**Digital Communication.**
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**Lecture - 32**
**Conclusion.**

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Everyone welcome to the class, this the last course and the last class in this course on digital communication and we will not study any we will not discuss any new topic in this class, we will just we, will just recall what we have done in this course and where this different topic’s stand in a digital communication system. And then we will also see what we have not done in this course that is; what are other issues in digital communication that are important, but we have not covered in this course.

So, let us see what we have done in this course. We have basically discussed point to point digital communication different blocks in a point to point digital communication system. Initially, we started with back ground material that are useful in different parts of the course and the background was the background involved.

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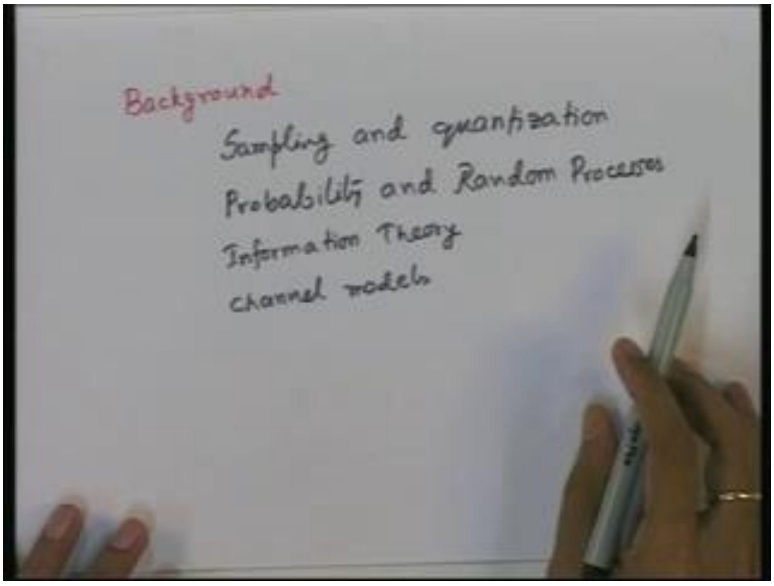


First we discussed sampling and quantization, we discussed sampling and quantization. We discussed random processes probability and random processes. Then we also discussed some basics of information theory. Then we discussed some important channel models that are useful that are important in that are important in this course. So, sampling and quantization was needed because even though even though we want to transmit the data in the digital form by using digital techniques the source that is generating the data of the signal may not be digital in nature.

So, the output signal coming out of the real source may not be digital. So, as result if you want to transmit that signal which maybe analog by using digital techniques in the form in the form of the digital data then we would like to first digitize the data that is coming out of the source and then transmit using digital communications techniques. So, the conversion from analog signal into digital involved mainly two operations 1 is sampling which is discretization of the signal in time and then quantization which is the discretization of the signal in amplitude.

In both time and amplitude we have to discretize to digitize the analog signal. So, that is what we did in sampling and quantization we saw various results regarding sampling and quantization. In sampling we specially discussed about Nyquist rate that is the minimum rate at which it is sufficient to sample a an analog band pass signal. So, that there is no loss of information and. So, it is possible to recover the original signal back from the sample signal. And then quantization, we discussed uniform quantizers and then we also discussed non uniform quantization and there we specially saw 1 particular type of non uniform quantizer for a class of practical signals like speech signal where smaller values of the signal is more than the higher values.

So, as the result we would like to have more dense steps in the smaller value of the amplitude than the larger values and that was done by using compression in the coder site and expansion in the decoder site. So, these 2 blocks together compression and decode decoding expansion is called compander and this operation is called companding. So, any non uniform quantization in fact, we have seen that any new non uniform quantization can be done by using first a non-linear scaling device and a non-linear device and a uniform sampling.

And then at the decoder site we can do the reverse operation use an expander to get the approximate value of the original signal. So, we discussed the form of companding that is used the mu law and A-law quantizers. And after discussing sampling and quantization we also discussed some basics of probability on random process that were useful in the course in particular we discussed about quite noise there and then we discussed some channel models where we learnt about different channel models that are important in this course.

Here we saw that, we not only discussed some models for the physical channels, but we also discussed some models for the for a derived channel that is you have the physical channel, but you have a part of the system at the transmitter and a part of the system at the receiver and together we those 2 systems the channel at those 2 systems behavior of these 3 blocks together is modeled as another channel. And we can consider that channel model that becomes really important when you are designing the other parts of the transmitter and receiver.

We can take those that block at the transmitter channel and the frontend at the receiver together as a channel and that is the reason why we needed to consider such channel models because they are important for designing the rest of the systems. And it enables us to design the whole communication system in a modular way also because if we consider the physical channel and want to design the rest of the system that is the transmitter and receiver then the problem may become very formidable.

