Wireless Communications

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Lecture No # 09

Mobile Radio Propagation (Continued)

Let us first discuss the outline of today's talk. We will start with a brief summary of what we have already learnt. Then we will look at some interesting reflection models followed by diffraction models and then scattering models. All three are important propagation mechanisms and must be understood if we have to come up with a realistic channel propagation model. First, a brief recap as to what we have done.

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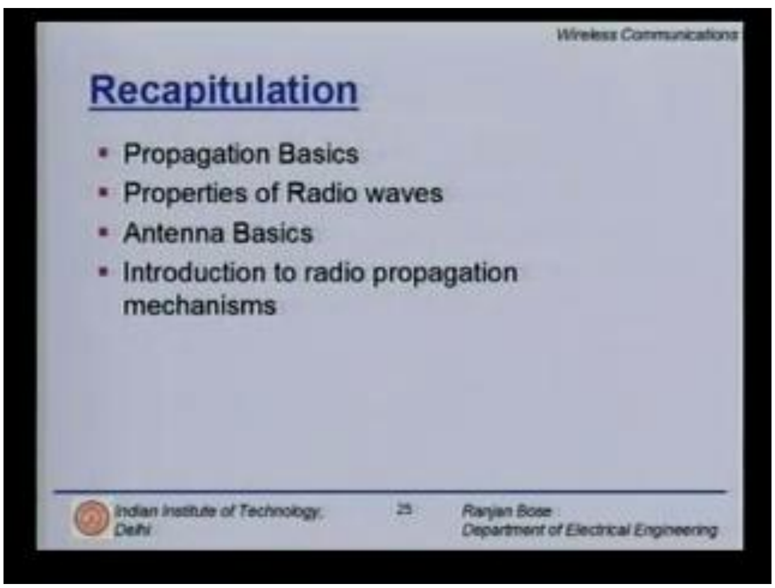

We looked at propagation basics last time. We saw how the radio waves propagate, scattering, reflection and diffraction in brief. Today we would like to go more into details. Hopefully, we come up with a mathematical model which can explain how the propagation effects take place. Last time we looked at certain properties of radio waves. We went on to discuss certain antenna basics. We of course did some examples. Then we looked at the propagation mechanisms.

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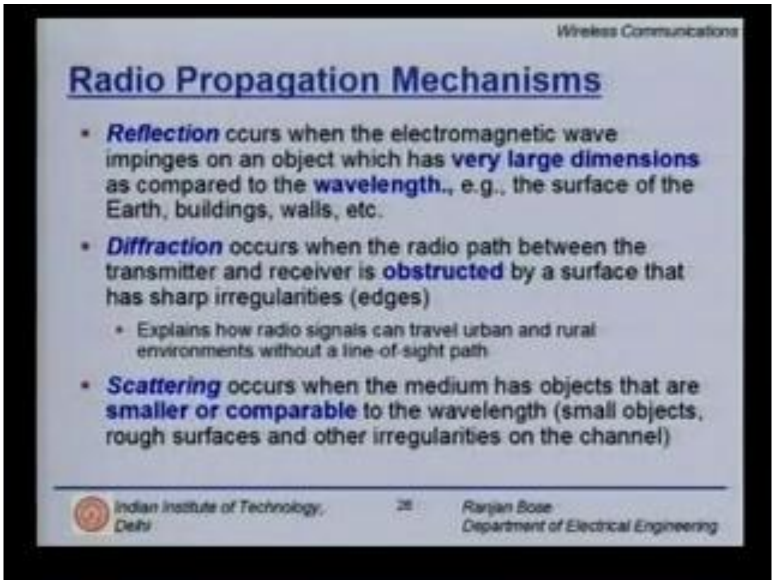

Now continuing with the recap, we learnt that reflections occur when the electromagnetic wave impinges on an object which has a very large dimension as compared to the wavelength. So it's all relative. If i go into higher and higher frequencies, that is, smaller and smaller wavelengths, i tend to have more reflecting surfaces in the same room. Of course, the big surfaces like the earth, the buildings, walls, the table top, etc. form reflecting surfaces. The other methodology is diffraction which occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities for example, edges. Normally, we may not have line of sight. However we still get a radio signal. We can still talk sitting inside the room without a direct line of sight to the base station. So diffraction is the methodology which explains how radio signals can travel in urban and rural environments without a direct line of sight. All this is important because if we do not understand the effects of reflection, diffraction or scattering, we will not be able to come up with a good propagation model and hence we cannot theoretically test our systems.

The third is scattering which occurs when the medium has objects that are smaller or comparable to the wavelength. Again small and large is always with respect to the wavelength. Small objects, rough surfaces and other irregularities in the channel will cause scattering. If we just consider for example, very high frequencies above 10 GHz, then rain drops start scattering. as mentioned before rain drops will form an impeding factor when we go into for example, I EEE 82.16 which will work at higher frequency ranges above 30 GHz. however rain drops do not matter much at GSM frequencies. So it is important to understand what causes scattering and how to overcome it.

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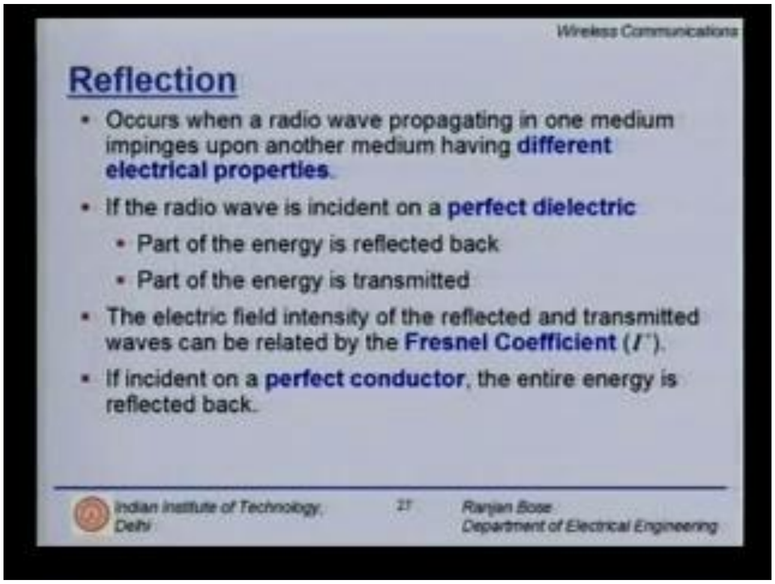

Let us now have a deeper understanding on how reflection works specifically for radio signals. Reflection, as we have said occurs when a radio wave propagating in one medium impinges upon another medium having different electrical properties. So that is important. It may impinge on an dielectric. It may impinge on a conductor. i will have different kinds of reflection but reflection will occur as long as there is a different electrical property in the other medium. If a radio wave is incident on a perfect dielectric, then part of the energy is reflected back into the original medium whereas part of the energy is actually transmitted through the dielectric. A lot of materials in the room which cause reflections are made out of dielectrics. Brick walls, simple wooden table, all form part of the dielectric reflecting surfaces. The electric field intensity of the reflected and transmitted waves can be related by the Fresnel coefficient gamma. If the radio waves are incident on a perfect conductor, the entire energy is reflected back. This is important because if we have metal frames in the windows, a strong scattering effect and reflecting effect will happen from these metallic surfaces. So metal conductors, building tops, surfaces which have metallic surfaces will form perfect reflectors.

