Optical Wireless Communications for Beyond 5G Networks and IoT

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Lecture - 43
Hybrid LiFi/WiFi Network Simulation

Hello, everyone. Today, we will cover the lecture on Hybrid LiFi WiFi Network Simulation. Let us know that what is hybrid LiFi WiFi network first. As we know that day by day there is a rapid growth of mobile devices, as well as the demands of data are increasing for various uses of applications. These huge demands create an issue of crisis in the availability of RF spectrum.

Therefore, the researchers are exploring extended parts of the electromagnetic spectrum such as visible light which is used for the visible light communication. This spectrum is used for the visible light communication as an alternative technology of the RF communication technology. LiFi is an extended technology of visible light communication where LiFi is an access network technology which is a counter part of WiFi.

These two technology, LiFi and WiFi can coexist together and also complement to each other because the spectrum of LiFi and WiFi are non-overlapping. Therefore, there is no interference. When LiFi and WiFi coexist together that forms a hybrid network.

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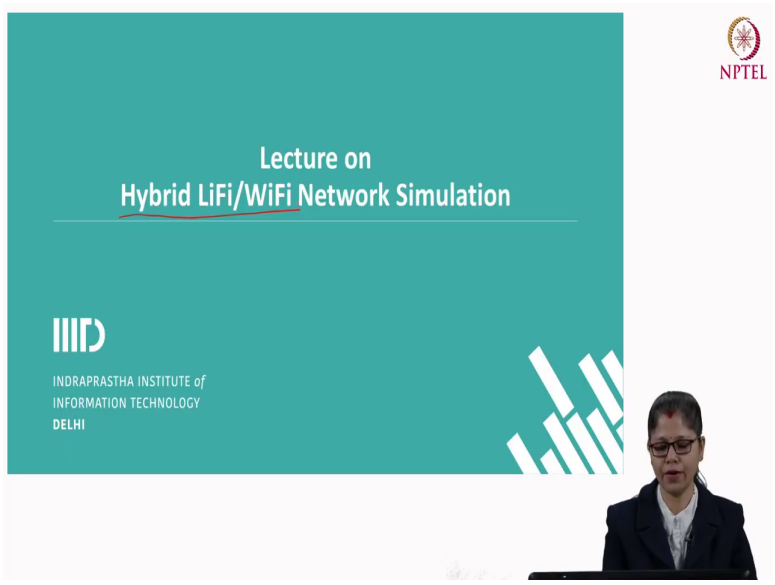

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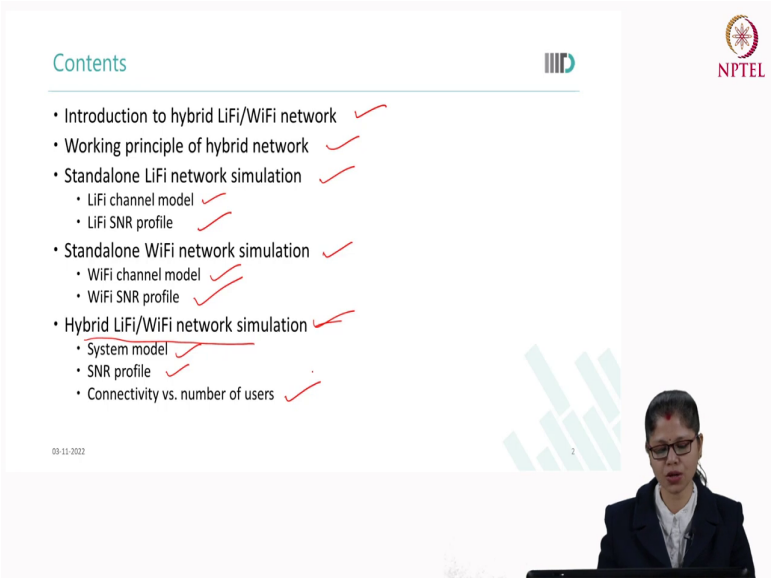

So, this is just brief idea about hybrid LiFi, WiFi network. Let us see in this lecture we can cover introduction to hybrid LiFi, WiFi network, working principle of hybrid network, standalone LiFi network simulation. In that simulation, we can see that how to model LiFi channel model and how to get the LiFi SNR profile for different position of the user and we can see that standalone WiFi network simulation.

There also we can see how to model the channel for the WiFi network and how to get the SNR profile for the users under that WiFi network. After that finally, we can see this hybrid network and hybrid network simulations consist of system model SNR profile for different users under LiFi or WiFi and finally, we can see that connectivity versus number of users one of the application of the hybrid LiFi WiFi network.

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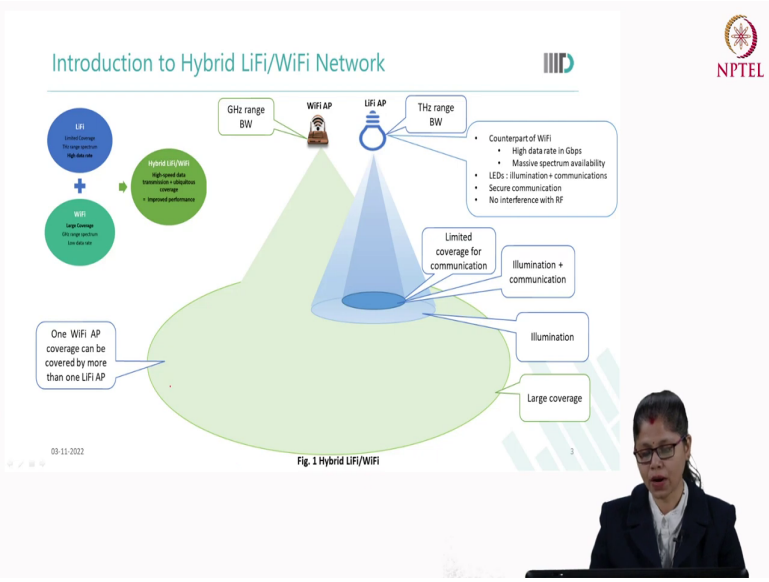

Let us start with the introduction of hybrid LiFi WiFi network little detail. So, here we can see LiFi – LiFi is a network which is having the access point repeat. Let us start introduction to hybrid LiFi WiFi network in detail. The LiFi is an access point which has the limited coverage and it operates in the terahertz range spectrum.

It provides high data rate whether as an counter part of the LiFi we can see in WiFi it has large coverage, it operates in gigahertz range spectrum, it provides low data rate. While using LiFi and WiFi together, then they coexist together and form hybrid LiFi WiFi network.

This hybrid LiFi WiFi network provides high speed data transmission with ubiquitous coverage and ultimately, we get the improved performance as compared to only LiFi network

and only WiFi network. Let us see small animation of this hybrid network. In the network first WiFi access point is placed here and this access point has large coverage here.

We can see that access point operates in gigahertz range bandwidth and it provides large coverage as well as in this network if we include one of the LiFi access point we can see that the LiFi access point illumination is in this region. And, it has this small region inside that which is showing that it has the limited coverage for the communication. The communication happens in this region. This position this region is used for the illumination only.

And, we as we know that LiFi access point operates in the terahertz range bandwidth. Therefore, here if we are considering the hybrid network, we have to take wife one WiFi access point or more than one of WiFi access point with one LiFi access point or more than LiFi access point that depends upon the different types of the system modelling what is required for our different applications.

So, we can summarize this a LiFi access point is nothing but contour part of the WiFi technology and this LiFi provides high data rate in gbps and it has massive spectrum availability. In LiFi, we use light emitting diodes which is used for illumination as well as for the communication as we have seen here these portion is used for the illumination here also these portion is used for the illumination plus communication.

And, LiFi provides secure communication as light cannot penetrate to the walls. That is no interference between the light signal and the RF signal. Therefore, there is no interference between the LiFi and the WiFi access points. Therefore, we can say that whenever we are going to analyze one hybrid LiFi WiFi network then it is better to take more than one LiFi AP to substitute the coverage of the WiFi access point.

