Optical Wireless Communications for Beyond 5G Networks and loT
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Lecture - 08
Part 1
MIMO channel

Hello everyone, so, today we are going to discuss how to model a MIMO channel.

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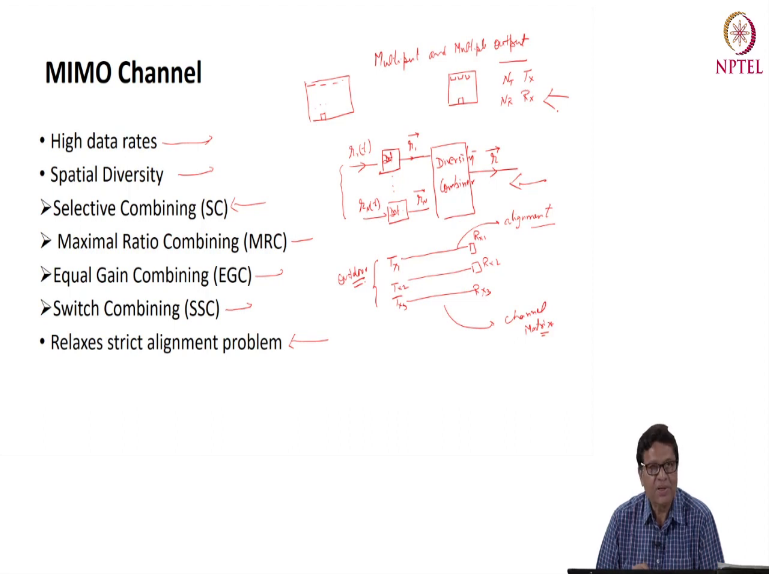

MIMO as all of you know is Multi Input and Multiple Output. On the earlier class we had a little flavor of MIMO channel where we had considered many transmitters in the ceiling and there was one receiver. So, now we are going to extend this logic and we want to include say N T transmitter and NR receivers; so, we will try to model such a channel.

So, first let us understand the what is the use of a MIMO channel in optical wireless communication? So, it can give you high data rates, because if you see in a room there are multiple LEDs and there can be multiple receivers. Suppose, there is a user he has a device which has more receiver's more than one receiver.

Then you know there are individual channels between one transmitter and one receiver and those are not very high speed. But if you can have many such individual channels then you can get advantage of high data rate. So, this is one use of MIMO channel and also we can use as in rf for special diversity; so, let us try to understand what I mean by special diversity.

So, for example, in a suppose, you know they you get N receivers, I mean there are N received signals. So, this is a r N, this is detector, this is detector and when you process it, you get some corresponding vector r 1 and you get some corresponding vector r N. And then this goes to some diversity combiner and you find out the final received vector and then you can process it to get your data out.

So, what actually is happening here? You are getting signal from different directions and you can process the signals and get the output, and from there if you decode data it is likely that your estimate is going to be accurate. So, in the diversity combiner they can be you know different types, one is selective combining. So, basically in this case you see the signal to noise ratio for each channel.

Whichever has the highest signal to noise ratio, you pick up that and that becomes your output; so, that is called as selective combining. And the other could be a maximal ratio combining where you make use of all the inputs which you have received. Because in the earlier case of selective combining, you have to every time the data is continuous and every time, we have to measure which has the highest SNR.

So, in order to do away with this procedure, one can use maximal ratio combining and then you combine in terms of the weight-ages. You assign different weight-ages depending, upon channel, conditions and things like that. You assign different weight-ages to different inputs and then try to find out your output which is called as maximal ratio combining.

So, it takes care of the weight-ages in terms of signal air, channel conditions, and whether you are getting low quality signal or high quality signal. The third could be equal gain combining, where you co-phase all the inputs which are coming and then you know give same amount of gain to everyone and then try to find out the output signal.

So, this is another method of you know getting output signal equal gain combining. The fourth one is switch combining; so, you basically keep on scanning the inputs whichever has the threshold higher than some threshold value. Then you select that and you continue to work with that signal till it falls below that threshold value.

