Evolution of Air Interface towards 5G

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Lecture - 33
Channel models for Performance Evaluation -Part – 1
(Large Scale Fading)

Welcome to the course on Evolution of Air Interface towards 5G. So, till now we have been discussing various methods for generating waveforms, which would be essential for taking care of new requirements and advanced new methods, which would take care of several additional capabilities of the waveforms that may be desired in future. So, once we have done that, it is now high time that we start taking look at other important aspects, especially multiple antenna based signal processing.

So, let me first tell you that there are NPTEL course; there is an NPTEL course which is now available in archive which talks about MIMO communications which deals in details. So, we do not make a point over here to go into the details, but only give you the summary of the results, all details can be found in such an NPTEL course.

However, to make this particular course complete, we need to over view some of the methods over there. But, before we study such issues, it is important that we understand the propagation effects, and there will again be a short review of the entire thing we will do it pretty fast with an assumption that people either know it, it is just a revision or for others to make up for the material based on what we just show to read up additional things.

So, what we will do is our plan is to discuss the propagation which will basically be large scale effects, then small scale effects, then will go into the MIMO effects; MIMO propagation effects the issues that will lay the foundation of the various things that are needed to understand the MIMO methods, why do they work and what are the issues. And we will also highlight, some of the aspects where MIMO is restricted. So, once we are aware of these things, then will be able to appreciate the different MIMO techniques, thereafter, the entire course will proceed towards it is showing the different applications and system level concepts which are useful for the fifth-generation.

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So, let us begin with our study on the propagation effects. And so, we will study the large scale, and small scale and as quickly as possible.

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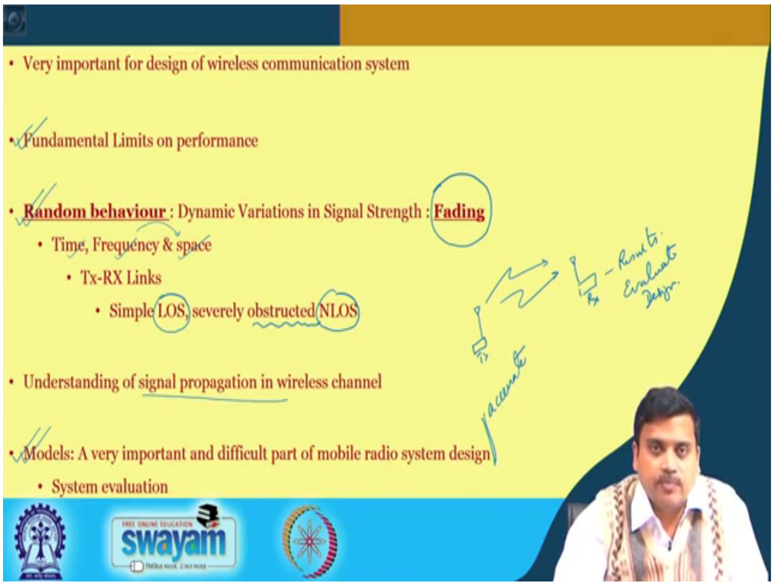

So, we begin with our study of the large scale. Now, it is very important to study wireless for various reasons which we have already highlighted. Amongst then the other important aspects are it provides a fundamental limit to the performance of communication systems. And as we said we also wanted to review the various performance evaluation methods. So, therefore we need to understand the system or the propagation characteristics through which these things get evaluated.

The second important thing is the wireless channel is random and that is why, it is given the term fading right. So, again although things are random, but still you can understand some of the properties by modeling the entire thing as a random process and hence, if we can characterize the random process, then we have characterized the system in a statistical manner. And hence that will be useful for us in evaluating the statistical performance of any communication system.

So, what we have is we will study the time frequency and which will help us to study the space characteristics. And typically, there are various kinds of links between the transmitter and receiver one of them is the line of sight, the other is non-line of sight which is mainly due to obstruction. So, these things have to be we have to be aware of.

And therefore, we need to study the signal propagation, because whatever signal we said, whatever we have discussed earlier goes through the wireless channel. And when the signal is received, after it has gone through the channel, we need to reconstruct the original transmitted signal. So, if we know the kind of distortions and the effects that the channel brings in will be able to only recover the effects in a nice manner. Otherwise, without knowing what has happened to the signal will not be able to recover the signal just blindly.

Again to study all of these things, models are very very crucial, because if there are no models, then one would have to resort to only experimentation. So, if there is only experimentation, then we one has to go out with transmitter boxes, receiver boxes and which will contain entire circuitry of the signal generation, entire receiver signal processing do experiments and then get the results and then evaluate, whether the design has been proper or not.

So, this is not only cumbersome, it is time taking and it only delays the entire execution. So, it is better that if we have models, we can do lot of evaluation in the lab, in our rooms and we can come up with designs which are pretty good working versions. And then one can go up and create prototypes, go for testing, field trials, and finally design the actual system of operation.

So, therefore models play a very very vital role. So, if the models are very accurate; if they are accurate, then you design and the needs minimum modification, when it goes for actual implementation. And if they are inaccurate, there will be a lot of discrepancy between the result that we observe in our studies, in our experimentation in the lab, compared to when we go to field trials and further when we go for the actual system design, and hence it increases the time of implementation.

So, the entire process of standards, which you have discussed earlier is dependent heavily on lot of simulation results, which in turn depend on the models. And ITU does provide a lot of models for evaluation, 3GP provides a lot of models, I triple E provides a lot of models. So, what will do here is we will look at the fundamental aspects the main issues. And once you are equipped with this, then you can easily understand the various parameters the model structures, which are described by different standards and organizations. So, they also depend on models and systems which are more fundamental.

