Optical Wireless Communications for Beyond 5G Networks and IoT
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Lecture - 06
Part 1
Indoor OWC Channel Modelling

Hello everyone, so today we are going to start a new topic. So, today we will discuss Indoor Optical Wireless Channel Modelling. So, before starting indoor channel modelling for indoor optical wireless let us understand the different environments of optical wireless communication.

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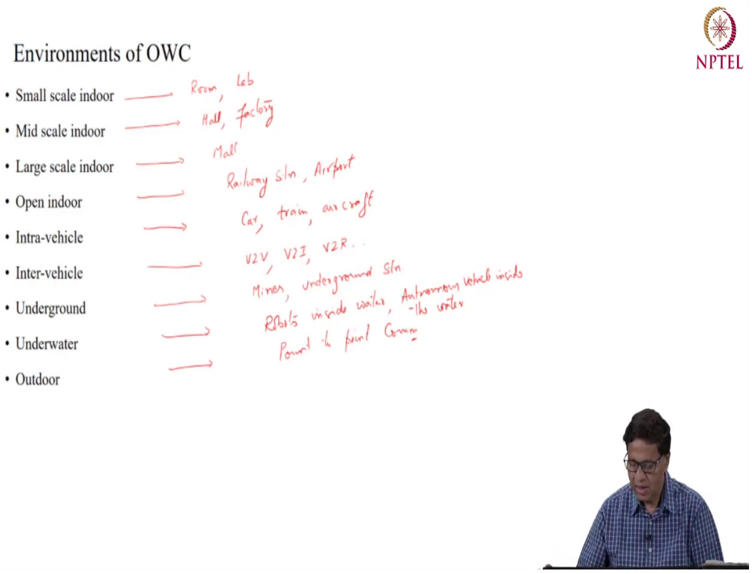

So, one of them is small scale indoor this basically refers to within a room, for example or within some lab. The next one is mid scale indoor it refers slightly bigger area it could be some hall; it could be some small factory and so on. Next is large scale indoor it could be a mall, for example where the length and breadth of the room and the height is quite high.

So, it is classified in large scale indoor and then you have open door open indoor. For example, this could be in a railway station for example or airport, then you have intra vehicle intra vehicle meaning within the vehicle. So, it could be within a car for example within a train or aircraft use of optical wireless.

For example, inside the car for entertainment or in an aircraft when you are travelling you can be connected to a light which is above you, which can give you know good communication. Then inter vehicle this could be for example here I can utilize the head lamp of the car and the tail lamp of the car.

So, vehicle to vehicle communication or you can communicate from vehicle to infrastructure which is a headlight oh sorry it is traffic light so this is V2I or vehicle to road so on and so forth. Underground this could be for example in mines use of optical wireless communication in mines or underground railway station for example under old station.

Another environment could be under water this is you know robots moving inside the water they may communicate through optical wireless channel inside water, autonomous vehicle autonomous vehicle or ships inside the water. So, these are the different environments of optical wireless and each has different channel modelling and each has you know different set of challenges.

So, we will discuss maybe small scale indoor or mid scale indoor and also we will discuss about say inter vehicle. So, some of these OWC we will study during this course last one I missed could be outdoor this is point to point mid point-to-point communication in outdoor setting using optical transmitter and optical receiver.

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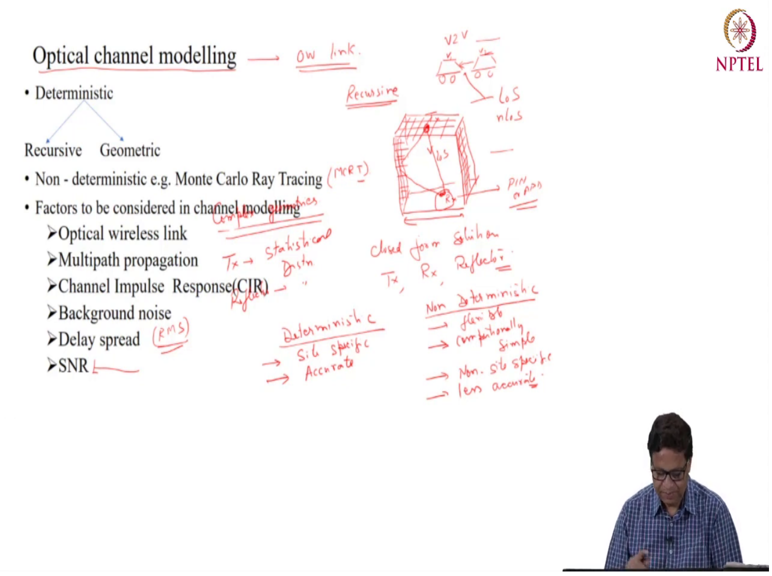

