Optical Wireless Communications for Beyond 5G Networks and loT
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Lecture - 07
Part 2
Channel model for multiple sources

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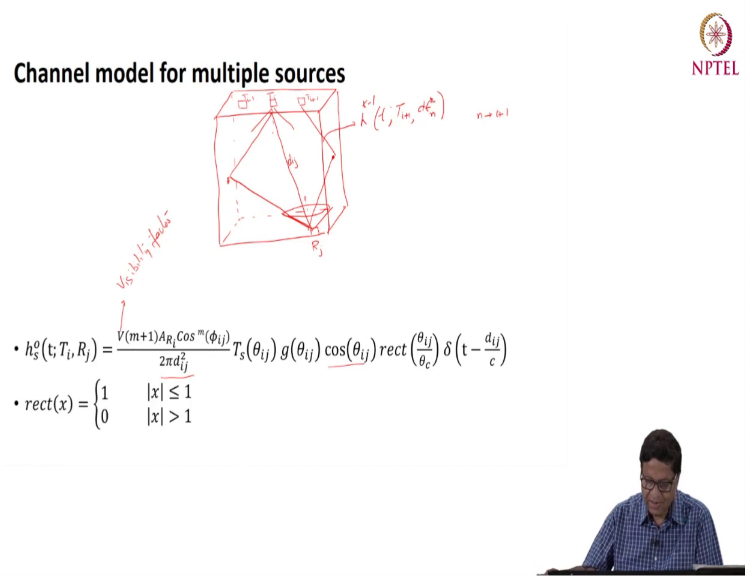

Now, let us try to understand Channel model for multiple sources. I have assumed an earlier case was single source now let me try to explain for impulse channel model for multiple sources. So, before that let me again draw the line draw the room which has multiple sources. So, assume that there are many sources.

So, this is a T i, this is a T i plus 1 and this is a T i minus 1 and then there is a receiver here which is a R j and this receiver has as earlier has some cone where it can accept light and so, there will be a direct light falling. So, let me show the this is radiation pattern of the source and this is the normal.

This is the normal and the light is falling from here and getting collected here and also we have seen that there can be a reflected light also from this point. So, this is for a single source this we have studied and we have named different angles. So, you can refer the previous diagram for clarity on the different angles and then also there is a contribution from T i plus 1 both line of sight as well as non line of sight.

So, let me draw a non line of sight here. So, light from T i plus 1 gets reflected from the wall and it is collected here and suppose this is k minus 1 reflection then it will have impulse response h k minus 1 this is function of t and this is coming from T i plus 1 and R j. Sorry this will be because there is a small area here because this now acts as a transmitter for this R j.

So, this will be sigma r or let me write this as epsilon sorry epsilon r and this is for i plus 1 transmitter. So, this can be n where n could be you know in this case it is i plus 1 otherwise n can vary depending upon the number of sources you have at the top. So, if I write try to write you know channel model for such a case this is multiple case, but there is only one receiver.

So, this can be written as for the line-of-sight h s 0 t of say source T i R j as before. So, this is your visibility factor depending upon the blockage either 0 or 1 and A R i is the collection area, this is related with the radiation the source radiation pattern. This in the angles which are mentioned here phi i j and theta i j you can refer to the earlier diagram.

So, and this distance is 2 pi di j square. So, this I am referring this as this is for one source T i. Similarly, you will have for T i minus 1 and T i plus 1 and whatever number of sources you have. So, cos theta i j and this is a rectangular function theta i j theta c depending whether the light is falling within the cone.

And then as we know that these are line of sight they are all Dirac delta function. So, this is represented here delta t minus d i j is the distance this is d i j d i j divided by c. This rectangular function again rewritten here.