And then you again start re-scanning and look for a signal which has more than that threshold value and continue to work with that value with that threshold till it drops below that particular threshold value. So, this is switch combining there are various methods, each method has different advantages.

So, this is what I mean by spatial diversity and also it also useful in relaxing you know alignment problem. Because for example, in a outdoor system your T x; suppose, there are many T x 1, T x 2 and this is R x1, R x2, R x3. Ideally there has to be a strict line of sight requirement or alignment requirement, you know you require strict alignment requirement.

But in practice it does not happen that way there may be a misalignment, the R x might have moved or the T x might have moved. So, there is some degree of misalignment between the transmitter and the receiver. So, once you have many channels and then you then your system can actually learn what is your channel matrix.

And even if there is misalignment and if you know the channel matrix, you can do some sort of electronic processing and try to correct it. Because, once you know the channel matrix those cross-talk element can be found out and you can subtract and some electronic processing can be done; so, that your strict requirement of alignment is done away with.

So, this is another example of having MIMO channel, this is a case of a outdoor system for example. So, you get diversity advantage, you get speed advantage; so, that is why we are we will now explore how VLC or Visible Light Communication inside the door can be used in a MIMO context.

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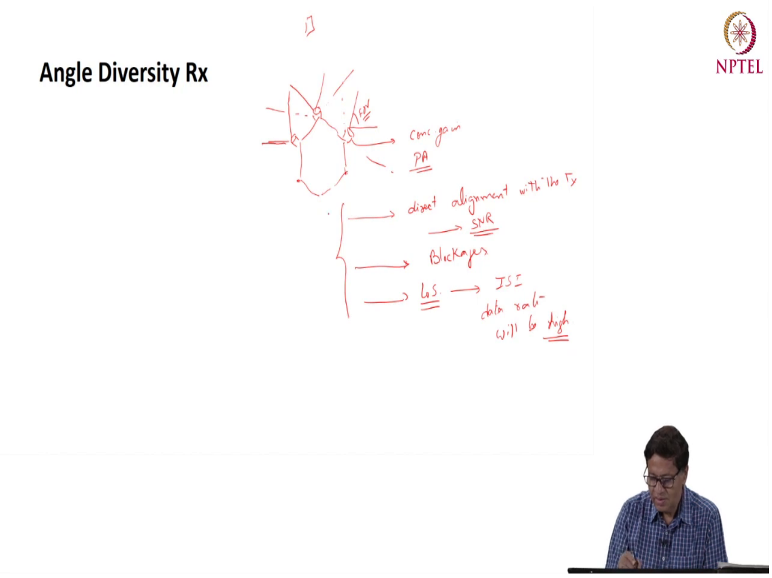

Also let me tell you before finding out the channel modeling for a MIMO system angle diversity receiver. So, angle diversity receiver in this case what happens actually, you have you know many receiver at different angles. For example, this is hexagon; so, there may be a receiver here, there may be a receiver here, there may be a receiver here, and there may be a receiver here as well here as well.

And this receiver collects light say; for example, in this cone this collects light from this cone. I mean it is designed; so, in such a way that there is no area which is left out I mean any receiver will get light from can get light from any direction; so, this may get from this. So, these are you know receivers which are in at different angles, though it is cumbersome to make such a receiver, but it gives much better performance as compared to a single receiver.

So, for example, an each receiver for example, has its own concentrator game has own pre amplifier which will amplify the signal; so, this is a individual receiver and you can always change this angle of FOV and can make in such a way that you know there is no area which is left out.

So, for example, if you make a wide FOV here and this is also FOV here; so, basically you know light is captured at least by one receiver. So, this is how angle diversity receiver looks like and the advantage is that you know there will be a direct contact or direct alignment with the transmitter.

So, wherever the transmitter is, there is some direct contact; so, once you have a direct alignment with the transmitter that is direct alignment with the transmitter. So, this will result in high SNR and you can get good performance right. So, and suppose there is some blockages coming in one particular receiver.

