Wireless Communications
Dr. Ranjan Bose
Department of Electrical Engineering
Indian Institute of Technology, Delhi
Lecture No. # 12
Mobile Radio Propagation (Continued)

We will start today's lecture with mobile radio propagation models and look at some more interesting models for outdoor as well as indoor propagation. The outline of today's talk is as follows.

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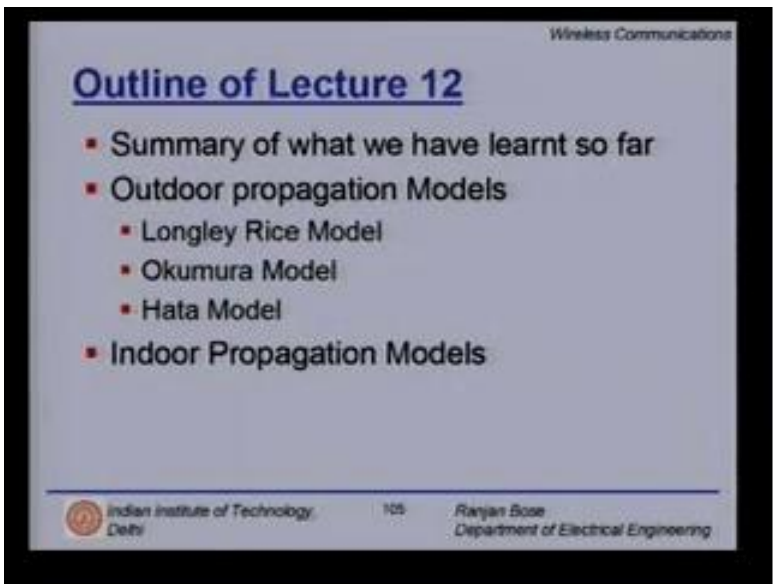

We will first summarize what we have learnt already. Then we'll look at three very useful outdoor propagation models. They are:

- Longley Rice Model
- Okumura Model
- Hata Model

Then we will talk about different kinds of indoor propagation models. It is important to note that the validity of your prediction and the accuracy of your prediction depends on how good your model is. As we will see, most of these models have been obtained by measurements. They are basically a mathematical phase to measurement data. We start with the recap.

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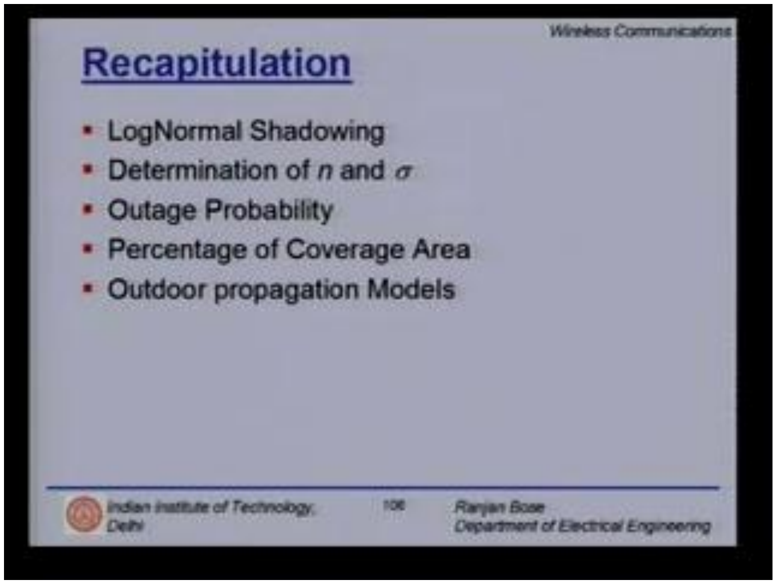

In the previous lecture, we saw what is lognormal shadowing. We looked at methods of determining 'n' - the path loss exponent and the standard deviation – 'sigma'. You can obtain this based on measured data. We then looked at outage probability followed by the percentage of coverage area. These are important and probabilistic because your lognormal shadowing also has a random variable x of sigma. We had a brief introduction to outdoor propagation models which we will follow through today.

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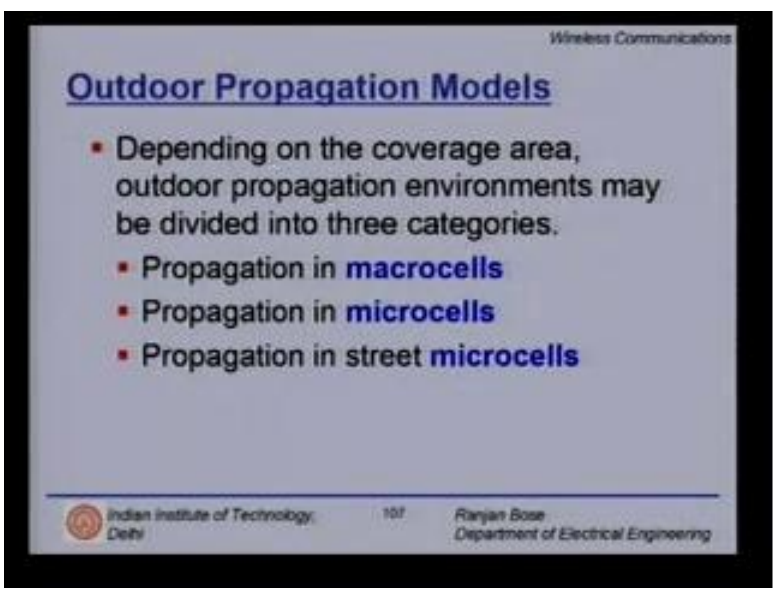

So the outdoor propagation models are as follows. Depending on the coverage area, the outdoor propagation environment may be divided into three broad categories. From the last time, we saw propagations could be classified within the macrocells, in microcells and in street macrocells - a special case of macrocells.

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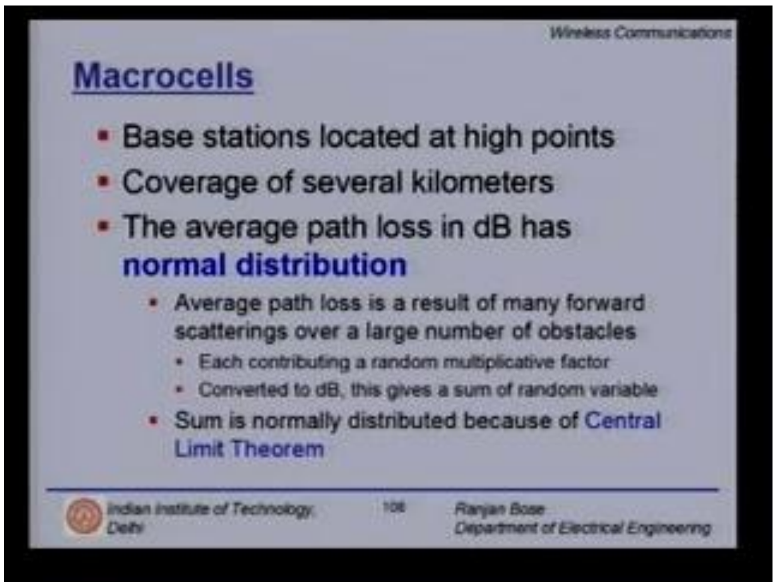

In macrocells, base stations are located at high points. The coverage extends to several kms and the average path loss in dB has normal distribution. So if you take the path loss in decibels, it is found to be in a Gaussian distributed manner. The reason is as follows. The average path loss is a result of many forward scatterings over a large number of obstacles, each contributing a random multiplicative factor converted to dB. This gives a sum of random variables from the Central Limit Theorem. We have the distribution to be normal.

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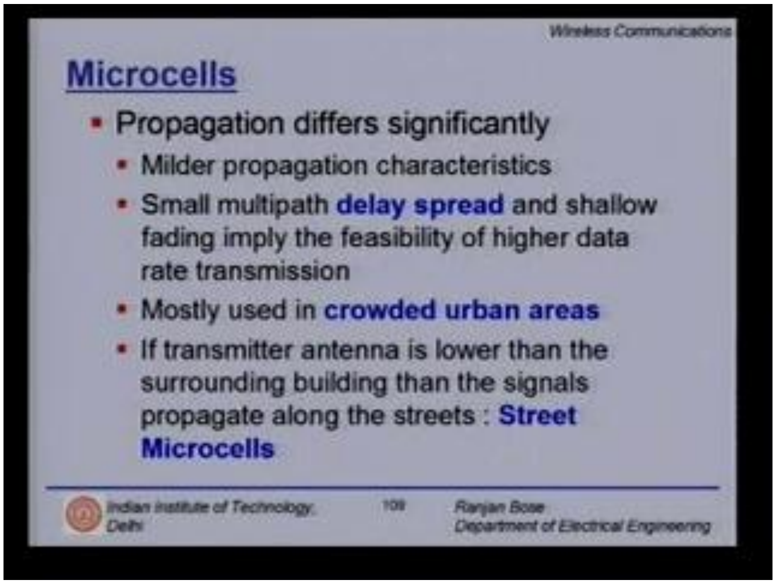

In microcells, the propagation differs significantly as opposed to microcells. We have a milder propagation characteristic. The delay spread is small and the shadow fading implies that the feasibility of high data rate transmission exists. These microcells are mostly found in crowded urban areas. If the transmitter antenna is lower than the surrounding buildings, then the signals propagate along the streets and this is called "the street microcell".

