Wireless Communications
Prof. Dr. Ranjan Bose
Department of Electrical Engineering
Indian Institute of Technology, Delhi
Lecture No. # 10
Mobile Radio Propagation (Continued)

Let us start looking at certain mobile radio propagation mechanisms in greater detail in today's lecture. The outline of today's lecture is as follows.

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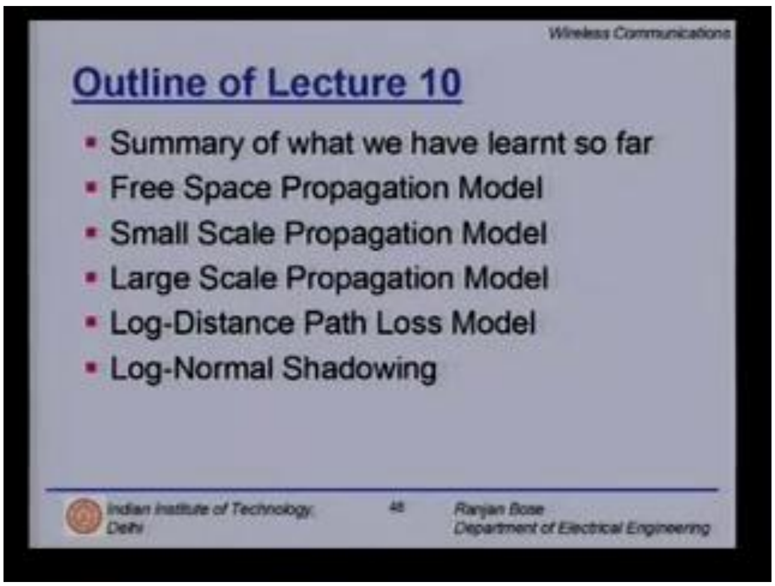

First we will start with summarizing what we have learnt already in the domain of radio propagation mechanisms. Then will revisit free space propagation model because it is still valid in many applications and it forms the basis for other models. Then we will look at something very interesting called 'small scale propagation model'. Followed by large scale propagation model we will look at a Log-Distance Path Loss Model. It is very important in urban areas. Finally Log- Normal Shadowing which is a more realistic model. Today's lecture will focus on various kinds of models and their applications. First let us recap what we have done already in the previous lectures. We have looked at reflection models.

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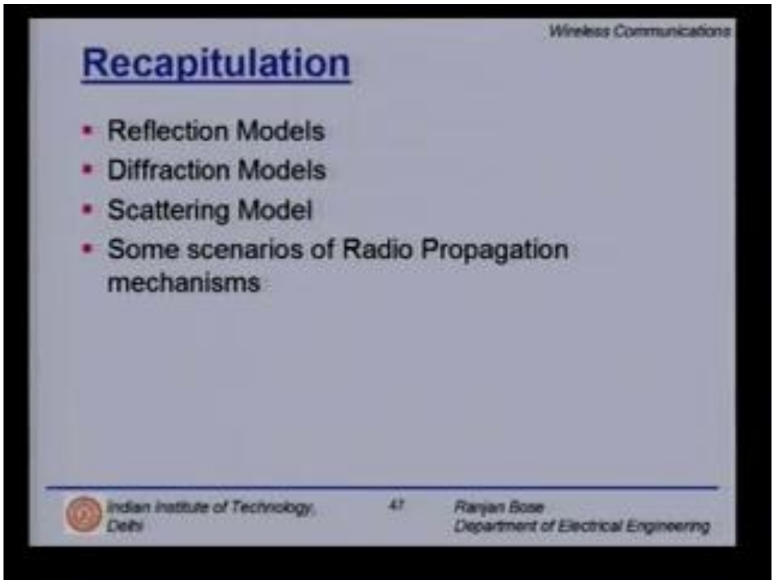

That is, when a ray travels from the transmitter to the receiver, it may get reflected from various reflectors. Now these reflectors could be metallic or dielectric. These two depend on what kind of material is being used. For example, you could have a sharp corner reflector from a window frame which is metallic or brick which is a dielectric break. So if it is a metallic reflector, you will get almost all the energy reflected back whereas if you are having a dielectric as a reflector part of the energy will be observed. Reflections form an important method for propagation and remember it is also used to illuminate regions which normally do not have proper signal strength. the other method is diffraction where you do not have a clear line of sight. However you can still get certain radiations by principle. We looked at the single knife edge diffraction geometry and also multiple knife edges diffraction geometry last time. Then finally we have the scattering model which will become important in the urban scenarios where even though, you do not have a line of sight. You get a lot of energy simply by scattering. All these things can be measured a lot of empirical propagation models are based on measurements. Lastly we also saw certain scenarios of radio propagation mechanisms wherein we saw reflection diffraction and scattering happening all at the same time. In today’s class, we will learn more in detail about these as well as the direct line of sight propagation.

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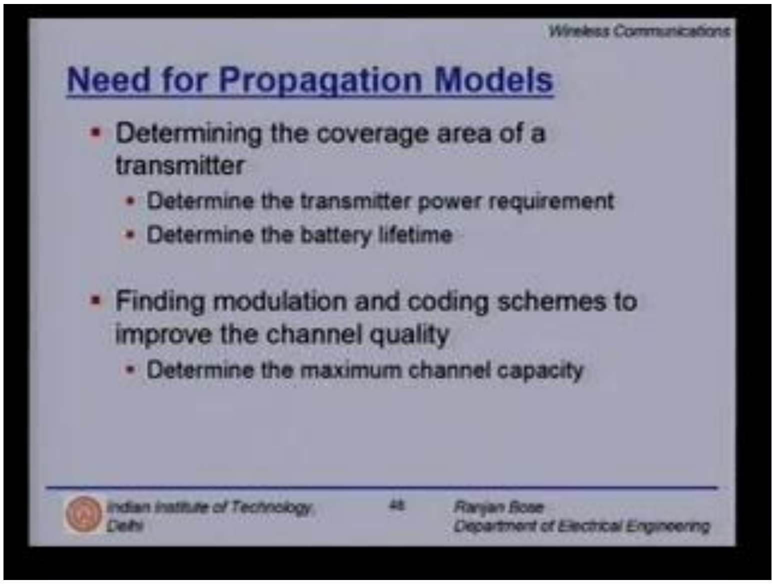

Continuing with the recap of sorts, we will remember that the need for propagation model is important because it helps to determine the coverage area of a transmitter. One of the important factors which tell us how large your cell size is is the link budget. The budget for the received power now if we have a good propagation model, I can accurately predict what will be the size of my cell if it is limited by the signal power. So it determines the transmit power requirements and also in effect determines the battery lifetime. So when I design my system, if I take into account, a proper propagation model, then I can actually optimize my cell life. the other interesting things is, it helps us predict what is the appropriate modulation and coding schemes that can be deployed in order to improve the channel quality. This is important because if I have a propagation model that is pessimistic, it does not predict very good signal strength available at a certain area. We would deploy lower modulation schemes. consider Emery digital modulation schemes and we would be probably going for BPSK because we think that the signal strength is weak and so signal to interference or signal to noise ratio will be poor and so to get this desired quality of service ,let us go with BPSK or utmost QPSK whereas, if your channel model and the propagation model was more accurate, you would have probably received more signal strength as per prediction and deployed may be 16 QAM or other higher modulation schemes thereby increasing your data rate. So the design perspective must take into consideration a correct accurate propagation model if it has to design the system.

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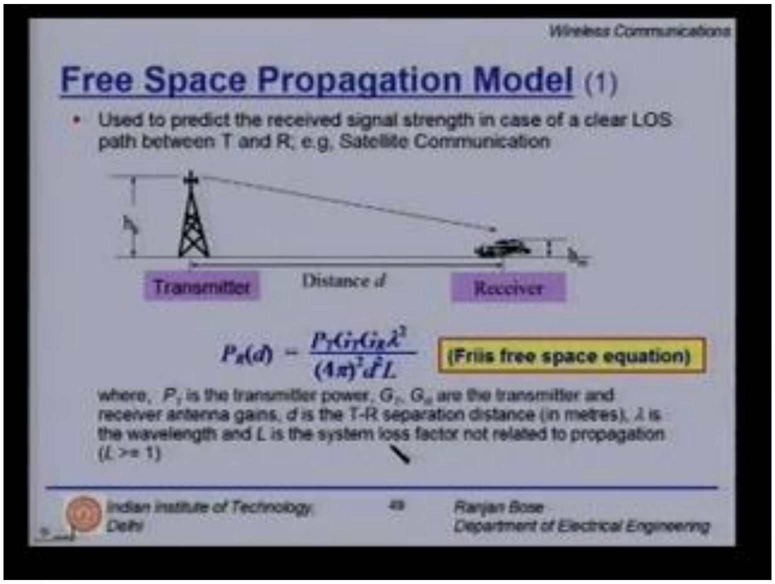

$$P_R(d) = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 d^2 L}$$

Now let us revisit free space propagation model. We have seen this before but it is important to emphasize on certain components of this free space propagation model. Clearly this is used to predict the received signal strength in the case when there is a clear line of sight between the transmitter and receiver. Now, many times we have indoor communication requirements wherein the transmitter and receiver do have a clear line of sight. In mobile communication where we use cell phones really, many times you do not have. So this free space propagation model will not hold. However, for example, satellite communications we do require a clear line of sight and hence this free space model will work. So it has its own applications. now consider a realistic situation where I have a transmitter, a base station antenna and a receiver antenna which is at a distance ‘d’ and let us assume that they do have a cleared line of sight. In this scenario we are not using the two path reflection model. Remember last time we also looked at the ground reflection model wherein not only a direct line of sight ray will come but one reflected from the ground will also appear at the receiver. In that case our receiver strength will be determined by the transmitter height and the receiver height. Here free space propagation model has no reflections. That is the first simplistic case. so the received power as we know has nothing but transmit power PT times that gain of the transmit antenna, GT gain of the received antenna GR lambda squared which is the wavelength squared whole divided by 4 pi or 4 pi squared d squared L where d is the distance between the transmitter and receiver. We know this is called the Friis free space equation. Now ‘L’ is the system loss factor which is not related to propagation. We will soon see that this L encompasses couple of other things as well. Let us spend a little more time on this equation and dissect it and see how the different parameters make a difference specially the lambda, the d and the L.

