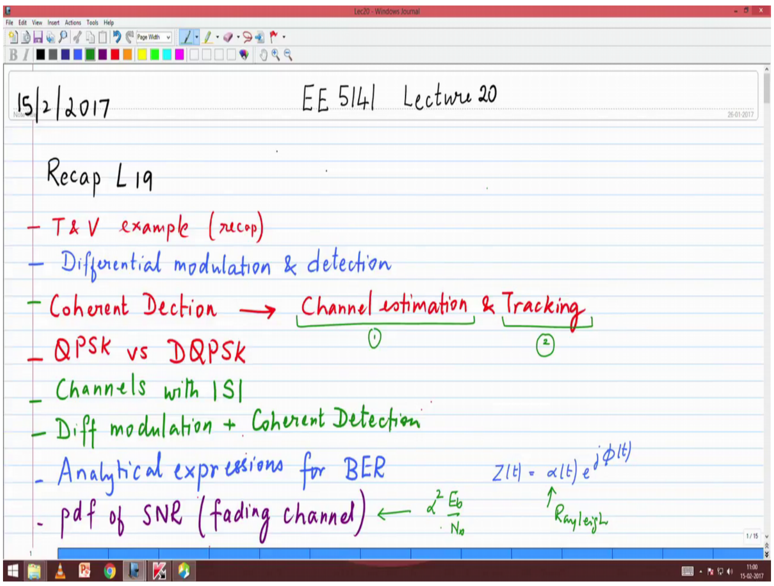
Introduction to Wireless and Cellular Communication
Prof. David Koilpillai
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 20
BER Performance in Fading Channels
Coherent versus Differential Detection

Good morning, we begin with a quick summary of lecture 19 and then move in to the topics for today's discussion. The recap will basically consists of our case 4 and case 5 of say I am Vishwanath, hope you had a chance to look at the examples basically to summarize and gain insights into the different aspects of the wireless channel. We introduced our basic understanding of coherent detection and also some of the challenges with coherent detection what happens in the presence of fading and there were several questions after the lecture. So, what I thought was we would spend about 10 minutes in today's lecture addressing some more aspects of coherent detection so that everyone; we will all be clear and have a good understanding of why; what are some of the challenges and why they occur and how they may be addressed in the context of a robust wireless system.

(Refer Slide Time: 00:53)



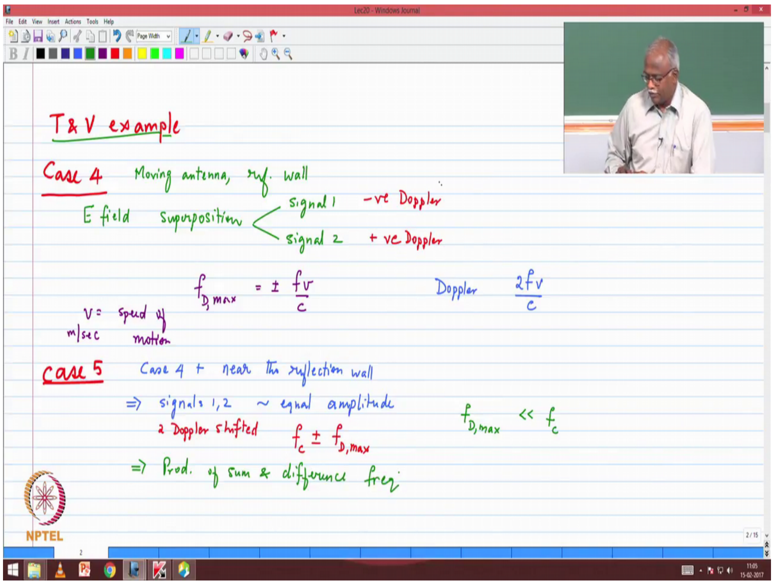
So, once we have done that then we can talk about what is the other option other than coherent detection; coherent modulation that would be differential modulation with non coherent detection and then look at some of the differences between the 2 that also gives us a basis to compare for example, 2 very similar modulation schemes coherent QPSK and non coherent QPSK or differential QPSK, both of them carrying 2 bits per symbol; which one would you use which one would be better which one would be more robust in a wireless system those are some things that we will comment upon.

Now, comes the question of non coherent detection yesterday we said well it is not suitable for channels with the ISI why is it not suitable let us give a quick answer to that can you have hybrid can you do differential modulation and coherent detection can you do coherent modulation and differential detection again interesting questions the answer to that you should know as a student of a digital communications and wireless with this background we will then start to look at the analytical expressions for bit error rate again the anatic expressions give us a lot of insight.

But we have to have the patience and the effort to actually go through the derivation of the analytical expression. So, again there is some level of integration and the you know some techniques involved the goal of our course would be to give you a hints on those methods and then help you get to the final answer interpret the answer get inside and then help us design good systems for wireless channels we will also talk about one of the things that we have studied. So, far is the probability density function probability distribution function for a wireless channel which is characterized in the following form z of t which is alpha of T E power j phi of t now alpha is a one that has got the Rayleigh PDF; Rayleigh PDF and we have also said that the SNR in a AWGN channel is given by e b by n naught now if the amplitude is getting modified by alpha then the signal power will be modified by alpha squared. So, when we talk about pdf of SNR in a fading channel SNR in a AWGN channel is a constant, but in a fading channel SNR is not constant you must specify alpha for it for it to say what is the instantaneous SNR.

So, what is the pdf of a fading channel and how does that help us to estimate the analytical expressions for BER.

(Refer Slide Time: 04:04)



So, again there is a fair amount of material that we would like to cover today. So, first to summarize this is to conclude our discussion of the T and V example again we looked at cases 1 2 and 3, case 4 was moving antenna plus reflecting wall this was a combination that gave us that the E field in this case was the superposition of 2 components superposition of 2 components 2 sinusoidal components let me call that as signal one at that is the first component this had a negative Doppler because it was moving away from the transmitter then there was a signal 2 which was after reflection that had a positive Doppler and these 2 were interacting to produce the resultant electric field.