So, we take some modulator and demodulator for example, other transmitter and receiver respectively and then we can consider modulator channel and demodulator together as a channel and model that channel and use that for designing for that blocks. So, we discussed about channel models in detail 1 in few classes and we also discussed some basics of information theory we where we learnt about source coding theorem which tell us what is the maximum compression that is possible for a source. And also we discussed about channel coding theorem which says: what is the maximum rate at which 1 can transmit information through a channel. After discussing this, basics we discussed about band pass signal representation and their some important things that we learnt are.

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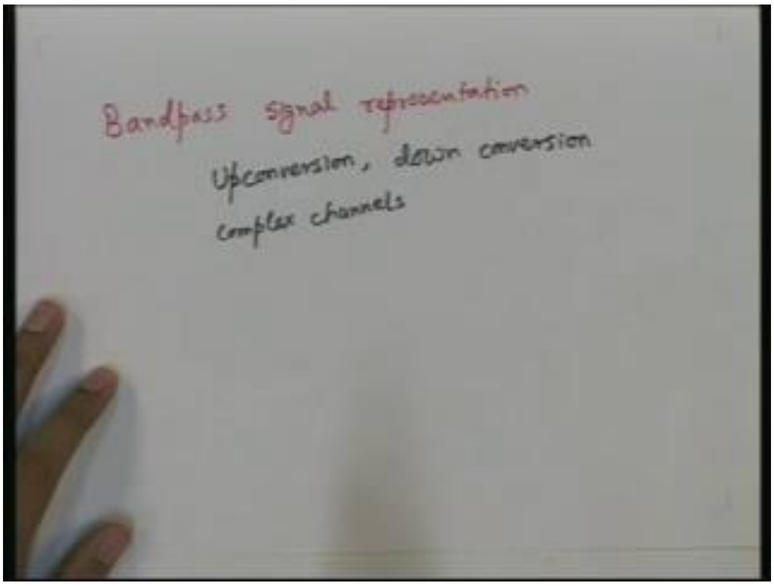


So, we learnt bandpass is a basically bandpass signal represented in terms of baseband signal. So, bandpass signal representation and here we discussed up conversion, down conversion and we saw why complex channels are important. So, we discussed about complex channels and complex systems. Though the in real life the physical channel is ADL channel and the transmitter and receiver both are dealing with real signals, but then why complex channels come into picture.

We discussed in detail and we saw that, if we have a bandpass channel that is channel for which we are going to use only a pass band a particular bandwidth then we can design the signal in the baseband after shifting that spectrum in the 0 near 0 and then we can design the signal at the base band then do something called up conversion which means shifting that spectrum to the pass band where we want to transmit it and then transmitting it and then at the receiver again we can bring it back to the 0 frequency that is called down conversion and then processor signal in the base band.

So, this is so, this is really the baseband's representation of bandpass signal when you down convert a bandpass signal that is you bring it down to the 0 near this in the low pass equivalent form then that becomes a baseband signal and we can design our transmitter and receiver to process the baseband equivalent of the signals. And that makes our electronics cheaper because we are not we are not processing. So, high frequency signal as the centre frequency of the communication may be.

So, we saw up how we can process the signal at the transmitter in baseband and then do up conversion and at the receiver you can do down conversion to bring the received pass band signal back to baseband. And then process the baseband signal. So, in this process the baseband equivalent that is the low pass equivalent of the of a band pass signal, real band pass signal becomes a complex signal and that is why the in the base band equivalent in the low pass equivalent the signal becomes complex and as a result the transmitter system as well as the receiver system has to deal with low pass low pass, but complex signals.

So, if we now consider up convertor at the transmitter and down converter at the receiver together with the physical channel that, can be considered as analog channel through which the baseband signal is passing through passing and then that signal that channel also becomes a complex channel. So, that is why we often talk about complex channels though the physical channels are real channels because in the low pass equivalent mode the channels can be considered as, complex channels which takes complex signal as input and which gives complex signal as output. After doing this we discussed some digital modulation techniques.

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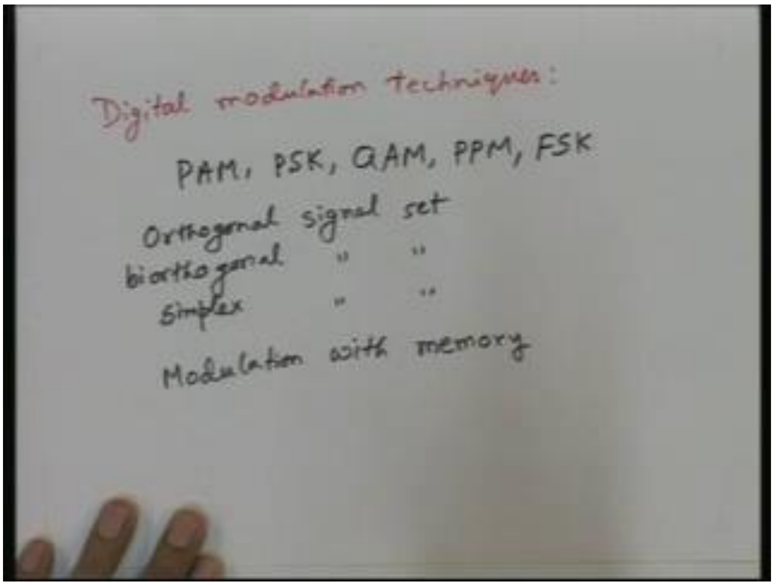


