Wireless Communications

Dr. Ranjan Bose

Department of Electrical Engineering

Indian Institute of Technology, Delhi

Lecture No. # 14

Mobile Radio Propagation - II

Welcome to the next lecture on wireless communications. We will continue our study of the mobile radio propagation channel. The outline of today's lecture is as follows:

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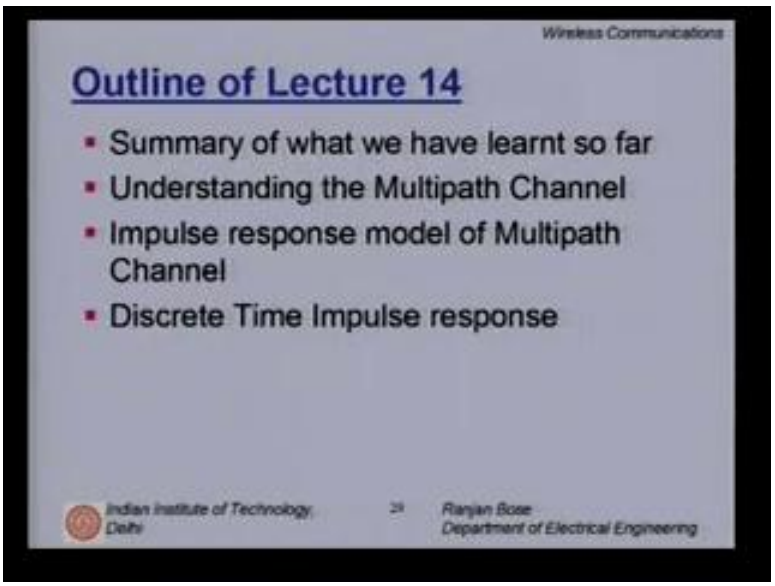

We will briefly summarize what we learnt in the previous lectures. We will then get a deeper understanding of the multipath channel. We will then look at the impulse response model of the multipath channel followed by the discrete time impulse response. So this is the outline of today's lecture. First we start with a brief recap.

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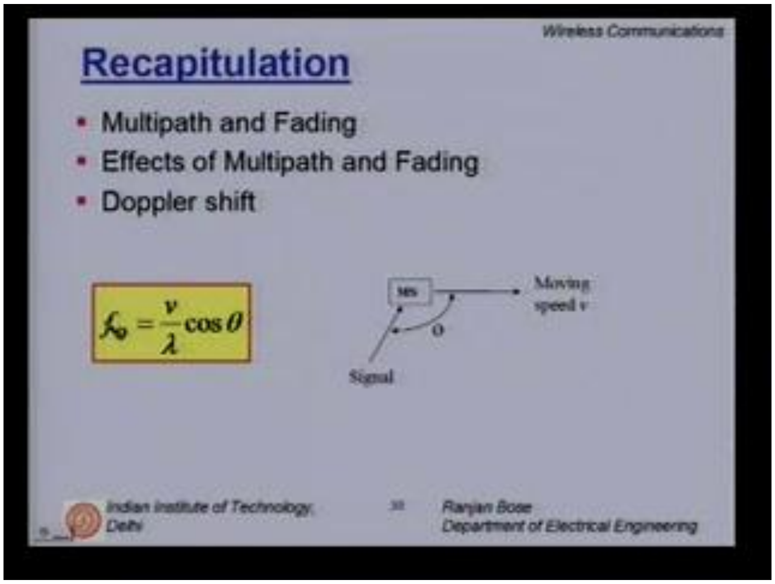

We learnt in the last class that the wireless channel is primarily multipath. That is, the transmitted signal reaches the receiver not by a single path but a number of paths either by reflection, scattering or diffraction. This multipath nature results in a phenomenon called fading. We then looked at the effects of fading, how it can distort the signal and what kind of a frequency modulation can happen because of fading. We then studied the Doppler shift because we are working in a mobile environment where the mobile station is allowed to move with respect to the base station. so we learnt that if the mobile station is moving with a constant velocity V at an angle theta from the incoming signal direction, then the frequency shift or the Doppler shift is given by velocity divided by the wavelength times cos theta.

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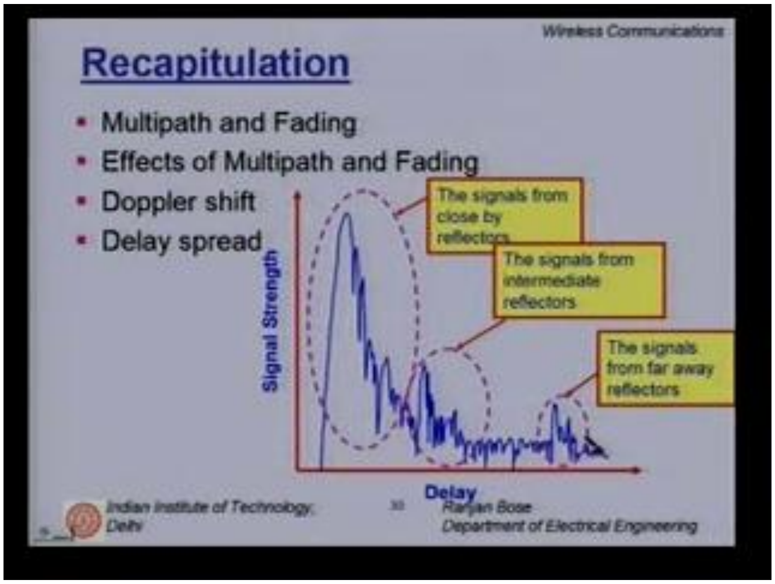

Then we studied delay spread which is a direct outcome of a mobile channel with multipath. We saw that if you plot on the x axis, the delay and the signal strength on the y axis, you get to see signals being reflected from close by reflectors. There are some signals being reflected from intermediate replaced reflectors and some signals coming from far away reflectors. What happens is there is a delay spread.

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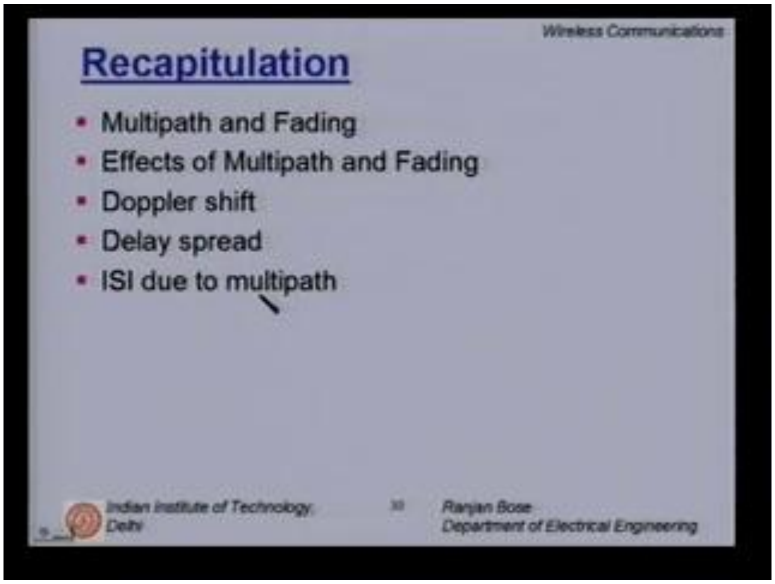

This delay spread results in inter symbol interference. So ISI is a direct consequence of the multipath channel. Today, we would like to look at the impulse response of the channel, how it can help us characterize and analyze the channel.