So, the observation that we made was there were 2 Doppler shifted versions that the f D max f D stands for Doppler the maximum possible Doppler shift can be plus or minus f v by c v is the vehicle speed; speed of motion I do not want to call it vehicle speed basically either transmitter or a receiver one of them is moving and the speed of motion of the moving antenna is v meters per second v meters per second. So, this also gave us that there is a notion of a Doppler spread various components that can be received by the received antenna and maximum Doppler spread will be from the most negative to the most positive that is 2 times f v by c.

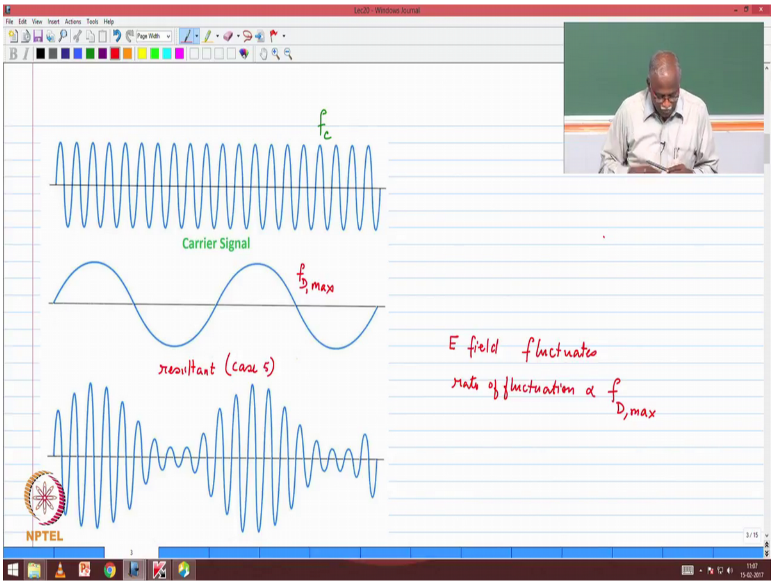
So, in terms of the spectrum shifting this spectrum can shift all the way to the left because of the negative Doppler can shift all the way to the right Doppler. So, when you have large number of Doppler components arriving give me a spectral interpretation what is your received spectrum look like you have a received spectrum which in the case of an AWGN channel would be a fixed one, now there is a smearing of your spectrum because some Doppler components are shifting because of negative Doppler some are shifting to the right and the resultant.

But from a filtering point of view it did not pose a channel because your received filter will allow all the Doppler components to come in now the as we said yesterday that where it is going to have an impact is in the time domain and that is what we would like to look at more carefully today. So, case 5 is basically case 4 this would be case 4 plus near reflecting wall I basically using short form notation the receiving antenna is near the reflecting wall. So, it turns out to be a special case again you just have to apply the approximation near the reflecting wall.

What we found was that both signal one and signal 2 because of the both of them are approximately traversing the same one signals one and 2 are approximately equal amplitude equal amplitude that was one observation that we made the second one of course, was that one of the components has got maximum negative Doppler the other one has got maximum positive Doppler. So, basically 2 Doppler shifted versions 2 Doppler shifted versions are available to us they are actually interacting with each other.

So, the Doppler shifted versions will be f c plus or minus f D max and we also showed through a numerical example that f D max in most of the cases that we encounter is substantially less than f c. So, what we have is a superposition of 2 sinusoids that are very close in frequency and then in physics we know that when this happens there will be beating of the; of the 2 sinusoidal components that results in a product of sinusoids. So, this resultant is a product of sinusoids which has won the sum and difference components. So, of course, you can look at it and recognize that there will be a component at f c and then there will be a component at f D max.

(Refer Slide Time: 08:44)

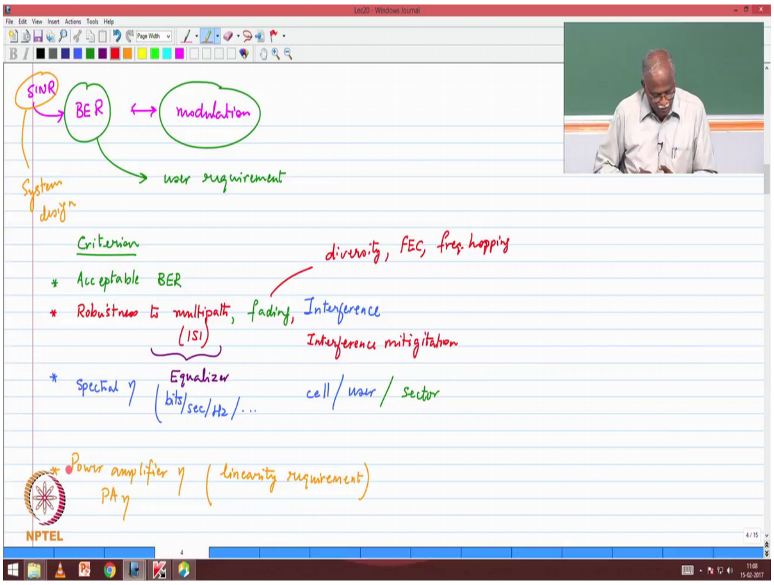


So, product of sum and difference frequencies and this is what gave us the insight that we were looking for which said that there is a carrier frequency at f c there is a Doppler frequency in our case we saw f D max both of them interacted.

So, f c plus f D max. So, these 2 interacted with each other and what we got was a product resultant where the signal envelope is not constant it depend; it is a fluctuation. So, the observation is that in such a scenario the e field fluctuates.

Fluctuates that is one very important notion and the rate of fluctuation is proportional to Doppler rate of fluctuation proportional to f D in our case it is f D max is what we are seeing. So, that that would more or less tell us how the system would have to be understood and interpreter. So, this was the say I am Vishwanath and I hope all of the different elements the coherence time coherence bandwidth coherence distance the rate of fluctuation all of these are have given you some level of insight into the what is happening in the winter the wireless channel.

