Fundamentals of MIMO Wireless Communication
Prof. Suvra Sekhar Das
Department of Electronics and Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture - 05
Wireless Channel Models – I

Welcome to the lecture on Fundamentals of MIMO Wireless Communication. In the previous lecture we have been talking about layered view of transmitter and receiver. In that discussion we were trying to say that if you take a look at the channel from the different points at a transmitter you would see different manifestations of the link between the transmitter and the receiver.

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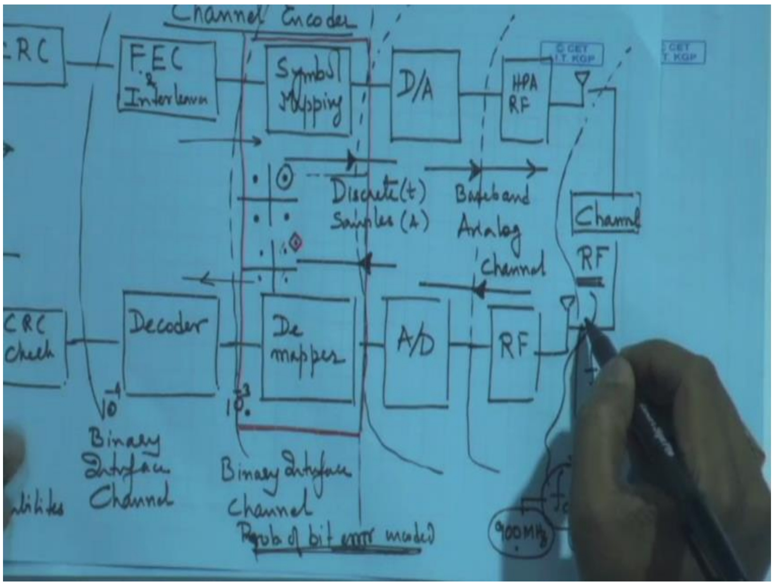

If we take a look at the picture that we had drawn in the previous lecture, we had drawn the schematic of the transmitter followed by the schismatic of the receiver while with the channel in between. What we summarily said, is that typically we would look at the channel as the RF channel for wireless communications. However, if we take a look at this section which eliminates the RF section we are usually looking at analog baseband channel.

If we take a look at the previous section we are looking at the discrete samples of the channel. That means, discrete samples go into the channels discrete samples come out of the channel. There is a transmitter processing unit there is a receiver processing unit. the input to this are, bits the output of these are again bits.

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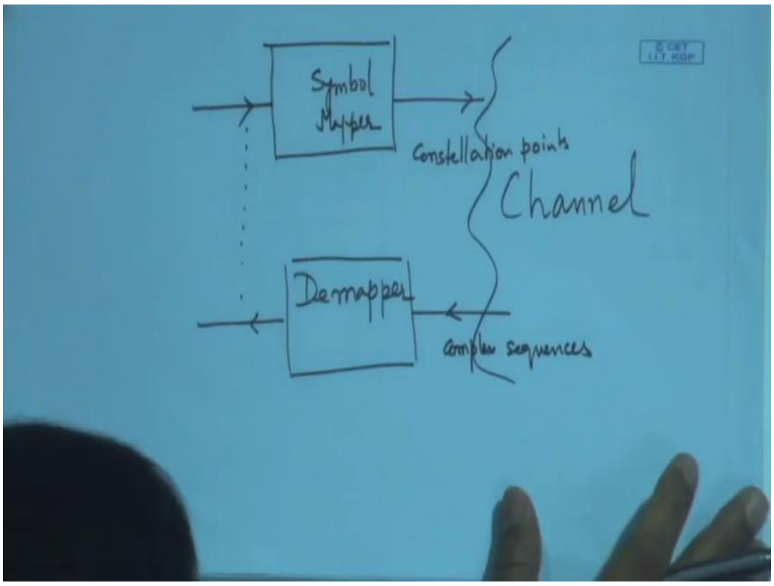

So, if we look at this part only what we have is the symbol mapper also sometimes called the modulator which send signal into a channel and channel gives output and it is the job of the demapper to reconstruct the bits which were at the input of the symbol mapper. Here clearly what we see inputs are constellation points, output is something in the signal space it can be for example complex sequences could be any others. If we take any other stage, for example if we are starting to look at the channel here that means, if I am taking sending signals in here and getting them out the channel would appear as a binary channel.

