Data Communications
Prof. A. Pal
Department of Computer Science & Engineering
Indian Institute of Technology, Kharagpur
Lecture-12
Multiplexer Applications-1

Hello and welcome to today's lecture on multiplexer applications. In the last lecture we had discussed the various techniques of multiplexing, a set of techniques that is used for multiplexing like Frequency Division Multiplexing, Time Division Multiplexing and Wavelength Division Multiplexing which is a variation of Frequency Division Multiplexing. And also we have discussed two types of Time Division Multiplexing that is your Synchronous Time Division Multiplexing and Asynchronous Time Division Multiplexing. These multiplexing techniques have numerous applications.

In this lecture we have chosen two applications which are very common and widely used in our day to day life. Let us see the outline of today's lecture. First we shall consider the telephone system which we are using in our daily life and in our telephone system you will see there are two types of services namely analog services which is in use for a long time.

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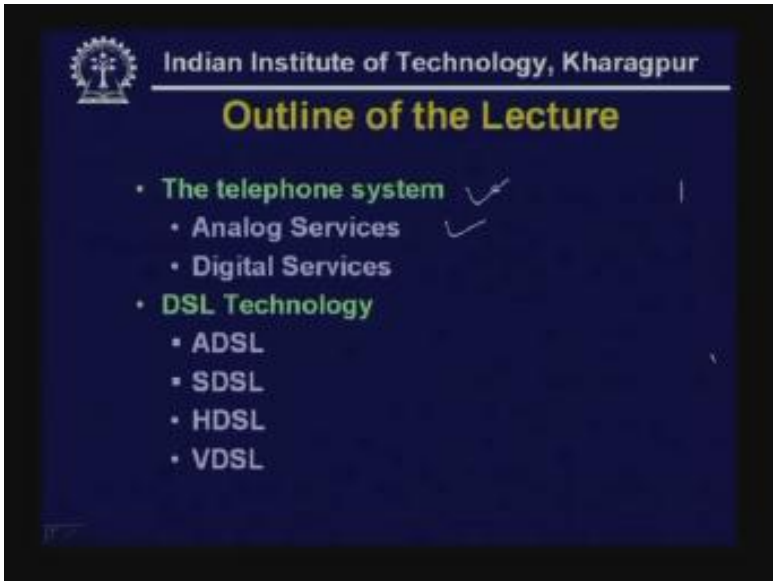

Now with the advancement of technology now the digital services are also available which I shall discuss in detail. Then another very important technology which is becoming very useful for broadband data transmission is your DSL technology Digital Subscriber Line technology. And this DSL technology has four variations such as ASDL, SDSL, HDSL, and VDSL. We shall discuss about them in detail.

On completion the student will be able to explain the operation of telephone system as to how a telephone system works, he will be able to explain different types of services provided by the telephone system, he will make you aware of the different types of services that is being offered by the telephone system and he can choose the service required for his/her application. Then we shall discuss about the DSL technology and we will be able to explain how the local loop is being used to provide broadband service by using DSL technology. We will be able to explain different types of DSL technologies.

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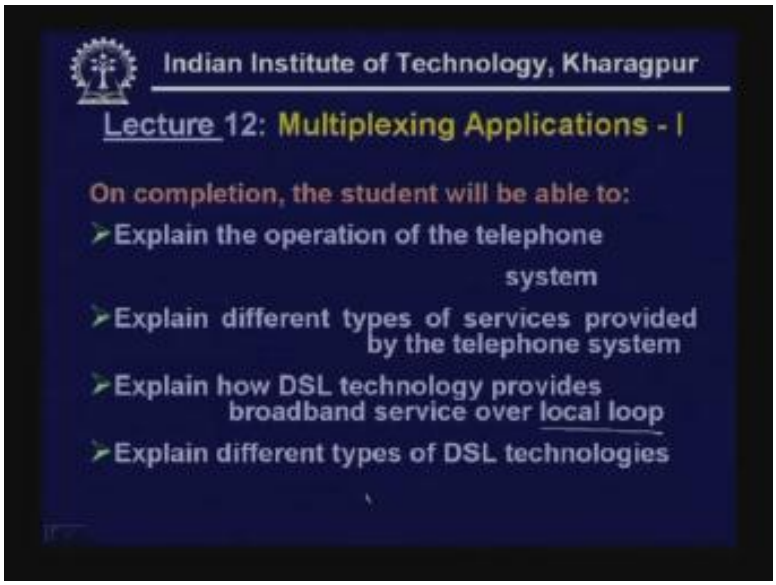

Let us have a look at the telephone system.

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As I mentioned one of the many applications of multiplexing is the telephone network which makes use of both FDM and TDM. So here it is a combination of Frequency Division Multiplexing and Time Division Multiplexing that is being used in our telephone system so it is a very interesting application. This is the telephone network as you can see. To the telephone network a number of telephone sets are connected which we call handsets. Handsets are connected. Obviously these handsets represent telephones in houses, in offices, in universities and in all the places. These telephones are now distributed in all places and this telephone network is a global network, it is no longer a small telephone network. That is, from anywhere you can call to any other place by dialing a number.

Let us have an inner loop of the telephone system or telephone network.

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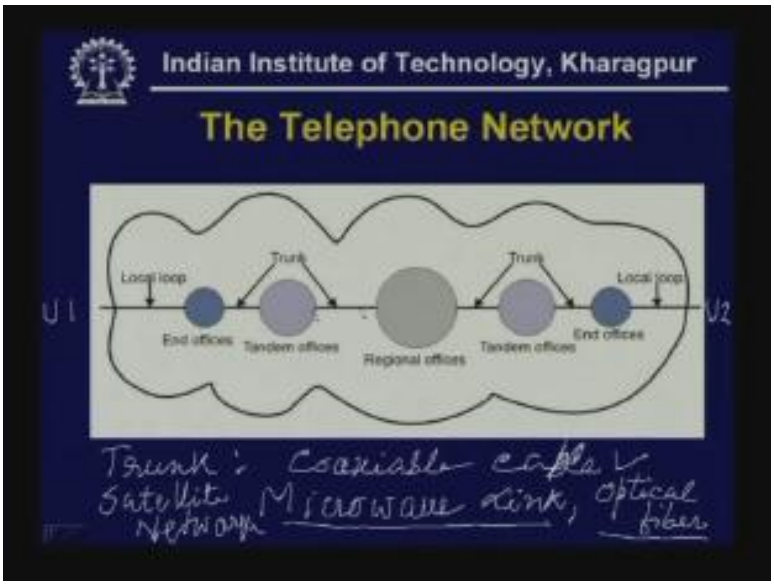

Telephone network as you can see has got these distinct components. First is this local loop. This local loop is connected to the user and through this local loop the user is connected, here you have got your handset and your handset is connected to the local loop. This local loop is essentially an analog line which has bandwidth of only 4000 Hz and that is adequate for voice communication. So it is simply twisted-pair of wire which is led from the end office which is essentially the telephone exchange and with the help of twisted-pairs of wire it is connected to our home or office and it provides you an analog transmission capability with bandwidth of 4000 Hz. Then as you can see these end offices are connected (Refer Slide Time: 6:03) using trunk lines to tandem offices and these tandem offices are in turn connected through trunk lines to regional offices. This is some kind of a generic representation of the telephone network.

Here I have shown only few trunk lines, it can be through a cascade of trunk lines. And obviously these trunk lines are implemented with the help of high speed lines. For example these trunk lines can be implemented by using coaxial cable, it can be

implemented by using microwave link, it can be implemented by using optical fiber and it can also be implemented by satellite network. So you may be asking why these are implemented not by using twisted-pair of wires?

The reason is here the trunk lines are of much higher bandwidth. The voiced lines are of only 4 KHz bandwidth but a number of such channels are combined with the help of multiplexing technique to have much higher data rates and these are connected through trunk line that's why you will require coaxial cable if the distance is not large or you have to use microwave link or optical fiber and satellite network. So at different links it can use either microwave link or optical fiber or satellite link so it is not uniform. This particular link can be microwave link, this can be a satellite link (Refer Slide Time: 8:15), this can be an optical fiber link and so on.

So in the path this user one is connected to user two and it can go through a number of paths through the trunk lines and that can be combination of various types of transmission medium as we have already discussed. So this gives an overview of the telephone network.

