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

Lecture - 44
Tutorial - Part 2

Hello everyone, I am Dilnashin Anwar, pursuing PhD in triple IIT, Delhi. In the previous lecture, we discussed Simulation exercise on color shift gain modulation scheme. How to generate the CSK constellation symbols in terms of optical power intensities such as PR, PG, PB and then the modulation, optical channel in form of metrics then demodulation. And, then we have shown the SER versus SNR plot of CSK modulation scheme. We even suggested few advance work. Hope the assignments were fine.

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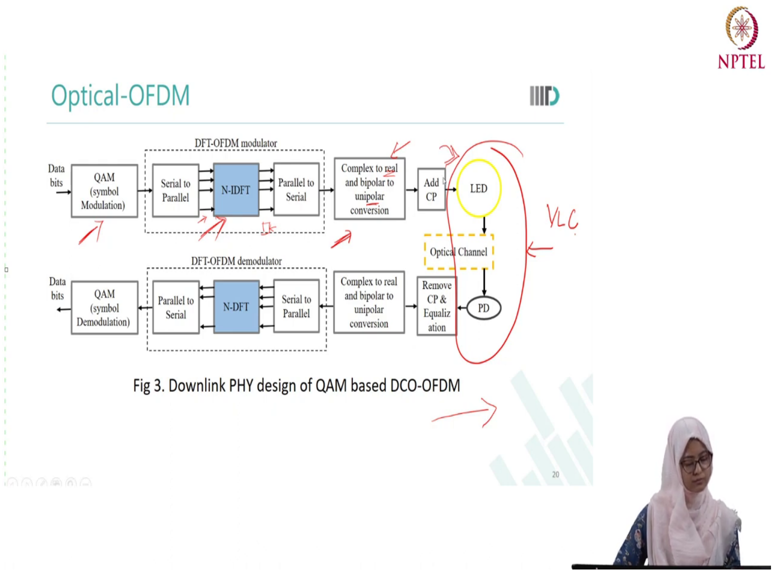

So, now coming to the optical OFDM part, in this part, I will be discussing how to simulate optical OFDM in MATLAB. OFDM orthogonal frequency division multiplexing is not new to everyone, but what is optical OFDM? So, the OFDM technique which is made suitable for visible light communication has been named as optical OFDM.

In this figure, you can see that most of the blocks resembles OFDM part. However, this complex to real and bipolar to unique polar conversion is a new thing and then this part is named. It is because of the visible light communication. The conventional OFDM used in WiFi communication have bipolar and complex symbols because we are using I 50 here and then also we have QAM modulation.

In order to make the complex bipolar OFDM signal compatible with IMDD, the conversion of complex bipolar signal to real and unipolar signal is done in optical OFDM which I have already stated. So, what happens actually, this IDFT, the input whatever input we give to the IDFT, it gives us complex form. So, we need to do something, so that we can get real and unipolar data. Why? Because, we cannot feed complex and bipolar data to the LED we need real and unipolar data as LED input.

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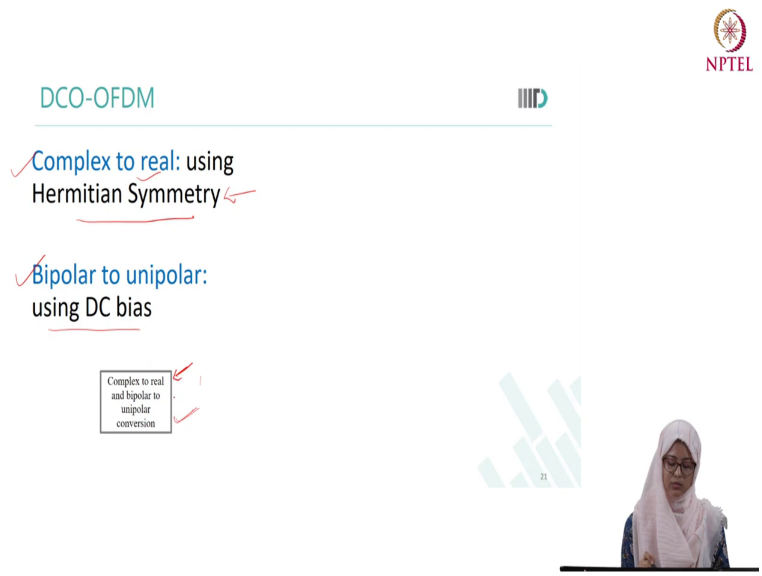