What we are effectively trying to say is channel depends upon from where you are seeing it and it encompasses the entire thing remaining on the right side of this particular picture. So therefore, we can see that if we are talking about symbol mapping the job of the symbol mapper and the demapper simultaneously is such that it should generate signals in such a fashion when it goes through this composite channel, is the composite channel of the RF channel the up conversion, the down conversion, the D to A converter, the A to D converter. And when it comes out after going through everything over here it should be able to reconstruct that means, the demapper should be able to reconstruct whatever is happening here.

So, this channel depends upon what we have obstructed. The symbol mapping and the demapper together is designed in such a way that there is minimal distortion happening to the particular channel that which it is observed. Symbol mapping is the module of the transmitter demapper is the module of the receiver. This is usually a baseband signal processing unit and this is usually a signal generation unit.

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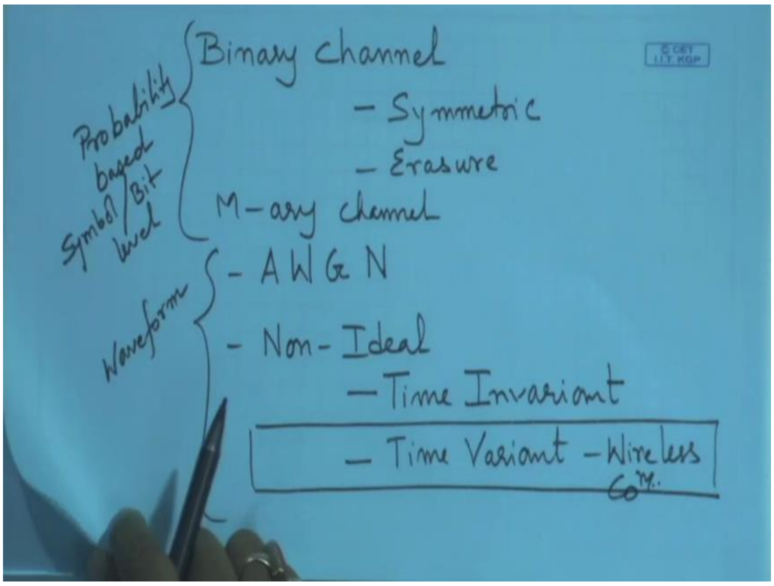

With this what we had also summarized is that when we talk about channels or the channels which you have come across could be listed down as binary channel which you may have come across as binary symmetric channels, binary erasure channels they could be instead of binary they could be M-ary channels, it could be symmetric or asymmetric. These are usually probability based and at symbol or bit level. Whereas, the next set of channels are usually the wave form channel which takes continuous output. One such example of a famous channel is the additive white Gaussian noise channel which you have come across in studies in digital communications. Then there would be non-ideal channels as if there is a filter between the transmitter and receiver, so here is the filter.

In case of AWGN, there is addition of noise. In case of non-ideal there will be some kind of a filter for example the telephone line. In non-ideal channels you would have time invariant which is typically involved in line communications and time variant which is the most important kind of channel in wireless communications. So, as we move ahead further in our study of channels we will mostly be concentrating on time variant channels and usually these models would be linear models.

Typically we say that the understanding of the channel is bread and butter for the wireless communication engineer. The reason is clearly apparent because if we take a look at the earlier picture specially this one the wireless communication engineer is suppose to design individual modules at the transmitter he should be able to design individual modules at the receiver. The job of the transmitting module is to generate signals which go through minimum distortion the job of the receiver module is to reconstruct the signal matching as closely as possible to the input at the corresponding peer point.

So, unless we understand what is happening to the signal in this part of the channel beep the RF section or the analog section or the discrete analog section; we have to understand the details then only we will be able to do a reconstruction. If we understand the details then we can shape the signals in such a way that it undergoes minimum distortion. So, it is absolutely essential to understand the communication systems. Typically before a communication system starts getting designed the channel is usually measured and well understood, For example, if somebody or if when 4G was getting designed or when 3G was getting designed one of the first things was that happen to identify the frequency of operation.