As will see in real life, streets, halls, corridors, etc. have a strong guiding effect and this sometimes result in the path loss exponent 'n'. Even less than two which is a kind of good news for us. We can have much lower transmit power and the antenna heights need not be very high if you are working in the street microcells. What are street microcells? Most of the signal power propagates along the street. The signals may reach with line of sight paths if the receiver is along the same street as the transmitter. However this may not always be the case. The signals may reach via indirect propagation mechanism. If the receiver turns to another street but once a diffraction or scattering at an edge occurs, the signal again propagates along the next street.

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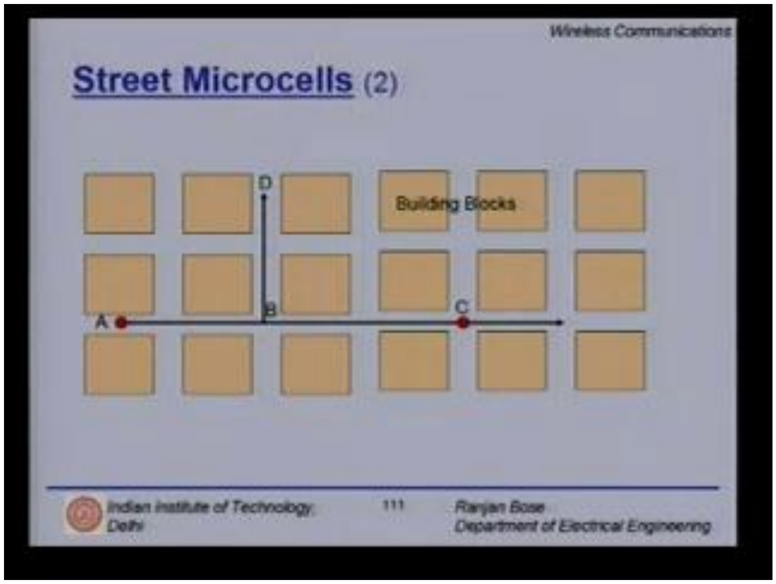

This simple example tells us how street microcells work. Assume A is your base station 1. C is your second base station. So these are marked by red dots. Suppose B is your receiver. In the beginning, B has a luxury to receive power either from A or C. these squares are building blocks and these are the various streets. Now there is a clear line of sight here between B and A and this signal is propagated along these streets and there is a strong guiding effect. However if B now moves to location D, then there will be propagation along the street. There will be diffraction, reflection and then the signal will again propagate along the street. So these are strong guiding effects. You don’t have to have A and C. the base station is very high up nor do you have to put a lot of transmitted power.

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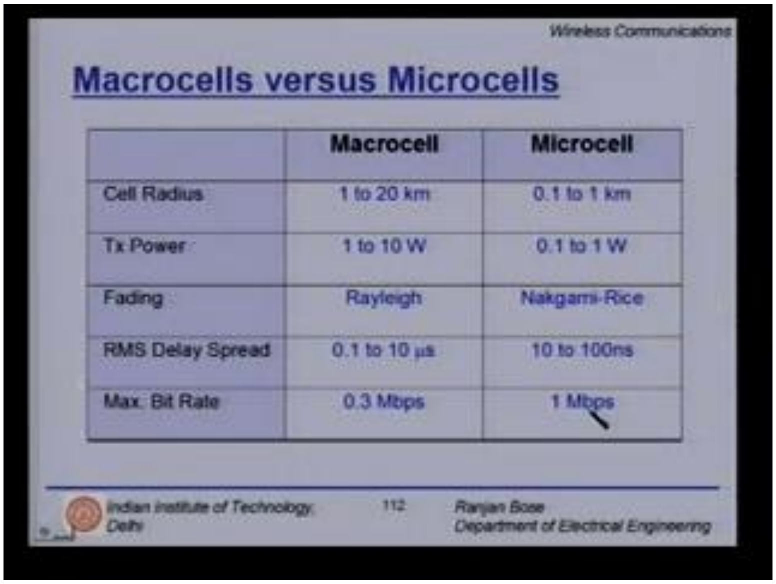

A slide on macrocells versus microcells:

Macrocells are larger. The cell radius is 1 to 20 km whereas microcells are much smaller. Its radius is 0.1 to 1 km. clearly the transmitted power is scaled accordingly from 1 to 10 watts for macrocells whereas 0.1 to 1 watts for microcells. Fading in macrocells is primarily Rayleigh because of the absence of line of sight whereas fading could be Nakagami Rice distribution because there is a possibility of a line of sight. The delay spreads are much smaller in microcells of the order of 10 to 100 ns whereas for a macrocells, the delay spread increases because the reflected paths travel much longer and there could be multiple reflections. Also in macrocells, the bit rate cannot be very high. It is less than Mbps. whereas in microcells, you can have more than 1 Mbps.

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Let us now look at specific kinds of outdoor propagation models. We will see why they are built and what do we derive out of them. So first thing we must observe is that the outdoor radio transmission takes place over irregular terrain. The model should be able to predict the received power and the path loss irrespective of the kind of environment you are working in. So your model should be normally as general as possible. The terrain profile must be taken into consideration for estimating the path loss. So what do you mean by terrain profile? You have foliage, buildings, hills and other blockings like towers, street effects, desert, water bodies, etc. All of these will have an effect on your propagation and hence the path loss. So we will see how these effects are taken into consideration for various kinds of models.

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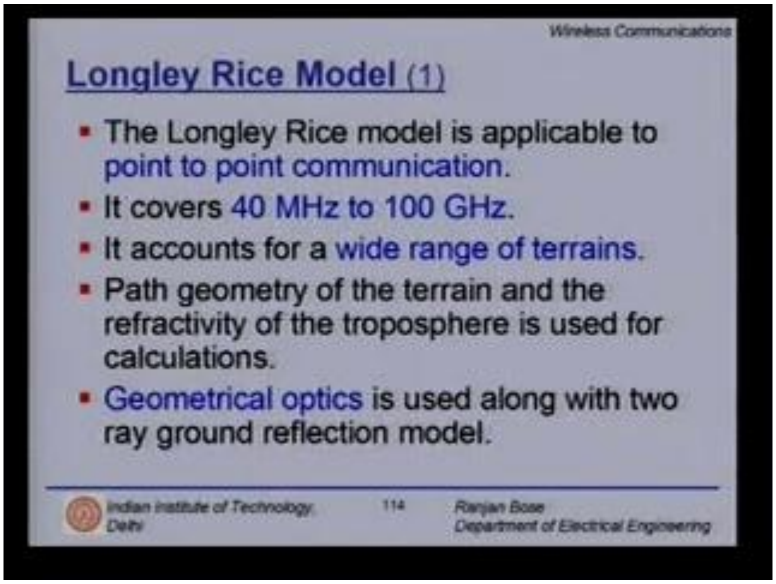

The first model that we are going to study is the "Longley Rice Model". This model is applicable only for point-to-point communication. This belongs to the old days when there were a lot of microwave links which operated from point-to-point. It's not useful for mobile communication but still today, we have a lot of communication taking place which is of point-to-point nature. What is interesting is it covers a wide range from 40 MHz to 100 GHz. it also accounts for a wide range of terrains. In the next slide, we will see how a variety of terrains can be incorporated into the Longley Rice model. The path geometry of the terrain and the refractivity of the troposphere is used for calculations. It actually takes in a lot of parameters. It calculates based on path geometry and then comes up with an answer. Geometrical optics is used along with the two ray ground reflection model. In our earlier lectures, we have seen the two ray ground reflection model and how the height of the transmitter and the receiver along with its separation between the transmitter and the receiver come into play for the two ray ground reflection model. So Longley Rice Model takes into consideration all these factors for giving you a predicted path loss.

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Normally, the Longley Rice model is available in the form of a computer program which is interactive. The program takes as input a couple of things. Some of the parameters are as follows. Clearly the transmission frequency is the most important parameter. The other parameters taken into consideration are path length, polarizations if any the antenna, heights both for the transmitter and receiver, the surface reflectivity ground conductivity and dielectric constant and climatic factors. So it takes in all these parameters and based on geometric optics it comes up with a path loss prediction. But what it does not take into account is buildings and foliage because in those days, it was assumed that your transmit tower antenna situated on top of a tower was way up and it would not be interfered by the presence of trees or buildings. But this is not the case in today's wireless communication scenarios.

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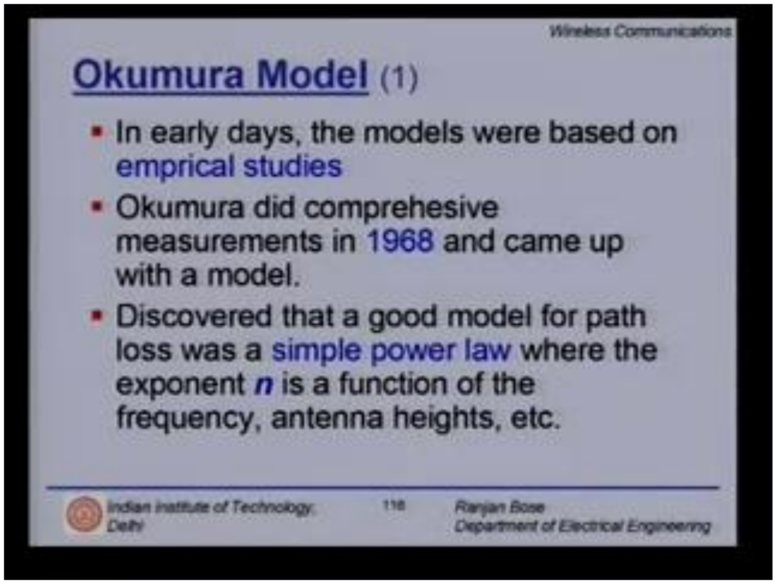

We now move on to the most popular model which is the Okumura Model proposed by a Japanese enthusiast Okumura. In early days models were based on empirical studies only. Okumura did a comprehensive measurement campaign in 1968 and came up with a model purely based on measurement. What is interesting is this model is reasonably accurate and is still used. d it is used for most communication design companies in Japan. Okumura discovered that a good model for path loss was a simple power law. it was verified by extensive simulations where the exponent ‘n’ is a function of the frequency, antenna heights, terrain, etc. whether it’s an open space, quasi open urban environment etc. all those factors will come into play. But at the bottom, it is the path loss exponent which matters and the extensive measurement verified the presence of a simple power law relating the received power and the separation between the transmitter and the receiver.

