Principles of Modern CDMA/MIMO/OFDM Wireless Communications
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Lecture – 20
Max Delay Spread

Hello, welcome to another module in this massive open online course on the principles of CDMA, MIMO and OFDM wireless communication systems. So, so far what we have seen is; we have seen how to model a wireless communication system, the Bit Error Rate performance of a wireless communication system, what are the problems with the Bit Error Rate performance, how to improve the Bit Error Rate performance, we looked at the diversity using multiple antennas, receive diversity and how receive diversity decreases the bit error rate.

Now, let us try to understand more about the wireless channel in a CDMA, MIMO and OFDM wireless communication system.

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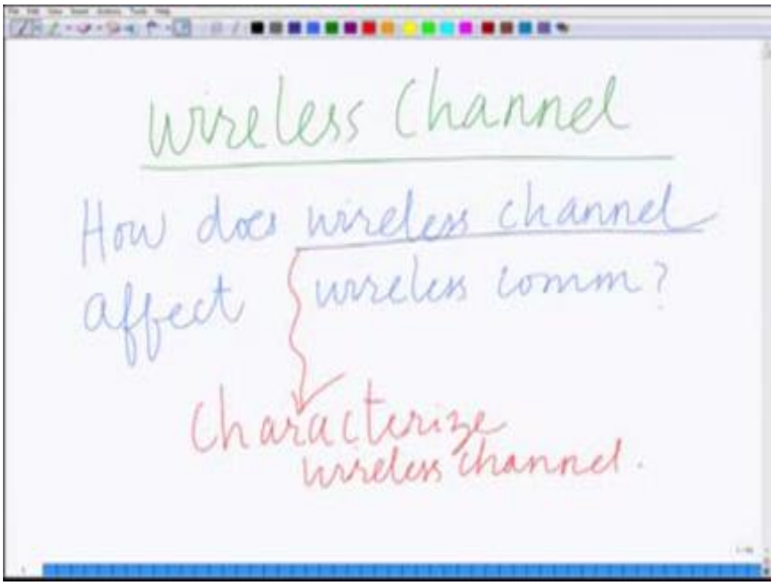

So what we are going to do, starting this module is to look at the wireless channel that is we want to ask the question how does the wireless channel affect CDMA, MIMO, OFDM wireless communications, that is how does the wireless channel or basically the radio propagation medium affect wireless; how does it affect wireless communication basically what we are looking to do is we are looking to characterize this wireless communication.

What we are asking is how does the radio channel, the propagation medium affect the nature of CDMA, MIMO, OFDM wireless communication system, for this we need to develop an in depth characterization of the wireless channel.

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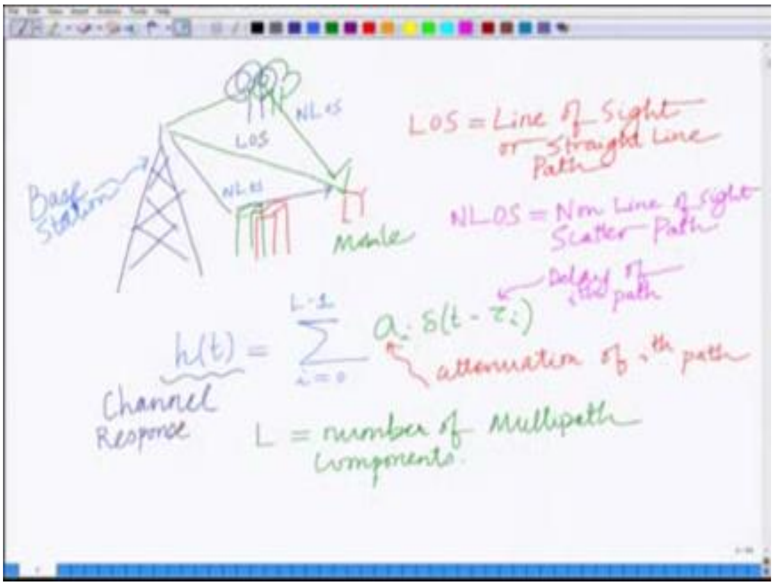

Let us briefly go back, let me refresh your memory regarding our wireless channel model. We said that we have a transmitter or let us call this a Base Station. So, we have a Base Station and we have a mobile and we said that there is a Line Of Sight path for the signal to propagate between the Base Station and the mobile.