Now let us see the types of services the telephone network provides us. The services can be probably divided into two types such as analog services and digital services.

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Analog services are available from the telephone components for a long time. That means we are using these analog services for quite some time and with the advancement of technology digital services have been introduced in recent times and nowadays we are able to use the digital services. So I shall discuss both analog services and digital services one after the other.

First let us focus on the analog services.

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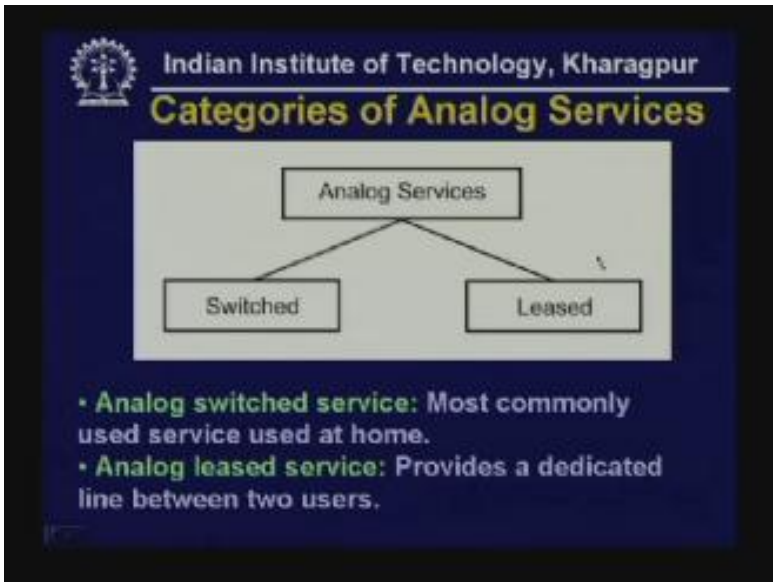

The analog services have got two different types of services. One is known as analog switch service and another is analog leased service. Analog switch service is the most commonly used service that we use at home. We get a telephone connection from the telephone exchange that is your local office using local loop which is nothing but a twisted-pair of wire and we get the telephone service at your home and that is the analog switch service and that is the most commonly used service. And analog leased service is one. That provides a dedicated line between two users. Let us see the difference between the two.

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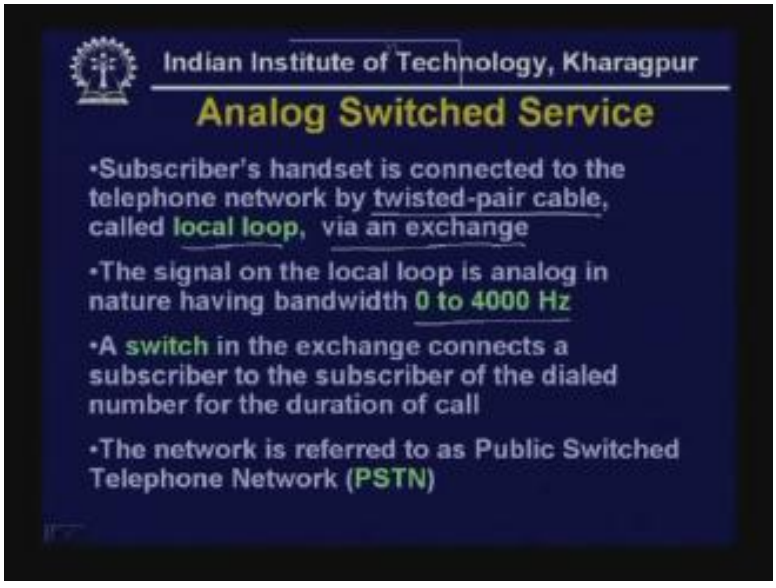

The first one is the analog switch service. In this particular case as I mentioned the subscriber's handset is connected to the telephone network by twisted-pair cable which is known as local loop by an exchange. So through that exchange our handset is connected to the local loop and the signal on local loop is analog in nature having bandwidth of 0 to 4000 Hz. Now there is a switch in the exchange that connects the subscriber to the subscriber of the dialed number for the duration of call.

As you can see here only for the duration of call we are getting this service and for other times it is not connected and the network that's why is referred to as Public Switched Telephone Network. That will be clear from this diagram.

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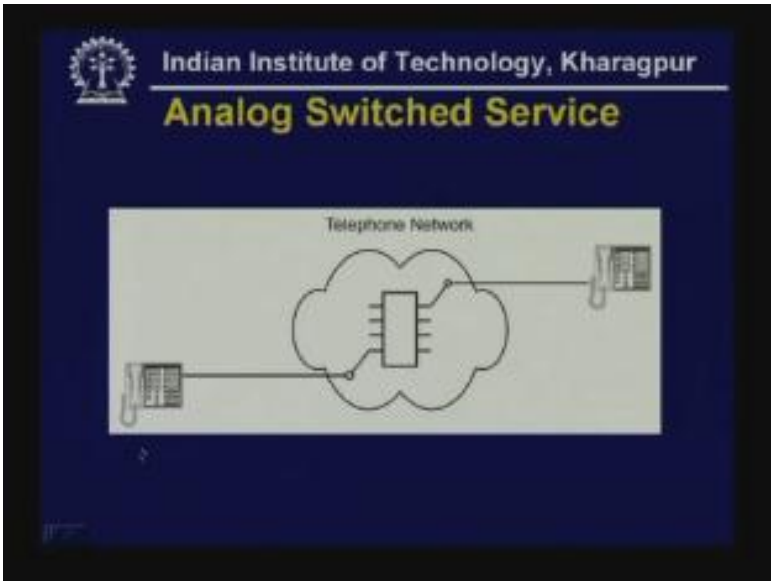

Here you see we have got a handset at home. There is another handset in the neighboring home that is connected through a telephone network. In the simplest case it can be the local exchange and these two telephones can be connected to the local exchange using two local loops, these are twisted-pairs. Now, only when the number is dialed from here this user one at home dials a number and this switch (Refer Slide Time: 12:25) establishes a connection from here to here.

So a connection is established from here to there and the home at the other end gets the dialed tone and only when it is picked up a link is established and only for the duration of call the link is established and when the call is terminated that is after the communication is over then the handset is put down at both ends and the link is disconnected. That's why I mentioned that this link is only for the duration of call and it is not connected otherwise. That's why the network is referred as Public Switched Telephone Network. So it is doing some kind of switching and only for the duration of a call it is establishing a link between two users through the telephone network.

Now it can be through a single exchange or through those trunk lines involving more offices as i have mentioned earlier. Now let us consider the other types of services analog leased service. There are many applications in which the user wants to send data continuously or once to communicate easily in such a case analog leased services are available.

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In this case the important point is although the connection is through an exchange and there is a switch here but the switch has established a permanent path between these two handsets as you can see. So the user one need not really dial a number to establish a connection to user B but already a link is established so whenever he wants he simply can talk or send data through this leased line. That means whenever the user rate is high people are talking all the time or people are sending data all the time so in such a case this kind of leased line can be established so it is dedicated. That means the whole bandwidth is available all the time and it is not switched one. This is in use in many situations where the user's rate is much high.

Now as I mentioned the various links can be of higher bandwidth and in such a case for better utilization of the infrastructure analog signals are multiplexed to provide lines of higher bandwidth. So you have to combine several signals or several low bandwidth channels to form high bandwidth channels which can be sent through transmission medium of higher bandwidth and the Frequency Division Multiplexing is used to combine many lines into fewer lines in a hierarchical manner. Therefore in a hierarchical manner this combination is done and there is a variety of hierarchy available nowadays. The hierarchical system is used by AT and T group companies is shown here. As we shall see the hierarchy is divided into groups, super groups master groups and jumbo groups as it is shown in this diagram.