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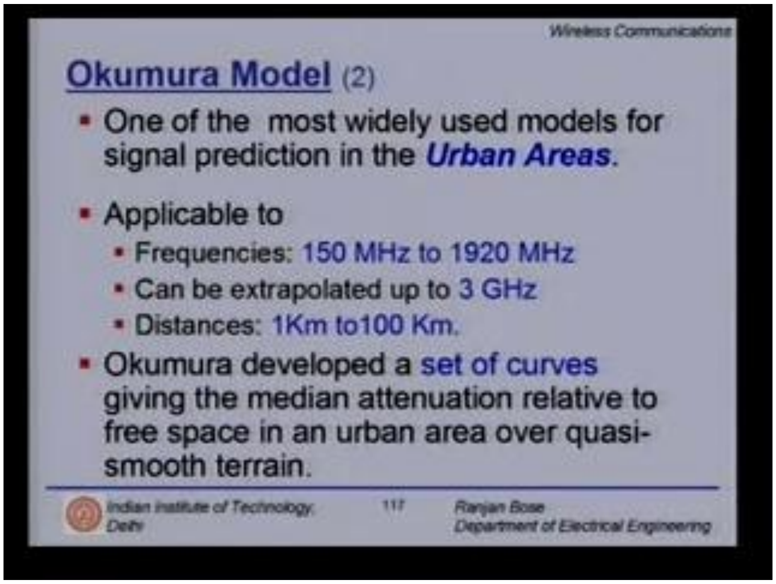

So the Okumura model is one of the most widely used models for signal prediction in the urban areas. This is important because most of the measurements he carried out were for urban areas. When we start moving from urban to semi urban suburban or rural areas, you have to put in a correction factor. But your model becomes weaker and weaker as you move from dense urban to rural areas. The Okumura model is applicable to frequencies from 150 MHz to 1.9 GHz. but it can also be extrapolated up to 3 GHz. the curves are very smooth. So basically what he did was he carried out a measurement and then he plotted curves. Today I can use this Okumura curves to come up with predicted path loss values. The distances he covered were from 1 km to 100 km. Okumura developed a set of curves giving the median attenuation relative to free space in an urban area over quasi-smooth terrain. So it's not that he is carrying out the measurements on flat grounds but on quasi-smooth terrain. So his results are valid over the frequency range of 150 MHz to almost 2 GHz. It can be extended up to 3 GHz and is valid from 1 km up to 100 km. so he did all that there was to be done.

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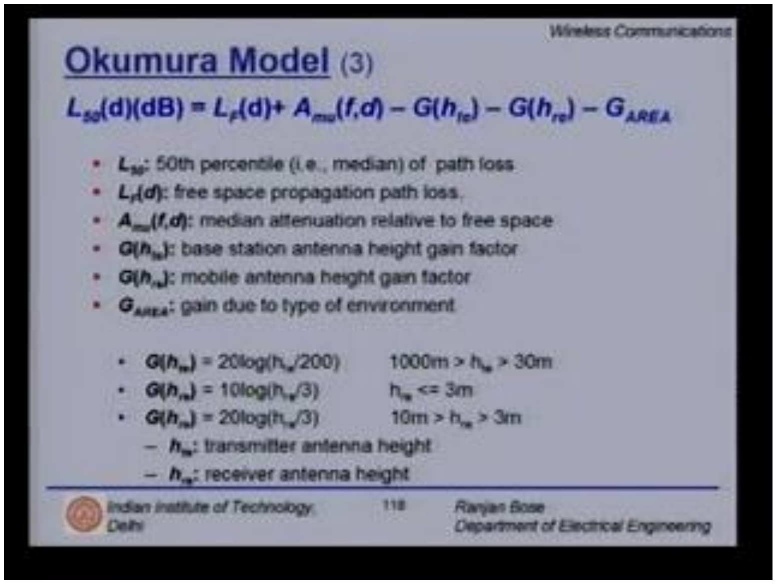

Mathematically, the Okumura model can be presented as follows. On the left hand side you see L_{50} (d). This is the 50th percentile. That is median of the path loss. So it predicts the median of the path loss and it is given by first L_F(d) - the free space propagation path loss and relative to the free space propagation path loss, it predicts the A_{mu}(f,d). Amu is the median attenuation relative to the free space path loss. So you still have to find out what is the free space path loss and only relative to that it gives you a correction factor. But there are couple of other things. What are those? It uses something called as the G(h_{TE}) - the base station antenna height gain factor. Clearly, if your antenna height changes, your received power at the receiver will also change. Same stands for the mobile antenna height gain factor- G(h_{re}). so you must specify the height of the base station and the height of the receiver station in order to calculate that. Now there is another factor which is G_{AREA}. It tells you what kind of environment you are working in like urban, semi-urban or is it rural.

You have a correction factor by combining G_{AREA} - the gain of the receiver antenna, the gain of the transmitter antenna and of course the measurement data A_{mu} which is the median attenuation relative to the free space. You can predict the path loss. This is the crux of the Okumura model. Now here at the bottom of the slide, I have put in how do you calculate the gain, h_{te} - the height of the transmitter antenna. it is 20 log (h_t /200) provided the transmitter antenna height is from 30m up to 1 km. of course, he never erected a tower. This is based on a tower situated on top of a hill. But the moment you have a value of h_t, you can calculate the gain factor and then you can plug in the values. Similarly for the receiver antenna height, you have this. So it is easy to come up with the computer program which asks for certain inputs and gives you a path loss prediction or you can use a set of curves.

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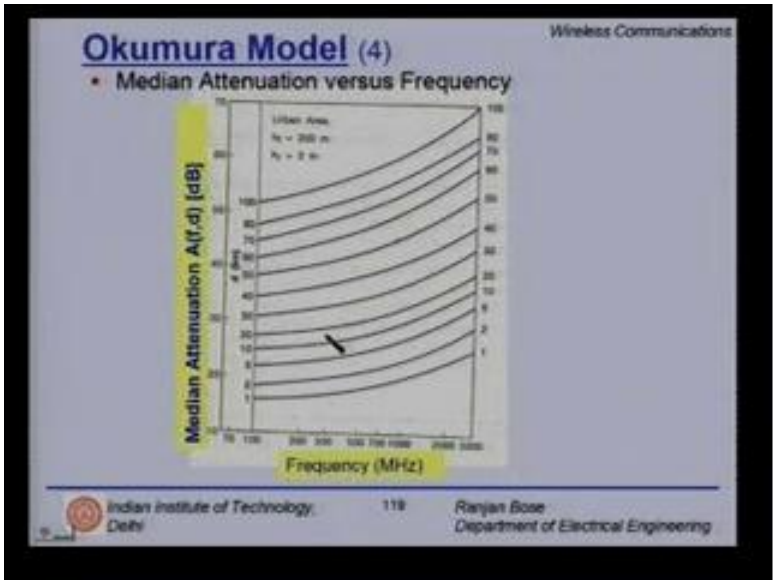

Let us see a typical set of curves for median attenuation. Of course that is verses frequency. So he carried out the measurements of the attenuation with respect to different carrier frequencies continuously. Here is one of the Okumura curves. On the x axis I have put frequency in MHz. so as you can see, it goes up to 3000 MHz or 3 GHz and at the y axis, we have the median attenuation in dB. Also you see a lot of curves which are criss crossing. these are distances in km. it starts from 1 km and goes right up to 100 km. but this set of curves is done in an urban area for a transmitter height of 200 m and the receiver height of 3 m only. Whatever value you get from this curve can be adjusted for a different antenna height at the transmitter or the receiver by using the $G(h_{te})$ or $G(h_{re})$. As expected, as you move from 1 km radius to 2,5,10 up to 100, the median attenuation goes. so for a certain frequency, say 100 MHz at 1 km, you have close to about 12 or 15 dB of median attenuation but whereas for the same frequency, 100 MHz if you go to 100 km, you have close to 52 dB of median attenuation. It's very easy to read these curves. What is interesting is these curves are fairly accurate.