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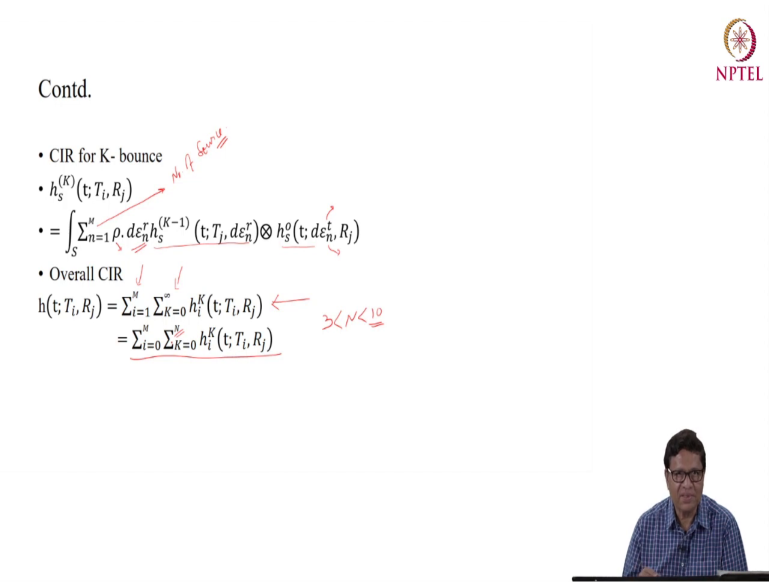

So, if I calculate for K bounce the way I had done for the earlier case that will be given as convolution of K minus n K minus 1 bounce involved with h s 0 and this is for every T j there is only one R j. So, and that is why you see the summation here. So, this actually tells you the number of sources. So, right now it is assumed that there are M sources.

So, this is n is equal to 1 to M and this is the coefficient here and this is the area of the area on the wall which if you are considering n is equal to 1 or n is equal to 2 or depending upon which source you are considering and then you have to convolve K minus 1 of the refraction point with the direct coming from the source which is a reflection point for one ray, but becomes a source when it is collected by the receiver.

So, this is given by d epsilon t n. So, let me again refer this n tells you the index of the source and this is actually the we will acting as a transmitter now. So, this is t n that small area on the wall. So, the overall CIR will include both the contribution coming from different sources which is captured by this summation and which is and the K bounces which is captured by this summation. And this K tend to infinity.

So, this is the overall response, but as explained earlier K is equal to infinity this value will be 0 the contribution of the to the impulse response will be to the overall impulse response channel impulse response will be 0. So, it is only limited up to N. So, that is why it is written as N and N as discussed earlier is between 3.

So, this becomes a channel response for overall channel response for the system which has multiple sources and single receiver which is summation i is equal to 0 to M, M is number of sources summation K is equal to 0 to N, where N is the reflection one can take the value of 3.

So, up to 3 reflections there will be some contribution to the channel impulse response beyond 3 it is negligible, but if you want to have some accurate value of channel impulse response one can go up to 10 and h i K is of the Kth reflection from T i to R j. So, this is the overall channel response for multiple sources and single receiver.

Similarly, one can do for multiple sources and multiple receivers. So, again there will be one more summation term which will be actually corresponding to number of receivers.

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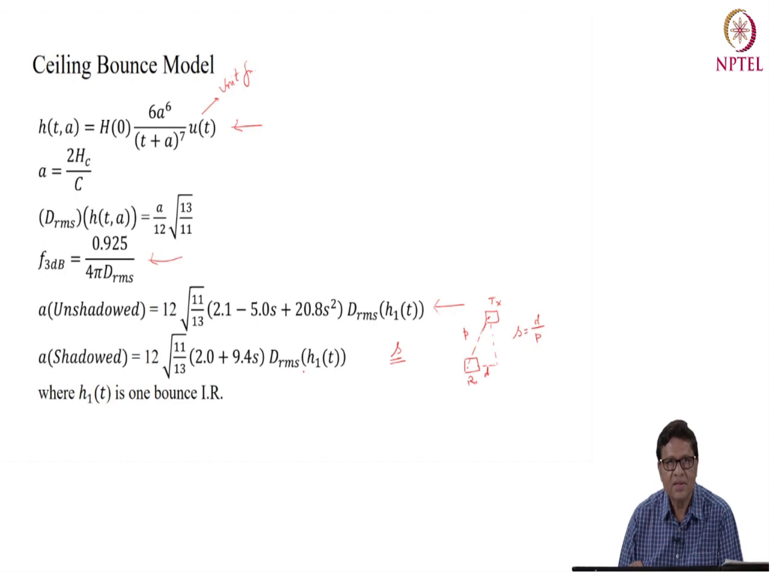

So, this is how you do recursive method of for modelling the channel, there are some other methods also. In the beginning we had discussed you know deterministic methods and non-deterministic method. So, far we have discussed the deterministic method. So, let us discuss some of them some methods which are non-deterministic. So, ceiling bounce method is one of them.