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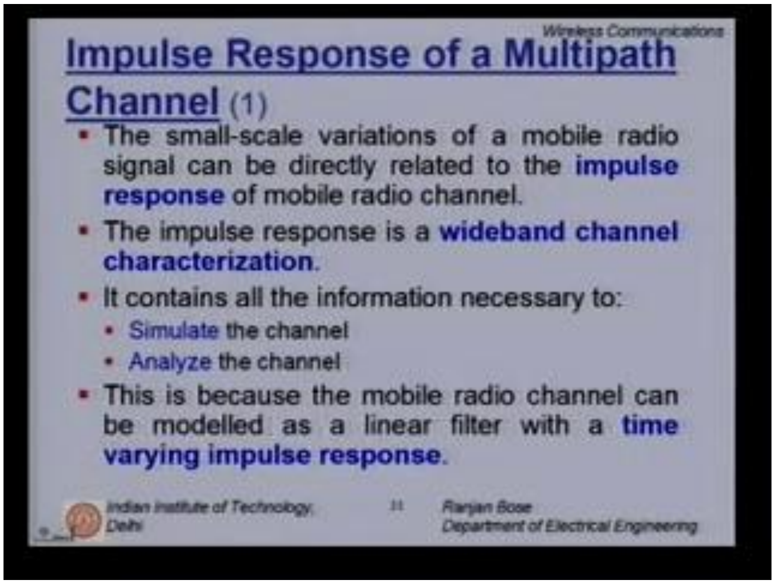

The small scale variations of a mobile radio signal can be directly related to the impulse response of a mobile radio channel. The impulse response is a wideband channel characterization. Please note that we are actually doing a wideband channel characterization which means, later on based on the impulse response, we can really analyze a channel at any desired frequency band. The impulse response of a multipath channel contains all the information necessary to simulate the channel and analyze the channel. So a lot of performance analysis is done based on the impulse response of the channel.

The example that we are following is the ultra-wideband channel. This also has its own impulse response and a lot of performance analysis are done based on that impulse response. What is interesting is we carry out certain measurements to determine the impulse response. How can we represent a channel simply by its impulse response? We can do so because the mobile radio channel can be modeled as a linear filter with a time varying impulse response. It’s not a time invariant system as we will soon see. The multipath channels are changing because of the position of the mobile. Hence, the impulse response is time varying. It makes it interesting as well as challenging to handle the impulse response.

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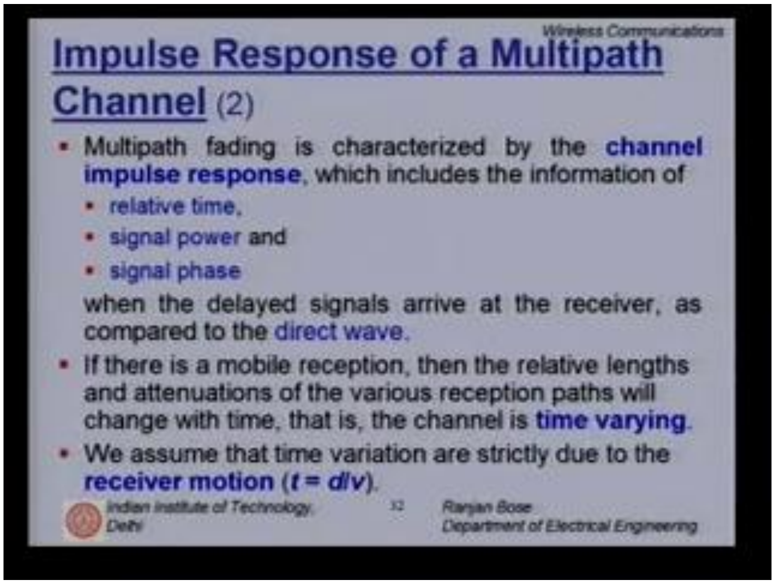

Note that multipath fading is characterized by its impulse response which includes the information about the relative time of the arrival of different multipath components, the signal power in the various multipath components and the various signal phases when the delayed signals arrive at the receiver. All this is done relative to the direct wave that comes. In most cases we do not have a direct wave. Then all the computation is done based on the multipath reflected components. If there is a mobile reception then the relative lengths and attenuations of the various reception paths will change with time. This is obvious. We have seen it before. Today we will also see it graphically. This makes the channel time-varying.

Depending upon the actual location of the receiver with respect to the transmitter, the multipath components will change. It is important to observe this. Hence your impulse response must be time varying. Please remember we have not put any restrictions on the variability of the channel. The different components which make the channel a multipath channel that is, reflectors can themselves alter in time regardless of the motion of the mobile station. So we must have somewhere two time axes. One for the mobile station movement and one for the temporal movement of the non-static channel. Here we assume that the time variations are strictly due to the receiver motion where t is given by the distance divided by the velocity of motion. We are considering a constant velocity.

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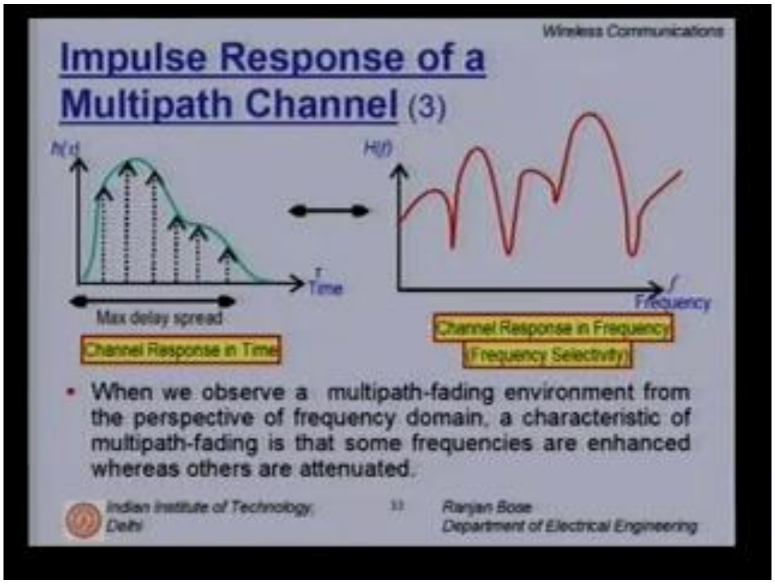

The first curve plots a kind of channel response in time verses the time axis. As you can see that it can be clubbed together with a lot of delta functions and this is the approximate channel response in time. There is a delay spread. So an impulse or a very narrow pulse that is transmitted is actually received as a very broad variation in time. In the frequency domain, it is very interesting to observe that the channel actually behaves like a frequency selective channel. It enhances certain frequencies and it suppresses other frequencies. So typical mobile radio channel would have a frequency response something like this (Refer Slide Time: 09:36). This would also change in time. So when we observe a multipath fading environment from the perspective of frequency domain, a characteristic of this multipath channel is that some frequencies are enhanced whereas other frequencies are attenuated.