However, if there are scatterers such as for instance trees in my environment then also there are several scatter paths, for instance let us say there are buildings in my propagation environment. So, these are some trees and some buildings and therefore, what I also have or I have scatter path. So, I have a direct path which is my LOS or the Line Of Sight path and I also have several scatter paths which are my non Line Of Sight or NLOS path. So, we have already defined this LOS equals the Line Of Sight or basically our straight line path and NLOS is the non Line Of Sight or basically our scatter path, these arise from the scatterers in the wireless environment. So, in the wireless communication channel is as we have already seen is a multipath propagation environment; which are arises because of the scatterers in a wireless environment, so there is a direct path or an LOS or a Line Of Sight path between transmitter and the receiver.

But there also several non Line Of Sight paths which are basically arising from the scatters that is the scattered signal components from the scatterers such as the trees and buildings in the wireless environment and we also saw that this wireless communication channel can be modeled as follows, so the channel impulse response of the wireless communication channel again this is something that we have seen before can be modeled as

$$h(t) = \sum_{i=0}^{L-1} a_i\, \delta(t - \tau_i)$$

So this h(t) this is my wireless channel; this is the response of my wireless channel.

This quantity, so we have L multipath components, so this summation is i equal to 0 to L minus 1 which means L equals number of multipath components. I have a_i which is equal to the attenuation of the i th path, this we have already seen; this is a_i which is the attenuation of i th path and I have τ_i, which is the delay of i th path.

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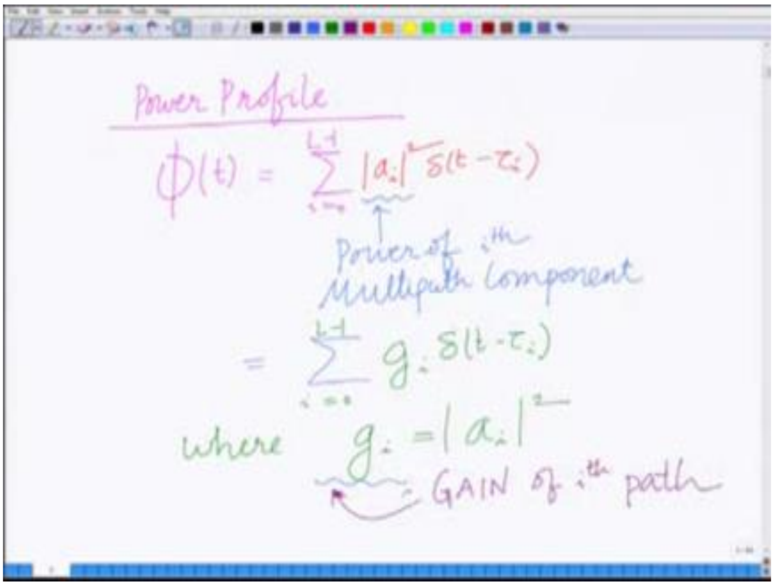

Now, what we want to do is let us look at the same thing in terms of the Power Profile that is

$\varnothing(t) = \sum_{i=0}^{L-1} |a_i|^2 \, \delta(t - \tau_i)$

I can also write this as

$$= \sum_{i=0}^{L-1} g_i \, \delta(t - \tau_i)$$

Where $g_i = |a_i|^2$

Let me just write this clearly this can also be termed as the gain of the i th path. This gives the Power Profile of the wireless channel which is the characterization of the arriving power with respect to the delay that is τ and now what we want to do is for instance, let us take a simple example to understand this better.

