Optical Wireless Communications for Beyond 5G Networks and loT
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Lecture - 08
Part 2
MIMO channel…contd

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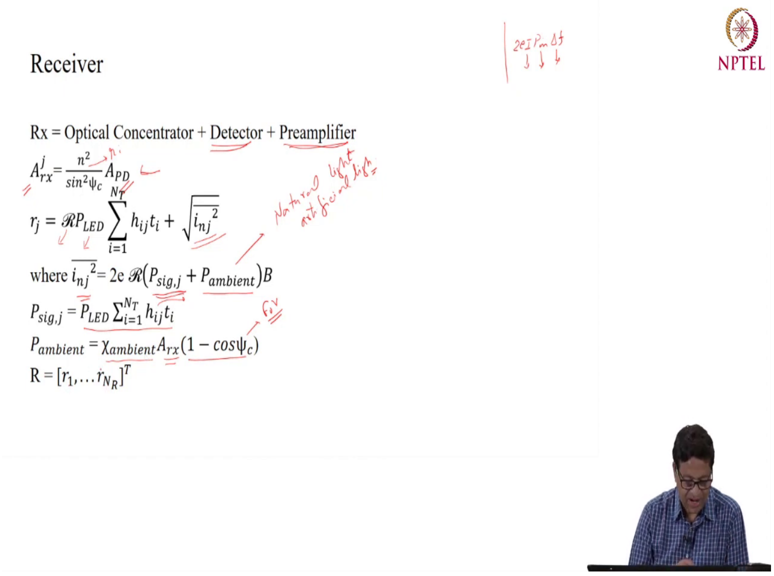

Let us now understand receiver and then we will see the you know how channel can be modeled. So, receiver I am assuming that there is a optical concentrator and which may have a gain of one and then there is a detector and there is a preamplifier which amplifies the signal and then it is given for further processing. So, assuming this is the receiver collection area, then this is the photo diode area once you are using a concentrator.

So, a rx j for the jth receiver is given by the total photo detector area and square which is a refractive index for the concentrator and sin square psi c psi c is the fov angle. So, the power received by the jth receiver is responsivity into the power is and this is the channel matrix h ij into t i, i is equal to 1 2 number of transmitters plus the noise part noise in the jth receiver.

So, this is the signal part and this is the noise part, and this particular noise is can be represented remember when we were discussing about the photo diode the noise was actually coming as 2 e I into P in and the bandwidth. This was the power input power and this was the bandwidth and the current generated and these was the charge.

So, on similar lines this noise is actually contains two components; one because of the signal to the jth receiver and these are ambient which is natural light, any other artificial light present in the room. So, there will be interference or noise from these two contribution also.

So, this is the noise in the received signal and P signal j signal power received at the jth receiver is given by this P LED. This is the channel matrix h ij component and it is from i to n 2, because it is getting contribution from all the transmitters into t i. And P ambient the power is actually some constant X ambient into receiver area plus into 1 minus COS psi c; where, psi c is the Fov of the receiver.

So, this is the contribution from the P ambient, this can also be modeled and the receiver on the receiver side you get vector which is r 1 to r N r at different receivers.

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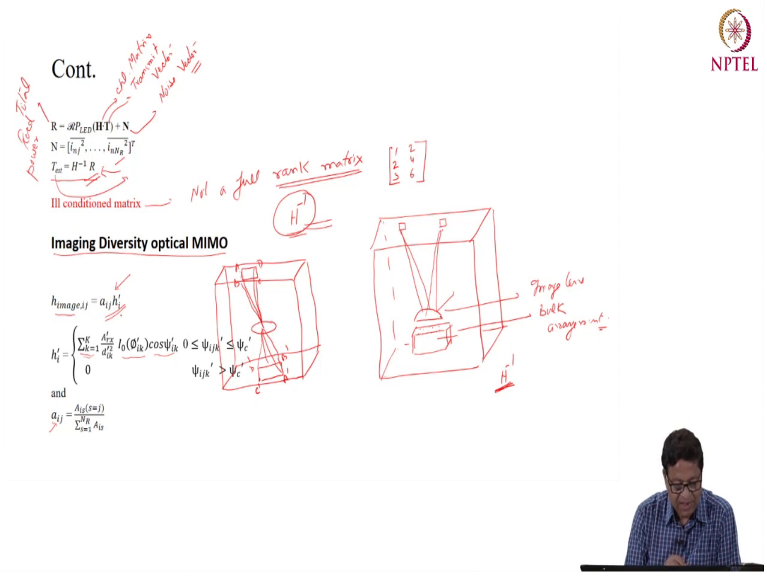

So, R total power this is the total power total received power is responsibility into P LED into H T. So, these are two matrix, this is H is a channel matrix and this is your transmit vector, this is your noise vector noise vector because there are many receivers; so, it will be a vector again.

So, this is the total received power and n is as I mentioned this is a received vector this is for the jth receiver and this is for the N R receiver. So, once you know the R and H is known it is assumed that H is known, I mean you have found out the channel matrix by doing some experiments. So, H is known and once depending upon what you get R multiply with H of inverse, you get the estimate of the transmitter vector.

