Wireless Communications
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Lecture No.# 13
Mobile Radio Propagation (Contd.)

Welcome to the next lecture on mobile radio propagation. Today we will look at something called small scale fading.

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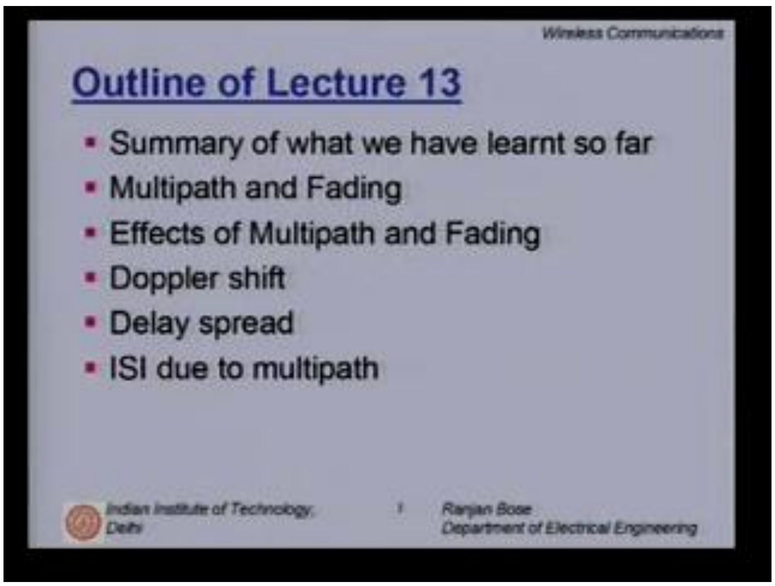

The outline of today's talk is as follows. We will first summarize what we have already learnt. then we will look at multipath and fading put together. What causes fading? How come multipath is an integral part of most mobile communication systems? Then we will look at what effect does multipath fading cause. We will then look at Doppler shift because we work in a mobile scenario where the mobile is free to move around and change its location with respect to the base station travelling at a certain velocity which causes Doppler shift. We will also look at the term delay spread and finally a brief introduction of how inter symbol interference or ISI is caused due to multipath. So this is the outline of today's talk. First let's recap what we have learnt so far.

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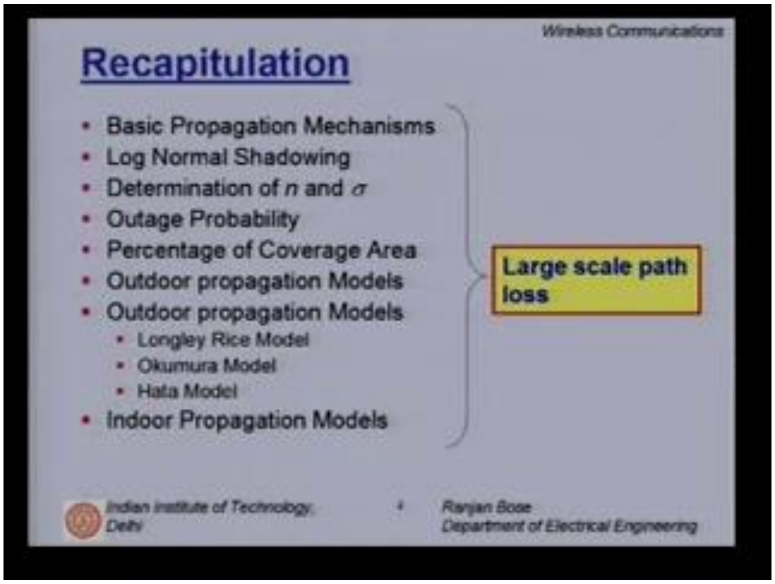

We started off with basic propagation mechanisms. We looked at reflection, diffraction and scattering as three basic propagation mechanisms and how they affect the received signal strength. We specifically looked at log normal shadowing because that forms the basis of most of the models. In log normal shadowing, we have two parameters 'n'- the path loss exponent and 'sigma'- the standard deviation. We learnt how to calculate 'n' and 'sigma' based on measurement data. Then we looked at outage probability followed by the percentage of coverage area. The percentage of coverage area is a probabilistic term which we can calculate based on a certain log normal shadowing formula. Then we moved on to outdoor propagation model. Specifically we looked at Longley rice mode, the famous Okumura model and then the Hata model. We learnt how to do basic examples, how to calculate the attenuation based on certain parameters. Finally we looked at indoor propagation models. Now please note all these are a basis of large scale path loss. What we want to look at today is slightly different. We would like to look at small scale fading.

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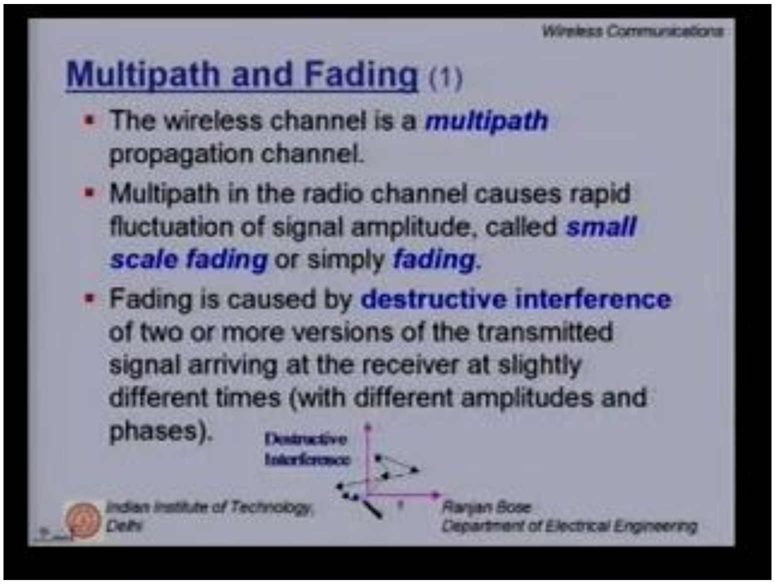

So let us first understand what is multipath and what is fading. The most important thing to realize is that the wireless channel is a multipath propagation channel. The raise are the radio waves that emanate from the transmitter do not reach the receiver only by a single path .in fact there are several paths and hence the name multipath. So multipath in radio channel causes rapid fluctuations of signal amplitude called small scale fading or simply fading. So whenever we talk about fading, we actually mean small scale fading as opposed to large scales path loss. So we should not be confused between fading and path loss. Fading is a temporary effect. It is much more frequent and much more temporal in nature. Fading is caused by destructive interference of two or more versions of the transmitted cell signal arriving at the receiver at slightly different times.

