Optical Wireless Communications for Beyond 5G Networks and IoT
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Lecture - 17
Part - 1
VLC based MIMO NOMA

Hello everyone. So today we are going to discuss about how MIMO NOMA can be used in VLC. In the earlier classes we have discussed about NOMA and how NOMA can be used in visible light communication systems. So, today we will discuss VLC in using MIMO and NOMA.

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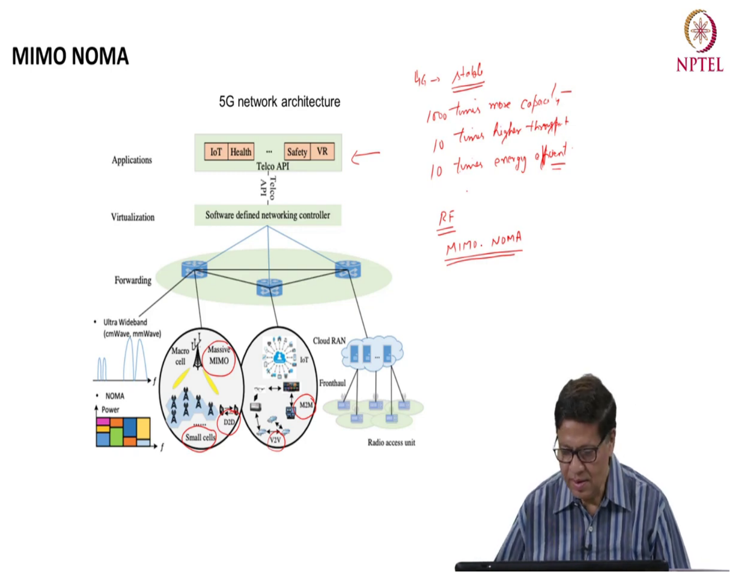

So, as you see in this slide this is a 5G network architecture. So, currently 4G technology is fairly stable. Different countries are migrating to 5G network and 5G gives you know high data rate as compared to 4G. For example, there will be 1000 times more capacity, system capacity, 10 times higher throughput and these they are 10 times energy efficient as compared to 4G systems.

So, these are the goals of 5G network energy efficient and this is required because the new applications are on bandwidth trusty. For example, virtual reality safety applications, healthcare, IoT. So, these are the applications and these high or these features like 1000 times more capacity, 10 times higher throughput, 10 times energy efficient energy efficient is basically a will use software defined networking will use massive MIMO devices, device to device communication, very small cells and machine to machine kind of applications, vehicular to vehicular applications and also cloud ran.

So, these are the technologies which will be which are being used in 5G. Now, in RF there are lot of papers which are MIMO, NOMA based. And the challenge is how to assign power allocation, efficient power allocation with low complexity in RF is a challenge.

So, we will see the applications of MIMO, NOMA in VLC and we will see that the algorithm the power algorithm which I used are fairly simple or they are simpler as compared to RF power allocation algorithms.

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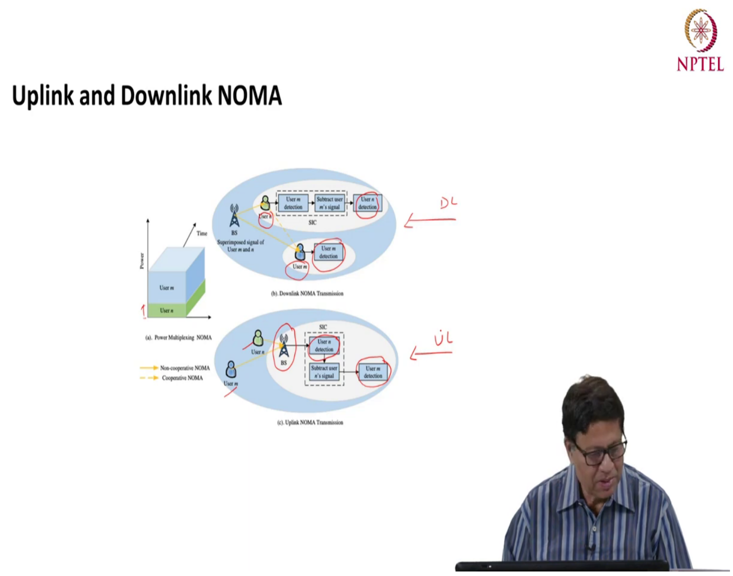

So, just to revisit uplink and downlink NOMA, so this is a case of downlink NOMA transmission; so, in this case there are 2 users. For example, user N and user M and they have different power levels, user 1 has this much power level, user M has higher power level. So, you do the SIC that is SIC operation, Successive Interference Cancellation at user N.