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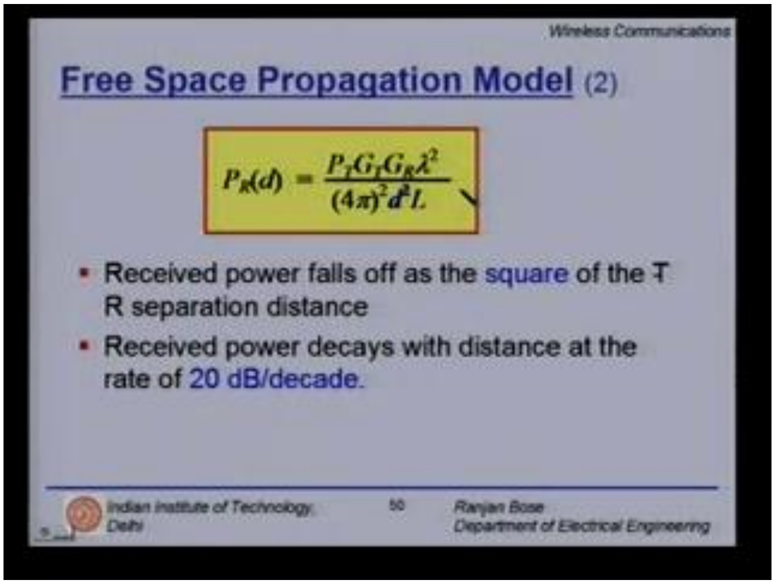

So this is our Friis free space equation. Let us focus our attention on the d squared- ‘d’ being the distance between the transmitter and receiver. Clearly the power falls as the square of the transmitter-receiver separation and received power decays with distance at the rate of 20 dB per decade. Very soon we will realize that loss used in the literature is expressed in decibels on the right hand side. you see a lot of products and divisions if we use the db scale, 10 log to the base 10 PR, then we will have all of the right side as summations and subtractions. So db scale is normally used to depict the received power as well as the path loss. Here we are expressing the received power as 20 db per decade.

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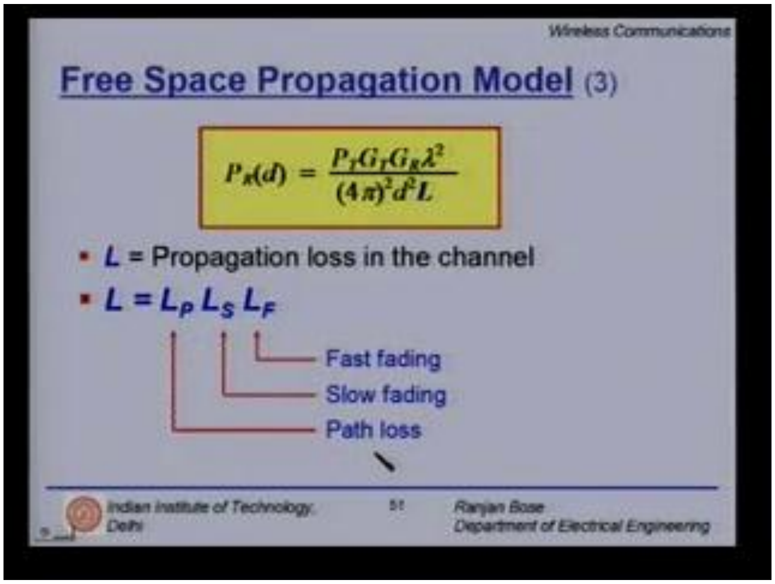

Let's look at the free space model but this time let us look at this 'L' because we are not tweaking with the transmit power PT, the gain of the transmitter GT or gain of the receiver GR. so L which is the propagation loss in the channel is expressed as LP times LS times LF. What are these? Well, they are very interesting parameters LF is fast fading. We will look at it very soon in the subsequent slides. LS is slow fading. So this phenomenon of fading will be discussed and LP is the actual path loss.

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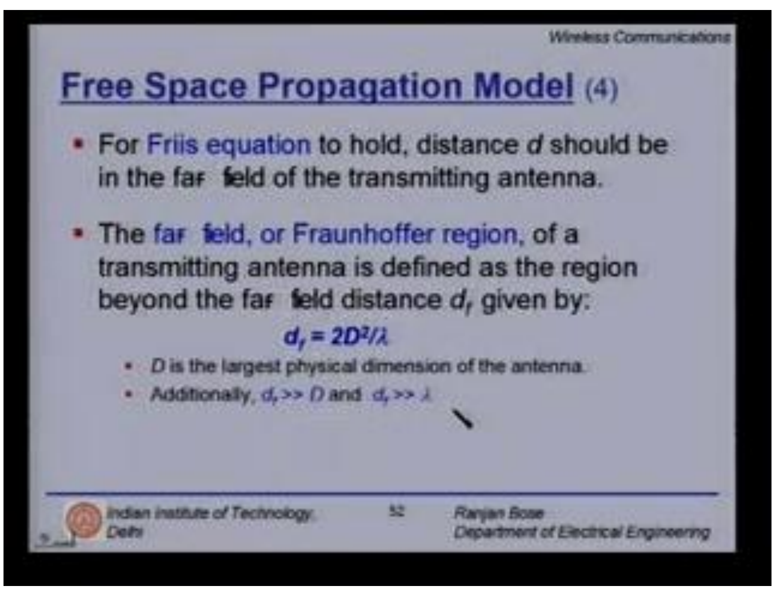

Now we have seen for the Friis equation to hold, the distance'd' should be in the far field of the transmitter. So it doesn't hold very close to your base station. As you have seen now what is this far field? The far field or the Fraunhoffer region of a transmitting antenna is defined as the region beyond the far field distance 'df' which is given by df = 2 D squared over lambda where D is the largest physical dimension of the antenna. So really the largest physical dimension also depends on the wavelength that we are going to use. So df is really dependent on the wavelength. Also you can say 'df' is normalized with respect to wavelength. Additionally we should have df much greater than 'D', the largest dimension of the antenna and 'df' much greater than lambda. Clearly a few meters or so in the GSM band will take you to the far field. So your equation will hold good beyond 5 meters or so.

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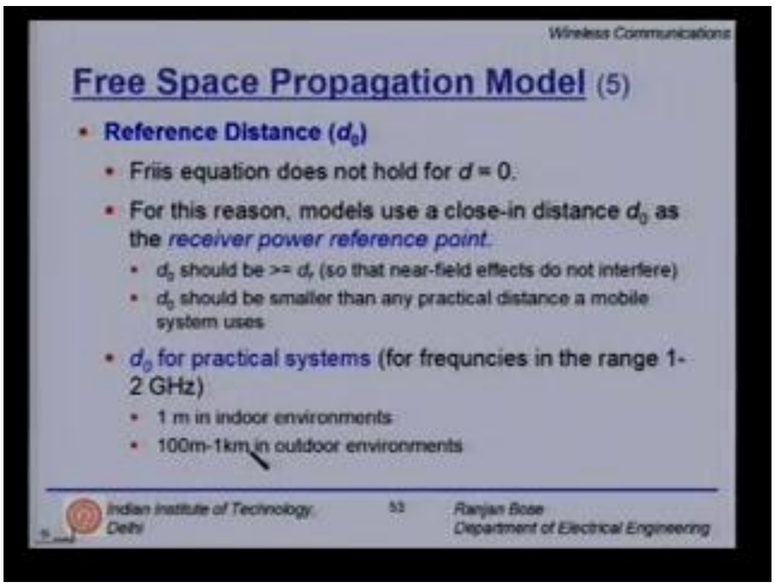

Now we know that the equation does not hold good for d = 0. For this reason, models use a close in distance d_0 as the receiver power reference point. Now d_0 should be greater than df so that the near field effects do not interfere. d_0 should be smaller than any practical distance of a mobile system user. So this is a reference distance and we can talk about any other received power strength at a further distance with respect to this d_0 distance. d_0 for practical systems could be from 1 meter in indoor environment to 100 meters to 1km for outdoor environments. What does this mean? This means that I can take a measurement and find out the power at a distance d_0 at 1 meter from the transmit antenna and with respect to that, we can find out all other distances. We have to go through this exercise because your Friis free space equation does not hold good in the near field region. For outdoor environments, we go from 100 meters up to 1km as a place where you have taken the measurement of power and then you can predict based on this near -close strength, what is the received strength at a further distance.