And there we discussed, PAM we discussed PAM, PSK, PSK, QAM, PPM, FSK and some general types of signal sets like: orthogonal signal set then biorthogonal signal set then simplex signal set. And then later we also discussed modulation with memory these are all memory less modulation techniques. So, then we discussed modulation with memory where what is transmitted in a particular symbol interval does not only depend on the information bits and, but also depends on what was transmitted before; that means, the transmitter remembers what it did before.

So, that is the why the modulation techniques are the those modulation techniques are modulation with memory. And with all these modulations with without memory this was we discussed, pulse amplitude modulation this is simplest. Then phase shift keying which is basic where the information is coded in the phase of carrier signal. And QAM where both phase and amplitude carries the information. And here pulse position modulation is a modulation technique where the position of a narrow pulse actually carries the information.

Here FSK is just the frequency domain counter part of PPM where a pulse in a particular frequency position is taken and that frequency carries the information. And PPM and FSK, if some conditions are satisfied we have seen that they are orthogonal signal sets. Then we also discussed biorthogonal signal set, where you also take minus of you take the orthogonal signal take an orthogonal signal set and take minus negative of those signals also and that kind of signal set is called biorthogonal signal set.

Then we also discussed simplex signal set where you take an orthogonal signal set first and then for orthogonal signal set the mean value of the signals symbols is not 0. So, we can shift all the whole signal set so, that the mean value becomes 0 and the important property of that signal set the new signal set is that it, will have the same performance, same probability of errors, same rate of transmission that is, the same because same number of signals, but it will have less average energy. So, it will have the same performance as orthogonal signal set with less transmitted energy that is better than orthogonal signal set. But of course, this we also discussed later about the how to receive. How to decode or detect this different types of signal sets?

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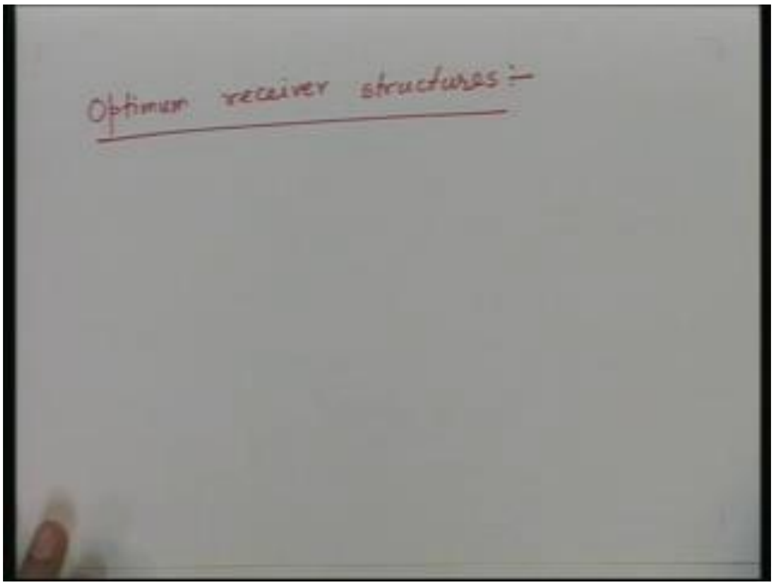


So, what we did later is to discuss optimum receiver structures where we talked about map detection, probability detection. And also then we discussed about email decoding that is maximum decoding and we actually saw what saw that email decoding comes simplifies to minimum Euclidian distance decoding for wgn channels and. So, this also can be implemented in terms of either correlation or corelators. So, or match filters.

So, the operation mathematically is basically the same, but the implementation wise there slightly different. And under this optimum receiving that is under this optimum detection what will be the probability of error for different of types of signal sets that also we discussed in few classes. So, we discussed later what is how to compute the probability of error.