So, now let us understand the optical channel modelling. We need to calculate this accurately so that you are able to understand about the optical wireless link, the performance of optical wireless link. And optical for optical channel modelling there are two methods one is deterministic approach, under deterministic we have 2 types recursive and geometric and the other approach is non deterministic Monte Carlo ray tracing.

So, let us try to understand this recursive first which is a deterministic approach. So, in recursive approach what normally is done? Suppose this is a room and you want to find out the channel impulse response inside this room. So, what normally you do you divide all the walls into small grids, similarly this wall is divided into grids.

Similarly, this side of the wall is divided into grids and suppose your transmitter is out here this is your Tx and Rx is here. So, in recursive you basically follow the ray how the ray moves from transmitter to receiver. So, it can go either directly which is called as line of sight or it can go indirectly gets reflected from one of the grid here which is which acts as a point source now and then after reflection it is received by the receiver here.

So, there will be many such rays. So, this is one recursive method and the other is geometric. Here basically is you get a closed form solution using geometric closed form, where you can model the transmitter, you can model the receiver and you can model the reflector. So, this is another way of finding out optical channel modelling. The second type is non-deterministic.

So, one of the example is using Monte Carlo ray tracing MCRT. So, it relies on repeated random sampling to obtain numerical results. So, this is useful for complex geometries. So, the ray and all each Tx has some statistical distribution of power depends on the source statistical distribution, similarly some reflector will have some statistical properties.

Because, it is now if the ray from transmitter strikes on to the wall that acts as a point source and then the light is selected by the receiver. So, it also has some distribution statistical distribution and similarly receiver will have some distribution. So, using all these statistical distribution you find out the ray coming from transmitter and follow all the way to the receiver when it is collected by the receiver.

So, this is done for by repeated random sampling and you obtain numerical results. So, this is another way of finding out optical channel optical wireless channel model. So, if you compare these deterministic approach and non-deterministic approach. So, deterministic here deterministic and this is say non deterministic.

So, deterministic approaches can be site specific depending upon the site you find out how much power will be collected when your receiver is moving in the receiver plane. So, receiver can move anywhere in this plane this is the plane of the receiver. So, it depends on site specific because each site has different settings. For example, there can be a room which has lot of furniture’s or it can be a place.

For example, in a hospital setting. So, you have to consider all the objects inside that room or inside that hall inside that environment so it becomes site specific and this is fairly accurate. It takes little long time to compute the channel model, but it is fairly accurate. In the case of dot non-deterministic thing, it is flexible and computationally it is not very intensive.

So, computationally simple not very complex and it is non site specific non site specific and as far as accuracy is concerned is less accurate as compared to deterministic. So, what are the factors which we need to consider when we are doing the channel modelling. So, first is optical wireless link which environment we are discussing, as I mentioned in my earlier slide there are different environments underwater, intra vehicle, inter vehicle, then indoor setting, outdoor setting.

So, it depends what kind of optical wireless link or under what environment you are considering this. Then you have to consider the multipath propagation, by multipath I mean for example, from this transmitter you get rays one is you know directly to the receiver if it is not obstructed which is called line of sight.

and then you can get then you get infinite number of rays coming which are reflected from different sides of the room and each it is not necessary that it gets only one it you know suffers only one reflection there can be multiple reflections. So, and when you consider you know different rays arriving at the receiver at different times.

So, it results into some multi path you know dispersion there will be dispersion because of the multi path. So, we need to consider both line of sight and non line of sight. So, this is what I mean by multi path propagation. Then we will try to calculate using one of these methods recursive or geometry or Monte Carlo retracing the Channel Impulse Response that is CIR.

