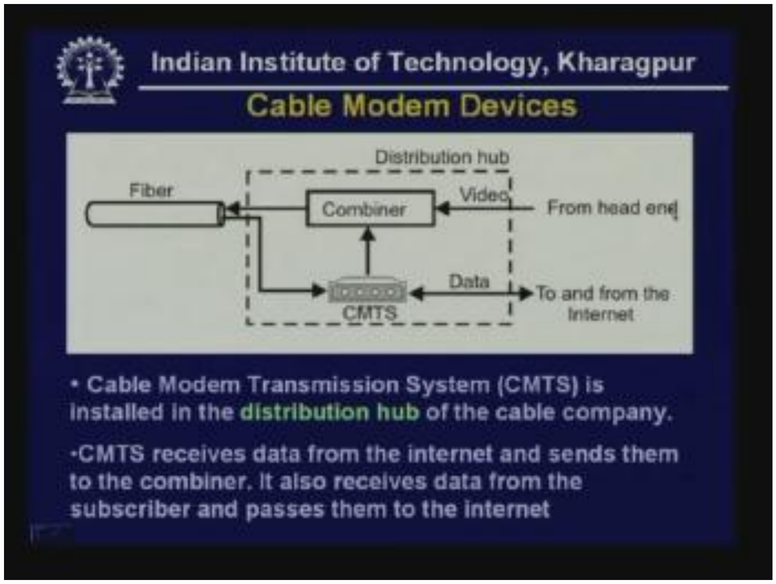
(Refer Slide Time: 23:42)



Here you see the cable modem that is being used in the residential premises. This is the customer residence (Refer Slide Time: 23:50) and this is the coaxial cable and a tap is made and from there the signal comes to a filter which separates out the video signal so that video signal will go to a TV television and the other data signal will go to a cable modem which will do the necessary modulation and demodulation and the signal will go to the computer. So here it is going to a computer. You can see here that both data as well as video communication is possible by using this device.

Now let us look at the system used in distribution hub.

(Refer Slide Time: 25:09)



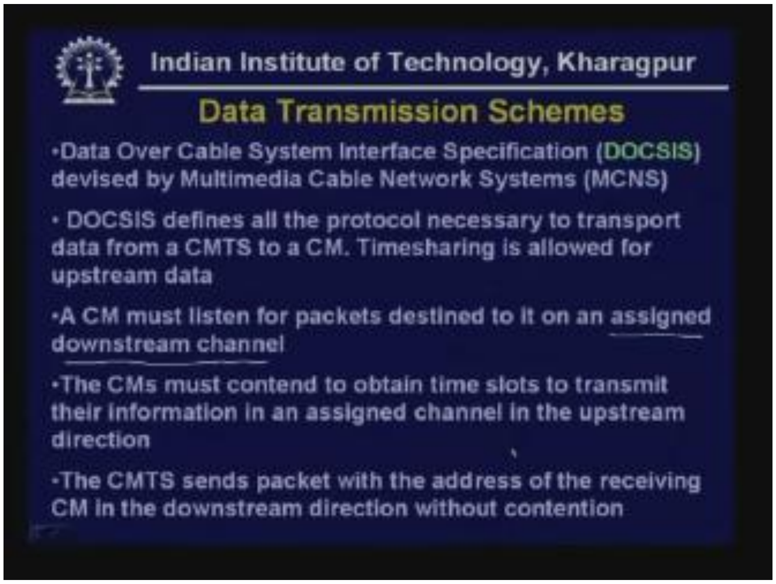
The cable modem transmission system or CMTS is installed in the distribution hub of the cable company. This is in the cable company. Here we see that the signal comes from the optical fiber. In the previous case it was the coaxial cable that goes to the residences but here the optical fiber is going to the distribution hub (Refer Slide Time: 24:55) and from the distribution hub it is bidirectional where you have a pair of optical fiber wires where the upstream and downstream fibers are there. Then we have these two signals coming in namely the video signal and the data signal. The video signal is coming from the head end the other signal is coming from the internet as you can see it is a bidirectional signal which is going to the CMTS which is combined here (Refer Slide Time: 25:26) and that goes to the fiber. That means the signal which is downstream goes to the user and the signal which goes to the internet comes in this direction and it goes to the internet. This is how the communication takes place.

That means CMTS receives data from the internet and sends them to the combiner this is the signal and it also receives data from the subscriber from here and it passes them to the internet. Therefore the CMTS communicates in both the directions.

Let us see the data transmission scheme used in cable TV system. As I have mentioned the cable TV system allows data communication. You can have both voice and video and you can have video on demand if necessary. How it is being done is explained here. it uses DOCSIS the Data Over Cable System Interface Specification devised by Multimedia Cable Network Systems so MCNS develop the DOCSIS for the purpose of data transmission over cable modem. DOCSIS defines all the protocol necessary to transport data from CMTS to CM and timesharing is allowed for upstream data. As I have mentioned the upstream data has to be time shared. A cable modem must listen for packets destined to it on an assigned downstream channel. That means a channel is assigned and obviously assignment is done based on some kind of contention. The CMs must contend to obtain time slots to transmit their information in an assigned channel in the upstream direction. That means it is some kind of contention based medium access control.

In local area network this kind of a technique is used. A cable modem has to contend for a channel and once it gets it then the CMTS will be able to send data to obtain time slot to transmit data. That means it is a combination of FDM and TDM. It is used here for the transmission of data from a large number of users.