Clearly, when I have several paths, what I receive will have different amplitudes of the same signal and clearly different phases because path difference causes difference in amplitude and phase. Here in the diagram below, I have a vector sum being displayed and the blue is the actual received signal. So the other arrows could represent the signals arriving from different multipaths. As you can see, each of them has an amplitude and a different phase. But when you add them up vectorially, you get something very different from what you set. In fact, most of the time their interference is destructive. That is, what you receive back is much lower in amplitude then what you actually said. So lot of large vectors adding up to a small vector. This is our primary enemy and we have to overcome the effects of fading.

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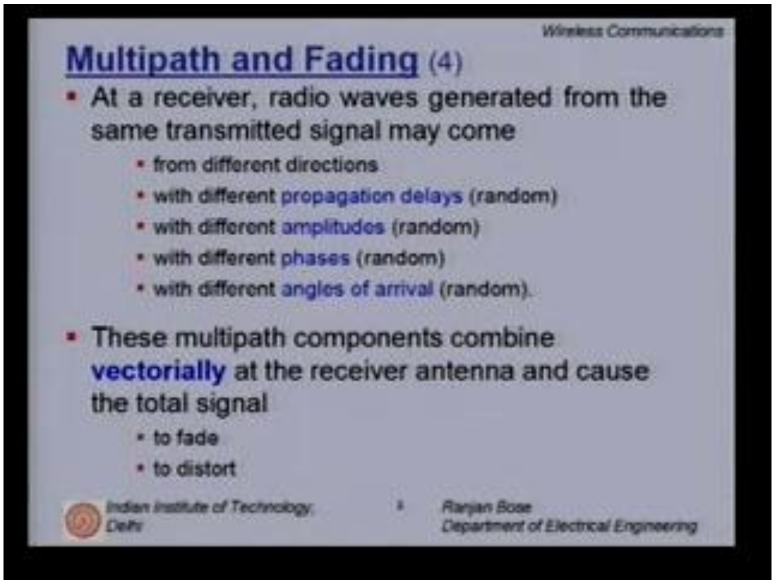

Now let us understand it a little better. Suppose you have a base station. You have a mobile and it is moving. at any instant in time, it receives the signal from the base station either directly or through a ground reflection or through reflection from building one, building two or a wall and so on and so forth. In fact, if we are in a dense urban environment, we will get more number of reflections. Why only reflections? You can get energy by scattering or diffraction. Whatever be the mechanism, you have multiple copies of the same signal being transmitted and received with different delays, different amplitudes and phases. Now what does this cause? Let us plot on the two orthogonal signal axes. Case 1: when the mobile is situated here. As you see can see, there are four distinct paths. For the sake of simplicity, we have taken four paths only and I have added up the received vector and obtained the resultant vector in blue. So at time instant one, while the mobile is on the run, it receives this blue vector. It has a certain amplitude and phase. However, since the mobile is moving when it moves a little forward, the multipath changes and in the next instant because of the reflections which are different now, you get a different vector sum. This time, the signal has really gone down.

Not only the amplitude has changed but the phase has changed also. Now the mobile has moved a little further and this time I have got another vector sum and so and so forth. As I move around, I get an Increase or decrease in the amplitude as well as a random phase associated with it. This is called fading. As you can see, what you receive can be modeled as a multiplicative number. You change your amplitude. That is, you scale it down. So you can multiply the received signal as transmitted signal times alpha + a phase term e raised to power j theta. So this multipath fading can simply be expressed in terms of a multiplicative factor alpha times e raised power j theta but theta is the change in the phase.

Now delayed signals are the result of reflections or scatterings from terrain features such as trees, hills, mountains or objects such as people, vehicles and buildings. Please note that all these from your environment. Of these trees, hills, mountains and buildings do not move by themselves where as people and vehicles do. So your environment is changing all the time and since all these cause reflections, what you receive here is faded signal. Thanks to all of these factors.

The received signal may vary widely in amplitude and phase over a short period of time or travel distance. So it actually depends upon how fast you're travelling and that is, the speed at which your environment is changing. We will later talk about fast fading and slow fading also. Please note that the receiver may be stationary or mobile. But the environment could still be fading. For example, consider the wireless local area network within the room environment. The transmitter could be fixed. It could be fixed on a wall or on a PC and the receivers could also be fixed for the time being. Still, because of the motion of the people in the room, the movement of the fan etc. is a fading environment. How to overcome the effects of fading is an entire chapter in itself which we will consider.

At the receiver, radio waves generated from the same transmitted signal may come from different directions. This is clear that it will come from different directions with different propagation delays which are clearly random. Of course, with different amplitudes. Again this is random with different phases, random again and different angles of arrival. So, all these effects have to be taken into consideration in order to overcome the effects of fading. for example, a very simple way to overcome the effect of fading is to have a very directional antenna .if I have a directional antenna, then I only receive signals from a certain direction most likely this strongest reflected signal and I cutoff all the other signals. Clearly, if I do not have a sum a vector sum of various multipath components I do not get the effects of fading. Of course there are other problems associated with having a very directional antenna. These multipath components combine vectorially has we have seen at the receiver antenna and cause the total signal either to fade or to distort. They are almost anonymous.

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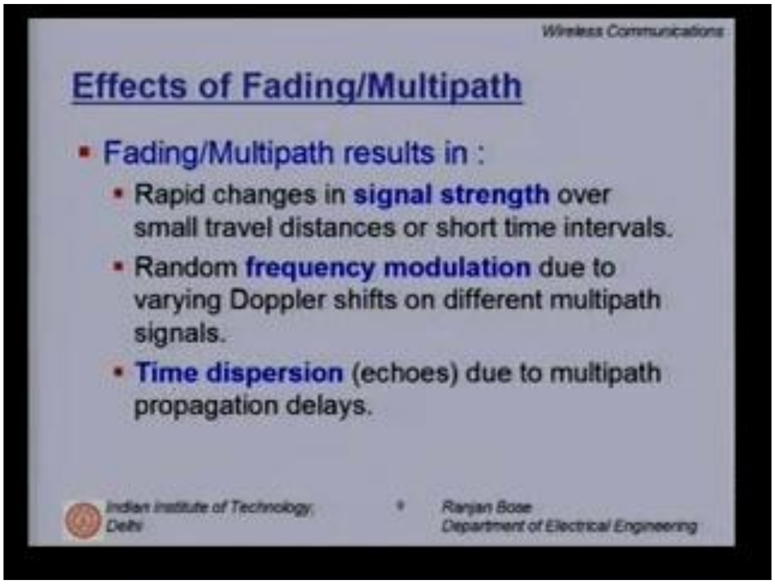

Now in this slide, let us look at the effects of fading and multipath. In literature, many times you will see the word multipath fading being used together. Fading and multipath results in rapid changes in the signal strength over small travel distances or small time intervals. Random frequency modulation occurs due to varying Doppler shifts on different multipath signals.

We will talk about Doppler shifts in the subsequent slides .but what is important is that you have random frequency modulation. Not only the amplitude but also the carrier frequency drifts. Time dispersions due to multipath propagation delay occurs. That is, if you had sent say, a narrow pulse, what you receive is not a narrow pulse but several copies of the pulse. This is clearly evident in ultra-wide band systems where we use very narrow pulses for propagation.