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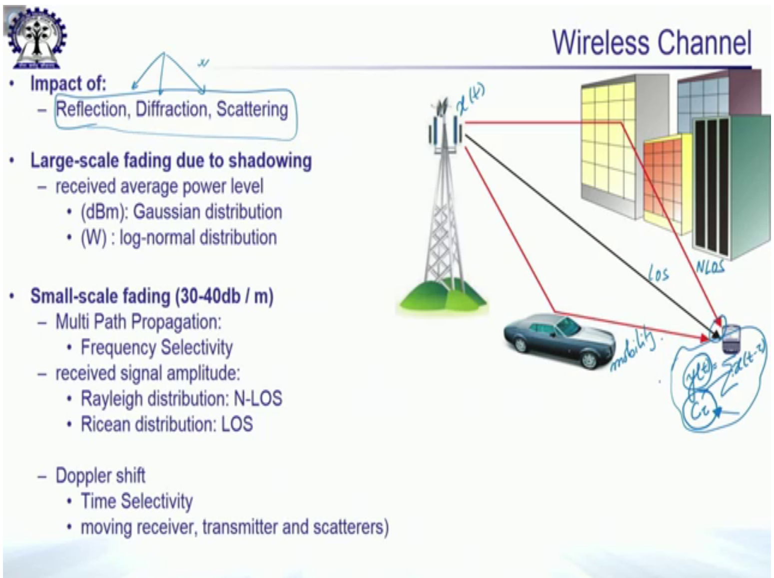

So, you know wireless propagation, the different things that happen to the signal or reflection, diffraction and scattering. And there are large-scale fading effects due to shadowing and we will discuss more of them. As well as there is multi-path phenomena that means, the signal which goes from the base station to the receiver, it propagates through multiple paths, there could be line of sight path, there could be non-line of sight path right, there could be obstruction which is not shown over here as well as there would be mobility in the picture right in the scenario. So, all of these contribute to various effects.

And again we would like to iterate that we are not going to study the physical phenomena of these things, but we are going to study the effect of these things on the signal. So, if we have sent x t, it has gone through various effects. And then finally, we received the signal y t which is an accumulation of the signals along with that there will be some multiplicative coefficient right.

So, we want to study, what happens to this and what characteristics of these coefficients, do capture the various effects that are over here. We do not want to get into the details of how these coefficients will be decided or how these will be designed or parameters chosen to capture these different effects. We will accept certain models and will go by using them.

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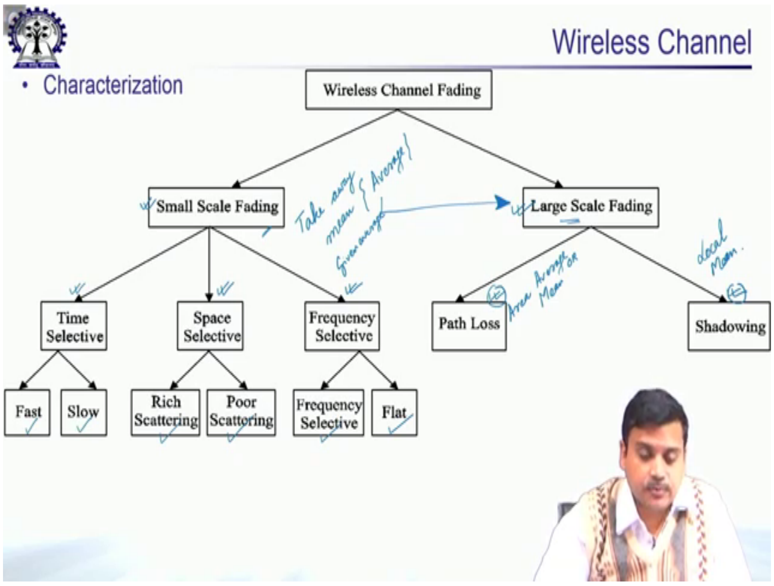

So, when we study the wireless propagation effects on the received signal due to the signal propagation over the wireless path. We categorized the study into various smaller components, so that the study becomes easier, it is more meaningful than to study the entire thing simultaneously.

So, what we see is that the wireless channel fading phenomena will describe what is phenomena can be broadly separated into small scale fading and large scale fading ok.

So, large scale fading, essentially talks about models or gives us models which helps us in predicting the signal strength over large separation distance between transmitter and receiver. And that we study again in two parts the path loss and shadowing which will discuss in this lecture.

The small scale fading talks about the fluctuations of receive signal strength. So, it predicts the fluctuation in a statistical manner, when the separation between the transmitter and receiver changes by orders of wavelengths comparable to the wavelengths. When we study this, we discuss it in three different parts; one is time selectivity, frequency selectivity and finally space selectivity.

In time selectivity, we classify the channel as fast fading or slow fading. Frequency selectivity, we classify it as frequency selective or frequency flat in the space selectivity either as rich scattering or poor scattering. One fundamental issue, why we study it in this manner is the reason that had we taken everything together. Then we would have reached a situation, where the received signal would be non-stationary.

So, when we study small scale fading, we take away the mean, you take away the mean or the average. So, this is without the average, it is a constant average signal and this average is studied in the large scale propagation effects. So, we studied separately, when we do the analysis we again do it separately, otherwise analysis would become very difficult.

So, when we study the average, again we distinguish the average into two parts; one is the area average or the area mean and the other is the local mean and that helps us study again in further details. So, when we go and study small scale, we consider usually a given average, which is predicted by the large scale fading, so that is how the overall study is distributed. However, when the signal is received, it contains everything. So, once we go through it, things will be clear.

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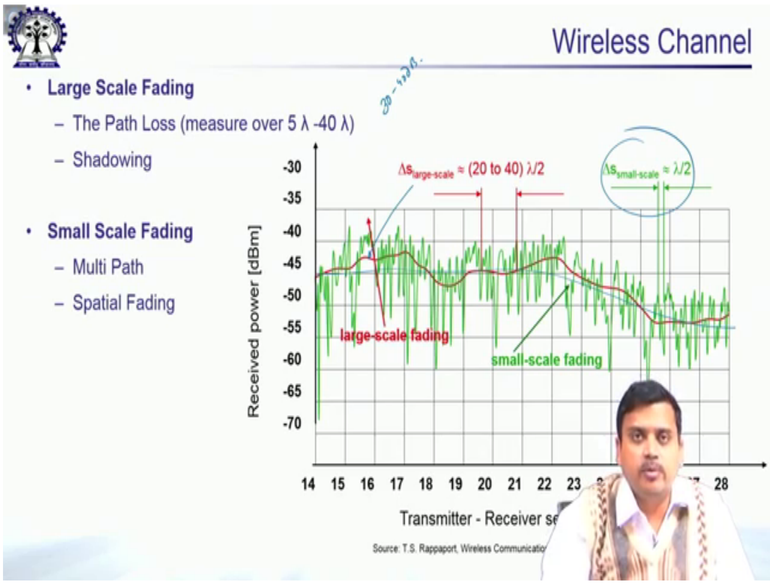

So, this picture one can find a similar picture in the wireless communication book by T-S Rappaport which describes the signal fluctuation over small separation distance. And here by the green color, we have identified the signal which is fluctuating over small separation distance as you can see and the large scale fading is nothing but the averaging of the signal, which is indicated by the red color.