(Refer Slide Time: 09:56)

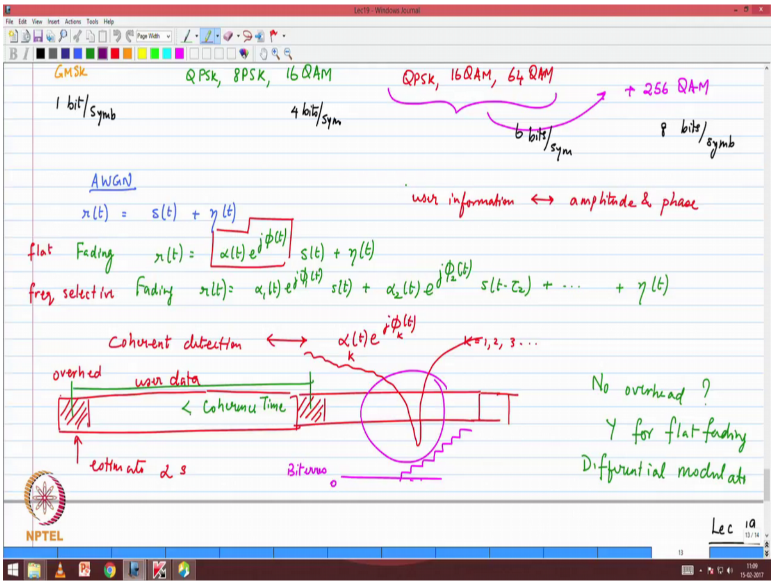


Then we said a given that we now understand what the wireless channel is all about I want to look at what are the criteria for choosing a modulation 4 things that we said one would have to be this basically the slide from last lecture acceptable BER.

You know what is the SNR that you will get or SNR what is the corresponding modulation scheme that will give you a acceptable BER and the modulation scheme that we choose must be robust to the impairments; impairments could be in the form of just fading; that means, there is no time dispersion there could be combination of fading and dispersion that would be multipath ISI then it could also have interference from co channel cells again each of these has got corresponding signal processing techniques we have or a techniques such as forwarded a correction we should be able to implement them with the reasonable complexity at the receiver.

At the end of the day how we will measure the goodness or the suitability of a modulation scheme it will be into through the selection of the spectral efficiency or estimation of the spectral efficiency which would be given by bits per second per hertz. So, that it that it would be our goal we also said not to forget that a very practical element would be the power amplifier efficiency that it would could offset the advantages of get in terms of BER if you have something that gives you a very good power amplifier efficiency.

(Refer Slide Time: 11:24)

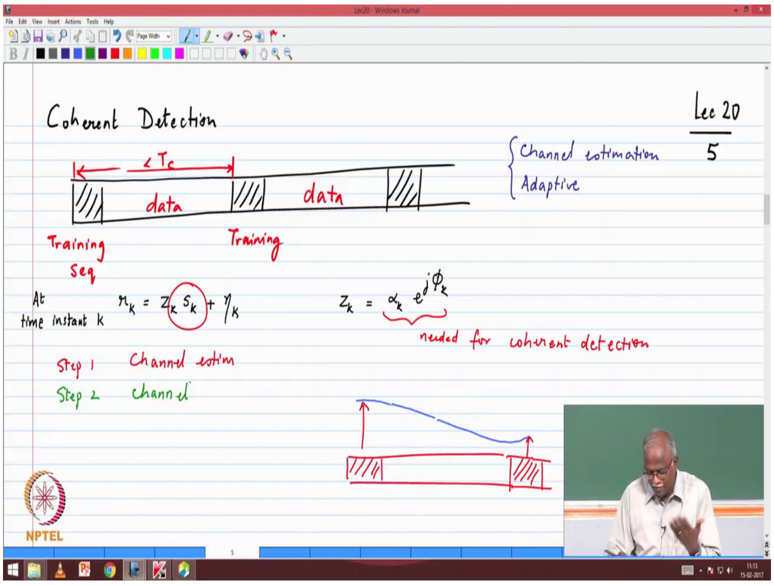


Now, let me just shift to the previous graph where there were lot of questions after the class several students stop by and asked said you have channel estimation happening whenever there is a at training system training scheme that is. So, basically there is an estimation that is happening here and estimation that is happening here this is less than coherence time. So, why is the channel changing within the coherence time?

So, let me elaborate a little bit more this was more of a dramatic description of watching usually what that is means is within the coherence time the change is small, but there is change. So, again depends on the amount of Doppler that you have designed for. So, for example, I assumed that my system is designed for 60 for Doppler's up to 60 kilometers per hour. So, I have design my training system trainings periods with the appropriate coherence time.

Now, if you are travelling at hundred kilometers per hour what will happen you have actually your coherence time is much less. So, therefore, there will be a change in the change in the channels. So, like that there are some cases where between the estimate there will be changed which you not in your control. So, in such a situation when there is a change and its unfortunately also leads to a fade during that period then there is some complications with that, but several students had asked I am very glad that you asked because that gives us a chance to clarify and build on that in today's lecture.

(Refer Slide Time: 12:53)