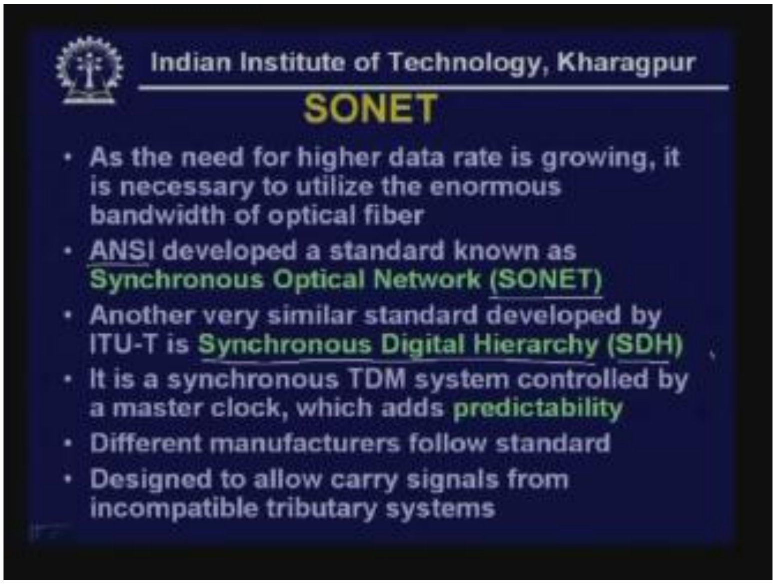
(Refer Slide Time: 28:09)



The CMTS sends packets with the address of the receiving CM in the downstream direction without contention. As I have mentioned here it is some kind of multicasting. There is no need for contention with the help of the address assigned to a particular subscriber so that the signal can be diverted to different users. This is the data transmission scheme in nutshell used in cable TV system.

Now we shift gear to discuss about another important application of multiplexing that is SONET.

(Refer Slide Time: 29:39)



As the need for higher data rate is growing it is necessary to utilize the enormous bandwidth of optical fiber. As you have seen optical fiber provides you very high bandwidth and to utilize it fully it is necessary to have standard. Two standards have been developed; one in US developed by American National Standard Institute ANSI. ANSI developed a standard known as Synchronous Optical Network or SONET.

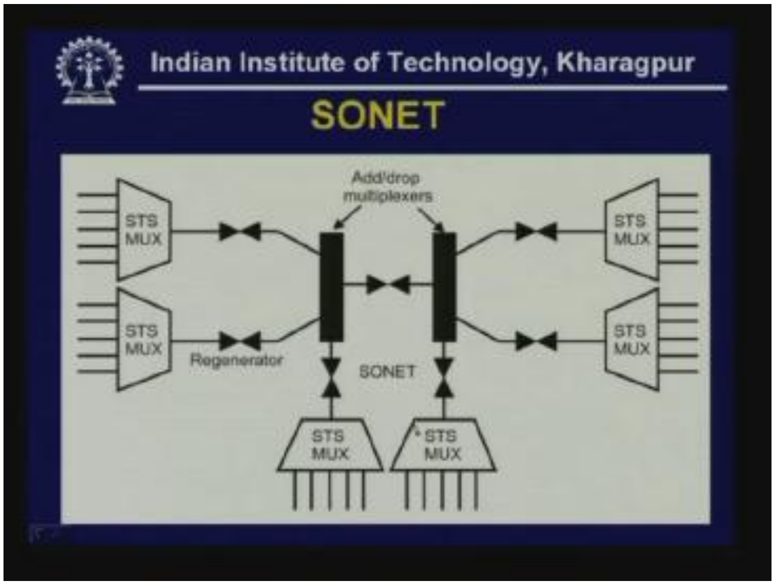
On the other hand in Europe another very similar standard was developed by ITUT which is known as Synchronous Digital Hierarchy or in short it is known as SDH. These two are very similar and they have three important features. First one is it is a Synchronous Time Division Multiplexing system controlled by a master clock which adds predictability. So it is essentially a network wise synchronous system and because it is synchronized by a master clock it is very predictable and dependable. The synchronous transmission synchronous communication has more efficiency.

We have already discussed this when we discussed about the Synchronous Time Division Multiplexing and Asynchronous Time Division Multiplexing. We have seen that Asynchronous Time Division Multiplexing requires higher overhead. But since SONET uses Synchronous Time Division Multiplexing it is quite efficient so the overhead is much less.

Second important feature is different manufacturers follow a standard. The standards which have been developed are being used by a number of optical fiber system manufacturers so we get standard based equipment for use in SONET system.

Thirdly it has been designed to allow carry signals from incompatible tributary systems. in the last lecture we discussed about the telephone network. There we have seen the DS Digital Signal System has been developed that's a hierarchy of signals that is used in telephone network. But there the bandwidth is smaller. So here we shall see that those DS signals can be also sent through this SONET network because of this SONET is becoming increasingly popular and widely used. Here is the schematic diagram of a SONET network.

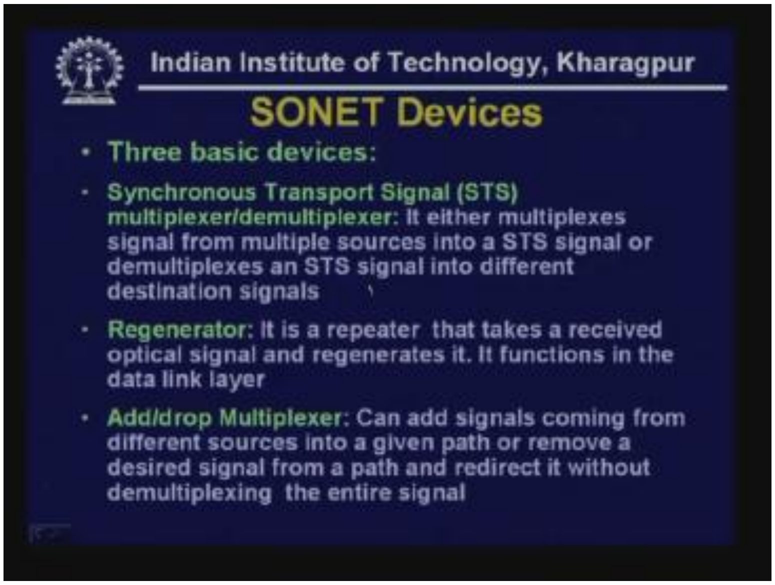
(Refer Slide Time: 31:39)



Here we see there are three different types of devices; STS multiplexer, regenerator and add drop multiplexers. These are the three different types of devices used here. Electrical signals coming from different users are coming to the STS multiplexers and then it is converted to optical signal. So here it is electrical and it is converted into optical signal with the help of STS multiplexer. The optical signal goes through and if necessary it is regenerated with the help of regenerator which is nothing but some kind of amplifiers such as the optical signal and the noise is removed and it is regenerated. In fact it does more than that as we shall see. From the regenerator it goes to the add drop multiplexer.
This is another kind of multiplexer and not the same as SDS multiplexer. The optical signals can be picked up or combined and then sent through optical cable and then it goes to another add drop multiplexer if necessary and if distance is long you will require one or more regenerators before it goes to the STS multiplexer and it goes to the other end where again it is converted into electrical signal and goes to the users. So between two users you have got STS multiplexer.