And one can clearly see that the average decreases slowly as separation distance increases, while the small scale fading fluctuates or the small over small distances the signal fluctuate significantly spanning a range of around 30 to 40 dB. And whereas in large scale fading, it required to move across few hundreds of meters to kilometers in order to get a similar fluctuations.

So, this gives us an indication of the range of fluctuation of the received signal, which is much more than 40 dB, 50 to 60 dB easily and even more. And accordingly, raises the imagination to the level, where one needs to question about how to design the receiver ADC and things like that. So, there are ways to go around that, and there is lot of adaptation in the signal transmission usually through power control and AGC which ensures that you do not have a huge constraint or a big challenge on the receiver component design. So, again if we understand these things will be able to appreciate, how things have to be taken care of.

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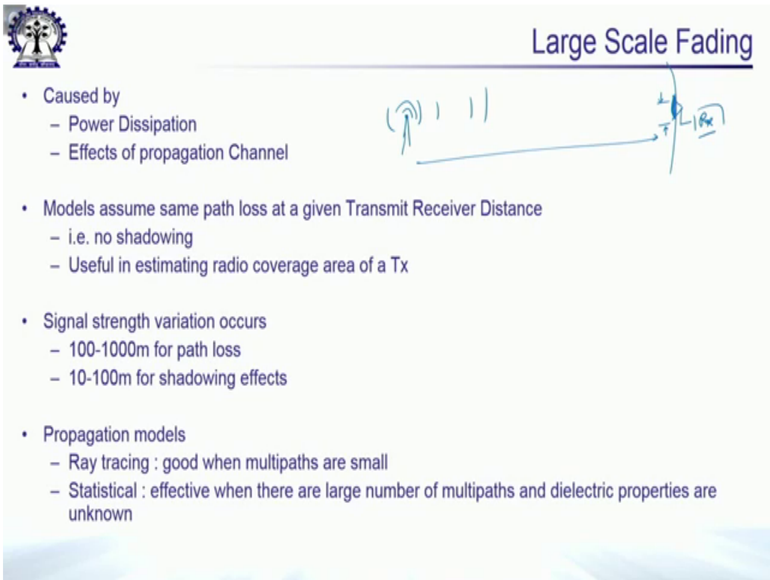

So, a large-scale fading phenomenon which is mainly caused by power dissipation because, generally when we see radiate the signal from a location, the signal usually propagates. And when we capture it, usually we capture a small area of the signal which has radiated across. So, when the signal radiates is a huge cloud kind of thing with how the signal expands and we capture only a small portion using antenna at the receiver.

And hence, we captured in a small portion of the signal energy and therefore there is and as you increase the distance. The fraction of the energy, which is captured by the antenna keeps on decreasing, because this fear over which the signal expands becomes larger and larger the surface area becomes larger and larger, whereas this remains the constant. So that is what we study under large scale fading effects, it is the effects of the propagation channel.

And when we study this we study about the path loss, where we do not consider any shadowing will discuss what is shadowing. And as said the signal strength fluctuation occurs across hundreds of meters. There are various ways of the models that people work on, there are ray tracing models, but what we look at is statistical models as we have been saying, since the beginning of the lecture.

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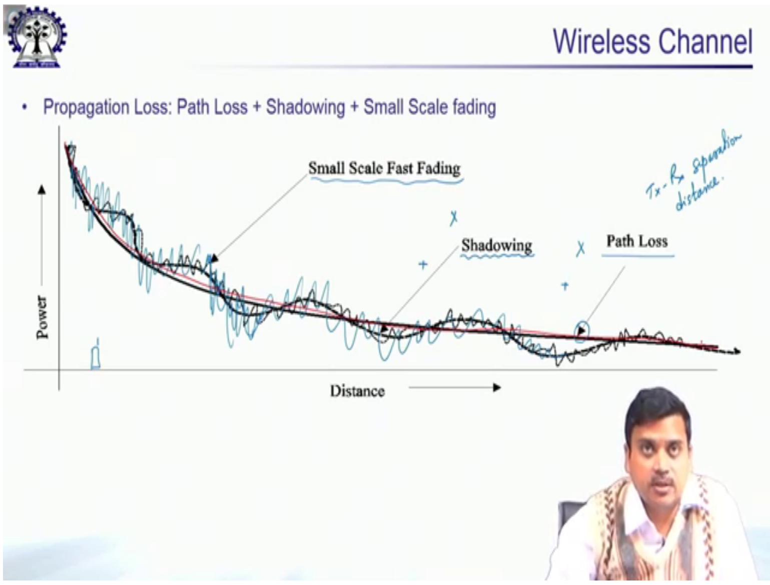

So, if we combine everything together and as we increase the separation distance from transmitter to receiver, one would find with the received signal, strength decreases. The monotonic decrease is usually studied under the path loss phenomena, which talks about decrease in signal strength as a function of T x R x separation distance only ok.

Now, around this there is the effect of shadowing will not call the phenomena shadowing, but the effect which we observe is basically fluctuation of the local mean, which will explain at an appropriate point of time. And that adds on top of it in the dB scale or gets multiplied in the linear scale, so that gives rise to local fluctuations and which is again a variation of the mean in a local region. On top of it there is small scale fast fading, where there is a huge fluctuation of the signal strength ok. So, everything is a cumulative.

So, in the linear scale these gets multiplied, and we get the signal. In the dB scale, obviously they will get add, dB scale is the logarithmic scale. So, as the as the separation distance in the transmitter and receiver increases, the fluctuation continues, but the average keeps on changing with distance. And if we study the average over the area, there is a continuous decrease of the average; as we can see there is a continuous decrease of the average, there will be local fluctuation of the average and there is instantaneous fluctuation. This is a cross picture, and you study each of the things separately.