The light might come through a different path it is collected by a different receiver which is at a different angle; so, it is a good solution when you have blockages in the system blockages. And since there is a direct alignment and you may not be getting signals from say other sources or from reflection.

I mean you can always make your reflectivity in such a way that your reflection coefficient is designed in such a way that not enough non line I say component is falling on to the receiver there is only los component falling. So, once you ensure that which can be ensured using angular diversity receiver.

Then there will not be any inter symbol interference, your data rate will be high. So, these are some of the advantages of you know angular diversity receiver. So, this is a case of actually MIMO I mean you can have many transmitters and here you know there are multiple receivers and you get you know these advantages using angular diversity receiver.

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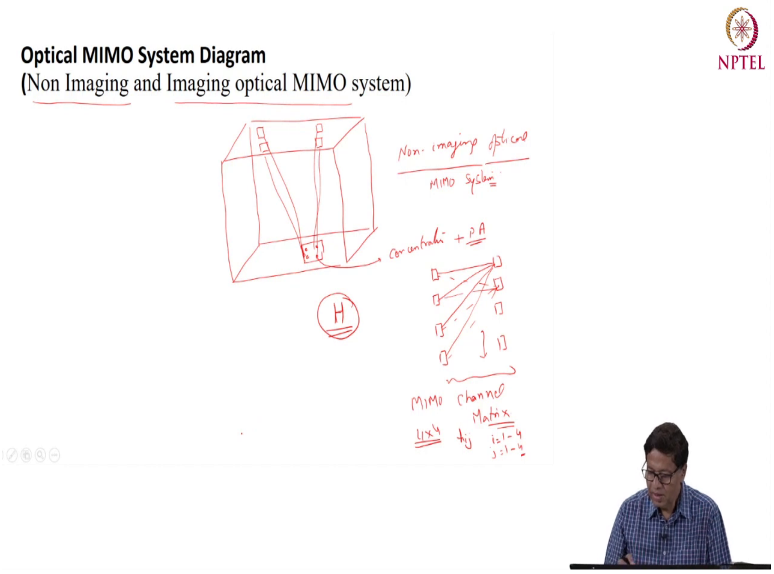

So, now we will study or try to find out the channel for a MIMO system. So, there are two types of MIMO system, optical MIMO system; one is non imaging and the second one is imaging optical MIMO system. So, first let us understand the start with non-imaging, to non-imaging system a non-imaging system.

Suppose, let me make a room here. So, you have transmitters or the LEDs installed here, it can have some specific geometry of putting the transmitters on the ceiling. And on the receiver your receiver actually; for example, has for say for example, 4 R x or there are four receivers. So, the light and each is independent it has its own concentrator and has its own pre amplifier.

So, the light will fall on to these receivers; so, this is a case of non imaging non imaging optical MIMO system. Now, let us try to find out the H; so, this is going to be a matrix, because let us try to understand this in this fashion. You have suppose, this is your transmitter; there are four transmitters.

For example, and say here and this is receiver here, this is receiver, here this is receiver here. So, this receiver can have light from here, can have light from here, can have light from here, can have light from here. Similarly, this receiver can have light from here, from here, from here, from here, from here and so on and so forth.

So, this actually is a matrix which is called as channel matrix MIMO channel matrix. So, in this case it is going to be a 4 cross 4 matrix, and each will have component H ij; where, i is equal to 1 to 4 and j is equal to 1 to 4. So, we are we will try to model this H which is a matrix this is what we want to do.