Therefore, we can use one WiFi AP coverage area for the more than one LiFi APs, then we can analyze the hybrid LiFi WiFi network analysis in better way.

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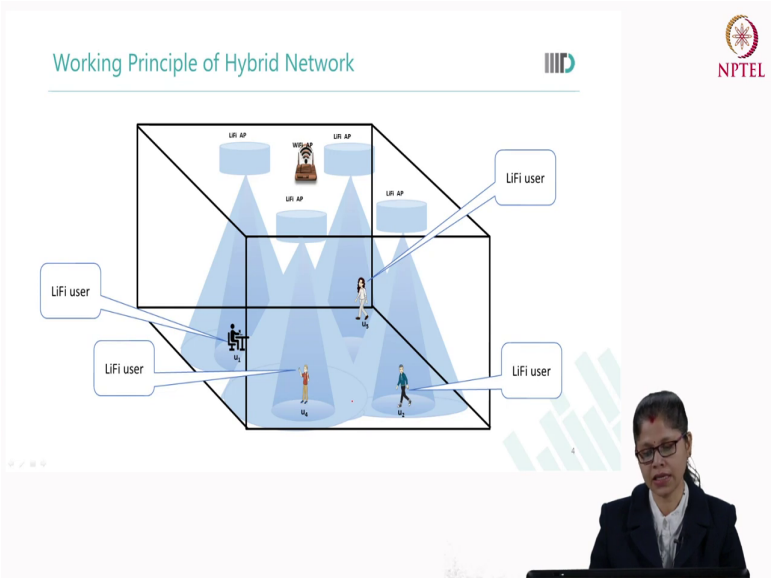

So, let us see how the hybrid network works. This is one small scenario has been taken here. We can observe here this is one room and under room ceiling, we have placed four LiFi APs and under that LiFi access point some users are available and here we can see that user 1 is static and user 4 is also static user 5 and user 2 are mobile. So, at one position then those LiFi users are under the LiFi access points therefore, they can get the signal from the LiFi access points.

One more case is that if we have placed one more WiFi access point on the ceiling, then that WiFi access point can also be used by the users whenever they are in mobile, they are moving out of the LiFi attocell, then they are out of the LiFi access point region then they can also use the WiFi.

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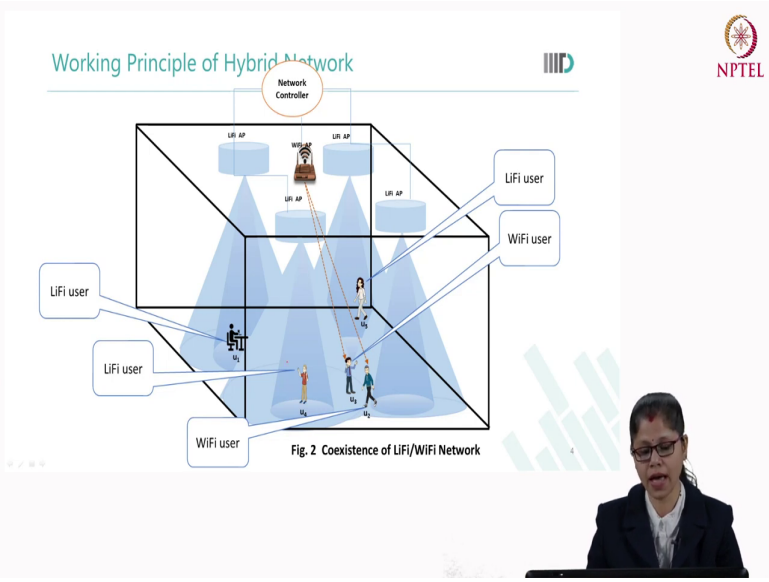

How it happens? As an example, you can see here. This user 2 is connected to this LiFi access point. And whenever he is moving, he has reached at the corner of the LiFi access point; that means, we can see that he is coming out of the at attocell of this LiFi, that time the user will get the access of this WiFi then this user can now be considered are the WiFi user.

So, here the hybrid network works in this way; that means, previously the user 2 was connected to the LiFi access point. Whenever he is moving and he is coming out of the LiFi region then he is getting connected with the Wi-Fi. In that way we can see that the consistent connection or connectivity will be maintained by this user 2. Similarly, we can see that user 3 is static here and he is present out of the all the attocell of the access LiFi access point therefore, this user is connected to the Wi-Fi.

So, this user 3 is called as the WiFi user. At the end we can see here from this scenario all this four LiFi APs and WiFi APs how they will know about that which user should be served by the which AP. Those information and those controlling can be done by the network controller which is centrally controlling the all the LiFi APs based upon the users locations and users requested data. In this way hybrid LiFi WiFi network works.

So, here we can say that LiFi AP and WiFi access points are co-existing with each other and forming the co-existence LiFi WiFi network which is ultimately called as the hybrid network.

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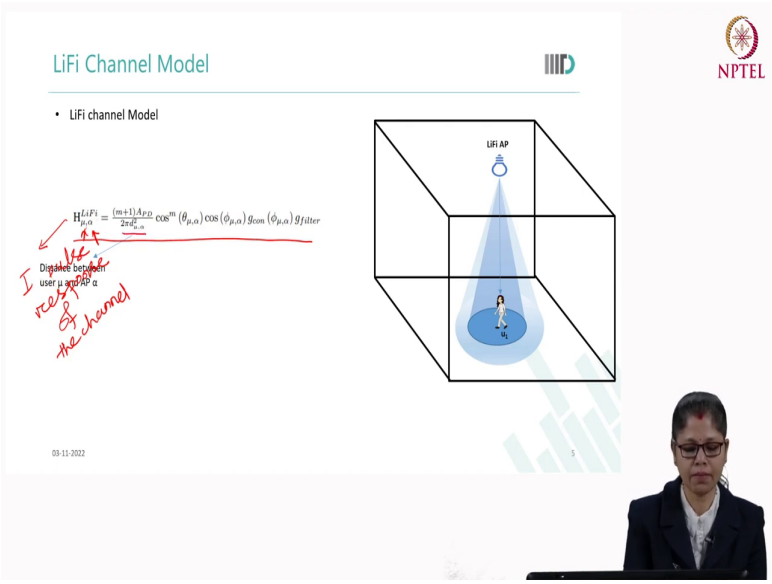

Let us see how to do the channel modelling for a LiFi network and first let us start with the single LiFi access point. Under the single LiFi access point one user is here and we have

observed in the previous slide that the user has this region for the illumination and communication purpose and this region is for the only illumination purpose.

And, this region may be based upon the number of LEDs available at the LiFi AP, this may cover whole room floor and accordingly the communication region also will be a increase based upon our field of view of set for the LiFi access point. Therefore, so, the channel can be formed from the LiFi AP to user if the user is present anywhere, we can model the channel. So, let us see first how to model it.

As we have seen in the previous lecture this is the channel model expression for the LiFi access point to the user. Here we can say that this is the impulse response of the channel which is formed between the user mu and the access point alpha. This d mu alpha is nothing but distance between the mu user mu and AP alpha.