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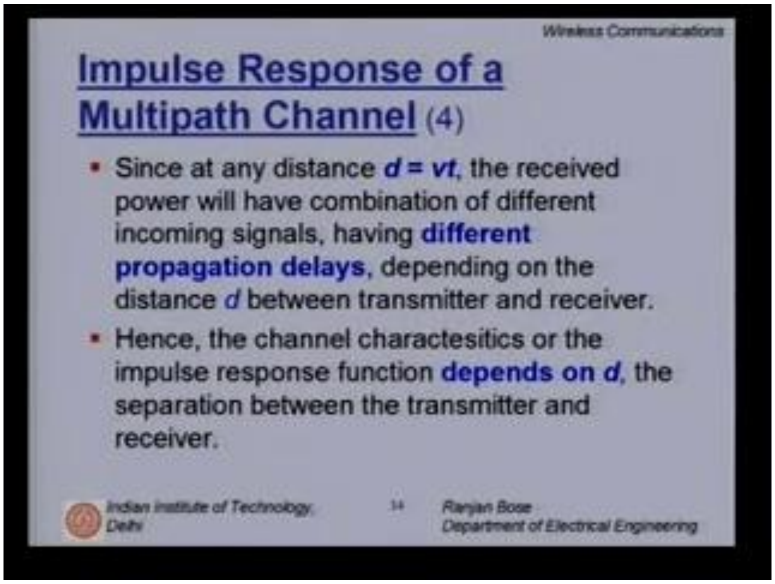

Since at any distance d, which is given by the velocity times t, the received power will have combinations of different incoming signals having different propagation delays depending on the distance between the transmitter and receiver. So the propagation delays of the different multipath component is a function of d, the distance of the receiver from the transmitter. Hence the channel characteristics or the impulse response function depends strongly on d. we will put that in an equation very soon.

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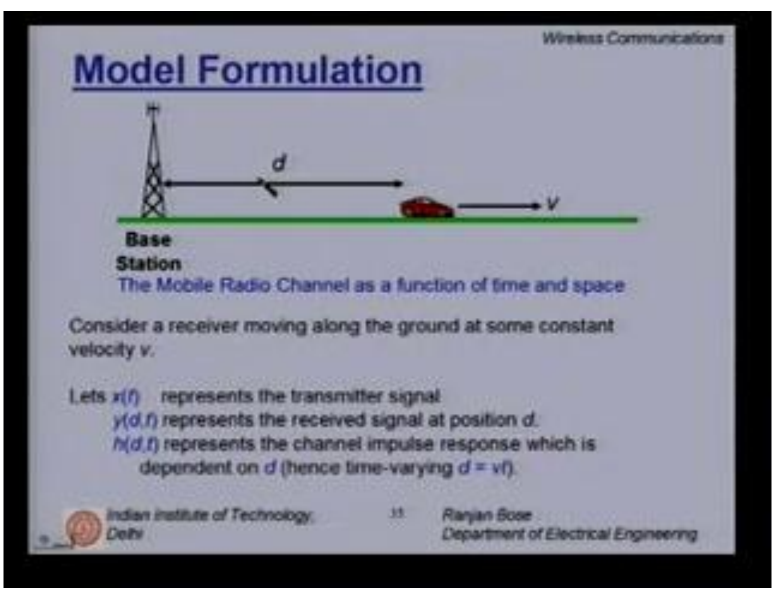

Let us now formulate a model. We are interested in finding a model for the mobile radio channel as a function of time and space. This space represents the location of the receiver with respect to the transmitter. Since it is moving with a constant velocity, we can translate this space as another axis in time. Let's put a base station and a mobile station. So this mobile station is moving with a constant velocity V. assume that the mobile station is located tentatively at a distance d from the base station. Let x (t) represent the transmitter signal. So the signal is being sent from the base station to the mobile station.

The mobile station currently is located at a distance d still moving with a velocity V. so what it receives is y which is the function of d. because it will change if you move the mobile station. It is also a function of t. It represents the received signal at a position d. now h (d,t) represents the channel impulse response which is dependent on d clearly. Because all the multipath components being received by the mobile station will change if I change my d.

Conversation between student and professor: the question being asked is: suppose instead of having one base station, do we consider the effects of two base stations if two base stations were present?

The answer is the mobile will have a certain channel impulse response with respect to base station1 and another one with respect to base station 2. Because the distances d will be d 1 and d 2 from base station one and base station two respectively. So we will have to consider two different channel impulse responses.

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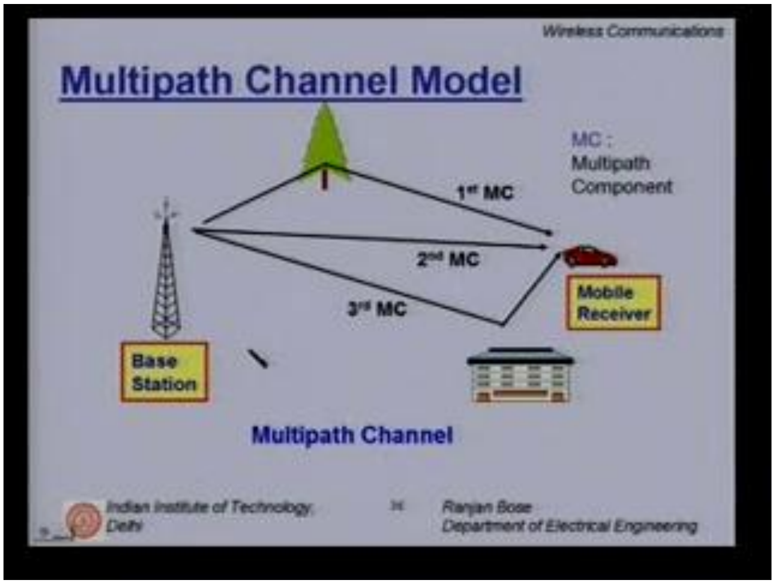

Now graphically let us find out how the various multipath components are going to affect the received and the final channel impulse response. Let us look at the same base station again a little more carefully. In the environment we just do not have a base station. We also have some scatterers, reflectors and diffracting objects. So we have a tree and a house as typical reflectors. Of course, the number of reflectors and how good the reflectors are will also depend on the frequency of operation. We have put a mobile receiver into the scenario. When the base station is radiating, there is a possibility that one of the waves reaches the mobile receiver through reflection 1 and we will call it as the first multipath component. Of course there is a possibility that the signal reaches the mobile station directly which is line of sight propagation. We can have another reflection and let's call it the third multipath component. Please note that this is true only for the receiver at a certain location d away from the base station. These multipath components will change as the mobile receiver moves. This is the multipath channel we are considering. We are clearly trying to find out a channel impulse response for this scenario. Real life is much more complicated. They are many more reflections. There could be a ground reflection as well. There will be diffractions and scattering effects.