Now again as you see over here, ultimately is the RF channel; ultimately it goes into the wireless medium. This RF one of the fundamental elements which is design define this is the carrier frequency. And as we have said earlier if the frequency is let us say 700, 800 or 900 mega hertz this is one common frequency which we know or if we look at 30 gigahertz, the f x of the channel are different. Although we can remove the RF section in our analysis, but the corresponding effects need to be captured in the baseband channel. The effects which are at 900 mega hertz definitely different then the effects are 30 gigahertz.

A model we will be able to capture both provided appropriate parameters are used. And therefore, all communication system designed begins with first identifications of the frequency band of operation so that the channel properties are well captured. Once the frequency band of operation is decided then the channel which lies between the transmitter and receiver is characterized.

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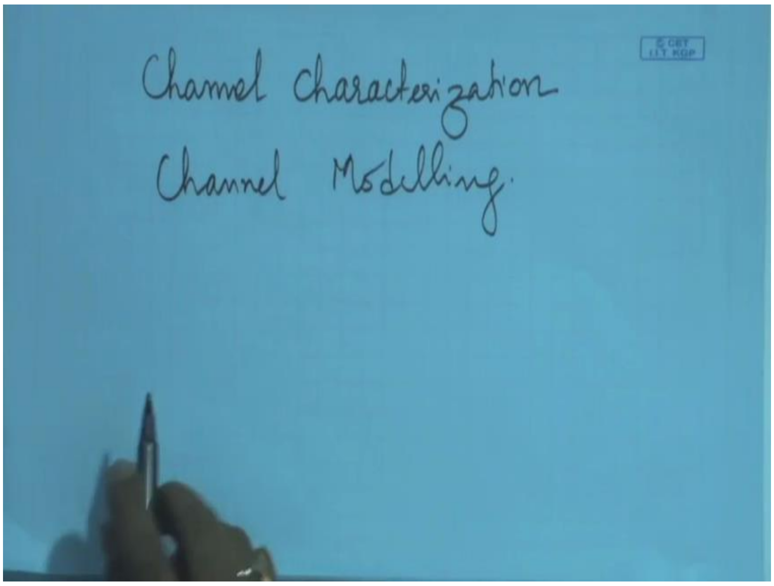

So, basically channel characterization precedes any activity on communication system. So, when we mean channel characterizations what we mean is, understanding the channel effects, what happens to the received signal when a particular time of signal is send from the transmitter. For example, we can study the effect on continuously of transmission or we can also study the effects on impulse transmission, depending upon the kind of communication systems that we are about to discuss. The other important thing we should note is when we talk about the channel it depends upon what is our end goal. If we look at this part one possible goal to design the communication system is to measure the bitter rate or to design these blocks in such a way that the bitter rate is minimized. The channel model that will produce should be able to provide sufficient details to capture the particular information that we are suppose to be using in the design of communication systems.

Therefore what we can see is the channel is very very important; is very important to know what we are doing, it is very important to know what we are suppose to do, what exact details we required from channel model. Now this channel modelling is a very very important activity. We are generally not concerned with channel modelling most of the time in these particular codes we will be concerned with channel models. Channel modelling is an activity which precedes communication system design which requires channel sounding by sending a particular training sequence measuring with very specific equipments coming up with curve fitting and various methods by which a particular model can be generated.

Now let us take a look at what are the important aspects of studying the channel.