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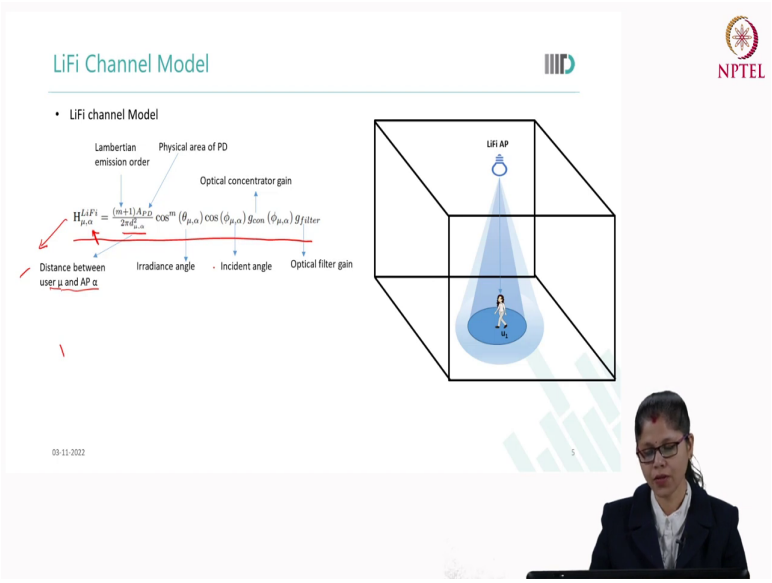

And m is Lambertian emission order as we have studied in previous lectures; APD is physical area of photodiode. This theta mu alpha is the irradiance angle for the user mu and the alpha A P a alpha ith A P and a phi mu alpha is the incident angle and g con is the optical concentrator gain and g filter is optical filter gain. So, we can see here this is the channel model which we are getting for the LiFi from the LiFi access point to the user.

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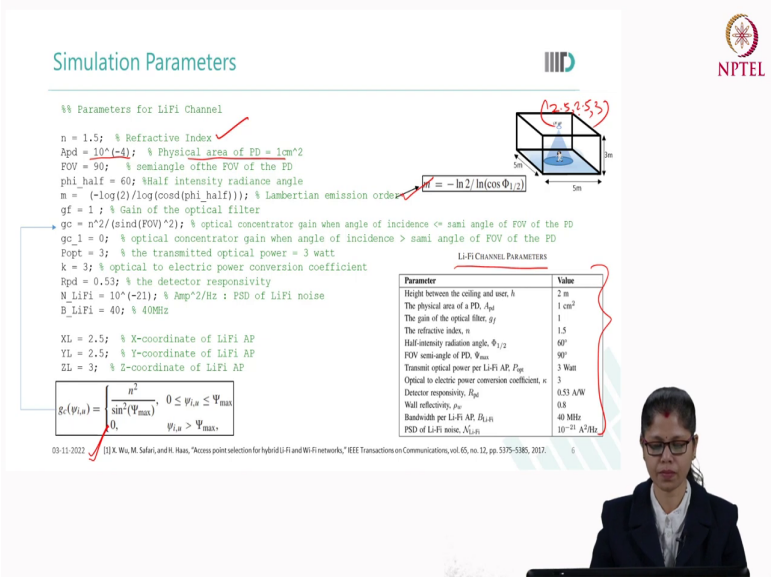

Let us see how to simulate it by using MATLAB. So, for this simulation we have used this LiFi channel model from this reference and these are the parameters we have considered for our simulation. This n is nothing but refractive index 1.5 it has taken based upon this table, APD is the physical area of photodiode. It has been taken like 1 centimetre square that is normally we can write 10 to the power minus 4.

FOV is 90 degree considered and half intensity radius angle is considered as 60. m as we have studied in the previous lectures that m is the Lambertian order and that can be expressed in this way like m is equals to minus ln 2 by ln cos phi a half. So, that same expression is used here. gf is the filter gain which value is 1 it has been taken as per the table and gc is the concentrator filter gain and this gain as per our previous lecture we have studied the concentrator gain is the function of the incident angle.

And, the concentrator gain is equals to n square by sin square psi max where the incident angle should lie between 0 to maximum value that is psi max is nothing but FOV. And, when the incident angle is not lying between this range then the concentrator gain is 0; that means, there is no channel form between your the access point and the user. Therefore, we can set the value gc as this one based upon the range and gc value is 0 whenever the range is in this.

So, optical a power we have considered here 3 watt based upon this a table and the optical to electrical power conversion coefficient we can take 3 based upon the table and responsivity we have considered 0.53 and power spectral density for LiFi noise we have considered here 10 to the power minus 21 ampere square by hertz and bandwidth of the LiFi access point we have considered here for 40 mega hertz.

We have located the access point under ceiling at the middle. So, here we have considered the room size is 5 cross 5 cross 3 meter cube. Therefore, the middle coordinate of the ceiling will be 2.5, 2.5, 3. Therefore we have fixed the LiFi access point here 2.5, 2.5, 3.

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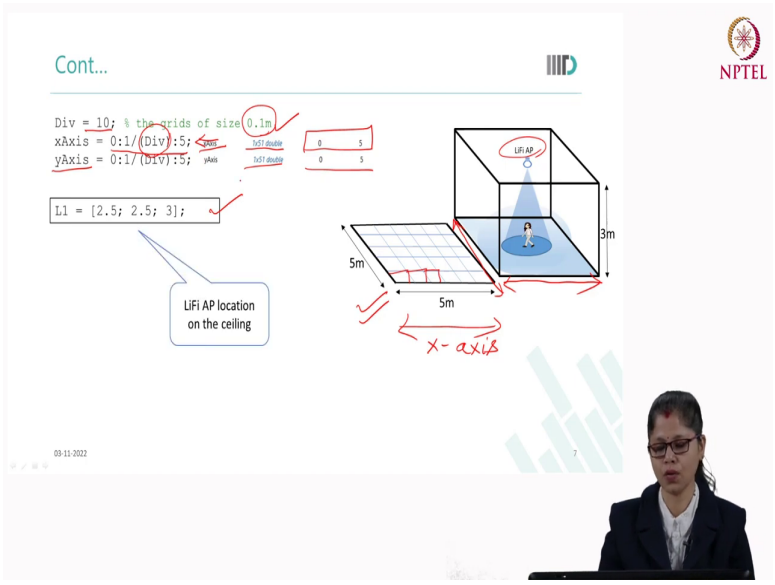

Let us see how to do the like a simulation for these and we can see that how the channel is formed between the access point and user. Before starting let us first set some access setting. So, here what we have considered, this total floor is divided into some grids. So, here you we can see here the floor is 5 cross 5 and the floor is divided into small small grids. This grid size we have to fix.

So, for that we have considered here some division and the division we have taken 10; that means, 1 by 10 will give the 0.1 meter of the grid size. And, total x-axis, this x-axis is divided into some grids that is why for that we have written this expression is nothing but the x-axis is from 0 to 5 meter and it is divided into 0.1 meter of grid size.

So, therefore, we will get the result of x-axis is having the 1 cross 51 grids and the total length of the x axis is 0 to 5 meter. Similarly, for the y-axis also we can similarly do the

division of the y axis and we can get the 51 grids total in the y-axis. Then as we know the LiFi access point is located in this coordinate.

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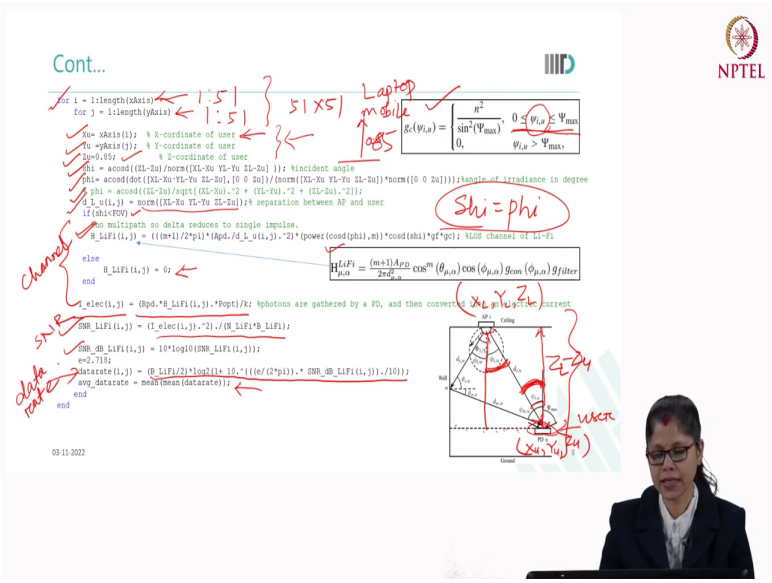

And, let us formulate the channel between the access-point and user. So, when we are formulating the access-point between the access point and user so, here what we have done? We have considered that the user may be present in anywhere of these grids. So, therefore, what we have done? First, we have considered that all the grids together; that means, the user may be present here, may be present here, may be present here, may be present here.