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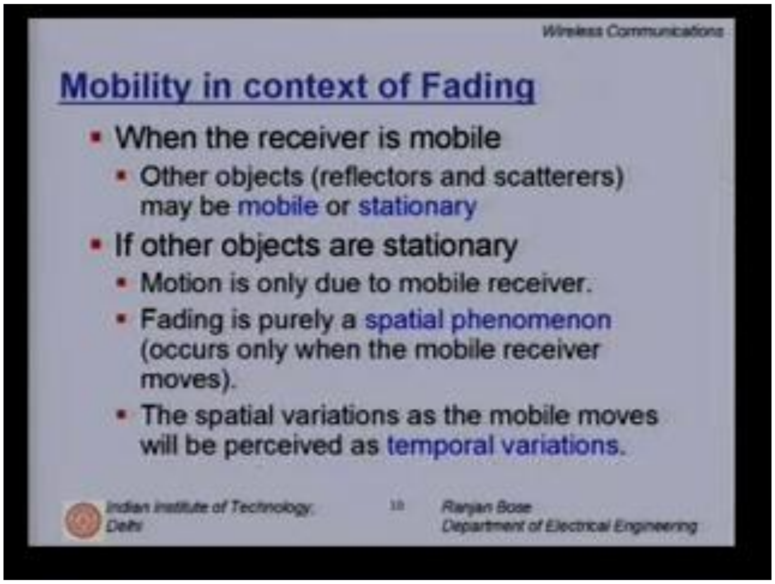

Now let's consider mobility in the context of fading because we are in a mobile environment. The mobile station is free to move. Let us look at the effects when the receiver is mobile. Other objects, reflectors and scatterers may be mobile or stationary. You have seen that if the objects are stationary, motion is only due to mobile receiver. Fading is purely a special phenomenon. occurs only when the mobile receiver moves. Please remember suppose you have a fixed point to point micro wavelength, so the transmitter is fixed and the receiver is also fixed. In that case, fading will be minimal because nothing is moving, nothing is changing and these transmitters and receivers are normally on top of tall towers. So you do not have very many scatterers. But still there could be some ground reflections. The scatterers present on the ground might cause fading effects. Clearly if I am in a dense urban environment which is full of scatterers, buildings, cars, vehicles, towers, then I receive a lot of multipath components and my fading is more prominent. The special variations change as the mobile moves and it will be perceived as temporal variation. So at the bottom line, either you move along the axis x in terms of distance or since you're moving at a certain velocity in terms of time, you see your signals changing. The received signal fluctuates as you go along the time axis. Now let us look at certain factors that influence small scale fading.

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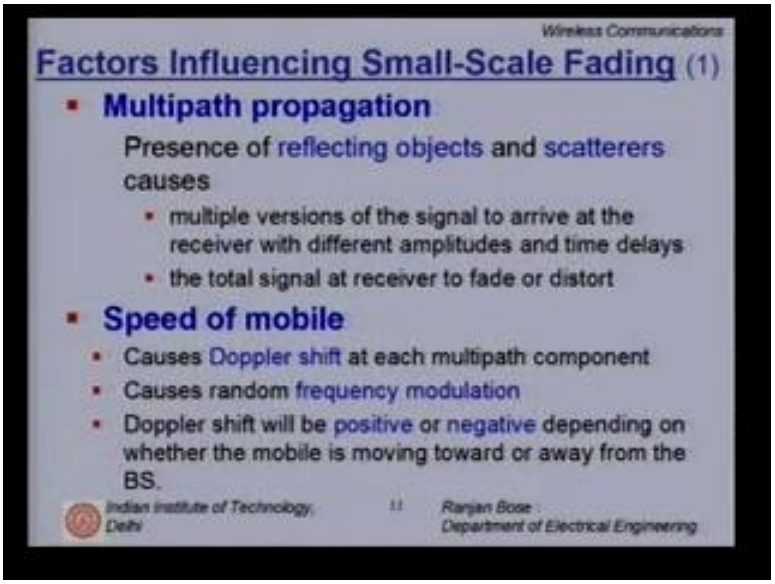

What is important first and foremost is the multipath propagation. To have that we must have reflecting objects and scatterers. So the presence of reflecting objects and scatterers cause multiple versions of the signal to arrive at the receiver with different amplitudes and time delays as we have seen. Please remember HF channel could also be considered as a multipath channel and it’s a fading channel. Then we have seen earlier the various layers of the ionosphere give you reflections and that causes multipath. So, reflecting objects and scatterers are being mentioned here from the context of mobile wireless communications. The total signal at the receiver tends to fade or distort. The other important factor which influences small scale fading is the speed of the mobile. Please remember the speed of the mobile will result in a temporal nature of fading. If you move faster, your fading curve will be different. Then if you move slower, the speed of the mobile also causes Doppler shift at each multipath component.

As we will see it is not important only to be moving towards or far away from the base station to cause Doppler shift. It also depends at what angle you are with respect to the received radio wave. Now since different multipath components arrive at the receiver at different angles, each one will undergo a different Doppler shift. Then they add up vectorially. So now you’re vectorially adding up the copies of the signal which are delayed. Change in amplitude, change in phase and the frequency modulations also take place. Then you vectorially add up. So consequently what you receive is very different from what you set and we have to somehow overcome the effects of fading. Speed of mobile causes random frequency modulation. In fact, when standards are finalized, then different kinds of data rates are prescribed for different speeds of the mobile. When you travel too fast, you cannot have too much high data rate. Fading is one of the primary problems. Now the Doppler shift will be positive or negative depending on whether the mobile is moving towards or away from the base station. So we will do an example to see how much is your Doppler shift in a standard scenario.

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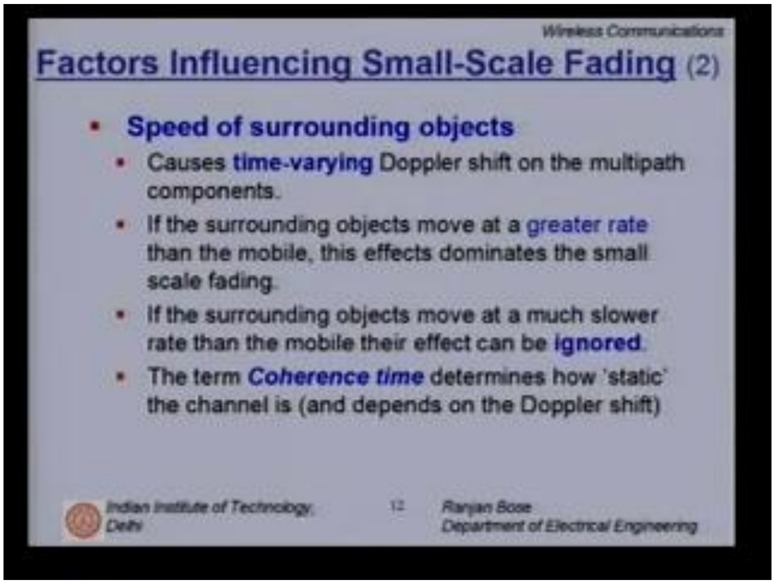