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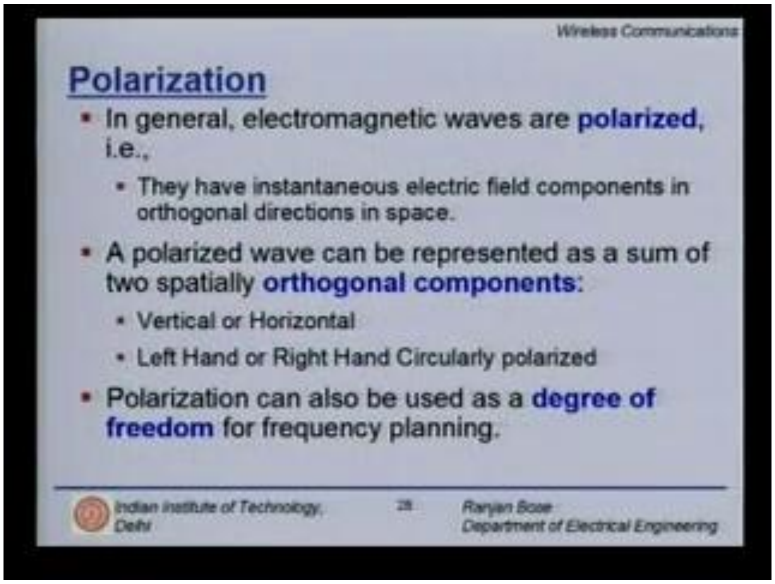

Incidentally in our earlier lectures, we had talked about it passive reflectors where we use these passive metallic reflectors to reflect energy to the areas which are normally not covered. So reflections may cause difficulty in sending waves because it will cause multipath but on the other hand, it can also be used constructively polarization. i would like to discuss in the next couple of slides because in general, electromagnetic waves are polarized. They have instantaneous electric field components in orthogonal directions in space. A polarized wave can be represented as a sum of two specially orthogonal components. For example, you can have a vertically polarized wave or horizontally polarized wave or you can have left hand circularly polarized or right hand circularly polarized waves.

If i have a vertically polarized antenna, then at the receiver i must have a similar antenna. Otherwise i will not be able to get the entire energy. If i use a horizontally polarized antenna to recover vertically polarized beams, i would miss out most of the energy. Of course, there is a notion of cross polar discrimination in which how good your antenna is will be described by this factor XPD or the cross polar discrimination. Polarization can also be used as a degree of freedom for frequency planning. Last time we learnt that frequency is normally reused. However if we add another parameter which is polarization, i can probably do better. i can actually use frequency polarization reuse pattern instead of only frequency reuse pattern. The idea is simple. For every frequency band, we have two options. Either vertical polarization or horizontal polarization.

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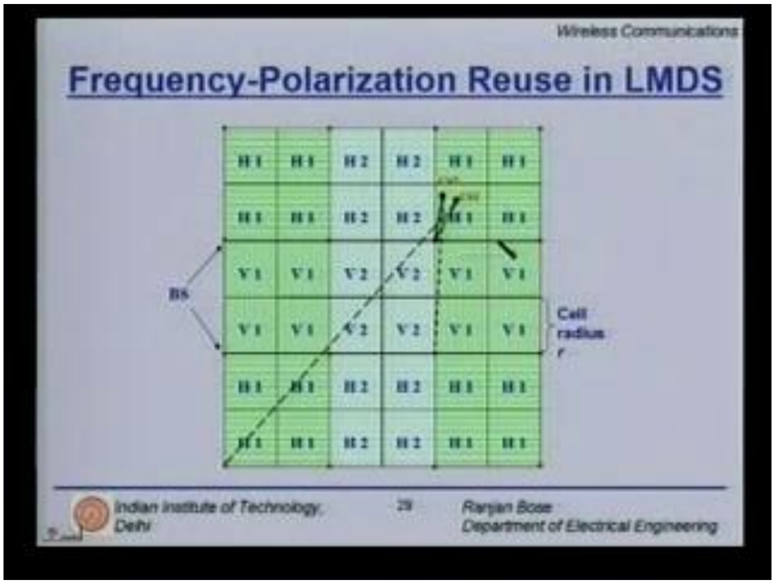

So just let's take an example. i would like to talk about LMDS – 'the local to multi point distribution services' which can be used in conjunction with the IEEE 802.16 the wireless man standard. Here i have shown a lot of square cells. So this example is illustrated in the sense that, i am using a different shape of the cell. Each cell is square in shape. If you look carefully, the red dots indicate the base stations. The square cells have a radius 'r'. As you can see, i have marked each cell either by a V 1, V 2, H 1 or H 2. V implies vertical polarization, 1 implies frequency band 1. H implies horizontal polarization, 1 implies frequency band 2. So H 2 simply implies second frequency band horizontal polarization. So in this diagram, i have four colors to color my map V 1, H 1, V 2, H 2 and this is actually deployed in order to obtain frequency polarization reuse. Clearly, you will have co-channel interference but this time the co-channel interference will only occur in the cells which are of the same frequency band and the same polarization. We have just extracted a little bit more by using two different kinds of polarizations. Just one of the uses. So here for example, if i put a customer station CS, it is hooked onto its own base station.

Please remember LMDS is fixed broad band wireless application. So, its fixed broadband wireless access. We are sitting here as a customer but the antenna is on top of my house and this is the base station. Probably on top of tower and i am focused at my base station. The other characteristic feature of LMDS is that it uses very low beam width antennas at the customer station. So instead of getting only energy from its own base station, it will also get some energy from the H 1 which is farther apart. But the reuse has made the first co-channel tier, almost five cells away. So the simple use of polarization has allowed me to increase my reuse distance thereby decreasing interference. However there will be still some interference between H 1 and V1 because H 1 represents first frequency band, V 1 represents the first frequency band with vertical polarization. Here it is horizontal polarization. So in the cross polar discrimination, the ability of your antenna to distinguish between vertical and horizontal polarization is not good, then you will also get some energy which is interfering energy from V 1 as well. So this is at a third tier. It is much closer. Typical values of XPD can be between 20 to 25dB. So it is pretty good.

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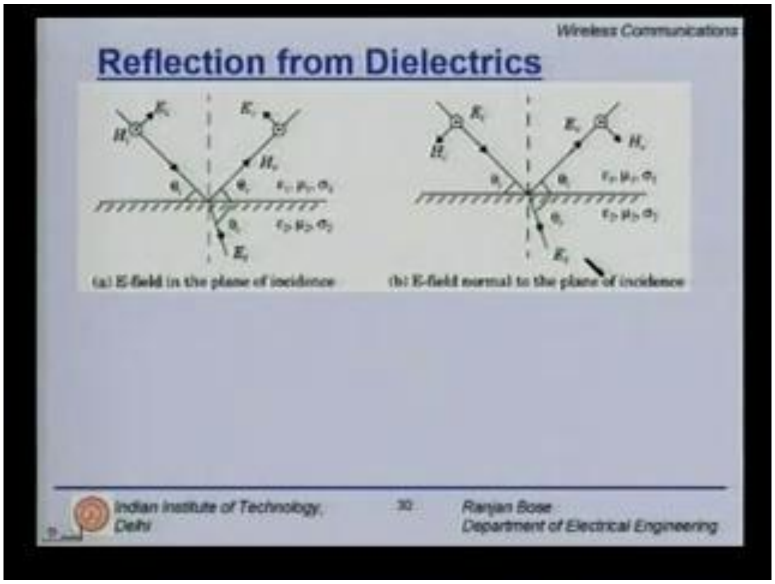

Now let’s go back to our original issue of reflection from dielectrics because a lot of the world that we live in is actually made out of dielectrics. Consider for example this diagram a which is depicting a reflecting surface which is a dielectric. There is an incident wave. i have broken up into two orthogonal components EI and HI. EI is in the plane of the paper. HI is orthogonal to the plane of the paper and it impinges on the surface with another dielectric. Part of it is reflected back as an Er and Hr and part of it is transmitted as an ET. Here i have taken the other example where the electric field E is normal to the plane of the paper.