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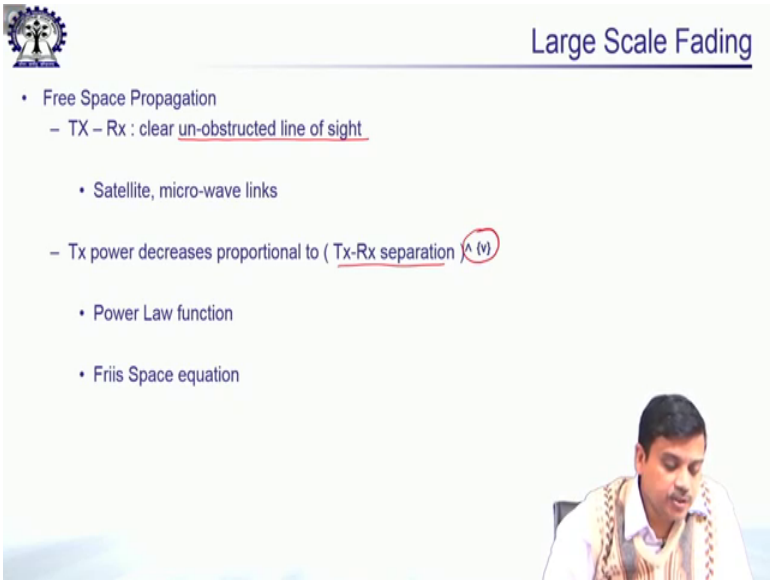

So, in free space propagation there is unobstructed line of sight between transmitter and receiver. Some of the examples are satellite and microwave links and TX-Rx the received power at the transmitter decreases proportional to Tx-Rx separation raised to a certain power. And it follows the power law function is a fries free space the space equation, which gives the details.

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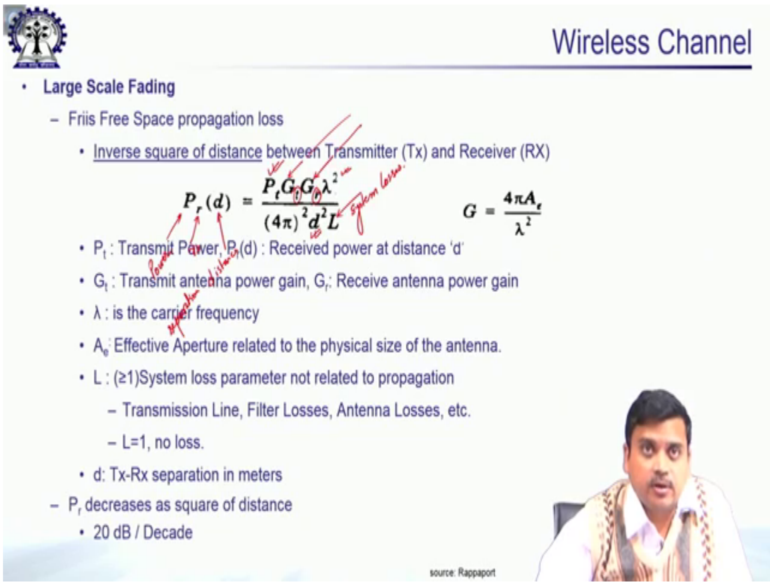

So, the fries free space equation tells us that the received power r indicates received, P indicates power at a separation distance d is equal to the transmit power divided by d square and this whole thing is multiplied by transmitter antenna gain indicated by t, receiver antenna gain r lambda squared and lambda is the wavelength of the frequency under use and L are the system losses ok. So, usually you can consider these to be Omni directional and then these gains will turn out to be unity and then you can get a simpler models so, all these what we have just described are given in the few bullets later on ok.

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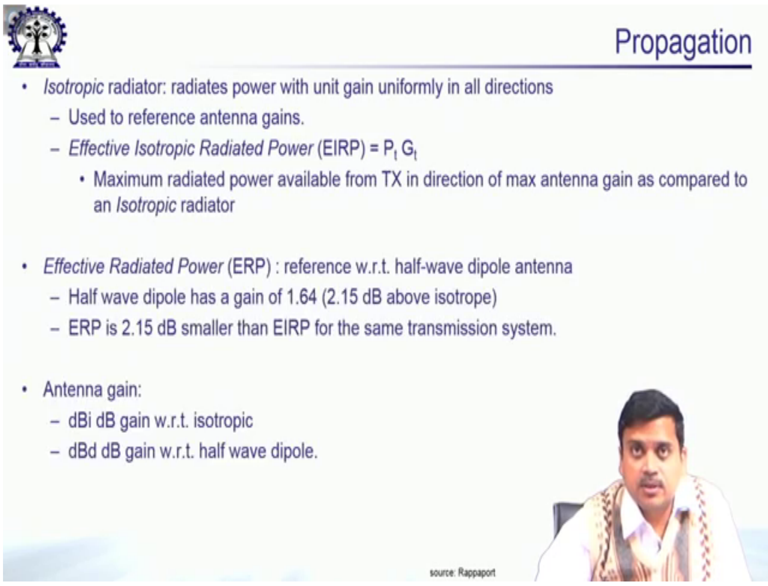

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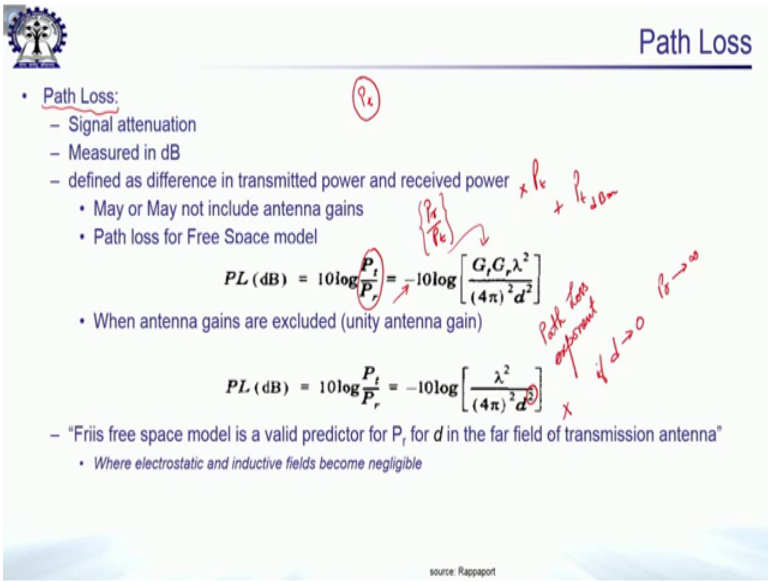

So, what we find, we will go further and what we usually measure the received a signal strength rather we describe the path loss, because the received signal strength is a function of the transmit power. And transmit power can be depend; is usually dependent on whatever settings we do, but this the loss is independent of the transmit power.

So, the model should capture a ratio of P t is to P r or P r is to P t. If it is P t is to P r, then you will get negative or positive sign according to the choice of the ratio, whatever its the loss? So, if we consider P r by P t as the ratio which identifies the loss and then given, so this is basically captured by this expression it is in the log scale, in the linear scale, you are going to get the appropriate expression which we saw before.