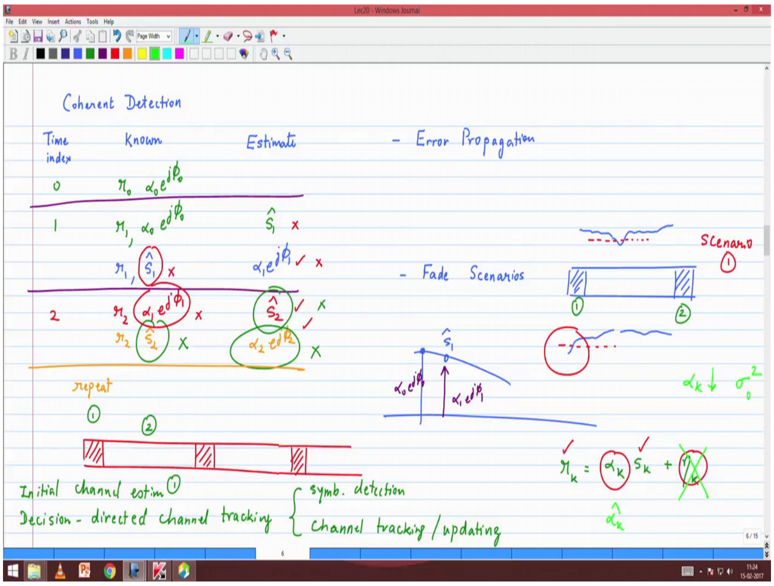


So, here is our explanation and insight into the methods. So, the way the data would be transmitted user data segments interspersed with overhead and we often call it as a training sequence and what is it that you are training why the name training because you have you are doing channel estimation channel estimation and usually this estimation is done using an adaptive algorithm and adaptive algorithms you go through a process called training and that is why it is called a training sequence. So, adaptive channel estimation is what you would typically use and that that would be also known as training of your channel estimates. So, that is why the original name comes from, but again its overhead you do not want to put too much of overhead because that will reduce your throughput.

So, you want to keep the through put the overheads as minimum as possible, but at the same time you must make sure that you have good channel estimates and reliable methods. So, let me just write down a few equations to remind us of the process that we are going to follow. So, the received signal I am going to write it in terms of the sampled notation. So, r k stands for r of t sampled at the k th time instant. So, at time instant k I am not going to use a continuous time notation I am going to use r of k this is going to be z k that is my channel coefficients sampled at that point s k that was the symbol or the transmitted signal at the k th instant of time given adding with the noise sample at the k th instant of time. So, this is the framework.

So, z k actually represents alpha k e power j phi k and for coherent detection I must have a good estimate of this; this is needed for coherent estimation needed for coherent detection and that is what we have indicated for coherent detection because if you do not have a good estimate of alpha and phi then you will make a mistake in your estimate of s k and then that that would lead to poor performance.

(Refer Slide Time: 15:30)



Now I would also like to tell you how actually coherent detection is carried out it is actually carried out as a 2 step process the first step. So, step 1 is called channel estimation channel estimation and that is what happens when you have given some number of known symbols call the training and you and estimate the channel here.

Now, at the next time the occurrence of the training or the overhead you can estimate the channel again noticed that there is some variation in the channel. So, the estimate of the channel let us say was something of this type some variation the channel is present. So, when you want to have very good performance in terms of your bit error rate and you have a dense constellation for example, like 64 q a m the even slight variations in the amplitude and phase will make a difference. So, you want to this channel estimation is good, but you must also follow it up with a step 2 which is called channel tracking you want to keep track of what changes are happening in the channel.

Now, this is very important and again it is a very simple concept; let me just explain it you in the following in the following graph or in the following steps. So, time index 0 k equal to 0 that is my starting point what is known at this point I know r 0 that is what is obtained and through the channel estimation process I know alpha 0 e power j phi 0 correct that is that is known for me.

Now, that is my initial estimates then comes the time index one what is known at this time I know r 1 I know alpha naught e power j phi naught that was my channel estimate that was given to me now the first data symbol has arrived that is represented by the sample r 1 using these 2 I estimate the first transmitted symbol s 1 hat that is the detection process that basically you plug into the equation that is in the in the previous one.

Now, what does channel this is detection of the transmitted symbol now the tracking of the take r 1 take s 1 hat and obtain alpha 1 e power j phi one; that means, you assume that the channel will change between symbol 1 and symbol 2 and you have already detected symbol 2. So, this is s this is s 1, this is s 1 and s 1 hat and what we are doing is trying to estimate what is slight changes occurred this is alpha 0 alpha 0 e power j phi 0 this is alpha 1 is e power j phi 1. So, there is a second step that you do for at time index one then go to time index 2 we use a different color time index 2, I use r 2, I use alpha 1 e power j phi 1 that will give me s 2 hat a second step at this point which will be r 2 combined with s 2 hat those are the known quantities and what I am going to estimate is alpha 2 e power j phi 2 and then this process is repeated.

So to notice that you do estimation of the symbol you do tracking again this is this was something that just do not wanted to get in the details, but this is how coherent detection is done especially when your channel is changing and you want to keep track of those small changes in amplitude and phase. So, that you can get the best performance out of your system now everything is going fine if your estimations are correct. So, I put tick; that means those estimates are correct.

So, therefore, my process completes and I get 0 bit error rate because I have been able to estimate now unfortunately if it turns out that let us say that one of these was wrong, let us say s 2 for whatever reason because of the noise sample was wrong where it will affect me it will affect this one will also become wrong because it is going to update in the wrong fashion because s 1 is wrong this one is wrong. So, this is wrong. So, because this is this is wrong; that means this one is wrong. So, this is most likely going to be wrong also now because this is wrong this is wrong this is going to be wrong also. So, notice that there is going to be a cascading or what we call as a propagation of error because one leads to error in the other.

Now, this is what we are worried about because between these 2 channel estimates this lets call this channel estimate number one this is channel estimate number 2 let say that the signal momentarily went into a fade all it needs is for you to make one symbol error and then slowly the error. So, the detection errors was what I had drawn in the previous graph the detection the bit errors no errors until you got into the fade situation, but once you hit the fade what happened your channel tracking got out of out of basically out of the in terms of the starting making errors and because your channel tracking started making errors your decisions started to be wrong and therefore, beyond that point error basically keeps filing up and you do not have a way of recovery until you get to the next training section where you can re estimate the channel.

So, I hope now this graph makes is because becomes a little bit clearer because yesterday just with this explanation I think several students had doubts channel estimation channel tracking why is channel tracking needed what happens why this error propagate in channel tracking and how are some of the issues that we need to deal with. So, the 2 scenarios that can happen is that the fade occurs between the 2 estimates that is what I have shown here. So, that is let us call that as scenario one this is scenario one you will you probably you will be able to detect until the fade occurs and then after the fade we do not know you may or may not have recovered and therefore, there could be errors in that situation a more serious problem is what happened if the fade occurred during the training sequence then you made error in your initial estimate. So, which means that the entire data after that is the questionable because your entire burst may be wrong and that is something that could severely effective in terms of your performance.