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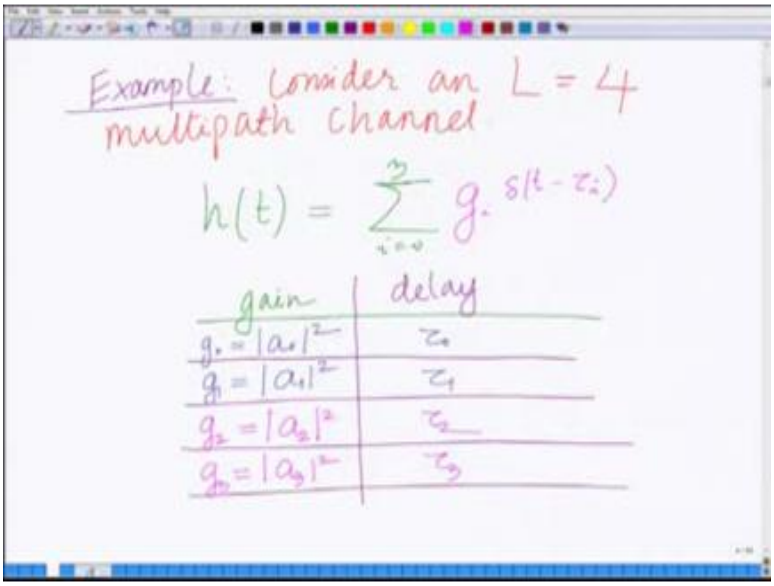

Consider an L = 4 multipath channel,

$$h(t) = \sum_{i=0}^{3} g_i \, \delta(t - \tau_i)$$

which means there are total of 4 multipath components, let me write this as a table.

I have the gain of the component and I have the various delays and this Multipath Power Profile tells me that there is a gain $g_0 = |a_0|^2$ at delay τ_0, there is a gain $g_1 = |a_1|^2$ at τ_1 there is a gain $g_2 = |a_2|^2$ at τ_2 and there is a gain $g_3 = |a_3|^2$ at delay τ_3 and if I represent this schematically, if I draw picture; let me now draw a picture for this example multipath power delay profile with 4 multipath components.

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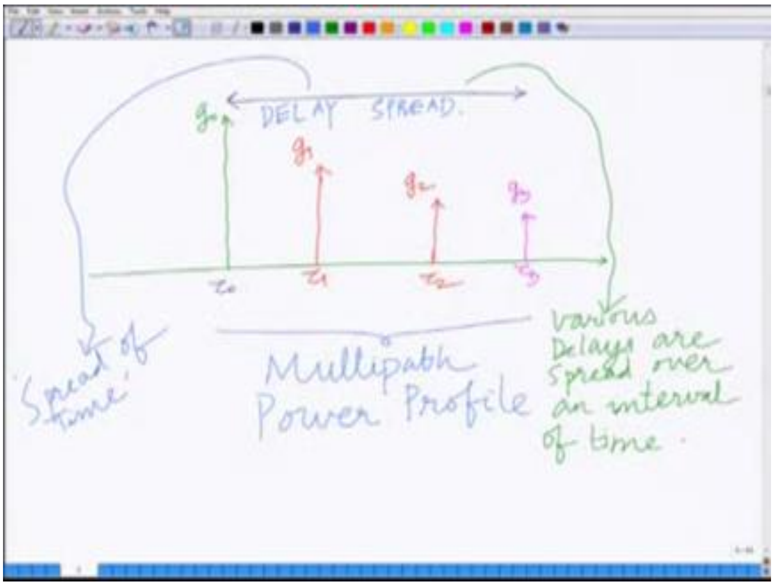

It is going to look something like the following thing; I have a path which is arriving with gain g_0 at delay τ_0, g_1 at τ_1 , g_2 at τ_2 and gain g_3 at delay τ_3 . This is the Multipath Power Profile that is this is the characterization of the power of the arriving signal component as a function of the delay τ at various values of tau what is the arriving power and therefore, this can be called as we already noted this is called as the Multipath Power Profile.

What you can see is that they there are multiple components that are arriving over an interval of time, it is not a single component which is arriving at a single instant of time, but there are multiple components arriving over a certain time interval or over a certain Spread of Time and this Spread of Time is termed as the Delay Spread. If you look at this time interval, so first what you will observe is there is a Spread of Time.