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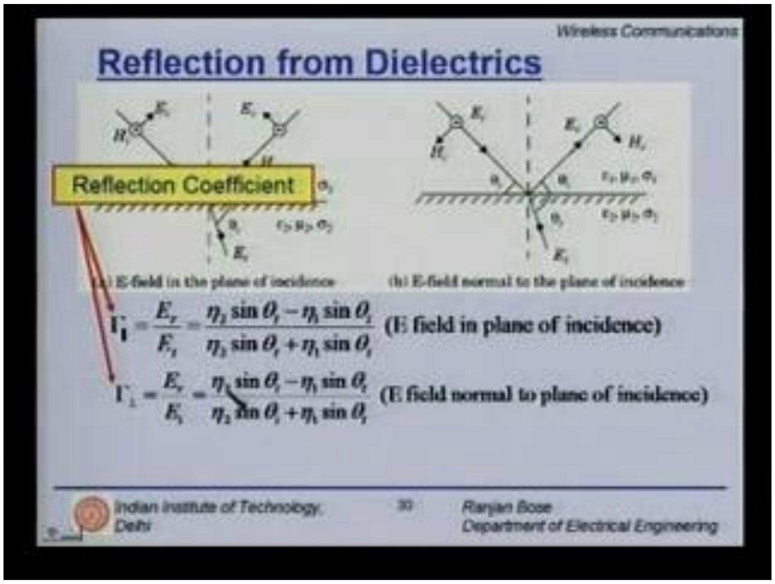

Now we were talking about the reflection coefficients specifically Fresnel's reflection coefficient. So gamma parallel is nothing but 'Er' the reflected energy, divided by 'EI' the incident energy. this is nothing but eta 2 sin theta T - eta 1 sin theta I divided by eta 2 sin theta T + eta 1 sin theta I. i'll talk about what eta 1 and eta 2 are in a minute. the gamma perpendicular which is E field normal to the plane of incident is given again by Er over EI as expressed as eta 2 sin theta I - eta 1 sin theta T whole divided by eta 2 sin theta I + eta 1 sin theta T.

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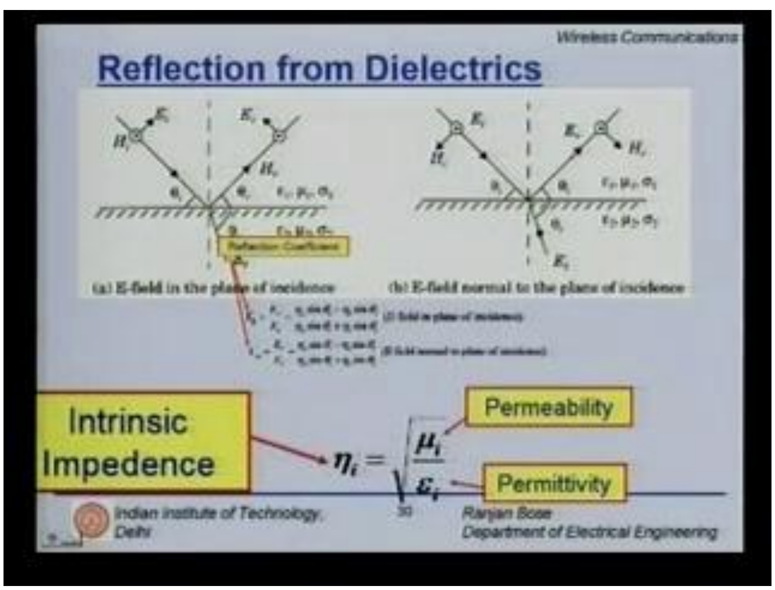

Now what is this eta? Eta is the intrinsic impedance which is defined as eta i = mu i over epsilon i. what are mu i and epsilon i? Mu i is a permeability and epsilon i is permittivity of the dielectric. Given these things, you can actually find out the reflection coefficient. So if you have a brick wall, you will have different values of mu i and epsilon i. if it is a wooden partition, you will have different values for mu i and epsilon i and so on and so forth. The point is you can have a deterministic model by virtue of which you could actually calculate the energy that is reflected off. Please remember statistical models fail to hold good above 10 GHz. above 10 GHz frequency, usually we have to resort to deterministic models where we actually do something called as a "ray tracing". We start from the transmitter. We trace a ray, look at the reflection, diffraction and scattering of the ray until the point that it reaches the receiver. We can calculate how much energy is actually reflected back by knowing the permeability and the permittivity of the dielectric. So all this is important if you have to do any deterministic modeling.

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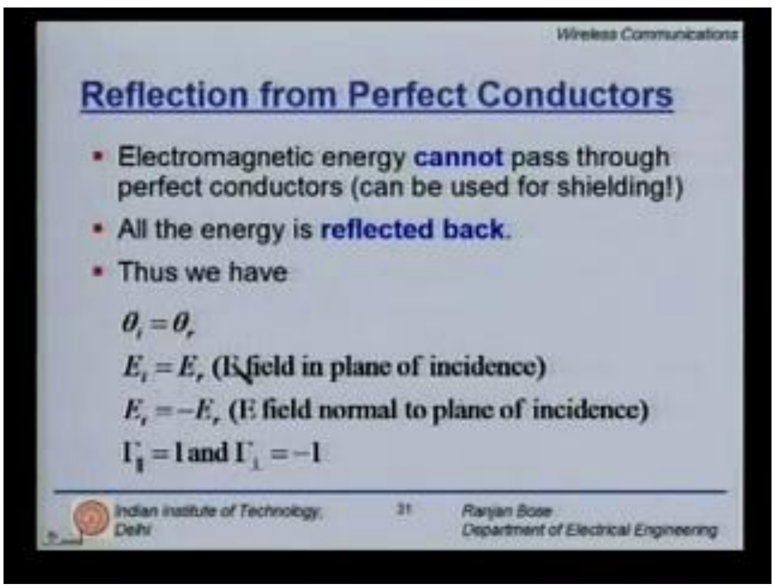

On the other hand, we also have perfect conductors or even good metals which will cause reflections. These are strong reflections. So the problem is that the electromagnetic energy cannot pass through perfect conductors. Therefore they can be used for shielding. If i have to shield a part of my circuit, i would rather cover it with an aluminum foil and i'll ensure that energy doesn't leak to the other side because all the energy is reflected back. Thus we have theta i is equal to theta r- Snell's law. EI is equal to Er which is the E field in the plane of incidence. EI is equal to minus Er, E field normal to the plane of incidence and your Fresnel reflection coefficient gamma parallel is 1 and gamma perpendicular is -1. So for a perfect conductor, a metal we have the following relations.

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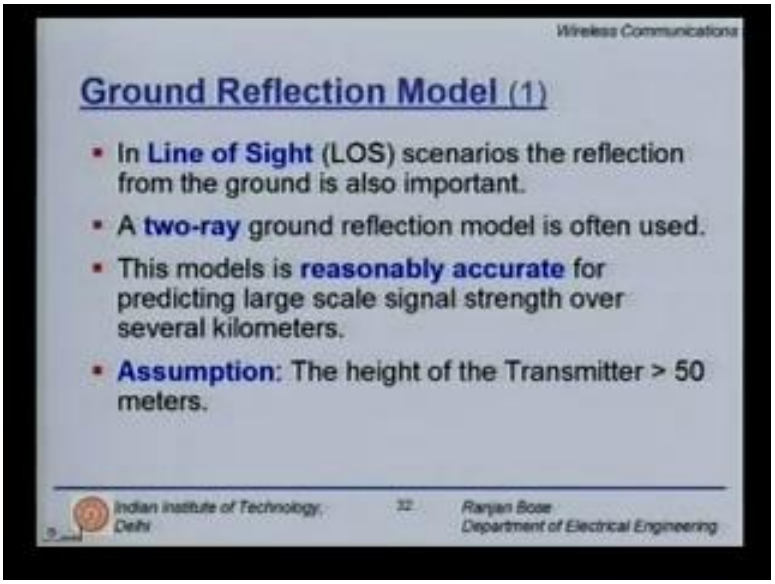

Now one of the important things that we encounter in mobile propagation is the reflection from the ground. This normally occurs when i do have a line of sight but that's not the only way we get. We also get a reflection from the ground as well. So in line of sight scenarios, the reflection from the ground is also important. How important we will soon find out. A two ray ground reflection model is often used. It is a simple model but it is a useful model. So we will understand what is this two ray ground reflection model. This model is reasonably accurate for predicting large scale signal strength over several kilometers. In fact, this model is good when the distance between the transmitter and the receiver is large. The assumption is that the height of the transmitter is about 50 m or more. This is true for your mobile applications.