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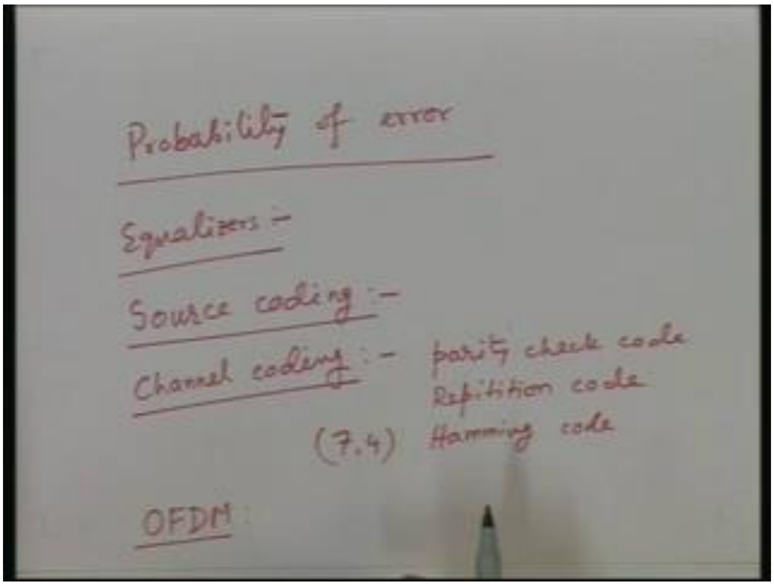


We saw that for some particular signal sets the probability of error can be calculated very easily in terms of Q function and for some others like FSK for orthogonal signal sets like: FSK the calculation is not. So, simple because it comes in the form of an integration inside which there are Q functions and there is no expression for the Q function. And for such types of signal sets it is difficult to compute the probability of error exactly in a closed from, but we can most of the times get a nice upper bound that is the union bound for such signal sets for the probability of error of such signal sets.

So, after that we discussed equalizers. So, we talked about 0 ISI what is the pulse shape that we should have for 0 ISI, but we also discussed that, it is it may not be possible to achieve 0 ISI in practice. So, in that case there will be some ISI, but we may like to minimize that by removing the ISI later at the receiver. So, there comes the role of equalizers. So, we discussed different kinds of equalizers like: feedback, feed forward equalizer then decision feedback equalizer and there for both of them we discussed 0 forcing and MMSE criteria that is minimum mean square criteria.

Then we discussed source some source coding techniques where, we discussed Huffman coding, Shannon Fano Elias coding and the same idea of Shannon Fano Elias coding was developed into a nice algorithm which is called arithmetic coding and which is basically incremental coding incremental Shannon Fano Elias coding and that is arithmetic coding. Now, we also one tabular method of source coding that is the Lempel Ziv coding. Then we discussed channel coding.

We discussed a only very few channel coding techniques the subject is quite vast and we discussed only in 1 class a few basic channel coding techniques how to detect up to 1 error the using parity check code with single bit parity check. Then we discussed repetition code. And we also discussed hamming code for correction of 1 error up to 1 error using seven four hamming code we discussed using that we could we saw how to correct up to 1 error for binary symmetric channels.

And at the end we also in 1 class we discussed about OFDM technology some basic structure of OFDM and we saw how a simple a simpler scheme a simple a tool like: DFT is used so, in a in so, nice way in a OFDM system. How circuit prefix is added and how circuit prefix enables us to do frequency domain equalization in a very simple way and how that effect of channel is cancelled by using the properties of DFT with that with some extra symbols in the form of circuit prefix.

So, we have discussed all these different blocks which are which come in a digital communication system and what we would like to emphasize here is that whatever, we have discussed is not the whole digital communication system. There are more to it and there are many more issues that should be studied to get a good feel of and good command of the subject. And it is not possible to study the whole the different techniques in a single course.

So, we will discuss, what are other things that we have not covered, 1 thing is that even in this point to point communication that we have considered there is there is only 1 transmitter one receiver and we do not care about what other users want to do we are just considering a particular spectrum of the channel and we want to transmitting information from 1 point to another point. But even there is a issue of synchronization. The carrier signal is generated at the transmitter and we assume that we know the carrier signal exactly at the receiver also.

But in practice it is difficult to know that, difficult to generate the same signal at the receiver because you cannot get 2 different oscillators giving the same output. The frequencies cannot be matched exactly. So, there is some precision of the oscillators. So, there may be some 1 percent error or 0.1 percent error whatever, but it cannot be made 0 percent error. So, the frequency cannot be made for example, if you want carrier frequency of 1 megahertz we cannot get exactly 1 megahertz there will be few hertz of difference or few kilo hertz of difference.

So, the transmitter clock will have transmitter oscillator will have some frequency that receiver oscillator, oscillator at the receiver we have some other frequency and there should be a way of actually synchronizing them the or correcting the receiver clock a little bit so, that we get at least the same signal same frequency signal that the transmitter is using at the receiver. And now it is not only need not only that we need this correct frequency we need the correct phase also we need the exact carrier signal that is being used to modulate.

So, we need the correct phase. And so, that must be synchronized then we need the correct symbol interval because a symbol is transmitted from 1 time to another time symbol next symbol starts from here and ends here. So, we need these time instances exactly otherwise the receiver which we, if we assume that instead of this start taking the signal from here to here and treating this as symbol then we will have the mix of 2 different symbols and we will not be able to detect what was transmitted. So, we need to synchronize the symbol timing at the receiver also.