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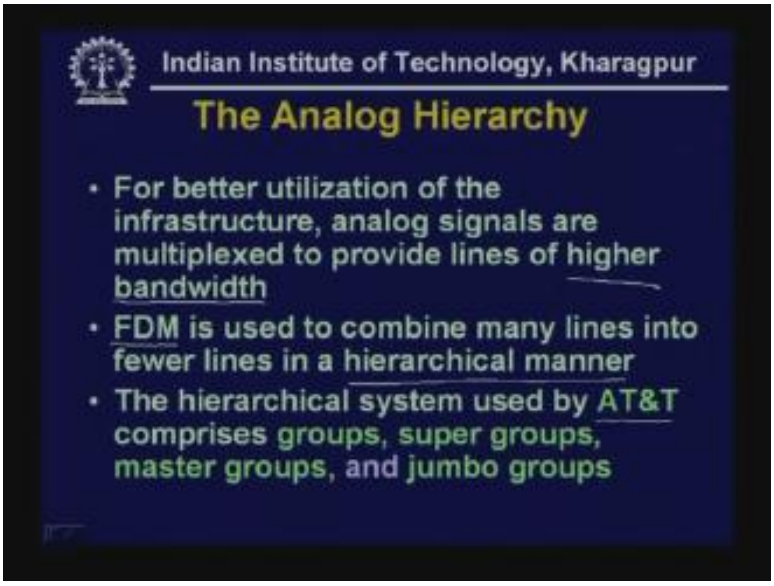

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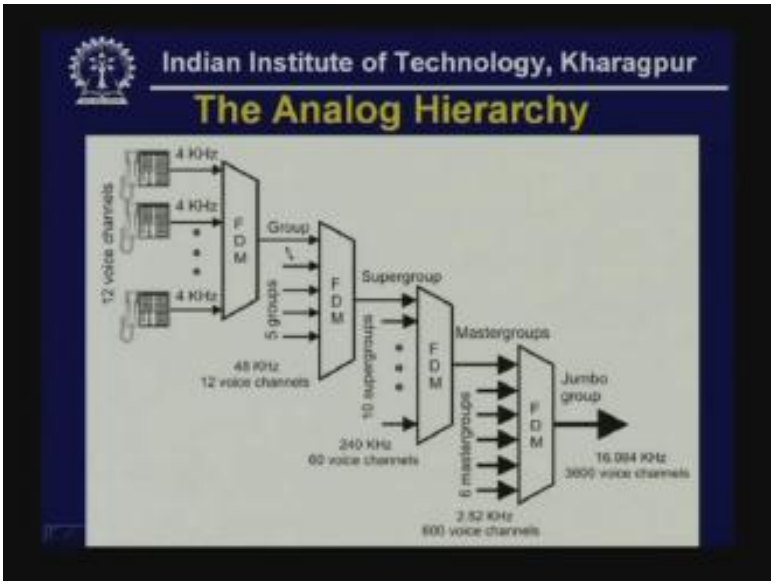

Here as you can see twelve voice channels are combined by using Frequency Division Multiplexing technology to form a group and this group here can be sent through a single telephone line and it need not be twisted-pair but it can be some other transmission medium. here (Refer Slide Time: 16:35) as you can see the bandwidth is 48 KHz. and again five such groups can be combined to form a super group where each super group will have bandwidth of 240 KHz and as you can see using this bandwidth you can send 60 voice channels.

In the previous case we were having 12 voice channels and then five such groups were combined to form a super group and through this line you can transmit 240 KHz bandwidth so it allows you to send 60 voice channels. That means there are two exchanges and if two exchanges are connected then it is necessary to establish link for 60 voice channels then a single transmission medium can be set up between two exchanges through which 60 voice channels can be sent then the super groups can be combined to form master groups and as you can see each master group line can carry 600 voice channels having bandwidth of 2.52 KHz and again six master groups can be combined to form a jumbo group and this jumbo group has bandwidth of 16.984 KHz which can carry as many as 3600 voice channels. So as you can see a transmission media of higher bandwidth is a twisted-pair it can carry 4 KHz and a single line can be used to carry 40 KHz or 240 KHz or 2.52 KHz or 16.98 KHz are providing you voice channels of different numbers starting from 12 to 3600 voice channels so it will lead to better utilization of the lines of higher bandwidth.

Now let us look at the digital services.

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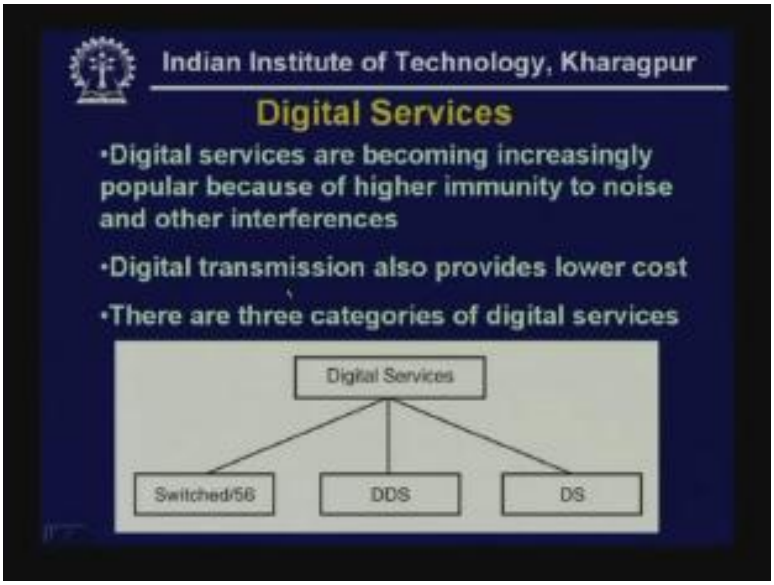

As I mentioned because of the advancement of technology now the digital services are becoming increasingly popular because of higher immunity to noise and other interferences. If you send in terms of zeroes and one it is very unlikely that it will get corrupted. On the other hand the analog signals get corrupted with noise. And if you are sending digital signals with the other end with the help of repeaters the noise can be separated and you can get back the original zeroes and ones. And also another important aspect is the digital transmission provides you lower cost compared to the analog transmission because digital processing has become cheaper. There are three categories of digital services. First one is Switched/56, second one is DDS and third one is DS. I shall explain each of them one after the other.

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The Switched/56 service is nothing but a digital version of the analog switched line. I have already explained the analog switched line so it is essentially the digital version and it allows a data rate up to 56 KHz per second. Of course since it is digital in nature there is no need to have modem in this Switched/56 service.

However, there will be a need for another device known as Digital Service Unit or DSU and this DSU provides you better speed, less susceptibility to noise and better quality. This particular service provides you bandwidth on demand.
You may recall that when I discussed about that inverse multiplexing there a high speed line can be divided into a number of lower speed lines to provide service based on bandwidth on demand.

For example whenever we are sending voice signal then a bandwidth requirement of 56 Kbps may be sufficient. Whenever we are sending data the bandwidth requirement can be double of that. In such a case two lines can be demanded. Whenever we are sending video say 1.544 mega bits then 24 or more number of this Switched/56 lines can be provided. So this Switched/56 service allows you to have bandwidth on demand by using that inverse multiplexing. Therefore using this service you can have inverse multiplexing.

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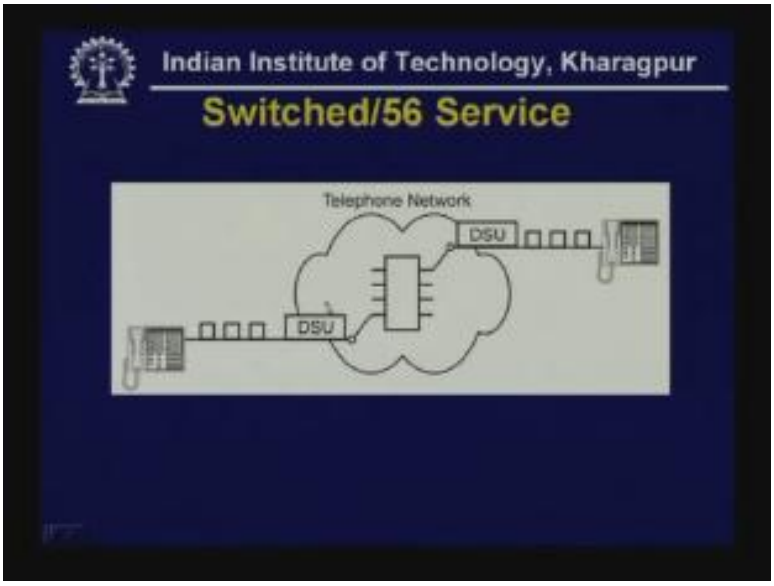

Here the Switched/56 service is shown. It is the same except that instead of modem you have got the DSU Digital Service Unit at both ends and it is connected through a switch at the telephone exchange. This is also a dialed connection with a dial-up line so whenever the dialing is done a link is established between these two DSUs and the communication is possible between two users connected through the telephone exchange.

