Introduction to Wireless and Cellular Communication
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Lecture - 19
Multipath Fading Environment
Choice of Modulation

Good afternoon, we begin lecture 19. We will do a quick summary of the points covered in the lecture number 18. We have started discussing the example from say Vishwanath, we will continue and complete the discussion.

As I mentioned the goal of this example is a very simple example, but gives us a lot of insight into the behaviour of wireless system, so that is the important thing that I would like to focus upon in today's lecture. After this having got an basic understanding of how Rayleigh fading works, and what are some of the other aspects of wireless channels from the example, we then move our focus towards what modulation methods can be used and which are the once that are most attractive for a wireless channel. So, we move into a broader area of modulation and the corresponding methods of detection, we will focus initially on the modulation and the performance of the modulation.

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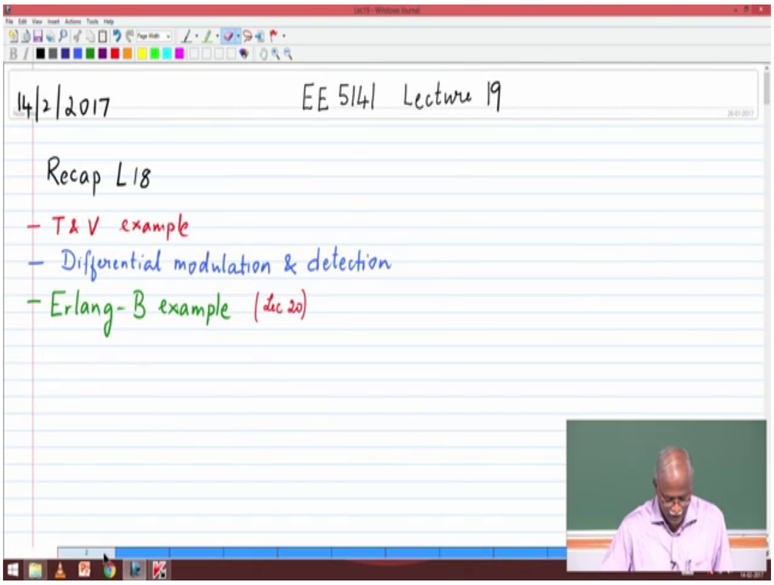

So, again it is a fairly vast topic. As you know there are different types of modulations schemes which ones are most suitable for our wireless channel. And maybe in today's lecture, we start to give you a feel for what are some of the considerations that we need to take into account once we want to make a decision regarding the modulation. During the doubt clearing session, few students indicated that they would like to have a full problems solved on Erlang-B. Again if that is a broader interest in the class I will do that in the next lecture just give me an indication after the class is over; otherwise we will do a worked example during the revision session on Thursday. So, this is again more to understand some of the questions that arose in the context of assignment number 3 and also in preparation for the first quiz.

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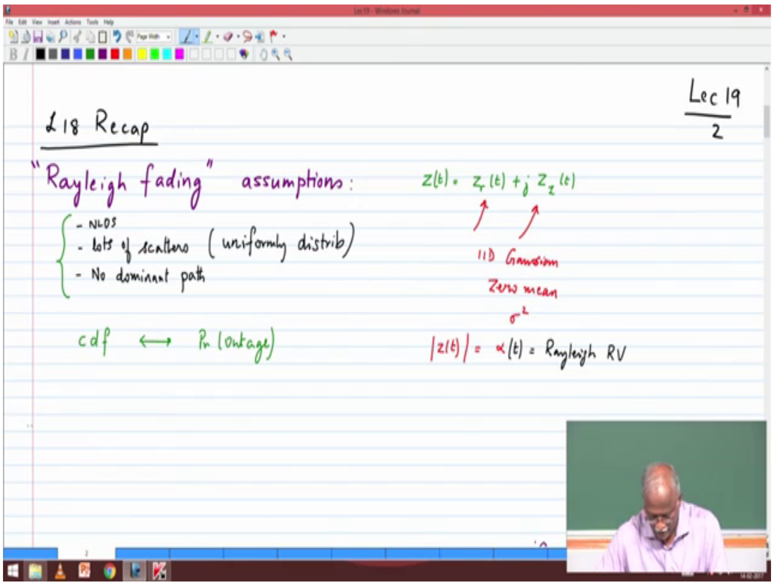

So, let us move into quick summary of the points that we have mentioned. So, as a student of wireless communications or having studied wireless communications if somebody were to tell you I am making the assumptions that the channel is Rayleigh fading channel. What are some of the assumptions that they are making, can you just quickly run through the things that you remember what is it that makes a channel a Rayleigh fading channel? Very quickly

Student: Non line of sight.

Non line of sight, very good. Anything else?

Student: (Refer Time: 02:39).

Lots of scatters that means, you are getting multi path reflections from many different sources.

Student: (Refer Time: 02:48).

They are uniformly distributed in angle that is correct, uniformly distributed in angle. Anything else?

Student: (Refer Time: 02:57).

Non line of sight outdoors, it could be non line of sight indoors also because there are we need could have the transmitter in the next room and the receiver in the next room. So, non line of sight situations can arise, but the number of scatterers are more likely in an outdoor environment and Rayleigh fading good probable occur there. So, but Rayleigh fading can occur in an indoor environment also like let us say you are in a place where there is lots of metal we are doing some experiments in our machines lab, most of you have seen machines lab there is a lot of metals. So, if the if there is non-line of sight inside a machines lab then definitely you will get lot of reflections in that environment.

Any other points, one thing is very very important no dominant path because if there is a dominant path it will skew the performance it will skew the. So, no dominant path is something that you should not omit. Anything else? Does it say that all multi path components are must are at the same time? Not necessarily you can have a time dispersive Rayleigh fading channel. So, basically which means that you have multiple taps each of those taps is a combination of several multipath components and therefore, each of them are Rayleigh fading.

So, basically if you have alpha 1 and alpha 2 as the two taps of your channel alpha 1 has got Rayleigh distribution alpha 2 has got Rayleigh distribution. Now when I say alpha its modules of the channel tap, which will be alpha e over j pi. So, alpha is the magnitude response. So, again this is something that I believe now you are comfortable with what are the assumptions, what is the distribution that that we derived what are the what are the expressions for the PDF and may be from the CDF the link to the probability of outage. Again that is an important one which gave us inside saying that you must have additional margin to protect yourself against the fluctuations that are present in the Rayleigh fading.