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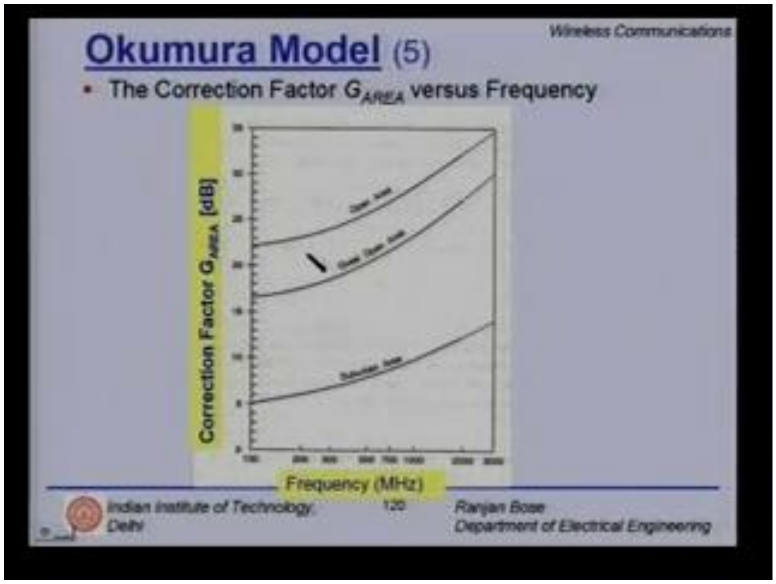

Now we also mentioned the correction factor G_{AREA} and there is a curve for G_{AREA} versus frequency. What Okumura found is that when you take the measurements in urban environment versus semi-urban versus rural environment, you see a variation in the path loss as expected and G_{AREA} will help you understand and you give the correction facto. Again as intuitive, G_{AREA} must depend on the frequency of operation. So again on the x axis, I have put the frequency in MHz. on the y axis is the correction factor G_{AREA} again in dB. Here there are only 3 curves - the sub-urban area, the quasi open area and the open area. What we see is that the curves have been obtained only up to 1.9 GHz but can be extrapolated up to 3 GHz. You work at a certain frequency - 100 MHz, find out and then you put the correction factor. Please don't be misled by the factor that how come for an open area the attenuation is much higher than in the sub-urban area. This is because intuitively we know that in an urban or sub-urban area, because of the presence of buildings, obstructions, etc. the attenuation should be much larger. The catch is that this is only a correction factor. That is, the Okumura model is much more accurate for the sub-urban area. It is very accurate for the urban area. It is still accurate but not so much for the sub-urban area. So the correction factor is less whereas when you go to quasi open areas, clearly the model starts failing and the correction factor is much more and the moment you go to open areas, you have to put in a large correction factor.

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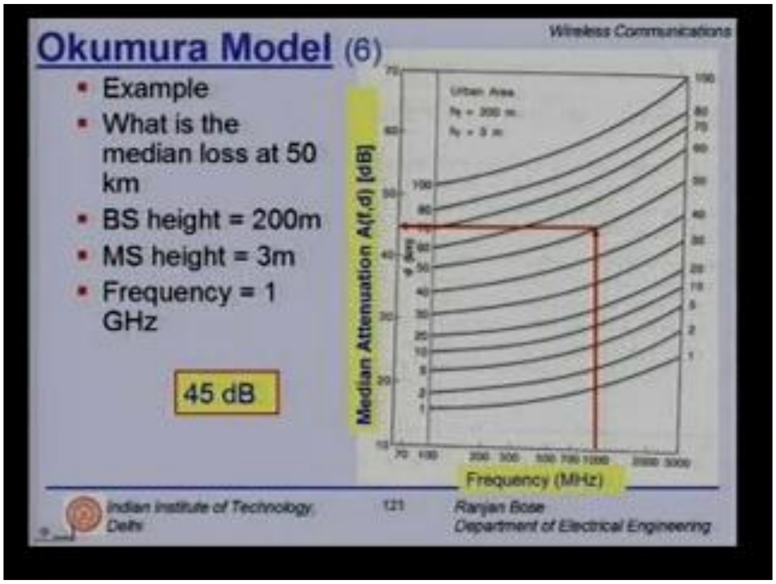

Let's look at an example of how to use Okumura model. Suppose we have to calculate the median loss relative to the free space loss at a distance of 50 km, the base station height is 200 m. so your base station tower is located on top of a hill whereas the mobile station height is 3 m. these values have been put so that we can use an existing curve or set of curves without using the correction factors. The frequency of operation is 1 GHz. so the objective is to find out the median path loss at a distance of 50 km when the base station height is 200 m, the receiver height is 3 m and the frequency is 1 GHz. We bring back our set of curves again. On the x axis we have the frequency in MHz. On the y axis we have the median attenuation in dB. Now our frequency of operation is 1 GHz. So we go on the x axis, locate where is 1 GHz or 1000 MHz. we draw this line. Clearly I stop at the distance line which is corresponding to 50 km which is this line. So here I would like to find out what is the median attenuation with respect to the free space and the value that I obtain is about 45 dB. The answer is: for this, relative to the free space, we have an attenuation of 45 dB. This is the median attenuation. Fairly simple.

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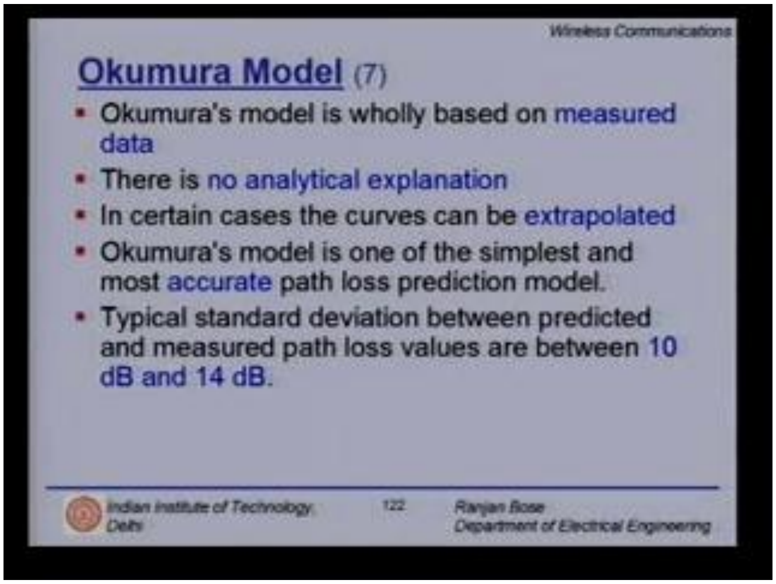

Now the Okumura model is purely based on measured data. There is no analytical explanation. in certain cases, the curves can be extrapolated as we saw. What is interesting is Okumura's model is one of the simplest and one of the most accurate path loss prediction models. It is still very accurate. Its typical standard deviation between the predicted and the measured path loss values are anywhere between 10 dB and 14 dB. So you can put in that margin of error and then be happy about using the Okumura model. The other path loss models can go beyond this standard deviation. So still relative to the other models, Okumura's model is fairly accurate and is still being used even though it was proposed in 1968.

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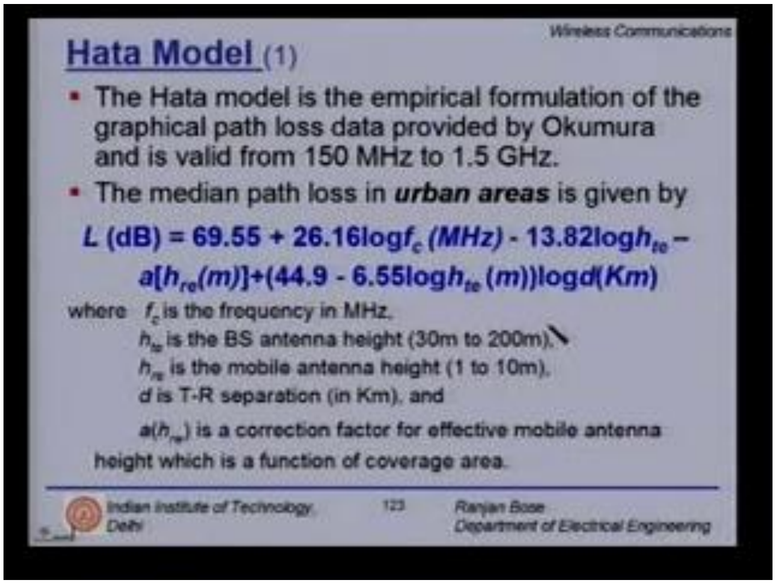

Now Hata proposed an empirical formulation of the measured data presented by Okumura. so the Hata model is the empirical formulation of the graphical path loss data provided by Okumura and is valid from 150 MHz to 1.5 GHz. Okumura conducted his experiments almost up to 1.9 GHz. please note Hata model is based on The Okumura model. The Okumura model was conducted in urban areas. So Hata model is also valid in urban areas. You can use a correction factor again to move from the urban to the sub-urban or quasi urban areas. the median path loss is given by L in dB based on some numbers because it is primarily curve fitting 69.55 + 26.16 log fc in MHz – 1.82 log h_{te} - which is the height of the transmit antenna - something called $a(h_{re})$. $a(h_{re})$ is a correction factor for the effective mobile antenna height which is the function of the coverage area + some more correction factors and finally your log d here is in km. these numbers are valid only if you put your carrier frequency in MHz, the distance in km and height of receiver antenna and transmit antenna in meters.

Please note, interestingly the height of the transmit antenna has come here as a multiplicative factor to the log d. it has a much stronger effect. The height of the transmit antenna is the base station height and the range is from 30 m to 300 meters. Okumura had conducted for a much larger range of transmit antenna heights. But Hata model is accurate from 30 m up to 200 m. only then you don't have a single equation to account for all the curves. h_{re} - the mobile antenna height is only from 1 m to 10 m. it covers most of the ground.