So, more precisely, DFT based OFDM outputs of complex bipolar signal which cannot be directly transmitted over LEDs. In order to make the complex bipolar OFDM signal compatible with intensity modulation, direct detection, we are doing these two things. How that can be done? We need to convert the data whatever we are sending to real using Hermitian symmetry.

And, then from bipolar to unipolar, we can add DC bias. At times we even segregate the real and imaginary components of data followed by DC bias addition or even signal negative signal clipping for real and unipolar data. So, this is the block which is very important which defines optical OFDM and different optical OFDM have different technique for this conversion.

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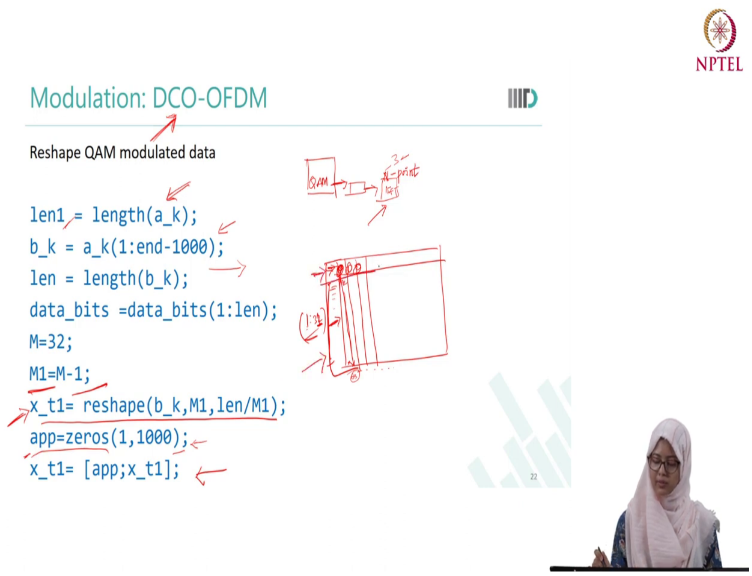

Now, directly coming to the modulation part of DC-OFDM. We have considered the basic optical OFDM starting with DC-OFDM. Why it is being named as DC-OFDM? Because DC bias is being used here. So, if you recall the block diagram of optical OFDM modulation scheme, QAM based, we see that we do the sub-career modulation. And, that sub-career modulation is QAM based.

So, whatever data we are getting from QAM, that modulated data has to be converted or you can say has to be reshaped so that it fulfills the end point IFFT. So, we are going to generate random data, do the QAM modulation and then reshape QAM modulated data. So, that 64 sub-careers can carry the optical OFDM data at a time. Assuming 64 sub-careers in one optical OFDM symbol and we have considered this end point to be 32 point.

So, let us assume this a k is the length of the QAM modulated data. In order to achieve Hermitian symmetry, we need to reshape the data in such a way. So, that we have 0 at the first position of the data. After that we have, we will have an array of data or you can say rows of data. So, let us say we have a k, it has some length. However, what we want? we want to reshape it in such a way, so that 32 data precisely 31 data because we are appending it with initial 0 so as to make that data array suitable for Hermitian symmetry.

So, this 0 is there and then we have string of 32 data here, 31 data here. So, that is why you can see here M is equal to M minus 1. So, here with the help of this reshape and you can say with the help of this line of coding, we are able to get data in form of this. So, you have 0 appended and then those data in terms of 1, 32, 31, then from 32 onwards till 63. So, so on till you exhaust this length 1.