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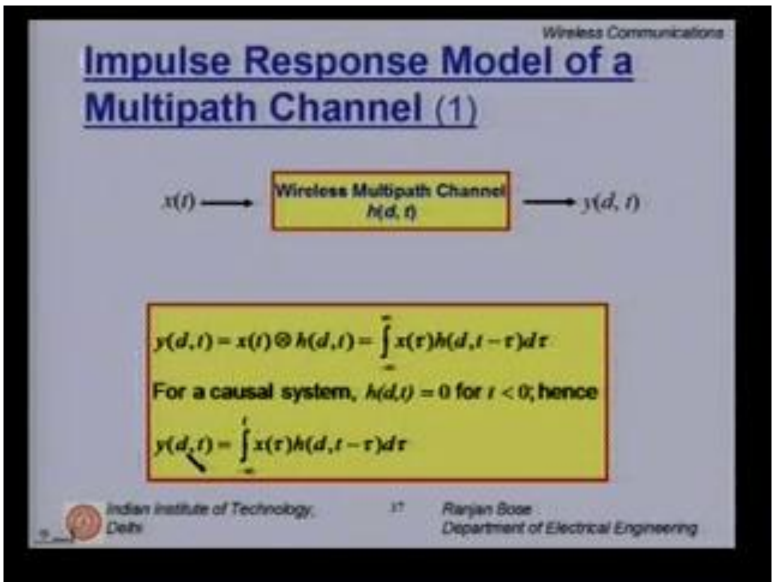

So let us say that the wireless multipath channel can be represented by the impulse response h which we have seen is a function of d, t. what is being sent from the base station is given by x(t) which is being input to the channel impulse response. What we get out is y a function of both d and t. so now we have the factor d coming into the picture. Clearly y (d,t) is nothing but x(t) and convolved with h(d , t) which is written in the integral form as integration from minus infinity to infinity x (tau) h(d , t- tau) d tau. For a causal system h(d , t) =0 for t < 0. Hence y(d , t), the received signal at a location d of the mobile station at any time t is given by - infinity to t, x (tau) h(d, t- tau) d tau. So if I have a handle on this h(d , t), then for any given signal x (t), I can probably calculate y(t).

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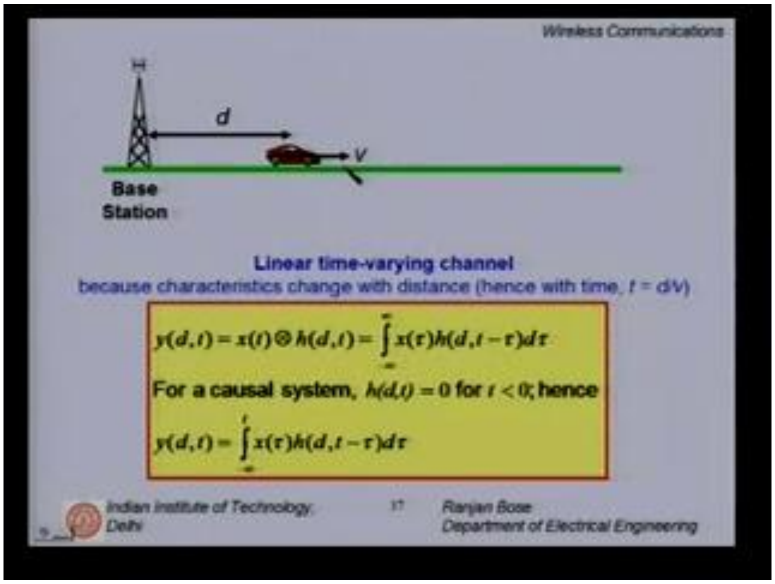

So this is the linear time varying channel. Please note d is the distance between the base station and the mobile station and V is the velocity. Now this constant velocity exactly will help me remove d and put another term time component.

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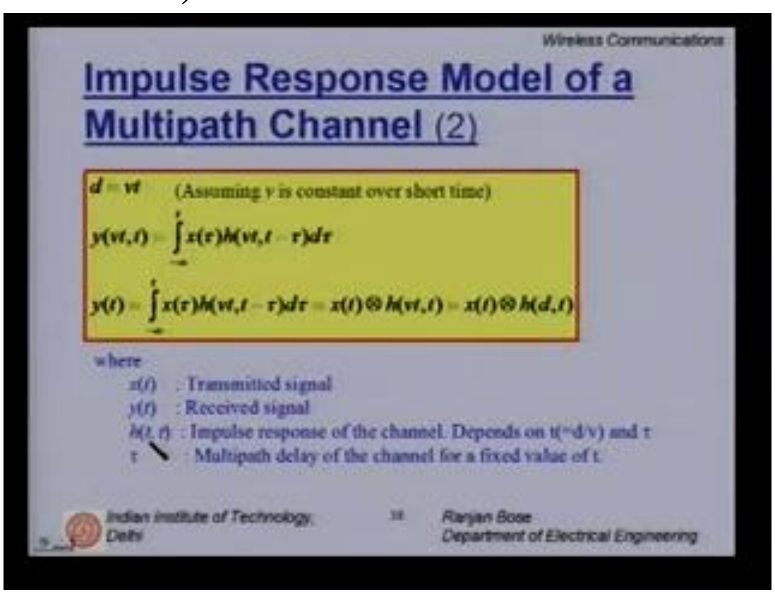

So d is given by V times t assuming V is constant over a short time. It's a fair assumption because in this short time, probably in terms of microseconds, the velocity of the car might be considered as constant. So if it is not accelerating too fast, it's a fair assumption to make.

So clearly y which was d , t has been now replaced with (vt , t) which is equal to x (tau) h(vt, t – tau) d tau and if you continue with this mathematics, you finally get the received signal y (t) because i have removed the d part. The location of the mobile station with respect to the base station has been eliminated. y (vt , t) so only a function of t is nothing but xt convolved with hvtt is nothing but xt convolved with hd t. here note x (t) is a transmitted signal, y (t) is the received signal, h(t , tau) is the impulse response of the channel.