So, there is symbol synchronization also that is needed. So, all these different synchronization issues are also important you can you can consult any good communication digital communication book like: Proakis to learn more on how synchronization is done. Now, this is 1 issue in point to point communication, but in practice there are more issues because specially because the real life situation is most of the times we are not dealing with a point to point communication system most of times we have either a single media shared by many users to transmit information through it or a network which is being used by many users.

So, it is not a point to point link we are communicating through, we are either communicating through a network like: a telephone network like a like: internet or there may be a wireless media like: space where my mobile is using the same channel as others. So, it is a signal media that we are sharing.

So, as a result there are lot more issues that we have discussed in a point to point communication system. So, this many interference related problems come because of this sharing of the same media or share sharing of the same network. So, let us discussed 1 or 2 such problems that we usually face. So, this the first that, we will discuss is a common problem that, we traditionally face even in telephone network that, is called cross talk. So, you might have might have seen this happening in your telephone when you are talking you have dialed some number you have got connected, but you are not hearing the your opposite end you are hearing some other voice. So, that is cross talk you not hearing from intended transmitted you are hearing from signal from some other transmitter. Why does that happen?

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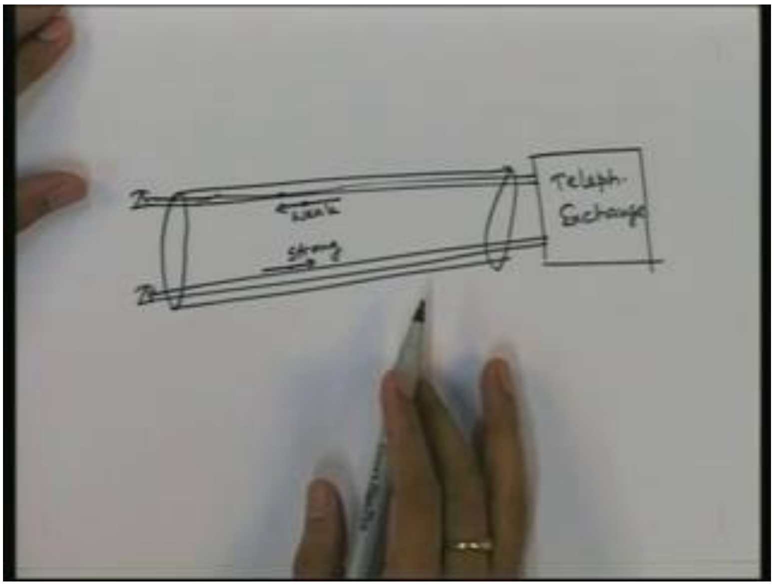


In a telephone line what happens is that. The line that is the pair of wires that is coming out of your telephone system is going to the exchange and suppose, there is another telephone from which another pair of lines is going to the exchange and suppose, these 2 are in the same locality then what happens is that, that these 2 pairs of wires are not going to the exchange independently they are put in a bunch usually and they are going to the exchange together.

So, now what happens is that suppose, you are receiving is some signal is going in this direction and some signal is also coming in this direction. So, from your opposite end you are receiving a signal in this direction and form here there is a signal going to the going to in this direction. Now, if this signal is suppose this is nearer to the telephone exchange and this is quite you are quite far from the exchange then what happens is the this signal is quite strong signal. Because this is going from a shorter distance and this signal is strong signal and this is coming from a long distance as result this is a weak signal and as a result this strong signal whatever, is induced into your pair of wires.

So, some this strong signal that current that is flowing through this these 2 wires is also inducing some current in your wire. So, there is some interference and because this signal is much stronger than this signal that is coming from opposite direction to you the induced current it is here from this signal itself may be stronger than this weak signal that you are intended to receive. But as a result what will happen is instead of hearing the voice from your opposite end you will be hearing the voice from here because of induction from this strong signal to your line.

So, that is what is called crosstalk you are not hearing the voice from the opposite end, but you are hearing some else. So, this is a simple form of interference that, we come across in telephone and there are other forms of interference that, we come across in wireless media because of sharing the same media by different users.

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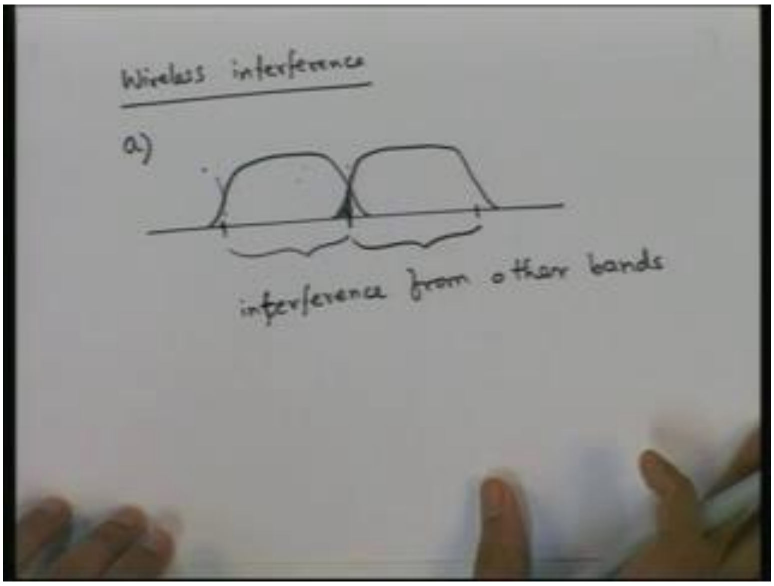