So, this is how the receiver you get the you know your recovered data. But, if you notice because of the structure of this non imaging lens, the matrix which you will get is actually a ill conditioned matrix or it is not a full rank matrix not a full rank matrix. For example, if you have you know 1 2 3 and this is say 2 4 6 it is a rank deficient matrix.

It is not a full rank matrix, because if you see the column here it is just double you know of each element here. So, it is a ill conditioned matrix or not a full rank matrix, for a full rank matrix your rank of the matrix should be either equal to the rows or column or both of the matrix. So, but this is not the case when your receiver is in the center of the room or moving along the axis.

So, you will find that the matrix which is coming using this concept of non imaging that matrix is generally a ill conditioned matrix right. So, once you have a not a full rank matrix and if you want to try to find out the inverse of it, it becomes a difficult area. So, for finding out the inverse the matrix should be a full rank and ah; so, finding out H inverse which I need for my for estimation of the you know transmitted signal.

So, this will pose a problem to me, because there as a matrix for such a case is ill conditioned or not a rank matrix. So, in order to do away with this problem we work on something called image diversity optical MIMO; so, if you see the image diversity optical MIMO, imaging rather imaging of diversity optical MIMO.

So, in this architecture you have suppose this is a room; this is a room and these are say transmitters here, then on the receiver side I use a lens which is hemispherical lens and below this I have a array of detectors; so, I have array of detectors. So, all the light coming from the source is imaged onto the receiver. So, the I am getting light from all the all the transmitters.

So, my the bandwidth which I calculate it will not be dependent on the location of my receiver. In the earlier case, the bandwidth was depending upon the location of the receiver, depending upon where I am in the corner or in the middle you know bandwidth is changing, but in this case all the light is coming from the transmitter.

So, my bandwidth will not will depend will be actually will not depend on the location of the transmitter. Although it is making the receiver very complex, because you require a lens here this is a image lens you may require, and this is a you know some bulky arrangement. But, if you see here in this case the matrix which you get is actually a nearly a full rank or conditioned matrix and that is the main requirement of MIMO.

So, that you are able to find out H inverse easily and there is no you know the noise also does not get amplified; so, that is the advantage of using imaging diversity optical MIMO. So, just to briefly tell operation of this, let me draw one more figure for better understanding.

So, this is the same room which we are considering; so, this is for example, say the lens structure which is here. And if I want to see the image of these; so, some particular transmitter which has say A B C D, A B C D this is say one particular transmitter. And then it will fall on to this, this will here, this will come here, this is a image lens.

And when you see on the receiver you will get something like this and this is nothing but your you know this is coming here, this is coming here, and this may be coming in this corner. So, you will get you know similar to A B C D, what you will get is? A A will be imaged here and C will be imaged here. Let me denote this is A prime, C prime and this will be B prime and D prime; so, this is how it is imaged here.

So, you require a large number of receivers or they are sometimes called as pixels. So, that makes the whole system bulky and you also require a hemispherical lens which is a wide fov lens. So, that you are able to image all the transmitters onto this you know on this receiver, the whole idea is because I want to have a full rank matrix.

And I have wherever I go I have the contribution from all the transmitters. So, this is the importance the importance of imaging diversity optical MIMO. And if you see the image the channel matrix I am referring this as h image, you know earlier was non imaging this is imaging. So, this is h image for i j is given by h ij h i prime.

So, this h i prime is similar to what we had discussed, only thing it is multiplied by a factor aij. So, h i prime if I see this is again the number of LEDs, in that panel receive collection area, this is the distance they are all represented with dash, because this is a case of imaging diversity or imaging optical MIMO.

And this is phi ik COS phi ik and then these are the conditions. So, this is the channel impulse response and a ij is defined as this is a ij is the you know total the area falling on the jth detector as compared to the total area. So, this a ij is defined in this way and u the h for the image diversity is h ij into h i prime; so, this is how it is modeled.

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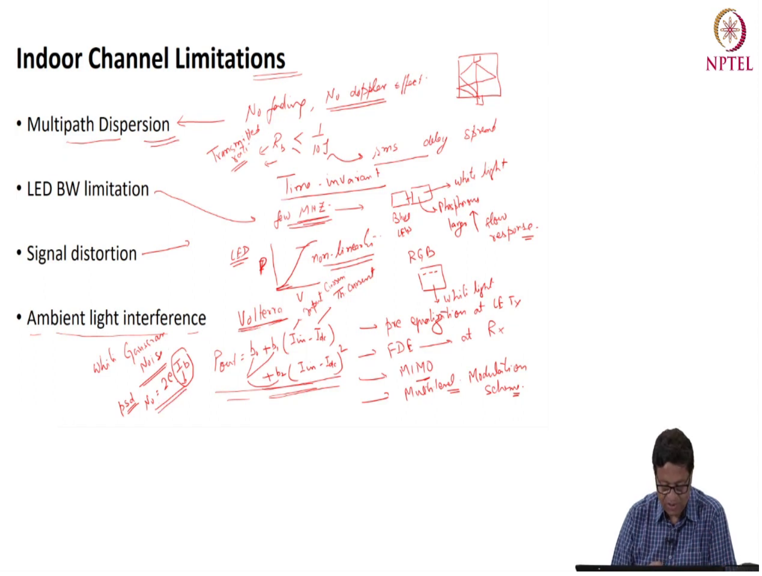

So, this was about two MIMO's systems non-imaging and imaging. And we have found out how it has to be modeled and how do you recover data once you know the channel matrix. We will do some examples in subsequent lectures; so, then the understanding will be better when we do some example.

