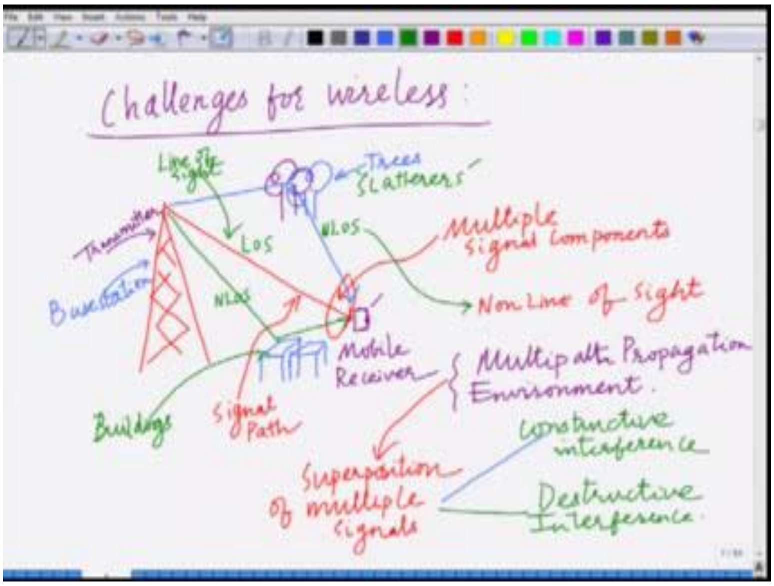
Principles of Modern CDMA/ MIMO/ OFDM Wireless Communications
Prof. Aditya K. Jagannatham
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

Lecture – 02
Modeling Wireless Channel

Hello. Welcome to another module in this MOOC on CDMA, MIMO and OFDM Wireless Communication Systems. In the last module we had seen the motivation or we had been basically seen how this wireless communication technologies that is MIMO, CDMA, OFDM technology have enhanced the data rates and reliability across different generations wireless communication systems.

Now, let us start our study of these communication systems to understand the motivation behind this let us first start by understanding the challenges in the context of wireless communication systems.

(Refer Slide Time: 01:00)



So what are the challenges for wireless communication system. That is, let us say we have a typical wireless communication scenario with a base station mounted on the top of a tower. So, this is my base station or my transmitter and I also have my mobile station or my mobile which is at the user and when the transmitter. Also let us consider a downlink scenario in which the base station this is transmitting and this is my receiver. And of course, when the base station is transmitting typically what I have is the signal which propagates and reaches the mobile. So, this is the signal which is propagating from the base station of the signal path which is propagating in a straight line from the transmitter to the mobile.

However, in a wireless communication scenario unlike a wire line channel there is no guiding medium there is no wire between the transmitter and receiver. So, while there is straight line path between the transmitter and receiver there can also be multiple reflected components which arise from for instance objects such as trees. So, this are some trees in the wireless propagation environment and you can also have some other objects which deflect the signal for instance such as buildings these are my. There are trees there are buildings and these what these are doing is these are deflecting these are scattering the received wireless signal.

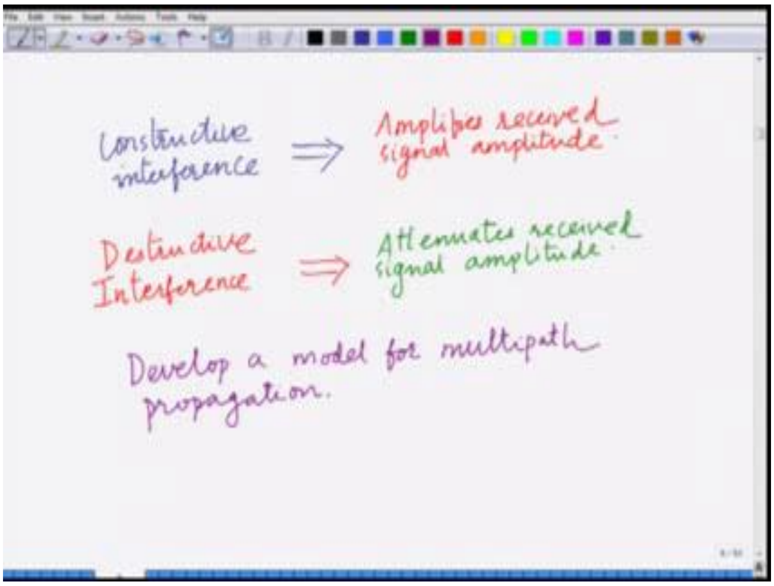
Therefore, these are also known as scatters. So, these trees and buildings are known as scatters scatter the wireless signal as a result of which you have not only the straight line component, but you also have this multi path components these component which are arising from the scattering action of the scatters that is the trees and the buildings in the multi wireless propagation environment. So, what you have at the receiver if you can see this at the receiver is multiple signal components.