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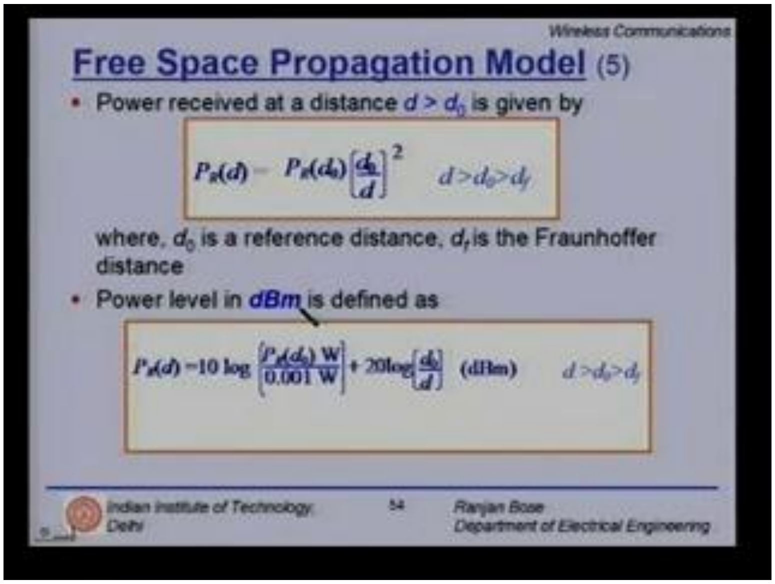

The received power at any arbitrary distance in the far field PR of d is given by PR d $_0$ the measure distance times d $_0$ over d whole squared which is giving you a notion of the inverse squared law that you get. Power level in dBm is defined as the receive power with respect to one mW and again we have started putting everything in log. So you have a dBm with respect to a mW of power.

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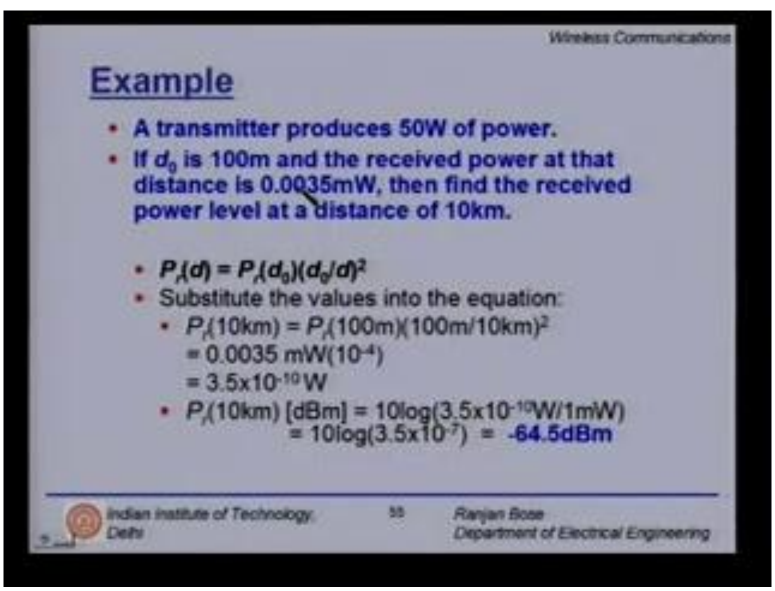

A quick example. a transmitter that produces 50 watts of power, if the d_0 is 100meters that is, we take a power meter put it at 100 meters and measure the signal strength and suppose the signal strength comes out to be 0.0035 mW. We are asked to predict what could be the receiver power level at a distance of 10 kilometers. Suppose your cell radius is 10 kilometers and one of your mobile stations are situated at the fringe, we would like to know what the received power is. So we use the equation $P_{rd} = P_{rd\,0}$times d_0 over d whole squared. We substitute the values, do some basic calculations and we get 3.5 into 10 raised to power -10 watts. We are not comfortable in expressing things in watts. So why not put it with respect to 1 mW of power and in dBm. It comes -64.5 dBm. This not too bad because your GSM phone receiver sensitivity can be as low as -100 dBm. So it still just gives you a feel of how weak powers can still be useful and you can actually calculate the received power at any distance provided you have a measured power. So this is a very simple model but a useful one.

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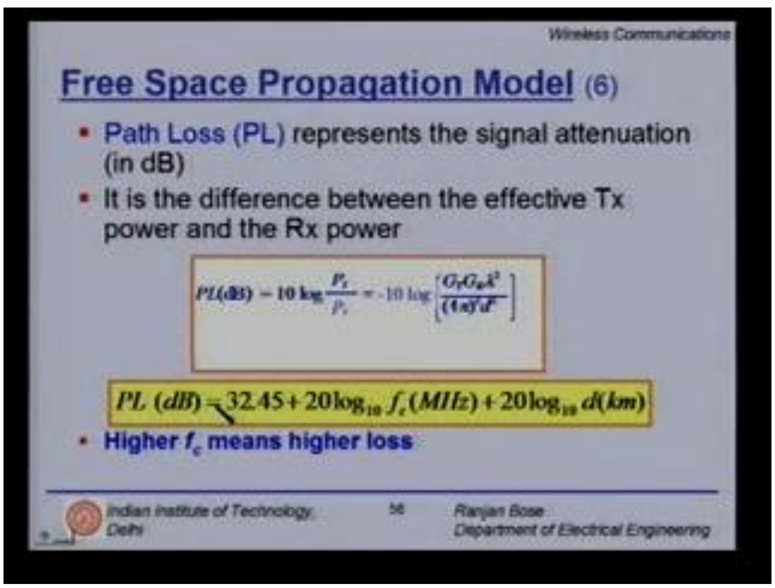

Now the path loss that we are talking about actually represents the signal attenuation period. It is typically expressed in db. it is simply the difference between the effective transmit power and the received power. So path loss in db is log 10 PT over Pr which is nothing but -10 log the Friis free space equation GT GR lambda squared divided by 4 pi squared d squared. if you go ahead and take GT and GR equal to 1, i.e., unit gain of the transmitter and receiver, then you can have the path loss in db in terms of a summation and this comes from choosing 4 pi squared here and then in terms of the frequency and the distance. So this distance 20 log to base 10 d in kilometer will give you the path loss in db. So these numbers have been normalized with respect to frequency in MHz and distance in kilometers. This equation is useful for predicting the path loss for mobile communication systems. Something to be noted: the frequency of operation is important. If you have a higher frequency, you have higher path loss. So as we go into higher and higher frequency bands, the loss is greater. So, higher frequency means higher loss.

Conversation between student & professor: the question being asked is: is this the ideal situation where we are not looking at interference or reflection or scattering? Yes. It is just the ideal situation. Not even the ground reflection has been taking place. So this will be perfectly valid for satellite communication for example. But in real life also, it can be all right. So I can use it to come up with a first level calculation to predict the receiver strength for mobile communication systems.

Conversation between Student and Professor: The question being asked is: Can we can predict the tolerance with respect to the scattering effect? The answer is no. what is done is, this model is too simplistic even to take into consideration the P 6 scattering reflection or diffraction. There is no amount of tolerance that can be added to this basic equation to make it good enough for a model that takes into account the scattering or the diffraction or the reflection effects. For that we need different models. Now how are those models derived? Well they can be either based on measurements and curve fitting or some theoretical analytical work. So we will briefly look at such models also but no matter how much tolerance you add to this, you cannot account for reflection scattering or diffraction here.

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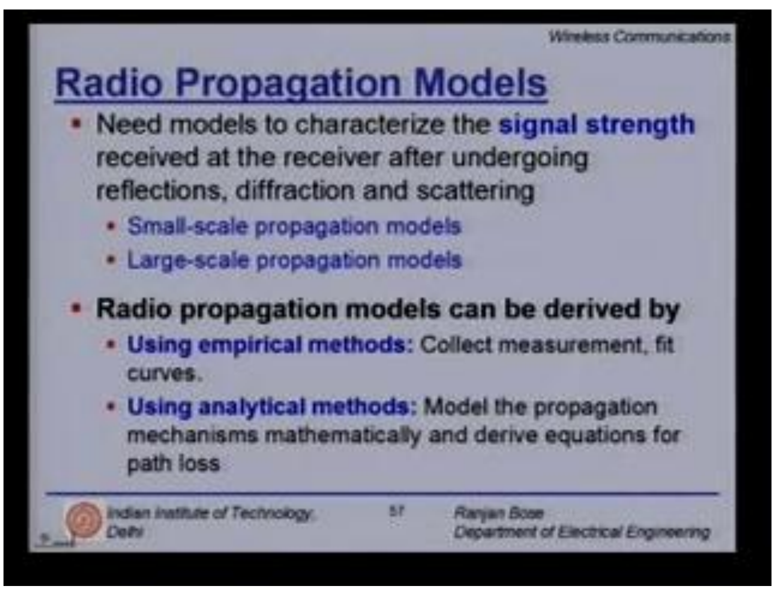

Now we would like to have signal models that characterize the signal strength received at the receiver after undergoing reflections, diffractions and scattering and they have to be different from that simplistic model we have been talking about for so long. But what is interesting is reflection, diffraction and scattering happen in two distinct manners depending upon the relative location of the transmitter and receiver. The actual number of reflectors present, how dense is the reflection environment and how dense is the scattering environment. So we characterize by saying that there could be a small scale propagation model as well as a large scale propagation model. We will define these two models separately. Radio propagation models can be derived either by using empirical methods.

That is, you collect measurement data and finally fit curves to it. A lot of this measurement campaigns were done where you take a power meter in a moving vehicle, move around the city in predetermined grid locations, take the measurements, plot the curves, try to do some curve fitting and figure out what could be the good propagation model.

They are realistic. You do it in density environment, rural environments, vegetative environments and unequal terrain environments or you have another choice. You use analytical methods where model the propagation mechanisms themselves mathematically and derive equations for the path loss. Both the models are used or a mix is used.