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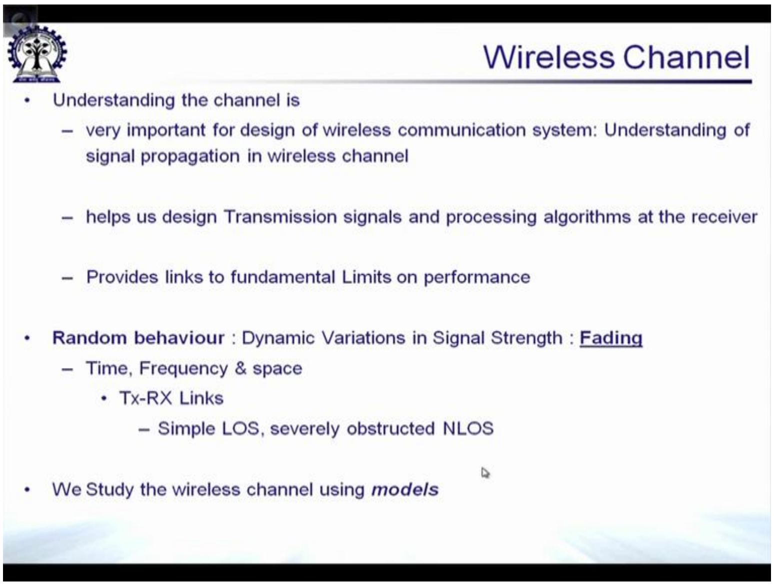

So, looking at the wireless channel models, understanding the channel model is important as we have said it is very important for design of communication systems, where interested to see what happens to the signal when it propagates through the particular channel. It helps us design transmission signals as well as processing algorithms which we have just explained. Also very importantly it provides links to fundamental limits on performance. What we mean by this particular point is that when we are having a transmitter and a receiver and there is a particular channel. Let us take one example where the transmitter and receiver is separated by a distance of 10 meters the maximum radiated power that is available is let us say 0 dBm. So we would like to understand, what is the maximum bit rate that can be achieved for this particular system if the band width is limited to a few megahertz?

If we take the same example and define it further say our operating environment is the indoor condition as case 1 and another the operating environment is outdoor, in a rich catering environment or let us say city centre region or if you take another region say the rural scenario. In all this three cases although parameters are different the operating environment are different and we would expect the performance limit to be different in each of the cases.

And if we add additional thing for instant mobility if we say the transmitter and the receiver are having relative motion and there is certain maximum speed between the transmitter and receiver again that will influence the maximum bit rate that is achievable in this condition. Very important thing about wireless communication system is the channel is random in nature. We will see why it is and the variation of received signal or the received signal strength is across the time domain. We have already said there is time variant channel. The received signal strength lies across frequency. For instance, I am interested in 900 megahertz band little bit to left of 900 megahertz band and little bit to the right of 900 megahertz the signal amplitude or signal strength is going to be different.

Similarly, space is another important dimension and for us in this particular course space is one of the most important dimensions that we will consider. Of course, time and frequency are definitely taken into a count. So, by space dimension what we mean is if I am receiving the signal at a certain distance from the transmitter let us say 10 dBm or 10 d f of s l r and I moved to a another location on the x y plane it could be moving closer to the transmitter or far away from the transmitter or even the distance remaining the same we have changed the angle, such as the radial distance between the transmitter and the receiver remain the same.

What we expect is that the average received signal strength could be different, simply because the paths of signal which propagates from the transmitter to the receiver could be undergoing different reflection refraction or scattering phenomena. There could be line of site, there could be severely obstructed situation. These will decide the kinds of effects in the signal undergoes.

Now, when we talk about the channel what we would be interested in is channel models. We will not be generating the models, but we will not be using the exact channel properties, but finally we will be using models. You have been using models in many studies. Now as the name suggests it finally a modelling. A model means it is an abstraction of the exact phenomenon that happens. For instance, again if we go back to this particular picture the same channel is present over here. It depends upon what we are interested in according to the channel is modelled differently.

Although it is a same effect it manifests itself at different locations in different ways. So therefore, we are we should remembered that we have end of the day using models and not the exact channels.