So in the simplest case you need not have regenerator you need not have add drop multiplexer essentially SDS multiplexers can be directly connected if the distance is small. However, if the network is complex you will require a large number of STS multiplexers, regenerators and add drop multiplexers.

(Refer Slide Time: 33:36)



So we have seen three different types of devices used in SONET. What are the functions of these three different types of devices? Let us see.

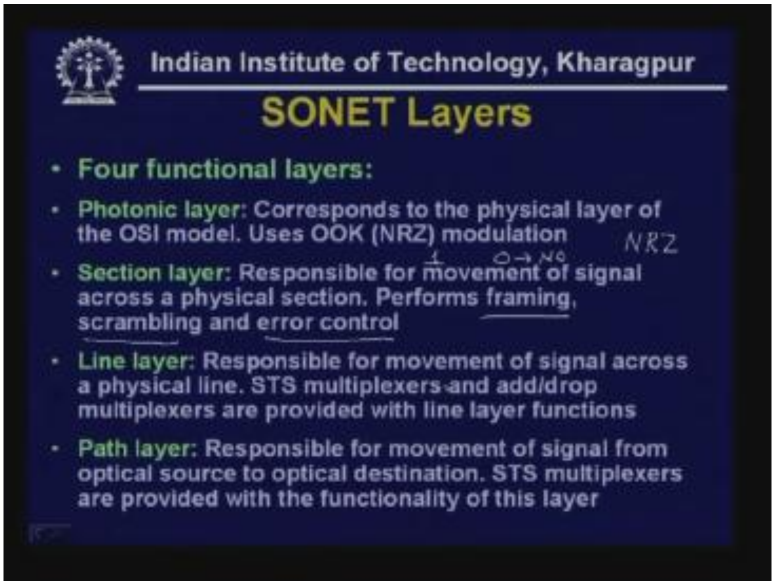
First one is the synchronous transport signal multiplexer demultiplexer. So it either multiplexes signal from multiple sources into a STS signal. The STS signal is the hierarchy of signals or it demultiplexes an STS signal into different destination signals. So here it gets converted from electrical to optical or from optical to electrical so both these conversions are done in this STS multiplexers. So a number of electrical signals are combined and then sent in the optical form or a number of optical signals are received by the STS multiplexers and converted into electrical signals to be sent to different destinations.

Then you have got regenerators. It is a repeater that takes a received optical signal and removes noise and regenerates it. It functions in the data link layer so it does something more than simply regenerating the signal. As we shall see it will take out some information adds some information in the frame that's why it works in data link layer as well as in the physical layer.

Then you have got add drop multiplexer. Add drop multiplexer can add signals coming from different sources into a given path or remove a desired signal from a path and redirect it without demultiplexing the entire signal. So the demultiplexing and multiplexing is restricted to the SDS multiplexers. On the other hand the add drop multiplexer can divert path or remove a desired signal from a path, it is done based on address and pointer.

The SONET has three different layers.

(Refer Slide Time: 37:28)



We have earlier discussed about the seven layer OSI model and we have seen the functions of different layers. Here the SONET is divided into four different layers to divide the complexity. Whenever the complexity of a system is very high it is divided into a number of layers. So here also the SONET is divided into four different layers. First one is photonic layer. Photonic layer corresponds to the physical layer of the OSI model and here it works in NRZ form, NRZ encoding is used and it does On/Off Keying. So it does the on off key modulation that means when there is 1 the optical signal is present and when it is 0 no signal is present. So 'O' corresponds to no optical signal and 1 corresponds to when there is optical signal. Hence that is essentially On/Off Keying using modulation.

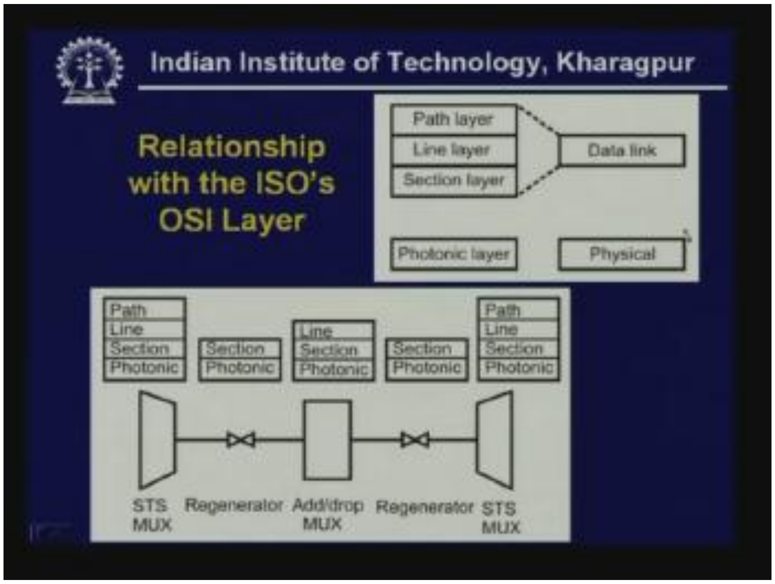
.

The section layer is responsible for movement of signal across a physical section. It performs framing, scrambling and error control. So the section layer performs three different functions and also it is responsible for movement of signal across a physical section. Later on let us see what we mean by section.

Line layer is responsible for movement of signal across physical line STS multiplexers and add drop multiplexers are provided with line layer functions. That means the regenerators do not have this line layer functions. On the other hand the STS multiplexers and add drop multiplexers are provided with this line layer functionality.

Finally it has got path layer. This is responsible for movement of signal from optical source to destination. STS multiplexers are provided with functionality of this layer. Only the STS multiplexer is provided with this functionality. Let's see the relationship of this four layer SONET model with the ISO's OSI layer.