So, let us take all the grids and form the channel of between these users position with the access point, so that whenever we are using in the any of the application we may extract the data from here and we can use it. Therefore, what we have done here? We have taken two for

loops. First for loop is saying about for the x-axis 1 is to 51 grids we have considered for y-axis we have considered 1 is to 51.

So, combined 51 cross 51 grid values we are considering for whole floor and for whole floor all the grids we will get the access channel from the access point to the user based upon that we can calculate the SNR, we can calculate the data rate and as per our requirement we can extract the data.

Here first what we have done? We have considered the users location. So, this Xu is nothing but the X-coordinate of user and this x-coordinate of user we can see that X-axis of i; X-axis of i means in the whenever the i is varying from 1 to 51. So, any of the grid means we can extract that is why we have considered all the grid values here 1 to 51. Similarly, for the Y location also 1 to 51. So, we can get all the grid a position is considered for the a user.

So, randomly we can choose any values from that and we can see that the user is there and for that user what is the a channel impulse response we can identify. And, Zu is nothing but the Z-coordinate of the user and here we have taken 0.85 meter why because the user may be present above 0.85 meter from the floor. The device whatever the user is using either mobile or laptop that will be present just above the 0.85 meter from the flow.

Therefore, we have considered the Z-coordinate is that. So, as we have seen in the previous lecture this kind of analysis we have done in previous lectures. So, we have found that what is our incident angle, what is our irradiance angle. So, here incident angle psi i, u is nothing but the i-th from i-th AP what is the incident angle we are getting for this user location.

So, for that if we are using the geometry then this is nothing but we are getting this height we can get and this distance also we can get because we know that AP is located at the location of XL comma YL comma ZL and the user location will be this photodiode wherever it is there Xu comma Yu comma Zu. So, if we know the coordinates then we can find out this height and this distance, then we can find this angle as well as this angle.

Definitely this angle is equals to this angle you can write in that way also for the understanding. So, whenever the user is moving the user is here here or anywhere, then accordingly the angle will be changing as well as the channel response also will be changed. Therefore, here the psi this angle is like expressed cos inverse of cos inverse is used here a cos d that is arc cos.

So, d is nothing but per degree and the angle is in degree that is why d is used ZL minus Zu, ZL minus Zu is nothing but this height divided by norm of XL minus Xu, YL minus Yu, ZL minus Zu. If we are taking norm of this vector will give this distance between this access point to the user this value that is why norm of this will give.

So, similarly if we can also calculate the our irradiance angle here. The irradiance angle by using this geometry also this height this height and this distance if we know then we can find. So, either of the formula you can use this formula or this formula you can also calculate the incident angle or directly you can write. So, is equals to phi if the all the dimensions are same then you can also write it down.

That depends upon the geometry and the position and the location accordingly you have to find it out. So, after finding so, we can find the distance this d i, u. This d, i, u means this distance changes whenever the use the PD location changes; that means, users location changes this d, i, u changes. So, that, we can find by using this formula. This is from the geometry we can find it out.

As we know the concentrator gain can be expressed in this way. So, here we can formulate our channel based upon the concentrator gain. When the concentrator gain is getting some value that value should be present when the our incident angle lie between 0 to f of v; that means, if psi is less than f of v then channel is present, then we can use this formula and we can implement.

Whenever shi is greater than f of v this condition will be; that means, there is no channel between the access point and user. Therefore, here we can use the expression of the channel

LiFI channel and we can build the channel between the access point and user based upon the user's location.

Finally, now, channel is built. After channel formed if we would like to know that what is the data rate the user received, what is the SNR the user received at that particular location also we can find it out that I electrical is nothing but the current which is nothing but converted from the photons are converted to the current form and we are getting the current is nothing but express by using this formula as we have studied in the previous lecture.

Then we can calculate the SNR received at that location; that means, I is nothing but ith and jth location means the coordinate of the user is present at the ith coordinate ith comma jth coordinate the user is getting this SNR. By using this expression, we can calculate the SNR and that from that we can calculate the SNR received in dB, we can use simple logarithmic on that.

Then if we would like to know that how much data the user is receiving at particular location if the user is located here what is the data, then we can use the Shannon capacity formula for the LiFi as we use it is also, we have discussed in the previous lectures then we can calculate it. If we would like to know that under the WiFi AP, if we have all the data rates so, we have collected then we can find it out the what is the average data rate we are getting under one LiFi AP.

So, by using this we can finally, know that what is the channel response and what is the SNR received by the user at all the locations under the LiFi access point as well as we can also find the data rate received by each user at all the locations. So, in this way we can calculate all these things. Let us see how to realize it in graphical form.

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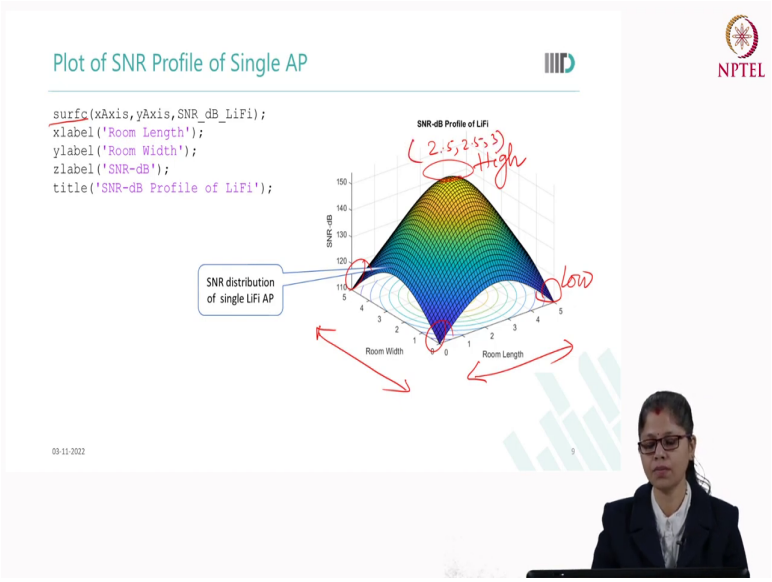

So, if we would like to plot the SNR profile of the user like receiving from the access point, then we can use the command of surfc. This is nothing but it will be the surface plot of the SNR profile. And, for that surface plot we need the three parameters one will be your x-axis parameter, y-axis parameter is another and another parameter is your SNR profile for plotting the SNR profile we need the SNR profile values. And, all these three should be array then only we can pass it to the surfc command.

If we are passing it to the surfc command then we can see the plot will be like this. So, here this is the room length that is x-axis, room width is y-axis and we can see this is the SNR profile and we can see here we are getting the high SNR values and here we are getting the low SNR values. Here we are getting the high SNR values and here we are receiving the low SNR values.

This is the profile under one single a one access point and the user may be located anywhere, but now we have considered all the grids we are considering users are present in all the grids then the received profile will be looking like this. So, let us analyze more than a one single one access point if it is present inside the room then how we can do it.