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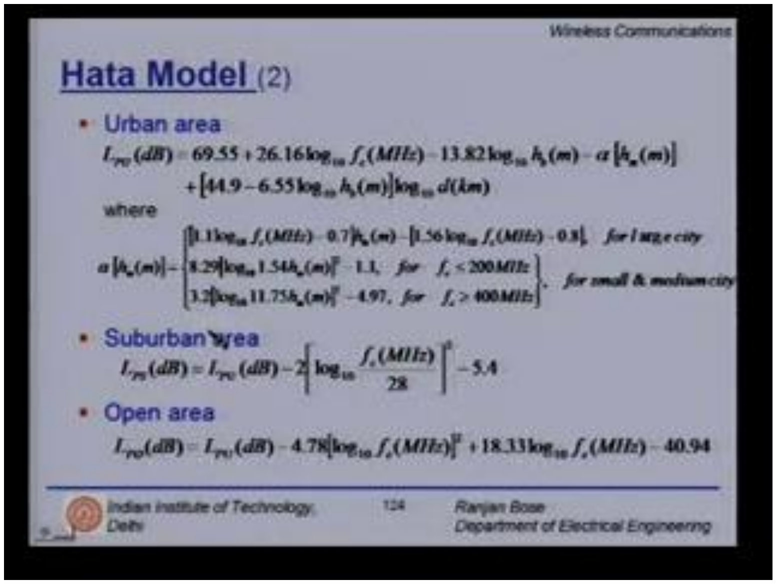

So in urban areas, we have the path loss exponent given by this equation which we just now discussed. The alpha rem is given by three equations either for a large city or smaller medium sized city depending upon what is your frequency of operation. Basically these are the different cases which have been somehow given a mathematical phase. So given whether you are in a small or medium city which will depend on what kind of buildings you have, the density of buildings, urban concrete jungle, etc. for large cities you have a different value of alpha h_{re}.

In suburban areas, you have the path loss predicted with respect to the urban area path loss L_{pu} - a certain amount of correction factor.

Conversation between Student and Professor: The question being asked is: Does this alpha value alpha h depend on theoretical values or measured data? The answer is: these are also based on measured data. All of these have been defined to exactly fit the curves presented by Okumura. nothing is analytical here. But we have tried to put in the mathematics to represent the set of curves. Suburban area as expected will have slightly lower path loss and there is this correction factor for open areas. You have another kind of equation which will help you calculate the path loss. These have been obtained by the set of curves given by Okumura including the G_{AREA} correction factor.

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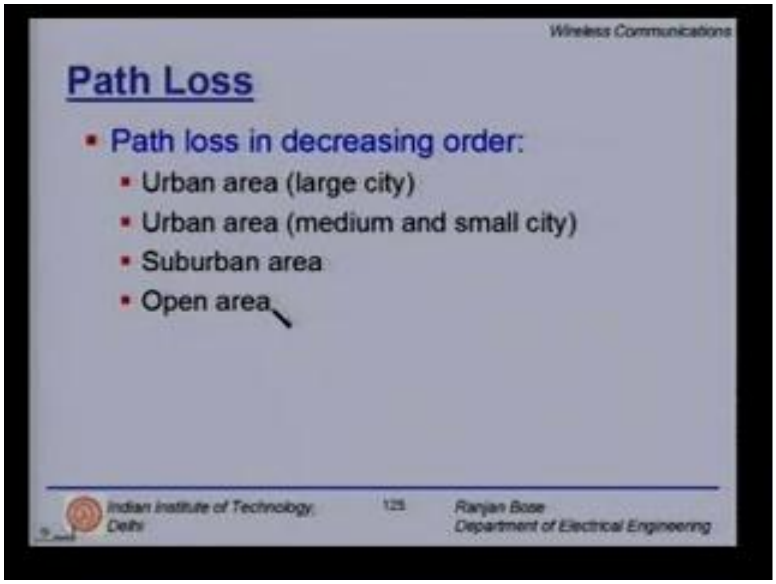

Now path loss in decreasing order is as follows. In urban areas of large cities, you have the maximum path loss. In urban area, medium and small cities clearly the path loss will go down. In suburban areas it will go down further and in open areas, you are close to free space like propagation. The path loss can be exactly predicted by the Hata model. Now, so far we have talked about outdoor propagation. Today a lot of wireless communication takes place indoors wireless local area network, personal area networks, body area network etc. in fact we have defined something called as a home cell. So tomorrow my TV will be networked to my computer which will be networked to my camcorder which will be networked to my DVD player and so and so forth all wirelessly. So we need to have certain indoor propagation models. Again the indoor propagation models will also be based on measured data and somehow curve fitting of this measured data.

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We will look at one or two different indoor propagation models and then try to come to some kind of a conclusion. Indoor channels are basically different from traditional mobile radio channels in two ways. First of all, the distances covered are much smaller and the variability of the environment is much larger for a small transmitter to receiver separation. So the room environment changes much more frequently. It is a time varying channel. Even the movement of people inside the room will change the channel considerably. The moving of the fan will change the channel considerably. The propagation inside a building is influenced by the layout of the building, the construction materials, building type, etc. whether it's an office residential, home, factory, godown, etc. in fact people have carried out all kinds of measurements through walls through partitions, cardboard boxes, plywood, metal sheet, etc. in order to come up with measure data that will help them predict what could be the received power. What has been traditionally done is for in house prediction; we actually use a ray tracing model and calculate depending upon a specific layout of the room. What is the received power and based on that the wireless local area networks could be set up.

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the indoor propagation is dominated by the same mechanisms as outdoors - reflection, scattering and diffraction. However, conditions are much more variable because doors, windows, etc. may be open or shut. Partition could be removed and fixed. Even where we mount the antenna, is it up on the ceiling, near the table, on top of the desk etc. will make a difference? Even the levels of the floors have been found to give different kinds of attenuation. We will see in subsequent slides that the indoor channels are classified as line of sight "LOS" or obstructed "OBS" with varying degrees of clutter.

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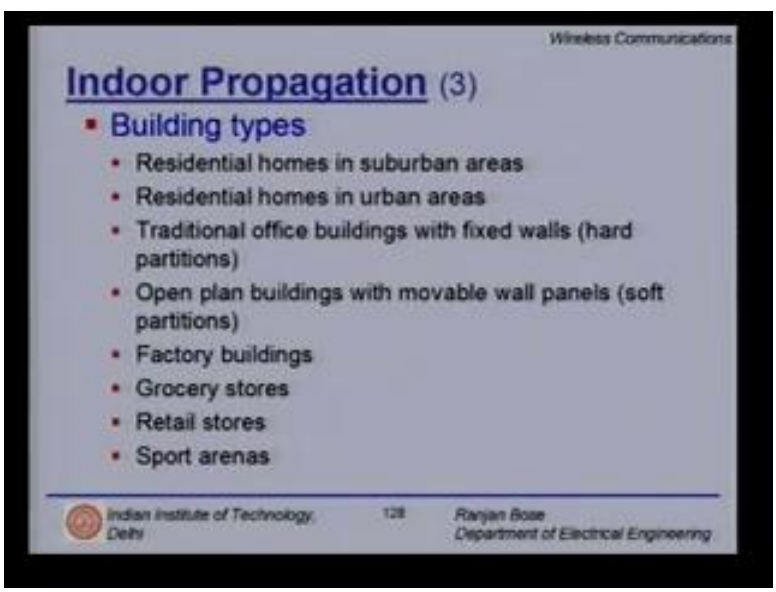

Now let us quickly look at the various kinds of buildings. All of them will have different characteristics. needless to say, researchers have carried out extensive measurement in all these kinds of buildings to come up with models and finally you have a computer model which will ask you the type of building, the types of partitions, walls, concretes, space, hopefully the layout of the room and then predict. So the different building types that have been used for measurements are residential homes in suburban areas, in urban areas - office buildings, factories, grocery stores, retail stores and even sport arenas.

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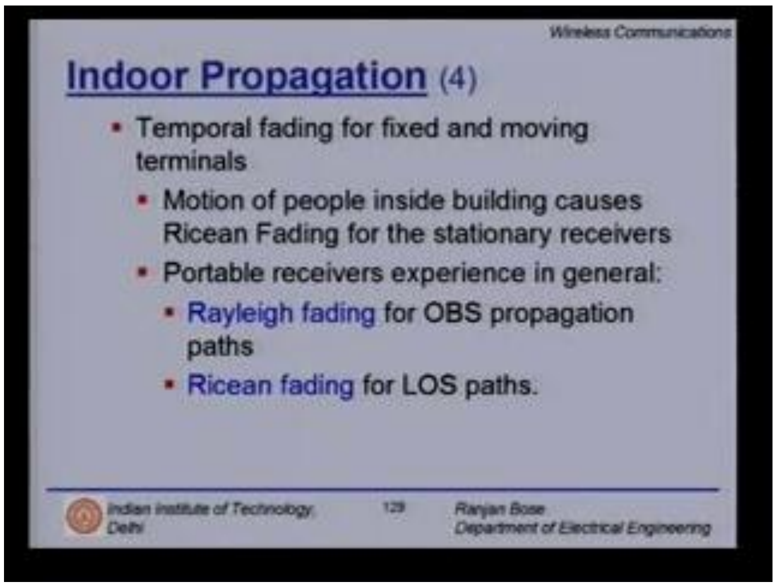

So what we see in indoor propagation is temporal fading for fixed and moving terminals. Please note: many times the transmitter and receiver within the room environment is fixed. However, the environment is changing. There temporal changes in the environment because people are moving equipment is shifting place, windows are being opened or shut. All these things will make a difference to the wildest channel. Motion of people inside the building causes Ricean fading for stationary receivers. Even though you have line of sight, you still have Ricean fading. Portable receivers experience in general, Rayleigh fading if there is obstruction. That is, no clear line of sight and Ricean fading if there is line of sight but still the environment is changed.