While doing so you also need to consider the background noise, because inside the room you may be connected to one LED, but the other light sources they maybe you know contributing towards noise. And similarly, if you have a if you are; if you are trying to calculate the channel model of a vehicle-to-vehicle communication.

For example and you have one car here the other car for example here and there may be other cars travelling here or travelling here. So, you are interested in this communication, but this car light is falling on to this which is a sort of interference to this communication between these 2 cars V1 and V2.

So, we need to consider the background noise, then another quantity which is important is delay spread or to be precise the RMS value of the delay spread I will explain this in a short while, what I mean by this? And then ultimately you are interested what kind of signal to noise ratio you are getting at the receiver.

So, receiver will have some interference noise coming from other sources for example and also receiver uses either a PIN diode or a APD diode which will contribute which actually as we discussed in earlier classes will contribute to noise thermal noise and short noise and if you are using APD excess noise. So, ultimately, we are interested in knowing what kind of signal to noise ratio we are getting at the receiver or what SNR is received by the user.

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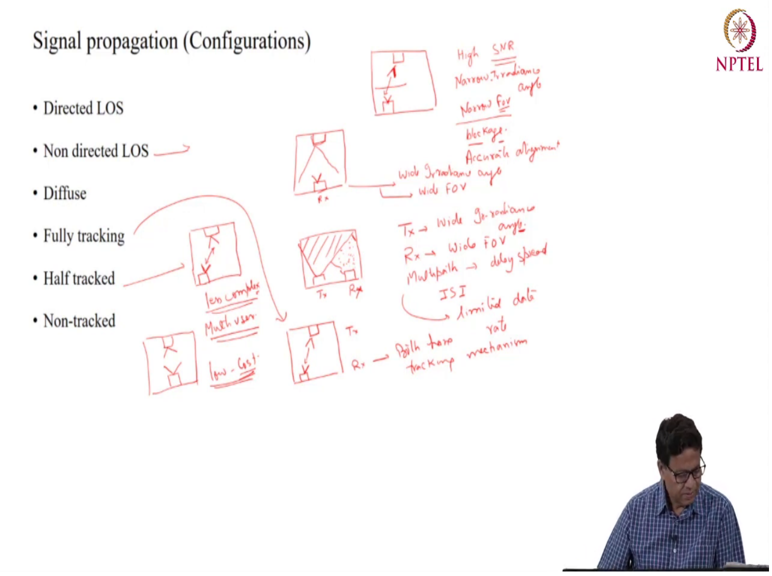

So, before going further let us discuss what are the different configurations of light propagation inside a room for example. So, it could be a directed line of sight. So, when I what I mean by directed line of sight? So, you have for example, this is your room and say this is your transmitter and your receiver is for example say here.

So, this is tilted and this is tilted in this direction. So, depending upon the location of the user depending upon the location of the user they aligned they are aligned the transport and the receiver this is the beam they are aligned. So, this is called as directed line of sight and you would get very high SNR here because your transmitter and receiver both are aligned and these sources, they have narrow irradiance angle.

The angle by which through which the light is coming is called as the irradiance angle. So, they have narrow irradiance angle and the receiver has narrow FOV because if it is wide FOV it will collect you know light coming from other sources as well which actually is noise. So, in order to have high SNR and directed line of sight we need to have narrow irradiance angle source and a narrow FOV.

The issue with this is that it is if there is a blocking somewhere in between the light will get stopped. So, this is an issue here blockage, so one has to be careful here. So, if blockages so it may not be a good solution when you know there is a blockage and you require accurate alignment. So, this is another accurate alignment.

So, this is directed line of sight and these are some of the plus points and negative points of directed line of sight, the other one is non directed line of sight. In the non directed line of sight you have a source which has wide irradiance angle and this is say receiver here this is also wide. So, whenever the receiver is moving in any direction it is able to collect light.

So, this is non-directed line of sight and this requires wide irradiance angle or it requires wide FOV. So, that you are able to capture the light from any site. So, this is an example of non directed line of site. The third one is diffuse, in the diffuse case suppose this is your Tx, this is wide angle and the light falls onto the ceiling and gets reflected.