So, first you detect the user M which is high power and then they subtract this user from rest of the signal you will get the signal of user N. So, this is how user N is detected and this is user M. So, the SIC operation successive interference cancellation is performed at the user level. So, this is a downlink transmission and in the uplink transmission you have 2 users user N and user M and the SIC operation happens at the base station.

And so, at the base station first you detect the user N because it is the signal is coming at a higher power level. So, user N detection is done and then this is subtracted from the signal and you are able to detect the user M. So, this is example of uplink. So, in downlink the SIC takes place at the user N, whereas in the uplink the SIC takes place at the BS base station and the performance gain for uplink and downlink they are different. So, this we have already studied when we were discussing about the NOMA.

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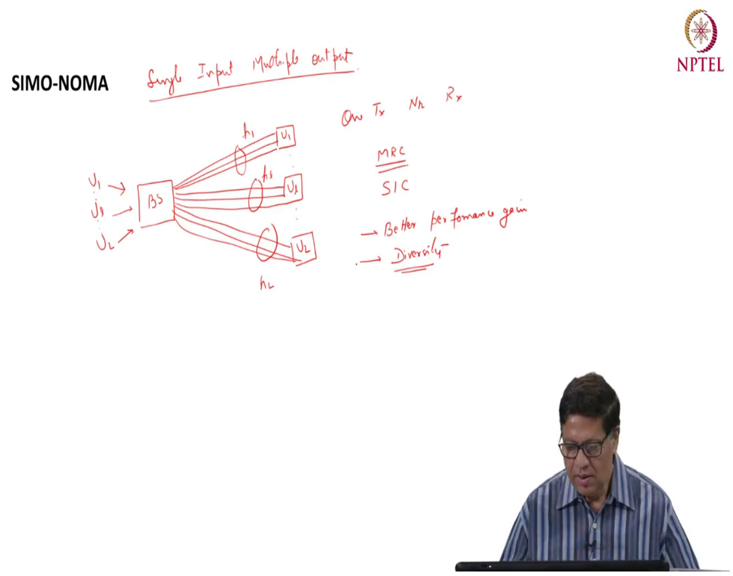

So, you can have not only MIMO, but you can have different versions of MIMO. So, one of them is single input, multiple output. So, in this what happens suppose this is the base station and these are the users U1, UL, U-capital L they are connected to base these base station. So, this information is superimposed here and then in the receiver end you have U1.

So, there can be multiple antennas at the receiver. So, this is a case of single input and multiple output and this say has h 1 as a channel coefficient. Similarly, say for U l, channel coefficient is h l and then you have capital L. So, this is h capital L. So, in this case you get 3 inputs there are N r receivers and one transmitter. So, in this diagram there are 3 receivers.

So, one can use MRC, Maximal Ratio Combining technique to detect the signal which is coming from here and then within U n, U 1, you can do SIC operations Successive Interface Cancellation to recover the single for U 1. Similarly, you can do for U L and U-capital L for different users. So, this is a case of single input and multiple output. So, this gives you a better performance game.

So, this I am talking in the context of RF and this also gives good diversity. So, these are the advantages. We will see how some of these things which have been used in RF can be used in VLC.

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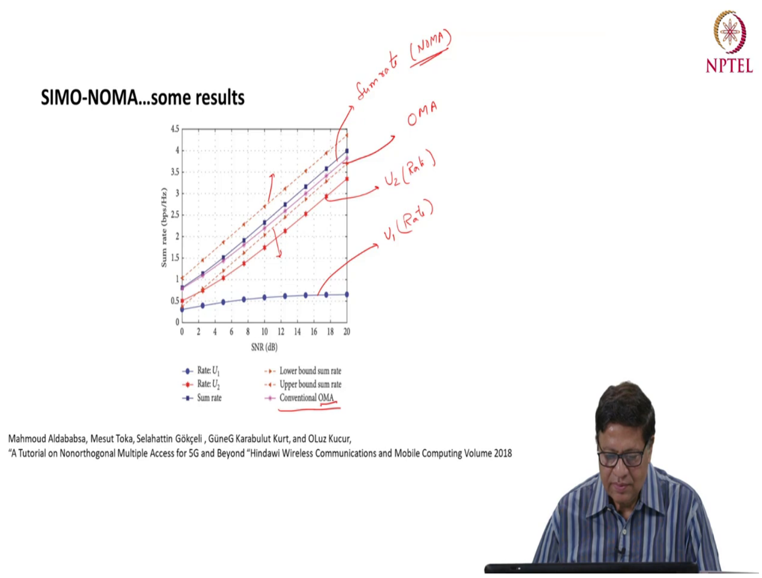

