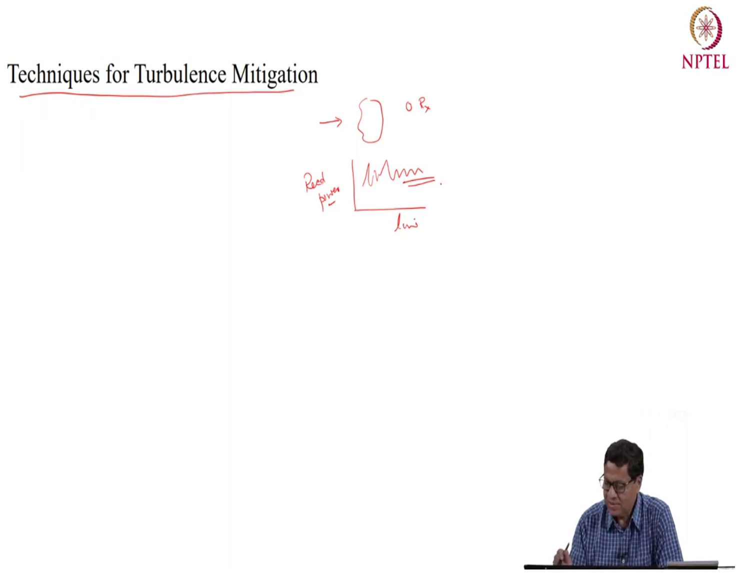
Optical Wireless Communications for Beyond 5G Networks and IoT
Prof. Anand Srivastava
Department of Electronics and Communications Engineering
Indraprastha Institute of Information Technology, Delhi

Lecture - 10
Part - 3
The Techniques For Turbulence Mitigation

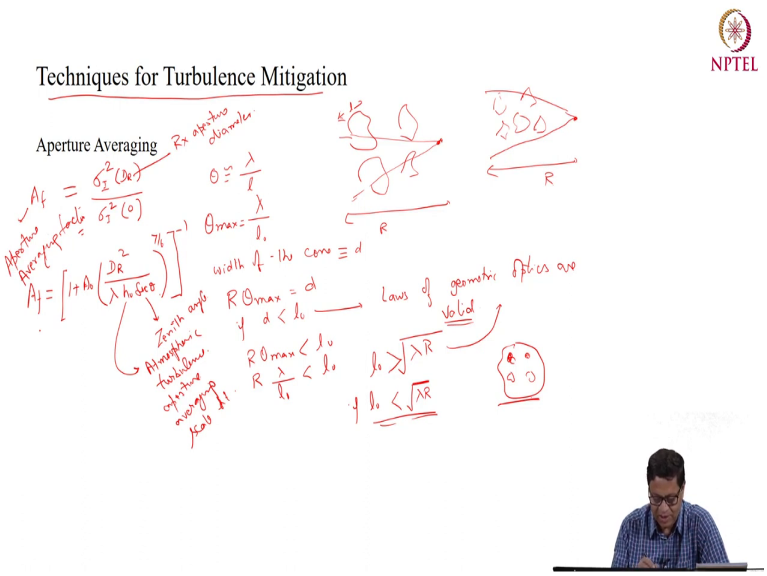
(Refer Slide Time: 00:30)



So, if the receiver size is very small. So, for this receiver size is very small. And, there is a laser beam and in the atmosphere because of the turbulence, there may be this laser beam will be either deflected, scattered, then you might miss the receiver. So, there will be lot of fluctuations which will happen the received power.

So, if you see received power versus time, the power will fluctuate because of the turbulence. So, let us now understand what are the different techniques, which can be used for turbulence mitigation.

(Refer Slide Time: 01:11)



So, one of the scheme is aperture averaging. Now, in aperture averaging, what as I explained in earlier that there are eddies in the atmosphere. So, there are there may be big eddies or smaller eddies. And suppose you have a point receiver here, then I say this is the cone and the light is collected by this receiver. This is a case of bigger eddies for smaller eddies, you can have something like this.

So, this is your say point receivers, where the receiver aperture is not very large and there are many smaller eddies inside the cone. So, what happens that if this distance is say R, that is, a range. And if I calculate what is the typical angle of the cone say theta is approximately lambda by l, where l is the size of the eddy.

So, this is for example, l. So, there is a typical theta and the theta max will be actually governed by the smallest eddy. So, this will be lambda divided by l naught, where l naught is the dimension of the smallest eddy and if I calculate the width of the cone, width of the cone and designate this as d.

