Spread Spectrum Communications and Jamming

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Lecture – 47
Concept of Fading for Wireless Communications

Hello students, today we will go little bit of bit and we will apart from the; we will deviate ourselves from the spread-spectrum communications. And we will today learn the fundamentals of wireless communication. The concept of wireless channel how do they be, how do does it we have, and what happens when signal is released from the transmitting antenna to a wireless channel, how the characteristics of a typical channel gets changed over the air, and how do we receive it in the frontend of the receiving antenna.

The aim of this class is to open you up about the fundamentals of wireless communication. And then with after gathering the knowledge of channel and the propagation characteristics of a wireless communication, we will be able to implement the spread-spectrum communication on the top of this wireless communication and hence we will be actually well iterate to design the transceiver spread-spectrum communication transceiver for wireless environment. And that is the final target, because this theory and all the learning over the spread-spectrum communications fundamentally need to be implemented in a practical situation where the communication between transmitter and receiver will be happening over a wireless channel.

So, it is a very important part to understand, how wireless communication happens between a transmitter and receiver. Today, we will concentrate behind that. We will also learn some very fundamental parameters associated to the wireless channel. And the probability in terms of probability also, we will try to learn actually the different models and their character this is the parameters of those models all that.

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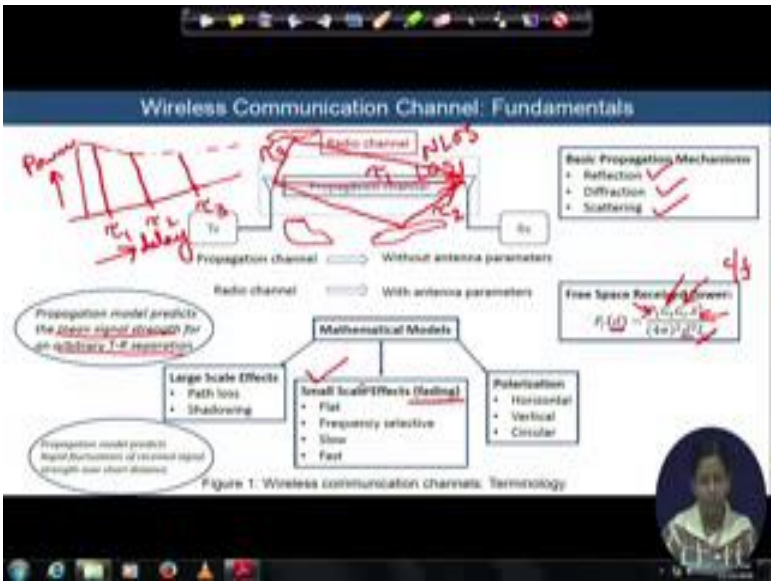

Wireless Communication Channel: Fundamentals

Propagation channel ⟹ Without antenna parameters

Radio channel ⟹ With antenna parameters

Basic Propagation Mechanisms
- Reflection
- Diffraction
- Scattering

Free Space Received Power:

Propagation model predicts the mean signal strength for an arbitrary T-R separation

Mathematical Models

Large Scale Effects
- Path loss
- Shadowing

Small Scale Effects (fading)
- Flat
- Frequency selective
- Slow
- Fast

Polarization
- Horizontal
- Vertical
- Circular

Figure 1: Wireless communication channels: Terminology

We will start with the fundamentals, this is a transmitting the figure says about there is a transmitting antenna, and there is a receiving antenna, some distance apart from each other. And the antennas are such that for this communication the signal will be released from the transmitting antenna in the expected to travel over the wireless channel, and it will be received by the receiving antenna. All the blocks that we have learned inside the receiver they come after this signal reception by the receiving antenna; also the all transmitter blocks base band blocks including the RF circuits that we have only do learn for the spread-spectrum communication transmitter, transceivers, they are all residing inside this transmitting blocks. So, transmitter blocks whatever you have learnt is inside this block box. Whatever the receiving blocks you have learnt till now they are inside suppose there inside this receiving block.

Remember when we talk about wireless channel, technically there are two different kind of the channels that we considered for our discussion and for our analysis. One is the propagation channel. The propagation channel is the channel in between the transmitting antenna and the receiving antenna. I mean excluding any other in excluding any R x circuitry and the and the antenna itself incorporated in it. But when you talk about a radio channel, radio channel incorporates the propagation channel and in the air that you see and also includes the antenna and the antenna parameters as well as a little bit about a backup circuit of this antenna. So, that until the signal can they circuit that are helpful to just release the electromagnetic waves. So, this is the radio channel, we will see that is random several times you will utilize the terms as radio channels, and some time you will talk about the propagation channel, the difference between the image like this.

So, what happens when a electromagnetic wave is released from a transmitting antenna. The wave once it is released, he actually traverse it is if it is a Omni-directional antenna the wave will be released over 360 degree angle. And remember the part of this energy only will be travailing towards the line direct line of sight path and we will be receiving will be reached to the receiving antenna like this. So, if I think that I can draw the electromagnetic rays, so this is a direct ray that is reaching from the transmitting antenna to the receiving antenna we call it a line of sight path.

And what happens to is there any other paths available it is yeah, it is there. And over the yeah in the wireless channel you will see that lot of the scatters I mean if it is outdoor communication going on, then lot of the high rise and all other elements on the scatters present in the environment, they will be actually responsible to give you the reflected rays after when the electromagnetic waves hit them. And they are sent by them the scatters and like this.

So, there are several scatters, and for each and every scatters there are the scattering rays scattered rays coming actually from each of them from each of their points and over multiple scatters there are multiple scatters is present in the environment. You are expected to get that huge number of the multiple paths to arrive in the receiver frontend. So, thing is that you released suppose one symbol, and now you are with respect to that symbol you are continuously going to receive the related electromagnetic waves for corresponding to that signal over multiple paths. So, the same symbol getting received in the receiver over after travailing over multiple paths.

It is unique phenomena that is happening inside the wireless channel. And this basic propagation, we call it the propagation of the waves - electromagnetic waves, and this basic propagation is basically controlled by the reflection, the diffraction and scattering, these are the three fundamental phenomena that happens and they create the multiple path due to the communication system. And remember all the paths which are not coming via the direct way we call it the non line of sight paths, they are NLOS paths. And these are called also the multiple paths.

And remember for all these paths to exist in practice, we have obviously the time that is associated over each and every path for the signal to traverse from the transmitter to receiver are not same. It is obvious that the time elapsed over the line of sight paths to for a signal to reach from a transmitter to receiver will be the least. And say if it is tau 1 time then for the next one say, for another path, it may be tau 2 after this delay this is a time elapse for the path for the wave to reach from the transmitter to receiver after scattering. And like that each and every path is associated with their corresponding delay associated to it.