Then we have the Digital Data Service or DDS.

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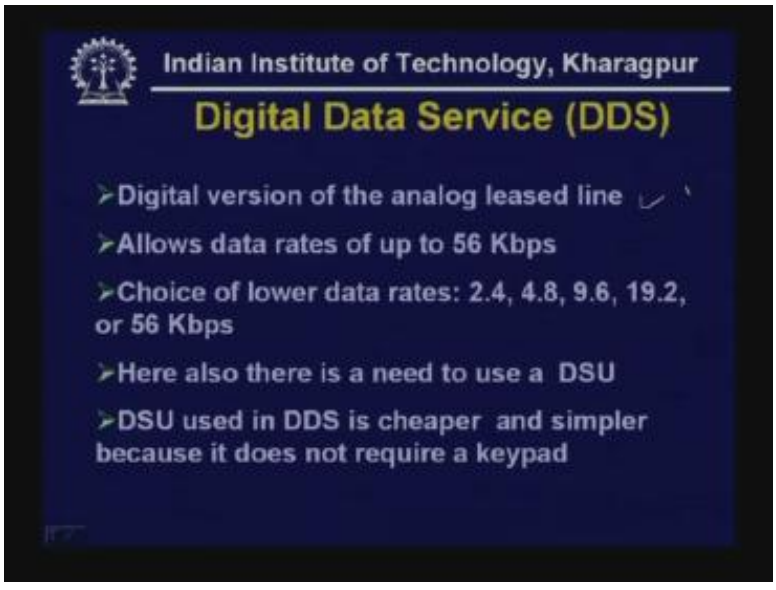

This is again the digital version of analog leased line. We have already discussed analog leased line so here also we can have leased connection or dedicated connection and it allows you data rate up to 56 Kbps. However, there is a choice since it is dedicated you may not be always using 56 Kbps. So in such a case you can choose data rates of 2.4 Kbps or 4.8 Kbps or 9.6 Kbps or 19.2 Kbps or 56 Kbps. That means whenever you are using this DDS service depending on your requirement you can specify the bandwidth you want. It can vary from 2.4 Kbps to 56 Kbps. So since it is available all the time you can make use of the bandwidth by sending data by scheduling data all the time.

However, as your need grows you can keep on increasing from 2.4 Kbps to 56 Kbps. Of course here also there is a need for the Digital Service Unit. You don't require a modem but you will require a Digital Service Unit. However, in this case the DDS that is being used is cheaper and simpler because you don't require a key pad. In the previous case where it was Switched/56 case there was a need for the keypad where you can press the keys so that a number can be dialed. But here it is leased service so already a permanent link is there and so there is no need for dialing a number so the DSU is simpler and cheaper because it does not require a keypad.

Here is the schematic diagram for Digital Data Service DDS.

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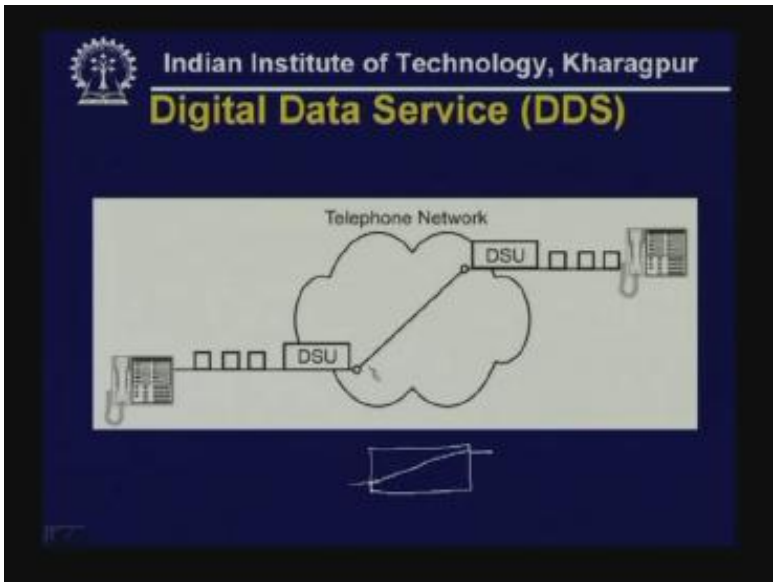

As you see here you have got two DSUs permanently connected through the telephone exchange. Of course there is a switch here that switch I have not shown so that switch is establishing connection from this to this. This is a permanent one so the data rate can vary from 2.4 to 56 Kbps through this line.
So this is the Digital Data Service.

Finally you have got the Digital Signal Service and this Digital Signal Service DS service provides you a hierarchy of digital services.

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Here the bandwidth requirement can be as small as 64 Kbps and as your need grows it can go up to 274.176 Mbps so the hierarchy is available through a number of services and these services are known as for example DS-0. The DS-0 service is similar to DDS. It's a single digital channel however the bandwidth here is 64 Kbps data rate that is being allowed instead of 56 Kbps. And DS-1 provides you 1.544 Mbps service however I shall explain then DS-2 service provides 6.312 Mbps and DS-3 allows you 44.376 Mbps service so through a single transmission media you can have this data rate 44.376 or you can have 274.176 Mbps service if you are having a DS-4 service. These services are implemented with the help of T lines so implementation is done by T lines.

I shall show you how it is being done.

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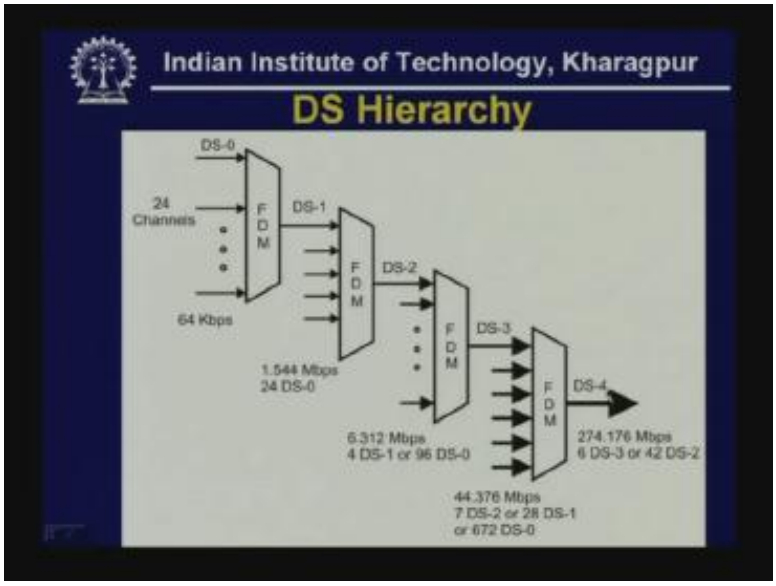

This is the DS-0 service each of 64 Kbps and then 24 such channels are combined by using Frequency Division Multiplexing to get DS-1 service and here the bandwidth is 1.544 Mbps where the 24 DS-0 channels are accommodated. And by combining 4 such lines you can have 6.312 Mbps and you can have 4 DS-1 or 96 DS-0 you have a choice through each of these services. then a DS-3 service provides you 44.376 Mbps where you can have 7 DS-2 or 28 DS-1 or 72 DS-0 channels and finally you can have DS-4 service which will provide you 274.176 Mbps and either you can have 6 DS-3 or 42 DS-2 equivalent number of DS-0 services.

So as you can see here you can have services of increasingly higher bandwidth and these are supported with the help of those T lines. For example, I can show you how a T-1 line can be used. T-0 is 64 Kbps, how a T one line can be used for analog transmission using PCM for conversion to digital signal? How you are getting 1.44 and that is being shown here.