So, the notation that we will follow is that tap or a channel coefficient is composed of a real part and an imaginary part plus j times Z i of t. Now, the assumption is each of these are independent and Gaussian, they are zero mean and they have a common variance sigma square. And based on this we say that magnitude of z of t this we call it as alpha strictly speaking you should call it as alpha of t, but again basically at a given point in time alpha is a random variable that has got Rayleigh statistics, Rayleigh random variable. So, again this is our broad understanding of Rayleigh fading channels.

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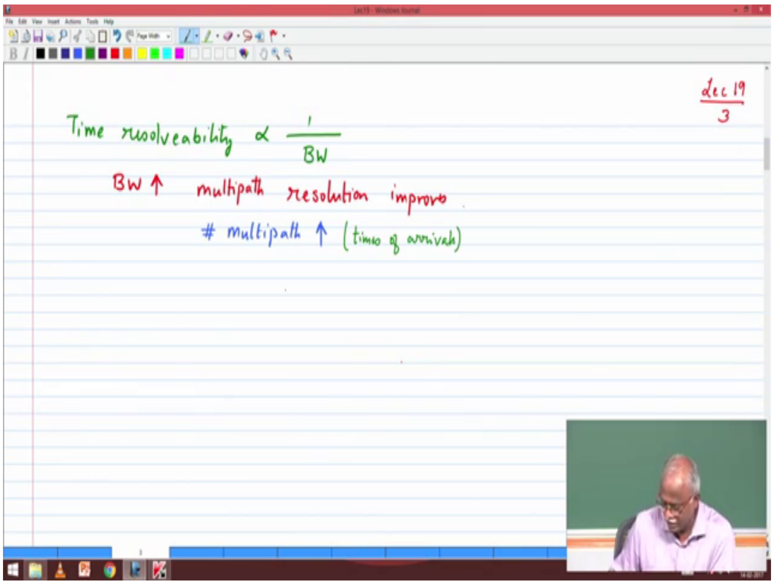

Now, in addition to this we also introduce the notion of time resolvability. And it is important for us to sort of keep that that picture in mind. Basically time resolvability in signal processing or in communications depends on the band width inversely proportional to the band width of the signal. And as you increase the band width of the signal your time resolution improves; and because of this of this environment, it looks like more multipath can be differentiated in terms of their times of arrival. So, this is more multipath components in terms of their times of arrival.

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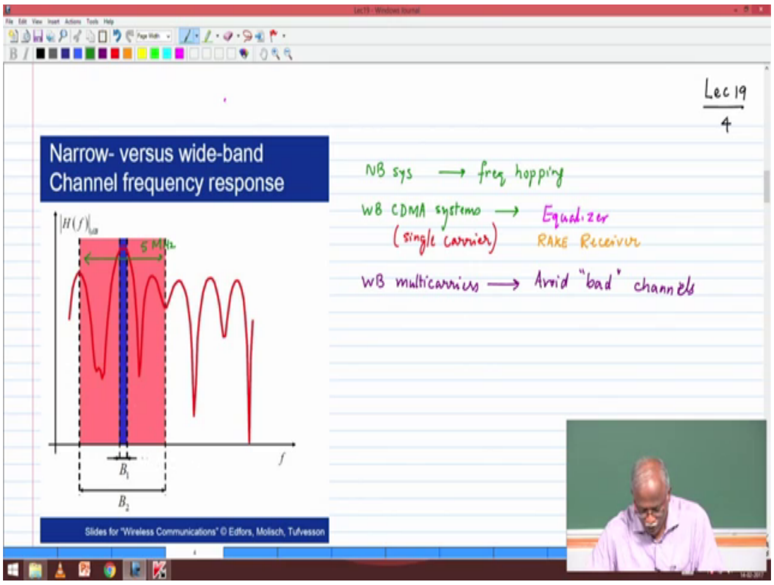

So, you can tell that they are distinct multipath components. So, that lot of it depends on the band width of the signal and to help us put this framework together we looked at 8 channel there is no difference in terms of the channel. The channel if you do a wideband characterisation you will resolve all the multipath it has got a frequency response, but if you were to transmit a GSM signal through this multipath channel at a particular centre frequency we said that it does not see much frequency variation because it is not resolving the multipath. On the other hand a wideband a CDMA system at 5 megahertz will be able to resolve the multipath and of course, we extended it to the OFDM system as well.

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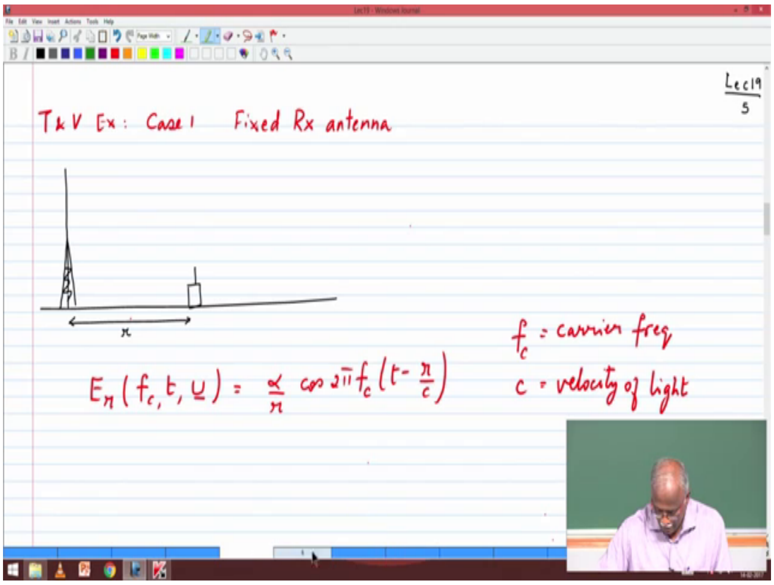

Now, we move onto discussing the say a machine of example. Again the notation we have kind of moved over to (Refer Time: 07:36) Vishwanath's notations that as you read the book you will be able to follow without any difficulty. So, the first three cases were already covered in the last class I will just refresh your memory, so that we will be familiar with the notation. Transmitter like a base station a transmitter that is the base station, a mobile station at a distance of r. We are looking at the electric field electric filed is the function of carrier frequency the time because it is a function of the time and the displacement vector. And u itself is a function of the displacement the azimuth angle and the elevation angle. So, considering the movement with inner plane we can say that the received vector is some proportional gain constant alpha gain term alpha inversely proportional to r which is the displacement cosine 2 pi f c t minus r by c, f c is carrier frequency c is the velocity of light, that was case one fixed receive antenna.