So, this width of the cone d will be R, that is, a range theta max is equal to d. So, that is a typical width of the cone. Now, width the if d is less than l naught, that is the width of the cone is less than the size of the eddy. In that case, the laws of geometrical optics will operate. Laws of geometric optics are valid.

So, let us find out a condition where we can have laws of geometrical optics. So, d less than l naught. So, this R theta max is d less than l naught and theta max is lambda by l naught. So, this becomes R lambda by l naught into l naught. And this gives me an equation which is l naught greater than lambda R square root of this. So, as long as this condition is valid, the laws of geometric optics are valid.

The other condition could be if l 0 is less than lambda R. That means, there are many smaller eddies or smaller cells inside the cone. And because of this, the light will get reflected or diffracted and you are likely to get speckle pattern at the output because of you know smaller eddies inside this cone which are made which are as per this condition.

So, in the receiver basically you if it is a point receiver, then probably you will get only one speckle pattern and sometimes there may be full intensity there or you know there may be no intensity. So, there will be lot of fluctuation there. So, if you use a bigger receiver not a point receiver increase the area of the receiver, then you may get several speckle patterns.

So, some will be high intensity, some will be low intensity and you can you know add them and average out. So, by increasing the area of the aperture, you can capture the laser beam or the light. So, idea is to increase the receiver size rather than using a point receiver in order to get significant of significant amount of received power.

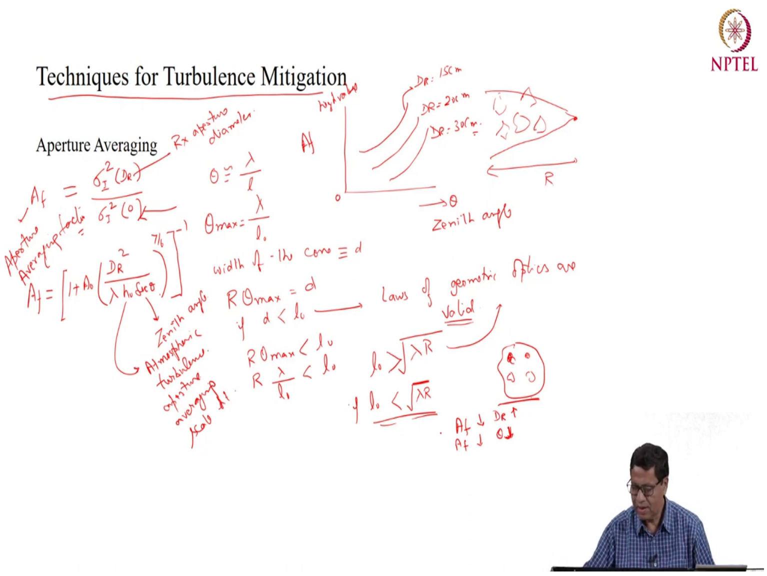
So, this is called as aperture averaging and this aperture averaging is we can define this by a factor let us call it A f where A f is the aperture averaging factor aperture averaging factor and this can be defined as the scintillation index when you have a wide receiver having received diameter as D R. So, I am denoting this as D R divided by scintillation index when you have a point receiver that is let me denote this as 0.

So, this is the receive aperture diameter. So, this is how aperture averaging factor is defined and we can calculate the ratio of this scintillation index when you have RX aperture diameter of D R and scintillation index when it is a point receiver. So, it can be shown that this is equivalent to 1 plus A naught where A naught is some constant into D R whole square into wavelength then h is 0 I will explain what is h 0 and sec of theta this is raise to power 7 6 and whole thing is minus 1.

Where theta is the zenith angle and h 0 is a height calculated this is atmospheric turbulence aperture averaging scale height and theta is a zenith angle it takes into account the slant because when the wave propagates it makes an angle. So, it takes care of that angle. So, that is why this sec theta is coming here.

So, this is A f and we want this A f to be as low as possible and for making this A f let us see what are the parameters, we can you know tune in order to get a low value F. So, let me draw a curve typical curve which has which is for different values of D R and zenith angle.