And, then these 0s are being appended here. So, at first we are actually reducing the data from here and then we are appending data here and you can see that we have appended the 0s, these 0s are being appended in this reshaped data, ok.

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So, for reference you can refer this also, but that is for actually if you want to have guard bands or if you want to have cyclic prefix in your code, then you can refer the optical OFDM code and you can add those sorry in your OFDM yeah optical OFDM code from this OFDM code which has been presented here.

For simplicity in our work this exercise we have removed those parts. However, you can refer this for better understanding and for including those guard bands or you can say CP, cyclic prefix.

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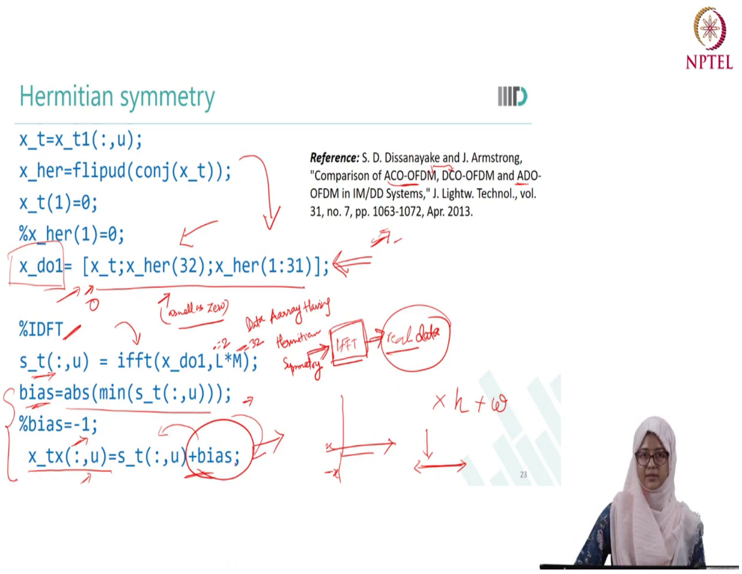

So, that was the modulation part. We have got our data which is reshaped and ready to have Hermitian symmetry in it. So, we need to again reshape the data in such a way so that this x do1, this data array becomes Hermitian symmetry. Why we are interested in Hermitian symmetry? Because we want the output of IFFT to be real not complex and if the data is Hermitian symmetry, ok.

Let me just write it you all may be knowing from lecture notes. So, data array having Hermitian symmetry, if it is input to the IFFT block then we get real data. So, one of the problem is solved. This is how we are going to have Hermitian symmetry and for Hermitian symmetry we need to have first element of this x underscore do1 as 0 and then the 32nd element as well as 0. So, that is how we place it in this form to get Hermitian symmetry.

After that obviously, this IDFT is being done with IFFT because it is much more fast this M is equal to 32 because we are using 32 IFFT. That is why L will be equal to 2 because in our optical OFDM we are considering 64 subcarriers generally it is being taken and then we are trying to give a bias.

Now, coming to the bipolar to unipolar part, so, what we are going to do? We are finding the minimum value of this data real data. So, we have got the minimum value; after that that minimum value the absolute minimum value of that is being added to it and then it is being DC bias. So, whatever value we will be getting here let us say if we will be getting something negative, now we will be having something positive from this x underscore underscore tx data.

For more understanding or in depth understanding of Hermitian symmetry you can refer to this work as well and it will give you an idea of AC OFDM, different types of OFDM also and the difference between them and for Hermitian symmetry you can always refer to this work.