Please note for the first time we have a tau which represents the multipath delay of the channel for any fixed value of t. Suppose I fix the location of the mobile station with respect to base station, still there will be changes in the channel because the channel is not static. Those changes in the channel are being covered by the factor tau. Whereas, the motion of the mobile station with respect to the base station will also affect the channel impulse response and that is being considered and covered by t.

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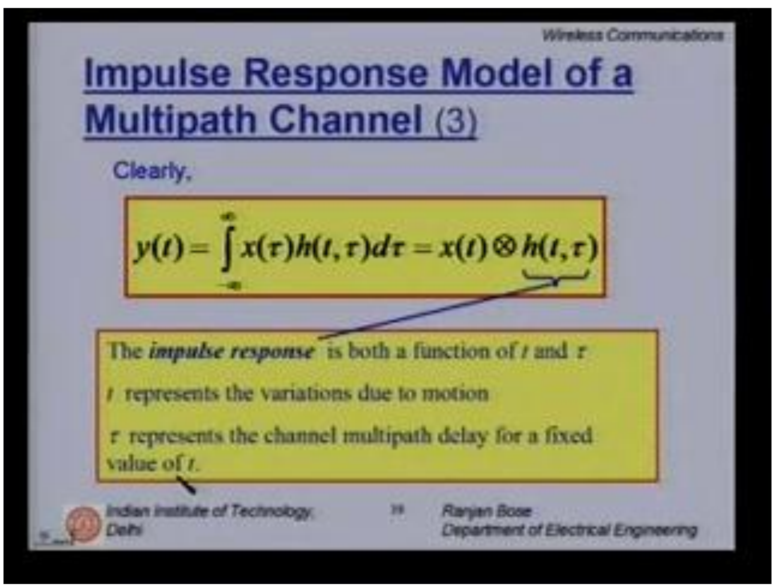

Finally, after all this effort, we have y (t), the received signal at the mobile station travelling with velocity V and located at a distance d is equal to x (t), the transmitted signal convolved with my impulse response for the multipath channel h(t , tau). If we can characterize, measure, estimate or predict h(t , tau), I’m in business. I can use this to predict my received signal. Please note that the impulse response is both a function of t and tau. t represents the variations due to the motion of the mobile station. Tau represents the channel multipath delay for a fixed value of t. We will learn how to figure this parameter h(t , tau) out.

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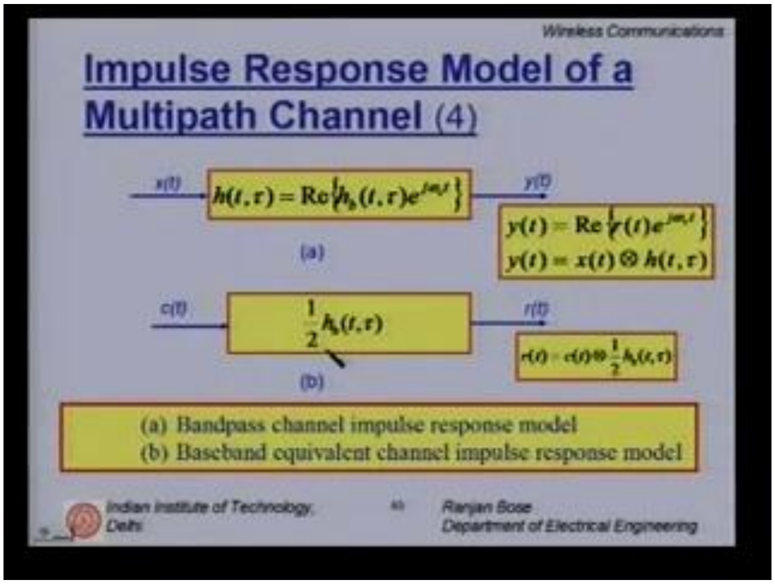

Now let us talk from the perspective of a bandpass channel and an equivalent baseband channel for the wireless mobile scenario. Let x(t) be the input to h(t , tau). R channel impulse response but in the pass band which is nothing but the real part of h_b (t , tau) where b is for the baseband representation. Exponential j omega $_c$ t where omega c is 2pi fc fc being the carrier frequency. y(t) is what we receive. This is the bandpass channel impulse response model.

Here y(t) is real part of Re e raised to power j omega ct and y(t) is given by convolution of x(t) and h(t , tau). surely we can have an equivalent baseband channel impulse response model which is given by the following figure (Refer Slide Time: 22:40). C(t) is what is input to the channel. Channel baseband impulse response is 1/2 h_b(t , tau) and r(t) is what we receive out. r(t) is convolution of ct times 1/2 h_b(t , tau). The factor of 1/2 comes in when you bring it down to the baseband. Then to conserve the energy part, you have to put the ½.

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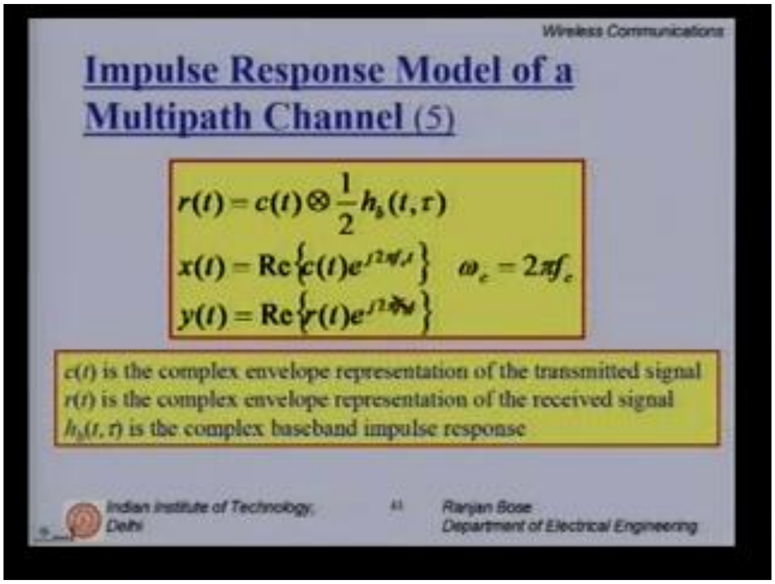

So let us see what we have learnt so far. we have seen that r(t) which is the complex envelope representation of the received signal is given by c(t) which is the complex envelope representation of the transmitted signal convolved with 1/2 h_bt , tau where hbt , tau is the complex base band impulse response. A lot of things that we learnt in digital communication now can be directly used. The results can be directly used because finally we have been able to put our wireless mobile channel simply in the form of h_b(t , tau). What is x (t), the transmitted signal? It is equal to the real part of c(t), the complex envelop representation of the transmitted signal times e raise to the power j 2 pi f c(t). Similarly the received signal y (t) is the real part of r (t) e raise to power j 2 pi f c(t). All the mathematics, the derivations that we have carried out for these complex representations can now be used in our scenario.