And that is I can see actually the replica of the same symbol getting received in the receiver frontend over a multiple delay. So, it is a replica of the same signal continuously coming over the different delay to the receiver frontend. And if I try to plot H in the receiver frontend, we call it and we try to see how the power is getting received here in the receiver frontend. So, it is expected that after tau 1, I will receive one path after tau 2; I will receive one path after tau 3, I will try to receive, I will receive another multiple path.

As the delay is varying as the same way the power that you are getting received, the power will also vary. The maximum power it is expected to receive by this direct path and whenever depending upon the characteristics of the scatters and angle also the angle of your direction of arrival to the scatters and the direction of departure from them, based on all that phenomena your amount of the power that you are going to receive by that where different multiple paths that will be different. So, if I try to plot the received power, so the tau 1, if it is the line of sight path power, so I will have maximum power at that moment. Followed by the next immediate multiple path who is arriving and he may have a relatively small of power and then the third-one and it will go on like this.

So, if I try to see the profile then this is a power received power. So, we call it a power delay profile where actually in the x-axis, you are plotting the delay of arrival all multiple paths, and you are plotting their corresponding power values. You will see that the power will be exponentially having exponentially decaying profile in a wireless communication channel. Most of the cases, we will see that, but it is not the only profile that we find in a wireless environment, we see lot of other profiles also. But most general cases, we see where the line of sight path is there; this is kind of the profile for the power received power in the receiver frontend.

Now, the power that we have received here, so if there is a free space supposed in the free space how the power will be received, it was given by frees. And according to him if the transmitter and the receiver is having a distance of d, the received power in the free space the frontend of the receiver will be given by this formula. Where actually the P t is the transmitted power, G t is the gain of the antenna transmitting antenna. G r is the again of the receiving antenna, it is the wavelength of the transmission. And lambda is equal to obviously c by f. And this is a constant parameter; d is the distance between transmitter and receiver; and capital L is the lost associated with the R f frontend that it has nothing to do with the propagation. But the propagation all other parameters that are involved to decide the received signal level they are these are the parameters. So, see actually the received power is the function of the transmitted not only that transmit power, it is a function of the transmit antenna gain receive antenna gain, the frequency of transmission and the distance between transmitter and receiver.

And let us come back again inside the channel, and if I see this channel can be mathematically modeled by lot of ways. Usually when the signal is a propagating through a channel, we understood that because of reflection, diffraction and scattering, because of this three phenomena lot of changes are expected into happen over the signal property. It is not only that the power is decaying. Power is decaying it means the amplitude of the signal of the received signal is differing from the transmitted signal. So, there is a change in the amplitude of the signal; there is also a change over the phase of the signal.

So, remember the phase with which you are releasing it that would not be the same after scattering over the multiple paths. So, there is a phase change happening inside the channel. Also if the transmitter and receiver they are moving with respect to each other because of the movement the Doppler effect will come into picture; and it is expected that there will be a change over the frequency also. So, there is a there are lot of things happening over the signal; the signal is getting disparaged over that time because a multiple replicas are expected to come. So, the same signal is now getting is spared over the time duration up to t 3 or tau 3 or tau 4 or tau 5 till it is the replicas are expected to come. So, signal is not confined on this time interval. Signal has got disparaged over the time. Signal will be disparaged over the frequency because of the Doppler effect when transmitter receiver will be moving any one of them will be moving or both of them will be moving.

And on the top of that there are lot of parameters that causes the environmental changes of the wireless channel itself, which will also have some impact on the received power level. And as an effect of all that and this basic propagation mechanisms, you are expected to get lot of changes on the amplitude, time, phase and frequency of the received signal. And all that effects we can actually divide that effects broadly under the large scale effects or under small scale effects of the channel. The large scale effects basically considered the path loss and the shadowing. And this large scale model basically actually predict the mean signal strength that you are receiving for an arbitrary transmitter receiver separation. So, when we talk about a large scale model of a wireless channel basically we give the output as a mean signal strength over a arbitrary transmitter receiver separation, that is a long term over the long time duration also the that large scale effects holds good.

But the most important part there we are interested in the wireless communication is the small scale effect. And the model wireless channel model which captures the small scale effects basically actually this model predicts the rapid fluctuations of the wireless channel that is happening and its reflection hence its reflection on the received signal strength over a short distance that is happening is captured by the small scale fading model propagation model.

This small scale effects basically we call in terms and by a term called fading. And this fading is basically of several types in a wireless channel, we realized it may be flat it may be frequency selective, it may be slow, it may be fast. And we will discuss about all these in the next slide. And the model sometimes also captured the polarization effects of the antenna, whether it is vertically polarized or horizontally polarized or it is circularly polarized, and based on that the model will be much more critical. So, for our basic understanding, we will mainly concentrate inside this small scale fading effects and a small scale channel models of wireless communication.

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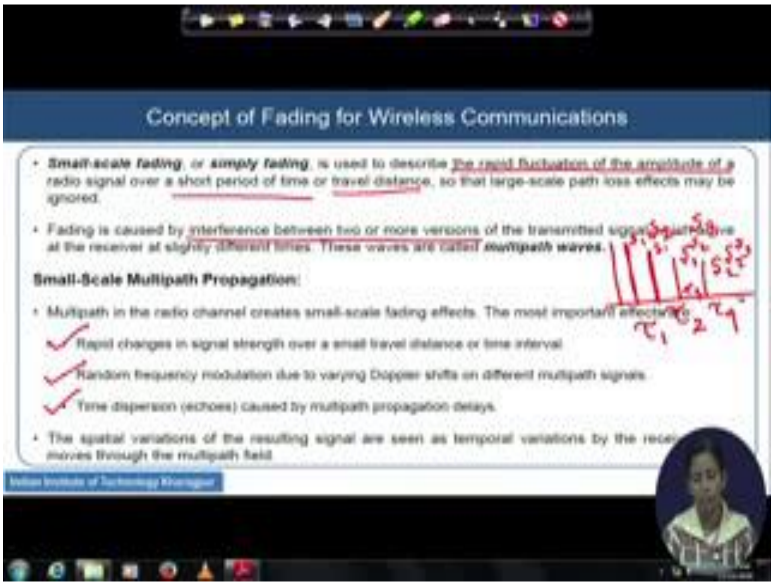

Concept of Fading for Wireless Communications

- ***Small-scale fading***, or ***simply fading***, is used to describe the rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance, so that large-scale path loss effects may be ignored.
- Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. These waves are called ***multipath waves***.