(Refer Slide Time: 09:04)



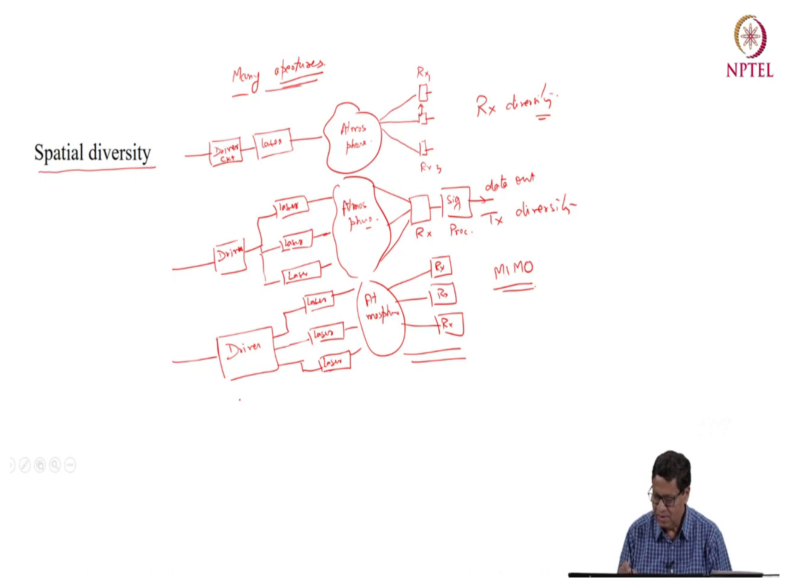
So, this is say on the x axis you have the zenith angle the theta this is zenith angle and this is aperture averaging factor A f and it is plotted for different values of D R. So, it would be something like this. So, this for example, is D R is equal to 15 centimetre, this D R is equal to 20 centimetre and this is equal to this is 20 centimetre and this D R is equal to 30 centimetre.

So, we notice here two things as angle and this is low value of A f say close to 0 and this is high value of A f high value of A f. So, as the angle zenith angle increases the A f value increases which gives a low aperture averaging factor and as you increase the value of D R, then there is an improvement in the A f value.

So, in effect the A f value because we want this A f to be very very low which means you know this quantity should you know tend to it should be high right. So, point receiver should be point receiver should be able to capture all the light. So, as A f decreases to get A f decrease there are I mean two possibilities one is the D R should be increased.

That is the receive aperture diameter should be increased or the theta that zenith angle should be which is the slant angle which makes which the beam makes with a normal that should be decreased. So, these are the two possibilities by increasing the receiver aperture and decreasing the zenith angle will make the A f value as low as possible. So, this is in brief how turbulence mitigation can be done using aperture averaging.

(Refer Slide Time: 11:24)



The other technique which can be uses spatial diversity. So, in aperture averaging you know in order to have you know multiple speckle patterns on the receiver the area of the receiver should be high so, that I can capture you know good amount of light, but the flip side is that if the area is high then that phosphoric noise which is captured by the receiver is also high. So, in when you cannot increase the area of the you know receiver aperture very high because it will you know also increase the atmospheric noise.

So, this is one issue with the average aperture so, instead of having a single aperture let us think of having many such apertures many apertures receiver apertures. So, and these receiver apertures should be kept very close to each other and the distance between the two should be more than the coherence length.

Because what we want that the received signal which is coming on to these receiver apertures they should be they should not be any correlation between them. So, and that is only possible if you keep those two apertures or whatever number you have you know it should exceed the coherence length should be greater than the coherence length.

So, one of the simplest example, could be if I have this is say for example, a driver circuitry for a laser and this is the laser part which is getting modulated and then this is the laser beam and then you have the atmosphere here this is say atmosphere and then you have a three different receiver for example, or there can be many.

So, this is a case of received diversity there are three zeros let us say and this is R x 1 R x 3 and you get signal on to all these receivers and the distance between these two receiver should be more than the coherence length. So, that the signal received by the receivers are highly are uncorrelated.

So, you get different outputs from here which can be processed. So, this is an example of a receive diversity. So, even if the light is affected by atmosphere you will get signal in one of the receivers and you can use different techniques for getting the signal back. So, this is a case of receiver diversity. Similarly, we can have a case of transmit diversity.

So, in this case you have the driver for example, for the source and there are many transmitters. So, laser 1, laser 2, laser n. So, I am drawing here 3. So, this is laser this is laser. And all these laser beams they are passing through a atmosphere and then you have all the signal coming they are collected by a receiver here this is the receiver part and then some sort of signal processing here to get your original signal back.