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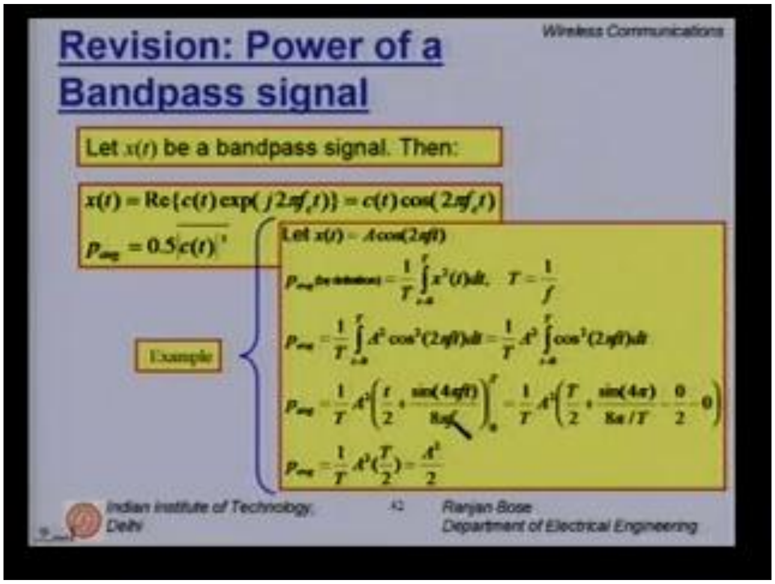

Just a quick detour. The power of the bandpass signal. If x(t) is a band pass signal in that case xt can be represented as you seen in the previous slide, as real part of c t exponential j two pi fct. This is nothing but ct cos two pi fct. in that case the average power is given by half ct absolute value squared. Let’s look at a quick example here. suppose your x(t), the band pass signal is given by A cosine two pi ft, then the objective is to find out what is the average power of x of t. so P $_{average}$ by definition is one over t integration from zero to capital t x square td t. t is one over f. you carried down the mathematics and finally the P $_{average}$ comes out to be A squared by two.

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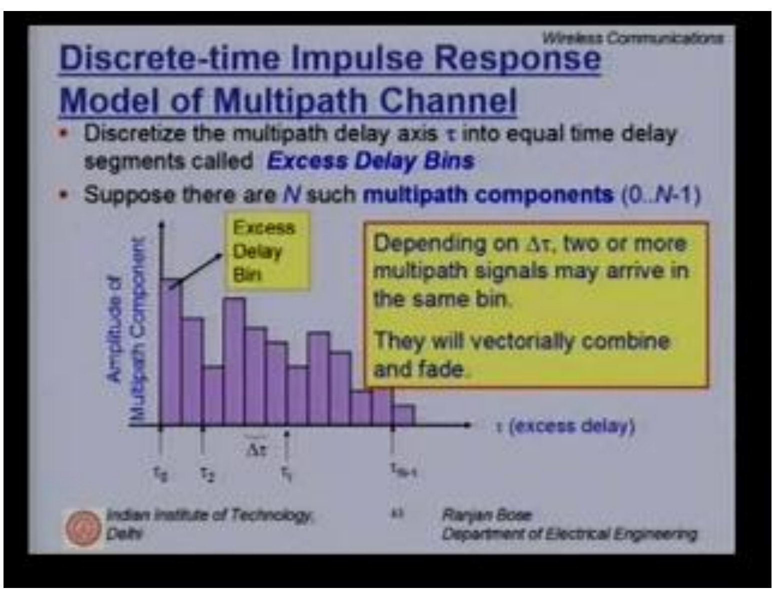

Now let us look at the discrete time impulse response model of a multipath channel. Here we discretize the multipath delay axis into tau which are equally spaced time segments which are called excess delay bins. Let us look at this more carefully what we want to do is to capture the multipath effect precisely. What is each multipath component doing? We receive the signal at the receiver through different delays. If we can capture the essence of these delays, if we can break up our impulse response in such a manner that I have time bins where I can capture one delay component per bin, I am through. So somehow I have to discretize in such a manner so that each multipath component can be taken in a single bin. Suppose there are N such multipath components, (0 to N-1), so what do we do? On the x axis we have the excess delay. Why do we call it the excess delay? Because this is the delay with respect to the first multipath component you get. So, all of the other multipath components can be measured with respect to the first multipath component that you get.

Therefore you call the excess delay. Clearly the first multipath component will reach the receiver with a standard delay depending upon how far the receiver is with respect to the transmitter. On the y axis, I have plotted the amplitude of the multipath components that i get. Please note that these columns are representing various bins. The width of the bin will be determined by what is the actual bandwidth of the signal that we are playing with. But for the sake of completeness, let’s label them. So the first one, tau zero starts right in the beginning. Each bin width is delta tau. We will do an example to find out how you determine this delta tau. Right now, we are in the process of figuring out how to come up with a discrete time impulse response of a multipath channel.

So we have divided the x axis into bins, each of width delta tau. The first starting point is tau zero. The first one will be delta tau. Tau one is equal to delta tau. Second one will be tau two is equal to two time delta tau. The i^{th} will be I times delta tau and the last one will be N minus one times delta tau. Hopefully in each bin, we will catch one multipath component. Of course there are two other possibilities. Either we miss out certain bins. That is, we do not get any multipath component in some of the bins or we may be unfortunate enough to have two or more multipath components coming in the same way. So this excess delay bins can have no components, one component or more than one component. We should choose our delta t in such a manner that typically you should have only one multipath component per bin. So for different applications for different bandwidth this delta tau should change. Depending on delta tau, two or more multipath signals may arrive in the same bin. If they do they will add vectorially, they will combine and then there will be an effective fading. So what signals strength we put in, in that particular bin will be the vector sum of all the multipath components coming in that particular bin.

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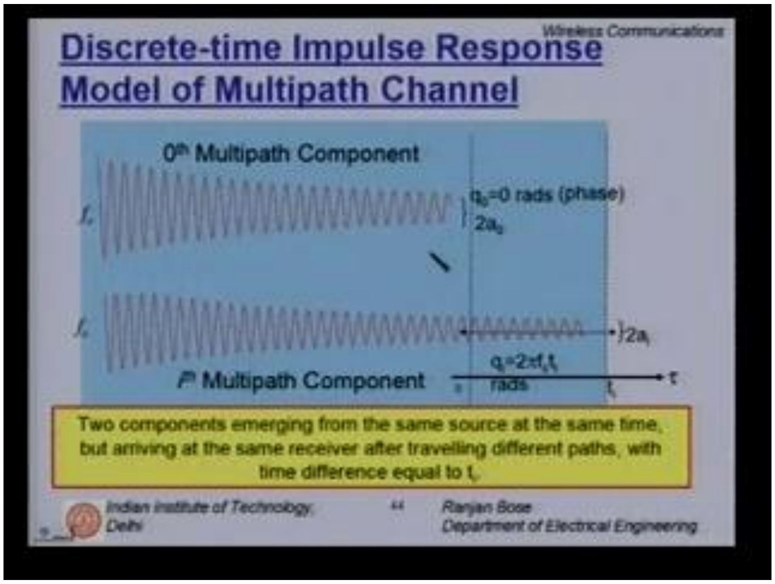

In this figure, let us graphically look at just two multipath components arriving at the receiver. So we have multipath component 1 and multipath component 2 arriving at the receiver. They will have different amplitudes. They will also come at different phases. The delays will also be different. so the two components emerging from the same source at the same time but arriving at the receiver after travelling through different paths with time difference equal to ti are been shown here. The first one is 0^{th} multipath component and the second one is the i^{th} multipath component. Note both of them are at frequency fc. If you observe then you will see that there is clearly phase a difference and a path difference. If they arrive in the same bin then you add them up vectorially and whatever you get is what you pick up.