Small-Scale Multipath Propagation:

- Multipath in the radio channel creates small-scale fading effects. The most important effects are:
  - Rapid changes in signal strength over a small travel distance or time interval
  - Random frequency modulation due to varying Doppler shifts on different multipath signals
  - Time dispersion (echoes) caused by multipath propagation delays
- The spatial variations of the resulting signal are seen as temporal variations by the recei
moves through the multipath field

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So, as I told that small scale fading or simply fading actually it is used to describe the rapid fluctuations of the amplitude of the received signal over a short period of the time and also for a short travel distance. So, fading is caused by the why the fading is coming up because there is a interference between the two or more versions of the same transmitted signal that are arriving in the receiver over the multiple instance of the time. So, basically the thing is something like this, when you have received the first multipurpose line of sight path for say signal 1, and if you are having a sample duration equal to that same multipath arrival duration say seconds tau 2, you are receiving when you have sample tau 2, tau 3, tau 4 at a gap of that, and suppose you have received the fast signal line of sight path here then it is replica is also expected to come here by the second multipath. His replica is expected to come here, his replica is expected to come here it is going on.

But by the time if it is a continuous transmission going on from the transmitter during this tau 2 interval, also you are going to release the second you are going to release the second symbol and his replica is also expected to come during the tau 3 and tau 4. In tau 3, we have already release the third symbol, so his replica is also expected to come in s 3. So, you see at each and every timing instant delay instant I should say, there is a very complicated signal model is you are going to receive. The addition of the multiple signals with their corresponding changes in the amplitude (Refer Time: 18:31) phase, you are expected to its additive effects is we are going to you are expected to receive in the receiver frontend. So, this combined phenomena the changes of the original signal because of the other signals that are coming that are superimposing on it at the receiver frontend is caught on as a term fading.

Remember, this the main causes the most important effects of this small scale multipath propagation is that the rapid changes in the signal strength over a small travel distance very random frequency modulation that happen because of the Doppler shifts on the different multipath signals and dispersion because echoes are expected to come over the multiple propagation delays. So, these are all about the small scale multipath propagation that is a coming phenomena about inside a wireless communication channels, and this special variation of the signal over in wireless over a space in wireless domain which case seen in the receiver frontend as a temporal variation that we have explained here.

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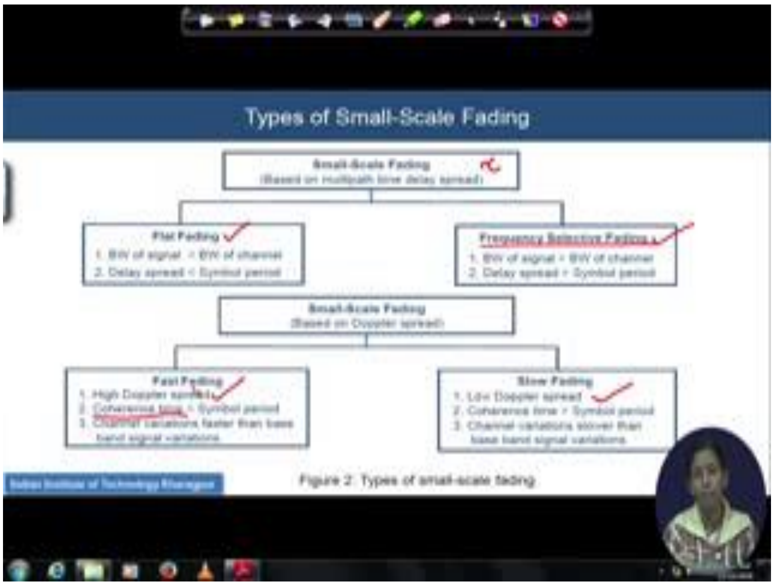

Types of Small-Scale Fading

Small-Scale Fading
(Based on multipath time delay spread) τ

Flat Fading ✓
1. BW of signal < BW of channel
2. Delay spread < Symbol period

Frequency Selective Fading ✓
1. BW of signal > BW of channel
2. Delay spread > Symbol period

Small-Scale Fading
(Based on Doppler spread)

Fast Fading ✓
1. High Doppler spread
2. Coherence time < Symbol period
3. Channel variations faster than base band signal variations

Slow Fading ✓
1. Low Doppler spread
2. Coherence time > Symbol period
3. Channel variations slower than base band signal variations

Figure 2: Types of small-scale fading

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So, this is about the fading. And let us quickly visit how many types of the small scale fading we encounter in a practical communication system. Small scale fading, if I divide classify, it based on the multiple time delay spread, time delay spread I wrote it in terms of tau. So, if it is a with respect to time delay spread; he will get it two part, one is a flat fading, another is a frequency selective fading. What is flat and what is frequency selective we will discuss in detail later on. But fundamentally just remember that flat fading what happens if the bandwidth of the signal transmitted is less than the bandwidth of the channel. Then you will encounter that all the signal components are experiencing the same kind of the amplitude change and the phase change by the channel. We call it the flat kind of fading.

And if there is, this is not and in the bandwidth of your signal is the higher than the bandwidth of the channel, then channel is expected to behave different way over the different portion of the signal. And hence the amplitude changes and the phase changes over the different part of the signal that you will be able to see in the receiver frontend would not be uniform, and it will be definitely different from the part by part. And we call it the frequency selective fading. So, different part of the frequency of the signal is expected to get different amount of the amplitude and phase change, and hence we call it a frequency selective fading. We will discuss the all this again in the later slides.

Small scale fading based on the Doppler spread. This is related to the movement and some velocity of the receiver is involved with respect to the transmitter; and because of which, the receive signal frequency actually it spreads and because of that we call it the Doppler spread and that incorporates at brings the two different kind of the fading concept in the received signal. One is the fast fading; another is the slow fading. The fast fading is coming and related to the very high Doppler spread, and this is definitely a low Doppler spread. To understand what is fast fading and what is the slow fading we have to understand something called the coherence time. What is this, we will coming detail.

And only points to remember here is that this is something related with the symbol period, it is not the bandwidth of the signal, it is the symbol period. If the period of the symbol is more than the coherence time and the time over which the channel gives channel coefficients or the channel properties does not change, so that is the time we call as a coherence time. If that time is less within the symbol time, so you are going to get the very fast fading, so channel will keep on changing, it is a time varying nature of the channel.

Question is for how much time channel is giving you a fixed kind of behavior. Fixed behavior I mean that same kind of changes over the amplitude, and the phase you can expect, how much time is defined by the coherence time. If your symbol period is more than that time of the channel, when you are expected to get different amount of the fading, and we call it a fast fading and opposite is a slow fading, where is your coherence time the time over which channel is remaining constant and not giving any kind of the change, it is showing uniform amount of the amplitude and phase change. If that time is more compared to your symbol time period, then you will see the very slow fading.