Spread of Time means basically there is duration of time there is not a single instant of time, there is duration of time or a spread of a time or what we can also see is that various delays are spread over an interval of time and hence this spread of the delays, this duration or this interval of time over which these various signal components are arriving is also known as the Delay Spread. This is an important quantity for a wireless channel. This spread of delays, this quantity here that is the spread over which these different signal components are arriving, this different multipath signal components are arriving this is also termed as the Delay Spread.

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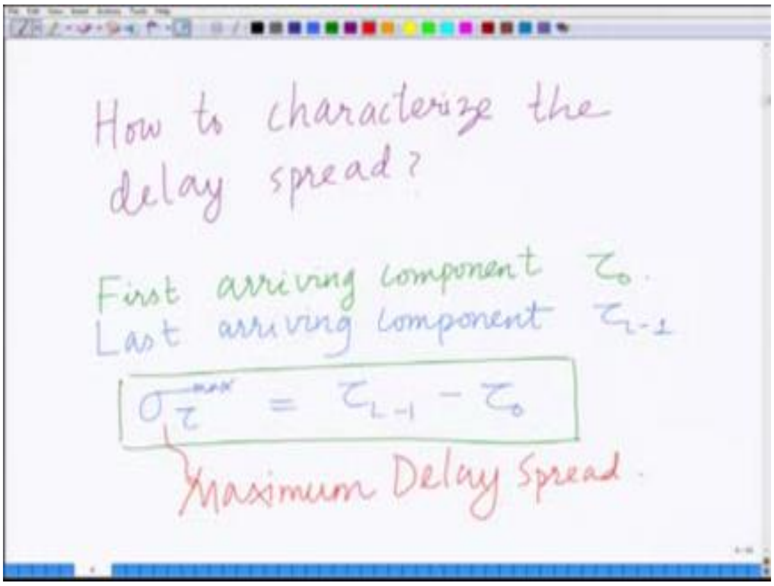

How do we characterize the Delay Spread of a wireless multipath channel? How to characterize the Delay Spread; that is the question that we want to ask and address right now so, how do we characterize the Delay Spread, how to characterize the Delay Spread? Well one way to characterize the Delay Spread is using a metric known as the Maximum Delay Spread. So, we have to develop matrix to characterize the Delay Spread, one of the matrix is the Maximum Delay Spread and that can be done as follows.

For instance let us say the first arriving component, the delay corresponding to that is τ_0 and the last arriving component, last arriving component arrives at a delay τ_{L-1}, this is the last L th multipath component arrives at a delay τ_{L-1}.

Then the Maximum Delay Spread which is termed as σ_τ^{max}; or let me, write it this way

$$\sigma_\tau^{max} = \tau_{L-1} - \tau_0$$

So it is a difference in the delay between the First arriving component and the Last arriving component. So, this is the definition of the metric one of the matrix to characterize the Delay Spread, this is termed as the Maximum Delay Spread which is equal to τ_{L-1} - τ_0 that is the delay of the Last arriving component minus the delay of the First arriving component.

That is the delay of the L - 1 th path, minus the delay of the 0 th path. This is the very simple matrix; basically it sees what is the Last arriving component and what is the First arriving component and what is the delay between, what is the difference in the delay, what is the time interval or what is the duration between these two components and that is the duration over which the multipath signal is spread. This is known as the Maximum Delay Spread we have denoted this by σ_τ^{max}, so this is the Maximum Delay Spread.

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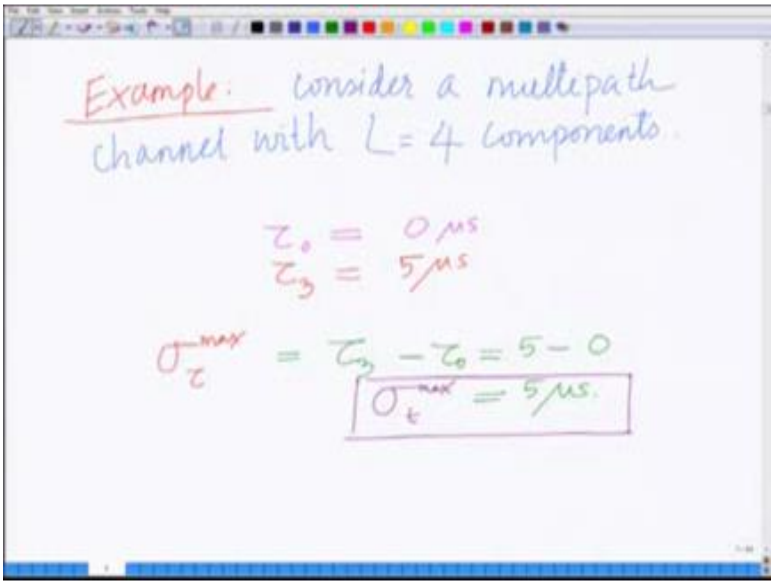