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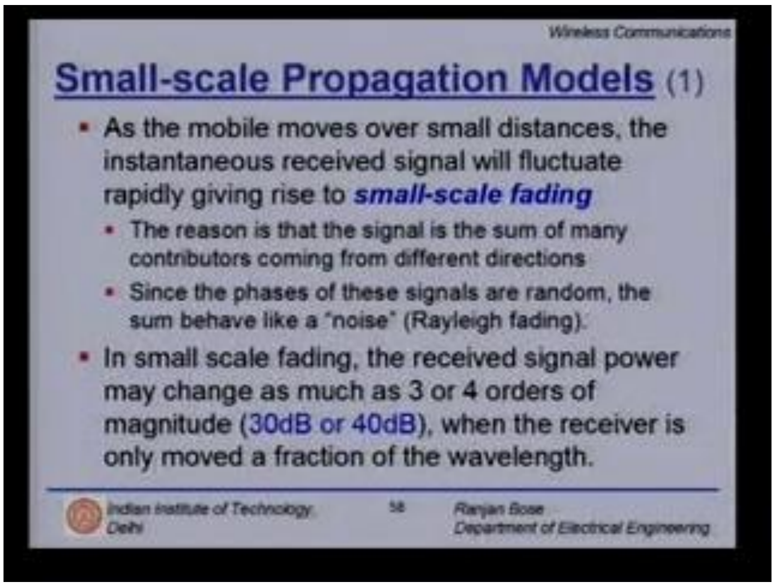

Let’s now consider small scale propagation models. What are small scale propagation model? As the mobile moves over small distances, the instantaneous received signal will fluctuate rapidly giving rise to small scale fading. Please note that we are talking about small distances and when I say small, it has to be small with respect to the lambda. The reason for this quick fluctuation is that the signal is actually the sum of many contributions coming from different directions either from reflections or diffractions or scattering. I do not know how but the bottom line is I am getting at the same time, multiple copies of what I sent but delayed in time and different in phase. Since the phases of these signals are random and they truly random, you can assume them to have a uniform distribution between 0 and 2pi. The sum of all these different components actually behaves noise like. So one of the ways to model them is that it’s a random variable. it could be modeled as Rayleigh fading. In small scale fading, the received signal power may change as much as 3 to 4 orders of magnitude. That is 30 to 40 db. When the receiver is only moved a fraction of the wavelength, what does this imply? This has serious repercussions on your handoff strategy. You should not handoff simply because you are in a fade. fade is a region where suddenly you receive a lot less power simply because the vector sum of the various reflections and scattering components add up to a very low value.

So I should not handoff simply because I am sitting in a fade because somehow the small scale fading has resulted in a very low received power. Now what is interesting to note is only when the receiver moves, a fraction of the wavelength or utmost a wavelength, it gets out of fade. That means tomorrow, if I have the luxury to put two transmit antennas or vice versa two receive antennas, one antenna might be in fade and necessarily the other antennas may not be in fade. I have achieved receiver diversity. I can combine the signals and then I will be able to overcome fading.

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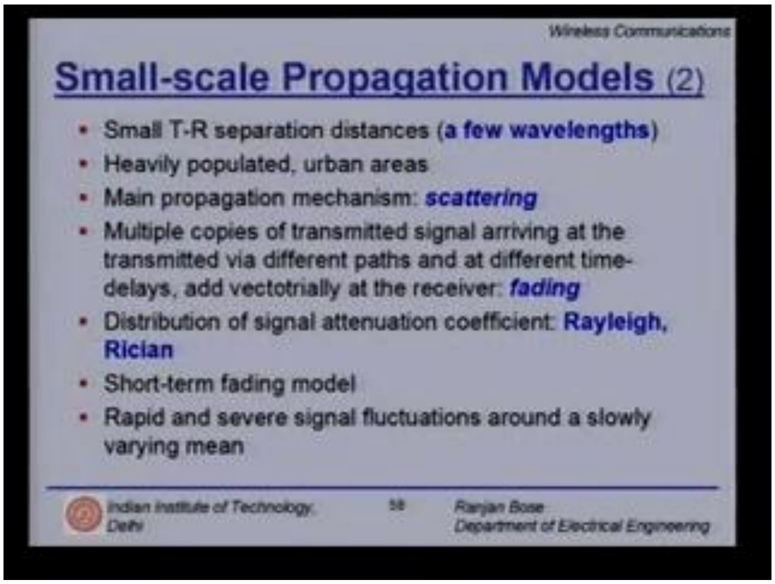

Continuing with small scale propagation models and some of the characteristics of small scale propagation model, it depends on the small transmitted receiver separation distance changes - a few wavelengths. It is typical of the urban areas which is heavily populated in terms of buildings, scatterers, strong reflectors, etc. The main propagation mechanism is scattering. Multiple copies of the transmitted signals arriving at the transmitted via received paths and at different time delays add vectotrially at the receiver and this results in fading. The distribution of the signal attenuation constant could be either Rayleigh distributed or Rician distributed depending upon whether you have a line of sight or not. So if you have a lot of scattered components but no line of sight, then the attenuation coefficients can be effectively modeled as Rayleigh distributed. However in addition to that, if you also have a line of sight, you can get something called as a Rician distribution. So this is the short term fading model and rapid and severe signal fluctuations usually happened around a slowly varying mean. We will soon look at an example where will see rapid fluctuation over a slowly varying mean. The other part is the large scale propagation models as oppose to the small scale propagation model.

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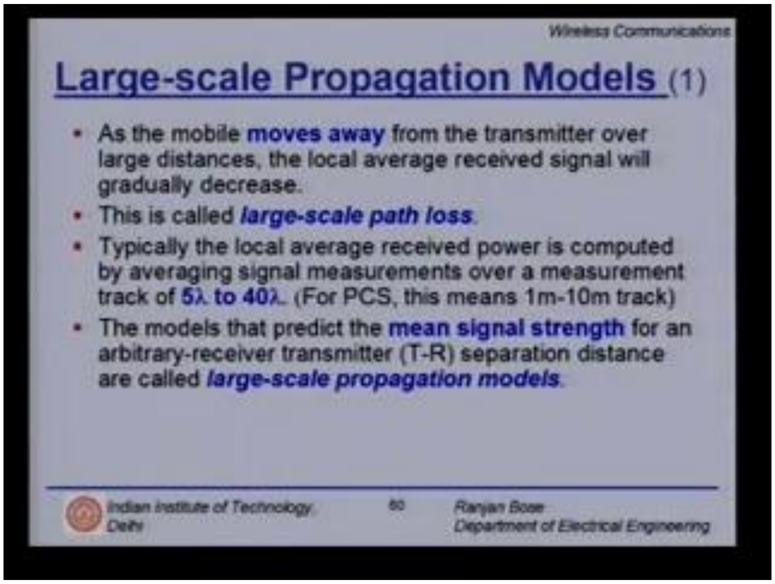

Let us see what is a large scale propagation model. As the mobile moves away from the transmitter over a large distance, the local average of the received signal will gradually decrease. Note we are talking about a local average. This model still takes into account reflectors but this is valid not for dense reflections or dense scattering environments. So you will have slight variations but we are talking about the local average. This is called large scale fading. Typically the local average received power is computed by averaging the signal measurements over a measurement track and that can range from 5 wavelengths up to 40 wavelengths. This translates to about 1 m to 10 m track for personal communication services. what does it mean if I have to come up within appropriate large scale propagation model for Delhi; one way is to carry out measurement campaigns and how do I do the measurements? I go over 5 lambdas to 4 lambdas at a stretch moving radially away from the base station, average the power received and go and plotting it so on and so forth till I get the curve that will be my large scale propagation curve. The model that predicts the mean signal strength for an arbitrary receives transmitter separation distance also called large scale propagation models.

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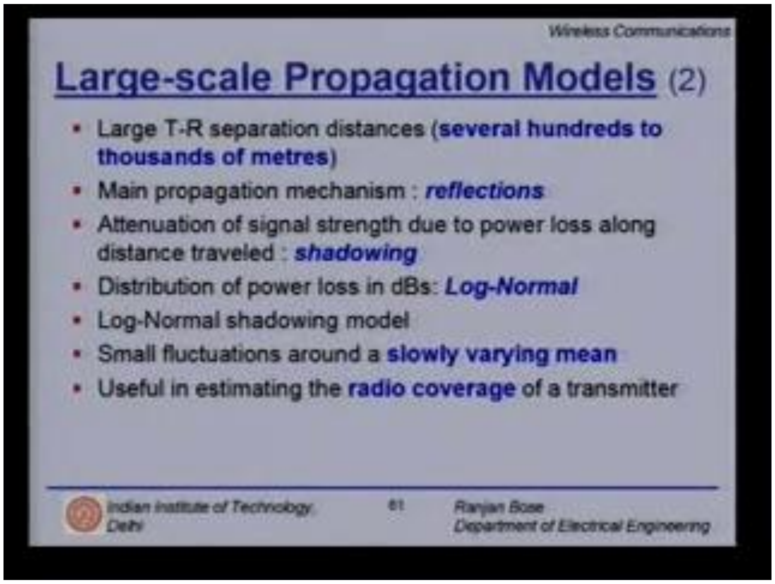

Continuing with this large scale propagation models, the basic characteristics as opposed to the small scale propagation models are, these work for large transmitter receiver separation distances. How large? About several hundreds to thousands of meters. So we are really covering the whole cell. The main propagation mechanism is not scattering but reflection. Not too many reflections. The attenuation of signal strength due to power loss along the distance travelled is termed as shadowing. The distribution of power loss in dBs can be represented as log normal distributed. We will talk about log normal distribution towards the end of this lecture. So we have to have something called as a log normal shadowing model for large scale propagation. There are small fluctuations around a slowly varying mean as opposed to rapid fluctuations around a slowly varying mean for small scale propagation models. This is useful in estimating the radio coverage of a transmitter and this will be actually used for your cell sight planning.