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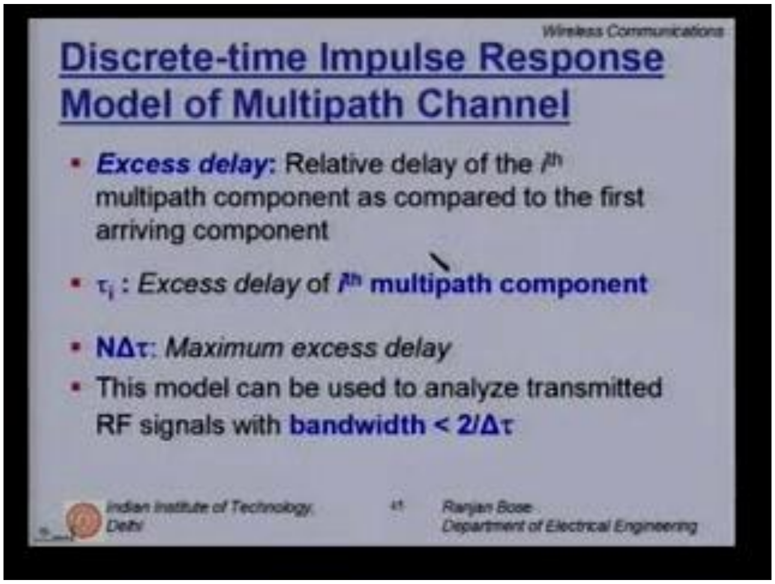

Now elaborating on the excess delay. Excess delay is the relative delay of the ith multipath component as compared to the first arriving component. 'Ti' represents the excess delay of the ith multipath component. The maximum excess delay is N times delta tau. This is important because this will have a direct bearing on the inter-symbol interference and hence your data rate. If your maximum excess delay is large, then you will either have to do some kind of an equalization to overcome the ISI - the inter-symbol interference or you have to slow down your data rate or do both. This N times delta tau can be found out easily by measurement.

This discrete time impulse response model of a multipath channel can be used to analyze the transmitted RF signals with bandwidth less than or up to 2 over delta tau. So if you have a certain bandwidth you can come up with a certain delta tau for that bandwidth for analysis. Once you do that, you can calculate the maximum excess delay. The excess delay, how wide are the bins and then you can model your channel for that bandwidth only. Clearly if you increase the bandwidth, your delta tau will also go down. So the larger the bandwidth, the narrower is the pulse you require to probe the channel.

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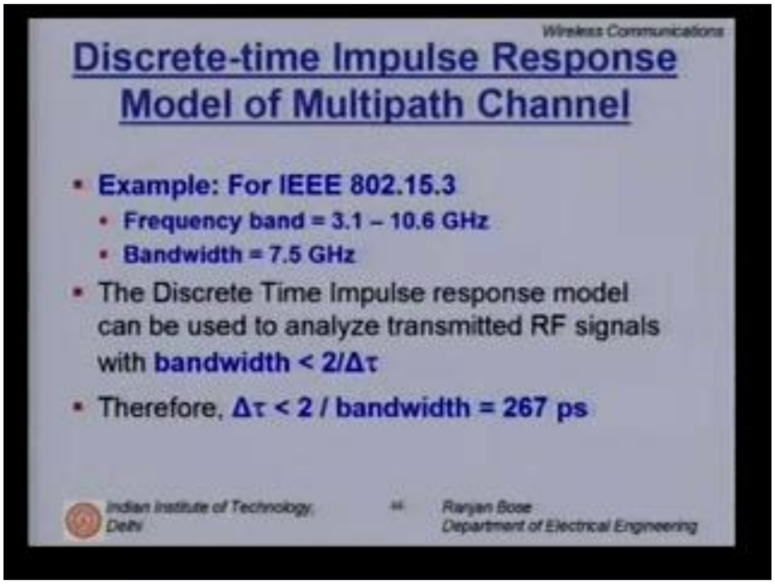

Let us take a quick example. Let us consider the IEEE 802.15.3 which is the ultra- wide band standard. The frequency band allowed is 3.1 to 10.6 GHz. it's a warping 7.5 GHz of bandwidth which can hopefully give us hundreds of a megabits per second data rate. Our job is to find out the delta tau for this scenario. Now we know that the discrete time impulse response model can be used to analyze a transmitted RF signal with bandwidth less than 2 over delta tau. Therefore in our case, delta tau is 2 over the bandwidth. It is close to 267 ps or .267 ns. So if you have to characterize a channel, suppose you have to find out the impulse response of the channel, the probe in the channel using a very narrow pulse, then you have to have a pulse at least this small or smaller. Then of course you have to ensure that the channel bandwidth is limited to the 7.5 GHz. you can find out the discrete time impulse response model of this UWB system.

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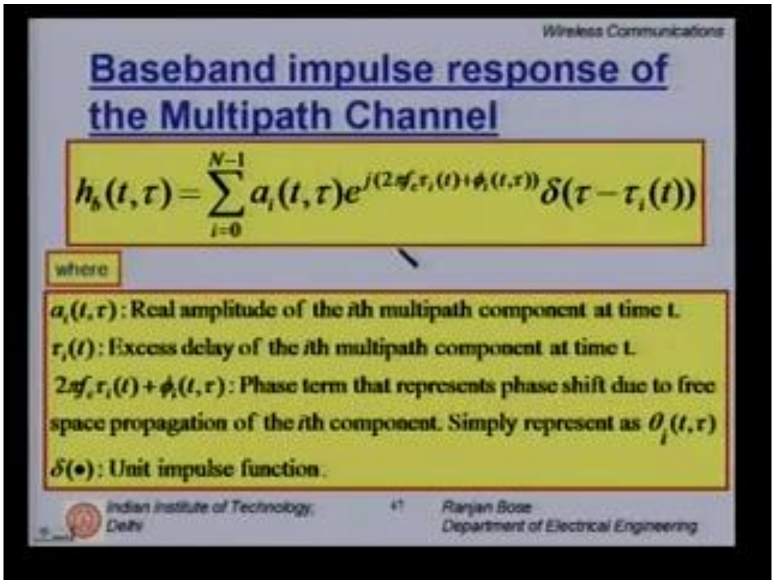

In the next slide, let us look at the baseband impulse response of the multipath channel. The baseband impulse response actually captures this arrival of the various multipath components in the various bins. So this is a direct fall out of the discrete multipath channel that we have just studied. On the left hand side of the equation is h $_b$ (t , tau), the baseband impulse response is a summation. It is a summation of lot of delayed delta functions- delta tau - ti coming directly from your discretized impulse response model. However, each of the delta functions are multiplied with the scaling factor a_i(t , tau). The scaling factor is both a function of t, the location of the mobile station and tau, the temporal variations in the channel.