So, you have multiple signal components at the receiver this component which is the straight line component is known as the line of L O S or the line of sight component. These components which arise from the scattering action and which are not which basically are the deflected components these are known as N L O S for the non line of sight, these are known as the non line of sight components. We have wireless propagation environment in which there is a line of sight path between the transmitter and receiver and there are also multiple non line of sight component and together what we have is multiple signal component at the receiver. And therefore, this is also known as a multi path propagation environment the wireless communication environment the fundamental aspect of wireless communication environment is that it is a multipath propagation environment.

So, this is a multipath propagation environment and therefore, what we have in this multipath propagation environment is we have the superposition of this multiple radio waves or this multiple electromagnetic waves or this multiple radio signals this multipath propagation environment this leads to superposition of multiple signals as a result. Now we know from our basic knowledge of physics that this multiple electromagnetic signals interfere or superpose with each other they basically interfere and that can lead to interference which either constructive in nature or destructive in nature. So, this leads to first interference and this interference can either be constructive interference or this leads to interference which is either constructive or destructive.

If the interference is constructive that enhances the signal amplitude if the interference is destructive then that basically attenuates the signal. So, when we have constructive interference.

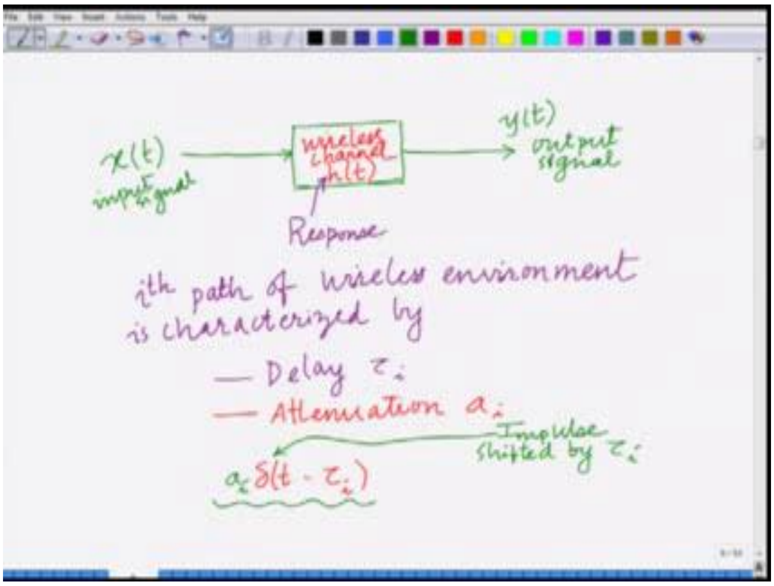
(Refer Slide Time: 07:16)



So, constructive interference amplifies constructive signals amplifies received signal amplitude destructive interference this therefore, attenuates. So, the destructive interference attenuates the received signal amplitude. This leads to an interference environment multipath signal propagation wireless environment leads to interference of these multiple signals at the receiver, which if it is good can be constructive in nature constructive interference which enhances the signal strength, but also it can also be bad that is when it is destructive interference it leads to an attenuation of received signal. So, what would we do, what we would like to do is we would like to develop a model for this multipath propagation environment.

So, our aim is to develop a model for this multi path propagation environment and therefore, to understand this wireless propagation environment better. We would like to develop a model for this multipath propagation scenario and how do we develop for the model for this multipath propagation environment, when we talk about a model in the context of engineering or communication we are talking about input or output system.