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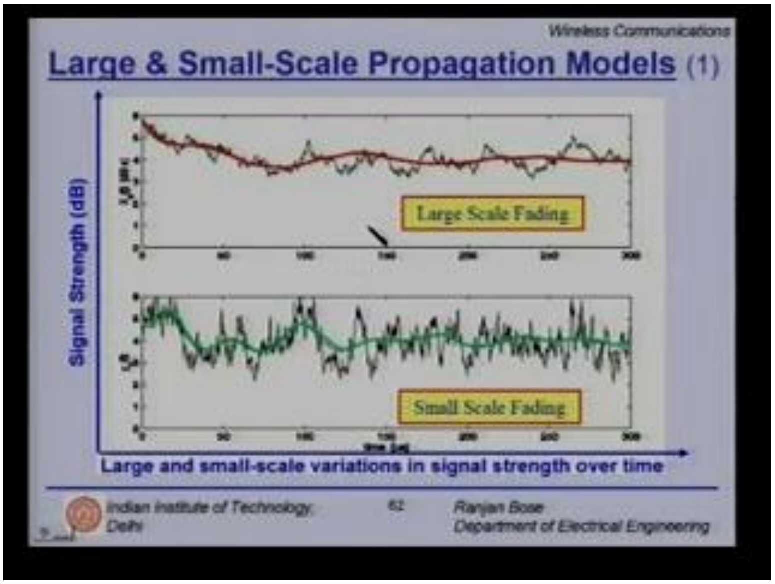

Now let us look at large and small scale propagation models together. so let me draw two axes. On the x axis, let me plot the large and the small scale variations in signal strength over time. So suppose a mobile, a person sitting in a car talking on the mobile phone or holding a power meter is moving along the x axis. On the y axis, I would like to plot the signal strength but in dB. So these are much more smooth. So on the top I have plotted the large scale fading. The bottom diagram represents the small scale fading. Now what is interesting is both have a slowly varying mean but the variations in the small scale fading even in the mean is more than what you see in the large scale fading. Again there are fluctuations about the mean for large scale. But these fluctuations become much more rapid for the small scale fading. If you look at the y axis it is in dB and you can have the signal jump more than 10 to 20 dB because of the small scale model. So here I have highlighted the mean of the large scale fading in red and that of the small scale fading in green. This clearly tells us that there two distinct phenomenon that is taking place and I'll illustrate them with the case of an example and we will also look at how to model them separately.

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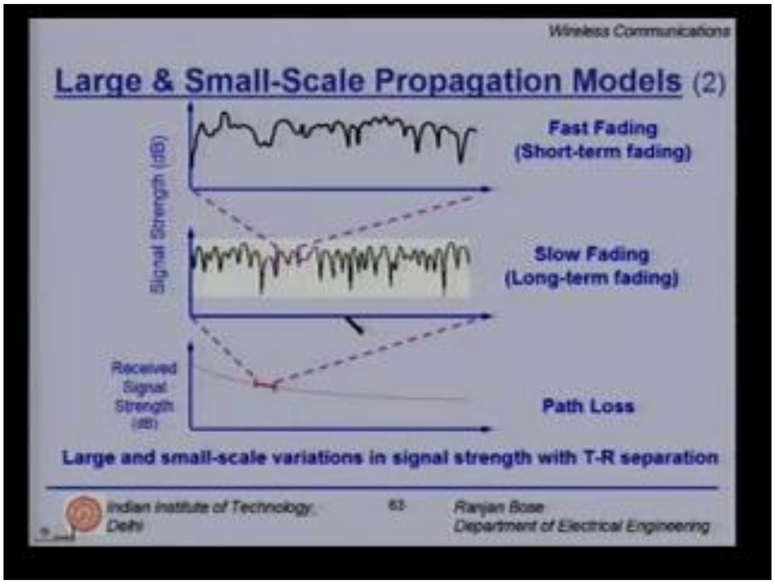

Suppose I have the received signal strength plotted in dB, on the y axis and on the x axis again, I make the mobile move with a power meter so that I can plot the signal strength. But these are very well averaged over 5 lambdas to 40 lambdas. I have got a neat path loss decay model so as we move away from the transmitter. Clearly in dB, my signal strength drops. Now what we would like to do is take a small section and go deeper into it and try to amplify and see what is actually going on. So over and above this averaging thing, if you actually deeper inside, then I find really if you do not average, you have this slow fading also called the long term fading. This is well rounded simply because I have plotted in dB. However if I get more enthusiastic and curious I would like to explore what is going on within a small section of this slow fading. So if I go ahead and expand this further, I will see more variations than the slow fading. So that is your fast fading. So fading itself can be subdivided into slow fading and fast fading. The actual mathematical definitions of slow fading and fast fading will be given at a later end this is for your intuitive understanding.

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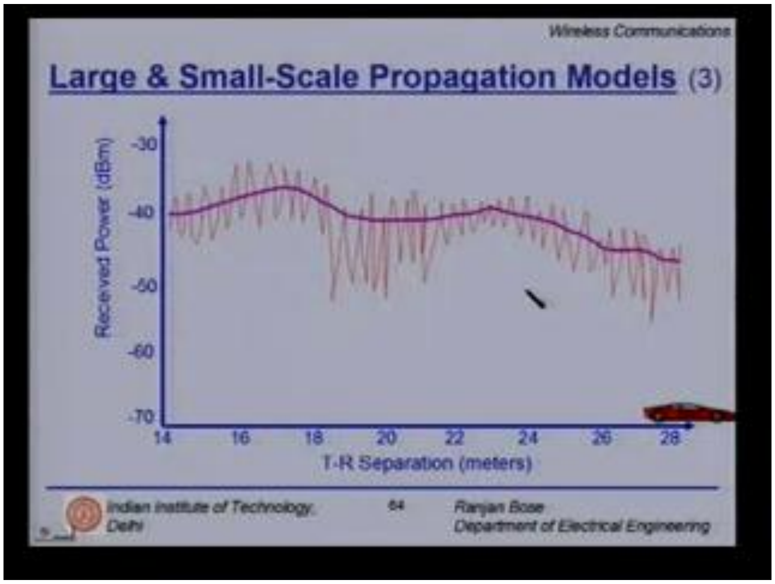

So I have drawn two parallel lines. Now let us look at the transmitted receiver separation along the x axis and these figures have been picked up from a typical measurement. So look I am going only from 14 meter separation to 28 meter separation. So daily 15 meters and here the received power is in dBm. So with respect to a mW, how much is the received strength of the thing? So as the mobile moves away from the transmitter, clearly if you have the power meter, it will plot something like this. So if I do this experiment, this is the actual measurement data that we will get based on one random measurement taken. If you repeat this experiment, you will get something similar but not exactly the same. These are clearly short term fading and if you draw an average in general, the signal strength is dropping but it is fluctuating rapidly across a mean.

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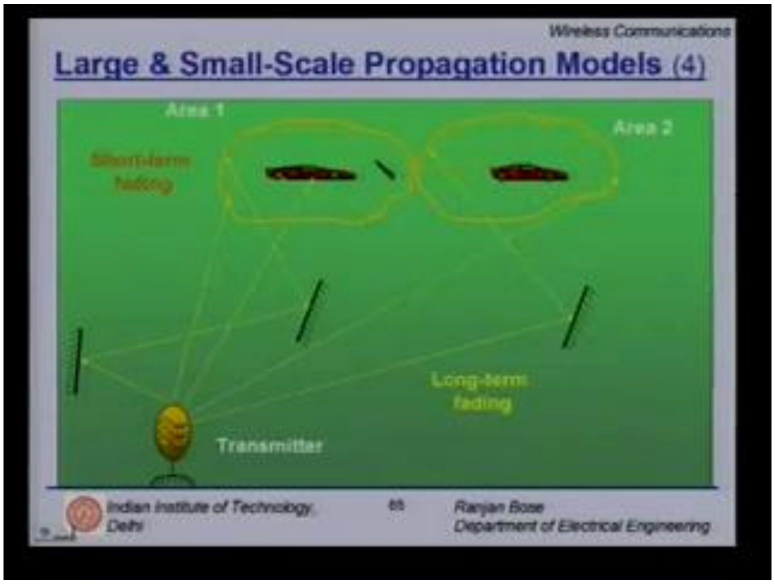

Now let us understand where large scale and small scale propagation is coming into effect. What is so different? What makes large scale and small scale fading different? To begin with, if we have that understanding, only then we can have an appropriate model. If we have an appropriate model, we can plan ourselves better. So let us put on a patch of green - a transmitter and we have our first mobile. I make it move and for the sake of more realistic scenario, I put a second mobile. Clearly in real life environments, these mobiles will not be in the open field. There will be a lot of reflectors, scatterers and diffracting edges around them. So let's draw that. So I have drawn here a shell which basically tells that there is a series of reflectors and scatterers here and there are some distant reflectors here. The signals going from the transmitter may either reach directly or it may not have a direct path. So it will go here, go through scattering and reach the reflector or it may reflect and reach through one or more reflections and scattering. So you have reflections. You have scattering and further reflections here but what is interesting is this area 1 and area 2 for the two mobile stations actually form the short term fading. the rapid fluctuations which is leading to short term fading is coming from this local shapes whereas the long term fading is coming from key reflectors in the larger scheme of things. So primarily long term fading comes from reflections where short term fading is coming from scattering. We can take enough measurements and then do a curve fitting to come up with a model.