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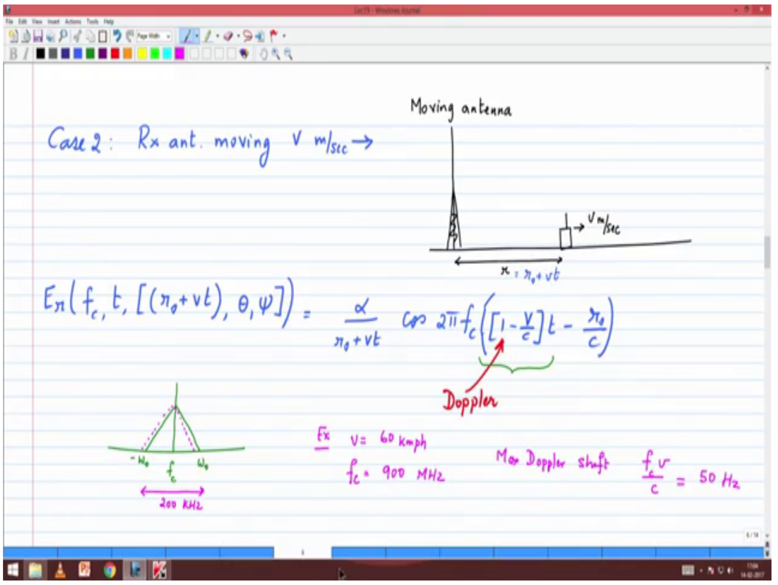

We move onto case 2. Now, we have the mobile station moving to the right away from the transmitter at a rate of v meters per second. So, the received electric field is a function of f c and t no change there. The u vector does not no change with respect to theta and pi psi the only change is that it is no longer fixed displacement, but it is a initial displacement plus v times t, where v is the velocity vector, t is the time that is will lapsed. So, the received vector would be alpha divided by r naught plus v t that is your now net resultant.

So, basically this is resolved into two components r naught plus v times t and cosine 2 pi f c t basically if you substitute for r in terms of r naught plus v t, we showed that you get this expression that clearly shows the introduction of Doppler shift into the system. Now, maybe it is an interesting point for us to just make a simple observation in this particular case. So, if I had a signal whose spectrum was centred like this, so a base band spectrum let us say goes from omega naught to minus omega naught base band spectrum, and it will be modulated to some carrier frequency let us say it is some f c. The presence of the Doppler what does it do to the received signal shifts which way?

Student: (Refer Time: 10:18).

If I moving away from the transmitter, it will shift to the left, basically it will reduce the carrier frequency. So, it will look like that my signal has been shifted to the left and the shift is proportional to the Doppler shift and of course to the right. Now, one of the important things that we would like to emphasize is the order of magnitude. So, let us do a quick example that will probably help in clarifying this particular aspect. So, we are looking at a vehicle moving at 60 kilometres per hour, the carrier frequency is 900 megahertz, I want to know what is the maximum Doppler shift positive or negative does not matter maximum Doppler shift. Maximum Doppler shift is f v by c carrier frequency times velocity times the divided by the speed of light this comes out to be 50 hertz.

Now, here it is important thing is not the calculation of 50 hertz, but the relationship between 50 hertz and 900 megahertz. So, you see that there is a very significant difference between the carrier frequency and the Doppler shift. So, it looks like the carrier has been slightly petal that is one observation. Now, take the second aspect. So, supposing this had been a 200 kilo hertz signal, basically it is a 200 kilo hertz signal. So, the receive filter will have a 200 kilohertz bandwidth. Now, what happens if you have the presence of Doppler the signal looks like it is shifted slightly to the left or to the right?

Now, if you had your receive filter exactly to at 200 kilohertz, what will happen the portion of the signal will fall outside and you will lose part of the signal. So, what is the strategy you keep your receive filter slightly wide. What is the penalty that you will pay if you keep your signal receive filter little wide,

Student: (Refer Time: 12:33).

You will receive you will allow more noise to come in slight penalty in terms of if your signal to noise ratio and receive a sensitivity, but you will not lose the signal you will still able to capture the signal. Now, when we go to the third generation and fourth generation, we are talking about signals of the order of 5 megahertz or up to 20 megahertz, 50 hertz in 5 megahertz you cannot even tell the difference. So, the receive filter is probably wide enough to accept this. So, the frequency domain impact of the Doppler shift as an from an engineering intuition is not much because the only thing that will get affected is the receive filter and receive filter is will most in most cases will be sufficiently wide to capture the signal of interests. Then where is Doppler showing up, why is Doppler why are we even studying Doppler if it is not problem.

Student: (Refer Time: 13:23).

In the time domain it is far from a solve problem because in time domain is when you will see the signal fluctuations and that is where you see this big fluctuations in terms of the received signal amplitude. So, Doppler in the frequency domain is a impairment that you can easily characterised in the time domain, it is not so simple. So, that is what we are going to see how is it going to affect me in the time domain, how I am going to handle this and that is hopefully what the remaining cases of the say Vishwanath which should give us an insight into this particular aspect.

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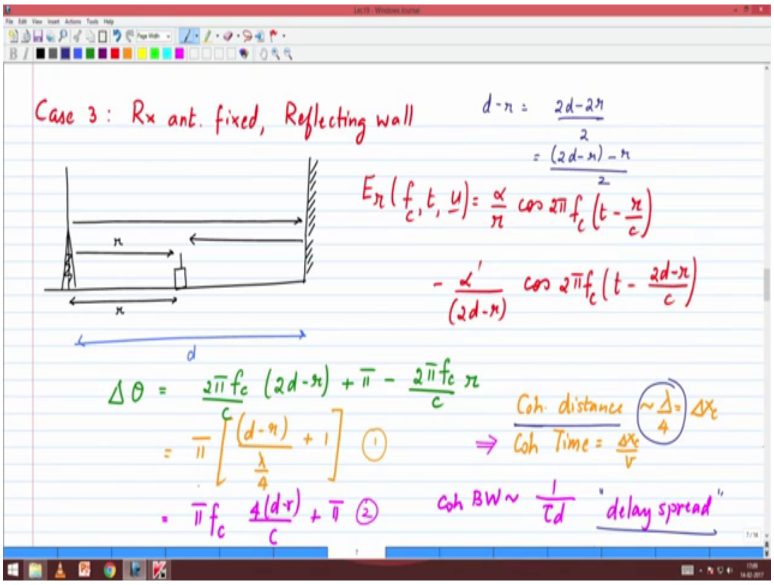

Case 3 again is a review. So, we would not spend much time, the receive antenna is fixed that the mobile is not it is not moving, but there is a perfectly reflecting wall. So, the signal that is received at the mobile is a combination of two - one is the direct path other one is the reflected path the direct. The direct path is travelling at distance of r, the other one the reflecting wall is at a distance of d. So, if you take the round trip its two d then the distance travelled by the second path is 2 d minus r. So, the second term is what we need to focus on, it will be some gain alpha rime based on how much you lose at the in the prose of reflection, and also given that the electric filed is going to have a 180 degrees phase change you will have to incorporate minus sign also. In addition to the loss that you will occur in process of reflection the total distance travelled is 2 d minus r and then you substitute the expressions for the displacement is 2 d minus r.