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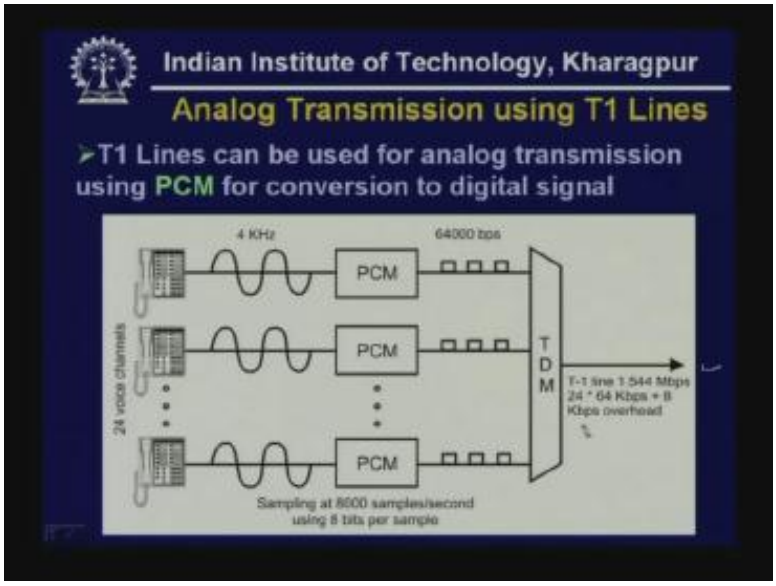

Here as you can see 24 voice channels are combined to form one T-1 line and as you can see each voice channel of 4 KHz is converted to 64 Kbps using Pulse Code Modulation technology. That means since it is 4 KHz bandwidth you have to sample at the rate of 8 KHz then by using eight bit quantization that means analog to digital conversion by using 8-bit AD converters you can have 8 KHz into 8 KHz that means 64 Kbps for each channel. Then the 64 Kbps channels are combined by using Time Division Multiplexing. Here as you can see you are not using Frequency Division Multiplexing because here this is digital transmission and it is no longer analog. In the earlier case for analog services it was Frequency Division Multiplexing but now as you can see it is Time Division Multiplexing.

So the Time Division Multiplexing is combining those 24 voice channels and as you can see you have 24 Kbps voice channels and it has got 8 Kbps channel overhead and this overhead is essentially for the purpose of synchronization. The synchronization bits are present as it is shown in this diagram.

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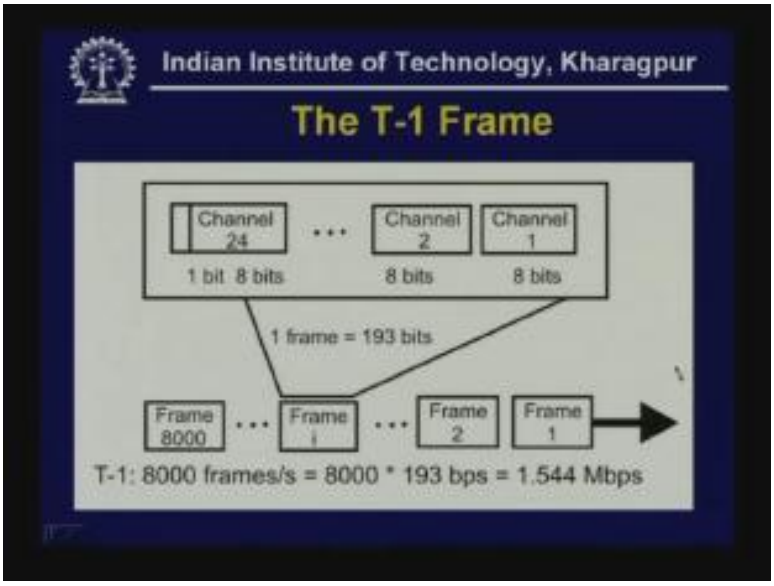

Here as you can see this is a frame where from each channel eight bits are taken, eight bit from channel 1 and eight bit from second channel and this way twenty four channels are there and for each frame there is a synchronization bit of 1-bit and this frame therefore comprises of 24 into 8 plus 1 is equal to 193 bits and you have got a total of 8000 frames. So T-1 lines supports you 8000 frames each of 193 Bps giving you 1.544 Mbps that's how you get T-1 frame of 1.544 bps.

Now this has opened up a new option. Earlier suppose a particular house or a business organization were in need of 24 telephone lines then from the telephone exchange it was necessary to connect 24 different twisted-pair of wires so 24 pairs of wires were coming from the telephone exchange to the business house.

Now it is no longer necessary. You simply take one T-1 line and in the business house you have a small PCM exchange as you can say so from there you can get back the PCM lines. So there is no need to take 24 pairs of wires instead just one cable one transmission media will do depending on the length it can be either a twisted-pair or some other transmission media and then here that conversion is done from TDM that there will be a small PCM exchange which will convert to give you 24 voice channels. So, small telephone exchange can be set up in your home or in a residential complex or in a business house to give you 24 separate voice channels or 24 different telephone sets.

Now there is another possibility. For example can these T-1 lines be shared? A small business organization may not require the full T-1 service or T-1 line bandwidth that means 1.544 mega bits may not be required so can it be shared? This is possible only with the help of DSU CSU unit. This is Customer Service Unit.

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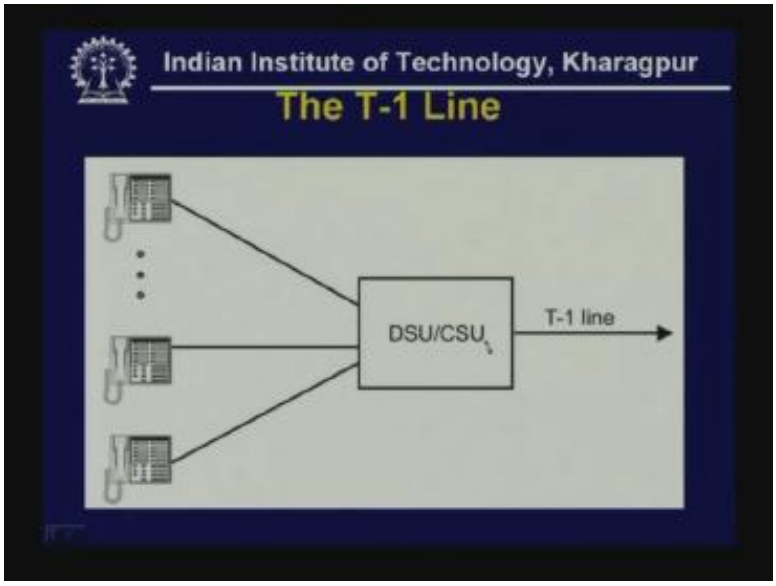

What can be done here is for example say four subscribers wants to share a T-1. Say in a building there are four business houses and each of them having requirement of one fourth of the bandwidth of T-1 line then these four subscribers can share a single T-1 line with the help of a DSU CSU unit and from each of these business house it is connected to the DSU CSU say here it is one fourth of T-1, one fourth of T-1, one fourth of T-1 and there will be another one and they are combined and this goes to your telephone component and you get some kind of shared T-1 service. So this kind of flexibility is being offered by these T-1 lines.

Now let us switch to another important technology that is your Digital Subscriber Line, DSL technology.

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This DSL provides you a much higher bandwidth, broadband and that is being done by using the local loop. Earlier we were having only 4Kbps bandwidth through the local loop. But although the twisted-pair of wire has the capability of transmission of much higher bandwidth that is 1.1 Mbps we are restricting it because of our requirement. We were filtering using low pass filters so that only 4 KHz signals go but now that filter can be removed. So inherent bandwidth of 1.1 MHz of these wires that is being used in existing local loop can be exploited or has been exploited in DSL technology.

Of course for that purpose it has to use suitable modulation techniques as well as multiplexing techniques. So here you will see that it has used the combination of modulation and multiplexing techniques to achieve this high bandwidth using local loops. And DSL again has got several versions namely ADSL, VDSL, HDSL SDSL so this family can be represented as xDSL so x can be A, V, H or S any one of them. Let us see these four different versions one after the other.