So, this is a case of single input, multiple output, NOMA. So, these are the some of the results of NOMA, single input, multiple output, NOMA. So, if you see this is user 1, this is a rate for user 1, rate for user 1 and this is user 2. This is rate of the user 2 and the sum rate is given by this curve, this is a sum rate. And if you see the conventional orthogonal multiple axis that is OMA, which is given by this, this is I would say OMA. So, this is sum rate, basically it is NOMA.

So, you see there is a clear advantage in NOMA as compared to OMA. And the other lines which are the dash lines, this one and this one, these are the lower bound sum rate and upper bound sum rate.

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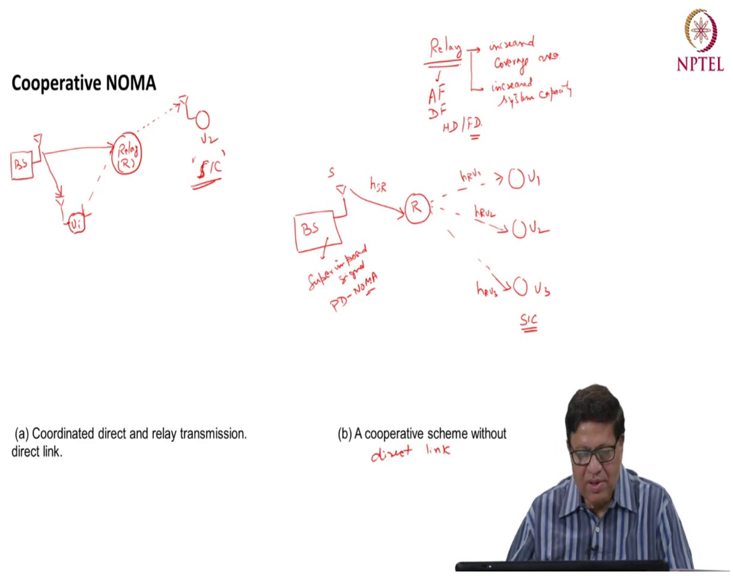

So, using SIMO and NOMA, so this is the performance gain you get as compared to conventional orthogonal multiple axis schemes. There is another possibility of using NOMA in a MIMO context which is called as cooperative NOMA. In this we use our relay and the relay basically will give you increased coverage area. Increase coverage area and also it will give you high increased system capacity.

Increase system capacity we will just see how this is possible. So, increase coverage area. Basically, if your users are far away from the base station, one can put a relay in between. The relay could be of amplify and forward type or it can be decode and forward type and also it can be half duplex or full duplex.

So, by putting a relay you basically can increase the coverage area and also because you are directly interacting or the base station is directly linked to the relay. So, multipath fading is also avoided. So, let us understand through a diagram how this NOMA using relay can give you advantage in terms of increased area and in case of in and also increase of system capacity.

So, first I am discussing a coordinated direct and relay transmission direct link. So, suppose this is your base station, this is the antenna and relay is somewhere here. This is relay r and suppose your one user is here, this is say U user 1 and this is say user 2 and they have their antennas here. So, there can be a direct transmission to user 1.

There can be a direct transmission to user 1 or there can be a transmission first from base station to relay and from relay to user 1 and from this relay this, there can there is a transmission to user 2. So, this dash line actually I will explain this. So, this is the antenna for user 1 and also so if I put the arrow also this is the direct transmission to relay.

This is direct transmission to user 1 and you can have transmission from relay to user 1 and this is the direct transmission to user 2. So, by putting this relay you are able to increase the coverage area and also the performance can be increased because U 1 is getting signals directly from the BS and also directly from the also getting signal from the relay.

So, this might result in increase of system performance or system capacity. So, this is an example of a coordinated direct and relay transmission direct link. The other could be a cooperative scheme without direct transmission without direct link. So, this example could be for example, this is your BS base station, this is the antenna and then you have the relay here and this channel coefficient is this is say S. So, this will be h SR and there are many users connected here or here.

So, this will be h RU1, h RU2, this is the channel coefficient, this is user 1, user 2, user 3, this is h RU3. So, this is a cooperative scheme without direct link. So, there is no direct link to the user, but it is through a relay. So, this is another form of cooperative NOMA. So, the signal the NOMA actually the NOMA is performed at the user.