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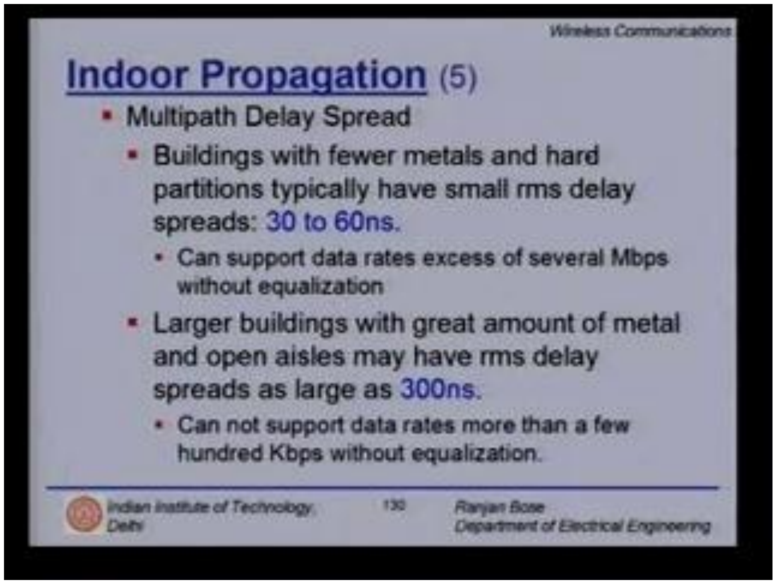

This slide covers the different kinds of multipath spread. Remember, when I send my signal, it reaches the receiver from not just one path but through several paths obtained either by reflections, scattering or diffraction. This multipath causes a spread called “multipath spread”. This multipath delay spread changes from building to building. It depends on the size of the room, the number of obstruction, the number of reflections, etc. buildings with fewer metals and hard partitions typically have small root mean square. That is, RMS delay spread ranges only from 30 to 60 ns. So we are fine because if the delay spread increases, it will cause inter symbol interference .therefore we will have to have some kind of equalization to overcome the effects of multipath spread. But of course, buildings with fewer metals and hard partition is not a serious problem. We have a delay spread of 30 to 60 ns only. What does it have? It has a strong relationship to the data rate. If the delay spread is less, the data rates that can be supported can exceed several Mbps. however in larger buildings with a larger amount of metal and open aisles can have larger RMS delay spreads, even as large as 300 ns. In these cases, we cannot support high data rates. Not more than some 100s of kbps. So delay spread within the room environment has a direct baring upon the data rate that you have. When you design wireless local area networks, for example, IEEE 802.11 b, you will have to consider the delay spread aspects also.

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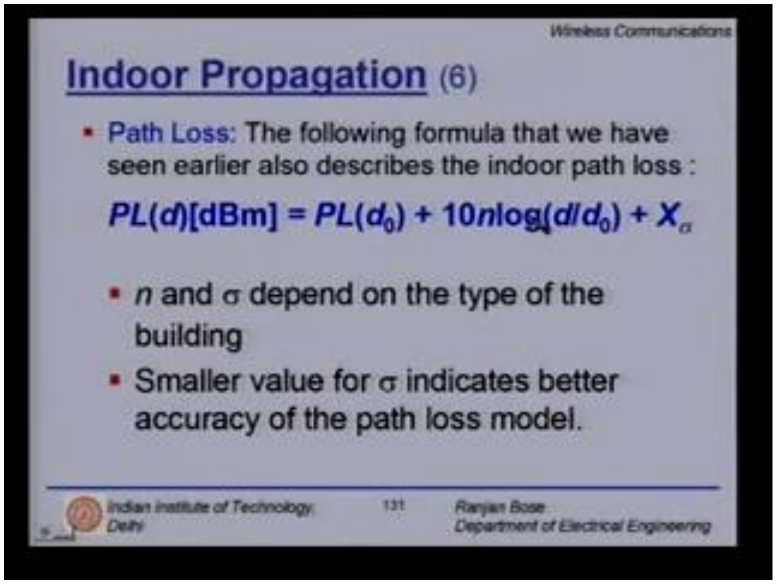

Now path loss can surprisingly also be predicted using an equation that we have seen before. The "PL" path loss has a function of distance of d between the transmitter and receiver. It is given by $PL(d_0) + 10\ n\ log\ (d/d_0)$ + X sigma. Remember the 'n' and the 'sigma' depend on the type of the building. Currently we are carrying out some in house measurements for ultra-wideband communication where we are measuring the channel from 3.1 to 10.6 GHz and this model for path loss has been found to hold true for that measurement data also. This is pretty general. The only problem is the sigma. The smaller the value of sigma, the better the accuracy of the path loss model. Later today, we will look at some more collected data and how curve fitting can be done to obtain 'n'.

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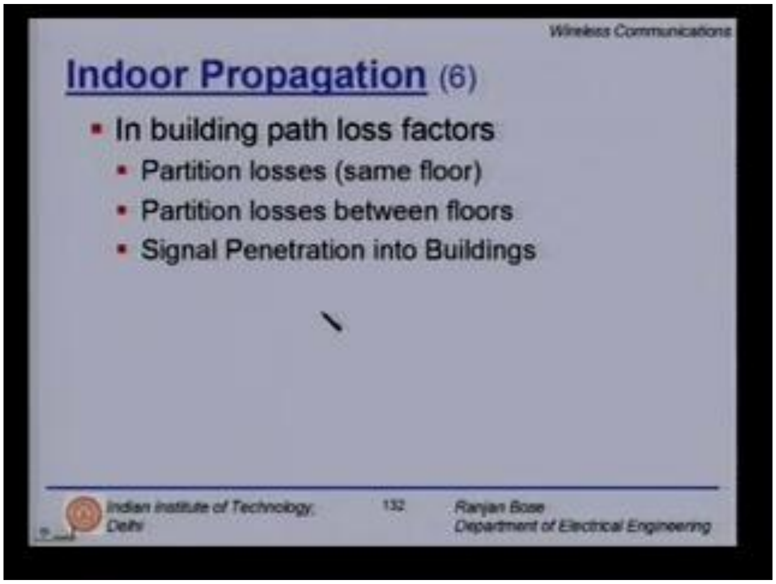

In building path loss, it depends on partitions within the same floor, partition losses between floors and signal penetration into buildings. So we will talk about all these three factors today.

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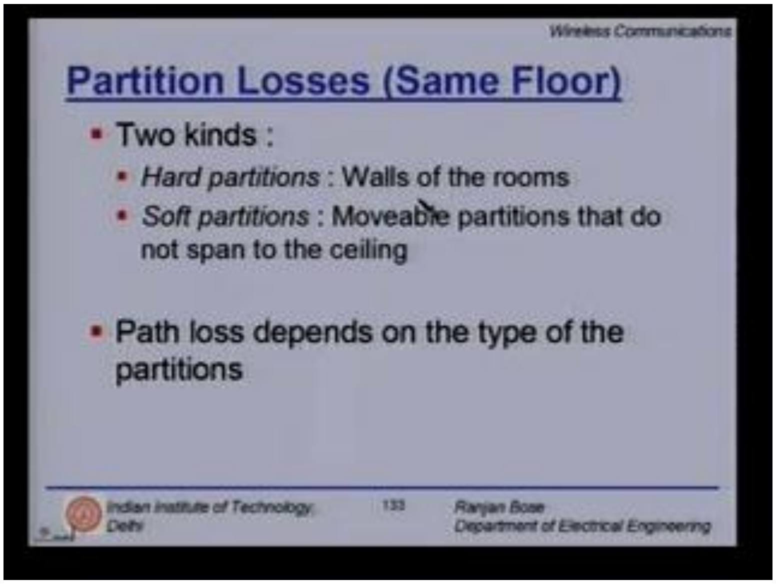

The path loss for the same floor can be described in terms of hard partitions and small partitions. What you can do is divide the room in hard partition. It could be cardboards, plywood partition, absorbing materials which are found in the normal office buildings or you can have soft partitions which are movable. Path loss depends on the type of the partitions. We will see that path loss for partitions is separate from path loss between floors. This is important because certain models have been proposed based on partitions alone. Here hard partitions also include walls separating different rooms. Tomorrow if I set up a wireless access point here, I can still use my laptop in the next room which is separated by a wall because the signal penetrates the wall. We will soon find out what is the drop in the signal strength. We have measurement data here.

