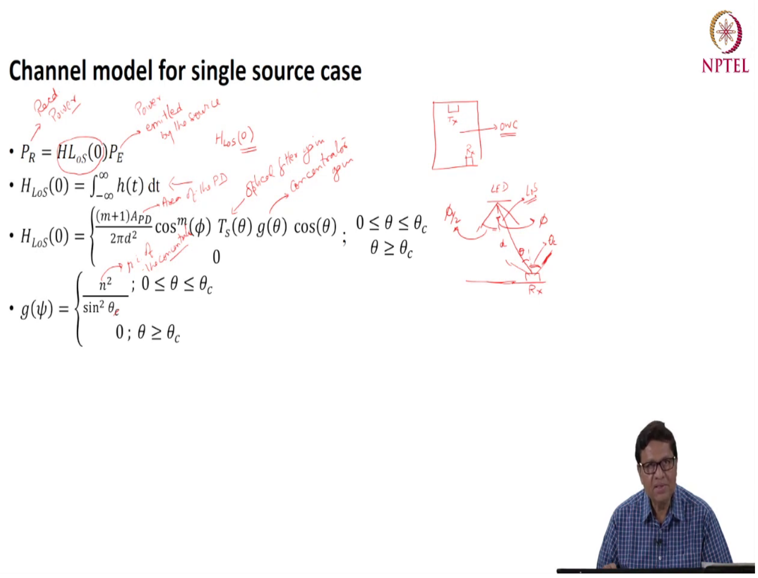
Optical Wireless Communications for Beyond 5G Networks and IoT
Prof. Anand Srivastava
Department of Electronics and Communications Engineering
Indraprastha Institute of Information Technology, Delhi

Lecture - 07
Part 1
Channel model for single source

Hello everyone. So, today we are going to discuss how to model a channel for a single source which will include both line of sight as well as non-line of sight component.

(Refer Slide Time: 00:37)



So, for this we will do for indoor system. So, suppose this is your indoor, you have one transmitter here and receiver here and we want to model the channel optical wireless channel here. So, suppose the P E is the power emitted by the source and P R is the received power at the receiver.

And this is the optical wireless channel transfer function actually this is this should be written as H L O S the 0 actually stands for d c this is for d c assuming this is d c channel gain and then H L O S can be defined in terms of channel impulse response in this fashion. So, now let us try to understand how do we model that optical wireless transfer function.

So, suppose this is your LED, this is the receiver plane and your receiver is say somewhere here and this LED can have a radiation pattern depending upon the value of Lambertian parameter m it can be a narrow emission it can be a broad emission let us consider LED which has a broad emission and assume that this is the and this is a normal let me this is not coming clearly here.

So, this is the emission pattern and this is the normal and then this is the receiver and it has some f o v and this is say the normal air. Now the ray from source falls on to this receiver and it is collected by the receiver because it is falling within the cone of the receiver f o v. So, this angle let us see let us say is phi and this angle which the emission pattern makes with the normal is actually half irradiance angle which we had discussed in the last class.

So, let us denote this by half irradiance angle and this angle at the receiver the ray makes with the normal let us denote this as theta and the total f o v is this angle normal with the with this side is say theta c if the ray falls beyond this, it will not add to the receiver and you will not get any output. So, with this understanding let us try to understand this the optical wireless transfer function.

So, this is given by m plus 1 m, m is the Lambertian parameter a this is area of the photo diode this is area of the photo diode of the P D 2 pi d square and this this distance between the source and the receiver is d this distance is d cos m phi this is the radiation pattern this term is coming because of the radiation pattern and m is m as I mentioned is a Lambertian parameter.

And T s theta is optical filter gain if you are using some optical filter. So, this will have some gain. So, this is represented as T s theta and this is the concentrator gain because at the receiver you want to have a wide receiver so, that you get light from all possible you know directions.

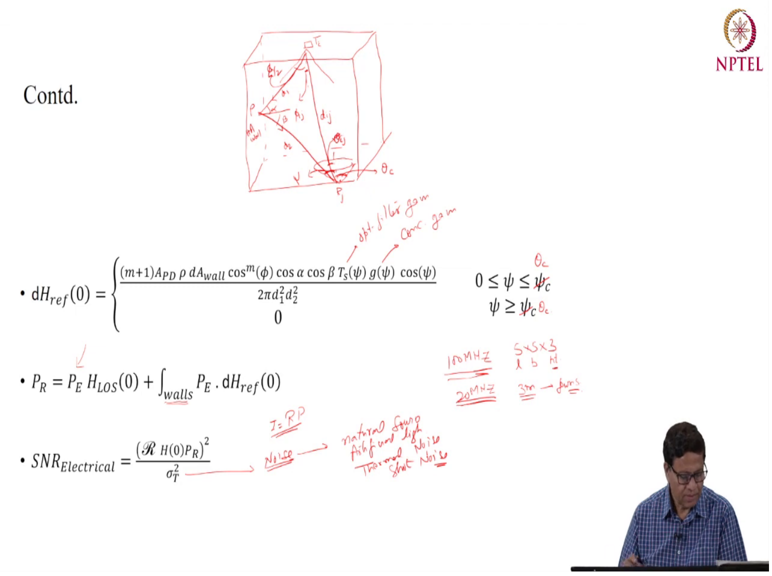
But when you have once you have a large photo diode area, it will have more capacitance and it might limit the data rate. So, in order to take care of this issue one uses some sort of concentrator near the receiver and that concentrator may have some gain ah. So, which is g theta. So, this is concentrator gain.