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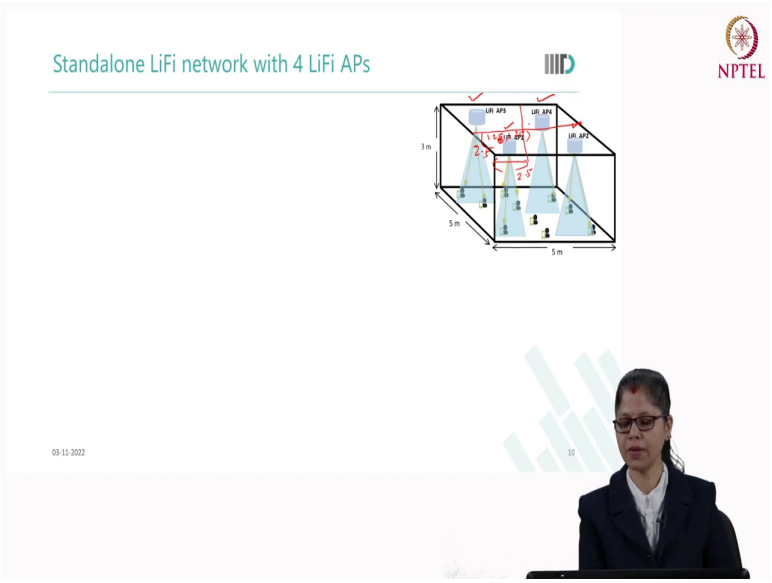

So, similarly here what we have done? We have considered single LiFi access point that is present are the like a 2.5, 2.5, 3 the coordinate the on the ceiling the access point is fixed at that point. If we are considering a room of 5 cross 5 cross 3 same and we are trying to place the first access point here, second access point here, third access point here, fourth access point here, then first what we have done?

We have divided this ceiling into the four parts and on these four parts at the middle of this first quadrant we have placed this first access point. So, this will be 2.5 and this will be 2.5,

then it will be placed at the middle of this; that means, 1.25, 1.25. Similarly, here also this access point is middle of this quadrant and this access point is middle of this quadrant and this is middle of this quadrant. In this way we have placed the access points and fixed it.

If we are trying to build the channel of all the access points based upon the grids how we have done in the previous a slide we can first create the channel for this access point considering all the grid value were in the floor on the floor. Then, we can get the SNR value at each grid for this access point. After getting it very simple way we can also find it out for this LiFi access point 2, 3, 4 as they are similar in nature.

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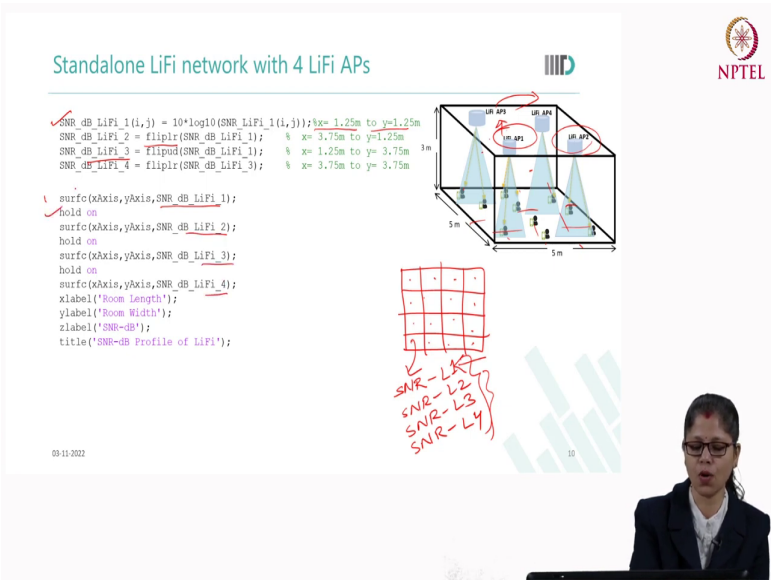

So, we can duplicate it by using the simple command like flip up flip left. So, here what we have considered? So, SNR dB we have calculated for first LiFi access point as we have calculated in the previous slide, only we have changed the location of the LiFi access point at

1.25, 1.25 a any other parameters are remaining same then we are finding the SNR dB LiFi – one is this one.

So, where the x and y location of the AP'S are this, then we are using simple command L fliplr; that means, it will just flip to the left right side then we will find out the SNR profile of the LiFi access point 2. Similarly, if we will flip up this then we will find the SNR profile of the third access point and whenever fliplr we are using again we will get the SNR profile of the LiFi access point 4.

In that way we can find the SNR profile of all the LiFi access point and by considering the user is present in each grid of the floor then we can get in each grid. For example, here we can see we can see that if the floor is here and the floor is divided into the grids. So, at each grid we will be getting the SNR value from the LiFi AP 1, SNR value from LiFi AP 2 SNR value from LiFi AP 3 SNR value from LiFi AP 4. Then in this way we can find the SNR value of the user in each grids.

From this we can understand that the user is below which of the access point because if the SNR value is coming high from particular access point, then we can understand that the user is just below that user. If the interference, here also we have considered if one access point is interfering with each other access point then definitely from the SiNR value also we can get that the SiNR value of the one user from one LiFi AP will be a very high and from others very low.

In that way we can consider also the user's location and user is connected to which of the AP. So, now we can plot the SNR profile together by considering all the access points. So, we have used the same command like surf c and here we have plotted this for LiFi 1, for LiFi 2, LiFi 3, LiFi 4.

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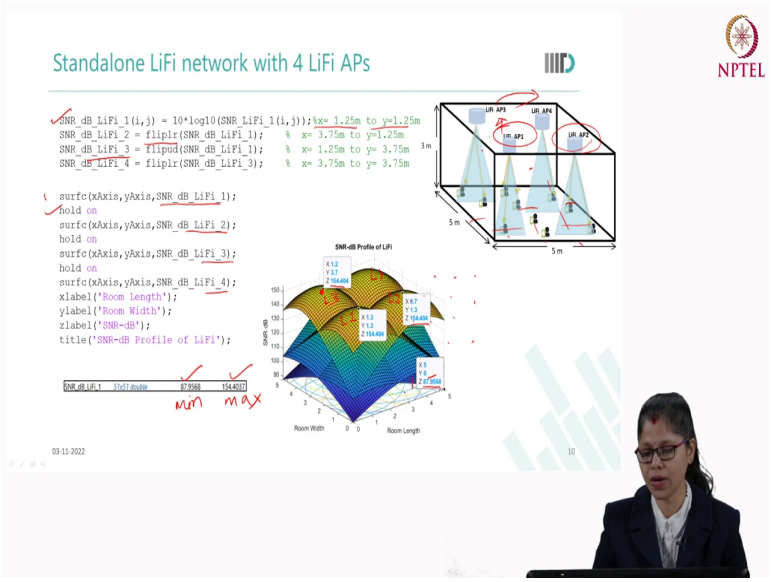

Together if we want to plot then we have to keep this hold on command and we can see the profile will be visible like this and this is the LiFi profile for all the LiFi access point and we have considered that all the grids we are receiving the data we we are receiving the SNR a value from each of the AP. So, we can see here the maximum value we are getting for the SNR is 154.4 dB and minimum value is 87.95.

So, we can understand here from this profile this for LiFi this is for LiFi AP 3, this is for LiFi AP 1, this is for LiFi AP 2, this is for LiFi AP 4. Similarly, here also we will get the maximum value and we can see that the maximum value we are getting just at a centre of this profile; that means, this is just below the access point if the user is there or the point whatever we have located on the grid on the floor then we are getting the highest SNR value.

Whenever the grid is considered just corner of the room, then we are receiving the SNR value of the 87.9 that is which is the minimum value. So, in this way if we are able to get the SNR profile of the user or of the LiFi access point at each grids then we can analyze it for different application by considering the positions randomly for the user and we can extract those data from here and we can use in our applications.