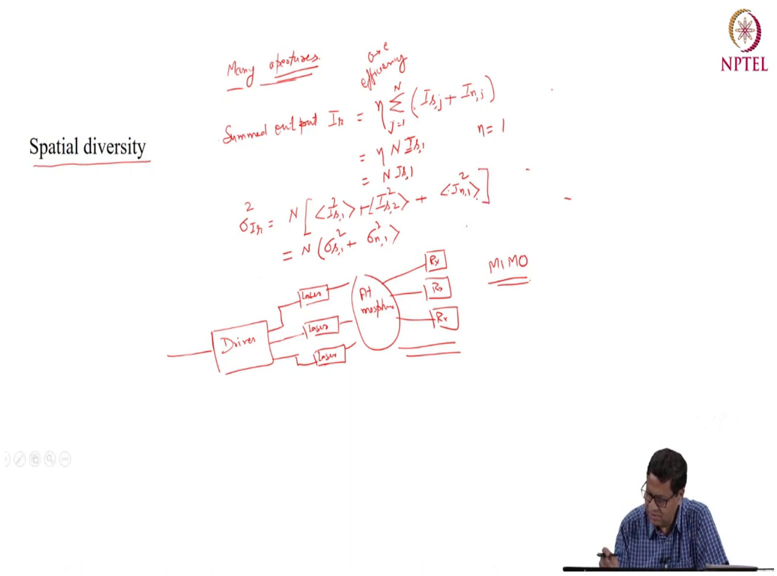
So, this is a data out. So, this is a case of this is transmit diversity atmosphere. And the third option can be we can have a multiple important multiple output which means there are many transmitters and there are many receivers. So, it will be something like this. So, this is your driver circuitry laser driver and then you have multiple transmitters. Here I am showing 3. This is multiple transmitters.

So, this is laser 1, laser 2, laser 3 and then you have the atmosphere here. This is the atmosphere and you have multiple receivers.

So, it is a case of MIMO where you have multiple input multiple transmitters and multiple receivers. So, this is a case of MIMO. So, using these techniques either receive diversity or transmit diversity or you know MIMO configurations you can mitigate the atmospheric turbulence.

Let us now understand how this MIMO will help in reducing the in actually you know improving the performance of the system. So, let us try to understand this. Maybe we can remove this part here. So, let us see what is the maximum input or maximum input you get at the receiver.

(Refer Slide Time: 17:34)

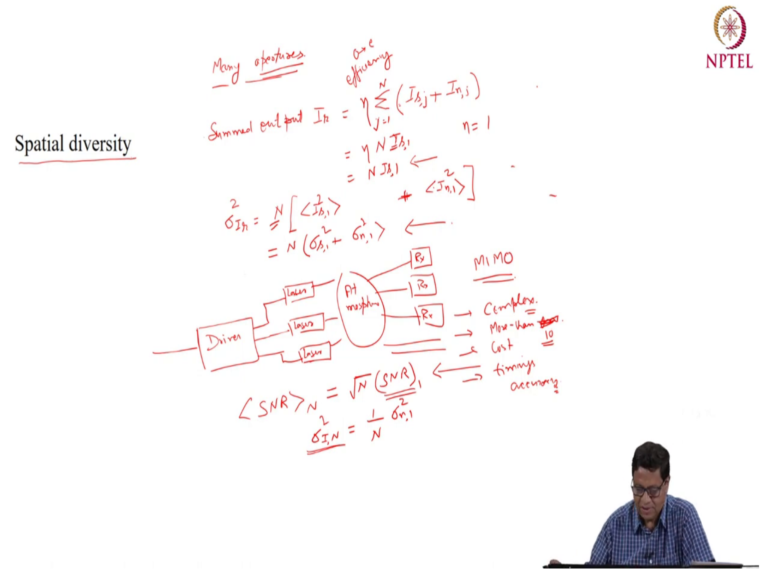


So, let us that will be a summed output. Let us denote that as I r will be equal to eta. This is some efficiency parameter which is converting from optical to electrical. So, this is efficiency because you will be using some device which will convert from optical to electrical. So, this eta is a efficiency parameter and then you will add the signals coming from all from all the receivers. So, this will be summation I is equal to 1 to or j, j is equal to 1.