And then cos theta there is the angle the ray makes with the normal of the photo diode. So, this will have some value when the as long as theta is between 0 and theta c and this will be 0 when it is greater than theta c. So, this is true for both sides. So, theta c I have shown here as a half f o v otherwise the total f o v is 2 theta c.

So, this is the optical wireless transfer function and g theta this concentrator gain is actually given by n square divided by sin square theta c and this theta should vary between 0 and theta c. So, this is sin square theta and it is 0 when theta is greater than theta c and n is the refractive index of the concentrator, this is a refractive index of the concentrator.

And normally when we do analysis sometimes you take T s and g theta as 1 so, that your calculation become little simpler, but here I have represented T s theta and g theta in the expression.

(Refer Slide Time: 08:06)



So, now, let us try to. So, this was the case this was the case when you had only line of sight. So, this is line of sight, but there will be components from non-line of sight. The ray or the light getting reflected from the walls or from the ceiling or from the receiver plane and then it can be collected by the receiver. So, those are referred as non-line of sight components.

So, let us try to find out the optical wireless channel transfer function when you consider non-line of sight. So, in order to understand this, let us draw a diagram where we will consider one non-line of sight component and then try to understand this expression. So, let me draw again a room where I will show both line of sight as well as non-line of sight. So, say this is.

So, this is a room and then you have a source here right now let us assume there is only one source because we are trying to model the channel for single source and single receiver and let us denote this as T i there can be many sources, but right now I am assuming only one source T i. And then you have a receiver here which I called as R j.

This T i will have some emission pattern or radiation pattern and let us see this is the normal and similarly receiver j will have a cone which will accept the light. So, this is the cone and let us say this is the normal. Now let us try to identify the. So, this is let us draw for the first line of sight as we had known earlier.

So, this is line of sight and let this distance between the source T i and the receiver R j is d i j and this angle which it makes with the normal is phi i j and as usual this is our the irradiance angle which is say phi phi half half irradiance angle. So, this is referred as phi half and this angle the maximum angle where the light is accepted by the receiver is theta c.

And this angle which L O S makes with the normal this particular angle this is phi i j sorry this is theta i j this is theta i j. So, this is for the line of sight. Now also we need to consider non-line of sight components. So, let us consider just one line of non-line of sight component for example, ray which is coming from the radiation pattern of the source strikes the surface of the wall with some area say d wall d a wall or here I have used as d a capital wall.

So, let me write capital A and it will have some reflection coefficient say rho, this is the direction and if I draw a perpendicular here this angle is given by alpha and this angle is given by beta and the angle which the reflected non-line of sight from the wall makes with the normal meaning this particular angle this angle is let us represent this by as psi and this distance from transmitter to this point on the wall is say d 1 and this distance is d 2.

So, the component the d H reflected this I am referring this as reflected from the walls that optical wireless function I have written d here because a small area wall is considered here normally you know when you do the recursive method for channel modeling you divide the whole wall into grids. So, each grid actually represents one small area differential area.

So, this is given by m plus 1 m is Lambertian parameter area of photo diode and rho is the reflection coefficient of the wall and then d A wall is the area particular area on the wall and then cos m phi this comes from the radiation pattern of the source and then cos alpha this angle alpha which it makes is the normal and then cos beta this angle into as usual our T i psi which is filter gain optical filter gain and g psi.

So, let me write this optical filter gain and g psi is concentrator gain because I am using concentrator at the receiver. So, that the response of the photo diode is not limited concentrator gain and cos psi this psi angle which is the reflected ray makes with the normal of normal at the photo diode and divided by 2 pi these two distances earlier it was d square when I was considering line of sight.

Now, there are two distances involved. So, this will become 2 pi d 1 square d 2 square and this angle this is valid when you have when the ray reflected ray is falling between 0 and psi c or this should be theta c because theta c is the theta c is the maximum angle and this is psi this is theta c. So, this is how you represent the contribution from the non-line of sight component.

So, if I try to calculate the receipt power because of both non-line of sight and line of sight, this is given by P E emitted radiation power and this is the d c optical wireless transfer function H L O S plus this d H ref into p integrated over all the surfaces wherever the reflection is taking place. So, this is includes all the walls. So, P E d H ref at d c.