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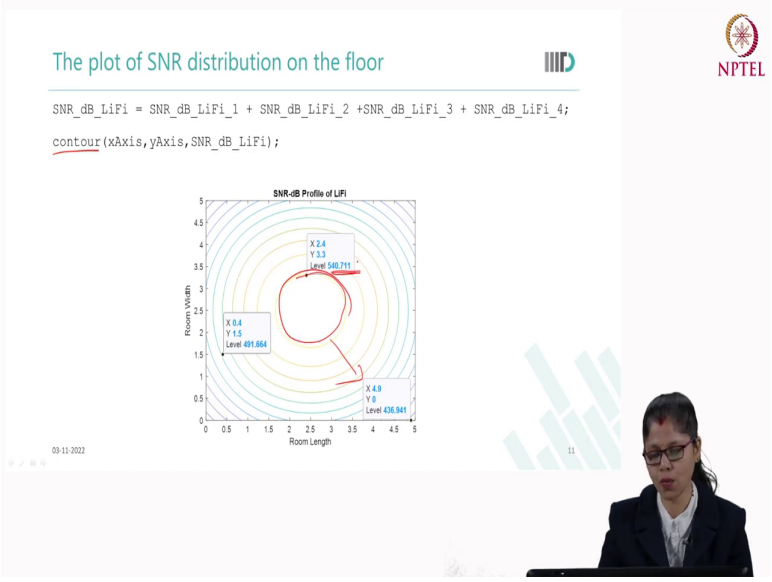

Let us see like how we can plot the contour plot of this SNR distribution? By using the command contour and if we are going to plot the SNR profile whatever we have received from each user each access point we have seen here from each access point we are getting if we are just adding all the SNR values then we will get the net SNR received from all the LiFi access point; that means, overall LiFi network receives SNR will be this one and that we can plot by using the contour.

And, we can see here we are getting the maximum value and slowly it is decreasing. So, because this is just addition of all the LiFi access point SNR values.

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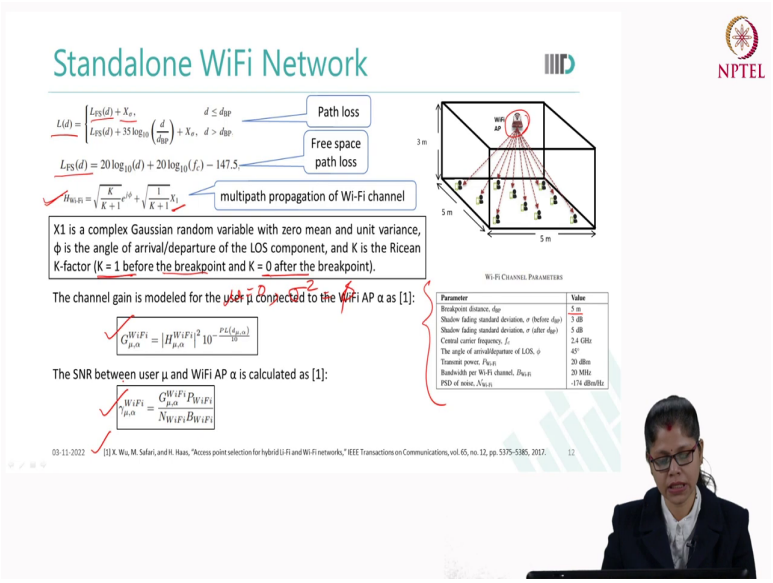

Let us go ahead and we can see the standalone WiFi network. So, why we are going to look into the standalone LiFi network, standalone WiFi network because this standalone LiFi and WiFi if we understand then we can build the hybrid network it is very easy to build. So, in the standalone WiFi network also we have considered this reference and we have taken these parameters from the reference, and we have modelled the channel.

And, here the channel is Rician channel model and we have considered the access point is placed at the middle of the ceiling and we have taken the users at the grids we have similarly divided into the grids and we have built this. So, for this just I will briefly just let you know that how we have used these parameters this L d is nothing but path loss. So, here this path

loss is modelled by using this expression, L FS is the free space path loss and X sigma the shadowing component.

So, the path loss model is this we have used in our simulation and free space path loss is used from this reference this one and we have used in our simulation. Finally, the channel like WiFi channel, multi path propagation WiFi channel impulse response is modelled by using this expression and here K is nothing but Rician K factor and that K factor is 1 before the breaking point and K factor is 0 after the breaking point.

Here we have considered the room sizes 5 cross 5. So, that is why the breaking point distance as per the reference it is 5 meter. So, therefore, always the before the breaking point only we are considering here that is why K equals to 1 value we are considering and this X 1 is here the Gaussian random a variable which is complex in nature. It has mean 0 and variance is phi.

So, we have modelled this by using this reference and finally, we got the channel gain is this one and this is the expression for the SNR and we have used this expression for modelling the channel in the simulation scenario.

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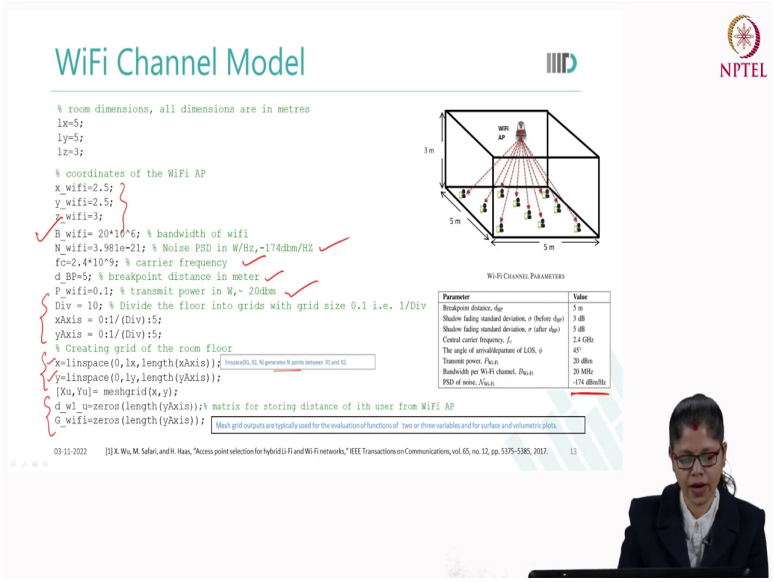

So, let us see the simulation here. So, whenever we have simulated this a WiFi channel we have considered the same like room size of 5 like length of the room size, breadth of the room size 5 5 and the height of the room is 3 meter. Coordinate of the WiFi access point we have considered at the middle of the ceiling that is why 2.5, 2.5, 3. And, we have considered bandwidth of the WiFi access point is 20 mega hertz and power spectral density as per this reference we have considered.

And, we have considered the carrier frequency and breaking point distance, transmit power based upon the table. Then as we have done in the LiFi we have taken the division and x-axis, y-axis we have divided to get the grid and the grid whenever we are creating n points means we have created like a 51 points between this 0 to 5 meter.

That is why here little different way I have expressed here linspace I have used; that means, we we have created 51 points from 0 to 5 meter. So, we can use this x and y values are nothing but the each grid x and y location, then we can place the user in on the grid like by using mesh grid x, y. And, d w1 u is nothing but distance between the WiFi access point and user. Just I have initialized here because I am going to fill all the values in this and G WiFi is nothing but our channel gain.

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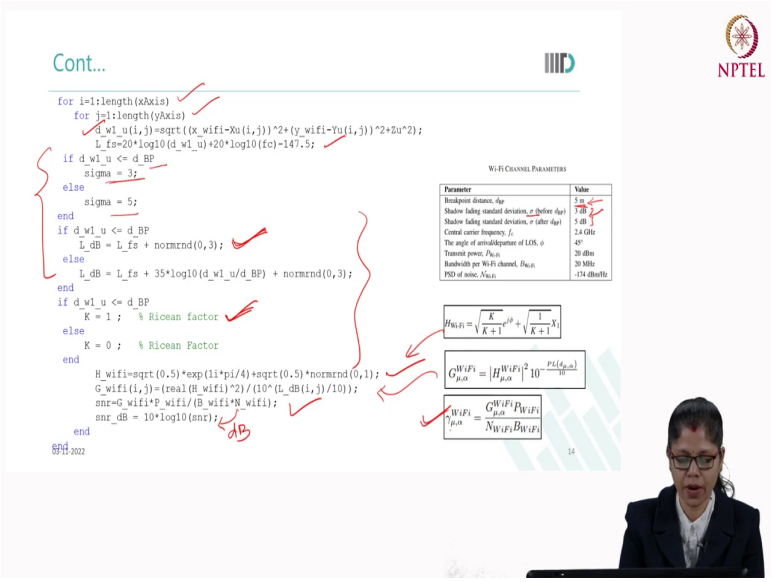

So, similarly in LiFi how we have considered we have a considered two for loops because we have to calculate the channel impulse response and channel gain at each grid that is why we have taken these two for loops. Then we have calculated this distance between WiFi AP and user by using this x minus Xu whole square plus y minus Yu whole square plus Zu square using the geometry the value we have calculated.