Continuing with the factors influencing small scale fading, this speed of the surrounding objects is important. how fast is your environment changing if you are in a static environment say wireless local area network but in your room, how fast is the people moving, how fast are the fans spinning, all these effects will influence the small scale fading. The speed of the surrounding objects causes time varying Doppler shift in the multipath components if the surrounding objects move at a greater rate than the mobile. This effect dominates the small scale fading. Hence in wireless local area networks, any movement of the environment dominates and will cause small scale fading whereas, if I am sitting in a car talking on my handset and relatively my environment is not changing, only my motion in the car will result in the small scale fading. Not that of my environment. So if the surrounding objects move at a much slower rate than the mobile, then their effect on the small scale fading can be ignored. We have to keep all these factors in to consideration while designing, a wireless mobile system.

Now we coin a term called ‘coherence time’. The term coherence time determines how static the channel is. So it is a measure of how fast your channel is changing. In a room environment which is a multipath environment, the coherence time will be very different than outdoor mobile propagation. It will be very different in a rural environment as opposed to an urban environment. So later on, we will actually relate coherence time to the Doppler shift and will find an inverse relationship. it is a measure of how fast your channel is changing whether the changing is occurring because of the movement of the surrounding objects or whether the channel is changing irrespective of the movement of the mobile station.

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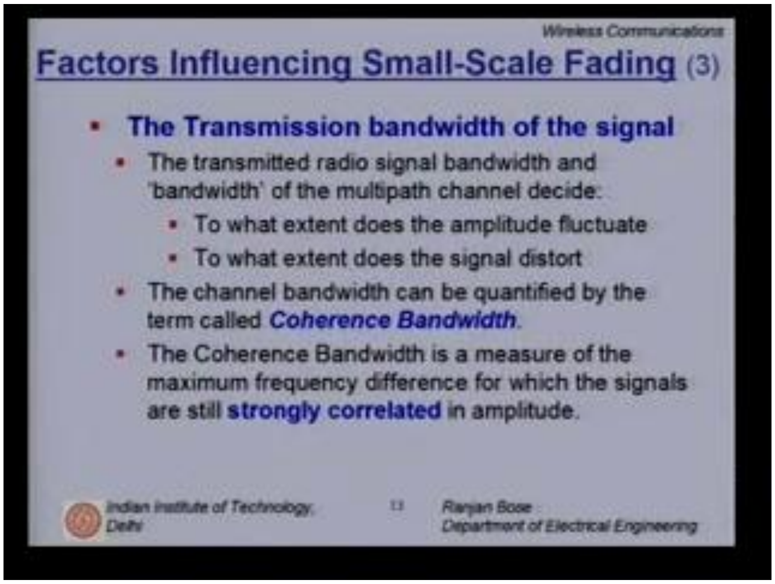

The factors influencing small scale fading is the transmission bandwidth of the signal. This is another important parameter. What is the transmission bandwidth of the signal? Is it large or small vis-à-vis, the bandwidth of the channel. The transmitted radio signal bandwidth and the bandwidth of the multiple channel decide two things. To what extent does the amplitude fluctuate? Please note the amplitude will fluctuate but the question is to what extent and to what extent does the signal distort. So the questions that are being asked is: what is the relationship between the actual transmitted signal bandwidth and the so called bandwidth of the multipath channel. The channel bandwidth can be quantified by a term called "coherence bandwidth". We will mathematically define the term "coherence bandwidth" in one of our subsequent lecturers. But right now the coherence bandwidth is a measure of the maximum frequency difference for which signal s are still strongly correlated in amplitude. What does this mean? That means suppose I sent a continuous wave at frequency f_1 and it undergoes fading. That is, the received signal strength is much lower than what I send simply because it is faded.

So I slowly increase my frequency from f 1 to f 1 + delta f. as I increase my frequency, I decrease my wavelength. Now at the receiver, what I receive and add up vectorially is different when I transmit my signal at different frequency. I keep on increasing my frequency and at a certain frequency 'f 2', I start getting out of fade. That is, my signal is no longer faded for frequency f 2 where as it was faded for frequency f 1. That is, I have been able de-correlate the fading. So this difference f 1 - f 2 gives a rough measure of the coherence bandwidth. We will define it mathematically.

Later it tells us another interesting thing that if my transmitted signal has a bandwidth larger than the coherence bandwidth, by default, I will overcome some of the effects of fading because my signal will not get faded for all the frequency bands because it is larger than the coherence bandwidth. I can also do frequency diversity where I transmit the same information at frequency f 1 and also at f 2 which is larger than the coherence bandwidth. So if my frequency at f 1 fades, my frequency at f 2 more slightly will not fade and between f 1 and f 2, I will be able to recover my signal. Fading is a big impairment. I can have 30 to 40 DB fades which means I'll completely miss out my signal.

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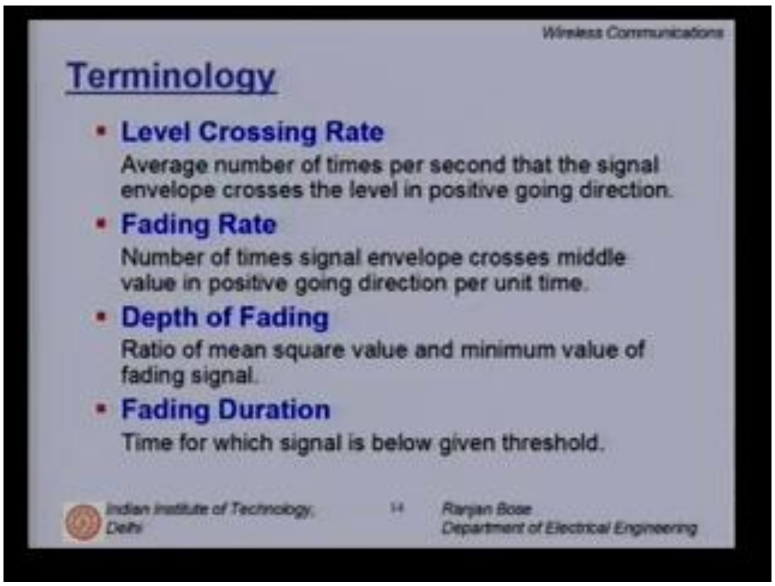

Let us look at certain terminologies that we use. These terminologies are in the context of fading. First is level crossing rate. "Level crossing rate" is defined as the average number of times per second. The signal envelope crosses a level in the positive going direction. So I have defined a level. It could be my threshold level and I have defined level crossing rate 'a' with respect to my predefined level. Fading rate is defined as the number of times the signal envelope crosses a middle value in the positive going directions per unit time. Hence the name fading rate. These two can help us quantify how good is my reception.