(Refer Slide Time: 38:24)

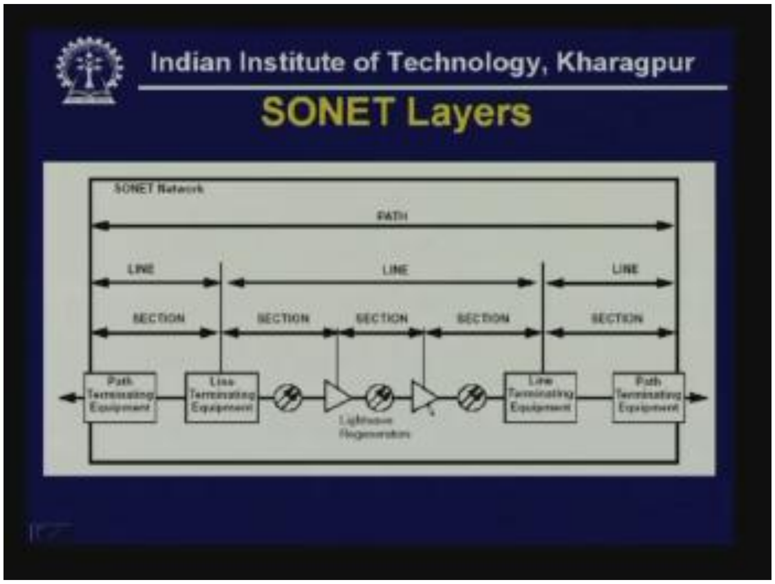


We know that ISO's OSI layer has got seven layers. The lower two layers are physical and data link. So the photonic layer belongs to the physical layer where it decides the signal level, distance and all this parameters for physical transmission of optical signal so that is done in the photonic layer. On the other hand the data link layer has got three different sub-layers that means all the three upper layers of SONET belong to the data link layer of the OSI model. That means the path layer, line layer and section layer all these three belong to data link layer. And here as you can see (Refer Slide Time: 39:07) the functionality is incorporated in different devices of the SONET system as shown here.

The STS multiplexers are provided with the functionality of path, line, section and photonic layers all the four layers. On the other hand the regenerators are provided with only the functionality of two layers photonic and section layer. Since it has got the functionality of photonic and section layer that's why we say that regenerators belong to both physical as well as data link layer.

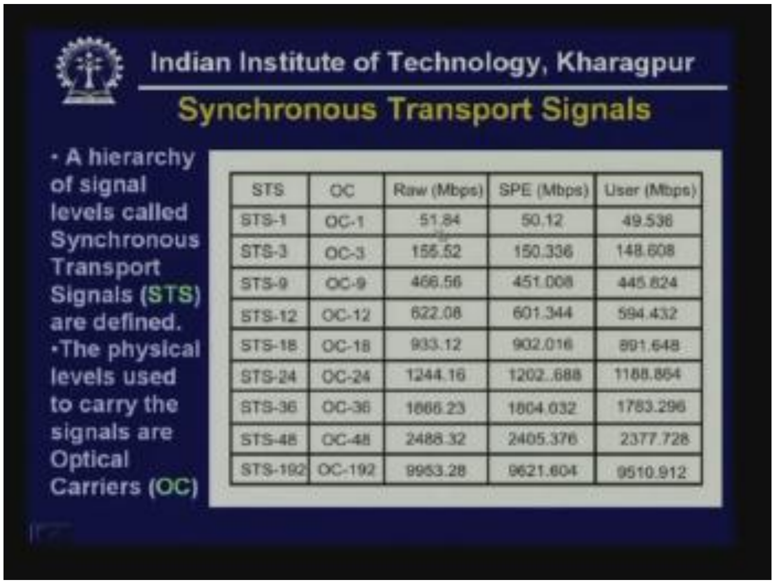
On the other hand the add drop multiplexers has the three layers photonic, section and line layers and the STS multiplexer as we have already mentioned has got four different layers photonic, section, line and path layers. Here let us see what we really mean by section, line and path. Between any two devices between two regenerators this is one regenerator and (Refer Slide Time: 40:15) this is another regenerator so between any two regenerator there is a section.

(Refer Slide Time: 40:17)



Between the regenerator and add drop multiplexer is a section. Between the add drop multiplexer and STS multiplexer is a section. That means between any two devices a section is formed. On the other hand between the line terminating equipment or between two line terminating equipments or between path terminating equipment and line terminating equipment the path terminating equipment is essentially the STS multiplexer line terminating equipment is essentially the add drop multiplexer. Between each of them forms a line. and the end to end from user to user, electrical to electrical optical to optical that means when it is converted from electrical to optical and optical to electrical it is essentially a path. So this end to end is the path and between a path you may have several lines and between each line you can have several sections as it is depicted in this diagram.

(Refer Slide Time: 42:06)

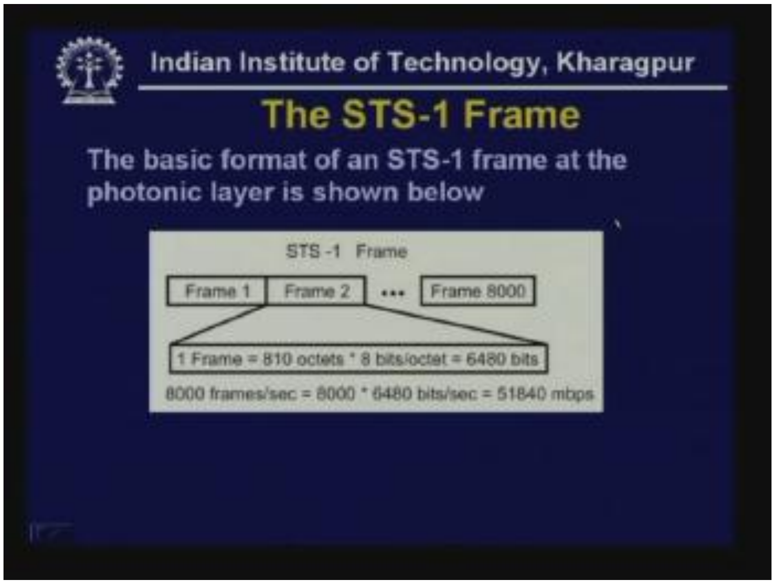


Now as I have mentioned a hierarchy of signal levels called Synchronous Transport Signals are defined. These Synchronous Transport Signals has a hierarchy just like DS signals we have seen in telephone network. Here as you can see (Refer Slide Time: 42:03) we have got STS-1 which has raw bandwidth of 51.84 Kbps, STS-3 which is three times of that has got 155.52 you have got STS-192.