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ADSL stands for Asymmetrical DSL Digital Service Line and this has been primarily designed for residential users. as we shall see although it will be able to provide much higher bandwidth but based on the condition of the local loop the data rate is selected in adaptive manner because the local loop wire is twisted-pair, this twisted-pair of wire can run for a kilometer or 2 Km so the length can be different, the quality of cable can be different, the cable can pass through different areas where the noise levels can be different so based on that the data rate is selected in adaptive manner and it uses a novel modulation technique known as Discrete Multitone Technique DMT which I shall explain in detail. This uses a combination of QAM Quadrature Amplitude Modulation and Frequency Division Multiplexing. And we shall see the available bandwidth is 1.104 MHz which is divided into 256 channels each having bandwidth of 4.312. So the entire bandwidth is divided into 256 channels out of which the channel 0 is dedicated for voice, channel 1 to 5 is not used it has been left for future then there are 24 upstream channels (Refer Slide Time: 38:15) where one of them which is control channel from 6 to 30 and downstream channels 31 to 254. So you have got a larger number of downstream channels compared to upstream channels.

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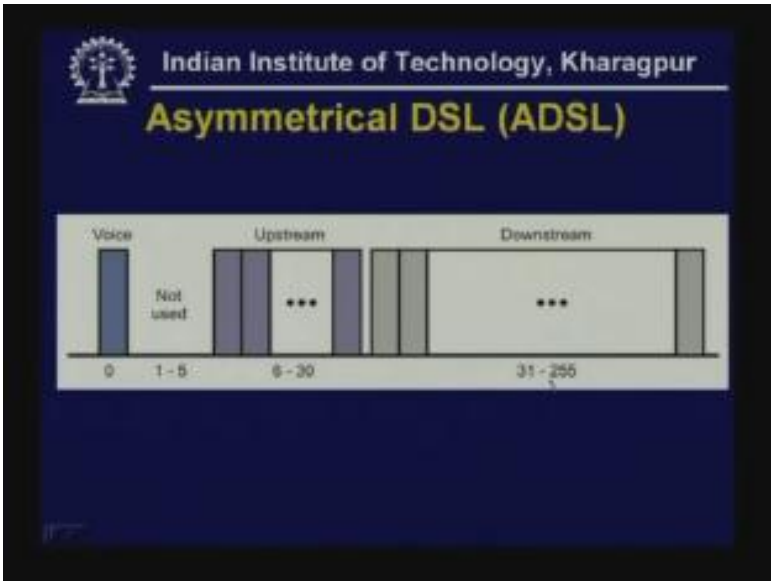

You may be asking why? Suppose you are having internet service through a DSL line. then from the home to the internet service provider the data rate is much lower because most of the time you are downloading something which has much higher bandwidth so you require much higher downstream bandwidth that's why the number of channels allocated for downstream is much larger. So as you can see it is 31 to 255. So here the Discrete Multitone Technique is explained as you can see here it uses voice channel. This is your channel 0, then channel 6 to channel 32, here there are some serial to parallel converters so upstream bits are coming which is converted into 24 channels and each of these channels is encoded by using 15-bit QAM and each of them is connected to a FDM Frequency Division Multiplexer. Similarly in the downstream signals there are 31 to 255 channels and whatever is coming in the digital data from these channels are again converted to QAM that is your Quadrature Amplitude Modulation

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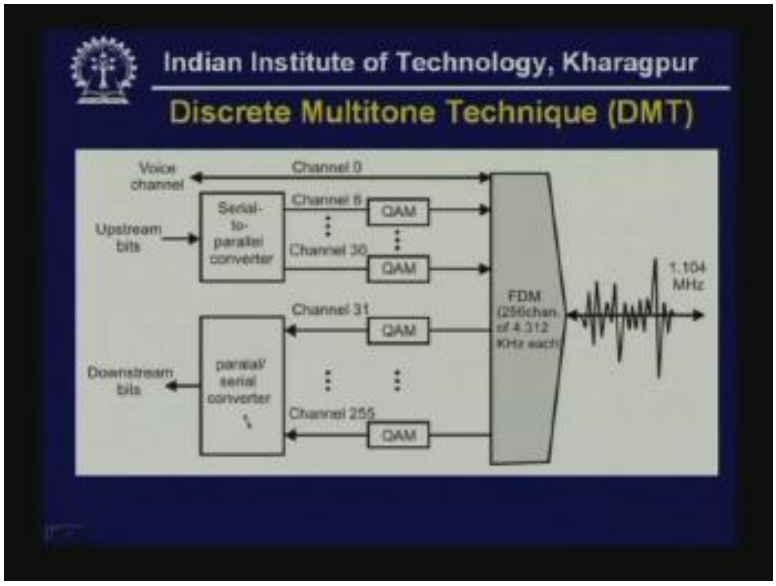

Then you are doing parallel to serial conversion and here you get the downstream bits. This is where at the end of this Frequency Division Multiplexer you have got 256 channels which are combined each having a bandwidth of 4.312 KHz gives you a bandwidth of 1.104 MHz. These signals can be sent through the twisted-pair of wire from home to the telephone exchange using local loop.

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Here as you can see channel 0 is reserved for voice in this Discrete Multitone Technique and channel 1 - 4 is not used idle as I explained earlier then upstream data and control uses 24 channels from 6 to 30 and for upstream data and control one channel is used for

control that means 23 are available for data transmission and this is how you are getting 1.44 Mbps that is 24 into 4000 into 15, by using QAM we are getting 15 bits so it gives you 1.44 Mbps for upstream. Upstream means from the home user to the internet service provider or the telephone exchange and downstream data and control provides you 255 channels from 31 to 255 for downstream data control so you can see that actual bandwidth is 244 into 224 actually here it will be 224 channels (Refer Slide Time: 42:02) so 224 into 4000 into 15 gives you 13.4 Mbps. so these are the maximum possible bandwidths available for upstream 1.44 Mbps for downstream 13.4 Mbps.

But in practice because of the line condition the data rate is dynamically varied. In practice you will get only 64 Kbps to 1 Mbps for upstream and 500 Kbps to 8 Mbps for downstream. So it is far lower than the 13.4 Mbps because usually the local loop quality is not very high. So unless it is very close and quality of cable is very high you will not get very high bandwidth. But this itself is quite high compared to 4Kbps.

The equipments used in ADSL is shown here.

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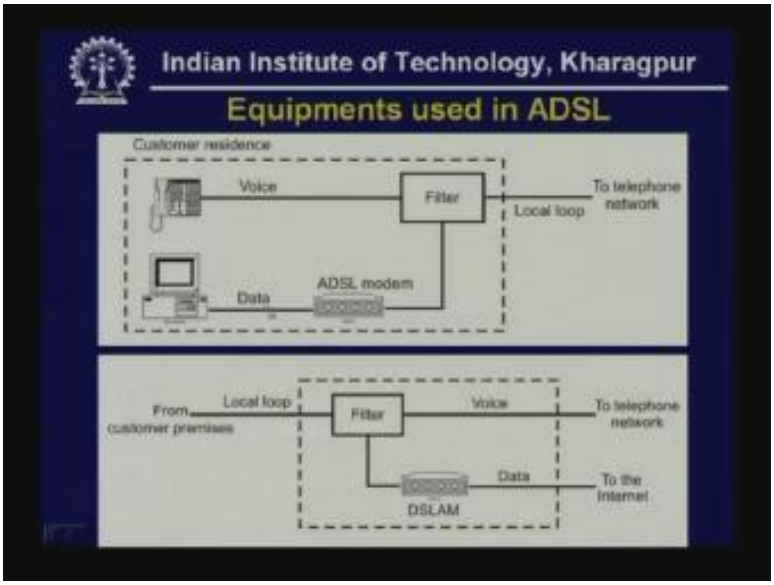

This is from the customer residence that is home. The local loop is coming here with the help of a filter (Refer Slide Time: 43:20) you are separating out the voice channel and it is going to ADSL modem. The ADSL modem is getting back the data and here as you know Frequency Division Multiplexing is done and it is performing the conversion demodulation giving you data of much higher rate which is going to your computer.

Similarly from the customer premise it is going to the telephone exchange and here there is a filter it is going to the telephone network and there is a DSLAM that is Digital Service Line Access Multiplexer. So this access multiplexer actually not only does the necessary multiplexing and other things but it also does the framing needed for internet

communication to the internet service provider so this goes to the internet service provider. So using this equipment you can have ADSL service.