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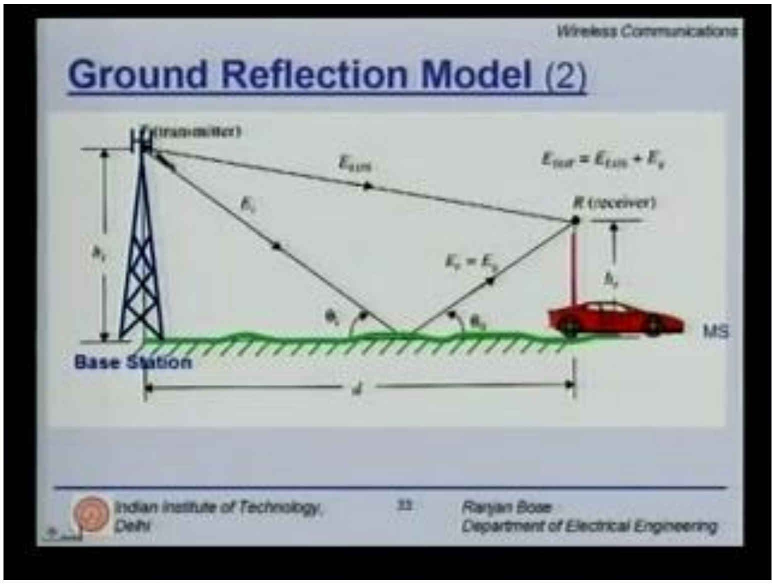

So let us look at this ground reflection model in greater detail. Consider for example, a base station and your earth. The base station as we have said should be tall enough about 50 m or higher. Typically base stations mounted on top of a tower or a small tower on top of a building. We had discussed earlier the base stations are called so because in earlier versions of the base station the actual circuitry and other components and battery and backup were so heavy that they could not put on the top of the tower. They put it at the bottom and hence the name base station. Only the antenna was at the top.

Today everything goes on the top. So let us put a mobile station and the idea is to find out how the mobile station receives signals from the base station directly as well as through a reflected path. The first assumption is that the base station and the mobile station should be separated by a certain distance. The ground reflection model does not work when your mobile station is very close the base station. So let's put it slightly apart and let's see how the mobile station would like to set up its communication link with the base station. So there is clearly a line of sight because there is no obstruction which we depict by E_{LOS} the subscript LOS stands for line of sight. However that is not the only energy that we are getting. We will also have a reflected path which goes, hits the earth and is reflected back. Not all the energy is reflected back because earth is a dielectric.

To simplify scenarios, i have put a horizontal line here and shaded it to make sure that it is forming a reflecting surface. Now couple of things are important here. Firstly the total received energy at the receiver is the sum of the line of sight path as well as the reflected path. But the sum just doesn't happen as a scalar sum. What we get is a phase difference because of the path difference. So the addition is actually a vector sum which will result in a very different kind of a E total. The other important things is the height of the base station h_T as well as the height of the receiver h_r. we will see both these parameters would play an important role in the amount of received power that you get. Of course the distance must also play a role. So if i have to move from this actual scenario of a base station and a mobile station and a ground reflection model. Let us somehow remove that and put a more simplistic model. So what i would like to do is to phase out the mobile station and the base station and simply put it as a vertical line for transmitter and a receiver and this is the model which you find in most text books.

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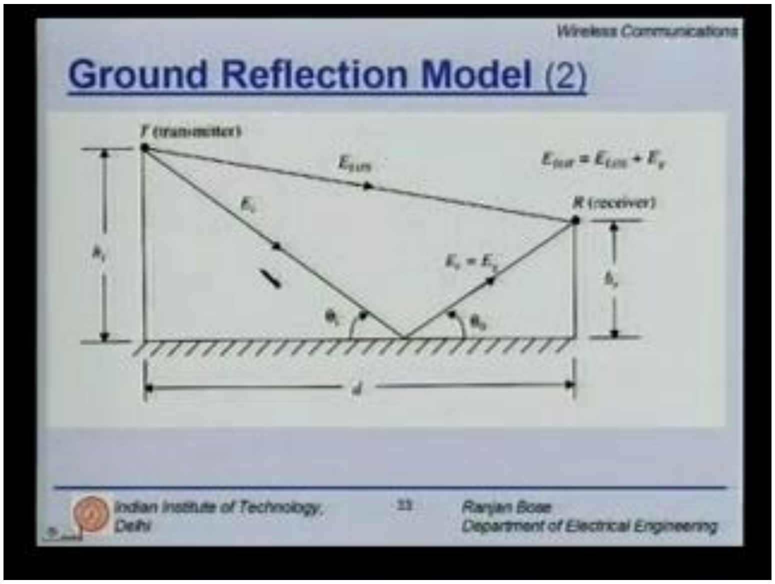

Distance‘d’ is between the transmitter and the receiver height of the transmitter h $_T$, h $_r$ height of the receiver. Please remember this is the absolute height. So if the base station is situated on top of a building, we take the height from the ground. If the car or the mobile station is sitting on a small hill, we take the height from the ground level.

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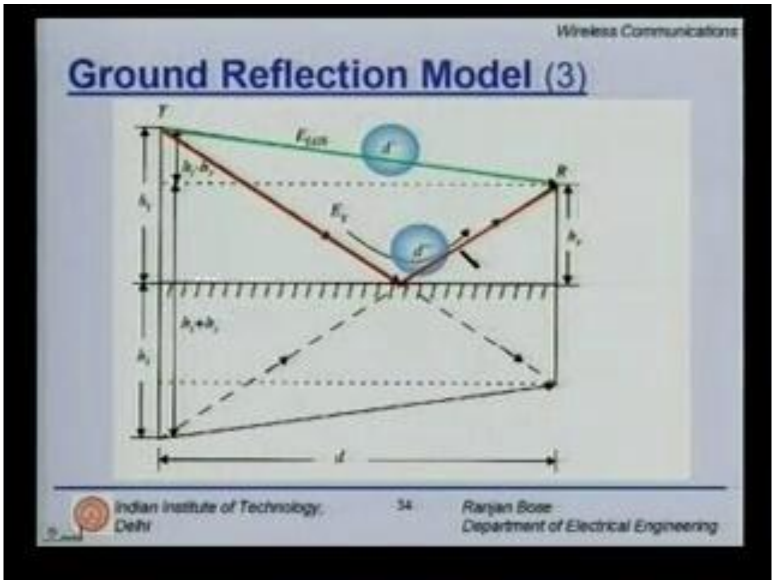

So to carry forth the calculations, we just look at the method of images and how we can calculate the received power. The basic philosophy is that the total received power is the sum of E $_{LOS}$ and the reflected one. What is interesting to note is what will come into the calculation using this method of image is a relative height (h_T - h_r) here. The idea is to first find out the path difference that will give us a phase difference and time delay using these two parameters. We can actually calculate what is the net received power. So the two paths that are important is the line of sight path which we depict by d prime and the reflected path which we depict by d double prime.