However, that STS-1, STS-3, STS-12 and STS-24 these four are the most popular hierarchical levels commonly used. So the raw data rates electrical data rates are given here in this third column starting with 51.84 Mbps and as you can see STS-192 has got 9953.28 Mbps. So you see it is a very high data rate that is supported by optical fiber SONET network. This is called the services (Refer Slide Time: 43:01) and it is converted into optical signal which are sent by optical carriers. So this is your optical carrier, the STS-1 is converted into optical signal corresponding to OC-1 so optical carrier 1 carries the STS-1 signal, OC-3 carries the STS-3 signals and so on. So in this way here you have got the physical levels used to carry the signals or the optical carriers so these are the optical carriers used.

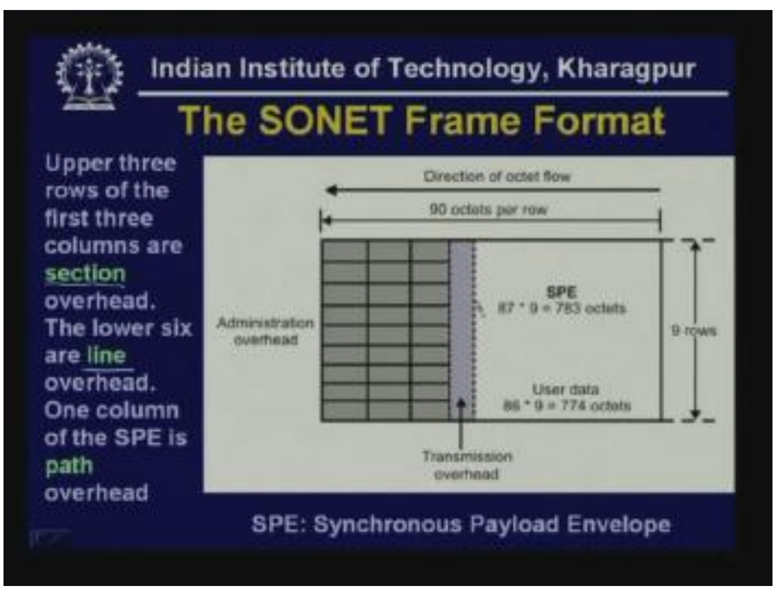
Now, although the third column gives you the raw mega bandwidth Mbps of the Synchronous Transport Signals there are overheads. first of all as we shall see in this STS one out of this 51.84 Mbps this is your envelope that synchronous payload envelope is only 50.12 Mbps out of which there is some overhead like section, line etc. Of course path overhead is covered here in SPE some overheads are there and if you exclude these overheads you get the payload of only 49.536 Mbps. So this is the actual payload that you get from the SONET system. So as you can see here the overhead is not really very high it is 51.84 and this is 49.536 so the overhead is about 4% which includes the overhead of the layers that we shall see.

(Refer Slide Time: 45:02)



This is the basic STS frame format at the photonic layer. Here as you can see you can transmit a single STS frame comprised of 8000 frames. So one after the other these frames are sent like frame 1, frame 2 then frame 8000. On the other hand each frame is divided into 810 octets and each octet has got eight bits so a single frame comprises 6480 bits and these 8000 frames are sent per second so your data rate is 51.840 Mbps. So here as you can see a single frame is shown where you have got 810 octets.

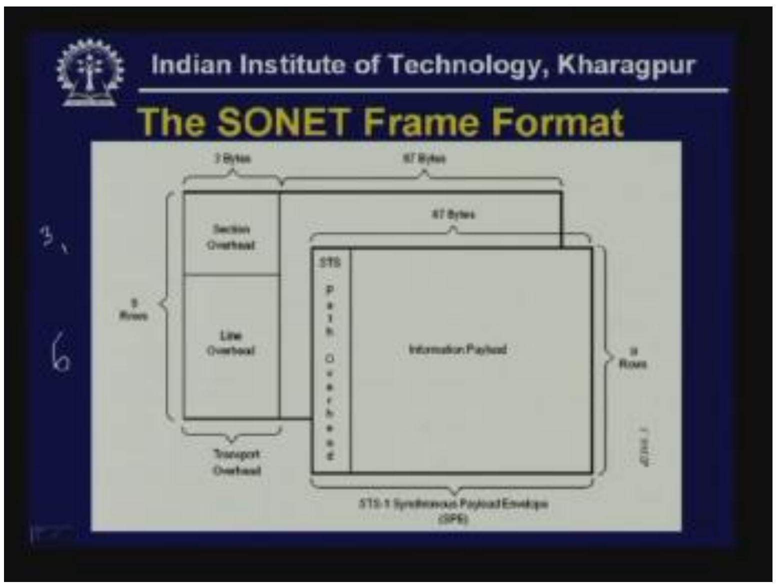
(Refer Slide Time: 46:50)



As you can see here each row has got 90 octets out of which the first three columns are used for section and line overhead and the upper three rows the top three rows and the first three columns gives you the section overhead and the first three columns that is the six rows of the first three columns is the line overhead and the path overhead is one column. That means you have to exclude four columns which are essentially the overheads and if you exclude from nine to one ninety octets you get eighty seven octets which is known as the Synchronous Payload Envelope SPE out of which one is used for path overhead giving you user data of 774 octets so you have got nine such rows of 90 octets per row.

Now this diagram gives you more detailed information.