So, given a transmit power, you just multiply it in the linear scale or add it in the dB domain and you are going to get the received signal strength that is how we usually discuss these things. Usually, antenna gains are omitted to keep things simple and this is the expression that you get. And here what we see is that d is raised to the power of 2, so that is the path loss exponent all right. And this is pretty good in the far field of the antenna.

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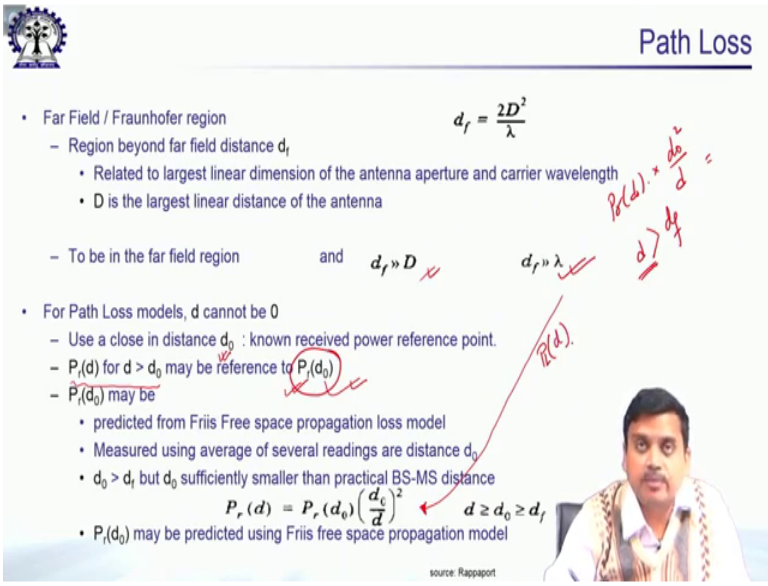

Now, what we see is that if you let d tend to 0 right, then we received signal strength tends towards infinity. And hence this model is not a very very correct model, so what we do is we define these things in the far field region, which is the region beyond the far of a distance, which is defined by 2D squared upon lambda, d is the largest dimension of the antenna, linear dimension lambda is the wavelength. So, this front of a distance should be greater than the largest linear dimension of the antenna as well as should be greater than the wavelength.

And then the for path loss models, d cannot be 0. So, we use a close in distance d 0 and that is a reference point. So, usually the received signal strength for some distance d 0 is measured and you are given this particular value. So, if you are given P r d 0, then you simply multiply this by d 0 squared and divide by d for d greater than d f and this entire thing works out.

So, since we put this constraint, we do not have any further issue of d being going to 0, so that is what is what we explained is simply given in these few expressions here in. So, this P r d 0 is usually mentioned, where d 0 is also mentioned and P r is also mentioned at d 0, which is used to translate the received signal strength at a particular distance d.

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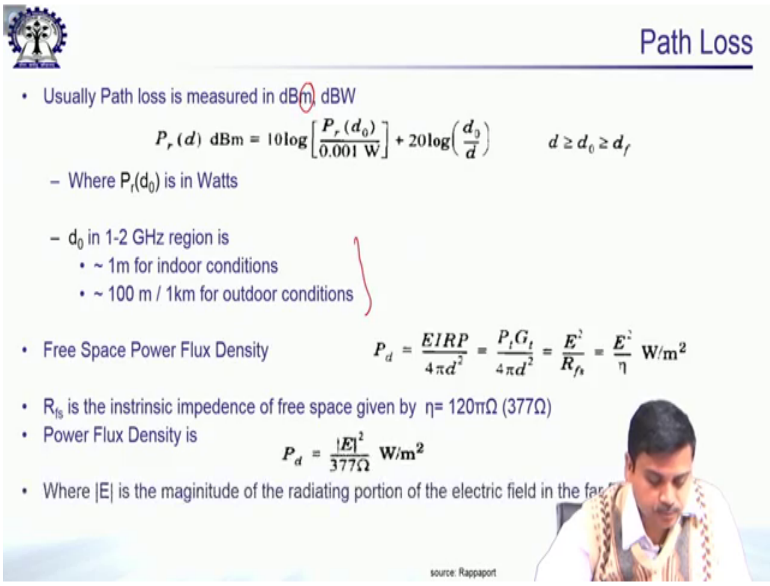

In the same thing, hence can usually easily be translated for path loss as well path loss at distance d can be referred to the path loss at reference d 0, so that is what the received signal strength in dBm would mean dBm is milli watts, we will always refer to signal power in milli watts in most of the things that we do. So, d 0 has various ranges which is usually used this is thing, something one can know and then we move ahead further.

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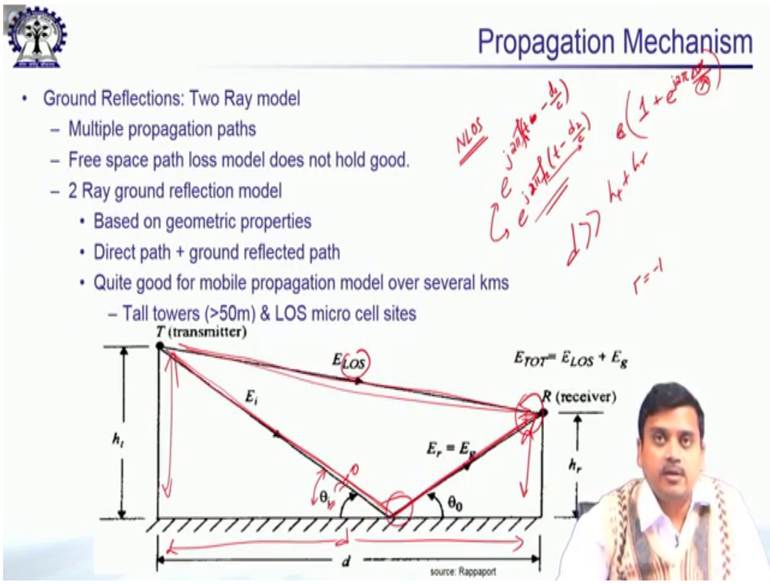

So, there is a very important model, which is known as the 2 ray propagation model. So, in the 2 ray propagation model, what we see is from the free space model, there is usually non-usually line of sight. But, in most of the communication systems that we are going to encounter would be non-line of sight right.

So, when you have non-line of sight, what you have is, there is one line of sight path and one path which is reflected from the ground and goes to the receiver end. So, under various set of assumptions, for example this incident angle is almost 0 and that happens when the separation distance is very very large compared to the heights of the transmitter and receiver. So, when d is much much larger than let us say h t plus h r under those conditions, you can get this angle which is almost equal to the raising angles. And then there is a certain condition on the reflection coefficient, which gives us the value of minus 1 right, which will be use in this particular model.