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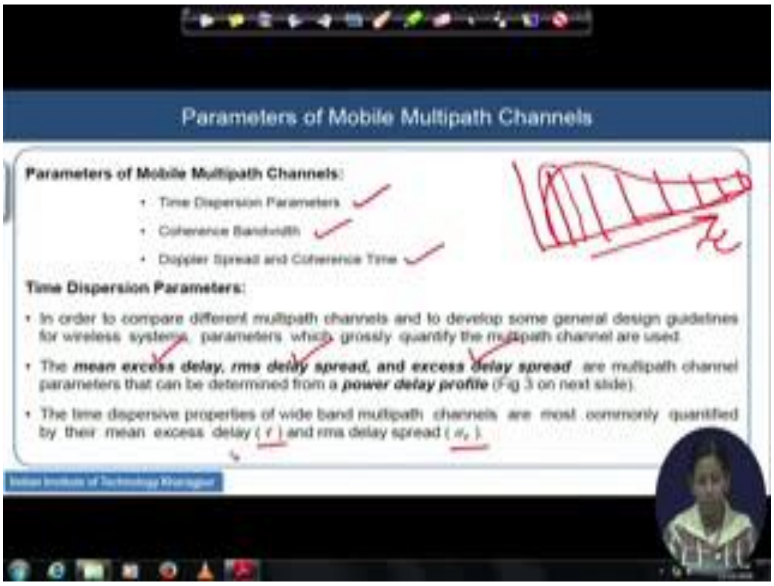

Parameters of Mobile Multipath Channels

Parameters of Mobile Multipath Channels:

- Time Dispersion Parameters
- Coherence Bandwidth
- Doppler Spread and Coherence Time

Time Dispersion Parameters:

- In order to compare different multipath channels and to develop some general design guidelines for wireless systems, parameters which grossly quantify the multipath channel are used.
- The ***mean excess delay, rms delay spread, and excess delay spread*** are multipath channel parameters that can be determined from a ***power delay profile*** (Fig 3 on next slide).
- The time dispersive properties of wide band multipath channels are most commonly quantified by their mean excess delay ($\bar{\tau}$) and rms delay spread (σ_τ).

So, we will slowly enter into the different parameters that are associated with the mobile multipath channels. The parameters are basically the channel with respect to channel it is a time dispersion parameter, the coherence bandwidth and the coherence time. We need to actually clearly understand the terms, and because we will repeatedly we using it in the system design. The time dispersion parameter basically all it is the fact that we that we have already discuss that the replica the echoes of the same signal or same symbol is you are expected to receive in the receiver over a large time delays. And because of that we are saying that there is dispersion is happening the signal is getting disparaged like this. So, signal is not like the even if you have transmit the signal like this now it has got disparaged like this. So, it is time dispersion happened over the signal.

And hence we define some parameters over this dispersion which is called the mean excess delay, the rms delay spread and the excess delay spread over the power delay profile. And remember them mean delay and the delay spread they are expressed by the term tau bar and the sigma tau. They are very important to understand because always arrival of the multi paths are very random process I told that the profile will approximately follow the exponential decay profile. But where will be the mean of this guy and where will be the rms delay spread or the rms value of this spread that is very important for ask to understand. Because based on this mean value and rms delay spreads we were going to define the lot of characteristics of the channel.

And as this is a random phenomena that arrival of the multipath the random phenomena and how long will they keep on coming continuously that is also is a random phenomena. Hence, we define this two parameters to understand the randomness associated with this multipath profile; one is the mean excess delay, another is the rms delay spread.

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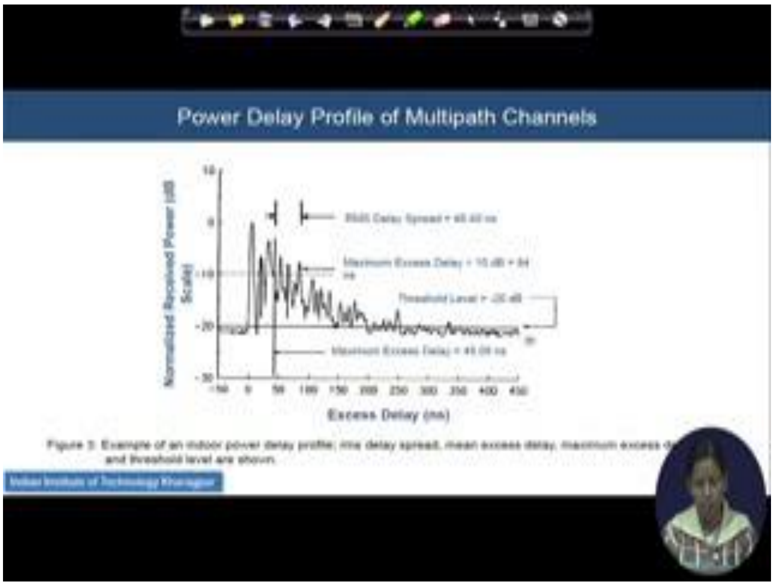

Power Delay Profile of Multipath Channels

Figure 3: Example of an indoor power delay profile; rms delay spread, mean excess delay, maximum excess de
and threshold level are shown.

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We will first quickly look into the power delay profile here. And see here in the power delay profile, we are seeing that this is the maximum signal maximum power came, and these are the slowly decaying profiles came. So, main delay is something that we have to calculate on the top of this is rms is from if this is the mean value then this is the rms delay spread I mean how much the division is happening with respect to the mean value.

What is this mean excess delays about it is about some extra amount of the delay for which actually we are thinking that the power will be considered to be down by certain dB level. And that is the maximum excess delay that we are trying to do sometimes which is the point verify findings the second level of the threshold on the power delay profile. And if it is going down by that when the power is going below that power delay value, so that is a maximum point of the delay we should wait for to capture the energy from the channel in the frontend of the receiver.