So, the SIC operation, SIC is performed at the user level and I am assuming the signal which is actually power domain NOMA is getting transmitted from the base station and the SIC operation is being done at the user to extract the data for that particular user. Similarly, here the SIC operation is happening here and here you get superimposed signal that is you know power domain NOMA and by doing the SIC operation at the user you are able to get the data of the spectral users. So, this is an example of cooperative NOMA.

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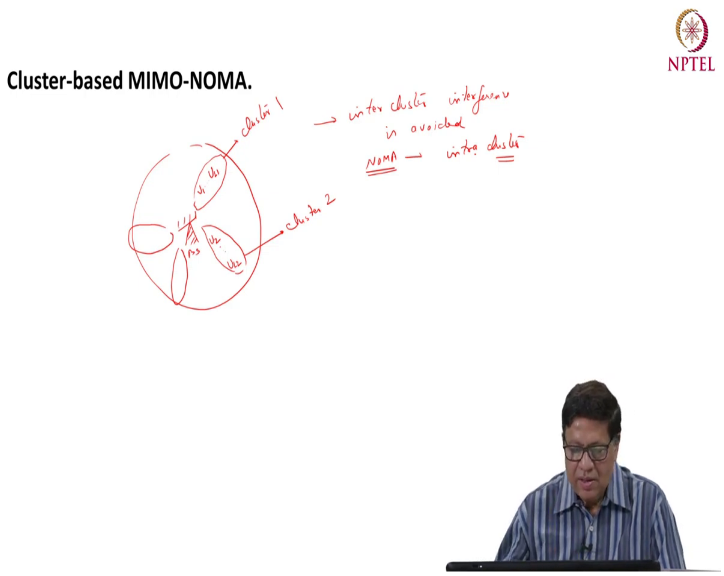

Now, there is also a possibility of cluster based MIMO NOMA. So, in this case what happens suppose the users are spread over in this area and this is for example, the base station here this is antenna. So, these users which are in this area they are actually grouped. So, for example, this could be from U N to U L 1, so this is cluster 1.

So, this is cluster 1 and there is similarly there can be another cluster. This will be say U 2 to U L users in the cluster 2, this is cluster 2. This is cluster 1 and similarly you can have cluster M or cluster different clusters. So, the beam formation is done in such a way by using transmit pre coding and detection.

So, that the users from cluster 1 and other clusters there is no interference from other clusters that is inter cluster interference is avoided. And within the cluster one can use one user is

NOMA technique to handle the interference which is caused by the other users. So, NOMA technique is used to cancel the interference which is caused by the users of that cluster.

So, inter cluster is by beam forming using some sort of transmit pre coding and then this way you can avoid an inter cluster, but within intra within the cluster or intra cluster one can use NOMA technique to avoid interference from other users. So, this is another example of MIMO NOMA which is cluster based.

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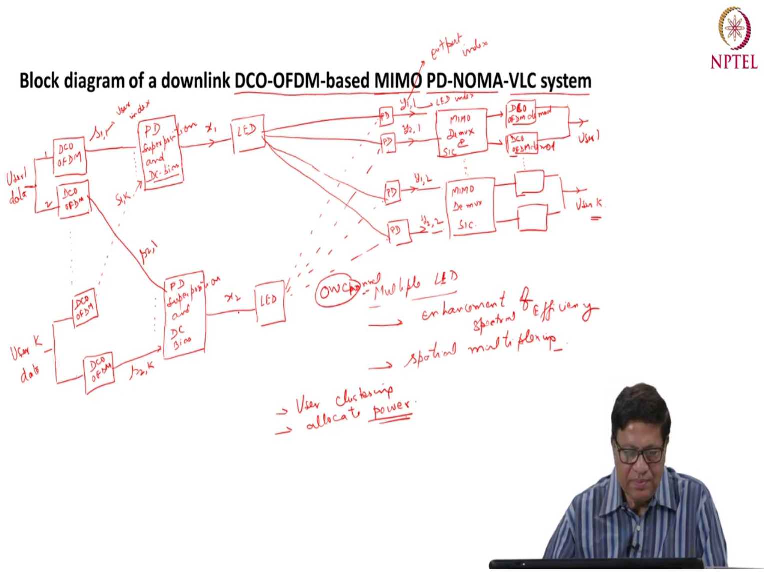

Now, let us shift how these MIMO NOMA can be used in the VLC environment. There is a lot of work which has been done in the RF environment and how these architectures or the MIMO NOMA can be used in OWC environment or optical wireless communication environment.