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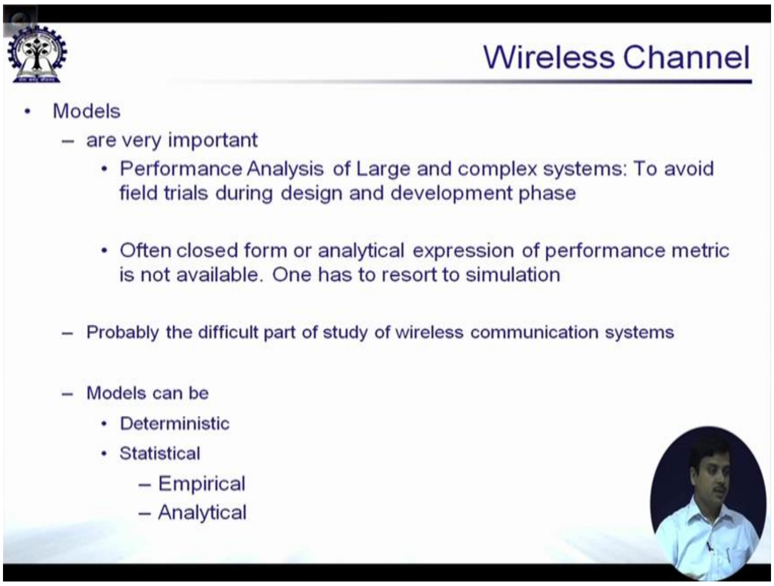

Now why we need models, because many times the systems are very very complex and it is not possible to get close form expression, it may not may possible to do even trials. For example, if I am designing the communication systems I would like to build the transmitter I have to build a receiver go and do field trials see what is the performance come back to the lab design the transmitter again design the receiver again and do it. It is hugely time consuming, it is very very complex. In order to avoid that we would like to use models so that while sitting in a lab or sitting in a rooms or in an office we are able to design transmitter and receiver components.

And many a times one has to resort to simulations we will see certain simulation things while we doing the course. While simulation means we imitate the effect that happens under transmitter or at the receiver and what happens in the channel. So, once we send a signal that goes out we model the impact of the channel and finally receive it. We can do all these things using a digital computer or specialized equipment. So, we do not have to go to the real field to the actual operation we can do it right sitting in our labs.

I think it is the one of the most difficult part of studying wireless communications and this is where we begin with. So, one of the messages which I would like to put forward is those who all are aspiring to pursue this domain of wireless communication it is very very important to understand the propagation effects and the channel models. At least if you understand one particular channel model you will get an idea how other channels are going to be, and due to variation of the similar kind of models that you are going to encounter.

Models can be deterministic, they can be statistical. Deterministic we mean we solve m equations for every surface that the wave hits then it gets refracted reflected or diffracted or even scattering and the account for the accumulating effect of these phenomena at the receiver which could give rise to fluctuation of signal strength across time frequency and space. These models are very very complex in nature, it requires huge amount of signal processing, and there are many many tools available for deterministic channel models; one of them could be like rate (Refer Time: 17:53). However, in the methods which we use for a special base band signal design we generally refer to statistical models.

These statistical models what they mean is there is a model with parameters and if we use the models it adheres to the certain statistical measures, for example the mean, the variance, the distribution or the coherence factors. So when the model, when iterated or tried over several several iterations for example, millions of 10,000s of iterations the statistical properties remains the same, and these are random in nature.

However, again the statistical models there could be analytical model there could be empirical models. In empirical models what we have is channels are measured from measurement curve fitting or in some other way models are developed which has the same statistical parameter as that of the measured channel parameters. End of the day we need very simple tools which we can use with pen and paper or in a computer so that we can design communication systems.

In this course we will be encountering a statistical channel models and mostly analytical. Of course we will look at some of the empirical model especially for large scale fading.

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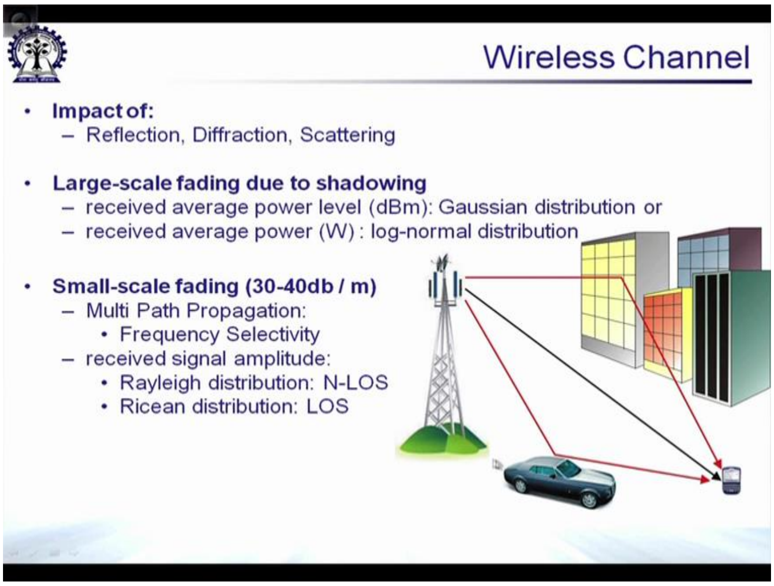