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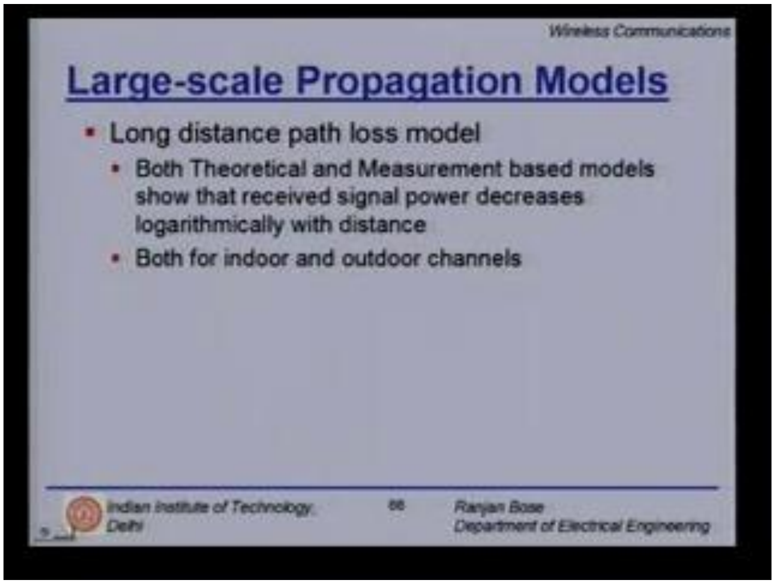

The long distance path models have both theoretical and measurement based models that show that received signal power decreases logarithmically with distance. So both analytically and by measurement, you can find out that the decrease in power is logarithmic. That's an important observation because then we will have log model but this is not only true for outdoors. It is also true for indoors. This is an observation based on measurement that the signal power actually decreases logarithmically with distance.

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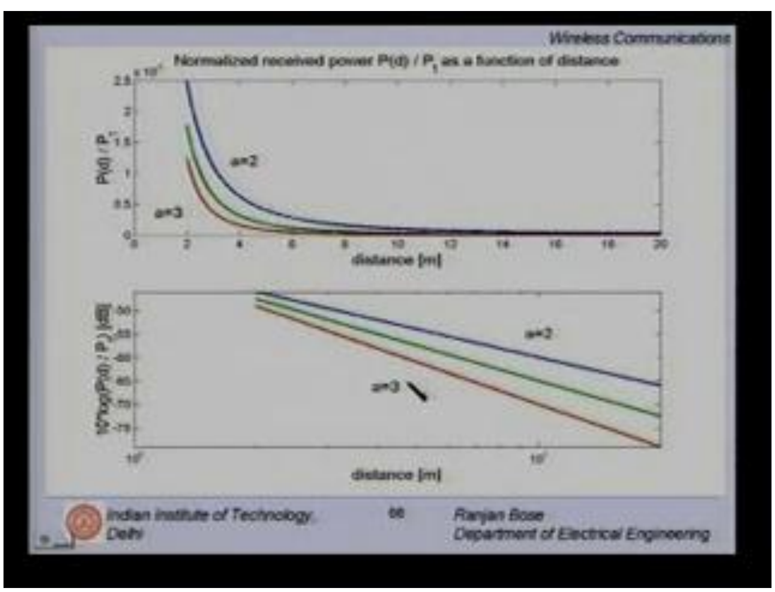

So if we actually do measurements and plot, let's look at the lower curve. On the x axis, I have distance. I have put a log scale here and on the y axis I have dB received power here. I get straight lines. It is actually decreasing logarithmically. If you do not take the log of the distance, if the distance is on the linear scale as depicted in the upper curve, then the decay is logarithm. Now what determines these three slopes is actually dictated by your environment. We will talk about what environment will get & what kind of slope. These slopes are important because if the slope is larger, my cell size will be smaller. The lesser my slopes then I will have larger cell sizes.

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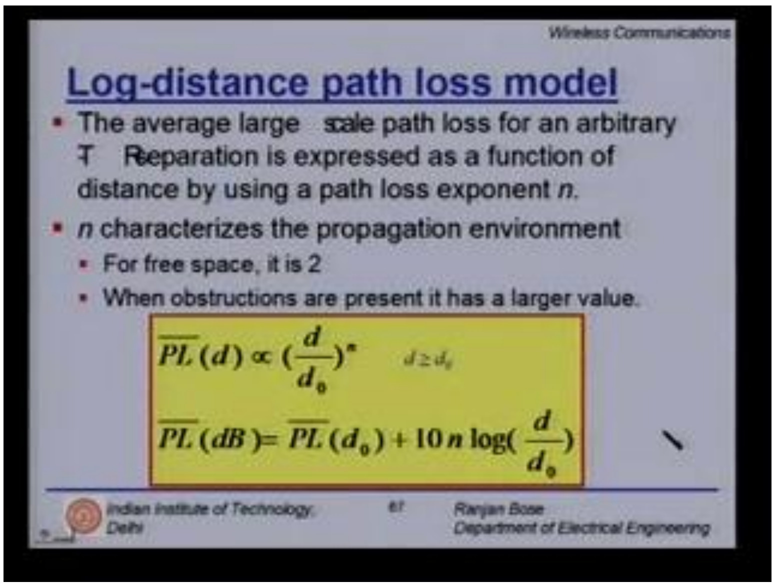

So let's look at this log distance path loss model. The average large scale path loss for an arbitrarily transmitter receiver separation is expressed as a function of distance by using a path loss exponent 'n'. we have come across this 'n' earlier also but here this is more based on measurements and empirical modeling. 'n' characterizes the propagation environment. For free space it is two whereas where we have more obstructions, it can get a larger value. How large it can have? 3, 4 even up to 6 but larger the value of 'n', larger is the slope, larger is the decay. Question is: can we have 'n' < 2? Can we have n < 2? Which is obtained for free space propagation? We will soon see yes, we can have certain environments where 'n' can be less than two. So let us look at the relationship. Please note on the left-hand side, I have put path loss at a distance'd' but an average value. The bar over the PL denotes that it is the average value. The average value is proportional to d over d_0 ^{n} where n is the path loss exponent. d here is greater than d_0. d_0 is one of the reference distances and in dB, the average path loss is nothing but average PL at d_0 + 10 n log d/ d_0.

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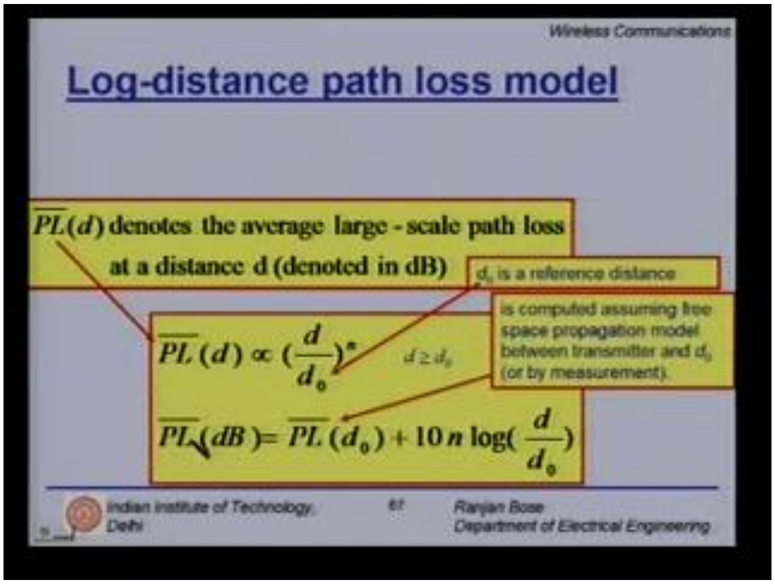

So if we want to look at this equation in greater detail PL(d) denotes the average large scale path loss at a distance 'd'. d_0 is a reference distance and this PL (d_0) is actually computed assuming free space propagation model between the transmitter and d_0. So there is a mix and match while I am computing this d_0. I have already either taken a measurement or calculated it using free space propagation but in free space, we have to Friis n=2 whereas here I have 'n' in the equation. So it's a mix and match. We assume that at a close distance d_0, you will nearly have a line of sight. Once you have that, then you can use this equation with an 'n' in your equation. These are useful models.