So, let us discuss one or 2 of them. So, there may be different reasons for, different types of interference 1 is the 1 is the wireless media may be used by different users in difference bands of spectrum. So, you are using 1 particular spectrum from here to here and someone else might be using the spectrum from here to here. And your signal may not be exactly limited in this band because there will be some leakage into the neighboring bands usually is difficult to filter out all the signals out of this band from the transmitter.

So, there will be some small leakage out of that designated band. So, the signal you are transmitting will be usually something like this. So, something is going outside your band. And similarly the signal the other user is transmitting will also be like this, it will not start from here, but there will be some leakage into your band. So, as result there is some interference here. So, this part of the signal is not desired it is coming to your band from some other user who is supposed to not use your band.

So, this part of the transmitted signal from the other user will interfere with your signal and that is the interference from other bands. So, this is interference from other bands. now this is 1 thing, but there is another form another reason why interference can come. The same frequency itself may be used by different users in different geographical locations. For example in a cellular mobile system there is a frequency reuse.

So, they are the cells. So, that in 1 cell a particular band in used in the neighboring cells possibly that band is not used, but little distance away from this cell there is another cell which is also using the same band because it is expected that, it is bit far away from it this cell and. So, there will not be any interference between these 2 cells because they are geographically separated. But still there will be little interference that, will leak into this cell from the other cell that is using the same band of spectrum. So, that is the interference from other devices in the same band.

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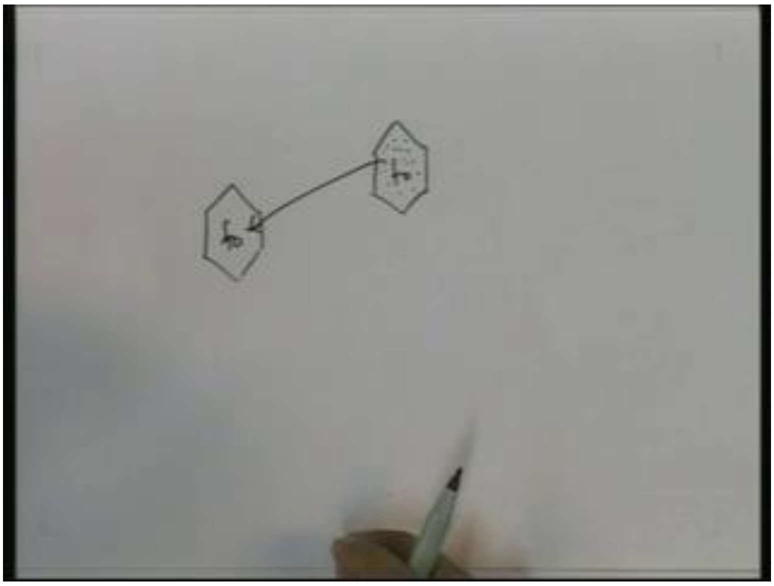

So, that will. So, you if you have 1 cell here there is another cell here and using the same frequency say f naught this will interfere with this the signal will come to some part of the signal will come to this. So, there are many users here and small amount of signal will come from all the users to this. And. So, this also has to be considered while designing a cellular mobile system, while designing the cellular structure the distance and the frequency reuse we have to keep this interference in mind also.

So, now just like we considered, we talked about the cross talking telephone there is a similar problem in wireless 2. It is not really exactly the same, but this is called near far problem. Suppose now you have 2 different say 2 difference mobiles using the same band in CDMA mobile. We will discuss what is CDMA briefly in a moment. But suppose they are using the same frequency at the same time using different codes. So, that their signals do not still do not interfere with each other much there is some very minor interference.

So, let us assume that the, in this scheme the 2 subscribers are using the same spectrum at the same time using 2 different codes. So, that there is very little interference from 1 code to the other. So, then this is fine, but this not fine when 1 subscriber is near the base station and the other subscriber is quite far away from base station. So, lets us consider that situation and see what happens.