(Refer Slide Time: 09:44)



Let say we have a signal x(t) which is input to my signal to my wireless system and this is my output signals. This is my input signal and this is the output signal and this is my wireless environment or my wireless channel between the transmitter and receiver, you would like to develop a model for the response of this system that is h(t) impulse response of the system, we would like to develop a model for the response of the system this is also known as the wireless channel.

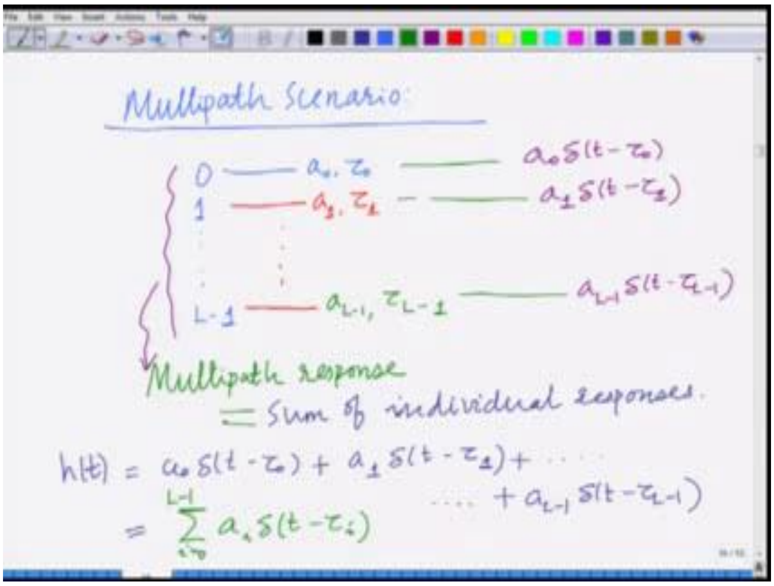
This is h(t) that is what is the relation between the transmitted signal and the received signal that is transmitted signal h(t) and the received signal y(t) to know that it is important extremely important rather to basically develop a model for this wireless channel, the intermediate wireless channel h(t) and once we develop a model for h(t) and then knowing the transmitted signal h(t) one can basically get a idea or one can derive the received signal y(t).

Therefore, we would like to develop a model for this impulse response of the wireless channel that is h(t). And now we can observe from the wireless environment that it is a multipath propagation environment and each path is characterized by 2 aspects, 1 is the delay because of the propagation the other is the attenuation which is arising from the scattering each path. Let us say there are L paths, the i-th path of the wireless environment is characterized by a delay that is τ_i and then attenuation that is a of i. So, each i-th path in this wireless communication system is characterized by the delay of the signal which is τ_i and at attenuation which is a_i.

And from the perspective of signals we can represent a delay as system with a delay can be model as delta of the response of the signal which delays the signal by τ_i can be modelled as : $a_i \, \delta(\tau - \tau_i)$ where δ is the direct delta function or this is the impulse, the impulse which is shifted by τ_i and this is therefore, multiplied by a_i which is the attenuation.

Now, this represents a system that is $a_i \, \delta(\tau - \tau_i)$ represents the system which attenuates the signal by a_i and delays it by τ_i and therefore, now if we have a system which as L multipath components from 0 to L minus 1.

(Refer Slide Time: 13:28)



So, we have a system multipath scenario with L components that is 0, 1. So, on up to L - 1 and for instance the 0 th path is associated with attenuation a_0 delay tau naught the first path associated with attenuation a_1 delay τ_1. So, on up to L – 1 path is associated with delay a L minus 1 and attenuation a L minus 1 and this gives rise to the channel for the 0 th path which can be modelled as we have seen attenuation τ_1 the impulse delta shifted by tau 0, that attenuation a_1 the impulse shifted from by tau 1 attenuation a_{L-1} impulse shifted by τ_{L-1} that is the delay corresponding to the $L - 1$ path and now what we will see.

So, this is the 0 th path first path and the L minus 1 path and the multi path impulse response is basically the sum of all these components. So, our multipath channel response because remember the received signal is a superposition of all the signal components therefore, the multipath channel response $h(t)$ is a sum of all these individual responses corresponding to the individual components.