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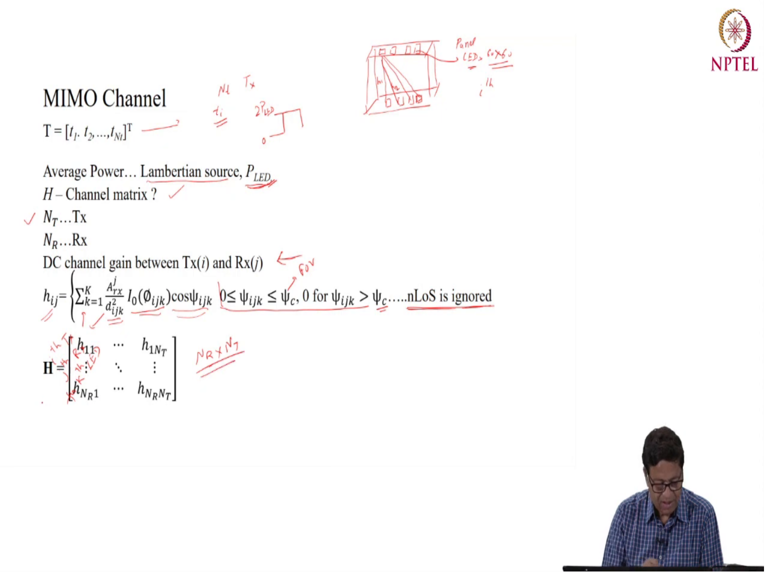

So, let me draw a system here maybe let me draw in the previous page if possible, let me draw in this page itself before we go to the more description. So, typical optical system will be optical MIMO system, system should look like this.

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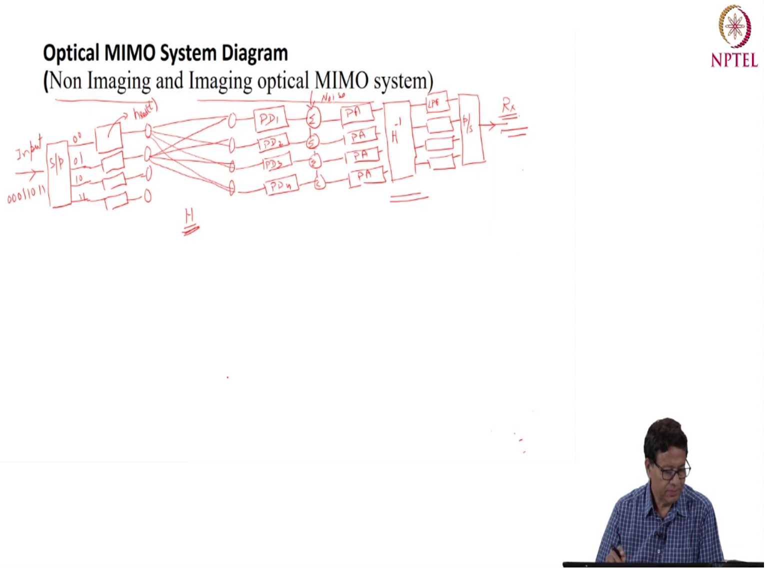

Suppose this is your input and it has input says 00, 01, 10, 11; so, first we will use a serial to parallel and I will get four outputs for this stream. So, this will be 00, this will be 01, this will be 10, this will be 11 and this stream is given to a LED which has impulse response say this is LED 1 which has a response H LED.

Similarly, this goes to this LED, this LED; so, each has a LED and response H LED t. And this output which is now optical output, you can have some sort of in optics here and on the other side you have the receiver. So, this is some optics here concentrator gain or whatever you want to have and this is your photo diode.

This is Photo Diode 1, this is Photo Diode 2; so on and so forth, this is PD 3, this is PD 4. Now, as I mentioned the light from this LED can fall on to all the systems, all the receivers similarly for this. So, I am not drawing for the third and the fourth one it will complicate here.

And then each PD you know there is some MIMO models there will be some noise added could be natural light or some artificial light and the noise generated by the photo diode itself. So, this is the noise part and then they may have some pre amplifier. So, basically you will get four such outputs; so, noise is getting everywhere, and this is PA for each branch.

And then once you have this, then you can have H inverse whatever the matrix you have H, if you have the H inverse then you will be able to get the output. So, this output will come here and then some low pass filtering, some processing and the receiver. This is low pass filtering and then you get back your outputs and then it is parallel to serial and what you get is a the estimated or recovered output the R x.