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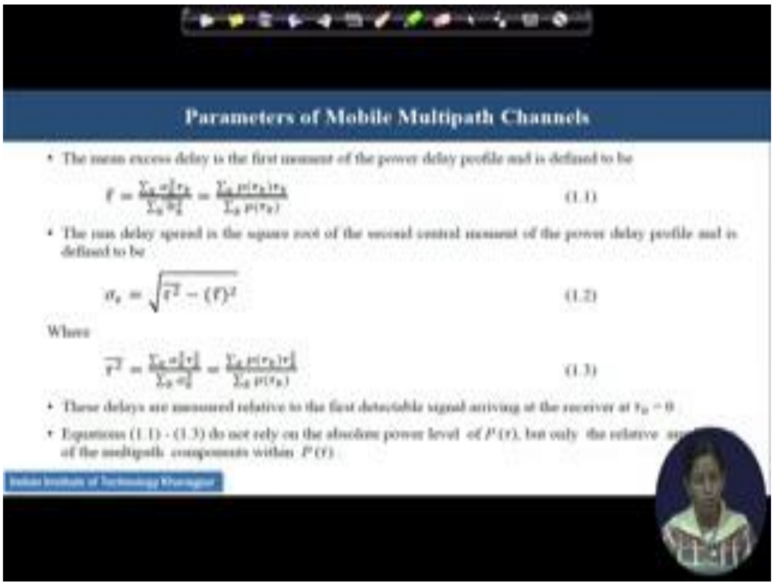

Parameters of Mobile Multipath Channels

- The mean excess delay is the first moment of the power delay profile and is defined to be

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \qquad (1.1)$$

- The rms delay spread is the square root of the second central moment of the power delay profile and is defined to be

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \qquad (1.2)$$

Where

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)} \qquad (1.3)$$

- These delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$
- Equations (1.1) - (1.3) do not rely on the absolute power level of $P(\tau)$, but only the relative of the multipath components within $P(\tau)$

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So, we will quickly this visit all the points, all the elements what is the mean delay. So, mean delay is basically given by this expression, where you are taking the for each and every path k, you are taking the power of that path multiplied with the delay associated with k, and you are averaging it over the power total power of it, so that is the mean. And the rms value will be actually that the delay square bar minus the tau bar square, where this delay square bar is basically now the squaring up over the each and every delay path. And remember that whenever we are continuing about this delay and the measurement of the delays are going ahead, first detectable signal, we consider that it is arriving at the delay equal to 0. That first arrival signal may be here. So, our zero will start from here. So, it is a time axis actually with related to the all the delays I measures with respect to the arrival of the first detectable path in the receiver.

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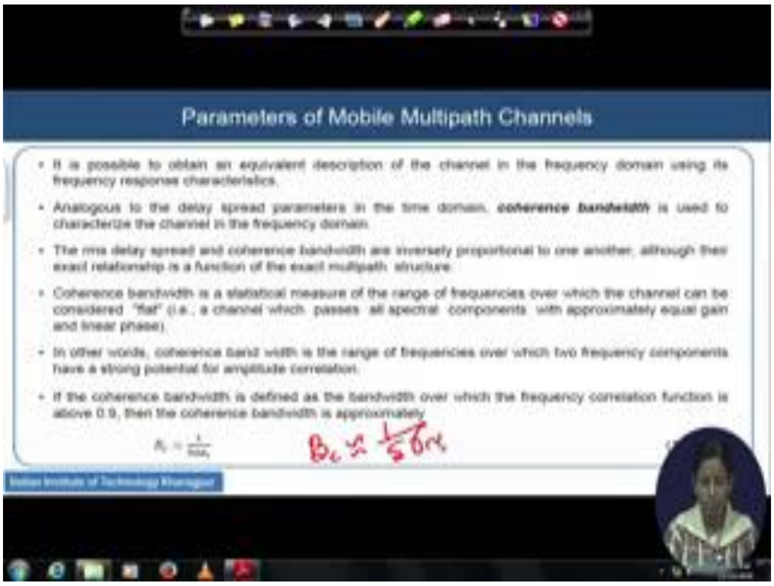

Parameters of Mobile Multipath Channels

- It is possible to obtain an equivalent description of the channel in the frequency domain using its frequency response characteristics.
- Analogous to the delay spread parameters in the time domain, **coherence bandwidth** is used to characterize the channel in the frequency domain.
- The rms delay spread and coherence bandwidth are inversely proportional to one another, although their exact relationship is a function of the exact multipath structure.
- Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat" (i.e., a channel which passes all spectral components with approximately equal gain and linear phase).
- In other words, coherence band width is the range of frequencies over which two frequency components have a strong potential for amplitude correlation.
- If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9, then the coherence bandwidth is approximately

$$B_c \approx \frac{1}{50\sigma_\tau} \qquad B_c \approx \frac{1}{5\sigma_\tau}$$

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So, quickly come into the domain that was the expression for the channel in the time domain, if you come to the frequency domain you can get a equivalent description. And here we define the frequency domain coherence bandwidth, and which we use to characterize the channel in the frequency domain. Like the time dispersion happened, it is the where it is the very good relation between the delay spread rms delay spread in the time domain and the coherence bandwidth. And we considered that give the coherence bandwidth is basically the bandwidth over which the statistical property of the channel will be remaining constant. And channel will behave as a flat channel, flat means the channel all the spectral components that will pass over that bandwidth, he will actually get in equal amount of the gain attenuation and the linear phase change.

And in other words you can also say that it is a bandwidth coherence band, it is the range of the frequencies over which the two frequency components will be heavily correlated, and amplitude correlation will be there. And if I considered that this correlation is about 90 percent then the coherence bandwidth and the rms delay spread is related approximately by this equation. If you considered it to be a 50 percent of the coherence is a observable between two frequencies then this comes consideration then this bandwidth B c will be approximated by 1 by 5 sigma tau.

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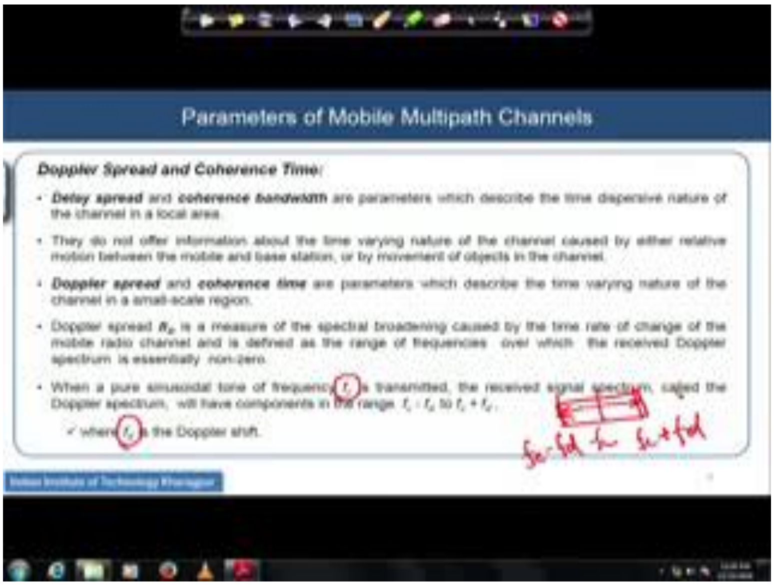

Parameters of Mobile Multipath Channels

Doppler Spread and Coherence Time:

- ***Delay spread*** and ***coherence bandwidth*** are parameters which describe the time dispersive nature of the channel in a local area.
- They do not offer information about the time varying nature of the channel caused by either relative motion between the mobile and base station, or by movement of objects in the channel.
- ***Doppler spread*** and ***coherence time*** are parameters which describe the time varying nature of the channel in a small-scale region.
- Doppler spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel and is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero.
- When a pure sinusoidal tone of frequency f_c is transmitted, the received signal spectrum, called the Doppler spectrum, will have components in the range $f_c - f_d$ to $f_c + f_d$.
    - ✓ where f_d is the Doppler shift.