So, in ceiling bounce method this impulse response is a function of t of course, and also function of a I just define what is this a. So, this is H 0 channel optical wireless channel transfer function 6 a raise to power 6 divided by t plus a raise to power 7 and this is the unit function, where a is given by H c, this H c is the height the distance between the transmitter and the receiver and C is the velocity of light.

And if I calculate the rms value of the delays, sorry this this is a you know multiplication of rms delay spread and channel transfer function which is a function of t and a is given by empirical formula a by 12 root 13 by 11 and if I calculate the 3 dB bandwidth it is actually given by 0.925 divided by 4 pi D rms.

So, this is also a fairly accurate model which is used generally used and this is a faster way of you know finding of the channel model, but it may not be as accurate as recursive model and it may not have you know flexibility, but this has been computed for two types of scenario where the value of a is different when you have there is no blockages or no shadow and there is no you know blockages coming in the inside the room.

So, under those cases a unshadowed value is not 2 H c by C is given by this formula and similarly a shadowed when you have blockages is given by this formula and here s is actually suppose this is your transmitters at the ceiling and this is your receiver. So, this will have some distance and this is there is a diagonal distance here.

So, this distance is say for example, d and this distance is say p and this s actually is defined as a ratio of this horizontal distance d over the diagonal distance. So, this is another formula which one can use for finding the bandwidth of the channel or the impulse response of the channel by using you know this formula and this expression, where h 1 t forgot to mention is actually one bounce impulse response.

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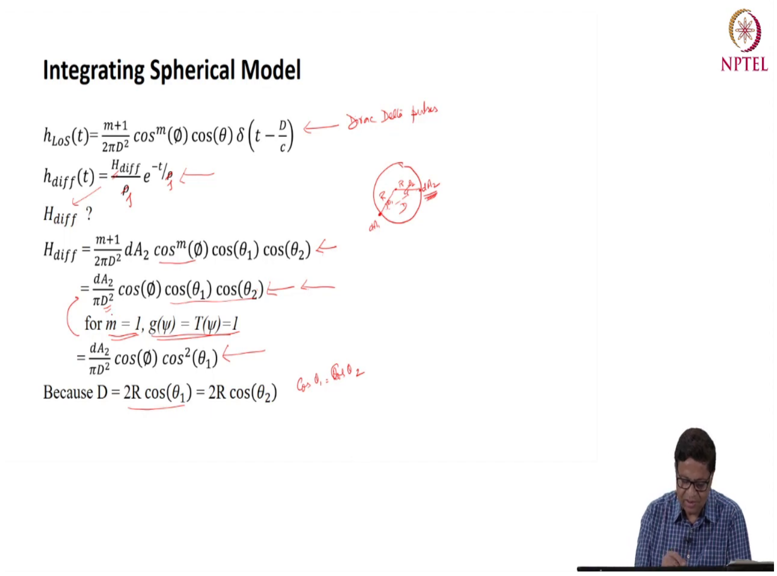

The other model which can be used is integrating spherical model. So, in this case there are two components one is line of sight. So, this is represented as Dirac delta pulses this is as usual. So, there is no change here Dirac delta pulses as we have discussed earlier and here in this I have assumed t s t s theta and g theta they are equal you know equivalent to 1.

So, it is rather simple simpler expression and Lambertian pattern and cos m phi cos theta and Dirac delta pulses. So, there is no change as far as LOS channel model is concerned, but for the diffuse case it is assumed that this impulse response for the diffuse case is can be represented as exponential function, where H this is the diffused case for optical wireless transfer function divided by this is tau.

So, let me sorry from this mistake this is tau. So, H diffuse divided by tau into e raise to power minus e by t tau where tau is the time when the ray almost dies or it is not collected by the receiver. So, how do you calculate to find out the impulse response for the diffuse case, we need to find out this H diffuse. So, H diffused if I assume this is based on a spherical model.

So, if I assume there is a sphere and see this is the centre and there is some area d A 1 for example, and then some area d A 2. So, how much light is collected by d A 2 from this d A 1 I am just trying to calculate from d A 1. Similarly, you can integrate over the whole sphere and find out how much light is collected by d A 2. So, if I.