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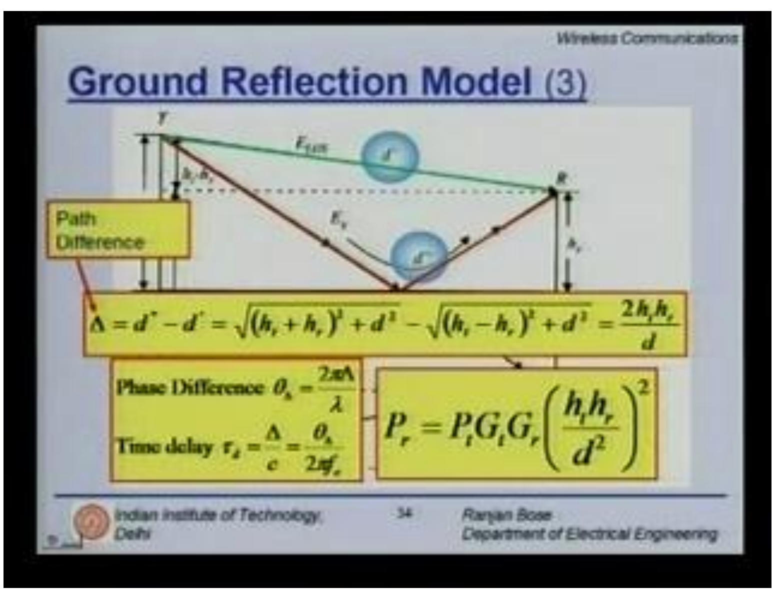

So the path difference 'capital delta' is nothing but d double prime minus d prime and can be found simply by geometry. If you do this basic geometry you find that the path difference the path difference between the green line and the bent red line is nothing but two hT hr divided by d. the product height of the transmitter and receiver divided by d. Normally hT is fixed. When we design the system we fix the transmitter height. The receiver height varies. If you go ahead and calculate the phase difference it is nothing but two pi delta over lambda where lambda is the wavelength. So phase difference does depend on the frequency and the wavelength. The time delay is given by delta over 'c' the speed of light is nothing but theta delta over two pi fc, fc is the carrier frequency.

Now based on the phase difference time delay if you try to calculate the net power received at the receiver, after a little bit of algebra, you can show that the received power Pr is nothing but the transmit power Pt times Gt the gain of the transmit antenna times gain of the received antenna times something very interesting - hr ht divided by d squared whole squared. This is what is important because normally for your mobile station, we cannot do much with the 'Gr' receiver gain. You have a fixed omnidirectional antenna. You cannot play with the receiver gain. You also cannot play much with the transmit antenna gain which is at the base station. Here i am talking about the down link because that's the design parameter that you have calculated and fixed. What you must calculate and fix for your system is the height of the transmitter and height of the receiver if you are considering line of sight propagation.

So d squared is there but now it is d squared again raised to the power 2. It is d to the power 4. It's still kind of free space propagation. i am not using any other path loss exponent but this ground reflection is making my signal drop faster than natural even in free space. It is important. This very simplistic model actually holds good in most mobile application at the GSM frequencies. It's a realistic model. So it's important to understand this thing. of course, if i give you the values of transmit power, the antenna gain at the height of the transmitter and receiver antenna, you can easily calculate that received power and received power will form the bottom line as to what should be your receiver sensitivity and also what is the amount of desired signal and interference signal you are actually getting. This is good news for interference because the received power from the interfering base station goes as 1 over D raised to the power 4 since the interference base station is usually far apart. The interference goes down but please remember as you increase a distance between transmitter and receiver, the line of sight condition ceases to hold. It's more difficult to find line of sight as you move further and further away from your base station. So you must keep all these factors in mind. Now let's move to the next method by which propagation takes place is diffraction.

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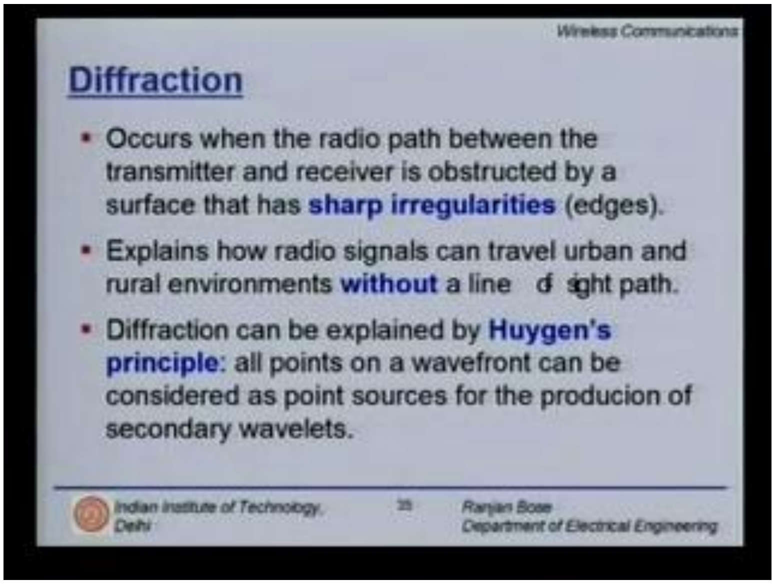

This occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities or edges. Edges, corners, bends, etc. will cause diffraction. Diffraction is very important because otherwise without line of sight sitting in this room, i would not be able to receive any signal from my base station. Hence this explains how radio signals can travel urban and rural environments without a clear line of sight and diffraction can be explained by Huygens principle. IT says that all points on a wave front can be considered as point sources for the production of secondary wavelets. That still holds good for our case.

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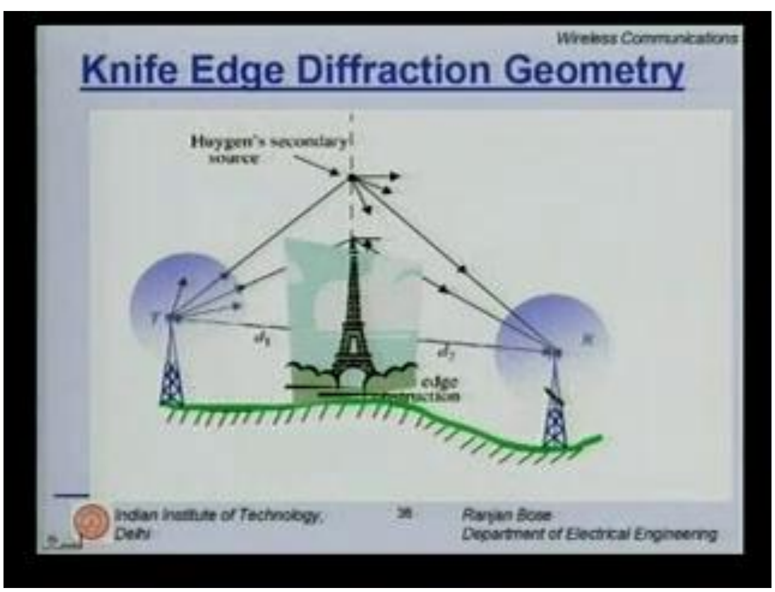

Now let us look some models and try to explain how diffraction might work and then it will be used for our calculations. If you are actually going to use a deterministic model then you have to put in diffraction models as well. So let us look at something called as the ‘knife edge diffraction geometry’. Again let us look at a realistic scenario. i have a transmitter and a receiver. This time i have not set one as the mobile station. It has one of the base stations and i just have a tower with a transmitting antenna and a tower with a receiving antenna and you can consider it to be a point to point communication microwave communication link or you can also consider it as communication between two base stations or between the base station at the mobile switching center. Now let us put an obstruction.