Suppose there are if suppose three there are n receivers then this will be j is equal to N and then I signal this is at the jth receiver the current at the jth receiver plus there will be a noise element so, I n at the jth receiver. So, assume that all receivers are identical and they are getting outputs. So, I am trying to calculate the best case. So, this will be eta and then it will be N times I s 1 that is the signal from the one receiver and they are all same. So, multiplied by N and I can for I can take this eta is equal to 1.

So, this becomes actually N into I s N. So, this is the summed output and if I calculate the variance which is sigma square of the current I r it will be N times I square s 1 plus I s 2 square so on and so forth plus I n 1 whole square. So, this will give me N basically s 1 square plus square n 1. So, this term will not be there I am sorry about this. So, this term will not be there.

(Refer Slide Time: 20:44)



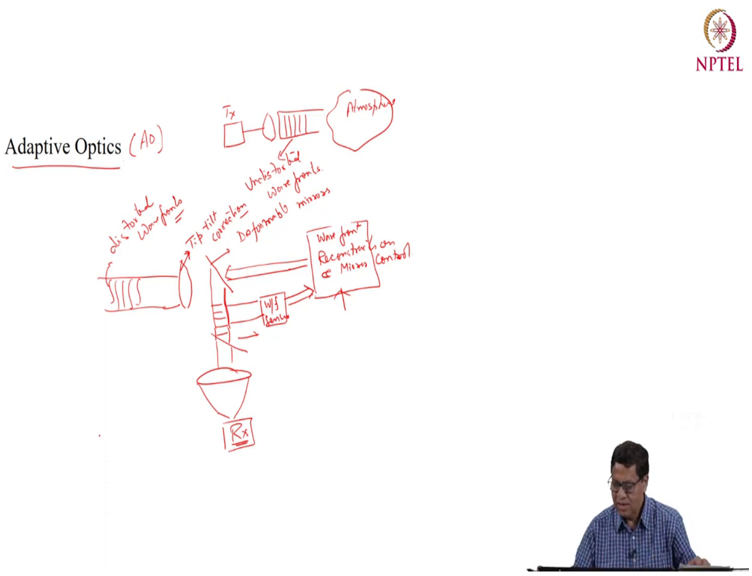
So, this is actually n times the same logic assuming they are all identical this will give me N i square s 1 plus the noise part and this is equivalent to N variance in the signal and variance in the noise of 1 multiplied by N times. And this is my noise power and this is my signal power and if I calculate the signal to noise ratio effectively for N such receivers will be SNR N and if I divide what I get is root N because this is this will be root of this so, root N into SNR of 1 link.

So, basically there is an increase of root N times there as compared to SNR of 1 link. So, effectively there is a improvement if I use multiple receivers and similarly on the same ground I can calculate the noise power and it will be noise power of N will be 1 by N of it gets reduced by a factor of N as compared to a noise power in a particular receiver. So, this will be s 1 sorry this is N 1. So, there is a reduction of effective noise power.

So, using a special diversity you gain in terms of signal to noise ratio and your effective noise power gets reduced, but such a receiver you know where you have multiple transmitters and multiple receivers it is actually complex and it require more space and also you know because a space constraint you cannot have a diversity you know more than 1.

So, typically you know more than 1 more than 10 you cannot have you know receivers or transmitters at either side and it will increase the cost there may be issues regarding the timing accuracy. So, these are the some of the issues timing accuracy. So, these are the few issues which are there when you use you know MIMO structure for combating turbulence effects using spatial diversity.

(Refer Slide Time: 23:44)



So, this is one method and the third method is use of adaptive optics which is also called as AO. So, in adaptive optics what happens actually there is a undistorted wave front at the transmitter. So, let me first make the diagram. So, this is for example, T x and you have this is a some sort of lens and you have undistorted wave front which is going to the atmosphere. So, this is the you know atmosphere part and these are undistorted wave front wave fronts and distorted wave fronts.

So, when they pass through the atmosphere these wave fronts they are distorted. So, these are the wave fronts which are you know distorted. So, let me make this diagram the receiver part here after the atmosphere. So, what I receive is the undistorted wave front this is sorry distorted wave front distorted wave fronts and I use some sort of correction here and is a it is a it is possible you know when the atmosphere there may be some phase fluctuation.

So, in order to you know handle those phase distortion or phase fluctuation these are the systems used in telescopes. So, we are also trying to use similar system for FSO system. So, this is a undistorted wave front and then you have some sort of arrangement which is it is a control closed loop solution. So, this is tip tilt correction this.