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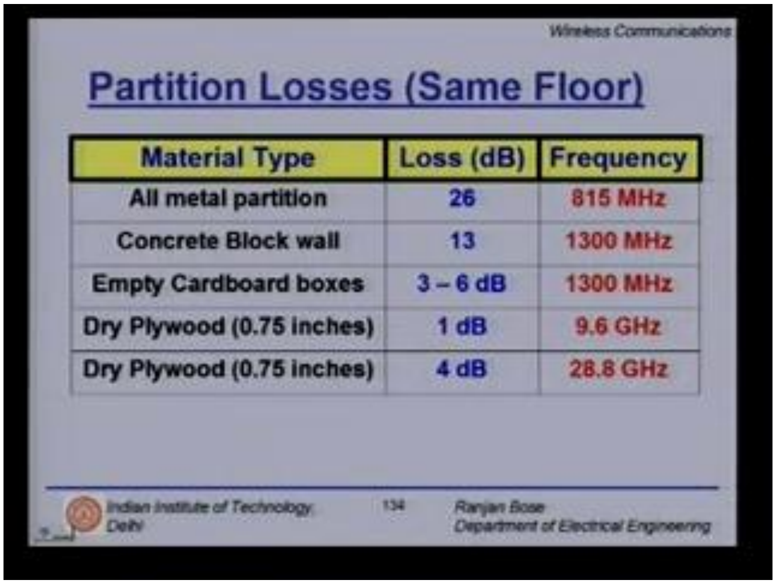

If you have an aluminum partition, the loss is as high as high as 26 dB when measured at around 800 MHz. if you have concrete block wall, the loss is 13 dB and the frequency is 1.3 GHz. clearly this loss will increase if you go to a higher frequency. If you go to say, measurement of empty cardboard boxes, they just give you 3 to 6 dB. dry plywood, 3/4 of an inch will give you 1 dB provided you are doing measurements at 10 GHz. but it will give you almost 4 times that loss if you go to 28.8 GHz. this is the frequency for local to multipoint distribution services in the US. So a lot of this is a representative set. A lot of measurements have been carried out for a whole range of objects partitions at various frequencies. Clearly your computer program will ask you for different kinds of data on the partition frequency of operation and give you a prediction. What is important is that these kinds of programs can fairly accurately predict the received signal strength.

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Continuing with partition losses between floors, it depends on the external dimensions and materials of the building. So I am now talking about an access point in the first floor and trying to receive the signal on the second floor. The losses depend on the construction material used, the external surroundings, and the number of windows and the presence of tinting on the windows. All these factors have been found to cause certain kinds of attenuation.

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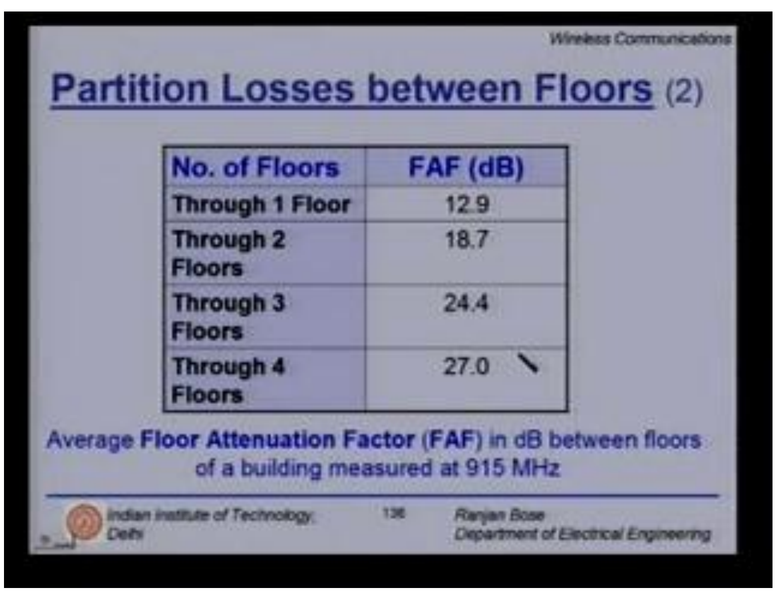

Let us pick up some typical values. Again talking about partition loss between floors, we have mentioned the floor attenuation factor FAF in dB. so if you go through one floor, it is close to 13 dB, two floors close to 18.7 dB, three floors 24 dB and four floors about 27 dB. It's not bad news. You can still receive signals even though your access point is situated on floor one. If you are situated on floor three, you can still get some signal. You cannot change the building construction material. What this will help you to do is to find out how much coverage you can obtain and finally what is the location and the placement of the access point if you have to give wireless local area network to the entire campus. If you have a three floor building, you can predict how much signal power will be received on different floors. It is very useful to do your home cell planning. All these measurements have been taken close to 900 MHz. the values will change as you go to higher and higher frequencies, needless to say at 2.4 GHz - the ISM band, these values will go up the attenuation. It will be much larger at 2.4 GHz.

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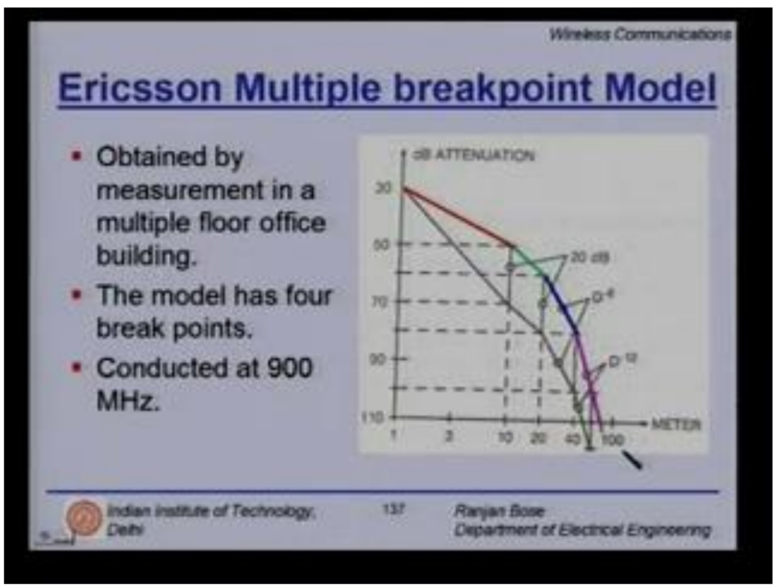

Now there is another interesting model which is the Ericsson multiple breakpoint model also conducted for different kinds of office buildings. It is obtained by measurement in multiple floor office buildings. So it's again based on measurement of data. The model has four break points and it is based on measurements conducted at 900 MHz. here on the right, I have put the Ericsson multiple breakpoint model on the x axis. Is distance the separation between the transmitter and receiver in meters? On the y axis is attenuation in dB. But what is interesting is there are four break points as highlighted by the four colors. As you move away from the transmitter, the path loss exponent increases. This is interesting. When you are closer to your transmitter in a building environment, you have more probability of line of sight and less obstructions. Whereas as you move away and away, your obstructions increases and somehow the path loss exponent increases. We will come back to it. In fact we are going to make a special note when you are below 3 or 5 meters distance between transmitter and receiver.

Even though you have a straight line, something more interesting happens. We will look at it very soon. This is the Ericsson multiple breakpoint model. What is important here is to understand that one single path loss exponent is not sufficient to characterize the path loss within an office environment.

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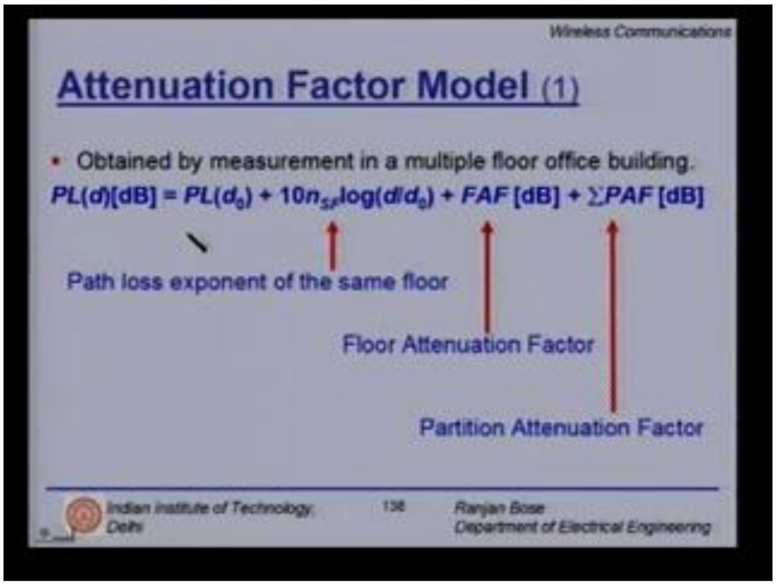

We look at yet another model. The attenuation factor model it is obtained by a measurement in a multiple floor office building. this is given by path loss as a function of 'd' - the distance between transmitter and receiver in dB as path loss measured at a reference distance d_0 + 10 nsf same floor log (d/d_0) + something called as a floor attenuation factor – FAF + summation of partition F attenuation factor PAF in dB, so if I can base that on my earlier measurements, predict the floor attenuation factor, compute the partition attenuation factor, I put it together and I obtain the exact path loss in multiple floor office building.

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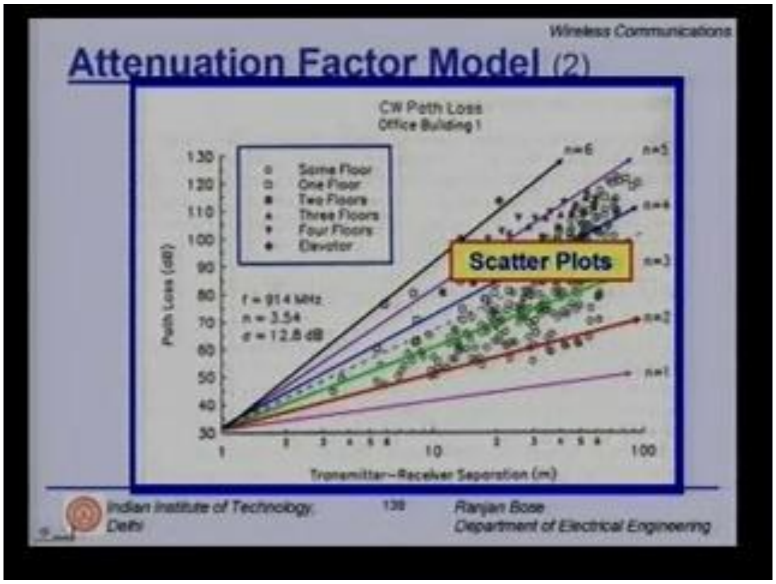

Let us now look at one set of measured data - An office building. It is office building 1. We are doing continuous wave path loss measurement. On the x axis, we have the transmitter-receiver separation. On the y axis is the path loss in dB. as you can see, there are lot of points scattered all over the place because these points correspond to the measurements on the same floor on one floor, two floors, three, four floors and even the elevator. In fact these dots on the elevator is actually giving you a path loss n =6. This is the metal casing. So we have various kinds of path loss exponents from n =1 where I get no data from 2,3 onwards up to 6. In the same office environment whether you are conducting the experiments on one floor, two floors or within the elevator, you get different kinds of path loss exponents and because of the nature of this curve you have a scattering of all the points. You call this as scatter plots. tomorrow if you have to plan a wireless local area network and determine the placement of access points within IIT, you will have to carry out similar kinds of measurement, then use your partition attenuation, floor attenuation factor, etc. to predict where and how much similar standards will be received and then finally put your access points. The simple way of course is to put your access points and see where you can get a service if not put another access point. That is a more expensive way to do things.