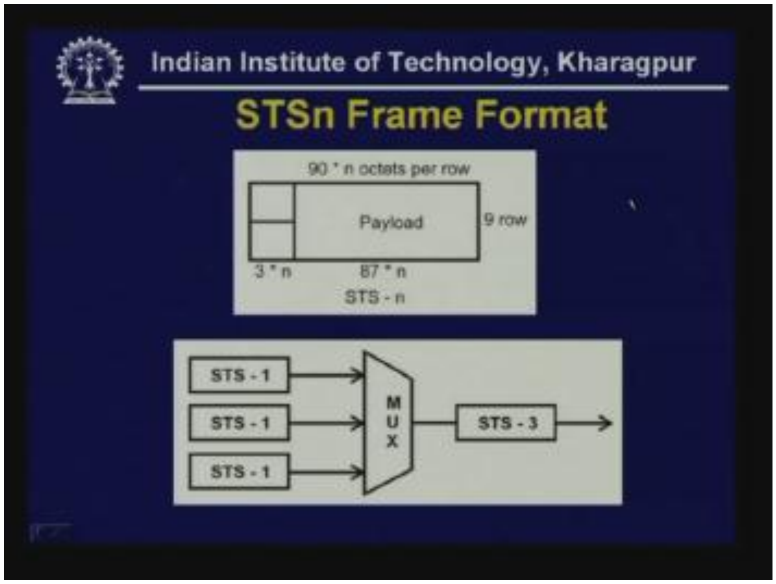
(Refer Slide Time: 47:27)



This is the section overhead that is your three rows and here you have got 6 rows 3 columns and 3 rows, and 3 columns and 6 rows and here 1 column for path overhead. So you have the section overhead, line overhead and path overhead. That means when the electrical signal comes it goes through first the path overhead then the line overhead then the section overhead. All the overheads are incorporated in a frame then it is converted into optical signal and transmitted in the optical form.

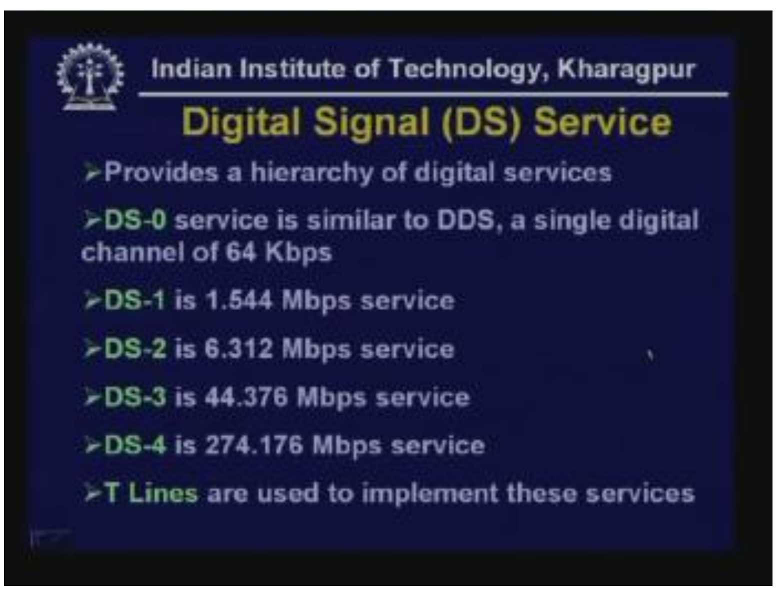
Now those STS signals can be combined to form higher order signals.

(Refer Slide Time: 48:15)



For example three STS-1 signal can be combined with the help of multiplexer to form STS-3 signal and in general you can have STSn frame format where as you can see that the overhead columns are provided at the front which has got 3 into n columns and remaining 87 into n are essentially the payload out of which there are path overheads present here which is not shown here. This is how the multiplexing can be done and you can create different types of hierarchical signals. So here as you can see again three STS-1 signals are combined to form a STS-3c concatenated signal so overhead columns are here and the payload 1, payload 2 and payload 3 columns are combined to have a concatenated payload and this can be sent through the optical network.

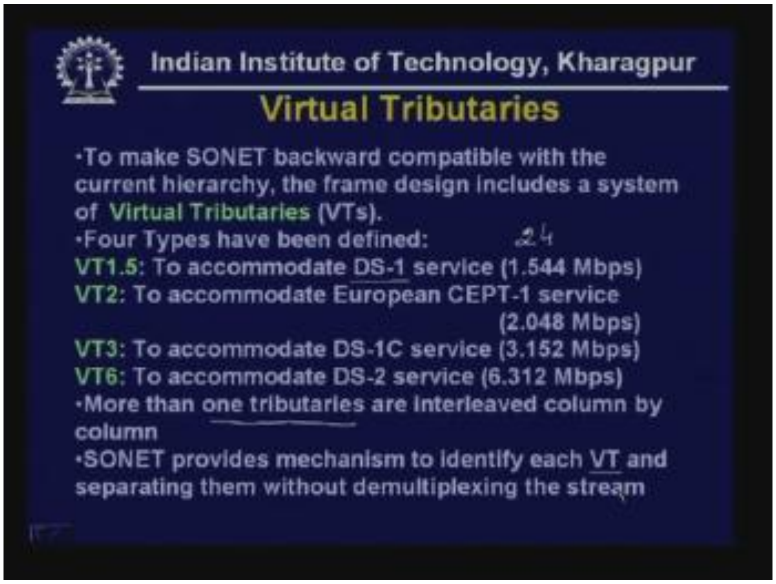
(Refer Slide Time: 49:27)



Now the question arises, is it possible to send the DS signals used in telephone network through the SONET network. We shall discuss how it is being done. As we know the Digital Signal service used in telephone network has got a hierarchy of digital services. DS-0 service is similar to DDS a single digital channel of 64 Kbps and DS-1 has got 1.544 mega bits service, DS-2 has got 6.312 Mbps service, DS-3 has got 44.376 Mbps service and DS-4 has got 274.176 Mbps and as you know the T lines are used to implement these services.