Then there is a term called depth of fading. Depth of fading is defined as the ratio of the mean square value and the minimum value of the fading signal. Fading duration is a time for which the signal is below a given threshold. Clearly this threshold that we are talking about is a sensitivity level at the receiver beyond which we defined the signal to be faded. If my fading duration is long, then I will tend to drop my call. Also please remember we had talked about handoffs earlier. Handoffs occur from one base station to another base station when the signal of one base station drops beyond a certain threshold where as I start receiving signals from the other base station. At that time we handoff. however if my fading duration is large and I have large depth of fading, then chances are that I will handoff not because I am close to the edge of the cell and I am moving to the new cell but because I am sitting in a fade. What has to be avoided is we should not handoff because of fading. All these factors, the level crossing rate, the fading rate, the depth of fading and fading duration must be taken into consideration while planning your cellular system. Let’s look at quality of service. The probability of blocked calls, the probability of dropped calls will be affected by these four terms.

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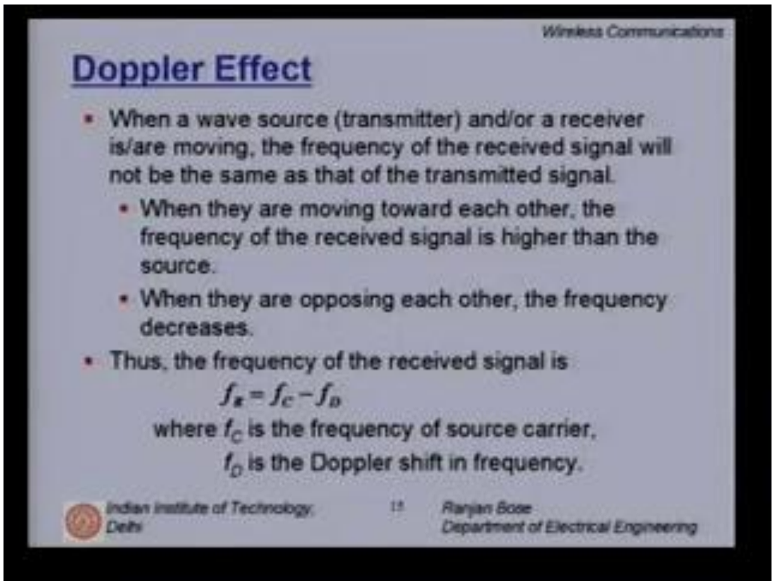

Now let us look at the Doppler Effect because we are in a mobile scenario and the transmitter or the receiver may be moving with respective to one another. When a wave source say, the transmitter or a receiver moving with the frequency of the received signal will not be the same as that of the transmitted signal. We know this from the Doppler Effect. When they are moving towards each other, the frequency of the received signal is higher than the source. We will look at it graphically in the subsequent slides. However, when they are opposing each other that is, they are going away from each other, the frequency decreases but having the correct frequency received at the mobile station is important for property coding of the signal. Does the frequency of the receive signal ‘fr’ = ‘fc’, the frequency of the source carrier - fd where fd is a Doppler shift in the frequency. So this fd may be positive or negative depending upon which direction is the mobile moving. This is the Doppler Effect.

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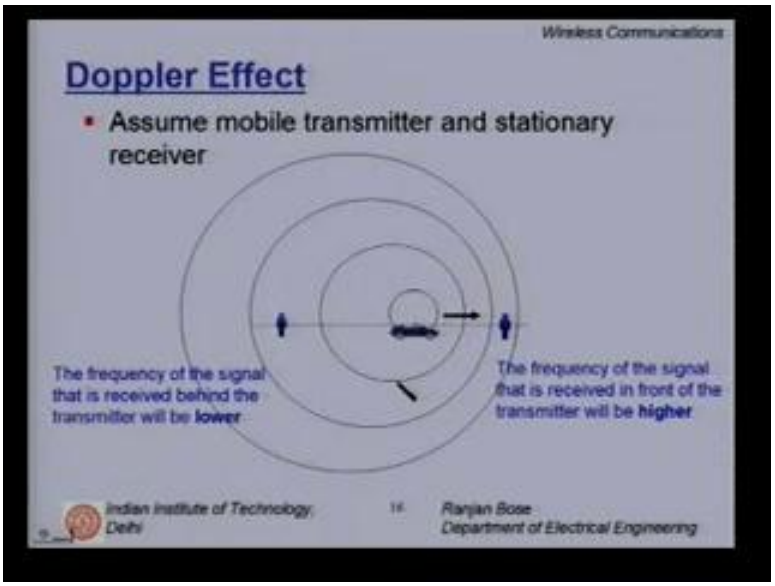

More graphically, let's assume that the car has a transmitter and these two people have the receiver if. The car is moving towards this receiver, the frequency of the signal that is received is higher than the transmitted signal because not only are the waves moving but the sources are also moving. So there is the kind of compression and what we receive is the higher frequency. On the other hand, if we are moving away from the receiver, the frequency that is received behind the transmitter will be lower because there is this expansion of this wave.

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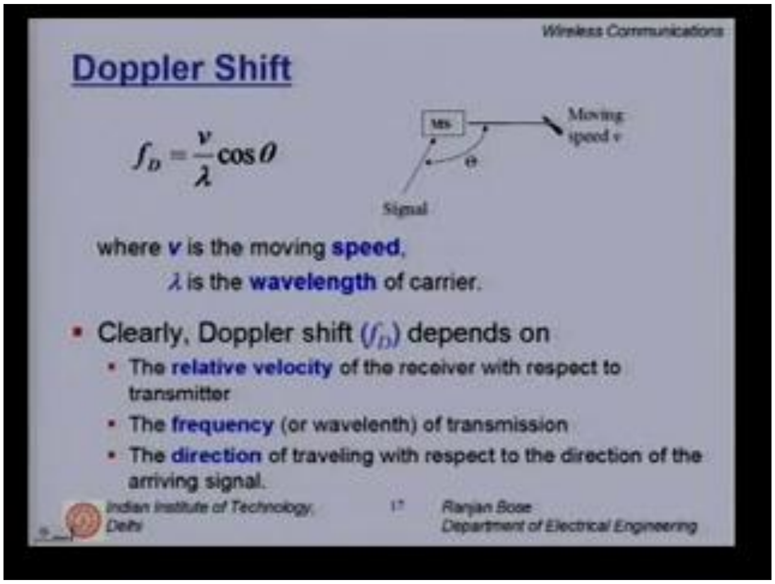

So what is important is not only the direction of the motion but what is the angle found between the signal received and the direction of the motion of the mobile station. Consider, in this diagram a mobile station. It could be a person sitting in a car, a person travelling in the train or a person walking in this direction. Where is the signal is being received from an angle theta? Please note that the speed of the vehicle or the person walking is V f_D. The Doppler shift is given by ‘v’, velocity of mobile divided by ‘lambda’, the wavelength cos theta. v is the mobile speed lambda is the wavelength of the carrier. Clearly the Doppler shift f_D depends on the relative velocity of the receiver with respect to the transmitter and the frequency of transmission which in turn translates to the wavelength lambda. The effects of the Doppler shift is more pronounced at smaller wavelengths. As we going to millimeter wave communication or higher. My Doppler effect becomes more prominent. The direction of travelling with respect to the direction of the arrival signal is also important. As we mentioned before, in a multipath scenario different rays after reflection and scattering are coming from different angles but the mobile might be moving in a particular direction. So each of the multiple components will undergo a different Doppler shift.