So, for that let us try and draw a downlink DCO-OFDM based. We have earlier when we were discussing about OFDM we had discussed about DCO-OFDM and ACO-OFDM. And here I intend to use DCO-OFDM and we will use you know a MIMO and then power domain NOMA and the channel is going to be a visible light or optical wireless communication system.

So, let me draw the diagram for the for this kind of system. So, this is DCO-OFDM, so I am not drawing the internal details of DCO-OFDM that we have done in earlier classes. So, this is DCO-OFDM. And this is say user 1 data, user 1 data which can be which is divided into 2 parts. This is the other part DCO-OFDM. This is the other part so user data is divided into 2 parts.

And then let me denote this as s 11 where this one basically tells the user; this is user 1. So, user index and this one tells the first part or first this is a; this is a 1, this is 2. So, this indicates this part of the data, the first part of the data and similarly this so we can have user k here. Let us draw one.

So, you can have k number of users, so this is user k data and similarly it is divided into 2 parts. This is DCO-OFDM, this is DCO-ORDM and there are in between other users. So, we are drawing the first user and the k th user. So, there are other users also. So, this is s 11. And this data is goes to a unit, which is power domain, superimposition, super position. And we are also giving DC bias, because here I am using DCO-OFDM. So, in order to make the system unipolar, we need to give the DC shift.

So, that the bipolar which is normal OFDM signal which is bipolar, first you make it real from complex by invoking Hermitian symmetry. And then you give DC to make it a unipolar. So, some DC bias is given to make it unipolar. So, this signal will go to this and this block and then there are from other users, this is from the kth user. And this will be s 1, the first part of the signal of the kth user. Similarly, I am drawing here this is power domain superposition and DC bias.

So, this signal will go here and this will be called, this will be the second part of the signal. This is s and coming from the user 1 and similarly this part of the signal is s, the second part of the signal and coming from the user k and there are many points in between. And this combined signal, the power domain, superposition with DC bias, let us call that as x 1, which goes through the LED.

Now, you are able to modulate the LED because you already made the input signal a real and unipolar and similarly, this, let us call this as x 2, it goes to a LED. And then you have the channel, this is transmitted through LED and then you have set of photo detectors. So, I am using here 2 LEDs and for and then photo detectors are here.

So, these are the PDs, photo detectors and this LED output will go to this photo detector will go to this photo detector will go to this photo detector, similarly here and this LED output will also go to this photo detectors. So, I am denoting this as from the kth user as from the second LED through a dash line and the signal which output signal of the photo detector will be y 11.

So, this one actually corresponds to the LED number and LED index. And this y1 is index of the output. This is output index so let me write the output index. So, and this will be y 21, this will be y 12, this will be y 22. And then this signal is given to this signal is given, there are many blocks in between. So, this is given to MIMO De MUX and you do the SIC operation here.

Similarly, this is MIMO, De MUX and SIC operation. And after doing this D multiplexing of the signal and doing SIC successive interference cancellation, what we get is DCO-OFDM De MORD is a reverse process and similarly for the other stream DCO-OFDM De MORD and similarly, you can do for this user.

So, this will be one more block there and then there are many here in between. So, this is DCO OFDM, De MORD, same as earlier DCO-OFDM, De MORD. And from here, you get the user1 data, user1 and then similarly you will get user K data. So, you are using multiple

LEDs because normally in a LED lamp, there are arrays of LED. So, you can be used as multiple transmitters.

So, this multiple LEDs and you are using multiple detectors. So, this will result into enhancement of the spectral efficiency; enhancement of spectral efficiency by using multiple LEDs and multiple photo detectors spectral efficiency. And you are able to do spatial multiplexing. By splitting into 2 groups and each group is served by a specific LED.

So basically, you get multiplexing gain as well as improvement as a spectral efficiency by using MIMO power domain NOMA and we have used this is optical wireless channel. So, the issue here will be how to you know do the clustering and user clustering and how do you allocate the powers. These are some of the challenges for with this architecture allocate power.

But this has been simulated and there are improvement or performance gain which are required for 5G systems. So, it basically uses DCO-OFDM which is a kind of OFDM technique in tuned for VLC and then uses MIMO. So, here you here you using two LEDs and two photo detectors. So, it is a MIMO system and it is a power domain and for extracting the information from the superimposed signal you are using NOMA technique.