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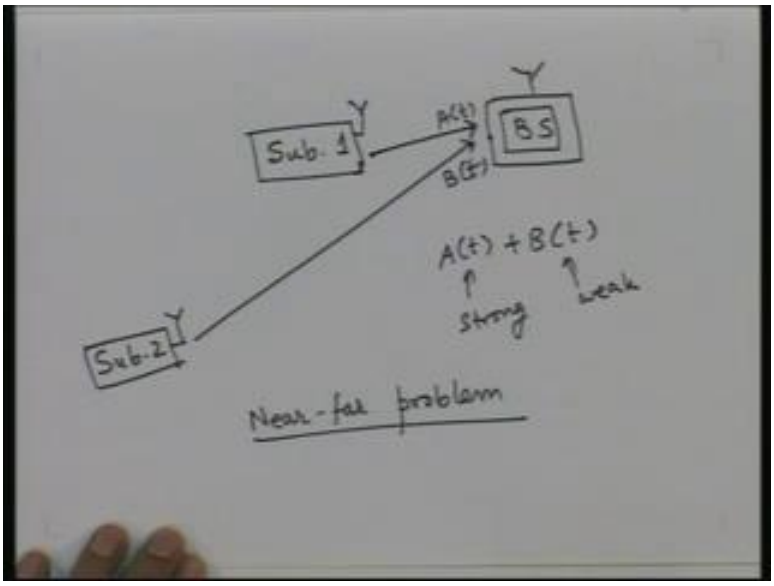


So, if 1 subscriber, subscriber 1 is near the base station. So, this is the base station and this is subscriber 1 and there is a subscriber here which is far away from this base station. So, suppose they are both transmitting together to the base station in the uplink. So, it is the subscriber 1 is transmitting some signal and subscriber 2 is transmitting some other signal using his code and they are using the same spectrum at the same time and there is some very slight interference between the 2 codes, but.

Now because this, signal is travelling a longer distance when it reaches the base station it will be attenuated much more than what attenuation this singles goes through this channel attenuation will be much more than this channel attenuation. So, as result if they transmit the same power they transmit the signals with same power then what will happen is that the strength of this signal when it reaches the base station will be much less compared to the strength of this signal when it reaches the base station.

So, base station is receiving 2 signals added because it cannot separate those 2 signals. It is receiving the sum of these 2 signals because they are in same spectrum in the same time. So, it is receiving the sum of these 2 signals and say it is receiving At plus Bt, At is this signal and this is Bt is this signal. Then this At is a strong signal this is strong and this is weak signal.

So, as result if there is little interference from the strong signal into the from this code to this code then this will totally corrupt this weak signal. The interference from the strong signal into the weak signal will be so, much that there will be nothing left of weak signal, weak signal will be difficult to detect base station will not be able to detect the weak signal. So, that is the so, called near far problem this is the so, called. And what the measure that is taken to avoid this in real life is that the power that this subscriber transmits is intentionally kept much lower than the power this subscriber transmits.

So, that when these 2 signals reach base station their strength, their power is almost same. So, base station sees, what is the channel attenuation from both the subscribers? And base station tells the subscribers to transmit at a certain power. So, that when it receives the signals from different subscribers they are of almost same energy. So, that there is no near far problem.

Now, there are other issues in communication then these interference also there as we discussed there is in most practical applications the commutation system is a network, it is not a point to point communication system, communication system, but it is a network communication network. So, there are more issues than just reliable communication from 1 point to another there is the point of the first getting a connection to the user you want to connect.

So, there is a network now you need to switch. So, if it is a telephone system like traditional circuit switch then you need to first establish a connection with the intended user another the other subscriber. So, there is a switching if it is a packet based transmission then you have to establish, establish a root through which your packets are going to reach the other user and so, on. So, there is a switching involved and then there is multiplexing because it is a network it is it is being used by many users.

So, a particular link in the network may be used by many users. So, all those data from different users need to be multiplexed together in that link. So, there is multiplexing needed and there is scheduling needed all the. So, user 1 have some data to transmit through this link user 2 has some data to be transmitted through this link whose data is to be transmitted first which packet is to be transmitted first. So, there should be scheduling.

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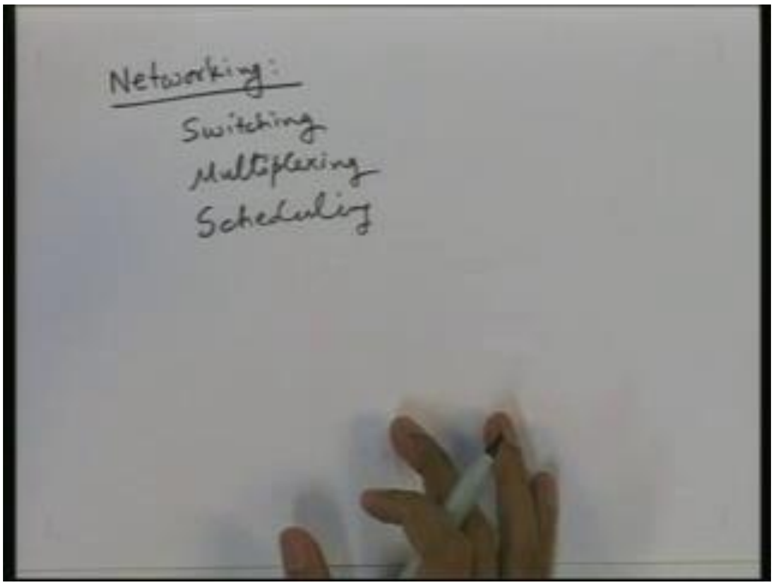