So i have to avoid the line of sight. Please note this time i have ensured that the two towers are not at the same height. Also it could have been a hill or building, a tower or any other thing. But in this knife edge diffraction geometry, the only assumption is that at the top where the diffraction is going to occur, you have a sharp edge. It’s not a building with a flat top. It could be a building with a thatched roof so that there is an edge here. So all i need is an edge at the top. There is no line of sight clearly but still by virtue of diffraction, signals being emanated from this first tower should somehow reach here. So what i would like to do is radiate signals from my first tower and here is the radiation pattern of the receiver antenna which is trying to absorb whatever energy gets through here.

Now let us look at how things work when you transmit form the transmitter T. you radiate in all directions assuming for the time being. It’s an omnidirectional antenna. For how many times an antenna. Look at the wave specifically in this direction. The one that hits here will generate wavelets which will travel from all directions. From Huygens secondary source principle, any point on the wave front will generate its secondary wavelets. So one here one, here one here and so and so forth but the ones which are present here will diffract and go and will be received at the receiver. So even though there is an absence of a line of sight, i still get my energy here. In fact a lot of communication in GSM band occurs like this is usually not obvious. So if you would like to make a model out of it a knife edge diffraction model. Let us look at how we can slowly phase this thing out.

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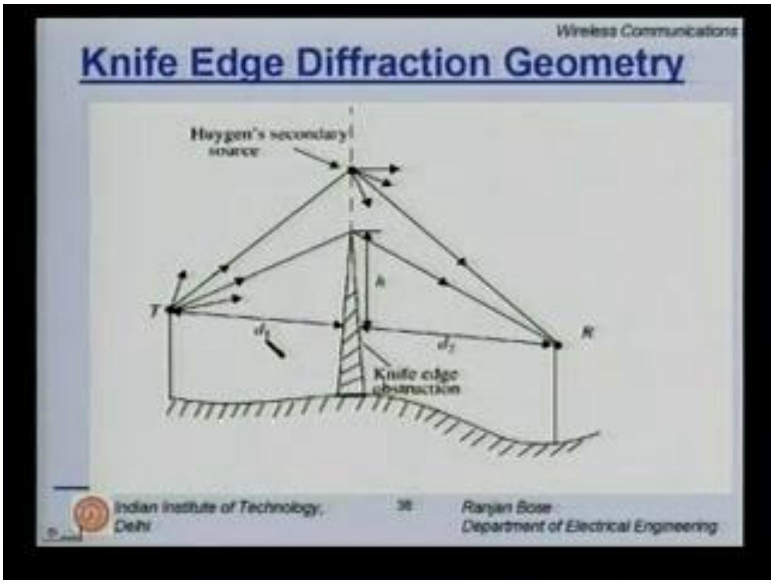

So we can actually replace our transmitters, receivers and the building by slowly vertical lines and a knife edge obstruction. So we move from reality to theory and this is my diffraction geometry for a knife edge obstruction. Please note that the distance from the knife edge obstruction‘d one’ from the transmitter‘d two’ from the receiver. Of course the things which will be important is the height of the obstruction. So what we would like to know is how much energy we get at the receiver having this geometry.

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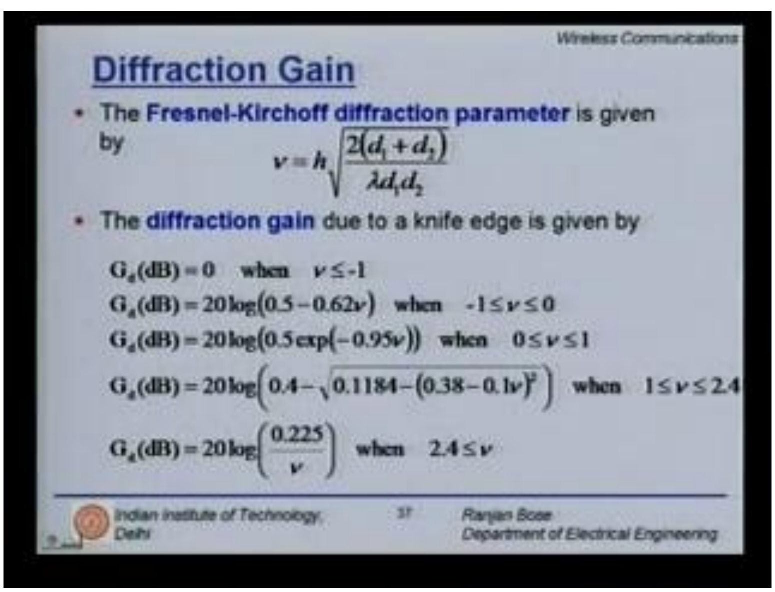

So what we would like to understand is what the diffraction gain is. Because of diffraction we get some energy. So first we define something as the Fresnel-Kirchhoff diffraction parameter which is given by mu = h under root numerator d 1 plus d 2 divided by lambda d 1 times d 2. What is h? h is the height. We saw last time between this line of sight and between the top of the knife edge diffraction diffracting obstruction, this is your h that is being used. d one and d two are the respective distances from the obstruction to the transmitter and the receiver lambda is the wavelength. Please note mu is inversely proportional to the square root of lambda. Now we will use this Fresnel-Kirchhoff's diffraction parameter to find out how much diffraction gain is possible due to a knife edge and these have been calculated by E and are being tabulated here. When mu is less than minus one, the gain in dB is zero.

Please note this is a dB $_G$ and G stands for the diffraction gain. However, as we gradually get a larger value of mu, my gain increases and then later it starts falling again. So there's a slight hump and if you put this diagram, you will find that the gain increases and then goes down. What is important is this mu depends on the distance from your obstruction and the wave length and of course linearly proportion to the height. For greater than 2.4, one way to do is to just increase the height. This gain falls drastically. In fact you can see an inverse relationship here. As you increase the height beyond a certain limit, you will get very little diffracted energy. This is intuitive also.

So i like buildings which are not very tall. They will help me get some good diffraction gain. So using these, we can actually calculate how much energy will get after diffraction. Please also note that the wavelength figures. So the same building will diffract two point four GHz frequency band differently than 5 GHz band or 900 MHz band. In fact, as you go to higher and higher frequencies or smaller and smaller wavelengths. This diffraction thing decreases. In effect scattering starts becoming more important.

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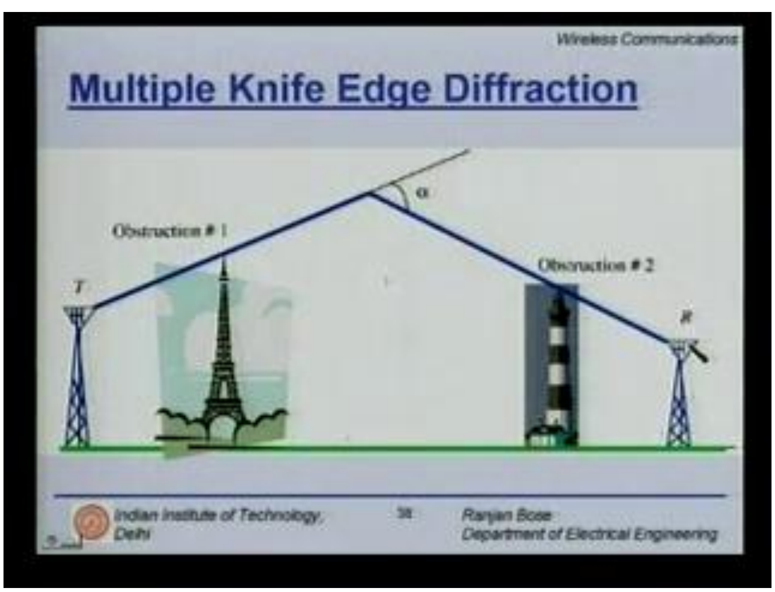

Now an objection could be raised that why do we consider this simplistic model of a single edge diffraction normally? It's not just one building. There could be multiple buildings. So let us try to do that this time. i have put a transmitter on top of a tower and a receiver again on top of a tower. But this time they are different heights. i am going to put not one, but two knife edge diffractors. So here is tower one and here is tower two. Now the question is: will we get any energy being transmitted from transmitter 1 to transmitter 2? The answer is yes. i will still get some energy here. It will go here and then this is the wave front. It'll go here and then there is another wave front and then there will be wavelets which will go there and received here. Let's look at it. So you send some signals. It traverses this path and then here, there is a wave front from where we have a secondary wave which will go here. There will be a lot of other secondary wavelets that will come out but none will go directly to the receiver and i am neglecting those. So please remember this is not the only wavelet that is coming out. But this path will ensure that at least this ray will reach the receiver.