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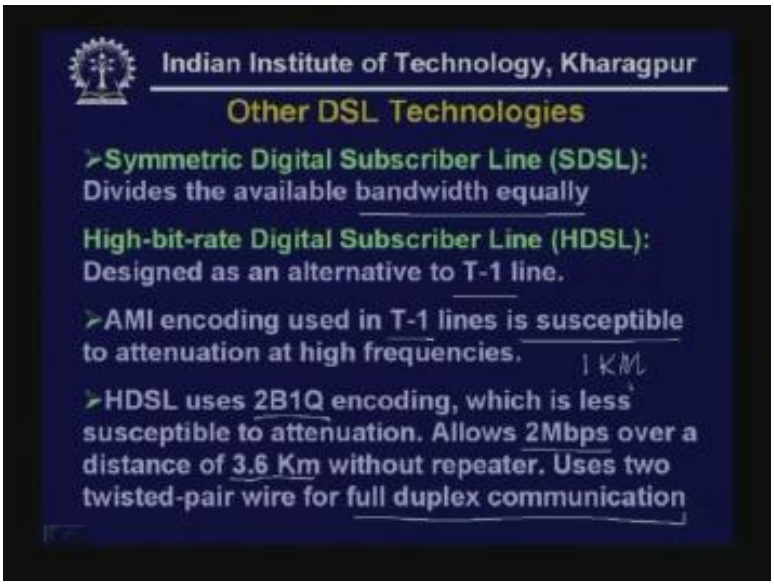

There are other DSL technologies like symmetric Digital Subscriber Line SDSL. This divides the available bandwidth equally. because in this case it is not for home users so there is no need to have separate bandwidth for upstream and downstream so here the bandwidth is equally divided. Then you can have high data rate Digital Subscriber Line HDSL which is an alternative to T-1 line. As we know the T-1 line uses the AMI amplitude marked inversion coding and it is very susceptible to attenuation and noise attenuation at high frequencies. As a result you don't get more than 1 Km without using repeater.

On the other hand in HDSL it uses 2B1Q encoding which is less susceptible to attenuation. It allows you 2Mbps over a distance of 3.6 Km compared to 1 Km without any repeater and it uses two twisted-pair wires for full duplex communication. It allows you to have full duplex communication. Finally we have the very high bit rate Digital Subscriber Line VDSL.

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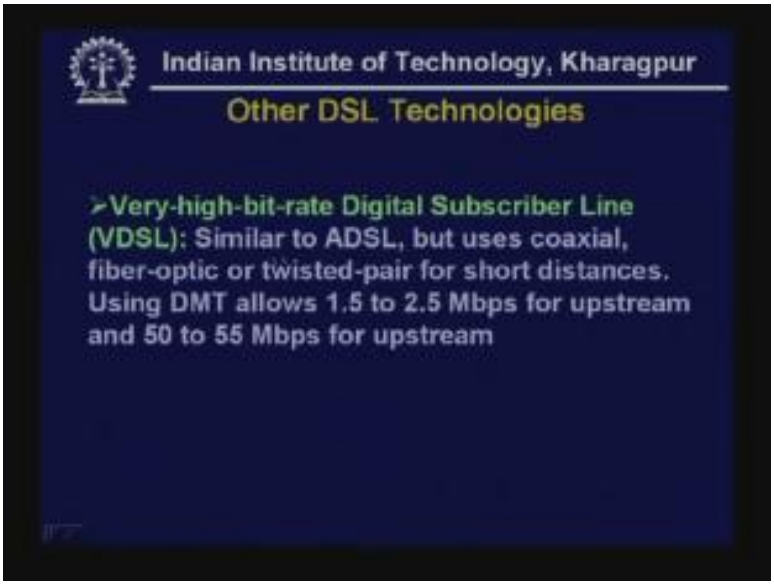

It is similar to ADSL but it can use coaxial fiber optic or twisted-pair wire for short distances and using this DMT modulation technique it allows 1.5 to 2.5 mega bits per upstream and 50 to 55 Mbps downstream. So these are the different variations of VDSL technologies that I have discussed. Here are the Review Questions:

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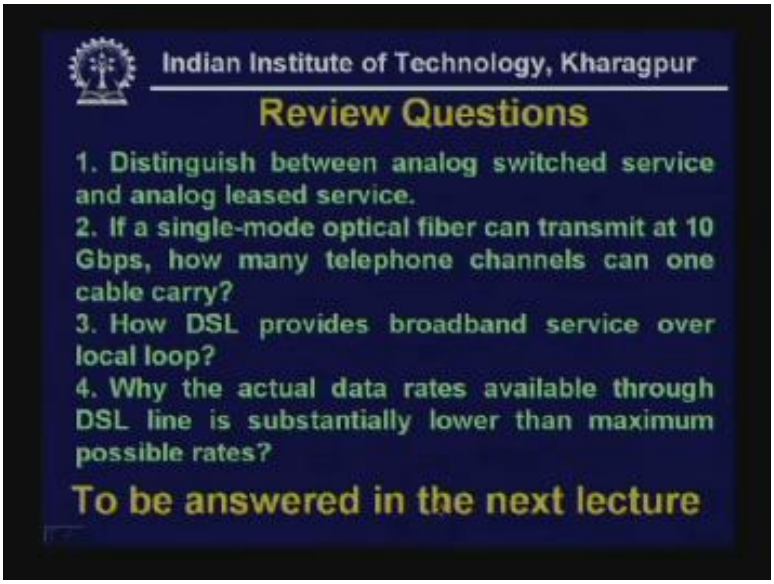

1) Distinguish between analog switched service and analog leased line
2) If a single node optical fiber can transmit at 10 Gbps how many telephone channels can one cable carry?
3) How DSL provides broadband service over local loop

4) Why the actual data rates available through DSL line is substantially lower than maximum possible rates?

These are the four questions which will be answered in the next lecture. Here are the answers to the questions of lecture minus 11.

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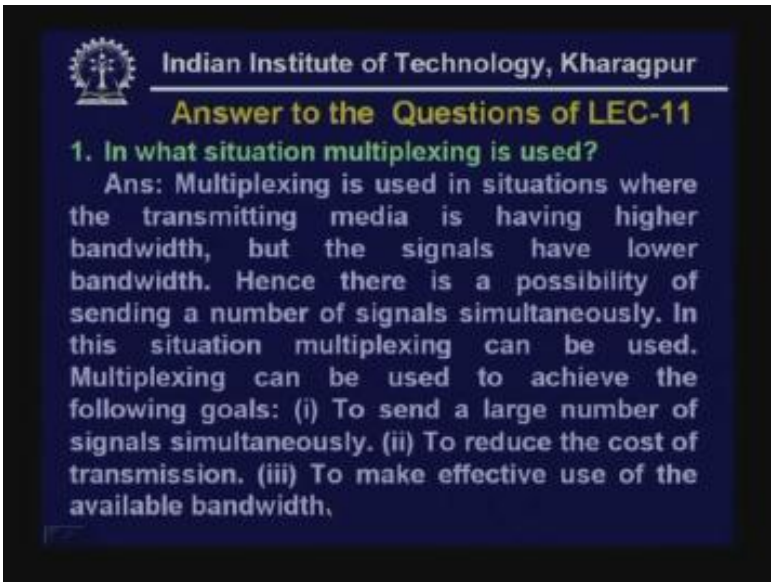

1) In what situation multiplexing is used?

Multiplexing is used in situations where the transmitting medium is having higher bandwidth but the signals have lower bandwidth. That means from different channels the bandwidth is lesser. Hence there is a possibility of sending a number of signals simultaneously. In this situation multiplexing can be used. Multiplexing can be used to achieve the following goals.

(1) To send a large number of signals simultaneously
(2) To reduce the cost of transmission
(3) Three to make the effective use of the available bandwidth.

These are the goals of multiplexing as I explained in the last lecture.

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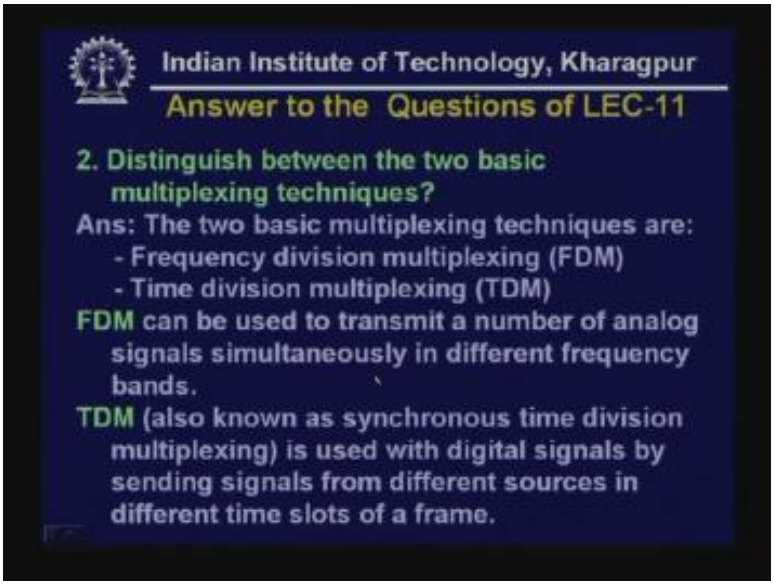

(2) Distinguish between the two multiplexing techniques?