So, let me this is the light coming from the Tx and here it is say Rx it will get reflected here. So, the light for example, will get reflected here and it may fall on to the receiver. So, this I am let me you know denote this with some dot. So, this is a reflected light. So, in this case the transmitter is a wide irradiance angle and Rx is also wide field of FOV the issue with this is that the receiver collects light from all paths.

So, there are different paths and they have different path length. So, it will basically result into a multi path, because of multipath so there will be a delay spread and there is a possibility that this delay spread is so much that it might exceed the bit duration and in such cases there will be a ISI.

So, with this configuration there may be limited data rate. So, these are the 3 you know configuration directed line of sight, non directed line of sight and diffuse. In addition to this let us discuss you know when you know you are able to make either the transmitter or the receiver you know track each other or only transmitter is tracking receiver or only receiver is tracking transmitter.

So, in the case of fully tracking for example suppose the receiver is user is say somewhere here and transmitter is here and both have tracking mechanism. So, it will align itself it will align itself in the direction of receiver so that effective communication takes place. So, both Tx and Rx both have tracking mechanisms both have tracking mechanism.

So depending upon the location of the user and orientation of the receiver the transmitter is able to align itself, so that you get maximum signal propagation. So, this is fully tracking the other option is Half tracked, in the half tracked you have only the receiver which is tracking the transmitter.

So, this is let me write this is fully tracked and this is say for example receiver and this is transmitter, this transmitter is fixed and receiver let me make the receiver somewhere in the corner. So, it will align itself so that it is in contact with the transmitter. So, this is less complex because you require only tracking mechanism in the receiver where the transmitter is fixed and it is this kind of solution is good for multi user scenario.

So, wherever the user goes it can orient itself towards the transmitter. So, this is sort of useful configuration for multi user setup and third and the last and the last thing is non tracked where both the transmitter and receiver they are fixed. So, in this is half tracked in non tracked you have one transmitter here one receiver here it can be both are fixed.

So, there is no tracking mechanism so it is the least complex because there is no tracking mechanism involved and orientation is also fixed. So, this is a low cost solution, but there is you sacrifice on the signal to noise ratio. And so, this is the typical configuration you will encounter while studying this course.

And we will be basically focusing our you know examples which we take will be non directed line of sight. Wherein you have transmitter fixed which is my LED which is there for elimination and then there is a receiver and it has wide FOV. So, depending upon wherever you go you either get a line-of-sight contribution of the light or you get non line of sight contribution of the light.

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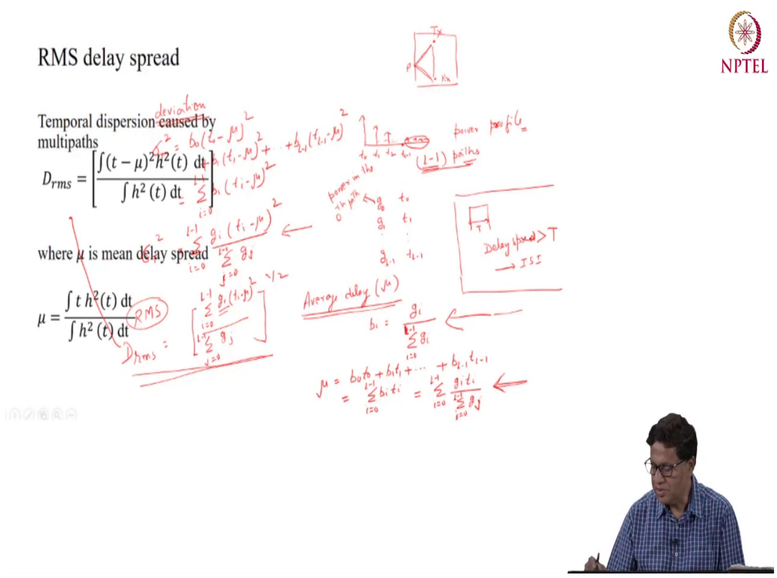

So, now let us discuss about the RMS delay spread. What we mean by RMS delay spread? So, as I had explained you this is say Tx optical source and this is say Rx here, now this can get light or intensity from directly from Tx or it can get some reflected path and this way there will be infinite number of reflections.