And, as we have seen in the previous slide the free space path loss can be expressed by using in the this way. Then we have to just put the conditions whenever the distance between WiFi AP and user is less than the breaking point, then sigma that is our for the shadowing component we have taken this sigma value is 3 dB and sigma value 5 dB. This is just as per the reference I have considered, but here our room size is 5 meters.

So, always it will work just before the break point. If we are changing the like room size, then we can use this two. So, here we have calculated the path loss then after calculating also we have to check the condition for this a Rician factor. We are considering this and this because of the room size we have 5 meter that is why always the condition will satisfy these two conditions. If we are changing the room size then definitely any of this whole loop will run for that.

So, finally, we are getting this is the channel impulse response by using this expression then this is nothing but our channel gain for the WiFi. Then finally, we can calculate the SNR received by the user mu from the alpha WiFi AP. So, SNR can be calculated, after that we can convert this SNR to the dB form by using 10 log.

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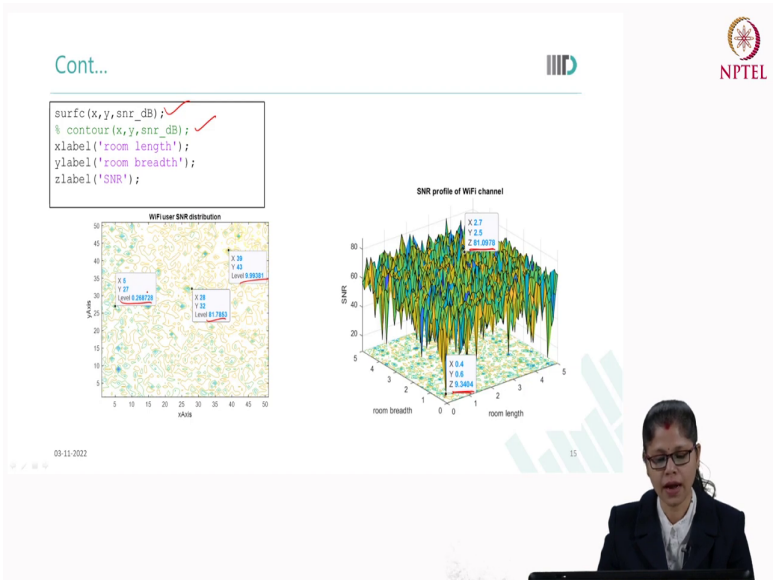

Finally, we have the SNR values of the user from the AP whatever we are getting at each grids. We can plot it by using the surfc as we have done in the case of LiFi. So, we will get this is the SNR profile for the single WiFi AP in each grid of the floor. So, we can observe here we are getting the 81.019 dB if at this location and here we are getting 9.8 that means, here the user is getting very less SNR.

So, data rate will be less here and here if the user is present here, then the user is getting better data rate or better SNR. So, this is the SNR profile for the WiFi channel. And, if we plot the contour if we will use this contour plot then this will be the contour plot. So, in the contour plot also we can see that different SNR values are different position we can based upon the path loss and channel and the user's location we can find it out.

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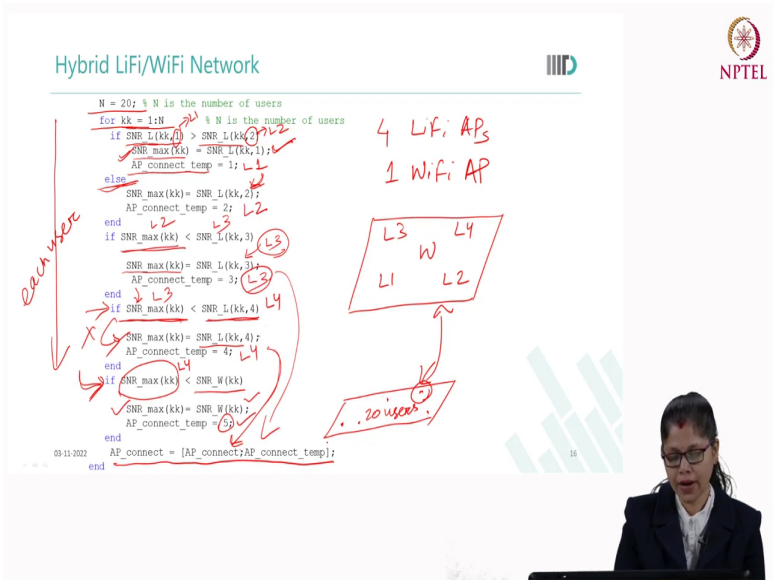

Let us see in hybrid LiFi WiFi network how can we analyze by using this LiFi channel model and WiFi channel model. So, once the LiFi and WiFi channel model is done, by using the same LiFi and WiFi channel model and the like we can consider the room of same like a 5 cross 5 cross 3 and the LiFi access point is present four LiFi access points are like this and at the middle we will place 1 WiFi access point. Then that time how the WiFi and LiFi together will coexist and we can see the hybrid network works. Repeat.

Hybrid LiFi WiFi network, let us see how it works by using a LiFi channel model and WiFi channel model. Once the LiFi and WiFi channel modelling has been done, here we have considered same 4 LiFi APs and one WiFi AP. So, the same way the; that means, on the ceiling we have a LiFi 1, LiFi 2, LiFi 3, LiFi 4 and at the middle WiFi is present.

In that case we have considered on the floor we have 20 users and those 20 users are connected to which of the LiFi and we and or WiFi we have to see that based upon the location where the user is there and at this location user is getting better SNR or better data rate from which of the AP the user will be connected to that AP. So, how this can be checked? So, for that we need to see the like log logic how to implement.

So, we have considered here total 20 number of users and these for loop is used for the user and the conditions if else is used for the AP connectivity. So, here if the a user loop is running 1 to 20. So, for each user we have to see that it is connected to which of the AP. If when the KK value is 1; that means, the SNR we are checking here SNR L KK comma 1 means 1 comma 1 is greater than SNR L KK comma 2. This 1 and 2 is used for the access point.

This 1 is used for the LiFi 1, this 2 is used for the LiFi 2; that means, the user if receiving from the LiFi 1 this SNR value if it is greater than the user receiving from the LiFi 2 value, then the maximum SNR value will be nothing but the SNR received from the LiFi 1; that means, temporarily now the user is connected to the LiFi 1.

If it satisfies then definitely it will come out from the loop and we have to, but we have to check for all the LiFi access point and Wi-Fi. Therefore, we have to check the else condition. In else condition again the SNR max is updated to the like if it is not satisfying, then it will be updated that SNR max value will be that is SNR received from the LiFi 2.

If it satisfies then it will come out the loop then finally, the connection will be user 1 will be connected to the LiFi 2; if it does not satisfy then it will check for the next condition; that means, SNR max value is now the SNR received from the LiFi 2. If that SNR is less than the SNR received from the LiFi 3, then the SNR max value will be updated to the SNR received from the LiFi 3.