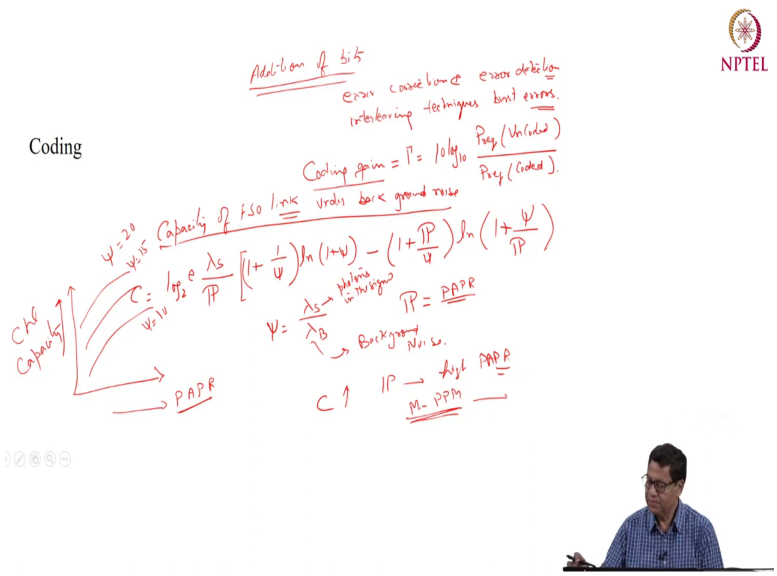
So, this thus tilting of the tip so, and then also you have some you know mirrors which is which are deformable D for. So, you can change the orientation of these mirrors Deformable reason mirrors and these are actually controlled by a device which is called as wave front reconstruction and mirror control wave front reconstruction and mirror control.

And these things when they are reflected through this beam splitter, you start getting the corrected wave from here and this also there is a wave form sensor here and this unit goes here and this the wave form the distorted wave forms actually comes through a beam splitter comes to the wave form sensor and then this block is wave form construction and mirror control.

It changes the mirror which are deformable mirrors and you get the corrected output and which can be collected using some arrangement here and this can be collected by a lens and then this is a receiver. So, basically depending upon the effect which atmosphere produces one can send some you know test builds or test patterns and you know calibrate the system.

So, that whenever the actual data comes it is corrected by a set of a tip tilt characters and deformable mirrors. So, basically the phase correction can be done or whatever the fluctuations are there in the phase they are corrected and it is received by the receiver. So, this is how adaptive optics can be used for turbulence mitigation which is happening in the wave front.

(Refer Slide Time: 28:38)



Another option is coding. A coding as you know is actually you add some bits addition of extra bits addition of extra bits and these addition of extra bits can be used for error detection and error correction. So, error correction and error detection one option is to increase the transport power which may not be possible every time.

So, you use you know insert some extra bits and so, that whatever errors have happened in the channel because of the channel turbulence they are detected and they are corrected. So, basically you do not increase the transmit power, but use some extra bits. So, the extra power can be traded against by adding you know extra bits for error correction and the error detection.

So, sometimes one there are you know in FSO systems there are some burst effects. So, you use interleaving techniques to take care of burst errors, interleaving techniques to take care of burst errors. Now, the reduction in power which you get by way of doing coding is normally defined by a quantity which is called as coding gain.

So, coding gain is very important concept coding gain. So, let us you know denote this as gamma this will be 10 log to the base P power required when you have uncoded signals uncoded divided by the power required when you have the coded signal. So, this indirectly tells about the reduction in power by having coding in the bits coding in the waveform.

So, this is called as coding gain and if I calculate the capacity of FSO link. Under background noise under background noise this can be given by a formula which is C log 2 exponential lambda S and this is say P which is PAPR I will explain about this into 1 plus 1 by psi log natural 1 plus psi minus 1 plus PAPR divided by psi into log natural 1 plus psi divided by PAPR. So, this P is peak to average power ratio PAPR what is the peak power in the signal and what is the average power in the signal?