And it can have multiple reflections as well this I have shown only one reflection and direct line of sight here, but there can be multiple reflections. So, when you see at the receiver you will see intensity profile or power profile. For example, line of sight maybe this at t 0 and then the light which is coming from say one reflection travelling a longer path and you know this has some reflectivity say reflection reflectivity constant as rho.

So, the light will get attenuated and this light will arrive at little later say t 1 with a reduced amplitude so on and so forth. So, this will go on decreasing t 2 and a stage will come when the intensity which is received here is actually very very low or it is some sort of equivalent to noise or spurious noise.

So, we will sort of ignore those things and we will only handle the components or the reflected light intensity which has got some significant value of amplitude or power. So, this is some sort of intensity or power profile power profile optical power profile ok. So, now let us see the power in this and suppose there are l minus 1 such paths which contribute to the light at the receiver which contribute you know significantly to the receiver.

We are neglecting these spurious or the components which are very low. So, assume that l minus 1 pass contribute to the power at the receiver and the power say g naught for the first path at t 0 and this is say g naught at t 1 and this will be so on and so forth g l minus 1 at t l minus 1. So, the last one here is a t l minus 1 this is the say power in the 0th path and similarly this power in the first g 1 and so on and so forth.

So now, if I find out the average delay let us first try to find out the average delay, let me denote this as mu. So, for finding out the average delay let us define one quantity say b i which is g i over some total power which is i is equal to 0 l minus 1. So, this is a ratio of you know one component ith component with respect to the total power.

So, the g i is the power in the ith component divided by the total power. So, I define this as bi. So, my average delay mu will be b 0 t 0 plus b 1 t 1 I am weighing it against the power of each component. So, the last one will be b l minus 1 t l minus 1. So, this is my average delay weighing each other weighing each delay by fraction of the power b i.

Now, this can be represented as b i t i where i is going to 0 to l minus 1. So, this is my average delay and I can put the value of b i here. So, this will become l minus 1 g i t i divided by i is equal to 0 l minus 1 g i. So, this is my average delay mu. Now, let us also try to calculate the deviation square of deviation.

So, square let me define that as v as sigma t square sigma t square will be again weighing by v naught this will be t naught minus mu whole square plus b 1 t 1 minus mu whole square plus b l minus 1 t i minus 1 minus mu whole square. So, this is the deviation and I can write this as b i t i minus mu whole square, where i is going to 0 to l minus 1 paths and I can put the value of b i from here.

So, this will give me i is equal to 0 l minus 1 g i t i minus mu whole square divided by summation g i i is equal to 0 l minus 1. Actually, I should use a different symbol here. So, this will become j actually otherwise there will be confusion this is g j. So, this is t i minus mu. So, this gives me deviation and if I want to calculate the root mean root mean delay spread that is RMS value of delay spread RMS value of delay spread.

Let me call this as DRMS will be this quantity square root of this quantity. So, let me write again here, so here also it is g j right. So, this becomes an expression for RMS value of the delay spread. So, this is how you define the root RMS value of the delay spread and if you want to calculate this in terms of to make it mathematically convenient to solve.

Then this can be also written as h square t is actually in terms of impulse response. So, g i is the power in the ith path which is equivalent to h square t and then t minus mu whole square divided by the power which is in terms of impulse responses integration of h square t d t.

So, one can write the value of D rms in this form as well and where mu is the delay spread which I have calculated and this was the mu part and you can also write this mu in terms of the impulse response which is given by mu is t, which is similar to this equation t into h square t which is your equivalent to g i divided by integration of h square t dt.

So, these are this is how the delay spread is defined and it is very important because you need to control this delay spread if you want to have high data rate transmission. Because in general if your bit rate is say t or symbol time is t and your delay spread is greater than t delay spread is greater than t, then there will be a heavy amount of inter symbol interference.

So, you have to ensure that your delay spread should be less than the t and that decides what is the data rate you will get inside a room or using optical wireless communication? So, normally a ratio of 10 factor of 10 is required your delay spread should be 10 times smaller than the symbol duration t. So, that is the ideal condition to have.