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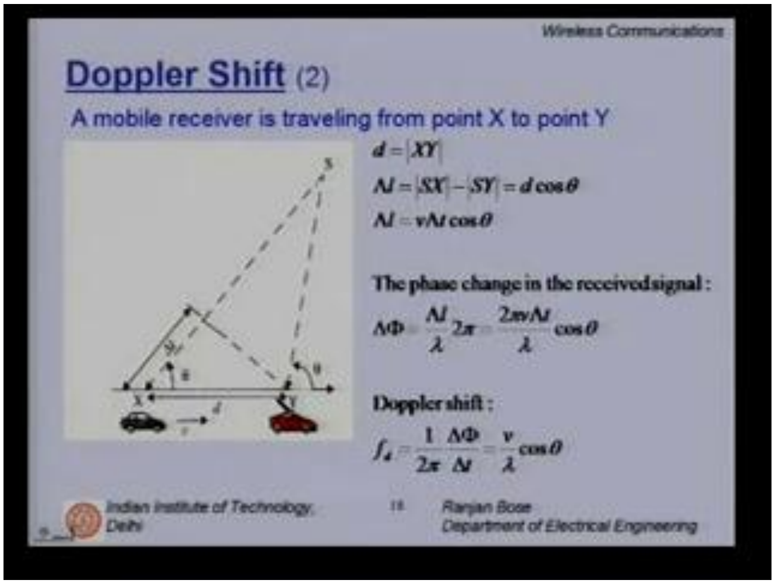

So consider a mobile receiver which is travelling from point x to y. here I have drawn on this diagram point x. mobile moving at velocity v from point x to y which is this, situated at a distance'd'. So'd' is the distance between x and y. we can find out what delta l is because here is the location of my source. when it moves from here to here, the signal which is coming in this direction translates to here and you first calculate the change in the phase of the received signal which is given by delta l over lambda times 2pi. Use basic geometry and you can calculate that the frequency shift because of Doppler is nothing but 1 over 2pi delta 5 over delta t. rate of change of phase is v over lambda cos theta. Let us do an example. Let's see as this mobile moves, at any time the Doppler shift f_d is given by v over by lambda cos theta.

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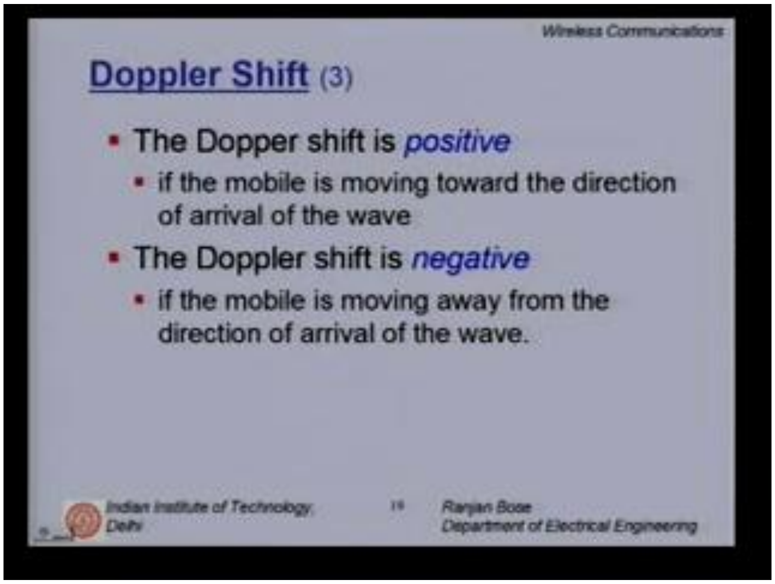

Let’s note that the Doppler shift can either be positive or negative. The formula that we calculate is based on the relative motion and the v is the mutual velocity. The Doppler shift is positive if the mobile is moving towards the direction of the arrival of the wave. The Doppler shift is negative if the mobile is moving away from the direction of arrival of the wave. Please note that as a car is moving towards the base station, it may be possible that certain multipath components experience positive Doppler shift whereas certain multipath components experience a negative Doppler shift for the same mobile station. So the situation is not that simple.

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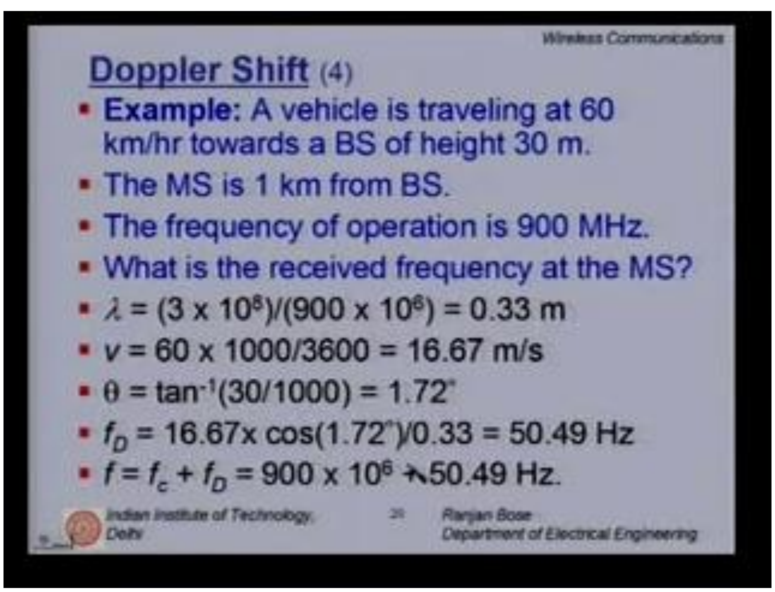

Let us look at an example. A vehicle is travelling at 60 km an hour towards the base station. the height of the base station is 30 m. It is important to know the height of the base station because the angle of arrival of the radio signal will depend on how high the base station is. Let us say that the mobile station is at a distance of 1 km from the base station and is travelling towards the base station. The frequency of operation is 900 MHz your GSM band. The question is: what is the received frequency at the mobile station? For this example, let us consider that we are only getting one direct line of sight and there are no reflections. Otherwise you will have to do this exercise for every reflected and scattered component. So the first thing to calculate is the wavelength. Wavelength is given by the speed of light divided by the frequency which is 900 MHz. It comes out to be 0.33 m. this is the wavelength of operation. So, about 30 cm is a wavelength of a 900 MHz GSM band.