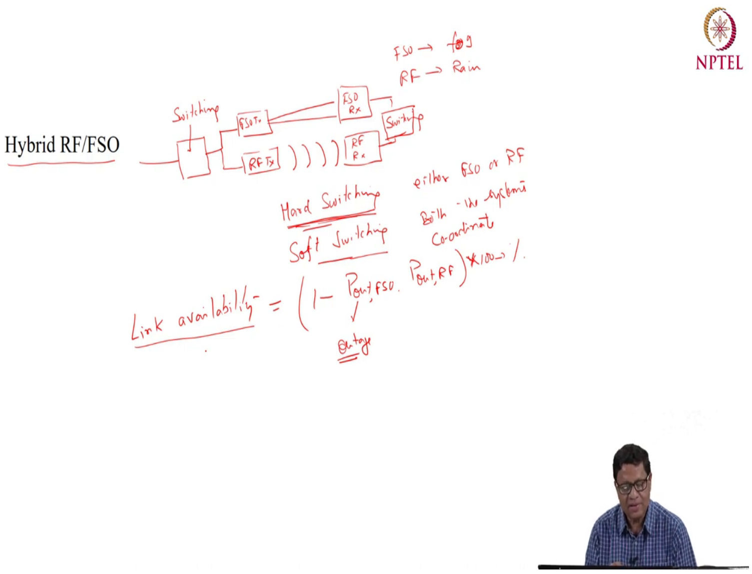
So, this ratio is called peak to PAPR peak to average power ratio and this psi is number of photons signal photons divided by number of background noise. So, this is a photons in the signal and this is the background noise. So, this is how the channel capacity of FSO link is defined in terms of you know PAPR parameters and this lambda S the number of photons required for the signal for correct or detection of the received signal and lambda B is the background noise.

And so, if you see here this C will increase if you have you know high PAPR and high PAPR can be obtained by using for example, you know M-PPM kind of modulation which we will discuss in later lectures when we discuss about the modulation part. So, that is why in FSO, system you will see you know use of this particular modulation techniques because it gives you enhanced capacity.

So, this is one way another way of handling or mitigating atmospheric turbulence. And the and then if I plot for example, in this case this is a PAPR and if this side is channel capacity it will be something like this for different values of psi and psi is lambda S by B.

So, this is for example, 20, this psi is equal to 15 and this psi is equal to 10. So, as your PPR increases there is a improvement in the channel capacity as you know given by this formula and it is plotted here in this graph and that is the main motivation for using multi-level or multi pulse position modulation techniques for FSO, communication.

(Refer Slide Time: 34:57)



Another method which can be used for mitigating the atmospheric turbulence is use of both RF and FSO. So, in normally what is done here, you have the input stream and then this is a switching block or switching at the transmitter switching at the transmitter. So, this is switching and then you have two systems one is FSO transmitter the other one is RF transmitter.

Because if you see FSO they are very sensitive to fogs those kind of disturbances and whereas, RF is more sensitive to rain kind of this is fog rain because the dimension of the rain droplet is somehow is similar to the lambda. So, under rain conditions RF may fail under fog conditions FSO may fail.

So, depending upon the situation either you switch to FSO or you switch to RF that is why one requires a combination of free space optics and a backup RF link. So, this is FSO link for example and this is you know the RF link. And this side you will have FSO receiver and you will have RF receiver and then you have another switch here this is switch or switching.

So, there are two options available one is hard switching which means either you are getting signal from the RF part or from the FSO part depending upon the situation. So, this is called as hard switching. So, either FSO link is working or RF link the second option is soft switching. So, here actually both are used for decoding so, both coordinate both the systems coordinate. So, essentially you get signals from both the palms and then you process it to get more advantage. So, this is called as soft switching.

So, if you do this having both RF and FSO link. So, your availability of the system or the reliability of the system increases and the link availability is actually can be defined as 1 minus P outage this is for the FSO part multiplied by P outage for the RF part. So, this is actually outage into 100 if you want to have in percentage this is in percentage. So, the link availability improves if you use two systems the transmitter and switcher and then there are two options available either hard switching or soft switching.

Soft switching is still better performance as compared to hard switching, but difficult to implement hard switching is easier to implement. So, this we will also analyse in you know future classes to analyse the improvement in the link availability if I am using both hybrid RF and FSO system. So, these are the few methods for controlling the or mitigating the atmospheric turbulence.

So, we will stop the discussion on outdoor modelling now and next time we will discuss about the how to model a underwater system. So, that will complete the modelling of all the parts. So, we started with indoor modelling we have now done outdoor modelling and the third is we are going to do underwater modelling and then we will move on to different modulation schemes which are required for different systems whether it is indoor or outdoor or underwater.

Thank you.