So, these are some of the practical issues with the coherent detection method and notice we are going back and forth between channel estimation and channel. So, basically at this point we do channel; channel estimation initial channel estimation initial channel estimation initial channel estimation is one and during this process during the data portion we do what is called decision directed channel tracking I will just explain that again many of you will familiar with it decision directed channel tracking that is another way of saying that my decisions are used to keep making adjustments on my channel,

channel tracking and that is basically consists of 2 steps at each step there is a symbol detection that is the step one at what we showed symbol detection and then there is a channel tracking or channel updating channel tracking and this goes back and forth channel tracking or channel updating and this is essentially what coherent detection is all about there is an initial channel estimate there is continuous tracking of the channel.

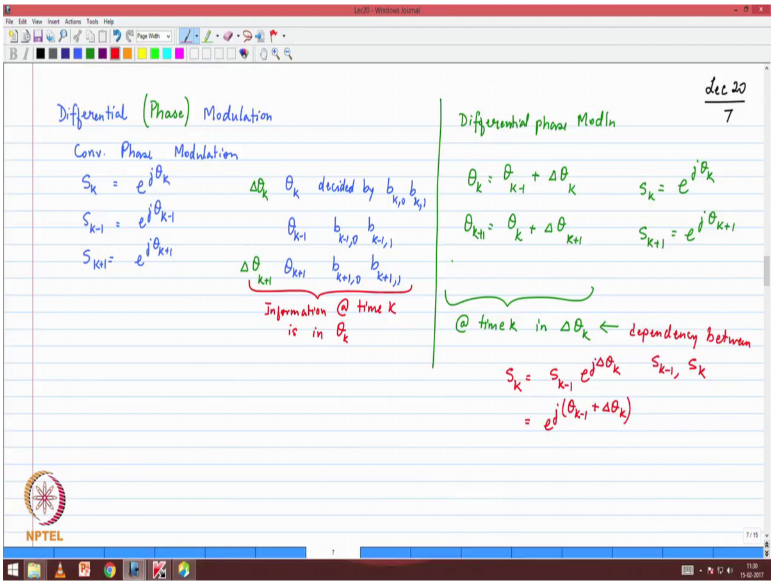
How do I how do in order to for you to be able to track the channel you must have known symbols the known symbols I use my decisions as my known symbols to do the updation of the channel with the being very aware of the risk that if I have made a decision error that could affect my channel update and then that could lead to error propagation in my system question is how do I know whether the estimate is correct or not I have no way of drawing.

So, basically I do the best possible estimate and then do my data detection and at the receiver hopefully if there are only a few errors my error correction code would have cleaned it up, but if there is a good chance that if there was a fade like for example, scenario 2 happened then I may not be able to recover that particular burst. So, that those are the challenges that we face in a wireless system I know what has been transmitted. So, therefore, why I am I not able to estimate the channel correctly so, here is the r k is equal to alpha k s k plus eta k correct that is the equation.

In during training I am going to put tick on what is known this is known this is known what is not known this is not known that is the random quantity this is not known now estimation of the channel co-efficience is done using the following assumption that my noise can be neglected I keep the received data the transmitted data which I know a priori and I estimate alpha k hat is that correct everybody is clear with that that is how I do because I do not know the noise and I do have no way of estimating what was the noise sample. So, I ignore the noise.

Now, what happens when you are in a fade alpha k becomes very small, but you are the channel noise which is controlled by sigma naught squared has not changed. So, therefore, your signal to noise ratio is very poor. So, where will it affect it will basically affect in your estimate of alpha k because you are assuming you are ignoring the noise, but really the noise is a very significant component. So, because you are ignoring something that is large that is reflected in your channel estimate and that is why you get a erroneous channel estimate when you are in a fade the question is very valid because r k I have received s k, I know what was transmitted why not why am I making a mistake in transmitting alpha k because I am ignoring the noise component were a very good question now we would like to quickly introduce a differential phase modulation again I am assuming this is a topic that is familiar to you from communication digital communications. So, many times we say differential modulation, it is more or less if understood that we are talking about differential modulation of the phase.

(Refer Slide Time: 26:27)



Let me quickly give you the differences between coherent versus differential. So, conventional phase modulation conventional phase modulation on the left differential phase modulation on the right conventional phase modulation again I am following the sampled data notation. So, which says at the k th time instant I am going to transmit e power j theta k that is my information is encoded in the phase which means that theta k is decided by decided by the bits b k comma 0 b k comma 1.

Let us take QPSK only 2 bits are there in the bit 0 bit 1 at the time instant k determine what theta k is now s k minus 1 the previous time instant it would have been e power j theta k minus 1, the theta k minus 1 would have been decided by b k minus 1 comma 0 b k minus comma 1 and let me just write one more because I need to have the full representation k plus 1 e power j theta k plus 1 this theta k plus 1 determined by b k plus 1 comma 0 b k plus 1 comma 1 that is your conventional phase modulation you will transmit this receive it and make the detection after you have estimated theta k you will then map it to corresponding bits b k. So, the observation that would like to make is that the information at time k information at time k time instant k is in theta k it is not in theta k plus 1 it is not in theta k minus 1 it is only contained in theta k.