So, what we aim to do over here is we know the received signal and the direct line of sight, the received signal along the reflected path, you add them together vectorially and then you receive the signal. You can do it in various space, we will follow the method which is described in Rappaport, but you can also follow the classical method that you consider the baseband signal as e to the power of j 2 pi f c t. And the other signal is e to the power of course t minus the propagation distance divided by c and the other part is e to the power of j 2 pi f c t, so t minus one of the distance is d and d 1 let us say, the other distance is d 2 upon c, add these two signals and then take the amplitude of the signal, and you are going to see what is the effect right.

So, so here effectively what we are studying is the path loss difference between the line of sight, and the line non-line of sight. So, effectively one of the paths is a direct path and the other path is one with a path separation of delta x upon lambda. So, lambda is the wavelength which will give us, so basically what you have is f c divided by c, which leads to delta which leads to lambda in the denominator. So, if we take the amplitude of this, we get the amplitude of the received signal strength. Take the square of this, you are going to get the received signal power. So, with all the steps that are followed we skip it here for brevity, which you can follow through in any of the courses or the books which are given in details.

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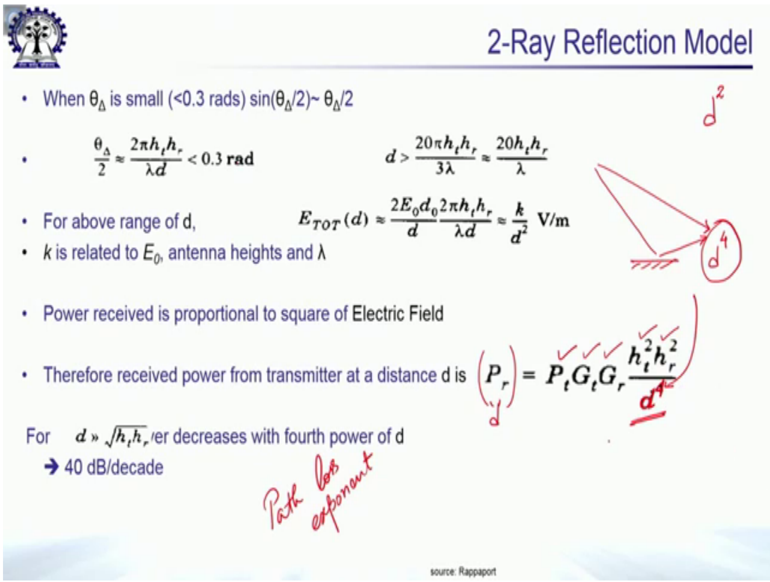

We will finally go into what we end up with; of course there is a few set of assumptions, one of the assumptions we have already stated over here, d is greater than the h t plus h r,] and for very very small angles which are used in the derivation our objective is not to derive over here, our objective is to mainly look at the end result.

What we find is that the received signal strength, which is a function of separation distance d is proportional to P t naturally G t antenna, gain a transmitter, G r antenna get the receiver, h t squared is the transmit height and then we have h r squared, which is the received height. And what we see most important in the denominator, we find d raised to the power of 4, this is a huge distinction from the model of the fries free space equation, this is to be noted.

So, what we find is that when we have one line of sight and one reflected path right, then compared to freeze free space equation which says the path loss is proportional to d squared. Here we find the path loss is proportional to d to the power of 4, which makes it significantly different compared to line of sight. So, this is a very very simplistic analytical model which only helps us in understanding how things happen, but in reality there is a huge amount of measurement which goes through in deciding this value. And usually, this value 4 that is over here is known as the path loss exponent, and which is a very very critical factor for characterizing the channel.

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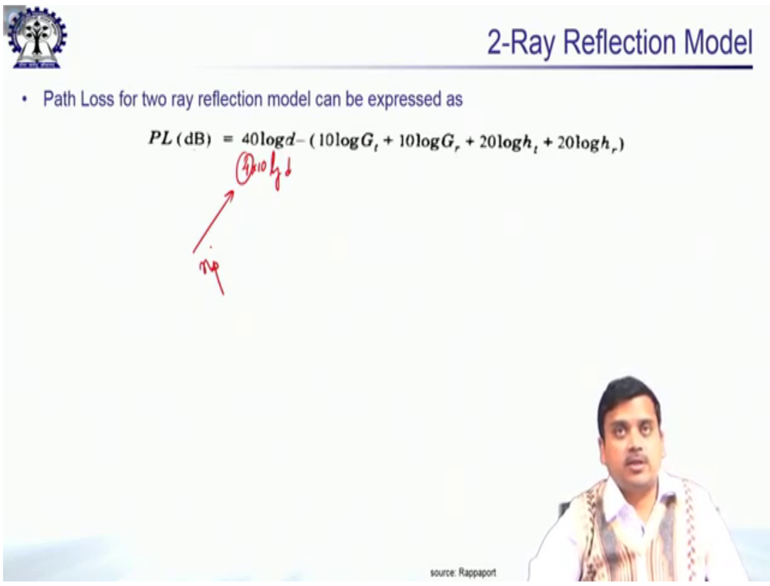

So, when we take in the dB scale, we write it as if you take the dB value of this 10 log base 10 of this, this is what you get, and what we see? There is a 4 multiplied by 10 log base of t and this is what you characterize as n p known as the path loss exponent right, so that is what is given over here as n p and everything is referred with respect to the closing distance d 0.