Now, the user is connected to LiFi 3 if it satisfy then it will come out from the leap loop then it will update here that user 1 is connected to LiFi 3, if it does not then it has to go for the next condition. In the next condition it has to check that the SNR max now the SNR max was like

SNR received from the LiFi 3. LiFi 3 is it lesser than the SNR received from the LiFi 4, if it satisfies then the SNR max value will be updated to the SNR received from the LiFi 4.

Then now the user is connected to LiFi 4 then it has to be updated here. If it does not satisfy, then, then it has to check for this condition. In this condition the user will check the WiFi. The SNR max value is now the SNR. Break. Repeat. If SNR max value is lesser than the SNR received from the LiFi 4, then this will be updated here in the SNR max that SNR received from the LiFi 4 because previously SNR max was the value SNR received from the LiFi 3.

If this condition satisfies then the L4 is nothing but saying that the user is connected to the LiFi 4 it will be updated in this. If it does not satisfy then it has to come to this, here it has to check for the WiFi connection. Now, if the SNR max is nothing but LiFi 4 from LiFi 4 how much SNR is received if that value is lesser than the SNR received by the user 1 from the WiFi AP, then the SNR max will be updated to the SNR W because the SNR received by the user 1 from the WiFi is more than from the LiFi.

Then, now the AP connect temporary variable will be updated to the 5 which is used for the connection of the user from the for the WiFi access point. Then finally, we can see that in this way all the conditions will be checked for each user; that means, whenever kk is running from 1 to N for first user all the conditions will be checked, again for the second user all the condition will be checked, third user all the condition will be checked, similarly up to 20th user all the condition will be checked.

Finally, this AP connect variable will be updated and we will be getting the connectivity of each user for each access point.

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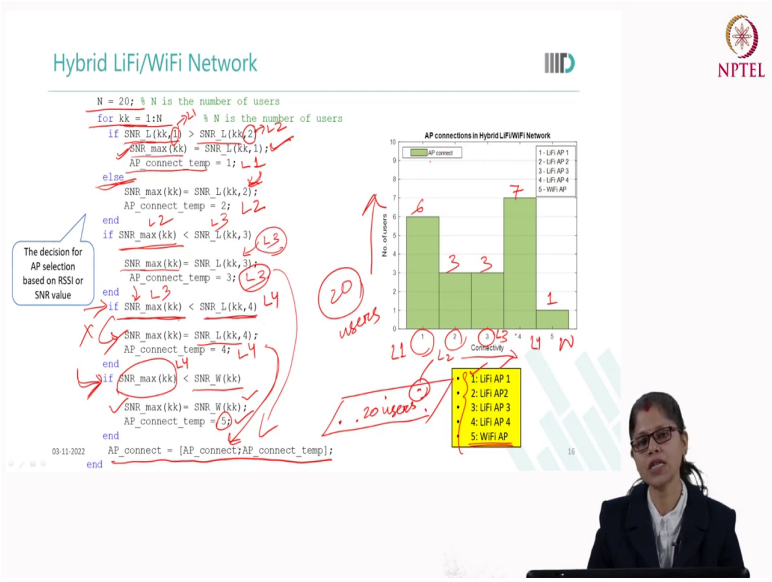

So, here we can see that the notation we have used 1 for LiFi access point, 2 for LiFi access point 2, 3 for LiFi access point 3, 4 for LiFi access point 4 and 5 for WiFi access point these are the connectivity we have considered in this. So, finally, we can see that we will be getting the result of the connectivity of each user for the five access points whatever we have used in our system. So, we can see here all the connectivity's are like here we have taken connectivity, number of users.

So, this is number of users, this is connectivity, we can see that here number we have for 1 means this is for LiFi 1 we have considered. So, LiFi 1 we have 6 number of users connected, for LiFi 2 we have 3 number of users, for LiFi 3 we have 3 number of users, for LiFi 4 we have 7 number of users and for WiFi we have 1 users. If you will add all these things so, we are getting total is 20 users. So, for 20 users we got the connectivity.

So, in this way we can do also many analysis by using this hybrid network SNR values and data rate. Once we are getting for all the locations we can locate any number of users on that grid and we can analyze the SNR profile, SNR values, data rates. Based upon that also we can use this logic for connectivity and we can find it out which user is connected to the which of the AP, then further analysis we can do based upon that.

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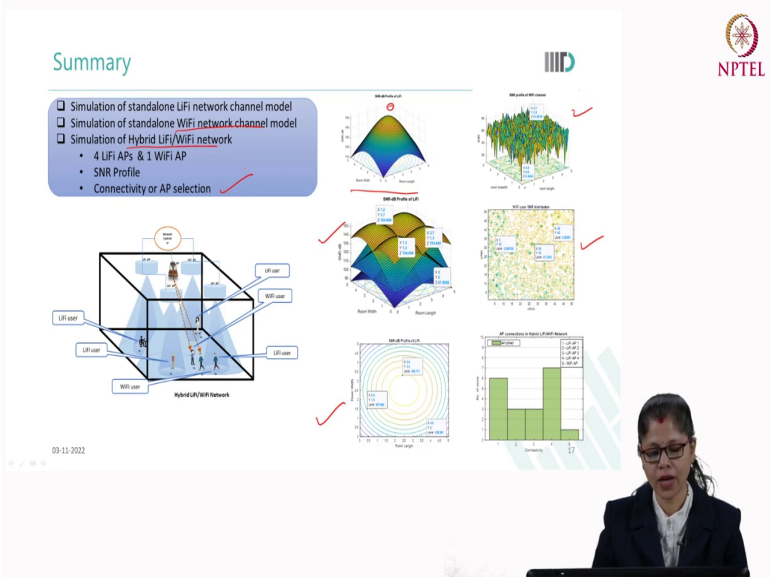

So, let us summarize this lecture. So, here we have first considered the simulation of standalone LiFi network and in that simulation, we have checked the channel model and in that channel model we found this is the single access point whenever we are considering and all the grids on the floor, we are considering this is the say SNR profile. And, whenever we are considered the LiFi network channel model and simulated we got this is the sorry. Break. Repeat.

Let us summarize today's lecture. So, in today's lecture we have first simulated standalone LiFi network channel model and in that break. So, let us summarize today's lecture. In today's lecture we have seen the simulation of standalone LiFi network channel model. Repeat. Let us summarize today's lecture. So, break. Repeat.

Let us let summarize today's lecture. Today, in this lecture we have seen the simulation of standalone LiFi channel model. In that simulation we have seen single LiFi AP we if it is present at the centre this is the SNR profile, we are getting and also, we have simulated standalone WiFi channel model and we have observed this is the WiFi channel profile SNR profile we are getting for the single WiFi access point and finally, all we have also seen the hybrid LiFi WiFi network based upon the standalone LiFi and standalone WiFi channel models.

And, we have considered 4 LiFi APs and one WiFi AP and 20 number of users. For that we have first model the 4 LiFi APs SNR profile, then 1 WiFi AP, then we found this is the SNR profile for the 4 LiFi APs and this is the contour plot for the 4 LiFi APs and this is the contour plot for the WiFi channel channel which is used for single access point, WiFi access point. Then finally, we have observed one of the connectivity or AP selection process how it happens in the hybrid network.

Finally, we found this results shows that how many users connected to which AP and this clear this gives the clear picture of that we can model the users on the floor based upon the users locations and access point locations on the ceiling. So, finally, we can see that there are many applications here by using hybrid LiFi WiFi network. When the user is not in the vicinity of the LiFi, then the user can use the Wi-Fi. Whenever the user is there and under the WiFi LiFi AP then the user can use the LiFi access point.

In this way we can see that the load of on single access point will reduce as well as the performance of the network will increase because the particular user is using the particular AP whenever the user is getting the highest data rate or highest SNR from the corresponding access point. In this way, many applications can be utilized based upon the simulations. This

is the just primary simulations whatever we have shown here, but based upon this simulation we can also consider many applications.

In this simulation we have seen that how the user is selecting to the particular access point. So, AP selection is considered here.

Thank you.