$f_c - f_d$ to $f_c + f_d$

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So, now we understanding that this coherence bandwidth and the delay spread, they give about the idea of the time dispersive nature. The delay spread is coming it is totally related with the time dispersion. And from the rms value of the delay spread we calculated coherence bandwidth. So, it is totally talking about the time dispersive nature of the channel in a local area, but it is not giving any idea about the frequency depressiveness over the channel. And that will be coming from the fact that there is a Doppler spread happening and there is a concept of the coherence time associated with the channel.

What are they, the Doppler spread is basically mentioned as B D here, it is a measure of the spectral broadening that will be coming up because of the time rate of change of the mobile radio channel. And it is defined as the range of the frequencies over which received Doppler spectrum is non-zero. So, let us take an example suppose I have transmitted pure frequency f c single tone, because of the presence of the Doppler phase shift, which is called the f d. The f c will have actually the component after the after passing through the channel it will have the component of f c plus f d, and it will also have the component of f c minus f d. So, its bandwidth is now spread from f c minus f d to f c plus f d. So, f c plus twice f d is a total bandwidth over which actually now the conservation should be going ahead with. And this is the total bandwidth this whole way whole change is a measure of the broadening of spectrum broadening happened, and this is called the received Doppler spectrum.

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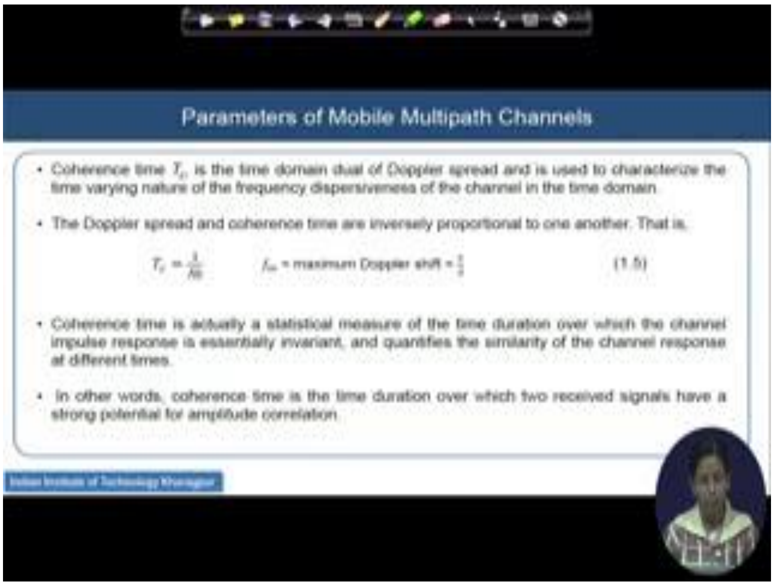

Parameters of Mobile Multipath Channels

- Coherence time T_C is the time domain dual of Doppler spread and is used to characterize the time varying nature of the frequency dispersiveness of the channel in the time domain
- The Doppler spread and coherence time are inversely proportional to one another. That is,

$$T_C = \frac{1}{f_m} \qquad f_m = \text{maximum Doppler shift} = \frac{v}{\lambda} \qquad (1.5)$$

- Coherence time is actually a statistical measure of the time duration over which the channel impulse response is essentially invariant, and quantifies the similarity of the channel response at different times.
- In other words, coherence time is the time duration over which two received signals have a strong potential for amplitude correlation.

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And remember one thing that once we understand that this has happened then we can really correlated this the Doppler shift - the maximum Doppler shift with respect to the velocity that you are having in the channel with a velocity of your mobile receiver that you are having we can actually compute the coherence time. And though there is Doppler shift and the coherence time I just in the inverse propose inversely proportional with each other.

But fundamental meaning of the coherence time is that it is a duration over with it is a time domain well basically of the Doppler shift, but it means that it is the time period, it is a time actually the statistical measure of the time duration over which such channel properties are again remaining in variant. For example, it is that after how much time the channel is expected to be changed as simple as that. So, by coherence bandwidth we defined that it is the bandwidth over which after which the channel properties expected to be changed. Coherence time talks about the time after which the channel properties are expected to be changed.

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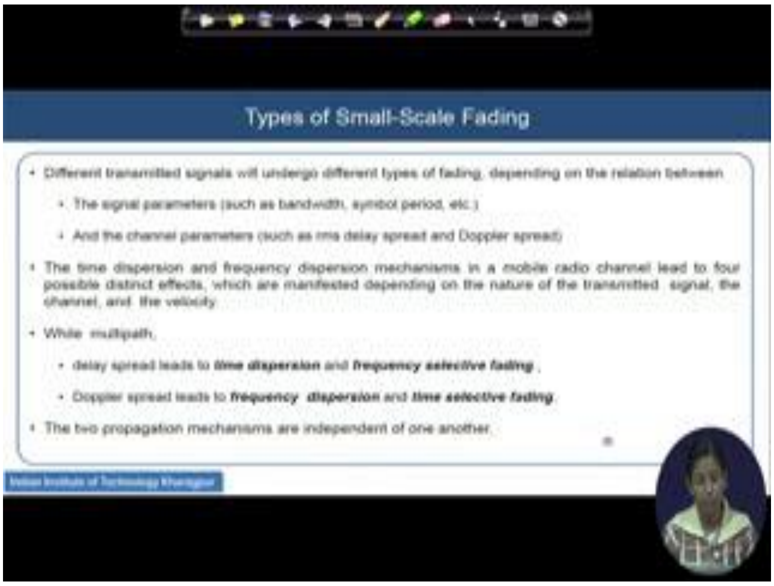

Types of Small-Scale Fading

- Different transmitted signals will undergo different types of fading, depending on the relation between
  - The signal parameters (such as bandwidth, symbol period, etc.)
  - And the channel parameters (such as rms delay spread and Doppler spread)
- The time dispersion and frequency dispersion mechanisms in a mobile radio channel lead to four possible distinct effects, which are manifested depending on the nature of the transmitted signal, the channel, and the velocity
- While multipath,
  - delay spread leads to ***time dispersion*** and ***frequency selective fading*** ,
  - Doppler spread leads to ***frequency dispersion*** and ***time selective fading***.
- The two propagation mechanisms are independent of one another.