So, the; so, regarding indoor channel we have studied indoor channel and we also studied you know different limitations of the indoor channel. For example you know multi path dispersion; so, there is no feeding this we know initially we discussed this. And of course, there is no Doppler effect, because the receiver is not moving at high speed.

And moreover, there is no change of frequency happening when the receiver is moving. so, there is no Doppler effect no feeding. But you do have multi path dispersion, because yeah inside the room you know that there are reflections and there is line of sight this is a receiver and there may be more number of refractions.

So, because of this different paths for different rays, it will result into dispersion and which actually limits your data rate. And your data rate is actually if you I mean this is a fairly approximate formula that R b that data rate should be less than 10 of tau which is this is the rms delay spread and this is your transmitted data rate.

So, as long as this condition is satisfied you will get this data rate. So, multi path effect has an effect on delay spread and accordingly your data rate will be affected; so, this is one thing we need to control right. So, and also is a fairly deterministic channel this channel is actually time invariant.

the second issue is actually a light emitting diode bandwidth limitation. The bandwidth of the LED the commercial LEDs which are originally installed for elimination have only limited bandwidth of the order of few megahertz. Whereas, the requirement is to have high data rate to the user.

So, this actually see what happens in LED commercial LED there is actually a blue led blue color LED and then you have some phosphorus layer on top of it. And when the blue LED passes through the phosphorous layer it gives you white light this is yellow in color; so, this gives you white light which is actually required for illumination.

The but the problem is that it is it has a slow response; so, which basically reduces the modulation speed of the device. So, instead there is different kind of LED which are called as RGB LEDs. So, basically there will be you know three elements giving different colors; red, green, and blue and when they combine there is no phosphorus needed now.

So, when they combine it gives you white light and each of them you know can be used for modulate modulation. And you can increase the speed I mean you can modulate R at different speed, G at different data rate, B at different data rate and you can do some processing to get higher data rate or use of WD W DM for getting higher data rate. So, this is and there are other ways other ways of you know increasing the bandwidth of the LEDs. You can do some pre equalization of the LED, circuitry pre equalization.

You can use pre equalizer at the LED transmitter pre equalization at LED transmitter. One can use frequency domain equalization at the receiver, one can use MIMO technique which we discussed earlier for increasing, or one can use a different type of modulation scheme. For example, multi level modulation schemes multi level which can increase the data rate.

So, there are different ways of increasing the response of the LED which standalone has a limited frequency response multi level modulation scheme. Also we should know that signal distortion, because the LED characteristic if you see it is not linear it is some this kind of curve s kind of curve. So, once if you have more constellation points in the system which you are trying to modulate, then there may be non-linearity.

And there may be some cross talk among the constellation points, because of this is non-linearity in the LED characteristic and moreover it has limited dynamic range; so, this is also limited. So, you have non-linearity in the characteristic I this is IV characteristic IV, this is you can say power sorry power PV characteristic voltage or control voltage or current. So, it is non-linear it may introduce some sort of cross talk and you have limited dynamic range.

So, in order to handle this one can use you know volterra kind of distortion modeling which is quite accurate. So, if I use this kind of modeling that is my power output of the las of the LED is b 0 plus b 1 I n minus I dc plus b 2 I n minus I DC whole square. So, if I use this kind of modeling which I dc is the threshold current and this is the input current and these are the polynomial coefficients b 0 b is are the polynomial coefficients.

And so, this gives a good fit to handle this nonlinearity and if I use this volterra; so, one can get some advantage in terms of performance in terms of modulation. So, this is one way of handling the signal distortion which comes because of LEDs nonlinearity and non-linearity and limited dynamic range. The other issue which we should worry in such systems is you know ambient light interference, this can also be modeled as White Gaussian Noise.

So, if I find out the one sided power spectral density one sided power spectral density N 0 will be 2 e into I b. Where, I b is the current which is coming from ambient light sources could be natural, could be other sources which are not part of the communication. So, this I b consists of these components and this can be modeled as White Gaussian Noise which is 2 e I b.

So, with this we complete the discussion about the indoor channel and we will also study in one of the lectures later how to simulate a indoor channel. And also we will study about one example for indoor channel, what kind of impulse response we get for some practical values. So, these are the things we will do at subsequent lectures and for the time being we stop the discussion of indoor channel limitations at this stage. And in the next class we will discuss how to model a outdoor channel.

Thank you very much.