There is a phase factor here e raise to power j two pi fc tau i corresponding to the delay tau i + phi i which is again a function of t , tau. It's a very general model. It's a baseband model. So what it tells you is tomorrow if you send a very narrow impulse, you do a channel sounding. You are trying to measure the impulse response of the channel by sending a very narrow pulse. Clearly a very narrow pulse implies a very large bandwidth. Impulse response happens to be a wide band characterization of the channel. Then what you receive is a series of impulses. Each impulse will be scaled and will have a phase associated with it. The impulses will be delayed as well. Delay term phase term and a scaling term.

What exact model you use will be dependent on what ai's are there. normally we can put some kind of a statistics on a_i phi $_i$ and tau $_i$. so if i have to characterize for example the indoor multipath channel, I can take a lot of measurements do some kind of a curve fitting, come up with a reasonably accurate statistical model for a_i, a statistical model for phi $_i$ and a statistical model of tau $_i$ and i am done. here let us elaborate a_i (t , tau) is the real amplitude of the ith multipath component at a time instant t. tau $_i$ which is again a function of t is the excess delay of the ith multipath component at time t. by definition the excess delay is with respect to the first coming multipath component. The term 2 pi f_c(t) tau $_i$ (t) + phi $_i$ which is the function of t and tau represents the phase term which is the phase shift due to free space propagation of the ith component. It can be simply represented as theta $_i$ (t , tau). Delta is the unit impulse function. So this is directly following from the discrete time impulse response of the multipath channel.

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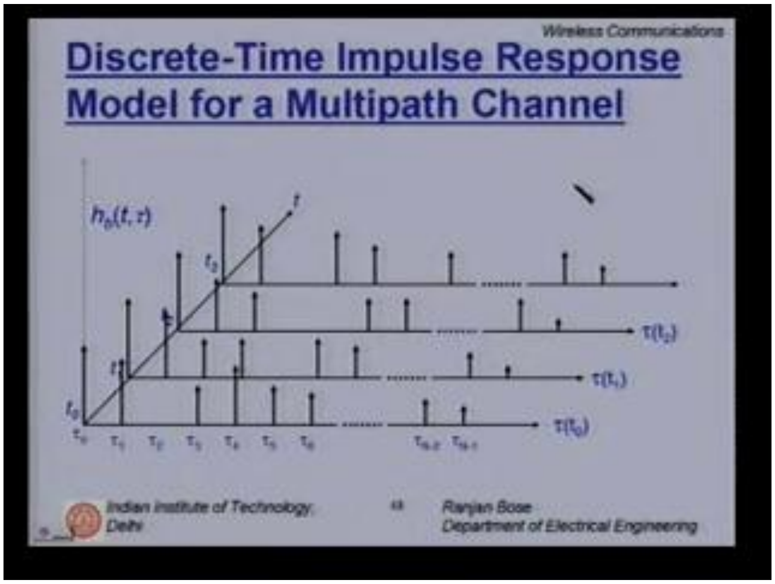
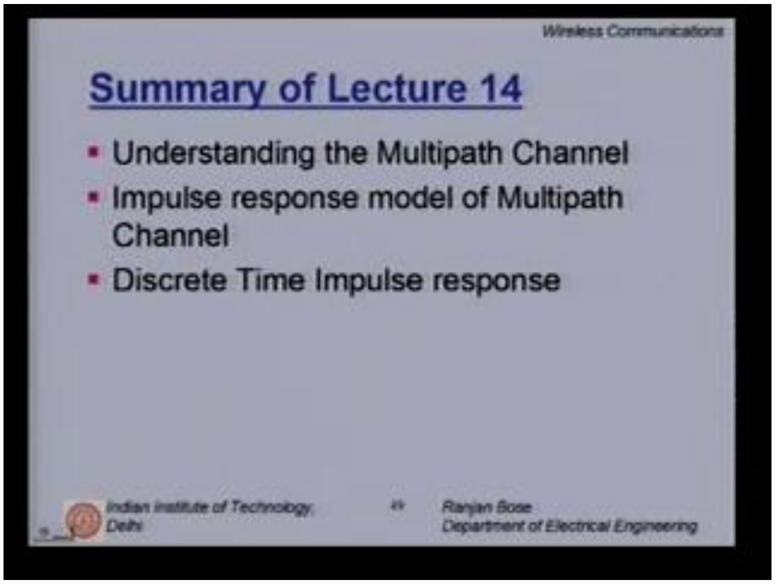


Now let us represent the h $_b$ (t , tau). The impulse response explicitly in terms of the 2 time axis. so what is going on is let us put on the z axis our channel impulse response h $_b$ (t , tau). It is a function of t. so if you can see, this is my t axis and this represents the current location of my mobile station (Refer Slide Time: 41:09). If I am working in a fixed mobile scenario for example, a local wireless area network or if I am looking at a W LAN inside a room, my transmitter and receiver are not shifting with respect to each other. Then I can pick one certain location on the t axis. So for every location on the t axis, I have a variation of tau. So this is tau as a function of t $_0$. Tau at t 1, tau at t 2. What is tau?

This tells me that because of the multipath one two three and so and so forth I receive multiple delayed impulses. Please note each one is scaled, delayed and the phase information is not clearly represented in this diagram but there will be a phase term also. Also note that certain bins do not have any multipath components like these (Refer Slide Time: 42:31). You do not have multipath components coming. At time instant t $_0$, you did obtain multipath component at location 1 but not at tau 2. Whereas after a certain time, when the mobile is progressed a little further, I would now have a multipath component at tau 2, again here and here (Refer Slide Time: 42:57). So it will be nice to plot a 3 D mesh to see how your h_b(t , tau) changes as we move along the time axis with respect to tau. If we have it, we know everything about the channel. We can convolve the transmitted signal x (t) with h_b(t , tau) and we obtain y(t).

(Refer Slide Time: 00:43:31 min)



So let us summarize today's lecture which was primarily focused on the impulse response of a wireless channel. We first dealt deeper into the multipath channel. We tried to understand how it works. Then we looked at a very simplistic impulse response model of the multipath channel. Later on, we talked about the discrete time impulse response. We will conclude our lecture here and will continue from the next lecture.