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And we can have a several combinations of all this when multipath situation for example, delay spreads can lead you to time dispersion and frequency selective fading, you can get a frequency dispersion and time selective fading.

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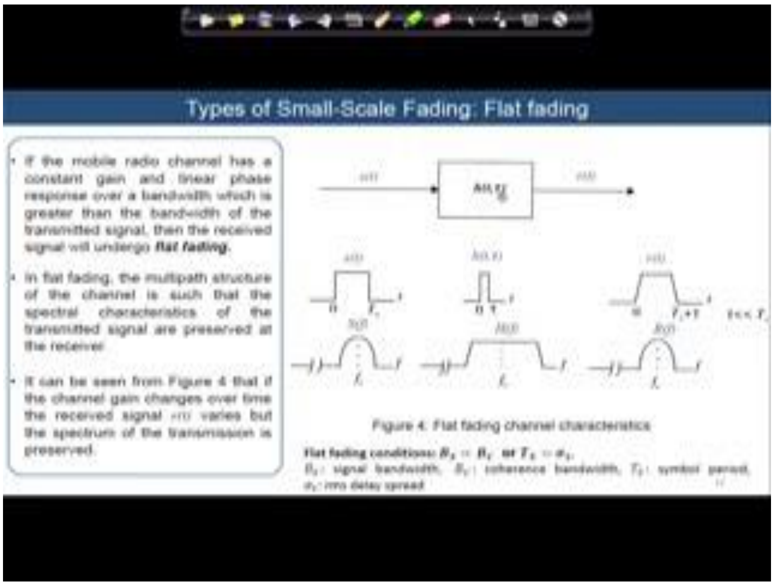

Types of Small-Scale Fading: Flat fading

- If the mobile radio channel has a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal, then the received signal will undergo ***flat fading***.
- In flat fading, the multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver.
- It can be seen from Figure 4 that if the channel gain changes over time the received signal r(t) varies but the spectrum of the transmission is preserved.

Figure 4: Flat fading channel characteristics

Flat fading conditions: $B_S \ll B_C$ or $T_S \gg \sigma_\tau$,
B_S : signal bandwidth, B_C : coherence bandwidth, T_S : symbol period, σ_τ : rms delay spread

We will take out very quick example of a flat fading and the frequency selective fading. This was a signal are coming and it is the channel in the black box which is having the time dispersion it is that t, which is having t and tau are the time as well as the delay message that is a time fading nature of the channel and that the variation over that delay is also captured here. And this is a signal coming out. So, the relative bandwidth of the signal and the channel is like this suppose. This is a time duration of the signal and this is the time duration of the channel and hence the bandwidth of the channel is more than the bandwidth of the signal.

Then how r t will behave, the bandwidth of the r t will be behave. If we see that is the bandwidth of the signal is less than the bandwidth of the channel then over the whole bandwidth of the interest of the signal the channel will remain constant. So, you are expected to give the same amount of the amplitude change and the linear phase change over the whole bandwidth of the transmitted signal, hence we call it a flat fading. You would not see any kind of the dispersion happening in the frequency spectrum of the received signal over when mobile passing through such channel. So, it is a relative relation of the bandwidth of the signal and the channel based on that the flat fading phenomena happens.

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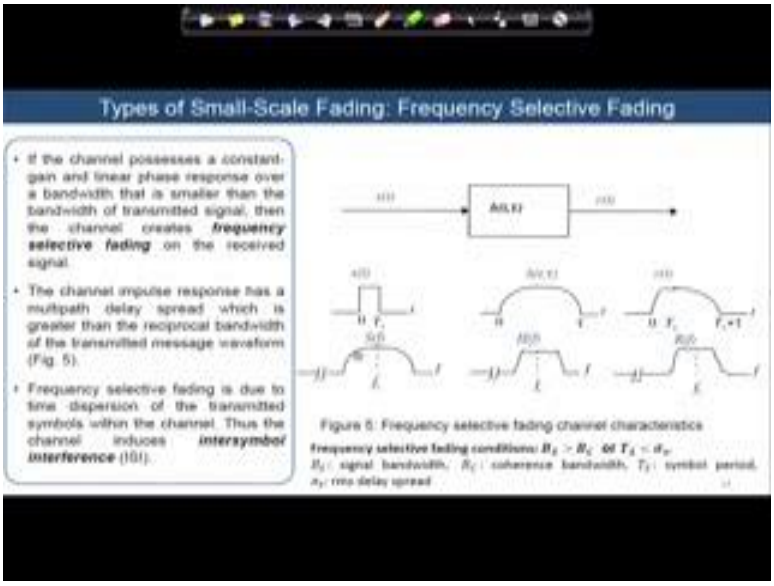

Types of Small-Scale Fading: Frequency Selective Fading

- If the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates ***frequency selective fading*** on the received signal.
- The channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform (Fig. 5).
- Frequency selective fading is due to time dispersion of the transmitted symbols within the channel. Thus the channel induces ***intersymbol interference*** (ISI).

Figure 5: Frequency selective fading channel characteristics

Frequency selective fading conditions: $B_S > B_C$ **or** $T_S < \sigma_\tau$

B_S : signal bandwidth, B_C : coherence bandwidth, T_S : symbol period, σ_τ : rms delay spread

Opposite to this, is this is a frequency selective fading when actually we see that the bandwidth of the signal is more than the bandwidth of the channel considered. In such a situation channel can never give you the uniform amount of amplitude change on the phase change over the whole all frequency band involved in the signal spectrum. Hence you are going to get a different amount of the different shape, the shape itself to the frequency components itself will be partially present and partially not. And different kind of the amplitude reduction and the phase changes are happening over the incoming signal, we call it frequency selective fading. See, the portion of the incoming signal we may transmitted signal here in this zone, I have got to completely different amplitude changes compared to that where channel is really present, we call it frequency selective fading.