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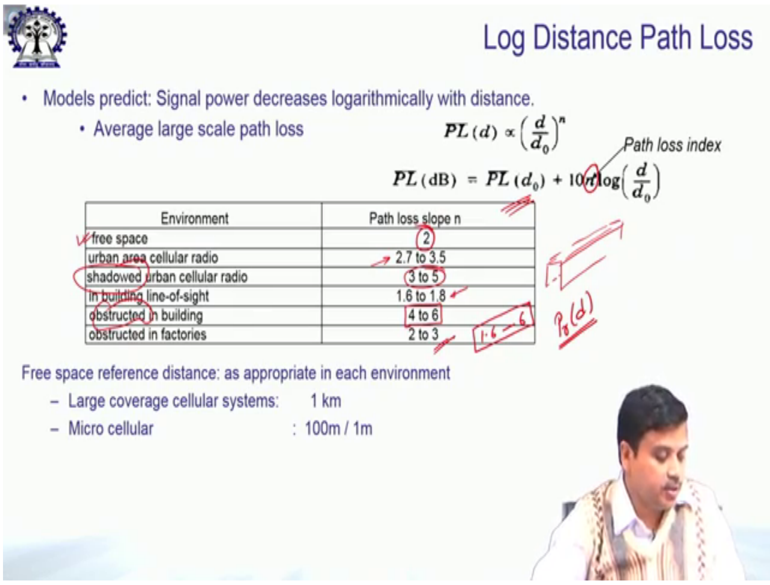

What we see is that this path loss exponent n p varies over different environment. In free space, it has a value of 2 which you have already seen. In urban cellular, it has a value in the range of 2.7 to 3.5. In shadowed urban area, it has range of 3 to 5 and in building line of sight it is less than 2, where there is this waveguide effect due to corridors right long corridors and so on, so that is kind of a situation which you can encounter.

In obstruction, what you will find, it is going to 4 to 6 that is one of the highest values. In factories, it is 2 to 3 because of a lot of reflections on metallic parts. So, what we see is that the path loss exponent can vary from 1.6 to 6 depending upon the situation case to case basis. And this would significantly influence the received signal strength prediction model. So, as per this model, if we know this path loss exponent, then we can predict the received signal strength given a particular transmit power.

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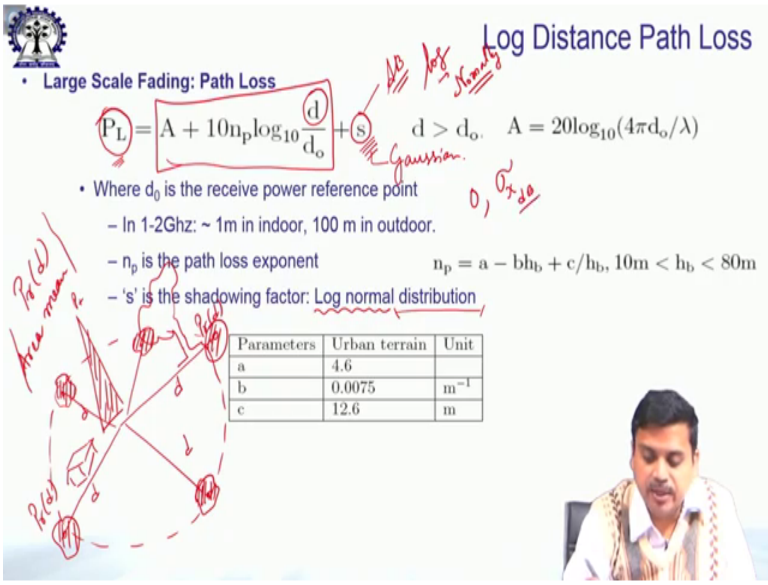

Along with this, there is also something called shadowing effect, which we bring in as the next parameter, and which is added to the path loss model, which would otherwise predict only the average as a function of only transmitter, receiver separation distance. However, if you look into practical systems, you will find or any realistic situation if you would like to imagine.

The path loss tells us that if you go to a separation distance d, there is a certain received power which is predicted by the separation distance d given a particular transmit power P t. If you would go to any other direction on with the same distance d, the received signal strength predicted by the path loss model would remain the same.

However, we know from real conditions that in one direction there might be a lot of foliage, whereas in other directions there might be line of sight or there might be other kinds of obstructions which is very different from the kind of obstruction that we receive in one direction. So, hence this path loss model, which is only dependent on the separation distance is not a correct or completely accurate way of capturing the propagation conditions and hence you add the shadowing phenomena.

The shadowing phenomena is one which is modeled with lot of details will briefly talk about it here again, because to only make us aware of the situation. So, what we know is that this shadowing phenomena has been modeled based on various observations and there has been huge detailed amount of papers which talk about talks about the correlation, these fluctuations. And since, there is randomness that means, we do not know, where we are going to do the measurement.

And since our evaluation should capture all possible scenarios, therefore one should be able to capture the various the fluctuations. And hence, we get into a stochastic process or a random variable is introduced into the model. So, once we talk about the random variable, we need to talk about its distribution. It has been observed from various measurement campaigns that this log normal distribution describes this in the best possible way compared to all other models.

So, log normal means that if we take the dB value of it or we take it in the log domain, then it is normally distributed, so that makes things simple. So, when we record or when we talk about path loss in the dB domain, we have a Gaussian distributed random variable which is added to the mean. So, simply taken things if one would take the average over here at a separation distance d, one would take an average over here, one would take an average over here, one would take an average over here, one would find that the averages are different.

However, if one would take average across all points which are separated at a distance d, one would average out these fluctuations and one would get received signal strength at a separation distance d. And hence which results in the path loss model, and hence it is the area mean. Whereas, when we are talking about the average in the local region, we talking about the local mean which is a fluctuation about this thing. And hence this is added on to this expression which only predicts the average receive signal strength is a separation of transmitter receiver distance. So, when we talk about log normal fading or the average local fluctuations this S as a 0 mean and variance which is denoted by sigma x in dB, and there are various ranges of the values of x dB.

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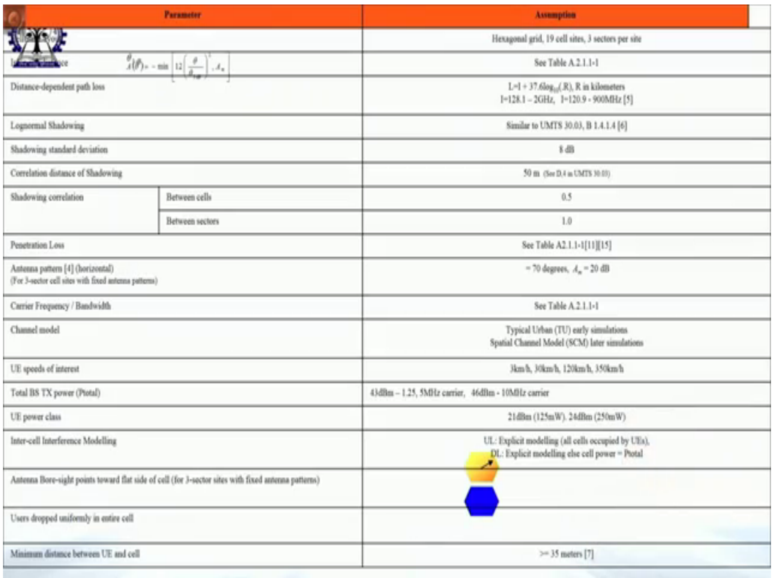