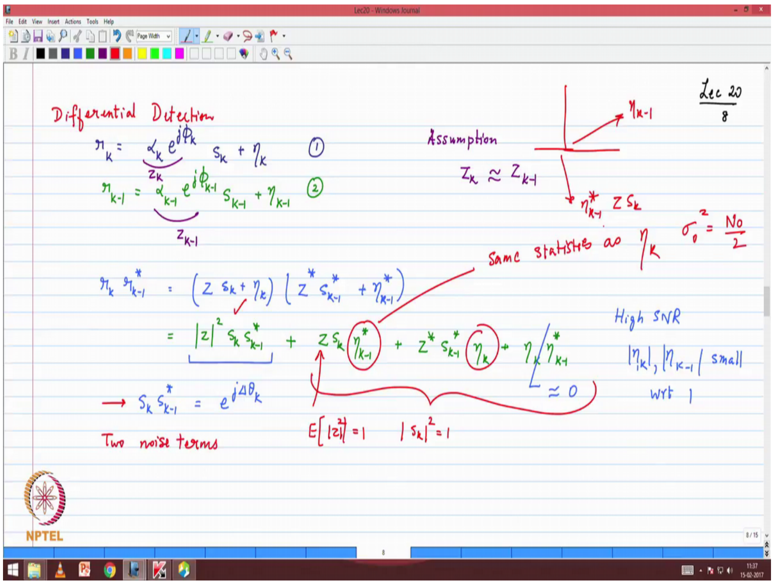
Now, on the other hand let us look; let us draw line and then say what is differential modulation differential phase modulation differential phase modulation again this is probably something that is familiar to you, but let me just highlight that. So, I have to transmit phase information. So, theta k is equal to theta k minus 1 plus delta theta k. So, whatever was my previous phase to that I add delta theta k and in this case delta theta k determined by b k 0 and b k one likewise then what will happen I will transmit the symbol s k e e power j theta k?

What is the transmitted symbol here it is also e power j theta k both e e to the j theta k, now let us look at theta k k plus 1, this be this would be theta k plus delta theta k plus 1 this is delta theta k plus 1 that is determined by b k comma b k plus 1 comma 0 and b k plus 1 comma 1. So, now, what notice s k plus 1 is equal to e power j theta k plus 1 previously the information was contained only in theta k, but now the information here in information here the information for us information at theta at time k at time k is in delta theta k delta theta k, but delta theta k introduces a relationship between s k plus 1 and s k right or in this case it will be s k minus 1 and s k.

So, delta theta actually introduces some dependencies there is a dependency between s k minus 1 and s k and the relationship is s k is equal to s k minus 1 e power j delta theta k that is that is another way of writing the same equation delta theta k this is the same as same e power j theta k minus 1 plus delta theta k notice that the resultant signal the transmitted signal looks very similar, but in one case there is a no dependencies between successive symbols in another case there is a deliberate dependency that has been introduced through the modulation process and again I am sure as as you probably have studied before there is a reason for doing that and we will just touch upon the elements that are.

But is the aspect of how differential in information encoding of information has been introduced is that clear. So, now, comes the detection part.

(Refer Slide Time: 31:59)



So, let me write down the differential detection when the information has been encoded differentially. So, differential detection lies on the following 2 equations equation number one says r k is equal to alpha k e power j phi k that is my fading coefficient s k plus eta k that is equation number one equation number 2 r k minus 1 depends on alpha k minus 1 e power j phi k minus 1 that is my fading coefficient at the previous time instant the transmitted symbol at previous time instant plus the noise n k minus 1 equation 2 we make one assumption in all forms of a differential detection and the assumption that is made is that the change between 2 successive symbols and that is a very valid assumption is that they that the channel looks almost the same.

So, we if you call this as z k; z k this as z k minus 1 that z k is approximately the same as z k minus 1 that is an assumption that that we are making under this assumption if we now do the following operation the operation is r k r k minus 1 conjugate I multiply the current received symbol with the previous received symbol conjugate of the previous received symbol if we just write down the expressions that will be z s k plus eta k I have made the assumption that alpha k and alpha k minus 1 are both represented by z this would be z star s k minus 1 star plus eta k minus 1 star that is the substitution of the 2 expressions.

Now, the expansion of this very straight forward, but let me just highlight it for you it would be mod z squared s k s k minus 1 conjugate plus there are going to be 4 terms the first one will be z times s k times eta k minus 1 conjugate next term will be z star s k minus 1 star eta k and then the last term is eta k eta k minus 1 star 4 terms just substitution and expansion again I am sure this is being familiar at you, but I just want us to get comfortable with what the insights that we have as far as differential detection are concerned.

Here is a another assumption that is made that is you have fairly high SNR or good SNR conditions what does that mean that the variance of the noise is much less than the signal variance. So, in other words I can I am making a qualitative statement eta k magnitude and eta k minus 1 magnitude are small compared to with respect to one because the magnitude of s k is equal to one it is a phase modulation scheme e power j theta is the transmitted signal. So, the noise samples are small relative to this if this is a correct statement then the first approximation the first thing that I do is to say that this thing can be ignored because the product of 2 small numbers I can ignore it.

Now, the first thing that I next thing that I observe is this is the detection step that I need because s k; s k minus 1 conjugate basically gives me e power j delta theta k that is exactly what I need to detect. So, yes this is good I need to keep that term what are the terms that I do not want these are the terms that I do not want one of them is very small the other 2 look like noise why because this is eta k conjugate does not matter that also looks like noise eta k is noise what is it getting scaled by it is scaled it is getting scaled by 2 para; 2 quantities one of them is a random parameter z.