The speed of the mobile in meters per second is 16.67 m which is 60 km per hour. Now the angle theta is $\tan^{-1}$ 30. The height of the base station divided by the distance from the base station 1.72 °. f_D is given by velocity v times cos theta divided by lambda and if you translate it, it comes to slightly over 50 Hz. this is a miniscule in compression to 900 MHz. please note if we make the base station taller and taller, the angle will increase and the cos value will decrease. So the effect will go down. However if the base station is at the street level not very tall in microcells and macrocells, then your Doppler effect might become more pronounced. So it depends on how tall your base station is. nevertheless even though this may appear to be a small quantity, this could be + 50 Hz for multipath ray number 1, - 45 Hz for multipath ray number 2, + 30 Hz for multipath ray number 3 and so and so forth because the angle is changing. When you add them up, the distorted signal is very different from what you set. That's what we have to take care of. So singly it appears innocuous but it can cause severe problems. Our question was: what is the received frequency at the mobile station? What you receive is $f_c + f_D$. The '+' is because we are moving towards the base station. It is 900 + 50.49 Hz. This is MHz. this is in Hz. There are several orders of magnitude difference.

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Now we come to another effect of multipath propagation which is called the delay spread. This is in aided when I send a signal from my transmitter to the receiver. I normally receive it through many paths. Therefore the name multipath. However if I go through a single reflection my path length increases with respect to the line of sight. If we go through several reflections or even reflections or reflectors faraway then my path length increases. So what I get is a delayed signal this is very clear if I sent very narrow pulses that is we try to measure the impulse response of the channel directly when I send a single impulse I get a train of impulses corresponding to the different multipath components. This causes a delayed signal and a spread in the received signal. This is basically the delay spread. Each multipath signal travels through different path lengths and the time of arrival for each path is different. A single transmitted pulse will be spread in time when it reaches the receiver. This effect which spreads out the signal is called a delay. Delay spread leads to increase in the single bandwidth.

The delay spread is a property of the wireless communication channel. please note this will cause inter symbol interference because my bit or the symbol duration might be overrun by the previous symbol transmitted, because they now arrive after a certain delay, in fact multiple copies arrive after several delays. So what you receive at time t_1 will be corrupted by previous symbols and will in turn corrupt the subsequent symbols and hence the possibility of inter symbol interference. In any case, delay spread is a problem and has to be taken care of. But not everything is bad. See, the good part is that whatever signals energy I could have lost out is being thrown back and me through reflections. so if I have some kind of a special receiver which can grab the energies coming after certain delays and put them together coherently because remember, all the signals which I get are of random phases. I just cannot combine them. So if I have a notion of a rake receiver, a receiver which can collect the energy corresponding to the different multipath, then I can put them together coherently and then recover back more of the signal energy and improve the performance of the receiver. So delay spread must be studied. It must be understood and must be overcome.

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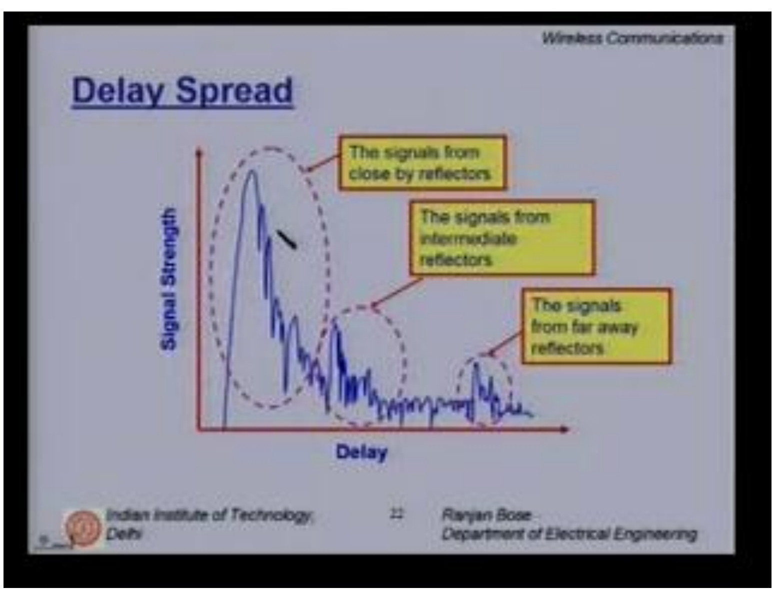

Let us see graphically what happens. On the x axis, let me plot the delay. So this could be described as an outcome of an experiment done where the signal is transmitted. It may be a pulse and I am trying to look at an oscilloscope what I receive back. On the x axis is a time axis which has a measure of delay. On the y axis we plot the signal strength. What I get is something like this (Refer Slide Time: 43:36) or a refreshing oscilloscope where you see it two times. Now clearly this is what I have sent. I sent it as a narrow pulse and what I receive is a very spread out funny looking shape and then I have ups and downs, several pulses and some other interesting shapes here. Now look at the first mountain clearly.

These signals are coming from close by reflectors. In fact, this is not what I sent. But I am not able to resolve this. So this broad peak has several small peaks but they are so close together in terms of the time that they appear to be together. Then I see some more pulses. These are signals due to close by reflectors and hence the delay is not so much. If I get a reflection from a faraway reflector, clearly the delay spread will be more because of those reflectors and longer path length. so here I see couple of more peaks corresponding to intermediate reflectors and then again some signals coming up from faraway reflectors. It is intuitive to see that the signals coming from faraway reflectors are also weaker as opposed to the signals coming from the nearby reflectors. They have travelled a larger distance. They probably have gone through multiple reflections and then received at the receiver. What is to be understood from this curve is that your signal spreads. This is the delay spread. Then you have signals coming from different reflectors. It’s possible that you cannot resolve all the reflections like in this case. I cannot resolve the multipath. They are clubbed together.

Conversation between student and professor: The question being asked is: how is delay spread related to frequency? Will a very high frequency reduce or increase the delay spread? The answer is: the delay spread is a characteristic of the channel. How many reflectors are there with respect to the transmitter and receiver, how far are they, how good are the reflectors, scatterers and so on. Once I fixed my transmitter, receiver and the scatterers, their impulse response of the channel is fixed. So the frequency will not have an effect on the delay spread because if my scatterers are far apart, yes, my delay spread will increase. If these reflectors were not present, my effective delay spread will be only half this much. But if your frequency increases, in other words, if I would be able to send a much narrower pulse, then probably I can resolve each one of the multipath components. If I can resolve the multipath components, yes I can work around and extract some more information.