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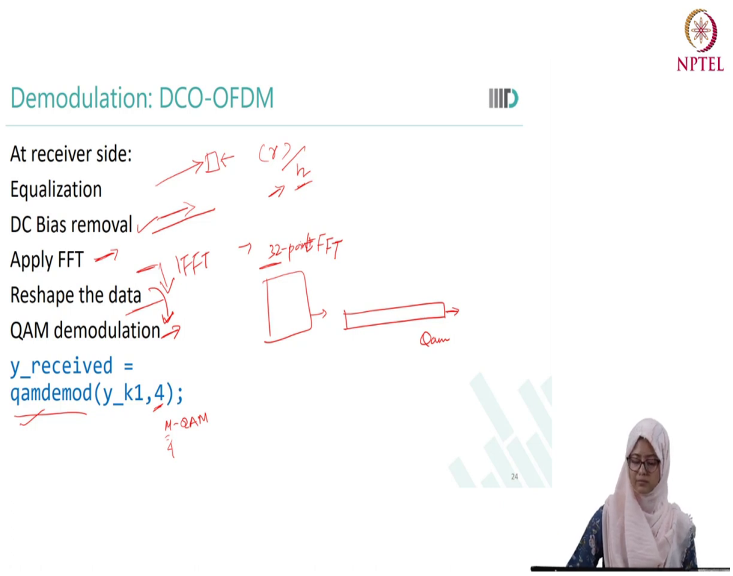

Now, at the receiver side what will happen is that the channel you can consider for optical OFDM the basic channel as has been considered in OK here no necessary or it is not required to have the channel in form of matrix form, as it was in the form in case of color shifting modulation scheme.

So, at the receiver side at first you will do the equalization; equalization is also being done at CSK as well. So, you can go ahead with the zero forcing equalizer where you can just divide whatever receive data with the channel gain. This is let us say receive data. After that you need to remove the DC bias.

So, at the transmitter side whatever is happening at the receiver side it will be just vice versa. So, at the last we had added channel gain. So, it will be the first to get removed after that DC bias will be removed if you just see the previous slide.

So, this is the bias. So, you are just going to subtract this bias from not this data. Obviously, this data will be multiplied with the channel gain and AWGN noise will be added. After that whatever received data, you have that data from that data you will do the equalization and then you will subtract this bias. So, now you have removed the DC bias you are going to apply the FFT in case of transmitter it was IFFT here it will be 32 point FFT. So, you are just trying to retrieve your data back.

After that the whole reshaping part you have got FFT then the whole reshaping part will happen so that the data is reshaped as per the QAM demodulation. So, the same thing that from 32 points this matrix form will be converted into a vector array form which is suitable for QAM demodulation. You can use a inbuilt MATLAB function QAM mod or QAM de-mod and this represents the order of QAM mod. So, it is like M QAM, M is equal to 4 here.

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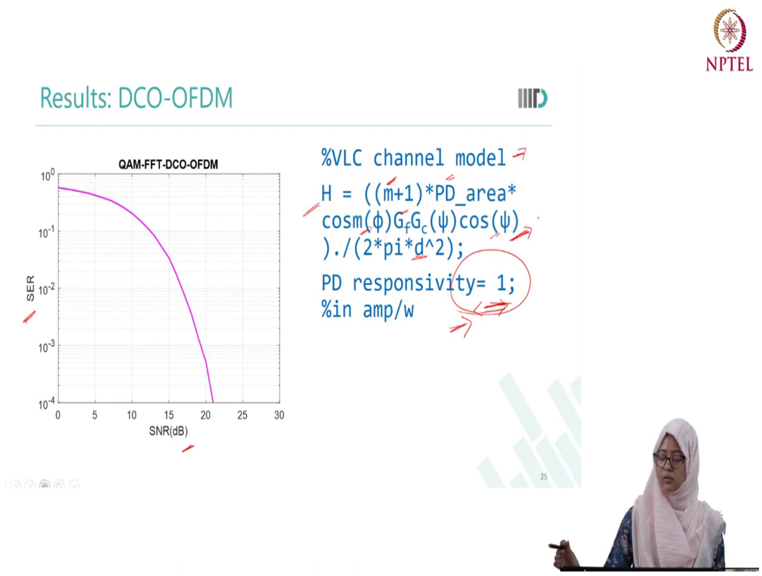

So, VLC channel model we have this you can take it from OK as well and. So, the basic you can refer to the previous to previous simulation exercise which was based on basic VLC for indoor applications and which includes optical on of QAM modulation keying. So, from that you can have an understanding of this edge.