So, this suppose this distance is D and let me this is with the centre. So, this is say theta 1 this is theta 2 and this is the radius of the sphere. So, the H diffused will be m plus 1 2 pi D square. Now, I want to find out what is the light which is falling on to the d A 2. So, this is the radiation pattern and then it is governed by cos theta 1 and cos theta 2.

So, this is the expression for H diffuse and this can be written as suppose I assume m is equal to 1 for simplicity and already I have assumed you know this as 1. So, this is simplified d A 2 by pi D square cos phi because m is equal to 1 cos theta 1 into cos theta 2 or it can be written as d A 2 this area d A 2 pi D square cos phi because cos theta 1 is equal to cos theta 2.

Because if you see here D is 2 R cos theta 1 and this is 2 R cos 2 cos theta 2. So, basically cos theta 1 is equal to cos theta 2 and if I put in this expression this what this is what I get d A 2 pi D square cos phi into cos square theta 1.

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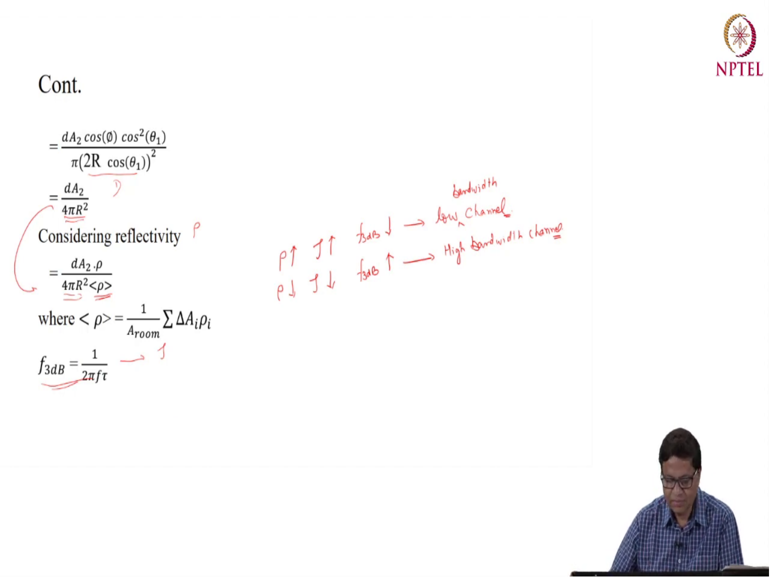

And this I can put in the expression the earlier expression of let me show you the expression. I can put in this area in this expression here and also replace the value of D and this is cos square theta 1 this we have seen cos theta 1 is equal to cos theta 2 and put the expression of for D then what you get is d A 2 cos phi cos square theta 1 divided by pi this is D actually 2 R cos theta 1, this is D and if you do some calculations.

So, this will be d A 2 4 pi R square. So, this becomes d A 2 4 pi R square. Now, considering reflectivity because I am not considered the reflectivity part that is say rho is a reflection coefficient then this expression will get modified as dA 2 into reflectivity part and this is 4 pi R square which is the total area of the sphere into average reflectivity from different parts in the room.

Whereas, the average reflectivity is defined by the total area of the room into some of those small areas multiplied by reflectivity for that particular area. So, this is how average reflectivity is defined and if you calculate the f 3dB part this is 1 by 2 pi f tau, the tau is the time when the ray almost dies.

So, that time is referred as tau I mean it is not getting collected by the receiver the value or the power intensity in after getting so much reflection is so low that there is no significant contribution. So, this is how you define tau and this 3 dB bandwidth is actually function of this tau so, 1 by 2 pi f tau.

So, you just to understand this value of tau so, if your rho is high; that means, it is getting reflected from the walls and it will suffer more reflections and this tau will increase actually before it the ray is insignificant. So, once this tau increases and then if you increase the tau here this f3dB will go down. So, this is a low channel a low bandwidth channel.

On the other case if the value of reflectivity is low; that means, the light the light is if it is low then the tau value actually decreases and f3dB increases. So, this is a case of high bandwidth channel alright. So, depending upon the value of reflectivity reflection coefficient one can you know find out or estimate the value of tau and then as this tau depends on this 3 dB bandwidth, one can find out the bandwidth of the channel whether it is a low bandwidth channel or a high bandwidth channel.