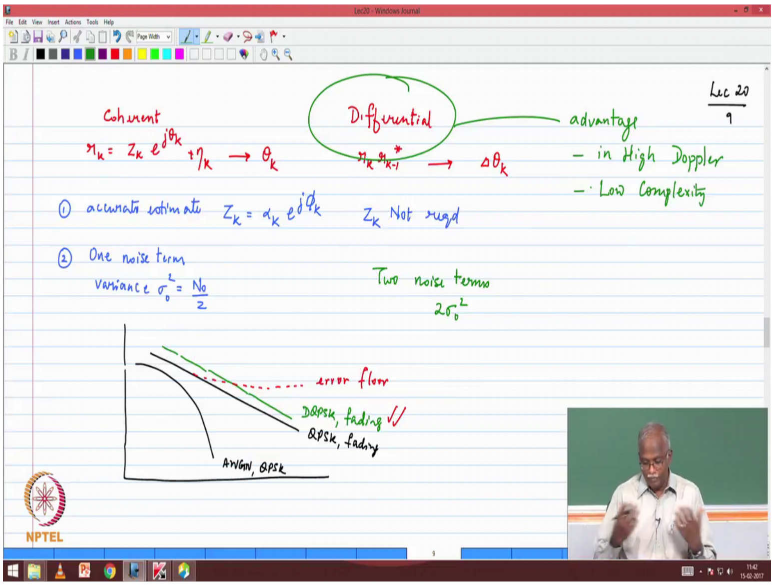
But we know that expected value of mod z squared is equal to one basically that is you are your basic you are looking at the case scenario where the Rayleigh fading with respect to the r m s value the is there is a certain expected value z squared is equal to one and of course, a magnitude s k squared is equal to one because it is a phase modulation scheme. So, if I am looking at a normalized equation where expected value of z squared is equal to one then this is the same has got the same statistics same statistics as not at as eta k as eta k.

So, what is a; what is eta k, it is noise of a certain variance which is related to sigma squared equal to n naught by 2 where n naught is your noise spectral density. So, what does this type of operation do it is called circular rotation. So, you take some noise sample conjugation flips it around z k and s k are random quantities which will basically rotate the noise. So, if the noise was originally pointing in a particular direction in the I q plane this random rotation moves it around somewhere else into the I plane and it really does not change the statistics of the noise. So, if this was eta k minus 1 this could be eta k minus 1 conjugate z times s k.

It is basically some sort of a circular random circular rotation of the original noise. So, therefore, it did not change the statistics, but very important to note that you are now going to be doing your detection not in the presence of one noise term, but 2 noise terms. So, there is this is the detections this is the detection metric and there are 2 noise terms. So, roughly speaking you have twice the noise in your decision statistic as you had in the coherent detection case will be that be a good summary.

So, differential detection has been defined as r k into r k minus 1 conjugate I expand the terms I get the 4 terms one of the terms is negligible the other 2 terms are noise with the same statistics as the original noise which was present in my system, but they are uncorrelated. So, therefore, I will get double the various noise variance and then I have my decision statistic which is going up or down based on z k squared, but they you know when you are what I am looking for is the phase any scaling of the phase is not going to matter I will still get the angle as the one that I am interested in. So, this is the differential detection.

(Refer Slide Time: 39:25)



So, let me summarize. So, let us write down coherent versus differential detection differential; differential this one would be r k is equal to z k e power j theta k plus eta k this one I will do r k; r k minus 1 conjugate and again based on that I will get an estimation of delta theta k which is of interest to me in this case the decision that I need to make is on what is theta k. So, that is the process that we are going to follow.

So, the first observation that we make about coherent detection is that I need an accurate estimate accurate estimate of z k of both the magnitude and phase alpha k e power j j phi k I need to know both of those now the question is do I need to know anything about z no though mod z square is present it does not affect my angle because I will take tan inverse of imaginary part by real part. So, alpha squared is not going to play any role. So, I can safely say that I do not require any estimate not required that is z k is not required I do not need to make the difference. So, it is make a huge difference because; that means, you are telling me that I do not need to worry about anything about the channel whether its fade not fade that really does not matter all I take is r k; r k minus 1 conjugate and I will be able to detected.

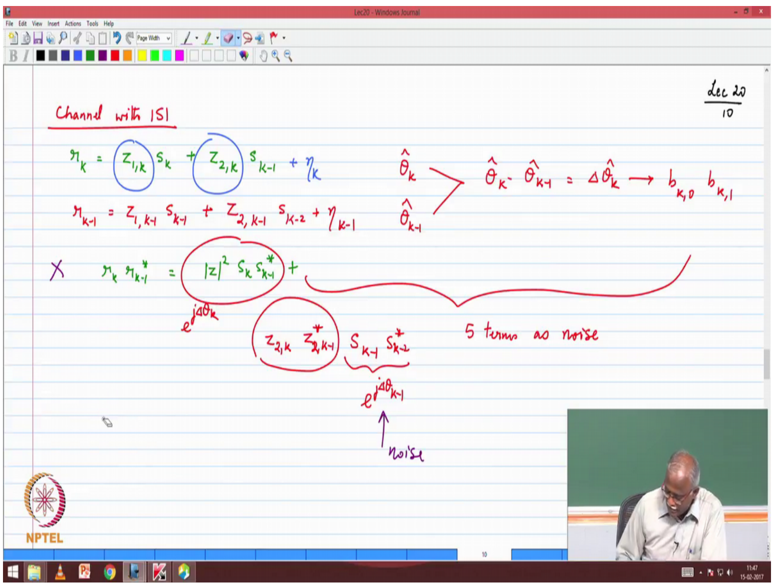
Another important difference is that I have one noise term in my decision statistic one noise term the variance is with variance sigma naught squared equal to n naught by 2 that is your noise spectral density now in this case I have 2 noise terms I have to be careful with that 2 noise terms the resultant variance will be 2 times sigma naught squared. So, there is a penalty. So, sometimes you will see people who tell who make the following statement that is a 3 db penalty for differential detection where does a 3 d b come from because you have twice the noise factor of 2 is a 3 db penalty.

So, again it is not a strictly correct statement just have to make sure that where the original; original impact is coming from. So, given that these 2 are the issues then here is the understanding of the performance. So, here is the performance again we have not yet derived the analytical expressions, but I will give you something which will give you. So, this is the performance in AWGN; AWGN performance of the; of BPSK. So, let us say that. So, this is AWGN performance of QPSK let us compare it now QPSK in fading QPSK in fading that is the graph and because of the 2 noise terms this you will have to take on faith the performance of differential QPSK will look like this it turns out that it is almost a shifted version.