So, this is the Lambashean order, this is a PD area, then you have irradiance angle, you have FOV angle, then the distance between the transmitter and the receiver these are the filter gain, concentrator gain. We are considering period responsibility to be one here just for simplicity. However, in practicality it varies because in case of CSK we took a practical value.

So, it was in some points. However, for optical OFDM we have just considered usual value. So, here from the simulation explanation and the codes you will be able to simulate the SER versus SNR plot for QAM-FFT-DCO-OFDM. And, the channel gain you can take it from that OOK simulation exercise.

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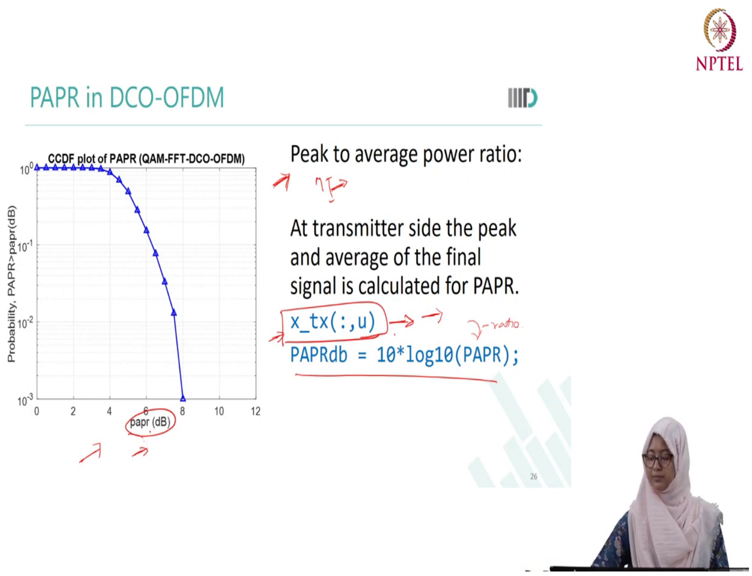

Interesting part in optical OFDM one of them is peak to average power ratio. So, what happens when we are going to apply DC bias to the optical OFDM. So, it actually increases the difference between peak and average power ratio and then that may cause clipping distortions at the LED side because LED do have some range of input. So, if it goes beyond that it just clicks.

So, with the addition of DC bias PAPR higher PAPR occurs. So, mostly in case of optical OFDM PAPR is a performance metric. So, that should also be calculated at times. So, here what we actually do at the transmitter side only when we got this data the modulated data,

data final modulated data whatever we are getting in this code I have shown x underscore tx as well.

So, in this you need to just calculate the peak of this data and then the mean or average of this data mean and average of this data. So, PAPR is the peak to average power ratio. So, you will be getting that from the transmitter side only and then you can find it in terms of db as well you can calculate it in terms of db as well. So, 10 log 10 PAPR which is in form of ratio.

This CCDF the complementary cumulative probability distribution is a standard way to show the PAPR performance of an optical OFDM modulation technique. CCDF is equal to 1 minus probability of PAPR less than some threshold or let us say we can see it in another words that what is the probability that a given PAPR is greater than a given threshold.

So, you can calculate it and this is how the PAPR the CCDF plot of PAPR is shown against the threshold PAPR. From lecture notes you can know that the CCDF of PAPR can be derived from the PDF of the optical OFDM symbol.