Now, we derived two equations from this a based on the phase difference. So, basically looking at the phase term of these two components, the phase difference gave us three inside full terms. One is if you interpret in terms of d minus r that is the difference because d minus r can also be related to 2 d minus 2 r. Let me just write that down d minus r can be related to 2 d minus 2 r divided by 2 that can be related to 2 d minus r minus r divided by 2 and that is the difference between the path lengths. So, ultimately d minus r can be related to difference in path lengths in this particular example.

But the most important thing is if you are path lengths are differing by lambda by 4 that results in phase change of pi. So, this is what we referred to coherence distance. So, any perturbation which is much less than lambda by 4, you can assume will cause only a minor perturbation in terms of the phase. So, if it was constructive before it will still remain constructive; if it is destructive before it will remain destructive. But if you have mode beyond lambda by 4 then like things are likely to change, so that is why we referred to this as coherent distance a very important quantity for us to understand by how much should you move before you start to see changes in the channel.

And again this is related to the notion that you know you have to change by order of the fraction of the wave length in order to see a change in the channel characteristics, this is only a simple example, but even in a complex example, you will find that this principle is preserved. So, coherent distance is very, very important for us. How long does it take for you to cover the coherent distance depends on the velocity which you are travelling delta x by v, and that tells you for how long the channel remain similar after that it starts to become dissimilar. So, coherence time is probably a more important parameter, when we talk about the receiver's design of receiver's design of the algorithm for receivers, because you always want to know how often should I adapt my channel estimate in order for us to be able to detect the signal. Again we will come to talk about that more when we come to the detection methods.

The same phase difference if you were to rewrite it in the form that is given. So, let me call this one of them as equation number 1, and the other one as equation number 2. The insides that we get are from these two equations this the second one says that if my carrier frequency changes by the reciprocal of 4 d minus r by c, then I am going to see a difference in terms of change of pi that will change the constructive addition to destructive or distractive to constructive. And we showed that 4 d minus r is basically related to again going back to the earlier expression, it is related to the time difference between the two paths.

So, the difference between the first multipath component and the last multipath component is what we referred to as the delay spread, and the coherence band width is inversely proportional to the delay spread. Again we also made an observation if there is no time dispassion tau d is 0, so which means your coherence band width is infinity, so that means, you know frequency hopping will not help even if you change your carrier frequency you are going to see the same channel. But if you had even a slight dispersion then frequency hopping is going to help because that will change your carrier frequency and then you can change the good channel a bad channel into a good channel through the process of hopping.

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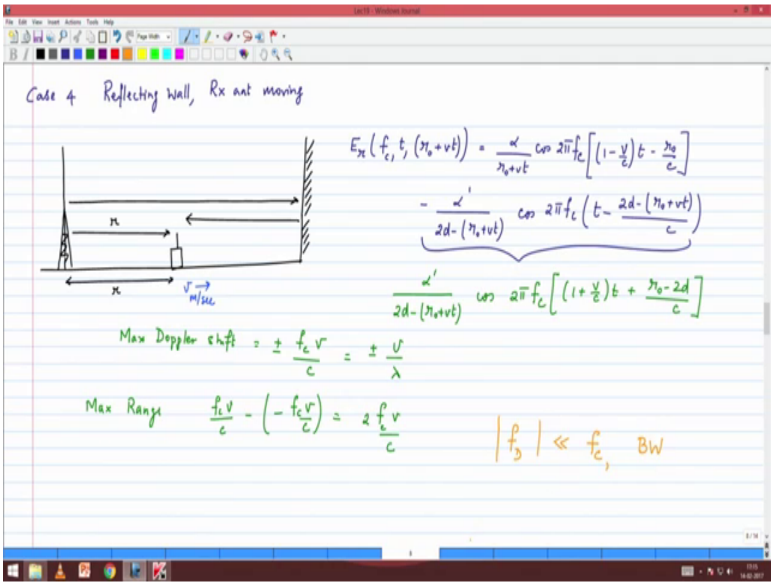

We move on. So, now we move to case four where we want to derive the case let me just write that down. So, case 4 is we have the reflecting wall at a distance d reflecting wall at a distance d and the R x antenna is moving at the rate of v meters per second R x antenna moving. So, more or less you would have to combine cases 2 and 3 to write down the answer that we want to have for this particular case. Again definitely would encourage you to make sure that you do write it down in full.

So, the received electric field has a function of the carrier frequency t and it is r naught plus v t that is your displacement now because the mobile is moving will consist of two terms. The first one will be alpha by r naught plus v t cosine 2 pi f c. Again you would have to substitute the expressions for r. So, I will pick advantage of the earlier expression. So, this will be 1 minus v by c into t that is the negative Doppler shift because the direct component is in the same direction as the direction of motion minus r naught by c, so that is the first term.

The second term I am going to write it in two steps minus sign because of the reflection which introduces change 180 degree phase change. And now it is again alpha dash divided by 2 d minus r naught plus v t because 2 d minus r previously when r we have showing it as r naught initial displacement plus v t. Just substitution, so nothing complicated here 2 pi f c t minus 2 d minus r naught plus v t. Again just substitute systematically this whole thing divided by c is the second term.

I have just changed r to r naught plus v t in the corresponding equation in the earlier case. If I have to rewrite this term rewrite this term, so that we get the insights that we want. So, let me rewrite it as alpha dash divided by 2 d minus r naught plus v t cosine 2 pi f c 1 plus v by c into t. Again this is the positive Doppler shift plus r naught minus 2 d divided by c. So, two components the minute I start moving; in this case, I have two components which are going to interact with each other one of them has got a negative Doppler shift, other one is got a positive Doppler shift.