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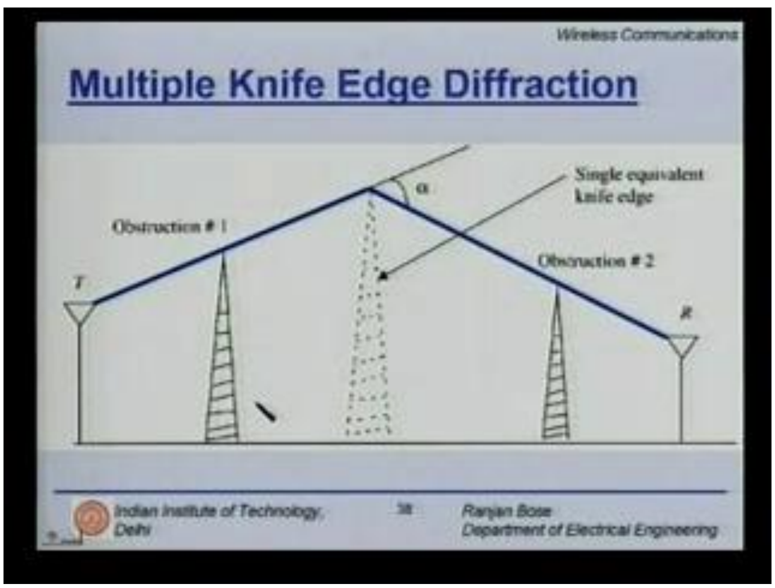

Now the question is if we want to model this, i will like to replace the buildings by two knife edge diffractors. So we are going from the single edge to double but this is the geometry we are talking about. Now very surprisingly the same geometry can be explained using a single knife edge or an equivalent single knife edge placed critically at this point. The position and the height of this equivalent knife edge will depend on the heights and distances of the first two original knife edges. So this is very interesting. We go from here. We first replace it by two knife edges. Then we discover that they can be equivalently replaced. In fact the equivalence is so good that i would like to do kind of phase out the other two reflectors and just focus on the single knife edge. But i have very good equations to explain single knife edge diffraction. so i can kind of represent the multiple knife edge diffraction using a single knife edge diffraction model and same logic can be extended to more than two knife edges but please remember the problem to be solved is what is the equivalent height and the distance of the equivalent knife edge.

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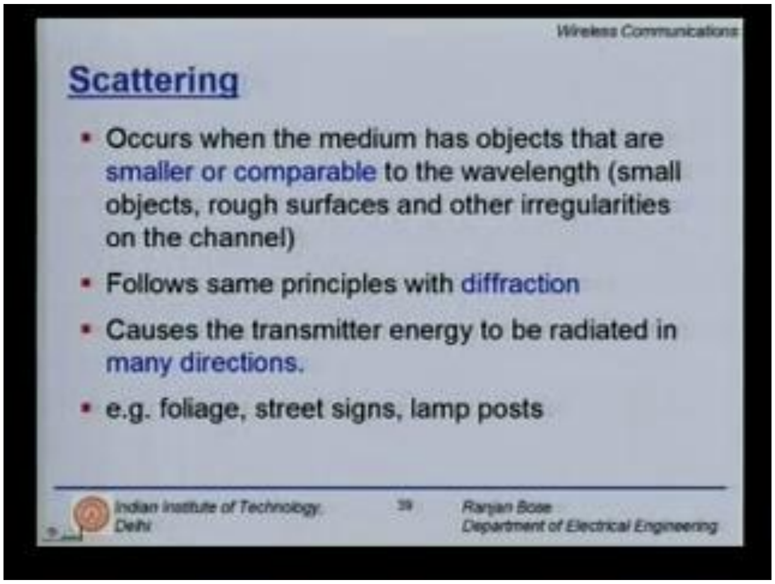

Now let us look at the third method which is scattering. Scattering as we all know occurs when the medium has object, smaller or comparable to the wavelength. Small objects, rough surfaces rain drops, other irregularities in the channel, dust dew drops will cause scattering. Scattering will also be caused by foliage for example. The moment we go to higher frequencies, our wavelengths become smaller and smaller and very soon they become comparable to the size of the leaves and suddenly the foliage becomes important. At GSM frequencies 900 MHz, 800 MHz, the propagation through trees is not a major impediment. But the moment you start going above 10 GHz, you face a problem. If you see a patch of green; a lot of absorption, scattering and diffraction will start taking place. It is important to have these effects in mind. Scattering follows the same principle as diffraction. It causes the transmitter energy to be radiated in many directions. So foliage, street signs, lamp posts, edges can cause scattering.

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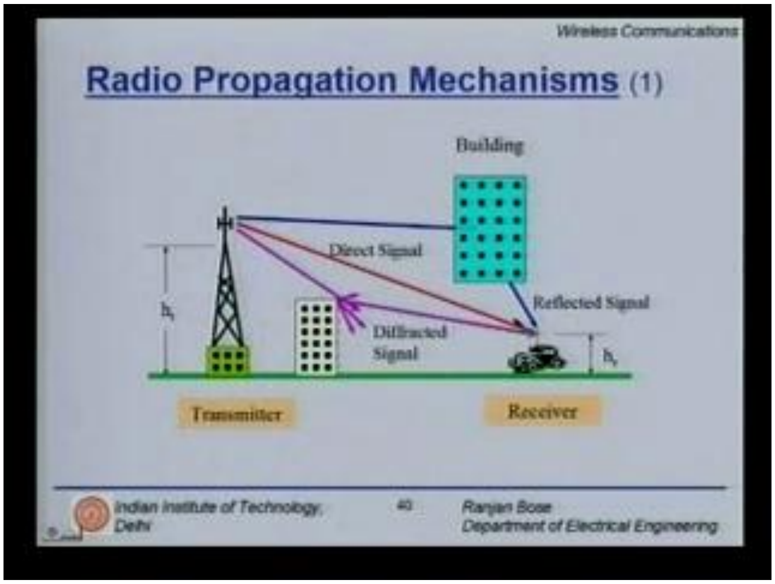

So let us now put in perceptive the three techniques we have learnt and how they happen in real life scenarios. So in a real life scenario, for a change, i have put may base station on top of a building because the system planner found out that this to be an optimal base station location. But there was an existing building. So they are going to pay royalty to the person whose is building it. They will erect a small tower. i have shown a big tower here and put the base station on top. Many times the optimal base station locations are not open for purchase. Then you have to put the base stations sub-optimally.

But putting base station at proper locations is itself a science. It is an optimization problem. It is a resource allocation problem. What is the minimum number of base station you would like to use to cover the maximum area? Now in a real life scenario, i have some buildings and i have a transmitter. So let's put a receiver here and since it is a mobile receiver with a small antenna sticking out, it is free to move into this environment where the buildings and there is a tower which is transmitting. This is your base station. So this receiver moves and it of course has a height of its transmitter antenna. We have learnt that the transmitter antenna height and the base station antenna height are both important. So let's mark them by h_T and h_r. let us see what are the radio propagation mechanisms that will happen in the real life urban scenario. i have tall building, i have towers, i have a ground and there is a mobile station. First i have a direct signal.