So I can probably work better and obtain inherent immunity against multipath but resolve in the multipaths if I have a large enough signals. That is, very narrow pulses. But the delay spread will not change. In ultra-wide band – 'UWB', this is what precisely happens. I send very narrow pulses of the order of sub-nanoseconds and you can calculate easily that in a room environment, your reflectors will be causing path loss which are of the order of a nanosecond. So you can still resolve these multipaths. Now in the last couple of slides I would like to mention Intersymbol Interference, a direct consequence of delay spread.

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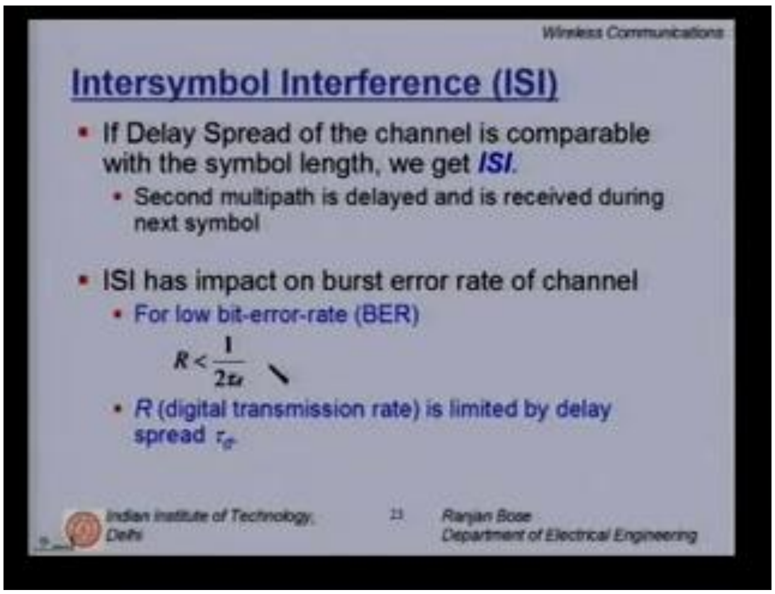

If delay spread of the channel is comparable with the symbol length, we get ISI or inter symbol interference. The second multipath is delayed and is received during the next symbol. That is, one of the symbols will start interfering with the subsequent symbols. ISI has an impact on the burst error rate of the channel. It has a lot of other impacts also and we would like to have a proper equalization to overcome the effects of intersymbol interference pulse. Shaping must also be done to overcome the effects of ISI in a fading environment. For low bit error rate, R should be less than 1 over t tau d because 'R', the digital transmission rate is limited by the delay spread. so if we have avoided intersymbol interference, we must have either restricted R transmission rate or do something to overcome the effects of ISI. We must either do pulse shaping or do some kind of a rake reception or do some kind of a channel equalization in order to overcome the effects of ISI. Please note these are the facts of life when we are dealing with wireless mobile situation. Small scale fading, multipath fading, ISI Doppler shift and all of these things have to be understood and then overcome.

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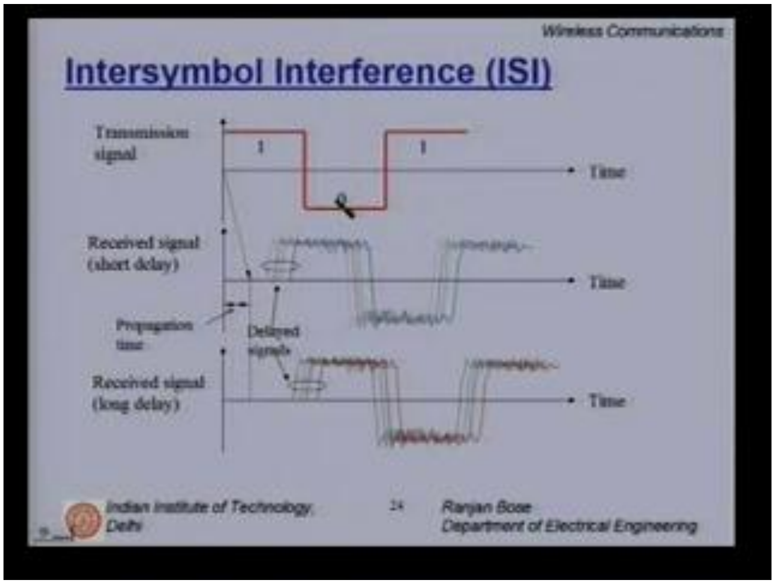

In this slide I have tried to graphically show how ISI will occur. Suppose you have this transmitted signal - 101, x axis represents the time, y axis the amplitude. The received signal is obtained after certain delay. Clearly there is a separation between the transmitter and the receiver. It's noisy and multiple copies of the same signal could be received after delay. Please note for the sake of drawing alone, we have shown it as overlapping here and no mention of the phase is taking place. Each of these will have a different phase at the time of arrival. What you receive by super position theorem, you add them up vectorially and you get completely different energy then what you set. Here for the case of long delay, I still get the received signal delayed and then each one of the components is delayed further. Here I have shown only 4 clear reflections. There could be more. They can start in interfering with your subsequent symbols and hence the ISI.

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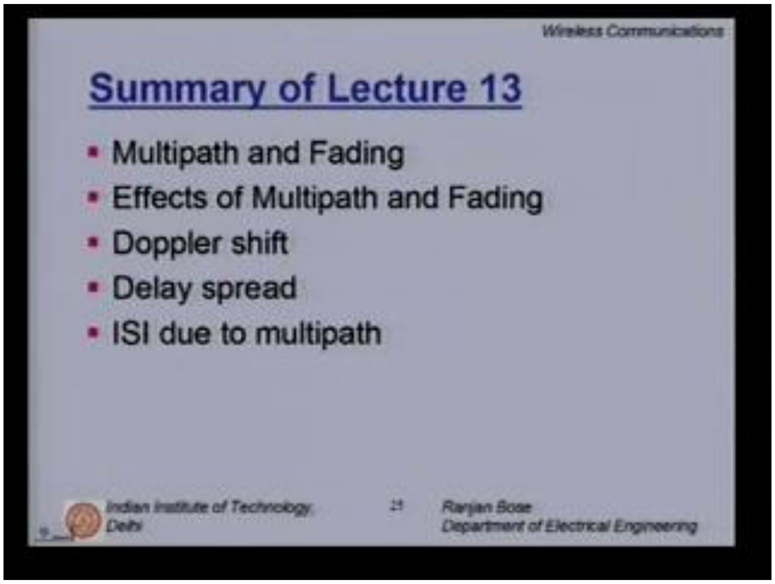

At this point, let me conclude today's lecture. The summary of lecture 13 is as follows. We started with an understanding of what is multipath, what is fading and why the term multipath fading is used together. Then we looked at the effects of multipath and fading. We looked at Doppler shift because we work in a mobile scenario. We then talked about delay spread and how it causes inter symbol interference when we looked at ISI graphically due to multipath. We will conclude here and continue in the next lecture. Thank you.