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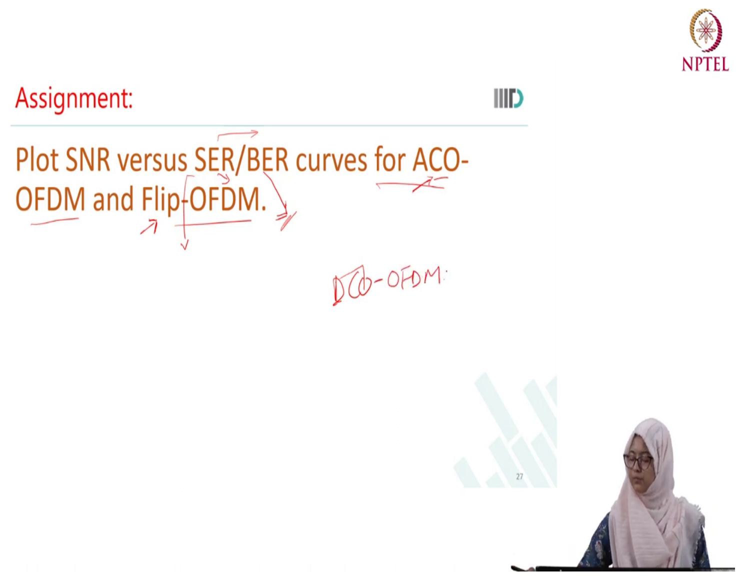

The assignment for this work is like you can plot SNR versus SER, BER curve for ACO-OFDM and Flip-OFDM ok. So, for SER and BER you must be having idea from the previous video. So, here we are just comparing it in the form of bits and here we are comparing it in the form of symbols. So, you can do the conversion anyway.

So, for the assignment the base coding for DCO OFDM will be same such as FFT, IFFT, equalization, QAM modulation and demodulation, the reshaping. However, the major difference will be in the complex to real and bipolar to unipolar conversion and the vice versa at the receiver side.

So, you can revise the lecture videos so as to have a clear understanding of what is happening inside the ACO what slight difference is happening inside the flip and only that much part you can change in the basic DCO OFDM code and you are good to go.

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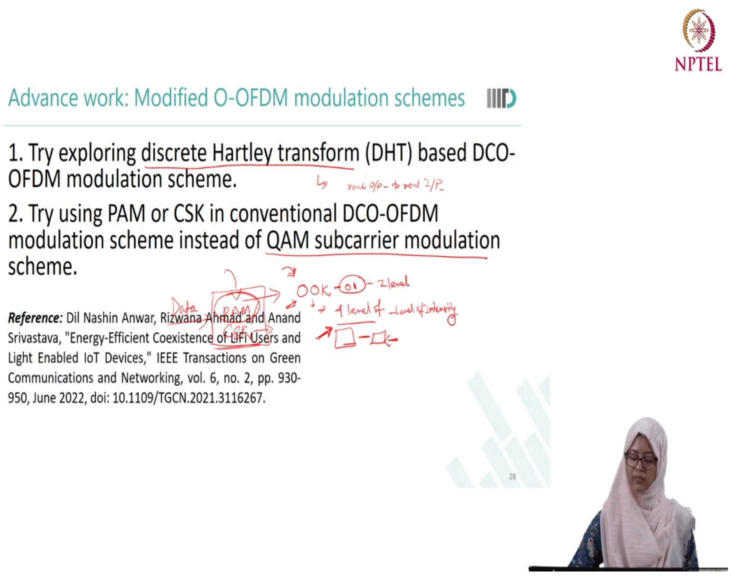

These are the advanced work one can prefer to do. So, what about going ahead with the modified optical OFDM modulation scheme? So, you can try exploring discrete heartily transformed based DCO-OFDM modulation scheme. Interesting part of discrete Hartley transform is that it gives real output to real input data.

Second is you can try using pulse amplitude modulation or color shift scheme in conventional DCO-OFDM modulation scheme instead of QAM sub-carrier modulation scheme. So, if you remember the block diagram there was QAM modulation at the starting data then you do the sub-carrier modulation that is QAM modulation. In that you can try to do PAM or CSK. From previous simulation exercise you already have an idea of CSK and this PAM is actually very very similar to ON-OFf Key.

In ON-OFF Key we have bits 0, 1. However, in PAM you have 4 level of intensities. So, from OOK you can try to simulate PAM as well. Here it was just 2 level and here it was 4 level of intensity. Just like to give you a hint in OOK we consider the basic BPSK modulation scheme as an analogy. Similarly, in case of PAM which is there in RF you can consider the PAM and you can easily convert it to the VLC PAM modulation scheme, ok. So, for that you can refer this work.

Thank you.