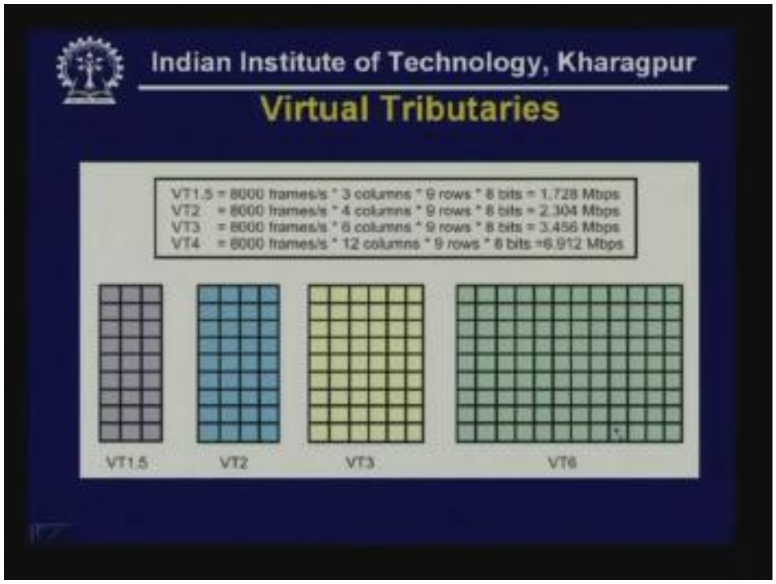
Now as you can see here even the DS-3 bandwidth is lower than the STS-1 signal. So how we shall send DS-1, DS-2 and DS-3 signals? For that purpose a technique known as Virtual Tributaries are created. Let us see how we can send those DS signal through the SONET signal by using Virtual Tributaries.

(Refer Slide Time: 52:04)



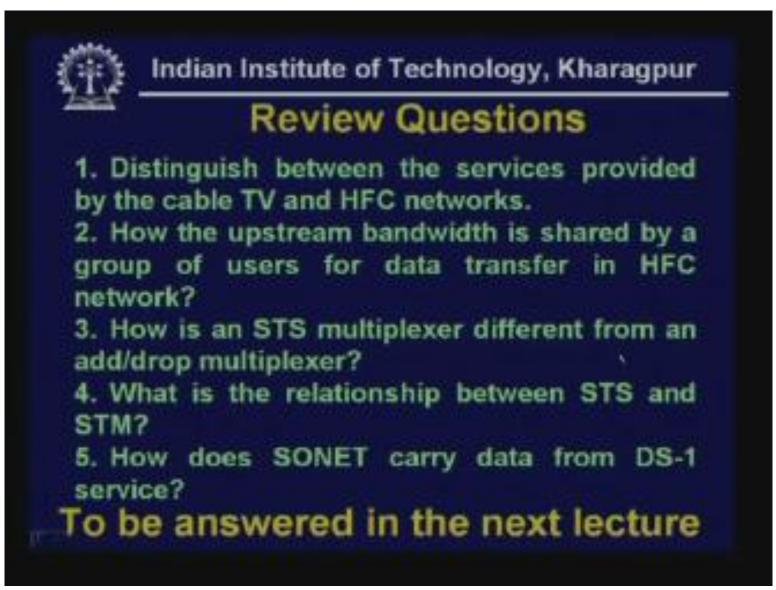
To make SONET backward compatible with current hierarchy the frame design includes a system of Virtual Tributaries. Four types of tributaries have been defined. One is VT1.5, this is used to accommodate DS-1 service which is only 1.544 Mbps and as you know this can accommodate twenty four voice channels. And VT2 which can accommodate European CEPT one service has bandwidth of 2.048 Mbps. VT3 can accommodate one DS-1c service having bandwidth of 3.154 Mbps. VT6 can accommodate DS-2 service 6.312 Mbps and more than one tributaries can be interleaved column by column and this SONET provides the mechanism to identify each virtual tributary and separating them without demultiplexing the stream. That means based on the pointers and addresses those VT signals Virtual Tributaries can be separated out and can be sent to proper destination. So here the Virtual Tributaries are shown.

(Refer Slide Time: 52:12)



This is VT1.5 if you multiply 1.5 you get three that's why it has got three columns and as you can see 1.728. This is 1.728. However, it is sending only 1.544 DS-1 signal and others are essentially overhead, there are overheads here. Similarly the other three tributaries such as VT2 has got four columns, VT3 has six columns and VT6 has got twelve columns these can be interlinked in a single SONET frame STS-1 frame for transmission through the optical fiber. Therefore we have discussed two important applications of multiplexing in this lecture, one is the cable modem and another is SONET. Now let us look at the Review Questions.

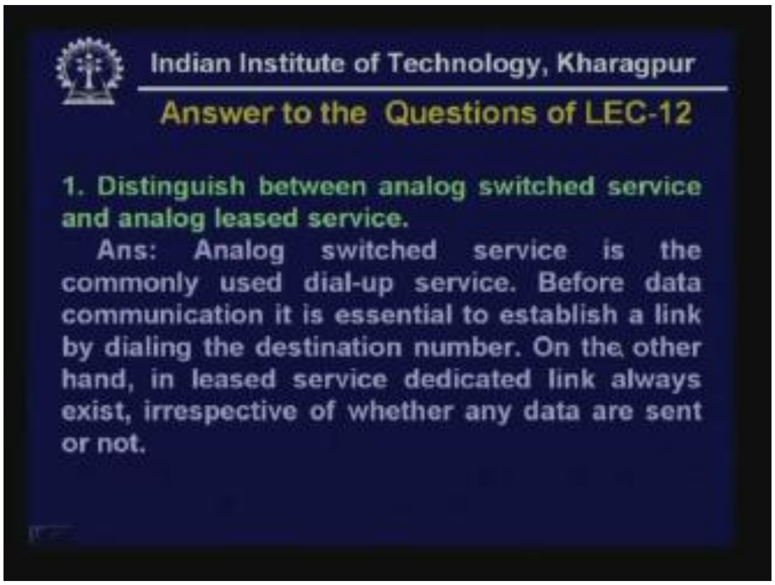
(Refer Slide Time: 53:48)



1) Distinguish between the services provided by the cable TV and HFC networks.
2) How the upstream bandwidth is shared by group of users for data transfer in HFC network?
3) How is an STS multiplexer different from an add drop multiplexer?
4) What is the relationship between STS and STM?
5) How does SONET carry data from DS one service?

These questions will be answered in the next lecture. Now it is time to answer the questions of the previous lecture - 12.