For instance again let us take a simple example, let us go back to our L = 4 multipath channel, consider a multipath channel with L = 4 components and also let us say now that τ_0 that is the delay of the First arriving component equals τ_0 = 0 micro seconds and τ_3 = 5 micro second. Then what we are saying is that Delay Spread that is

$$\sigma_\tau^{max} = \tau_3 - \tau_0 = 5 - 0 = 5 \text{ micro seconds}$$

as simple as that.

What we are saying is basically that, in a scenario where the first multipath component is arriving at 0 micro seconds, the last multipath component is arriving at 5 micro seconds, the Delay Spread or the Maximum Delay Spread is simply the difference between these delays that is 5 - 0 which is 5 micro seconds.

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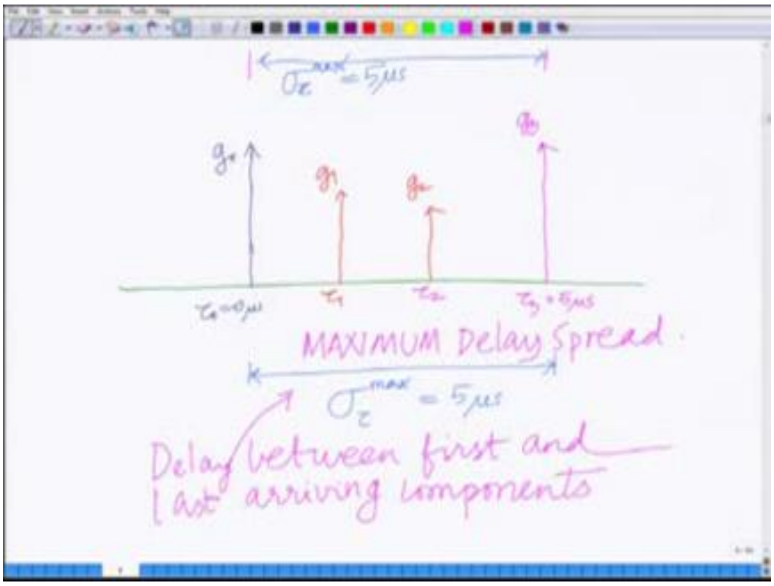

To look at this pictorially, we can again just look at a simple picture to illustrate this point. I have different paths gain 0, which is arriving at $\tau_0 = 0$ micro seconds then I have a second path, which gain 1, which is arriving at τ_1, I have another path with gain 2 which is arriving at τ_2 and finally I have my last path which is arriving with gain 3 at $\tau_3 = 5$ micro seconds and now what you can see is that the Maximum Delay Spread is the spread between the first and the last arriving paths. This is equal to 5 micro seconds that is my sigma tau max which is the Maximum Delay Spread, which is the delay between the first and last arriving component. So, that is the delay between the First and Last arriving component; that is equal to 5 micro second.

This is also termed as the Maximum Delay Spread, this is one of the matrix used to characterize the Delay Spread of the wireless channel. This is not the only metric, we are going to look at another metric shortly. So, the Maximum Delay Spread is one of the matrix and it is a simple metric to characterize the Delay Spread of the wireless communication channel, it gives us an idea of the time duration or the Spread of Time over which the signal components are arriving, that is starting from the first; time of arrival of the First component, to the time of arrival of the Last component and the interval between them is the Maximum Delay Spread.

So, we will conclude this module here and we will look at some other matrix for characterization of the Delay Spread in the subsequent modules.

Thank you very much.