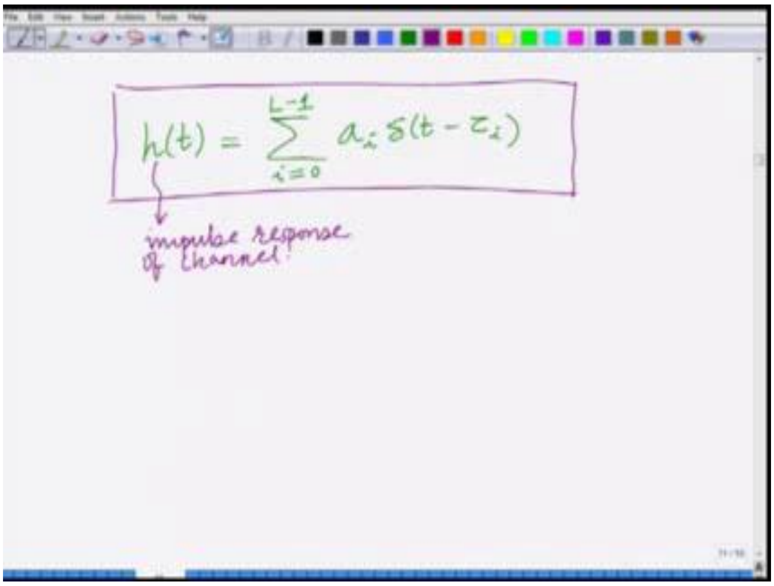
So, the multipath response equals sum implies my response –

$$h(t) = a_0\,\delta(t - \tau_0) + a_1\,\delta(\tau - \tau_1) + \ldots + a_{L-1}\,\delta(\tau - \tau_{L-1})$$

which can be subsequently written as

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

(Refer Slide Time: 16:28)

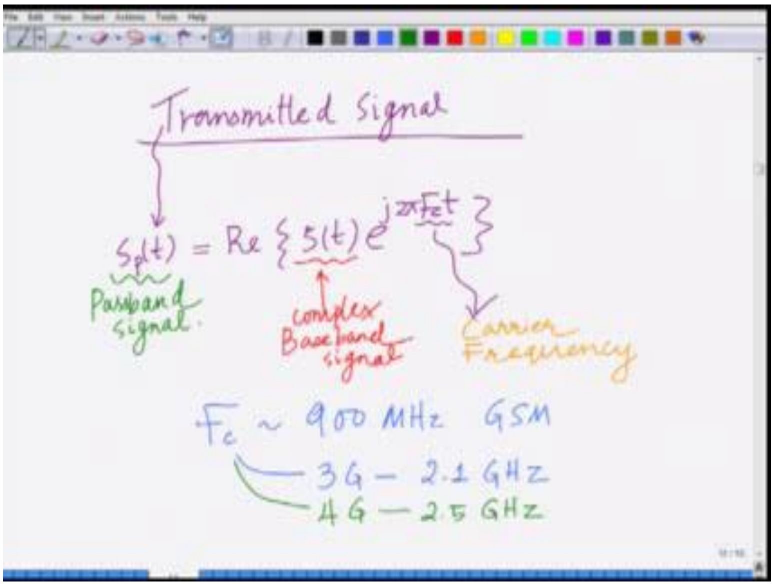


Therefore, what we have done is why we have now developed a model for this intermediate channel, that is the response of the channel $h(t)$ in terms of attenuation of the path and the delays of the path and what we are saying is this response h(t) is equal to

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

This is the impulse response of the channel. So, what we have done is we have been successful in developing a impulse response of the channel that is how to model the channel between the transmitter and receiver for this multipath wireless propagation environment.