So, let us just write the following observations regarding the Doppler. So, the maximum Doppler shift we are seeing in the this case one with positive maximum and other one the negative maximum is equal to plus or minus f c into v by c or this can be also be written as plus or minus v divided by lambda. So, that is the maximum shift that you can encounter in this. Again we saw earlier it does not matter whether it is positive or negative, the frequency domain impact is not going to be very significant. However, what we are interested in is the maximum range of Doppler shift that you will encounter in the received signal.

So, range of Doppler maximum range of Doppler will be positive maximum divided by c minus the negative maximum f c v by c. So, that is two times the Doppler shift in any direction f c v divided by c this is the maximum shift. So, somewhere in this has to be a every received component that is present. So, another or point that we have made is that the Doppler shift f d magnitude is much less than the carrier frequency again just an observation because in the next example we will be building upon this. Is this clear?

Basically what we have shown is the combination of case two and three that is the reflecting wall you have moving to the right there are two components basically there is a one component with the positive Doppler shift another component with the negative Doppler shift that gives you a maximum Doppler range, range of Doppler. And at the end of the day the Doppler shift is something that is much smaller than the carrier frequency it is also much smaller than the band width of the signal in most of the cases we are talking about band widths of several hundreds of kilohertz or in the order of megahertz. Now, comes the last of the cases that we want to study. Again now you may see well already exhausted all my cases all the combinations I have been looked at. Now there is actually one more very, very interesting case.

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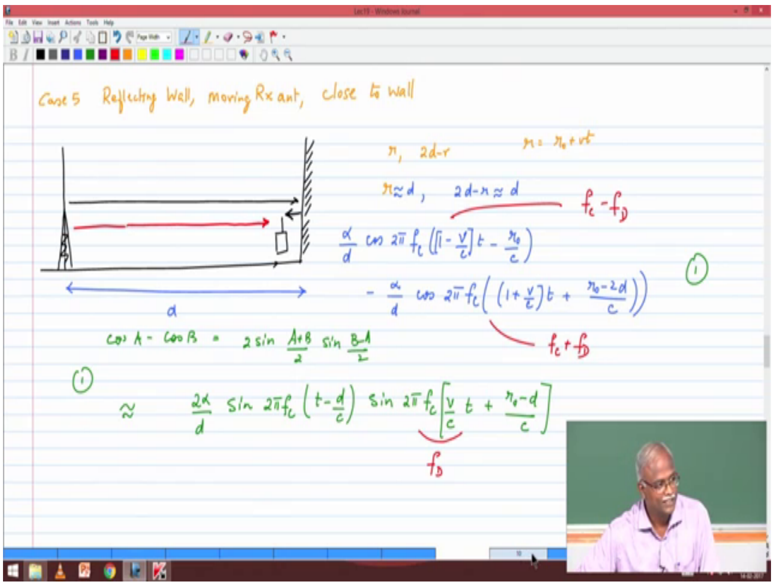

Case 5, case 5 is reflecting wall moving R x antenna except that you are act the very close to the wall basically almost bumping into the wall moving R x antenna close to wall close to the reflecting wall this is the scenario. So, again we do not have to rewrite just take the equation from the previous case. In the previous case, the distances where r and 2 d minus r correct, where r was given by r naught plus v t. Now, what we are going to make the approximation is that alpha is approximately d that is the distance from here to here from here to here is d distance. So, r is approximately d which tells me that 2 d minus r is also approximately equal to d, so which means that two components are going to be very similar in terms of their scaling because alpha by r and alpha was the one was alpha by 2 d minus r. So, the received signal vector now is going to be alpha divided by r or we less write it as alpha by d cosine 2 pi f c 1 minus v by c into t minus r naught divided by c that is the first term this is the negative Doppler shift.

The second term comes out to be alpha dash we are assuming is a lossless reflection. So, therefore, the gain is also alpha here alpha by d cosine 2 pi f c 1 plus v by c into t plus r naught minus 2 d divided by c. Now, notice that this first component corresponds to f c minus f d this component corresponds to f c plus f d. What is new is there any insight that can be gained from here turns out that trigonometry gives us a very, very good insight basically we have the form cos A minus cos B. So, this can be written as 2 times sin of A plus B by 2 sin of B minus A by 2, do not worry too much about the signs the magnitude the quantity inside is the important one, but make sure that you get the signs correctly.

So, this expression equation number one can be written as 2 alpha by d, just one second, let me finish and then I will be with you - Sin of 2 pi f c into t. otherwise basically I am adding those two terms and dividing by 2 t minus d c by 2. The second term will be the difference of the two components notice that f c will get knocked off, but you will see that. It is sin 2 pi f c v by c into t well you said f c is getting knocked off, but it does not seem like knocked yet v c by t plus r naught minus d divided by c. Please make sure that you just check the algebra the reason I said f c is sort of knocked off is for the following reason this is nothing but f D.

So, I get two terms a product of two terms one is a sinusoid at carrier frequency, the other one is the sinusoid at the Doppler frequency, yeah question.

Student: (Refer Time: 29:00) d plus v t and d minus v t in the first equation.

Sorry.

Student: The scaling term.

Your act the edge almost at the wall.

Student: OK.

At the wall. So, approximation is that the direct path and the reflected path are travelling almost the same distance and that is equal to distance there is slight approximation involved. But if you are very very close to the wall this equation is this is valid. Now, the question is what exactly did this did this equation tell us. Now, what are we trying to do we are trying to get an expression for the electric field. We said that the electric filed in a environment where there is multipath one is a positive Doppler shift, other one is the negative Doppler shift. And I am moving the only reason the reason is the Doppler shift because you are moving under this scenario the composite signal now turns out looks like it is a product of two sinusoids. And this I am sure you recognise is nothing but what would you have encountered in what type of modulation, amplitude modulation.