So, this has advantages in terms of you know enhancement of spectral efficiency, spatial de multiplexing and interference you are able to avoid using NOMA technique.

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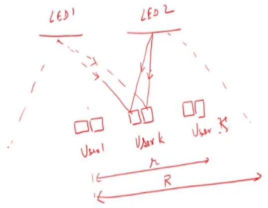
2×2 MIMO-NOMA-based VLC system with *K* users



So, let us try to do some calculations using a small example where I am using 2 cross 2 MIMO, NOMA based VLC system and there are K users. So, system diagram is something like this. This is say LED 1, this is say LED 2 and then you have users here and each user has say 2 photodiode. So, be this is a 2 cross 2 MIMO system and similarly here.

So, this is say user 1, this is user say small k and this is user capital K and let us see the area covered by LED is something like this and I let me put define user 1 as the reference. So, this is say reference and the distance between user 1 and user k the last user the capital K is say r and the total coverage area the total cover area where LED 2 light is available that is say capital R.

So, we will try to normalize we will see how the signal is received at different locations by using the these quantities. So, it is a 2 cross 2 NOMA based system then you are using

NOMA technique with K users. So, this is a system model let us try to analyse this and signal from LED this is the actually the area. So, the signal which is falling onto for example, user K will be to the other receiver and similarly from LED 2 which I am denoting by a hard line.

So, this is the light falling from LED 2 on the 2 detectors and similarly this is the light falling from LED 1 to the 2 detectors. So, having so we will try we will try to analyse performance for this 2 cross 2 MIMO NOMA based VLC system with K users.

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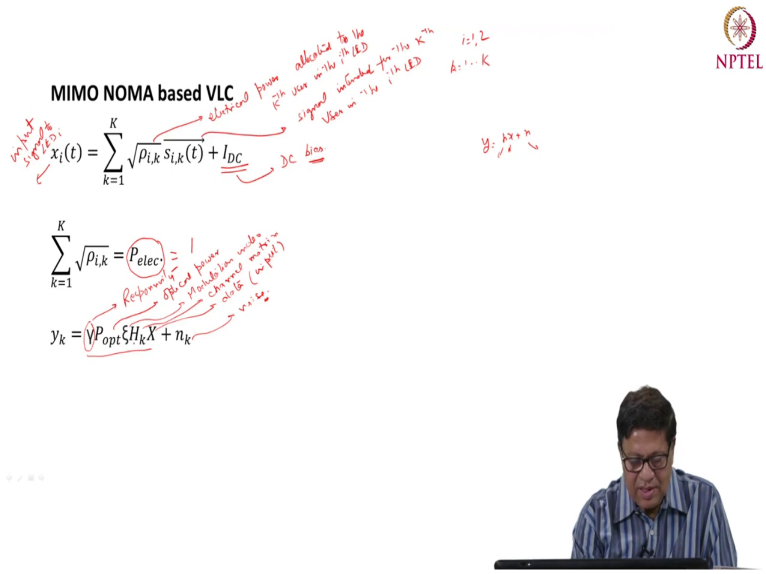

So, the signal x i t this x i t is input signal to the LED input signal to LED 1 or 2 LED i. So, this i can be 1 or 2 in our case is equal to rho i k and this rho i k is actually the electrical power allocated to the kth user in the ith LED. So, rho i k is electrical power allocated to the kth user in the ith LED and this is x i is the input signal to LED i where i is equal to 1 and 2 and this s i k t is signal intended for the kth user in the ith LED. So, as we know i is equal to 1 and 2 and this k goes from 1 to capital k.

So, this is the input signal and this is the DC bias which we have given because we are using DC bias, so this is the DC bias. So, this is the input to the signal LED i. So, if I sum over all the users because this is a electrical power given to kth user from the LED i, if I sum over all the users i get total P electrical and I can put this as equal to 1 without loss of any generality because this is going to be constant, so I can put this as 1.

Now, the received power y k by the photo detector is this is a responsivity and this is the optical power which is falling out of the photo diode optical power. And this g x i is the modulation index and this is a channel matrix. In this case it is going to be a 2 cross 2 matrix channel matrix and this is the data input data and this is the noise component. So, the received power is sum of this which is actually normally you have received power is hx plus n where n is a noise h is the channel coefficient x is the data.

But we have also included responsibility because it is the power is an optical domain. So, we have included received power responsivity and the modulation index. So, this becomes y k is equal to gamma P opt xi H k X plus n k.