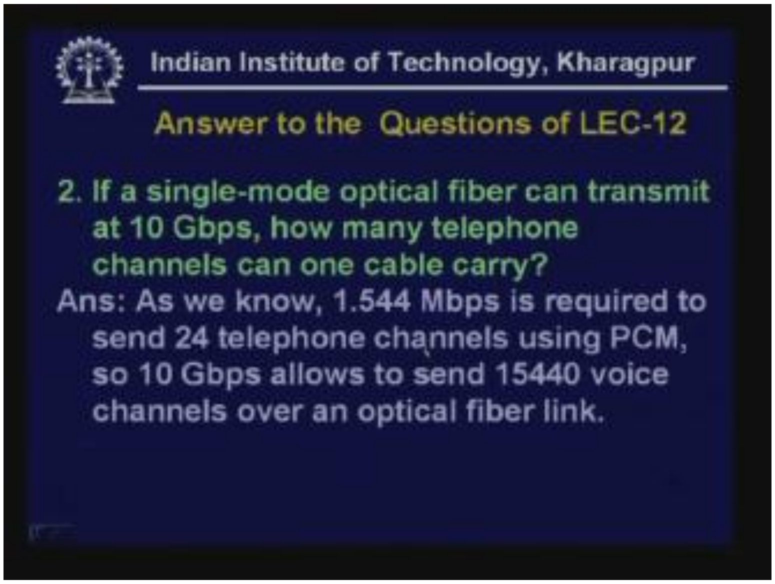
(Refer Slide Time: 54:14)



1) Distinguish between analog switched service and analog leased service.

As you know analog leased service is the commonly used dial-up service. On the other hand before data communication is performed in this dial-up service you have to establish a connection. It is a common experience to us, first dial a number establish a connection and then you transfer data. On the other hand in leased service dedicated link always exist irrespective of whether any data is sent or not. So there is no need for establishing a connection, the connection is already established.

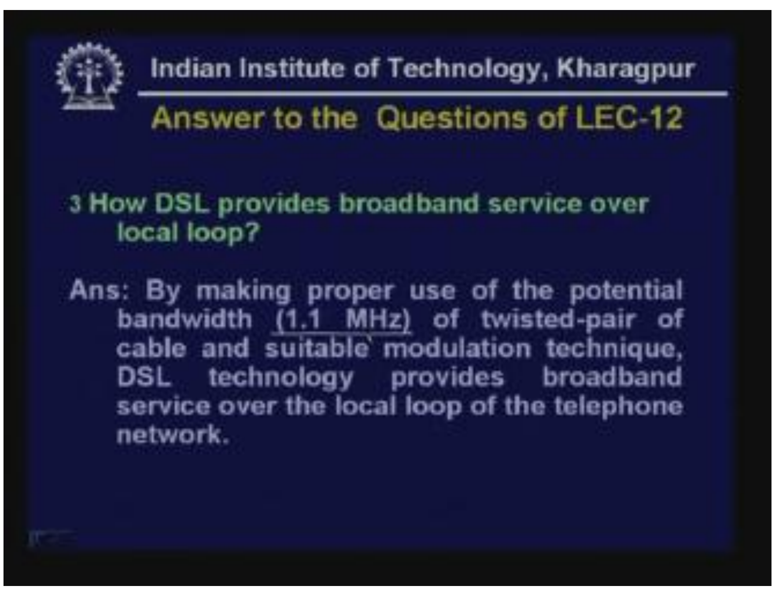
(Refer Slide Time: 54:52)



2) If a single mode optical fiber can transmit 10 Gbps how many telephone channels can one cable carry?

As we know 1.544 mega bits is required to send 24 telephone channels using pulse code modulation so 10 Gbps will allow sending 15440 voice channels over an optical link. You can do the calculation and you will find that considering 24 channels per 1.544 Mbps you will be able to send 15440 voice channels through 10 Gbps per channel in an optical fiber. So you can see that large number of voice signals can be sent through a single optical fiber.

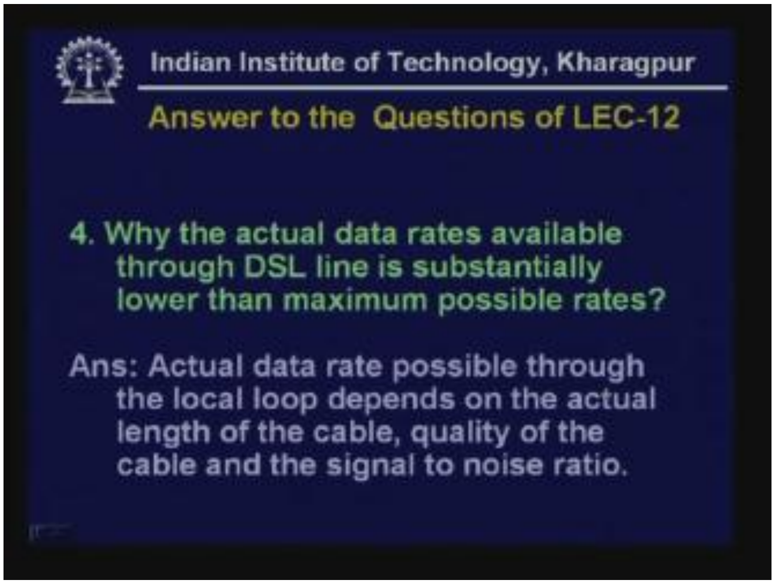
(Refer Slide Time: 56:15)



3) How DSL provides broadband service over local loop?

As we know the twisted-pair is used in local loop which has the bandwidth of 1.1 MHz. So by using suitable modulation technique it is possible to provide broadband service over local loop of the telephone network. So the filters that are commonly used in telephone network is removed and with proper suitable modulation technique it is possible to provide that broadband service in DSL.

(Refer Slide Time: 56:45)



4) Why the actual data rates available through DSL line is substantially lower than maximum possible rates?
As we have seen although the maximum data rate is high because of the long length of the cable, attenuation, quality of cable, signal to noise ratio it is not possible to send at that maximum rate so the rate data rate that can be sent is decided dynamically based on the line condition in DSL network. Usually it is much lower than the maximum network.

So friends in the last two lectures we have discussed four important applications of multiplexing. First we have seen the application of multiplexing in telephone network then we have seen the application of multiplexing in DSL technology which provides broadband service and third application we have seen in cable modem and fourth one is SONET and all these are very popular and widely used for data communication, thank you.