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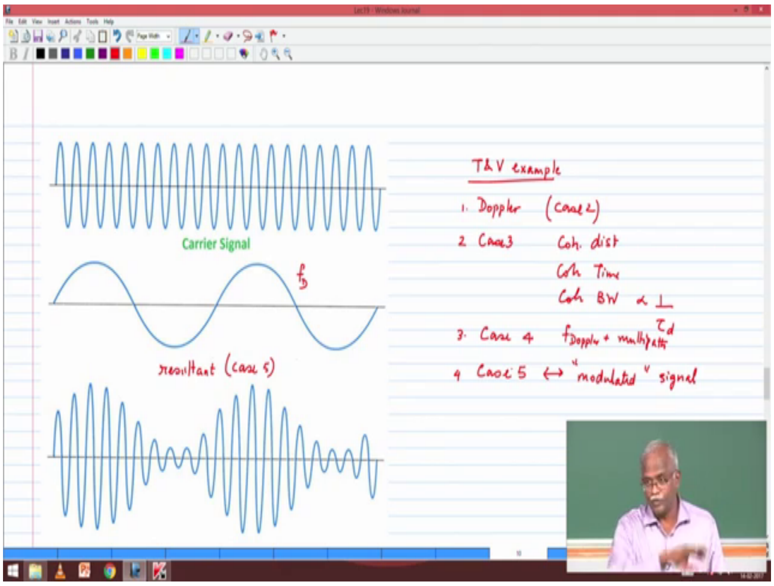

Student: Yeah.

There is a carrier signal, there is a message signal which is at a much lower frequency you multiply that two. So, I will not use the term message, this is the Doppler component, this is the resultant signal, this is for case 5, resultant for case 5. But in general what it shows is if you have multipath components with the in the presence of Doppler shifts what is going to happen is your sinusoid is at carrier frequency now gets modulated so that means, your electric filed is no longer at constant magnitude signal. It is something where the magnitude is going up and down, and how fast is it going up and down Doppler frequency. The faster you go the faster this is going to oscillate. So, this is this is the insight that we get and it is very, very important that we are able to capture or understanding and be able to applies.

So, what are the things that this example or this series of examples have has told thought us. So, if I went to summarise the (Refer Time: 31:27) Vishwanath example a very very simple example, but it is given us the following insight. Case 2 straight away gave us understanding of Doppler, when you move away or towards the system. The case 3 this was case 3, then case 3 gave us valuable insight in terms of coherence distance coherence time and coherence bandwidth, all three elements. And coherence bandwidth is inversely proportional to the time spread or we call the delay spread. And case 4 basically combined Doppler and the multipath components. And case 5 basically gave us the effect of the modulated signal I will put modulated within brackets, because it causes the signal they envelope of the electric filed to go up and down at the rate of the Doppler frequency.

So, this one case 4 gave us Doppler plus multipath and when under the right conditions you will see that the signal almost goes down to zero and then comes up again. So, in practice when you are adding a large number of signals, the envelope may not go all the way to zero or it may, but still what you will see is the effect of the fluctuation which is what is something that this we have to be careful. Any questions on what we have said so far, how does Doppler affect my signal? We have come at it from two very different aspects. The first one was we drew a lot of multipath components and then said I am going to characterize it statistically. Then we said let us take a very simple example and then see what happens inside the presence of Doppler and we have shown that there are two.

Now, take this understanding anchor it in the statistical characterisation that will now tell you how easy or difficult is going to be work with the fading channel as a whole. Any questions? The question is why did we call it as maximum Doppler shift I have I think may have mentioned earlier the maximum Doppler shifts happen when you are moving in the direction of the propagation direction of propagation or away from it. So, anything if you are moving at an angle will be less than that. So, this is like the worst case that you will encounter one is once side maximum positive Doppler the other side is maximum negative Doppler, so that it case two highlight the fact that you this is the worst case shift that can occur in the system.

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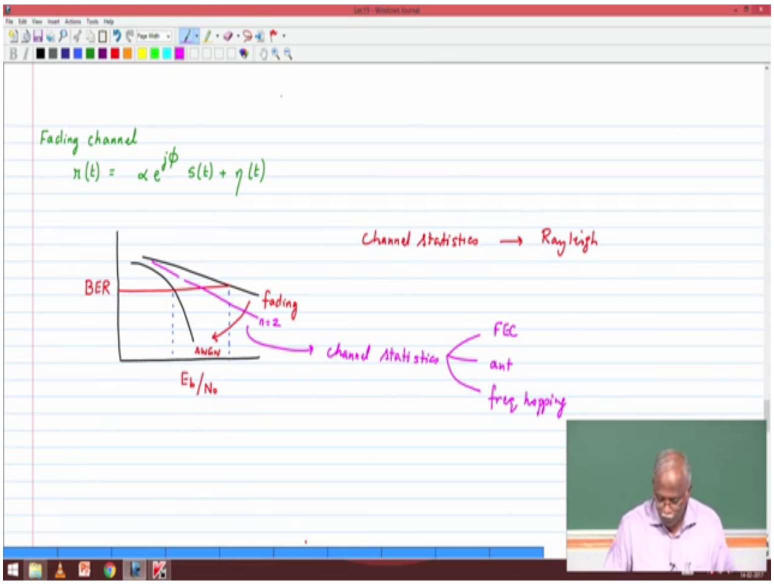

Good, we move onto the other elements that we want to cover in today's class. Now, another aspect that may be I wanted to highlight you is the notion of the change from fade AWGN to fading. And as we mentioned in the last class the goal of wireless communications is to see if we can move the fading BER performance to the AWGN performance. So, from a statistical description, I am trying to change the channel statistics when I have non-line of sight, large number of multipath components and no dominant component, this is going to give me Rayleigh.

Now, the whole goal of our study together is to change the channel statistics. If I basically when I draw the pink line and say the is n equal to 2, two antennas you may say yes in a sense the because I have gotten I can always choose the better of the two antennas or I can combine the two antennas and make the detection. But at the underlying it what have you done what you have done in the case of the, you have changed the channel statistic, it is no longer Rayleigh.

So, our goal is to find ways is in which we can shift the performance away from Rayleigh. And the ways in which we would do that possibly through FEC, possibly through antenna diversity maybe through frequency hopping or combinations of these things are all of these are attempts to change the statistics to make the channel look slightly different from what it naturally occurs in the wireless channel. And to make it more favourable for us in terms of the transmission of the data that we are interested in sending across.