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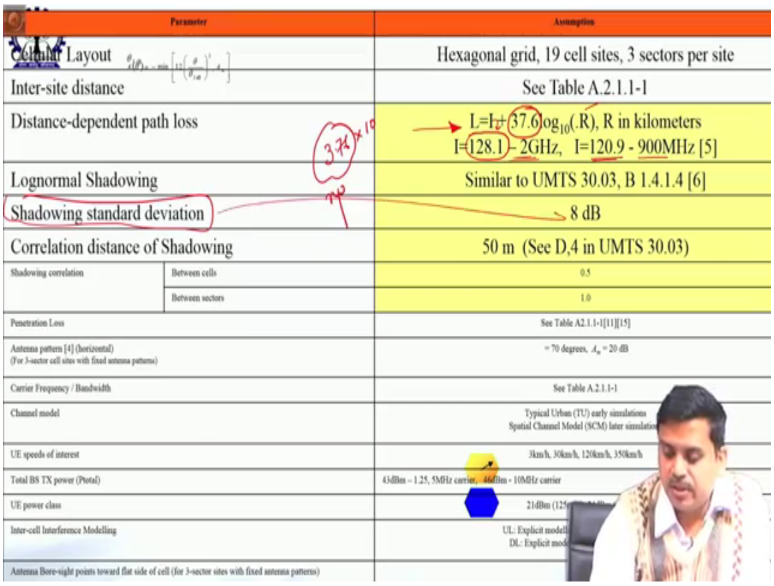

So, there are different models which capture, we will look into one particular model which is from the 3GPP. So, here what we see that the loss expression is given by this equation by L, I is a constant which captures several losses corresponding to systems. And it is defined for 2 giga Hertz as one particular value this I and it is given as another particular value at 900 mega Hertz. So, this is what the model tells and the separation distance R is in kilometers, if one is to use this particular model. And if one reads off, this particular coefficient one would find that it is 3.76 multiplied by 10 and hence 3.76

is the path loss exponent for this particular model. What we find here, another important thing is that the shadowing standard deviation is mentioned as 8 dB.

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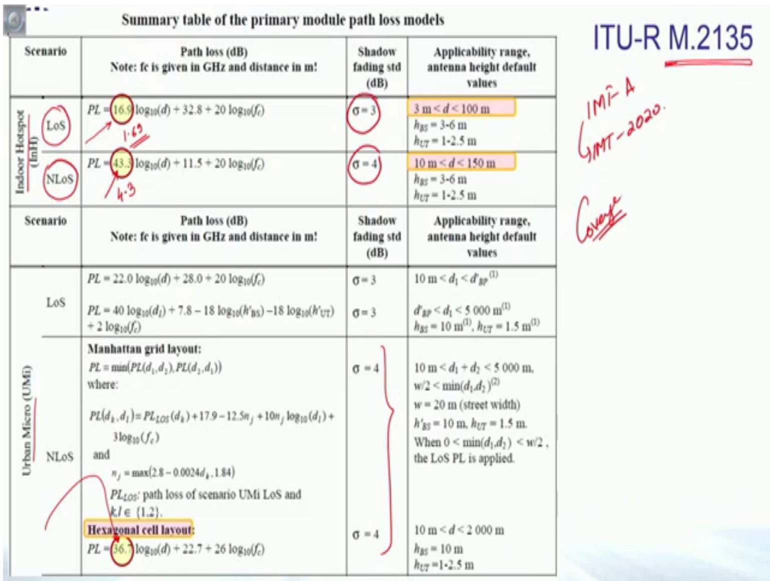

So, we will discuss all the various expressions, here we have it over here in this particular slide; that this particular slide actually captures is from the document M.2135, which we have described in our early lectures. So, one can refer to M.2135 which is a document which tells us about how to use different models in the performance evaluation of the communication systems, especially with respect to IMT advanced. So, this is primarily with IMT advanced, but then you go to IMT-2020, and there is not much a significant change in the models there are some new additional things that have been brought into.

So, we will just see a glimpse of what happens? So, in one scenario which is indoor hot spot scenario, in the line of sight condition, what we see is that the path loss exponent can be thought of as 1.69 as the coefficient. And remember we had said that in indoor conditions, they can be situations in path loss experiment is less than 2.

Here we see a non-line of sight condition in door and then it is can be I read off as 4.3. We will see another case, so in urban micro, we again see that as 3.76 as the path loss exponent. In all these things, we will find that the sigma values are also mentioned that is 3 in one case, 4 in another case and in different cases, it has been specified accordingly.

So, once we use these models in order to predict the signal strength to calculate the coverage due to the signal and one can proceed to plan the whole network.

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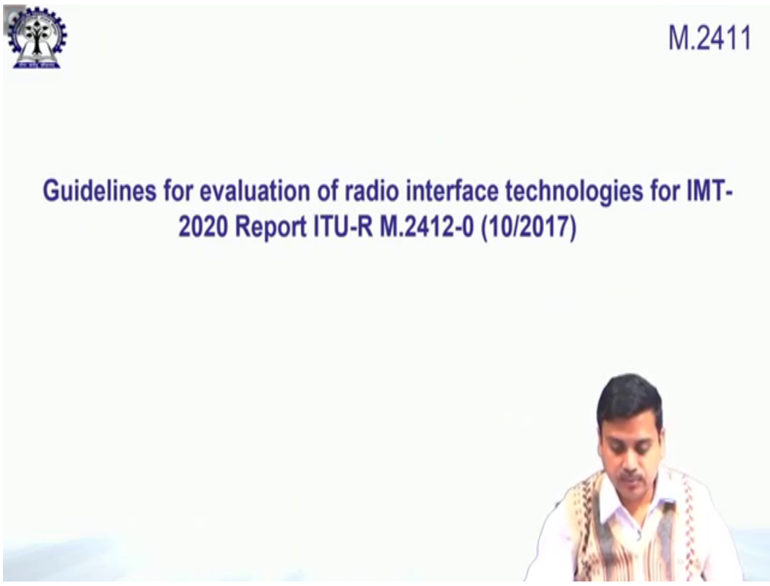

So, we stop our particular discussion over here. We will continue on to with this in one more lecture, we will talk about the effect of this shadowing on coverage and how to calculate the coverage area and the boundary coverage probability which is essential for evaluating the performance of various schemes that are there existing today and are going to come in future.

Thank you.