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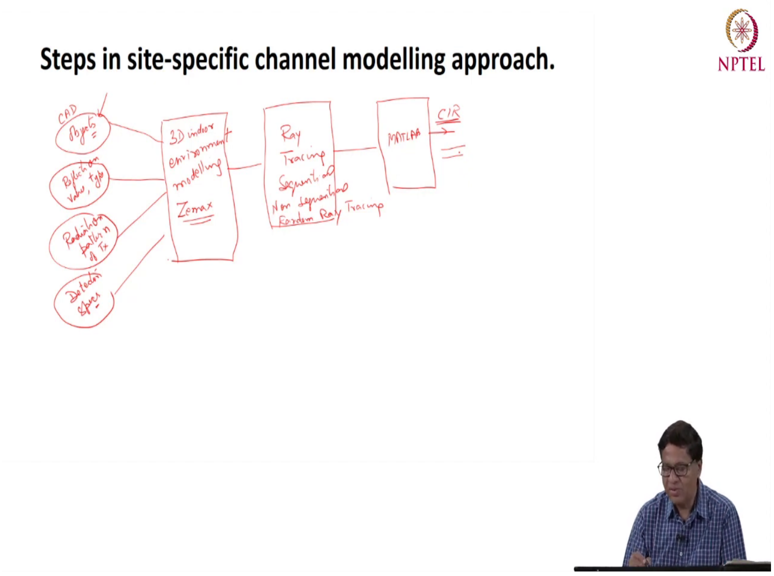

So, let us now understand what are the steps involved when you model a channel using recursive technique. So, what normally is done you know the environment will have some objects. So, you should have some you know you should know how to model those objects and also you should also have what kind of reflection is there on the wall reflection and the value and the type.

Also one should know what is the radiation pattern and also of the transmitter, also one should have detector specifications, what is FOV, what is the concentrator gain, what is the pre amplifier, if one is using pre amplifier in the receiver. So, all these things should be known and you should be able to model these objects and all these values are known and they are actually are the inputs to a 3D indoor environment modelling software so, one of the software which is normally or which is properly known as used as Zemax.

So, these they become input to this Zemax and then you can model your room which is you know 3D environment modelling and once you have done this then you can use ray tracing and this ray tracing can be sequential, can be non-sequential or some random trade tracing, using Monte Carlo random ray tracing.

So, one can use you know different types and then once you have done this ray tracing using one of these methods and then the data is imported to MATLAB for example, and you are able to you know model the channel. So, this is what you get is channel impulse response or modelling the channel. So, this is how you know when you want to model a particular channel.

So, these are the different steps which are involved because each environment may have different type of setup for example, you know there is a factory or a office environment or hospital for example. So, all these input conditions may be different and similarly you will have you know different channel impulse response. So, depending upon the environment you design your system or you find out your channel impulse response.

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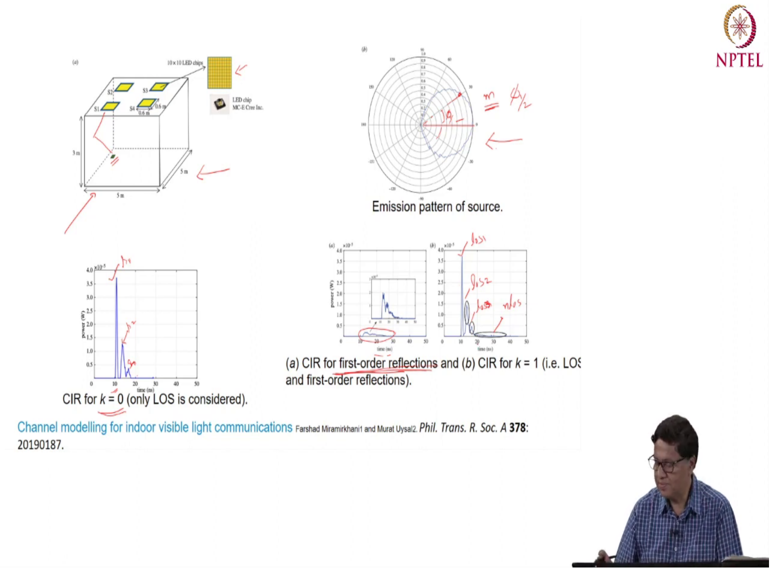

So, these are some of the examples how does the channel impulse response look like and what insight can it give. So, this is what I have considered here is a room which has got say 4 LEDs S 1, S 2, S 3 and S 4 and S4 for example, has some dimension 0.6 to 0.6 and each led has actually it is a array it is not a single LED. So, there are many LEDs or for example, here it is 10 cross 10 LED chips shown here.