The factors which influence the channel are the propagation factors which are basically reflection diffraction and scattering which we have been mentioning. We divide the study of channel in the two broad categories; large scale fading and small scale fading. The large scale fading are those effects or those models which capture the effect of a signal fluctuation over large separation distances between the transmitter and the receiver, whereas small scale fading are those models which capture the effect of signal propagation or signal strength fluctuation across small separations.

If we consider this particular diagram as shown in this particular slide let us imagine that there is a transmitter which sends out signals. When these e n waves propagate we will assume of course the transmitter and the receiver are in the far field they are not in the near field region. The signals propagates they can fit a building surface they can come to the receiver. There could be a direct line of site there could be reflection from the moving objects, so it could be multitude of things that happen to the signal. So when they come to the receivers they combine together give a combined effect at the receiver.

As a result of which there could be a signal strength fluctuations. So, when we studied small scale fading we actually take into account this so called multi path propagation. The main explains the propagations from the transmitter to the receiver happen through multiple paths. That we first path, this could be this could be a second path, this could be third path and so on. Theoretically there could be infinite number of paths, but on all practical purposes we generally model them finite number of paths. And that is usually dependent upon the resolution of the instruments that which we use to measure the channel characteristics.

The large scale fading is usually dealing with average signals strength, whereas the small scale fading is usually is to provide models which predict instantaneous signal strength fluctuations. There is also effect of mobility, because of moving object between the path of transmitter and the receiver which results in the Doppler shift we will see in details. And this causes time selectivity of the signal that means signals fluctuate in signal strength even though the receiver may be static at one point. The receiver could be moving that could be one case, the other case the receiver and the transmitter is fixed, but there are moving objects which reflects refract or diffract the signals which finally come to the receiver. Because of this there are time variations of the signals that are arriving at the receiver.

One thing we can grossly remember is that small scale fading phenomenon or this particular model captures instantaneous variation of signals strength in the range of 30 to 40 dB typically it is not the final numbered, but that is the usually the range of fluctuations of signal strength at the receiver even though it is located at a fixed particular point.

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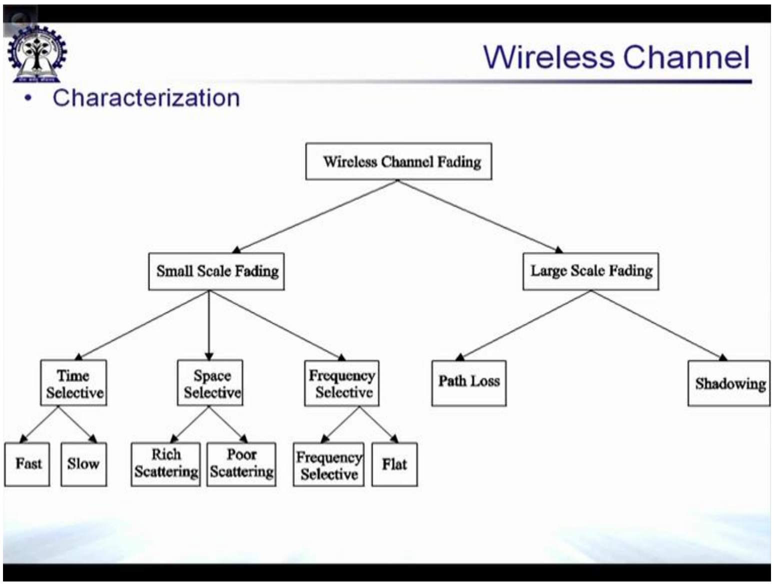

When we study wireless communications or the channel models the wireless channel fading effects that is a fluctuation of signal strength over time can be broadly categorized into small scale fading and large scale fading as mentioned in a previous slide. The large scale fading can be separated into two different models that is the path loss model and these shadowing models which we will see in subsequent lectures.