So, for recovery I need to know this channel matrix; so, that the receiver, I can find out H inverse and do the processing and recover my data; so, it is very important to understand how to model the channel matrix. So, question in front of us is to how to find out this channel matrix? So, let us assume that there are this is a transmit vector t 1, t 2 to t N T, I am assuming N t T x.

So, this is the trans transmit vector capital T; so, T i actually here is the T i is that input data stream convolved with the impulse response of the LED. So, this is what this T i is and I am also assuming that the source is a Lambertian source and it gives average power of P LED. So, if I am using on off key that is in the, on there is no output and in the off in the off there is no output in the off.

There is some output and the if the average value is P LED; that means, the range of low and high is between 0 and 2 LED, 2 power LED. So, that will be the maximum power corresponding to one and the average power is one. So, this average power is P LED and it is a Lambertian source and I am assuming anti transmitters.

There are anti-transmitters on the ceiling or an anti receivers. So, I am trying to find out the channel gain, DC channel gain between Tx i and Rx j. And this DC channel gain as I had earlier explained the bandwidth of the channel is quite high as compared to the bandwidth of the devices the LEDs and the receivers; so, it is actually a flat channel.

So, I need to just calculate only the DC channel gain between a transmitter i and transmitter j. And also I will assume that I am not; I am not having contribution from non line of sight. I mean this is a valid assumption to make, because if you see there is a strong component which is coming from line of sight. So, as compared to non line of sight, it is much higher and can be neglected.

Although, when you are doing some rigorous analysis, you will have to consider the non line of a component. But, just to understand about the modeling, channel modeling of a MIMO, let us for the time being ignored that there is no significant contribution coming from non line of sight. Because, it has it can be seen that you know the non line of sight component is actually 10 dB lower than the weakest line of sight you know signal getting receiver getting the signal from any of the LEDs.

So, if it is in the direct contact with any transmitter that difference is even higher, but even with the weakest line of sight which is coming from some other transmitter. The line of a component contribution is at least 10 dB smaller than the weakest line of sight link. So, for practical purposes we can ignore non line of sight and we are assuming here DC channel gain.

Assuming the gain of the channel is higher which we had discussed earlier that is about you know 100 megahertz where the devices are maximum 20 megahertz; so, the channel is actually flat. So, from our previous understanding h ij between ith transmitter and jth receiver is given by this. Now, let us understand what is this capital K.

So, in the system what I have assumed that you know there are for example, four transmitters. Now, each transmitter has LEDs; so, it is a array each transmitters is an array and this array has LEDs could be you know 60 cross 60 or depending on what elimination level you want. So, this value can be different cross 60 or it could be even smaller value.

So, this K is the actually number of LEDs in a panel; so, this is a panel which has you know these number of LEDs. So, this capital K actually depends number of LEDs in that panel, and A j rx is the receiver collection area for the jth receiver. And d square i jk actually is the distance between ith transmitter this is let me write here, ith transmitter and jth receiver for the Kth LED.

As I told you there are many LED 60 cross 60; so, this is for the Kth LED; so, that is why you see the sum over all LEDs. Here i 0 phi j K, you can again find out that angle ambition angle which is between transmitter i and transmitter j for the Kth LED. And this is cos psi psi j K, this is how we had modeled earlier and these are the conditions.

It will give some value when as long as it is between 0 and that FOV this is FOV and this will give you 0 when it is greater than FOV, psi c is the FOV. And again, here I have not included optical filter gain and concentrator gain assuming they are all one. So, it does not change the actually the theory; so, I am assuming those to be one.

So, the channel matrix H for such a system can be written as h 1 1, these are all components here; so this is for example, receiver here. So, this is going here, this is going, here this is going here, this is going here. So, this is h 1 1; for example, this will be h 1 2 so on and so forth; so, you get a matrix which is N R cross N T matrix; so, this is the channel matrix.