So, why I am assuming d c here every time? Because if you see the channel bandwidth is typically of the order of 100 megahertz which you can calculate for a room which is 5 cross 5 cross 3, 5 is the length and this is the length, this is the breadth of the room, this is the say height of the room.

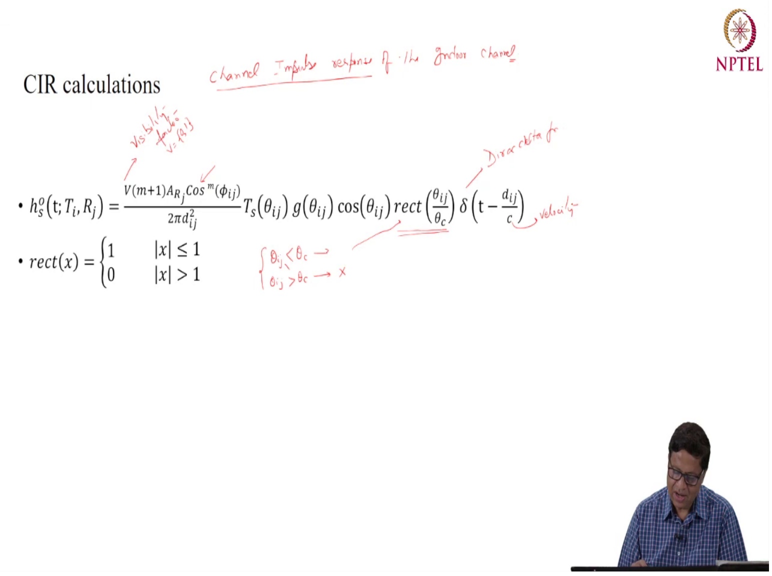
So, the maximum path difference which it can have is you know one the one between the line of sight and the other path which is covered by the long line of sight. So, the maximum would be says 3 meters for such a small room and if you see the delay will be of the order of very less few nanoseconds right.

So, basically if you calculate try to back calculate it will give you a bandwidth of about 100 megahertz whereas, the devices which are used here the receiver and transmitter they generally have about 20 megahertz a good device will have you know response something like this the LED the normal LED which I normally used in a room for elimination.

So, basically it sees a flat channel it is not a frequency selective channel. So, that is why you know d c gain is sufficient to represent the optical wireless transfer function and if I calculate the SNR which I required for calculating the b r. SNR electrical will be given by this H d c is actually combination of both the parts here the reflected optical wireless transfer function as well as the direct line of optical wireless transfer function into P R.

Because as we know I is equal to responsibility into P power. So, this is what I have assumed here. So, this become sort of phi square. So, this is the signal power and this is the noise the total noise that noise can come from some natural sources for example, or artificial light other than the light which are using for communication artificial light and the receiver also will generate some sort of noise which we had studied earlier thermal noise or short noise. So, this is the expression for SNR electrical.

(Refer Slide Time: 19:54)



Now, let us try to calculate the channel impulse response; channel impulse response of the indoor channel of the indoor channel. So, if you consider the last diagram which I had drawn here. So, I have written a generic expression for line-of-sight channel impulse response which is actually Dirac delta function coming from line of sight.

So, I am referring to this diagram and I have written the generic expression for impulse response considering T i as a transmitter and R j as the receiver. So, this is given by this h s 0 the channel impulse response because of the L O S coming from T i and received by R j v is a visibility factor because sometimes what happens? There may be a blockage between the transmitter receiver for LOS path.

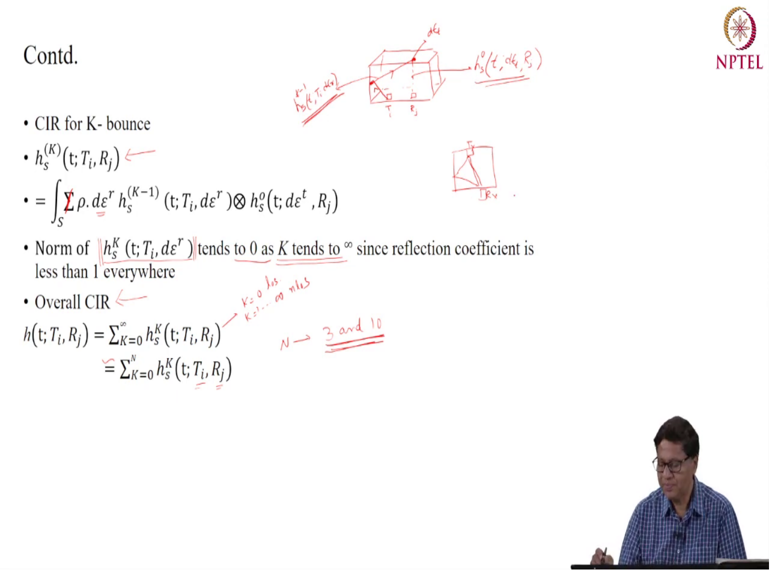
So, this will not give any contribution to the receiver. So, this could be either 0 or 1 depending on whether blockage is there or not there. So, this is called as visibility factor. So, this v can be either 0 or 1. A R j is the total collection area in the receiver of the jth receiver and cos m phi i j is the radiation pattern of the source of the T i source and T s theta i j and theta i j sorry g i theta i j are the optical gain optical filter gain and concentrator gain for the transmitter and the receiver.