The path loss models are also sometimes known as the attenuation model which describes the loss of signal strengths due to separation of path length between the transmitter and receiver. The shadowing on the other hand captures the effect of local fluctuations of average s n r and improves upon the details of which is captured by the path loss model, both give the prediction of average received signal strength.

If we look at small scale fading the small scale fading can be classified as time selective fading, space selective fading and frequency selective fading. Time selective fading has the name suggest there is selectivity that means selection and the selection across the time axis.

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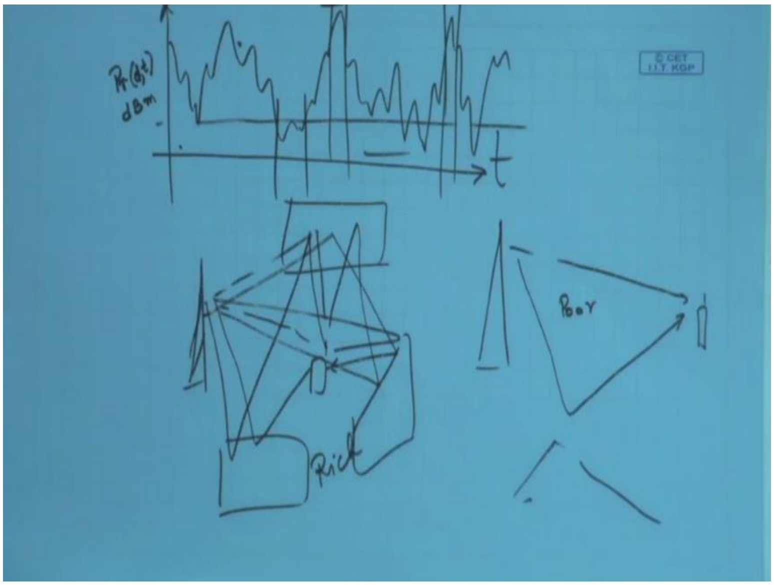

So, if we have time axis and if we have the received signal strength on this axis, across time if the signal strength is very low the channel is not allowing signals to go through. Across time if the signal strength is very high the channel would allow signals to go through on (Refer Time: 24:30) So, what we usually would see if I draw p received power at a particular distance as a function of time and measure it by let us say dBm, we might see this kind of figures where is like random fluctuations in time and these fluctuations would be in the range of 30 to 40 dB.

We call it time selective because across time there is selections in time windows where the signal passes through without much attenuation and there a sections in the time window where there is huge amount of attenuation of the signal strength at the receiver. One typical example that I can point at this particular instance is if you ever listen to amplitude modulation radio let us say the medium wave or the short wave transmission if you team into a particular station you will often find fluctuating signal intensity, and that is one representation of fading.

One thing I would like to remind it again in this particular subject or the things that we deal with it is very difficult to obtain situations where we can perceive the effects instantaneously. So, it is bit imaginative we have to extend our imaginations a little bit and that is why I mentioned as simulations is one way of getting closer and moving beyond imaginations towards practical systems. The next dimension is this space dimension. In the space dimensions it can be rich scattering or poor scattering. In the frequency dimension it could be frequency selective or flat fading. And the time that mentioned it could be fast fading and slow fading.

We will discuss the details of fast fading and slow fading when we talk about small scale fading. We will talk about details of frequency selective and flat fading when we talk about more details about small scale fading. About space selectivity I will briefly tell you now and we will take up in details. We have rich scattering and poor scattering, environment a rich scattering environment would be one where there is lots of reflections from the surroundings.

So, if we consider this particular room or the room where you are sitting the lot of walls, so there is a generation of a signal from the transmitter there are reflectors all around and there is a receiver let us say there could be one direct line of site path there could be reflected path 1, the reflected path 2, 3 could be multiple reflection and so on, so this is a rich scattering environment. Whereas, if we have the transmitter and it is a rural region where there is a not much obstruction available and there is a receiver and there could be one hill up will be a hill some point, it could be mostly line of site may be one reflected path moving to it; so this would be a poor scattering environment, this would be a rich scattering environment.