(Refer Slide Time: 17:26)



Now, let us look at the transmitted signal the transmitted signal in the wireless communication signal system. The transmitted signal can be written as follows what we call as a pass band signal Sp(t) equals –

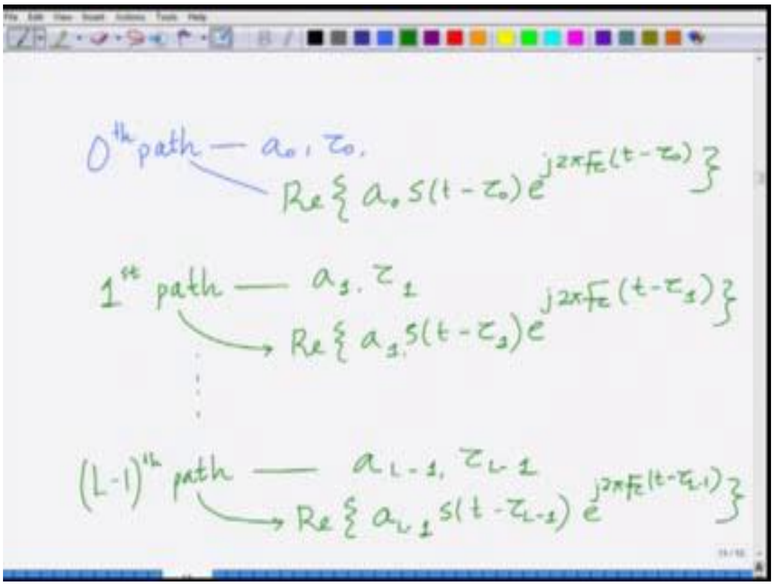
$$S_p(t) = \mathrm{Re}\{S(t)\, e^{j2\pi f_c t}\}$$

So, this signal S(t) is complex this is termed as the complex base band, this is up converted to a carrier frequency fc and this is transmitted over the air right this transmitted over the radio propagation channel. So, fc is basically this basically denotes the carrier and $e^{j2\pi f_c t}$ denotes the modulation with the carrier frequency.

So, fc denotes the carrier frequency S(t) is the complex base band signal and this Sp(t) this is termed as the pass band signal. So, I have Sp(t) pass band transmitted signal is basically the real part of base band complex base band signal s(t) times $e^{j2\pi f_c t}$ which represent the modulation by the carrier at carrier frequency fc for instance and this carrier frequency plays an important role in wireless communication system. For instance fc is approximately equal to for instance several countries operate G S M in the 900 mega hertz band and for 3G for instance for 3G fc is approximately equal to 2.1 gigahertz that is 2.1 gigahertz band and for 4G this is equal to 2.5 gigahertz band and of course, these bands are not fixed these band varies from country to country depending on the frequency bands allocated in that particular country that particular region.

So, these are rough indication of the different bands that can for instance are allocated, it is about the major countries across the world this various wireless communication systems and therefore, what we have is that when this communication signal Sp(t) is transmitted that is this pass band signal is transmitted across the multipath communication channel.

(Refer Slide Time: 20:37)



We have the different multipath components of course, component 0 is going to for instance we have looked at this previously that is the 0 th path, this corresponds to attenuation by a_0 and delay by τ_0 therefore, which means the signal corresponding to the 0 th path is basically the signal which is attenuated by a_0 and delayed by τ_0 that is

$Re\{ a_0 S(t - \tau_0) e^{j2\pi f_c(t- \tau_0)} \}$

Similarly for the first path which corresponds to $Re\{ a_1 S(t - \tau_1) e^{j2\pi f_c(t- \tau_1)} \}$

and so on and so forth. We have L paths. So, the $L - 1$ component counting from 0 that is $L - 1$ th path which corresponds to attenuation a_{L-1} delay τ_{L-1}.

So, that will give rise to the pass band signal $Re\{ a_{L-1} S(t - \tau_{L-1}) e^{j2\pi f_c(t- \tau_{L-1})} \}$. These are what we are saying we have L paths from 0 to $L - 1$, the i th path is associated with attenuation a_i and delay τ_i and therefore, the resultant pass band signal corresponding to the i th path given as $Re\{ a_i S(t - \tau_i) e^{j2\pi f_c(t- \tau_i)} \}$. These are the various signal components pass band signals components that are associated with the various paths, these are also known as the multipath components these are also the various multipath components of the signal that are received at the receiver in this wireless channel.

We will stop this module here and we will carry on with the analysis that is modelling receive signal at the wireless receiver in the subsequent model.

Thank you.