The two multiplexing techniques are Frequency Division Multiplexing and Time Division Multiplexing. FDM can be used to transmit a number of analog signals simultaneously in different frequency bands. TDM, also known as Synchronous Time Division Multiplexing is used with digital signals by sending signals from different sources in different time slots of a frame.

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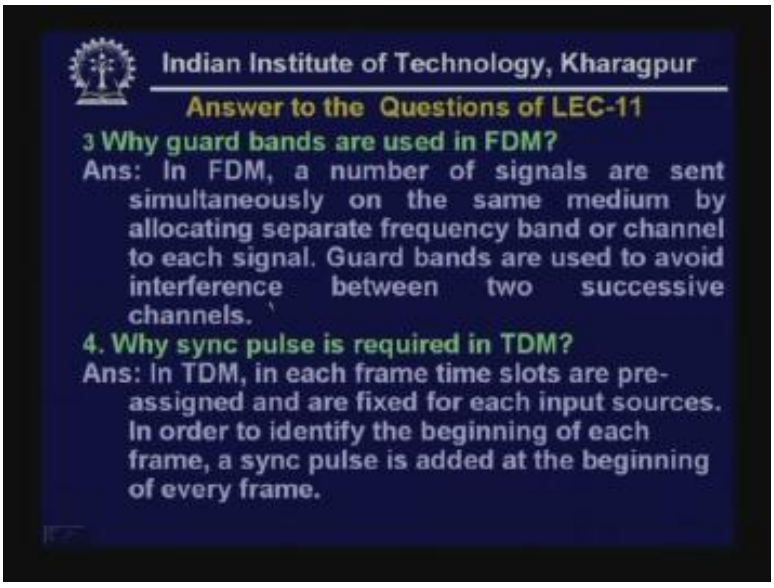

3) Why guard bands are used in FDM?

In Frequency Division Multiplexing a number of signals are sent simultaneously on the same medium by allocating separate frequency band or channel to each signal. Guard bands are used to avoid interference between two successive channels. If you don't provide guard bands then there is a possibility that signals of two adjacent channels will overlap leading to cross talk.

4) Why sync pulse is required in TDM?

In TDM each frame time slots are pre-assigned and are fixed for each input sources. In order to identify the beginning of each frame a sync pulse is added at beginning of every frame. So essentially the frames or the beginning of each frame has to be identified and that is done with the help of the synchronization pulse provided in the beginning of the frame.

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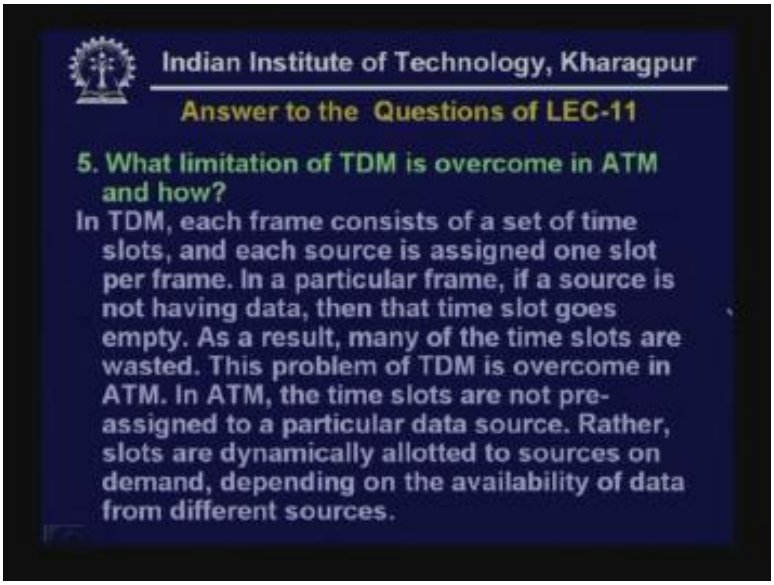

5) What limitation of TDM is overcome in ATM and how?

In Time Division Multiplexing each frame consists of a set of time slots and each source is assigned one slot per frame. In a particular frame if a source is not having data then that time slot goes empty or it goes wasted. As a result many of the time slots are wasted as we have seen in detail. This problem is overcome in ATM which stands for Asynchronous Time Division Multiplexing for statistical Time Division Multiplexing. And in ATM the time slots are not pre-assigned to a particular data source rather slots are dynamically allocated to sources on demand. So it is dynamically allocated on demand depending on the availability of data from different sources. That's how it makes better use of the bandwidth of the transmission medium.

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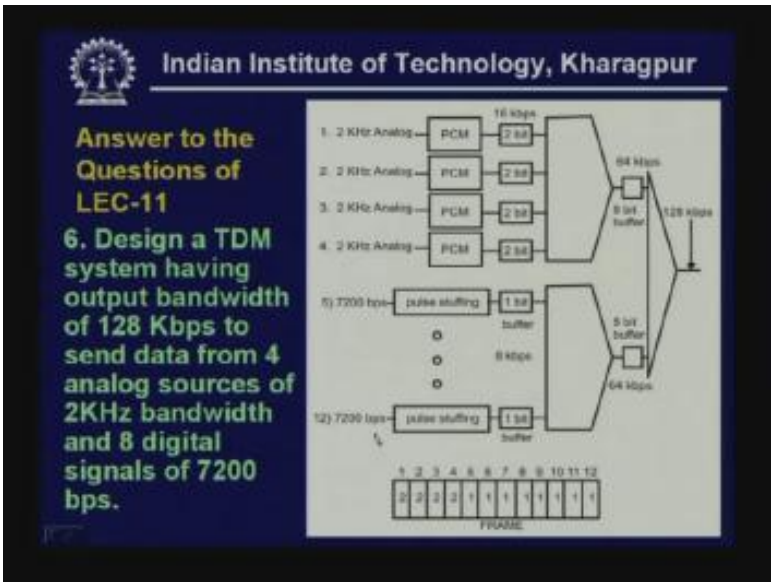

6) Design a Time Division Multiplexed system having output bandwidth of 128 Kbps to send data from four analog sources of 2 KHz bandwidth and eight digital signals of 7200 bps. Here it is shown that this 2 KHz analog signals which are coming from four channels are converted into digital form by using Pulse Code Modulation each is converted to 64 kilo bits so you see 2 KHz so you have to sample at 4 KHz then each PCM has 4-bit AD converter so you get 16 kilo bits per each channel then you have got buffers of two bits here.

Similarly here as you can see this 7200 bps here we shall be sampling at the rate of 8 Kbps. So you have to do pulse stuffing. As I explained in the last lecture you have to add additional bits by pulse stuffing and that's how you will convert this 7200 bits signal to 8 Kbps signals. So this 8 kilo bits per signal channels are each provided with 1-bit buffer and here you have got the multiplexers which are generating 64 Kbps signals and here you have got 8-bit buffer and here also you have got 8-bit per buffer and alternatively you are taking 8-bit and 8-bit from there to get 128 Kbps composite signal.

Here the frame is shown, channel 1 2-bit, channel 2 2-bit, channel 2 4-bit and channel 4 8-bit so here you get 8 bit from this source and another one bit from each 6 7 8 9 10 11 and 12 that gives you the signals coming from the channel 5 to channel 12 and this is the entire frame. Of course here the synchronization bit cannot be shown but just the multiplexing path is shown in this particular diagram and what is also shown is how you are getting 128 Kbps. So with this we come to the end of lecture-12. Here we have discussed two very important applications of multiplexing. In the next lecture we shall discuss three important applications of multiplexing, thank you.