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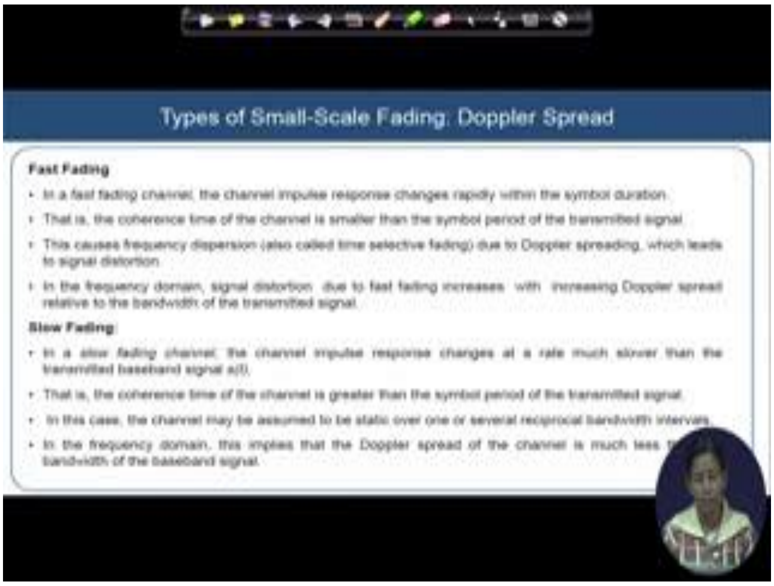

Types of Small-Scale Fading: Doppler Spread

Fast Fading

- In a fast fading channel, the channel impulse response changes rapidly within the symbol duration.
- That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal.
- This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to signal distortion.
- In the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal.

Slow Fading:

- In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal s(t).
- That is, the coherence time of the channel is greater than the symbol period of the transmitted signal.
- In this case, the channel may be assumed to be static over one or several reciprocal bandwidth intervals.
- In the frequency domain, this implies that the Doppler spread of the channel is much less t bandwidth of the baseband signal.

Fading can be also very fast and very slow base on that is if we are having a very high speed for the movement then actually channel is expected to change very fast over the time access. So, coherent time of the channel will be very, very small as your Doppler spread bandwidth will be very high. So, you are expected to get very fast changes and accordingly you have to design the signal processing in the receiver. Opposite to that is that slow fading, if you are moving with them moderate speed or a very slow speed or in a pedestal speed. Here you are going to see actually the large coherence time over which the channel is showing the constant effect and you are not going to see a large amount of the changes in the received signals profile.

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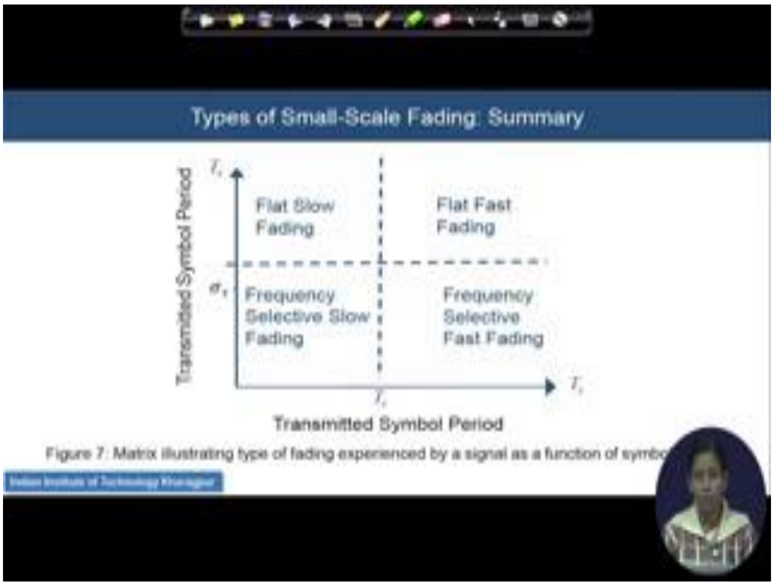

Types of Small-Scale Fading: Summary

Figure 7: Matrix illustrating type of fading experienced by a signal as a function of symbo

And hence actually the processing and the corrections of the due to the fading is less that it is less loaded, I mean the receiver processing will be less loaded in such situation. This is a picture which talks about the combine effect when the transmitted symbol period versus your rms delay spread value of the channel. Actually, if you are having a coherence time involved in it if you are having low coherence time, you will get a frequency selective slow fading, if your transmitter symbol is comparative to the rms delay spread. And based on this a combination of the T c, T s and sigma, tau you will get the whole portion can be divided into four part. Above the flat slow fading, flat fast fading, frequency selective slow and frequency selective fast. Based on whether you are crossing that this is a how height is or a how did the T s values are and what where is actually their location of this rms delay spread.

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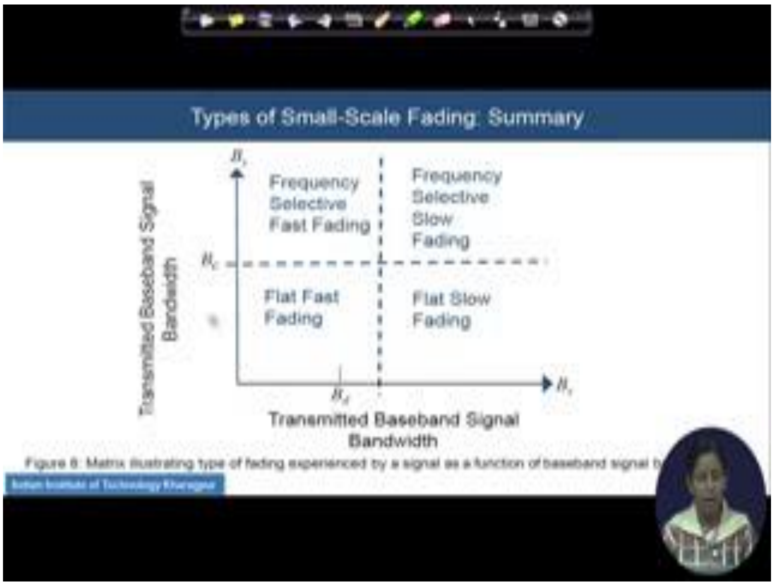

Types of Small-Scale Fading: Summary

Figure 6: Matrix illustrating type of fading experienced by a signal as a function of baseband signal b

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Similarly, in the bandwidth based in the frequency domain based on the transmitted base band signal bandwidth, Doppler spread as well as the coherence bandwidth, your signal bandwidth your same division is possible. So, this is a time domain division and this is equivalent frequency domain description, but fundamentally you can have any four of this combination when you are transmitting over a wireless channel. So, we have to actually be very, very careful when you are designing transceiver, and we need to know that channel kind of the channel we are dealing with whether it is a flat fast or the flat slow or it is a frequency selective faster, or it is a frequency selective slow channel.