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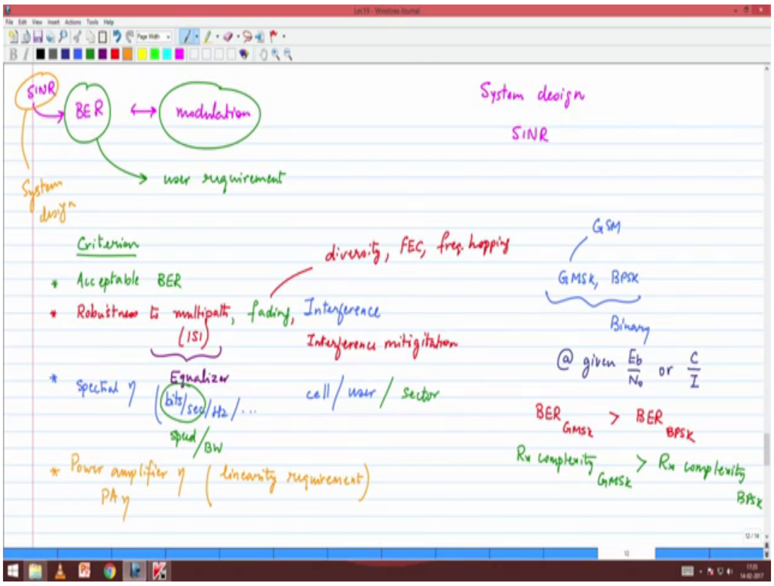

What we would now like to move forward is to understand the BER and the link to the modulation scheme. Ultimately, you know that through the system design, you have a certain signal to noise ratio or signal to impairment plus interference plus noise ratio. So, from your system design from your system design, you know the range of SINR that you will be able to offer to your receiver. Now, SINR will tell you what the BER is going to be SINR tells you what the BER is going to be and depending upon the modulation you will have different BER graphs. So, then once you know the SINR, once you know what is the target BER, so SINR is from system design that is from how you have design the transmit power, how much antenna gain you have done. The BER is your user requirement, user says I must have one percent BER or better, so that is the user requirement basically or applications requirements.

So, there are two different entities that come in and then you say ok, this is the SINR, I have from the system design this is the BER I must achieve. So, therefore, what is the modulation scheme that will satisfy the modulation index I am interested. So, the criteria for choosing a modulation, again we will approach it in a very intuitive way in this lecture and then build the detailed into the next one. So, the first one is you must have acceptable BER in the range of SINR that you have acceptable BER is the first and foremost requirement. If you have poorer SINR, you will go for modulation schemes like binary or quaternary; if you are have very good SINR conditions, then you may go for 16 level modulation or 64 level modulation.

So, the other element that also important is what is the how is this how robust is the modulation. Robustness to multipath, robustness to multipath; and multipath we are more specifically in concerned about ISI. If there is no if there is no time dispersion it will be Rayleigh fading. So, you will bring that case also, but if there is time desperation there will be interfile interference which means that then you will have to have an equalizer. So, this will automatically require, you to have any equaliser. So, you want to choose a modulation method that will have a equalizer complexity that is manageable for your receiver.

Then when the case there is no time dispersion, you will still have fading. So, again in the presence of fading, you should have good performance. So, you should have the ability to introduce diversity different types of fodder correction, the corresponding decoding methods, frequency hopping maybe, whatever are the techniques and your modulation method must lend itself other in any changes that you can. And in a cellular type environment we will always have to worry about it being an interference limited environment. So, therefore, we also talk about what are some interference separation methods, interference cancellation may be one, interference mitigation there are several of which so interference mitigation. How easy or flexible that it will be to do the different interference mitigation methods.

And this is the third element that we are always very interested in it is called spectral efficiency. Spectral efficiency and it is measured in bits per second per hertz per dot dot dot. What are the dot dots? It could be per cell you maybe measuring your spectral efficiency per cell or you may be measuring it per user, how many bits per second per user are you able to get. So, there are several measures depending upon what particular aspect that you are looking at, but at the end of the day, it is bits per second per hertz. So, bits per second corresponds to the speed of transmission, speed of transmission how many kilobits or megabits per second are you transmitting, then this is the bandwidth that you are using.

So, are you efficiently using a bandwidth? For a given bandwidth what is the maximum data rate that you can achieve that is bits per seconds per hertz, but then there is frequency reuse there is all the system design aspects. So, how do I actually measure it I should measure saying I have so much spectrum across my entire cell, but within one cluster these are the number of users I can support. So, it is per user or per cell sometimes per sector also, again depends on how you want to look at it, but the bits per second per hertz is very very important you want to do that.

Now, very often books will stop with this three. You must get better rate performance you must have a system that is robust to the different types of impairment. What are the different types of impairment fading, multipath which will result in inter symbol appearance and co channel interference. Again two types of interference that we have. Equalizer will mitigate the multi the inter symbol interference and you must have other techniques to mitigate the co channel interference. Spectral efficiency is very important.

Now there is yet another element that is that one more aspect that needs to be added, so but let me ask you this from in a slightly different way. So, at a given E b by N naught or C over I; that means, either in noise limited or interference limited the following statement is true. There are two binary modulation methods - one is GMSK we says that this the modulation method used by GSM and others and then there is of course, BPSK both these are binary modulation methods. So, here is the following statements are correct. For a given E b by N naught or C over I the bit error rate of GMSK is higher than the bit error rate of BPSK. So, which is the better modulation? BPSK is the better modulation.

Now, it turns out that the complexity the receiver complexity, complexity of GMSK is actually also higher than receiver complexity of BPSK actually receiver complexity of BPSK is very, very straight forward. So, this is also the case. So, the question is why did we choose GMSK for GSM. They must have known that these two are the obvious results everybody knows about it. The third or the fourth component that we should not overlook is the power amplifier efficiency. Power amplifier efficiency, it says that how much efficiency can you get out of your power amplifier, the higher the power amplifier efficiency the better because that means, because you will draw less power from your battery and your device is going to last longer.

So, power amplifier efficiency, we call it as PA efficiency, it depends on the linearity requirement how linear should you want the power amplifier to be. And the linearity requirement for BPSK is much higher than GMSK. So, GMSK actually runs at higher power amplifier efficiency. So, at the end of the day, if you wanted to build a device that is battery and power efficient then GMSK wins over BPSK, but all combination of all four need to be taken into account that we get good understanding of the modulation methods.