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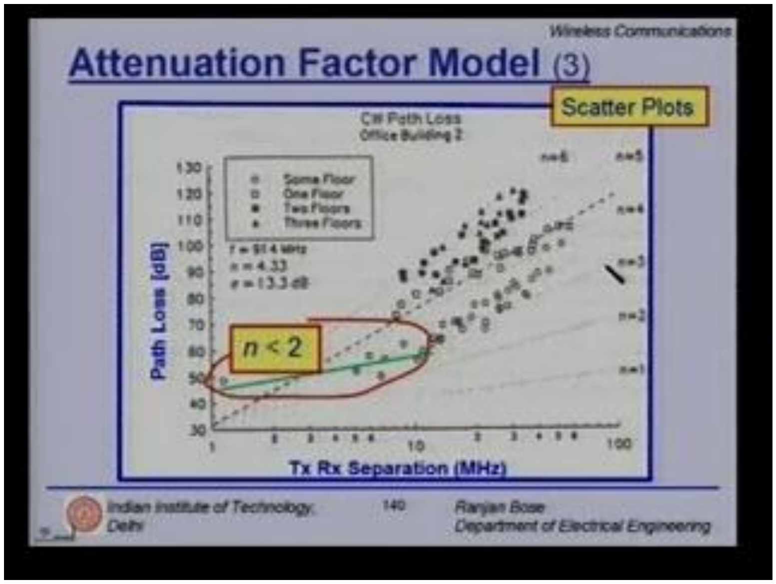

Let us look at another scatter plot for another office building. This has been again done in office building number 2. Measurements taken for the same floor, one floor, two floors and three floors. The elevator data has been left out. On the x axis, as you can see, we have put transmitter receiver separation. On the y axis is the path loss. The measurements have been done at close to 900 MHz. What I want to point out is the distance of separation between 1 and 10 m between transmitter and receiver. Here if you only focus on these points and try to put a curve fit here, what we find is that the path loss exponent ‘n’ is actually less than two. Please note whenever the curve fits are being done, they are being done for the whole measured data. even though all these points on a same floor have been obtained at 900 MHz and they give a path loss exponent close to 3, if you just focus up to 10 m only and your typical room is normally not larger than 10 meters on one sight, that is 30 feet, your path loss exponent is much lower than two. So this is important. You should not be carried away by the whole set of measurement data. It also depends on the application and how large is your local home cell going to be. if I am going to try out and make a small coverage area within my room where I have an access point and I want to put up couple of laptops which connects to the access point, I would probably use ‘n’ less than or equal to two and not three as predicted.

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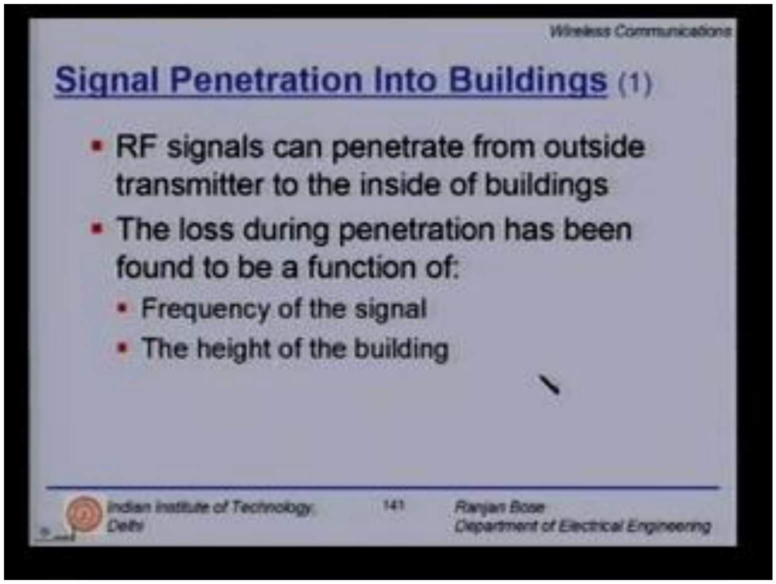

Now in the last couple of slides, I would like to briefly talk about signal penetration into the buildings. RF signals can penetrate from outside transmitter to the inside of buildings. This is a known news. We all know this. The loss during penetration has been found to be a function of frequency of the signal. The height of the building and the frequency is intuitive. The height is not.

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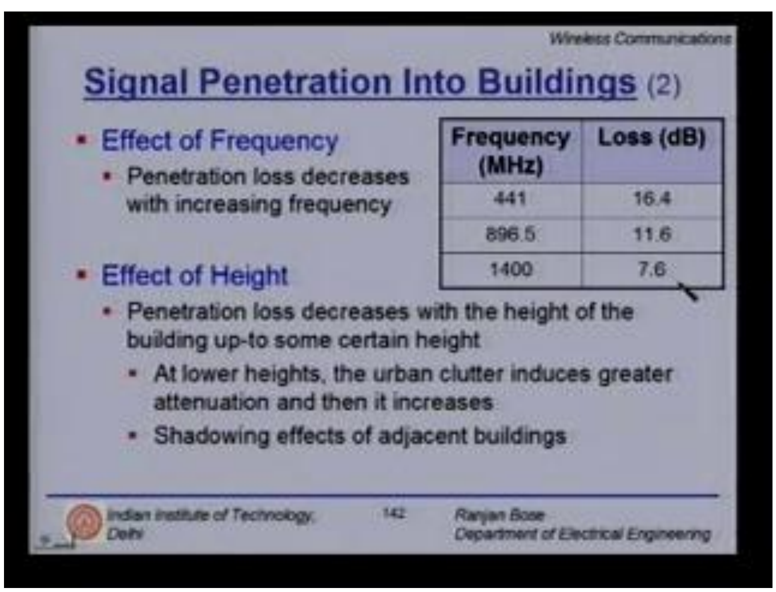

The effect of frequency is as follows. The penetration loss decreases with increasing frequency. The effect of height & the penetration loss decreases with the height of the building up to a certain height. At lower heights, the urban clutter induces greater attenuation and then it increases.

Shadowing effects of all adjacent buildings also take into come into picture if I talk about tall buildings. So these factors; the frequency and the height of the building effect, the penetration into the building here is a typical table which tells you for different frequencies what are the losses. Clearly if you go to higher frequencies, you have lower penetration losses. You can actually penetrate more easily ultra-wideband which is from 3.1 to 10.6 GHz. It will also be used for ranging operation because it can easily penetrate walls. So I can take an MH of somebody or an equipment sitting behind a partition if I use UWB.

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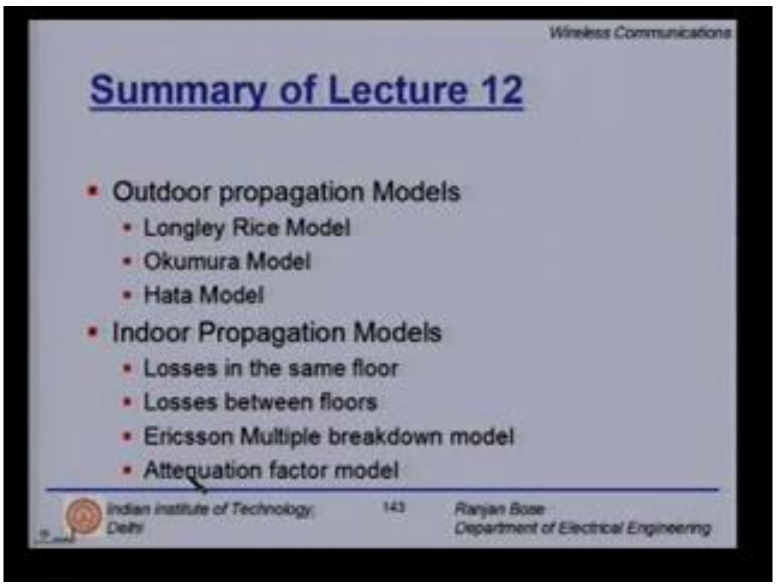

Here is the summary of the current lecture. We talked about outdoor propagation models. We specifically talked about three kinds of models. The Longley Rice model, the Okumura model and the Hata model. We then talked about the indoor propagation model where we looked at losses in the same floor, losses between floors. We looked at the multiple breakdown model of Ericsson and then we looked at the attenuation factor model. Finally we looked at penetration into the buildings. We will conclude this lecture here and will continue in the next lecture. Thank you!