So, DQPSK in fading and of course, these are the criteria one requires z k the other one does not one deals with one noise term slight better performance the other one has 2 noise terms, but this is a graph that you would. So, the question is why would we even bother with differential QPSK because if I have very high Doppler and I am not able to track my channel you know what will happen the bit error rate performance of QPSK will start to do this; this is called an error floor, it is not because of your modulation schemes just that your receiver is not able to track the variations in the channel and under such situations its probably much better to go with d QPSK because d QPSK does not care about the Doppler because and it is not trying to track with channel it will give you a good performance.

So, now you know why you are even interested in differential; differential detection. So, I suppose you would summarize it by saying that the reason you would even consider differential detection because it gives you a huge advantage in high Doppler environments advantage in high Doppler it is also very low complexity. So, if you want a low complexity receiver. So, these are some criteria that you would you may want to consider the why you would use a differential detection what is my channel has ISI channel with ISI again I will just frame the equation and I frame the question then leave it for you to discuss.

(Refer Slide Time: 44:19)



So, here is the channel received signal r k is equal to z one comma k at time s k plus z 2 second channel coefficient at time k times s k minus 1 I am just doing one symbol of ISI. So, the current received symbol is some is current received signal is a combination of the current transmitted symbol and the previous transmitted symbol both of which are corrupted by complex coefficient z 1 k and z 2 respectively and of course, there is noise which is eta k and write down the equation for r k minus 1 r k minus 1 is z 1 k minus 1 s k minus 1 plus z 2 k minus 1 s k minus s k minus 2 s k minus 2 plus eta k minus 1 same equation like before I am going to do that.

Now, the this will give me and estimate of theta k right when I look at r k it will tell me what was the resultant theta k r k minus 1 will give me an estimate of theta k minus 1 I have to take the difference of these 2 delta theta k minus theta k minus theta k minus 1 this gives me delta theta k estimate which will then get mapped to b k comma 0 b k comma one those are the 2 bits that were transmitted again the same framework differential encoding and this is the received signal in the presence of I s I again the right hand path of this equation is from the previous graph.

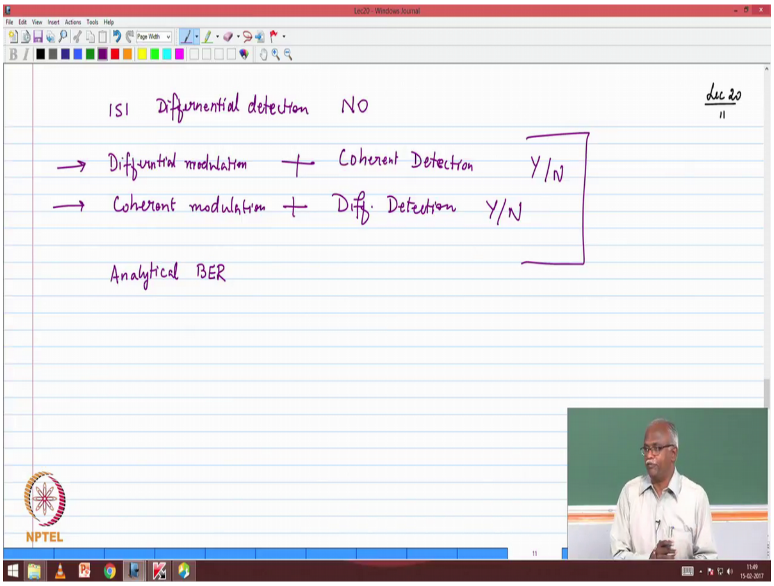
Now, without any hesitation if we go ahead and say well I know what differential detection is it is r k r k minus 1 conjugate please write down the expressions you will find that there are lots of terms there will be 6 terms, one of them is your desired symbol that is basically mod z squared s k; s k minus 1 conjugate plus there is a lot of terms which are we do not know what to do with it because there is one decision statistic there are 5 terms which are treated as noise because last time I i took 2 this time 5 what is the difference in a no problem slide; slide effect in the BER were not quite because take for example, just the second term that is there in the one of the terms that is there in in the in the expression.

What you what you what you can get for example, is z 2 comma k z one k minus 1 conjugate s k minus 1 that is not a good example z z 2 k minus 1 conjugate s k minus 1 s k minus 2 conjugate now this is a term that has got magnitude squared approximately equal to 1 because that is a Rayleigh coefficient this is a signal that is of magnitude equal to 1 s k; s k minus 1 conjugate. In fact, this is actually a useful information it is what is that it is e power j delta theta k minus 1 is actually, but I am interested in detecting e power j delta theta k and its. So, happens that delta theta k minus 1 is there in my expression, but I do not I am not using that information, but the important thing to notice if I treat this as noise if I treat this as noise what happens I have signal and I have noise of the same order of magnitude.

What is SNR in that case 0 db and if I have many terms like this; what will I get I will get negative SNR. So, which means that this is disaster not going to work that is why I s I if we go into channels with the; interfere with the with differential detection this is not going to work now one of the other combinations that you are we may ask the question. So, then leave this as side.

Now, can I do differential may be write it on the next sheet of paper I will just summarize the points can I do differential modulation; that means, I encode a differential modulation.

(Refer Slide Time: 49:10)



And can I combine it with coherent detection is it possible now you may asked why would I do that, but I am asking a very different question not why can it be done yes or no think about it you will tell me the answer now the other aspect that. So, this is very important element that we would like to. So, there is the issue of channels with I s I their differential detection is not going to work. So, that is a big no, no, but this is a possibility.

Now, I want to ask you even one more point possibility that you may not have thought of this is at least some most many people would have thought about this I want to ask you the question if I have coherent modulation coherent modulation can I do differential detection on that differential detection if you can answer these 2 questions we have fully covered the our understanding of differential detection and then the you know all the pros and cons where can we use it where can we not use it where are the advantages where are the disadvantages.

So, please attempt to answer these 2 questions its actually one line for both of those and its very easy to get the answer, but I would like you to think about it we pick it up from here the next thing that we are going to be looking at is the analytical BER. So, if you have studied this before please refresh your memory about how the analytical BER is derived for the different modulation schemes we would like to look at it in the context of fading.

Thank you.