So, we will have to understand what goes on in these particular channel models so that we are able to capture the effect of the channel.

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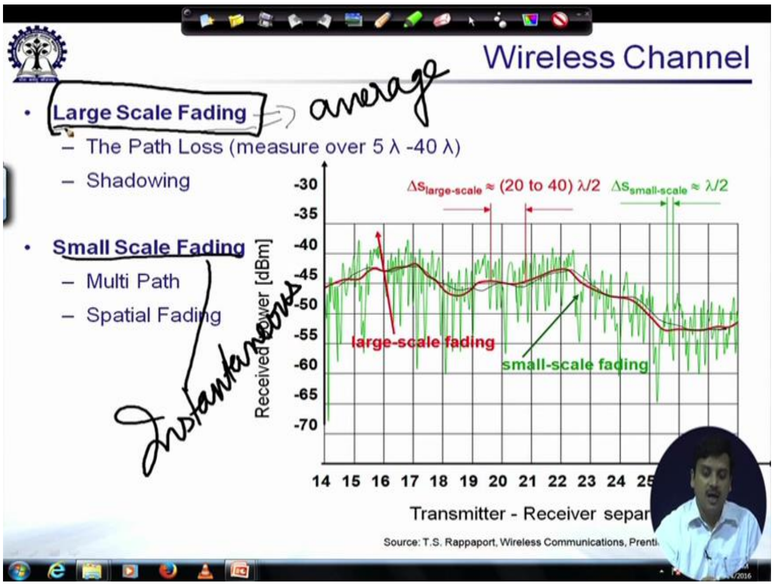

Before we close today's lecture I would like to explain this particular figure. This is available in the book by Rappoport. In that figure it is shown that the separation between the transmitter and receiver in the x axis represented in meters and the y axis it is a received power in dBm; what you see is the green lines fluctuating to a large extent is representation of the instantaneous variation of the signal strength or it can be called the small scale fading, because over small scale, this is a small scale within a meter which is within a few lambda or a fraction of a lambda or the wave length is huge fluctuation of signal strength.

You can clearly see it goes down nearly minus 70 dB from around minus 37 dB or so. So, there is around more than 30 dB of fluctuation in this particular snapshot, whereas if we start taking the average of these instantaneous fluctuations in this range what we get is the red line. So, if we are interested in the average or the model which predicts this average signals strength fluctuations are captured under the large scale fading in models. Whereas, the small scale fading model captures these small fluctuations, to show under large scale fading what we have is the average fluctuation.

So, this in term predicts the average signal strength, this is talking about the instantaneous. So, we will look at some details of large scale fading models which help us predict the received signal strength as a function of transmitter receiver separation distance across large distances. For instance, when the transmitter receiver separation distance increases by orders of hundreds of meters or by orders of few kilometres, whereas when we will be interested in studying the effect of signal strength fluctuation when the transmitter receiver fluctuation separation is in the order of lambda let us say a few centimetres or a few meters and then we will be resorting to the small scale fading models.

In the next few lectures we will start the briefly taking a look at large scale fading models before well being into details of small scale fading models. When we are concerned with the transmitter and receiver design we would be mainly interested in the small scale fading. For the sake of completeness we will briefly take a look at large scale fading model and just let me remind you our objective is to look at large scale fading model for the sake of completeness, but what we will be mostly needing in this particular course is the small scale fading models.

The reference books that you can follow for the future few lectures will be wireless communications by Rappoport mobile principles of mobile communication (Refer Time: 31:06), wireless communications by (Refer Time: 361:09) and many others. So, I would again request you to keep the references handy. Of course we will provide you with sufficient details in this and we may be able to provide you with some of the slides, but always reading such references would refine and provide more clarity to the details, because again iterate this is one of the critical parts of communications.

And successes in this course would depend primarily on understanding the details of these models or what is the abstraction that has been done in this model because the rest of the details MIMO communications would be using these models which we will not refer to a any further details once we cross over this section on this propagation effects of the wireless communication links, thanks.

Thank you.