So, there are different networking issues. So, there is switching there is multiplexing there is scheduling there are different issues. Now, the next the we have disused about the multiuser sharing of a media the most common example, in this case is the wireless media and their different technologies that, we often hear about in this regard and they are basically different ways to share the channel or different ways to multiplex the signals from different users through the channel.

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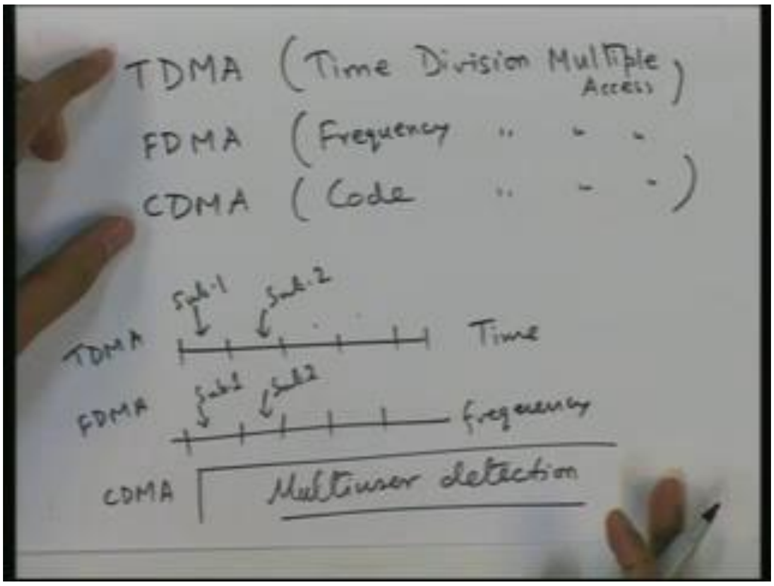


And there are different ways in which 1 can do that. And 1 is TDMA or time division time division, multiple access then FDMA frequency, division multiple access, CDMA code division multiple access. So, TDMA is where you basically have the time you divide the time into slots and let subscriber 1 transmit in this slot let subscriber 2 transmit in this slot and so, on.

So, this is you are giving 1 slot to each subscriber. So, that is the time division multiple access. Frequency division multiple access is basically the frequency domain counter part of this you instead of dividing the time you let all the users transmit at all time, but at different frequency slots. So, this is the time scaling in case of in case of TDMA. In case of FDMA this is frequency scale and you divide into bands and let, subscriber 1 use 1 band subscriber 2 use another band and so, on.

In code division multiplexing the whole time the whole frequency is used by all the subscribers at all times then there is a problem of interference right, but that is avoided by using different codes for different users different subscribers. So, different subscriber takes different sequence of real numbers or binary plus minus 1 numbers sequences. So, that the dot product between them is minimum. So, that will ensure there is very little interference from 1 code to other.

So, 1 user will use a particular code the other user will have another sequence of plus minus 1 and he will basically multiply his data bits that is plus 1 or minus 1 with this sequence and transmit. So, they will be using these this signature sequences, as carriers and then when they reach the base station these signals will be added together, but because these codes are. So, that that dot product is almost 0 the base station will be able to extract the indifferent information code in different signature sequences.

So, this is this cannot be made clear in a short time, if you are interested please read CDMA from any good book. And here we only say that, this is a scheme where different codes are used by different subscribers and they use the whole frequency all the time all the subscribers use. So, in CDMA the whole frequency is used by the for, the for all the times by all the subscribers.

Now, the base station of course, has to know how to detect the different symbols there are different ways of detecting because he is receiving the sum of all the signals that are being transmitted by different subscribers. So, he has to now separate the signals separate the information that is coming in different signature sequences, he can, he is not receiving them separately, he is receiving only sum of them they are being they are getting added in the channel and he is receiving only the sum.

So, now, the base station has to separate those signals separate the information from the received signal. And that is a that, is again an idea by itself is called multiuser detection. Again these are multiuser detection or even these should usually is studied in a separate course on wireless communication and networking is another usually studied in another separate course altogether.

So, we have studied in this course, what are the different blocks in digital communication system in a point to point digital communication system. And we have studied the most of the blocks to some detail and there are other issues, which have not discussed and there are and those can be studied further from any good book. And some particular types of course, are usually taught to cover the other things that, we have not discussed.

Thank you.