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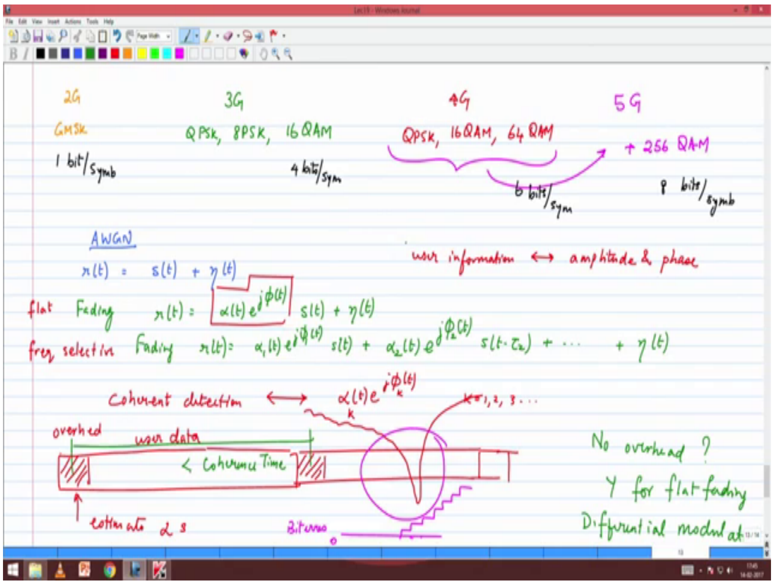

So, 2 G, we used a GMSK. Then comes 3 G, 3 G are the following methods that we have used or modulation schemes that we have used GMSK continue to exists. So, basically these are the methods, these are the things that we have added QPSK, we added 8PSK found that it was very difficult to work with the 8PSK, and also introduced 16 QAM. Then came along 4 G, we saw that we could now do more processing at the receiver. We also know that some of the users are going to be in good channel conditions. So, the modulation methods are QPSK, dropped 8PSK because of complexity reasons or performance reasons, 16 QAM and 64 QAM; and 5 G all of this plus possibly 256 QAM.

So, we are seen the fact that we are able to get the maximum out of the channel, but again the complexity of the receivers is growing very, very fast. And we know we have to be aware of that. So, basically at this stage, we were doing 1 bit per symbol, 1 bit per symbol or per channel use went all the way to 4 bits per symbol then came to 6 bits per symbol the highest. So, this will basically improve your spectral efficiency and this is going to 8 bits per symbol. So, in a sense you are achieving something like a 8x improvement over 2 G when you move on to this side, but again it is not strictly eight and there are several other factors that we need to take into account. It is in turns out its the factor that is much larger than 8, but simply from a spectral efficiency point of view one bit per symbol was what you are transmitting through the channel. Now, you are transmitting 8 bits per symbol again very significant difference and a significant change.

Now, let me move onto highlighting some one more important element. The received signal in AWGN, r of t is the transmitted signal plus the noise AW that is the additive channel noise. So, detection is straightforward, you have already done it in your computer simulation example. Now, I am going to write down two cases the case of a fading channel, r of t is equal to alpha of t e power j pi of t that is my complex gain term, which represents the fading, this multiplied by s of t plus eta of t.

Now, the reason I said I have to take two special cases, this is flat fading. There is only one channel one multipath channel that is present. Now, the other type of fading channels will be frequency selective that means, there is time dispersion frequency selective fading; that means, there is at least one additional multipath component. So, it will be r of t is equal to alpha 1 t e power j phi 1 of t s of t plus alpha 2 of t e power j pi 2 of t s of t minus tau 2. So, some delayed version plus more terms like this depending upon the multi number of multipath components plus the additive Gaussian noise. So, basically the noise is still present, there is interference happening between the different multipath components and that is frequency selective fading channel.

Now, an important point to note is that in all of the modulation methods, you know that we talk about in 2 G, 3 G, 4 G, the information is contained in amplitude and information regarding the user information. User information is present both in amplitude and phase is encoded in amplitude and phase, so which basically tells us that in order to do the demodulation process, one of the first thing is that you must do is to actually estimate the fading coefficient. So, without that there is no way we can detect the signal, because this phi if you assumed it was 0, will make you will make an error in the transmitted signal because you could be in the wrong quadrant. Alpha of t if you assume that it is equal to 1 you may not be able to differentiate between the different QAM symbols. So, again this is very, very crucial.

So, any time you want to do what is called coherent detection. So, coherent detection requires us to estimate coherent detection means that I must estimate all the alphas, alpha of t e power j pi of t and may I will just put a coefficient k, so that we recognise there will be several of these. So, k equal to 1, 2, 3 however, my you must you must estimate the estimate them correctly. And this is the reason why whenever there is transmission in a wireless system, what happens is if you notice in GSM right in the middle there were some what we called as some overhead information. This is the overhead, and this is the user data that is present. So, what is the overhead for to estimate your alphas, estimate the alphas alpha's and pi's, so very, very important. And why do you keep transmitting the next time you wanted to do a transmission, again you transmit overhead why because the channel has changed. Now, how often do you must transmit this information?

Student: Coherence time.

Coherence time because you want to make sure that when the channel has changed you must be able to re estimate the channel. So, this distance between the times that you transmit the information must be less than coherence time, this should be less than coherence time, so that is the strategy that we want to have. Now, even if you have designed using coherence time, there is one very fundamental problem that you will encounter. Can you tell me what that problem is? I have designed my system very correctly, I have designed them to have the overhead at the correct reputation rate so that I will get my estimates, so that I can do coherent detection.

What is the problem that I can run into? I hear the correct answer; the correct answer is fading. What happens the channel, let us say changed basically it went through the fade the coherent detection basically will lose track of the signal at this point. When you have gone into a fade, your coherent detection will lose track of the alphas. Now, after the fade the signal may come up above the level that you can detect, but you cannot detect because you have lost track of the alpha. So, this is a serious problem, because what happens in the typical coherent detection this is the bit errors, this is the zero level zero, zero, zero, zero at this point, you hit a fade error increasing every symbol is an error.

Basically beyond that point where a fade occurs you will have large number of errors happening the only way you can avoid this happening is you transmit the overhead more frequently. What happens if you transmit overhead more frequently, you will lose user data rate. So, overhead is really wasteful information from a user data point of you, so that constant trade of says how often should I transmit my reference or overhead information, so that I can get robust detection

Now, the question is can I get away without transmitting any reference information at all overhead information, and it turns out the answer is yes. So, no overhead because I do not want this overhead, I do not know how much overhead to put. So, is it possible? The answer is yes for flat fading channels only and that is a method called differential modulation, which we will explore in the next class. So, differential modulation, I am sure you would have studied it, but please do look it up any of the communication text books would give you a good reference differential BPSK, differential QPSK. So, it is possible only for non-frequency selective; in other word it is flat fading is the condition you will find that it is a very robust modulation that is used. And how does differential modulation work when coherent does not work, we will see in the next class.

Thank you.