So, this is one transmitter having or one LED which is array and which consists of 10 cross 10 LEDs and receive array say somewhere here. And if you see the transmitter pattern or the Lambertian pattern radiation pattern of the device which is something like this is emission pattern of the source.

So, you can find out the value of m from here and you can find out the value of half irradiance of the because there is some intensity here this intensity falls say half at this point. So, this angle will give you half rate irradiance and similarly half this side. So, and from there you can calculate the value of Lambertian parameter.

And if you see the impulse response for such a kind of scenario then suppose your receiver is here it is close to S 1. So, you see a peak there this is because of S 1 and the contribution from other LEDs S 2, S 3, S 4 is minimum. So, you see you know for example, this could be contribution from S 2 say, this is S 1, this S 2.

And this could be for example, this contribution can be from S 4 and probably S 3 is too far it is not able to it is not contributing to the detector. So, you do not see any p here. So, this is corresponding to you know only line of sight or k is equal to 0 channel impulse response and from here you can find out in terms of time what is the; what is the bandwidth if you are considering only line of sight.

Now, if you see include the first order reflection also then there will be contribution you know which you see here this is the contribution which is coming from first order reflections. So, for example, because it is travelling a longer path the first order reflection because it may come the it can strike here and then then go to here. So, this may be a longer path as compared to the line-of-sight path.

So, it is coming at a later time that is why you can see this coming beyond 10 or 50 millisecond whereas, the line of sight was coming in 10 millisecond. So, and this is magnified here. So, this is the contribution of the first order reflection and if I combine both the line of sight.

And the and the non-line of sight considering only first order one reflection then what you get is this is because of the source which is closest to the receiver some other source third source and this is the contribution from non-line of sight. So, these are the los components from different sources line of sight components from different sources los.

Say for example, this was 1, or this was 2, this was 3 and there may be nothing from los lo from the 4. So, this is how you can find out you know from this trace you can find out what is the bandwidth of the once you have the once you know what the channel impulse response then you know what is the bandwidth of the channel.

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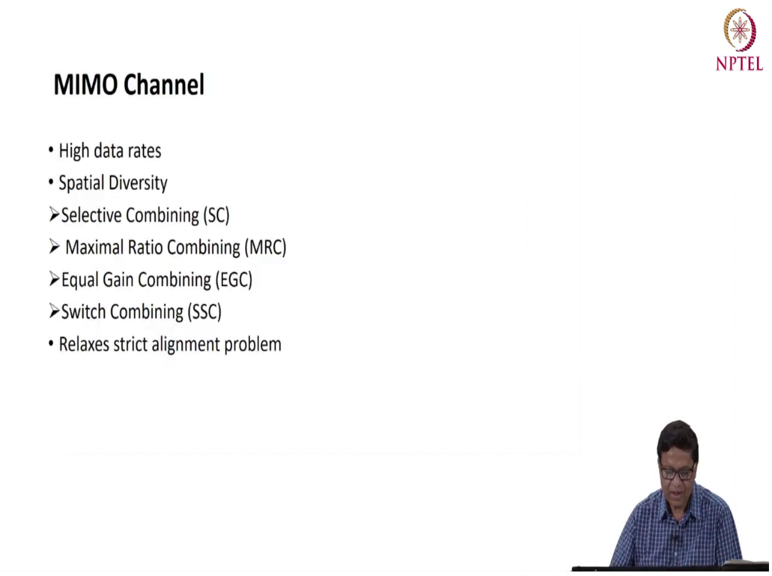

So, we will stop at this point for this was the discussion about indoor channel modelling where we had used only single source and single receiver and also we had used multi source, but now specifically we will try to understand a MIMO channel where there are multiple sources and multiple receivers how do you represent a channel for a MINO system.

Thank you.