Earlier wherever we started off with their where no direct line of sight. But this time because of its position it has a direct line of sight. Great but of course that's not the only thing. It has a reflected signal as well. Now this is not necessarily good news. More energy for once is not necessarily better because the received signal will superimpose on the direct signal and will in effect, cause destructive interference and might lead to something called as a fading. We will talk about fading effect in subsequent lectures. But reflection is not the only solution possible. So there could be a diffracted signal as well from an edge. So direct signal reflected signal and diffracted signal. All of these are going together adding up vectorially to give the net signal received which is very different from what was actually sent. Remember all these paths have different time delays, different phases and different signals strengths which add up to give you a net signal which is very different from what you have actually sent. What is important is the distance between the transmitter and receiver.

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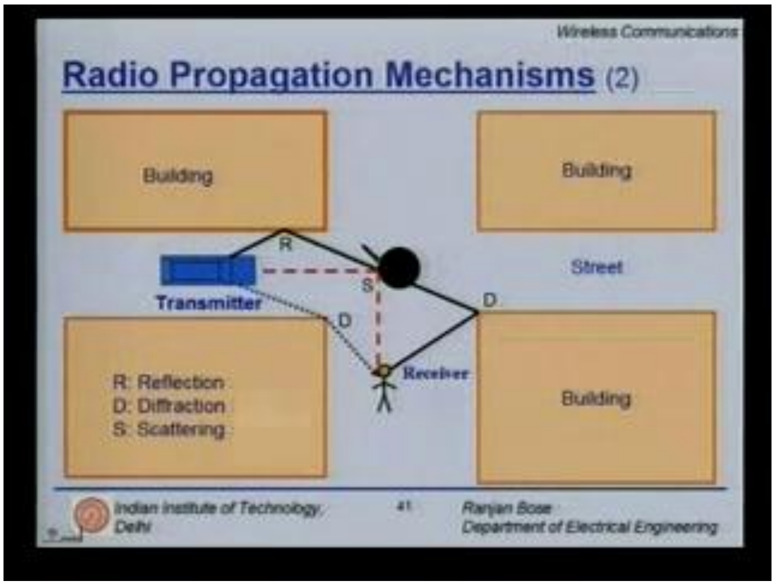

Let us look at another scenario. This time from a bird's eye perspective. So i am sitting on an air craft i am looking down on a city which has some buildings under street scenario. Let's look at how the propagation mechanism works in the scenario. So there is a certain central space where there is a small roundabout may be the police person can stand here and there are three buildings or four buildings here. Let us put a transmitting antenna here. So I'm talking about somewhere somehow a transmitter being communicating with another mobile station. It's a more of a walky-talky scenario not the mobile scenario. But it still falls under the policy purview of wireless communication. So this transmitting antenna would like to communicate with this receiver .so for a change no base station

Now this receiver is free to move. It's a street. So it's a pedestrian traffic .so this guy moves here so even though earlier they had a line of sight now the line of sight has gone. But that doesn't mean that this receiver will not receive an energy first it can get some signals through a couple of reflections. But note it's a reflection here but here it's not a reflection. When you have an edge it's usually a diffraction. but even though you don't have a line of sight, if another possibility of diffraction, the knife edge diffraction which is happening here, so the point that i am trying to make is it is not always that you have to have a tall building for the knife edge thing to work. It's a corner of the building which is causing a diffraction and this guy is still receiving energy. That's not all because it can get some scattering effects from this point as well. It depends on the wave length being used. So in this simple scenario, we are looking at reflection here, diffraction at two places. Please note we have to have an edge here and scattering. All three things are playing an important role.

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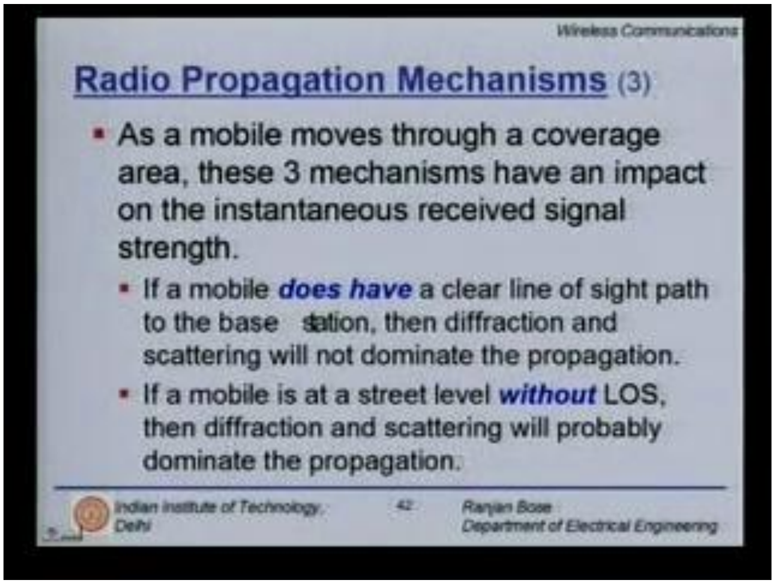

So as a mobile moves through a coverage area, these three mechanisms have an impact on the instantaneous received signal strength. Now if you are lucky, if the mobile does have a clear line of sight then diffraction and scattering will not dominate the propagation. The line of sight exists. i have a clear signal strength. however if a mobile is at street level without line of sight then diffraction and scattering will probably dominate the propagation. So this is important models exists for all of this. So it is possible to figure out theoretically and by stimulation how much is the received power actually obtained and whether we can work at a good level. So i would like to come to a summary at this point in time.

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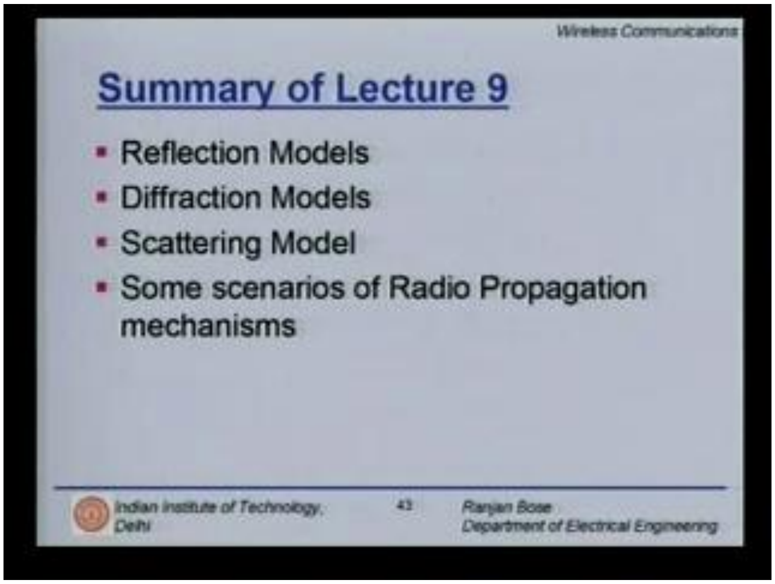

The summery of lecture nine is as follows. We looked at various reflection models. We looked at reflection from perfect conductor, reflection from a dielectric and we also found out that the gamma, the Fresnel reflection coefficient, gamma parallel gamma perpendicular. We then talked about the diffraction model. We talked about the single knife edge diffraction model and also the multiple knife edge diffraction models. We also saw how magically you can convert multiple diffraction models. The multiple knife edge diffraction models into a single knife edge diffraction model. We then also found out that scattering is there and can help you receive the signal without a clear line of sight. Then we also learnt that from basic scenarios, you can either have a line of sight reflection, scattering or diffraction. One or more a combination of these will eventually get you the instantaneous signal and what you get is a vector sum of the various kinds of signals that you received. So we would like to conclude here and in the next lecture we would go deeper into propagation models. Thank you!