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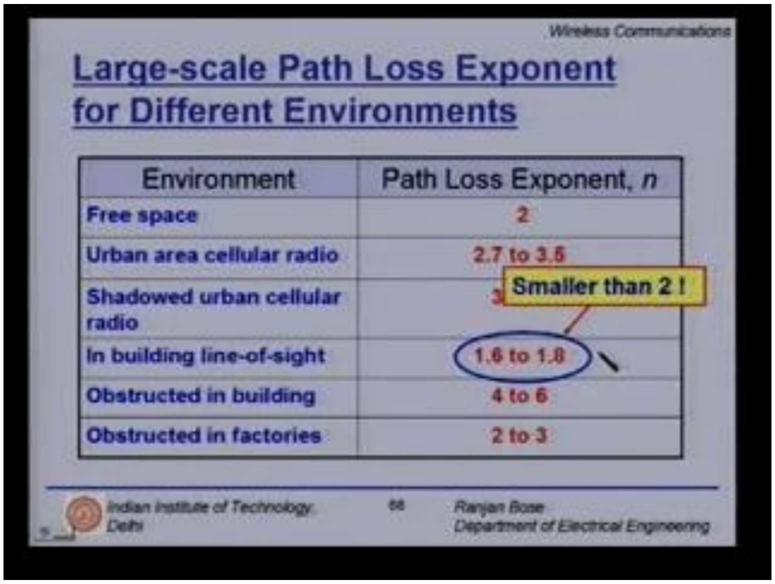

Now let us look at some typical large scale path loss exponents. For different environments free space we all know is two. but in urban area, cellular radio it must increase because we have more obstructions and it goes from 2.5 to 3.5. Here I have written 2.7 to 3.5. It is all based on measurement data. So for our city like Delhi, it can have a whole range of variations. If in the down town area, you can have close to the 3.5 whereas in south Delhi or in the suburbs, you can have close to 2.5. Shadowed urban cellular radio here either you have a hilly terrain or large building shadowing wherein you are in the shadow of a building. It is much higher from 3 even up to 5. Where are you getting all this energy from? By scattering & by reflection because clearly there is no line of sight when you talk about shadowing. You are in the shadow of a building. We will talk about this in building line of sight in a minute. If you are obstructed in a building again no line of sight. You can have as large as 4 to 6 because that really has a lot of obstructions. The other interesting thing is the measurements done in these buildings are usually done at a lower wavelength & higher frequency. What is misleading in this table is not all measurements have been done at the same frequency and you must remember that scattering, reflection and diffraction effects are dependent on the wavelength. So in that sense it is slightly unfair to compare each one but for a certain application for example obstructed in building, I like to use my 2.4 GHz ISM band. I'll like to have 4 to 6 exponent in my model if you are doing factories which have much more free space and less obstructions. You can go from 2 to 3. Now look at this in building line of sight is interesting is less than 2 is in fact from 1.6 to 1.8. What could be the reason? What could be better than free space? Well firstly there is line of sight. So I can at least have 2 but then buildings and corridors in the buildings and rooms have a neat guiding effect in free space. Whatever energy which is readily transmitted out does not go directly to the receiver. It is lost whereas in the buildings if you are in a hall or we are in corridor, there is a strong guiding effect and a lot of that energy also gets back. So it is much better than two. Buildings even sometimes narrow streets will give you close to 2. Line of sight narrow street propagation will also give you 1.8 or 1.9 as the path loss exponent. This is interesting. I can use this to my advantage.

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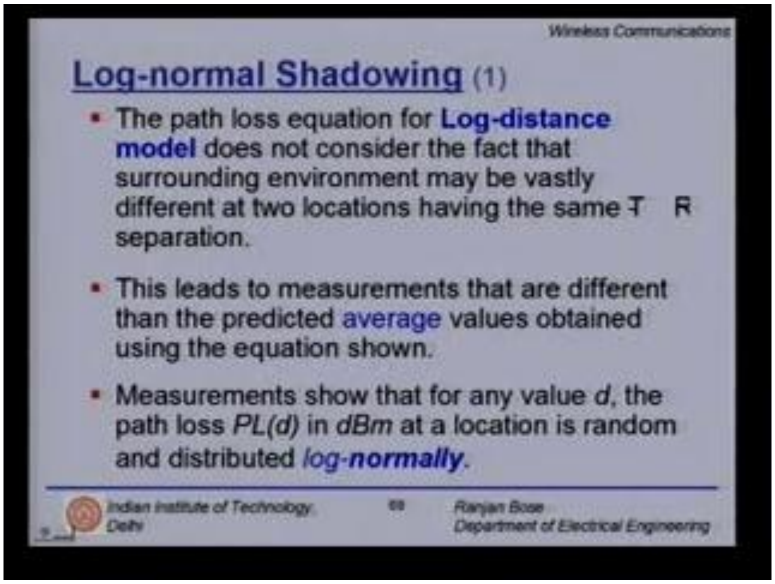

Now let us look at something called 'log normal shadowing'. The path loss equation for log distance model that we have already studied does not consider the fact that the surrounding environment may be vastly different at two locations. This the key point. The surrounding environment may actually be very different at two different locations having the same transmit receive separation. The log normal equation that we have seen so far only depends on the distance. Remember 10 log $d/d_0{}^n$ is nothing to do with environment. This leads to measurements that are different than the predicted average values obtained using the equation shown before. Measurements show that for any value'd', the path loss PL (d) in dBm at a location is randomly distributed log normally.

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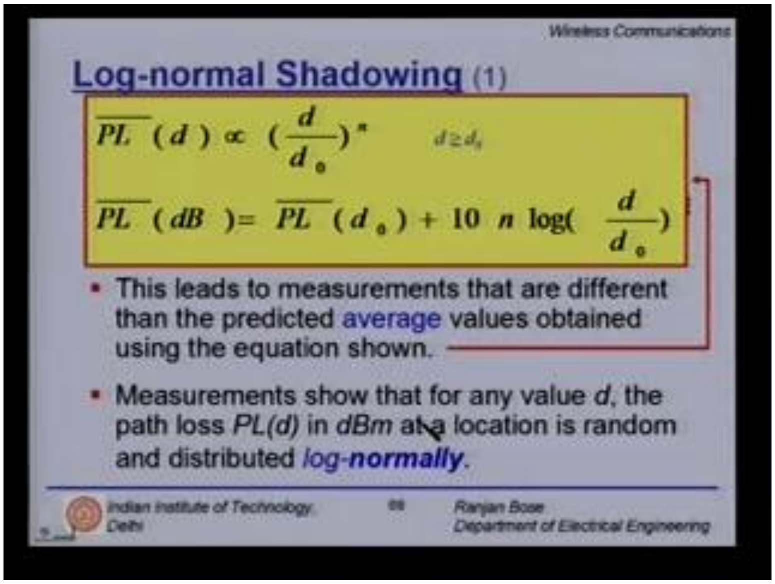

So let's go back to our equation. Something is wrong here. What is wrong? Well what was typically measured and predicted was at the average path loss is only a function of'd' - the transmitter receiver separation and the path loss exponent 'n'. 'n' happily takes care of the environment'd' the transmitter receiver separation but the environment may be different. In fact there has to be randomness. There has to be difference between scenario 1 and scenario 2. I need to put in some component of randomness which will encompass the various situations. Sometimes this equation will hold good. Sometimes this path loss penetrate will be slightly less. Sometimes it will be slightly more. so what was found that if you take actual measurements in general, it might hold but in reality measurements showed that for any value 'd' here, the path loss is actually a distribution and what kind of a distribution? They did a curve fading and they found it was log normal. If you represent the received strength in logarithms, that is in dB scale, the distribution is normal Gaussian distribution. That's a very interesting thing. It can also be proven analytically by using the central limit theorem.

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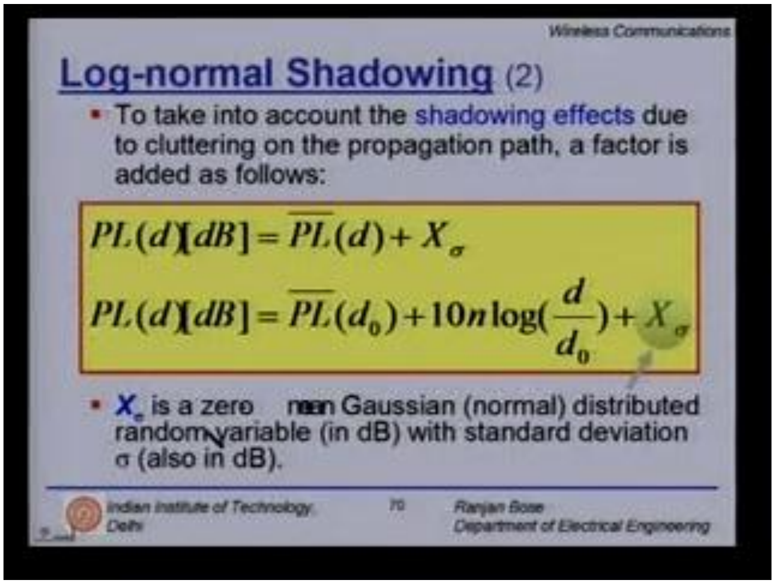

What is this log normal shadowing that has dropped up at the last minute? Well it is been proposed to take into account the shadowing effects due to cluttering on the propagation path. So what is it? Well we add a factor as follows. PL (d) in dB is PL(d) plus a correction factor. Now this correction factor is distributed log normally. So in general, we are not too bad. But we need a correction factor. But this correction factor is not a constant. It's a random variable. so if you put it more clearly in terms of a d_0 -a reference measure distance, PL bar (d) PL bar d $_0$ + 10 n log d / d $_0$ where n is the path loss exponent.

Conversation between student and professor: the question being asked is: what is the range for a correction factor? Clearly this is normally distributed Gaussian distribution. So it actually stretches from minus infinity to plus infinity. But we will truncate it. Otherwise you will have negative path loss. We cannot have more signal received than we transmitted. So we will give that as an example. So it's really a correction factor but a truncated log normal. So let us look at this in slightly more detail. So what is this X sigma? X sigma is a 0 mean Gaussian which we are talking about as normal distributed random variable in dB again with a standard deviation sigma which is also in dB. So let's focus on this X sigma that is the randomness added into your path loss equation. Now what determines the sigma? Well you can get it from measurements or even analytically.