I have used i j here because there may be many transmitters and there can be many you know receivers. So, that is its a generic expression into cos theta i j and this rectangular function actually basically tells you that this is how this is how it is defined as it is 1 when the absolute value of x is less than or equal to 1 and 0 when x is greater than 1.

So, if theta i j is greater than theta c this theta i j is i mean less than or equal to theta c then it gives a contribution here and if theta i j is greater than theta c, then there is no contribution it is 0. So, this condition this condition whatever I have described here is mathematically represented as this rectangular function of theta i j and theta c into say Dirac delta function this is Dirac delta function.

So, this delta is t minus d i j d i j is the distance with transmitted T i and receiver j divide by the velocity of light. So, this is the channel impulse response for the line of sight for one T i and one R j.

(Refer Slide Time: 24:01)



Now we need to calculate channel impulse response from non-line of sight component and non-line of sight component there will be many bounces. So, the light can come to the receiver after one reflection or two reflections or three reflections. So, this this number this number can go to very high value and normally k is tending to infinity.

So, we need to understand or calculate the channel impulse response for k bounce which I represent as this h s k t from transmitted T i and R j and to understand this how do you calculate channel response of when the light has suffered k reflections. So, let us just try to understand this I mean this is a typical say room.

So, for the simplicity I have kept the transmitter here this your here this is T, this is T this is say R R let me write R j this is T i and there is some area I consider here which I called as sigma sorry the differential area I called as this area let me call as sigma t. See the light from

T i strikes the wall gets reflected and which is say here now this becomes a transmitter for this receiver.

So, light will fall on to this receiver. So, I have shown here only one reflection, but ideally, but I am trying to calculate the c i f for a k bounce. So, K have to calculate the what is the channel response because of one reflection then then I will calculate based using this one for the second one and using the second for the third one and for finding out the kth I need to find out the k minus 1 reflection coefficient.

And then if you convolved with k minus 1 channel impulse response with this impulse response shown here then you get the channel impulse response after k reflections. So, this is what its written here. So, this will be if you see here this is h s 0, this is direct line of sight and this is function of t and this is coming from this is now acting as a transmitter.

So, this is d sigma t and this is R j whereas, if you see here this is as of the kth minus 1 because I am trying to find out the channel impulse response for k bounce. So, this is a h s k minus 1 t and this will be coming from the transmitted T i and this is some small area d epsilon r. So, I need to convolve this channel impulse response.

With this channel impulse response, I will get the channel impulse response for k bounce which is what is written here. So, this is by mistake this is not there. So, this is integrated over as this is the channel coefficient a reflection coefficient and then this is the area d epsilon r here, h s k minus 1 this is what is written here in convolved with this h s 0 for the direct line of sight.

When there is a differential area which now acts as a transmitter for this receiver is given by h s 0 d epsilon t into R j. So, if you take the norm of this that is the norm of this for high value when k is tending to infinity because every time the ray is striking the wall the it because the reflection coefficient is less than 1 it is getting attenuated.

So, when it does for very high amount of time for high number of times then this value tends to 0 as k is tending to infinity. Because your reflection coefficient rho is less than 1 everywhere. So, the overall CIR if I want to calculate, then it will be sum of all the reflections the all the K reflections this here in this expression.

For example, k is equal to 0 is a line of sight and k is equal to 1 to infinity is non-line of sight. And as I mentioned that as K tends to infinity, this value this contribution from high values of K will tend to 0 and effectively you can write this as equivalent to summation K is equal to 0 to n.

Where n is some number which has only significant which has significant contribution to the channel impulse response h s k t of T i and R j and it has been seen experimentally or using some software tool that this n value actually is between 3 and 10. After that if you have n value more than 10 it has very very low impact on the channel impulse response. So, for all simulation or practical purposes the n can be between 3 and 10.

So, this is channel impulse response of the for a system which has only one transmitter and one receiver. So, we have considered both a line of sight as well as a non-line of sight and I have we have seen that channel impulse response is basically combination of channel impulse response on the line of sight plus the reflected components, where this the this number of reflections which can be considered can be between 3 and 10 to give you an accurate value of channel impulse response.