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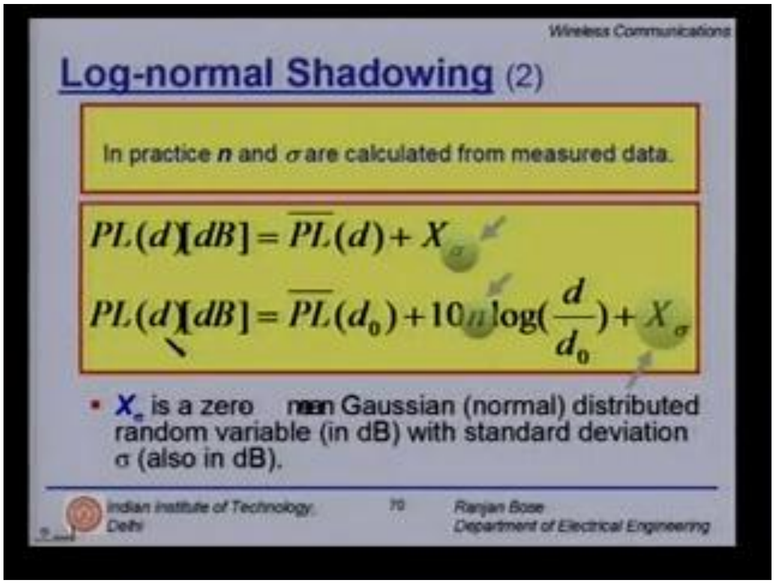

So in practice 'n' and 'sigma' are calculated from measured data. If I have this value, then I can actually predict what could be my received signal strength. What is the received signal strength? Received signal strength is nothing but the signal strength transmitted minus the path loss if I am talking in dB.

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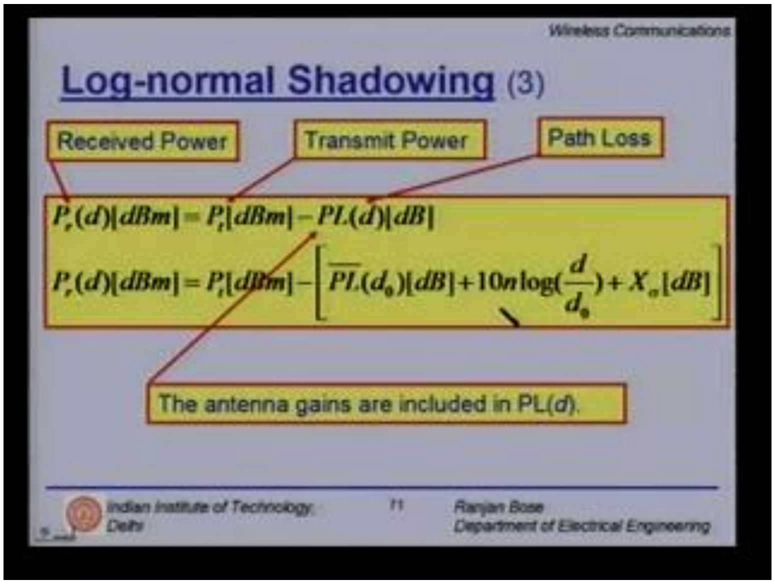

So Pr which is the received signal strength in dBm is nothing but the transmitted power in dBm minus the path loss. if you want to explicitly write "$P_r(d)$" the received power in dBm as nothing but the transmitted power in dBm minus $P_L(d_0)$ dB minus 10 n log d/ d_0 plus X sigma in dB. Why the path loss in dB? The question being asked is: why is the path loss in dB? Well it is clearly giving you a relative location with respect to d_0. So you have certain dBm subtraction starting from dBm and then this equation which will give you a dBm relationship can be equivalently written in parenthesis in terms of dBm as well. so received power transmit power path loss have a very simple equation but what is interesting to note is that this path loss itself has the antenna gains included in them. Earlier we had used antenna gains GT and GR as unity and if you want to explicitly write it out, those things will affect here.

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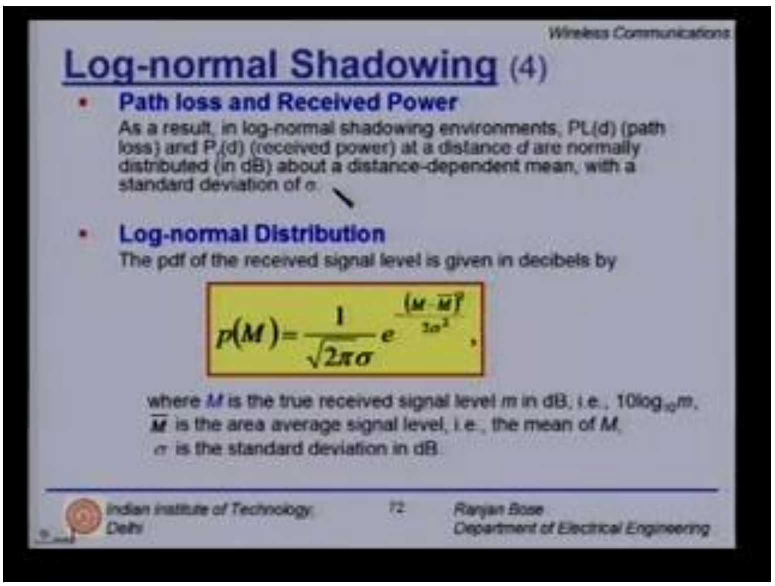

Let us look at this log normal shadowing. the result of path loss is log normal shadowing which is given by $P_L(d)$ and the log normal distribution has a p_df given by p (M) is equal to 1/ under root 2 pi sigma e $^{-(M\text{-}M\ bar)2}$ / 2 sigma squared. It is the normal distribution with variance sigma squared. Here M is the true received signal level. m in dB that is 10 log to the base 10 m. M bar is given by the area average of the signal level. That is the mean of M and sigma is the standard deviation in dB. So let us see what is this equation in log normal shadowing environments. the $P_L(d)$ - the path loss and $P_r(d)$ at a distance 'd' are normally distributed in dB about a distance dependent mean with a standard deviation sigma.

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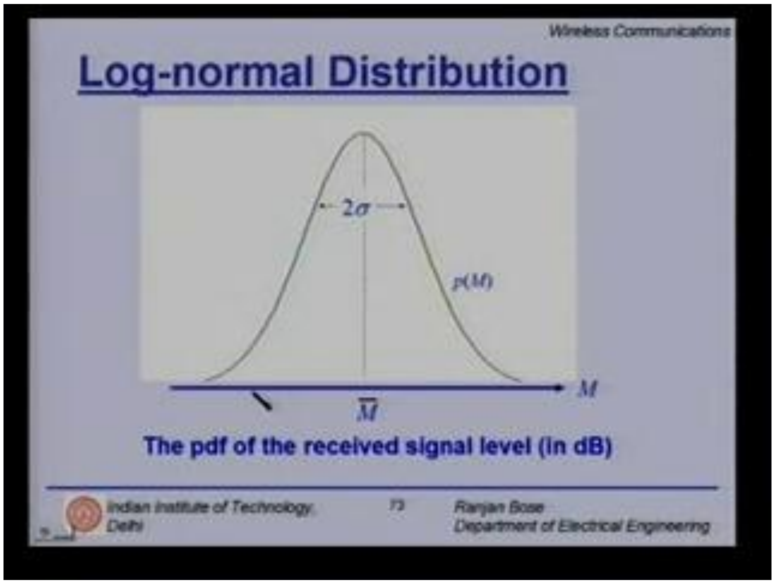

How does the log normal distribution look? Well here I have conveniently truncated it but on this axis is your M. it is around an average value M bar. This is the sigma. This is your log normal distribution. The pdf of the received signal level in dB. What is determining your M bar? Well this actually is determined by a distance and the path loss exponent and about this distance you are distributed. So this can be effectively be used to model path loss and come up with certain cell sight planning systems. So at this point, let us conclude and summarize what we have learnt today. We took a deeper look into the free space propagation model.

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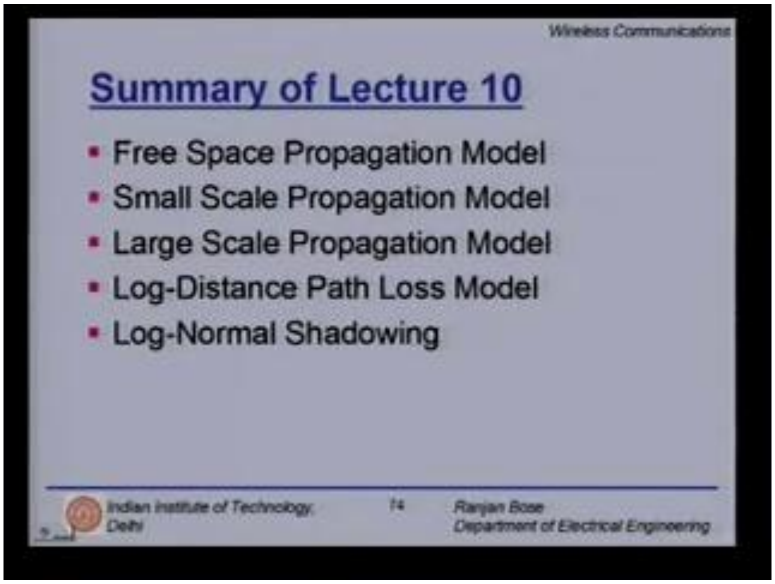

We looked at the different components - the ‘d^2’ part and the L. then we introduced the notion of small scale propagation model followed by the large scale propagation model. We understood why they happen, how they are different. Then we looked at the log distance path loss model. It is based on measurement data and then we realize that there it doesn’t work for all environments. We have to do something about it. We have to add a random correction factor and that let us to the log normal shadowing. Now there is more to log normal shadowing and we will start off with log normal shadowing in the next lecture.