Signal Processing for mmWave Communication for 5G and Beyond

Prof. Amit Kumar Dutta
G. S. Sanyal School of Telecommunication
Indian Institute of Technology, Kharagpur

Module - 02
Wireless Channel - A ray tracing model-Part-II
Lecture - 12
RMS Delay spread and Doppler Effect on channel

Welcome, to Signal Processing for Millimetre Wave Communication for 5G and Beyond. So, today we will be taking the last part of module 2 that is the Wireless Channel Model which is a which is based on the ray tracing, and it is the part-II. And today is the last class for the module 2. Today, we will be covering most of the things of RMS delay the spread and the Doppler Effect on the channel.

So, we will be starting the Doppler effect of the channel which is nothing but the time varying part of the channel.

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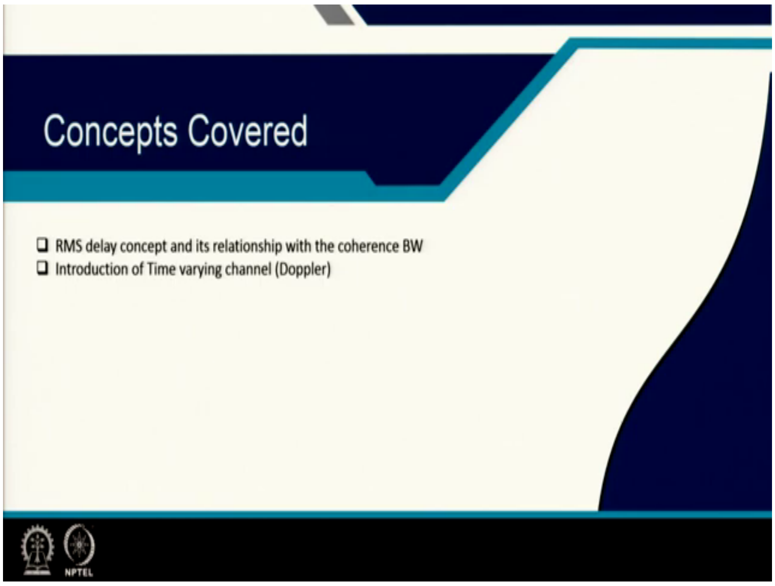

Things that we will try to cover here are the RMS delay concept which we did not introduce it so far. We have introduced only the delay spread concept, but there are certain issues with the delay spread calculation and its relationship with the coherence bandwidth, so that is the reason RMS comes into picture. We will explain in details what is the issue and why RMS was brought into picture.

And then we will also introduce the concept of time varying channel which is predominantly present in any cellular system 4G, 5G everywhere because you have Doppler. And that Doppler or speed, your transmitter, receiver, everything will be in motion right, in fact, the reflectors, scatterer, the complete medium can be in motion. So, when that is the case, then how the channel would be, because channel will be now a time varying channel.

So, we will be covering or it at least we will introduce the concept of time varying, and subsequently we will continue the time varying part.

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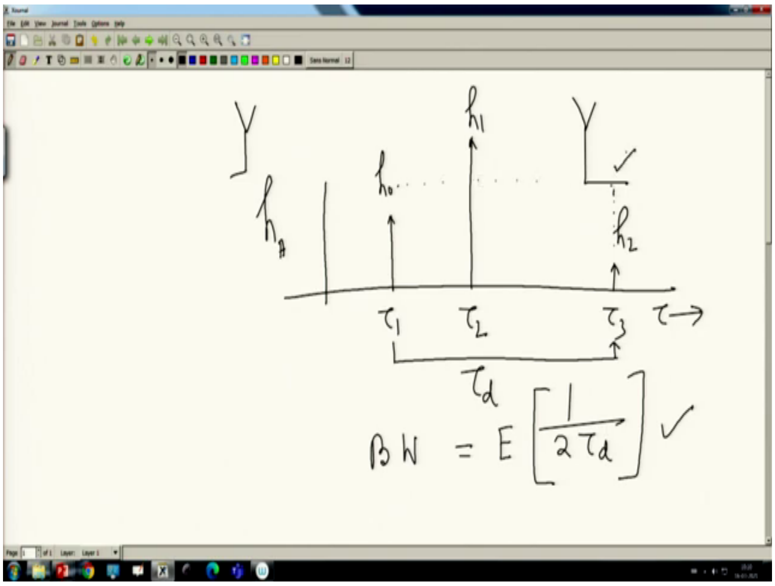

So, let us finish the RMS delay part. So, we know what is a delay spread. So, you have the transmitter antenna, you have the receiver antenna right. And we have said we are still in the single antenna case. And if it was an RF or analog domain, and we have shown you there might be delay like that right. So, you have a reflectors probably a tau 1, may be a scatterer tau 2, or something at tau 3.

So, this is your channel this is your channel RF or analog. I am not so paranoid about whether it is analog or RF, its analog assume it. So, these are all complex values. I can say this is my h 0 in the analog sense.

This is my h 1 in the analog domain, this is the h 2 in the analog domain, it is not the same digital after the ADC, and that is my tau that was my delay. So, what was the delay spread that we defined? Delay spread was this one. So, let us define it as a tau d.

Now, we also said the coherence bandwidth of the channel that is the bandwidth of the channel that would be let us put an expectation that is a fair things to do always it will be 1 by 2 into your tau d ok, so that was the assumption here. But there are issues with this kind of model, when you know the coherence band coherence bandwidth, when you try to find out the coherence bandwidth with respect to the delay spread.

The problem here is that this model predominantly assumes that all the points here are of equal gain; if not equal, at least there are comparable gains – at least the last part ok.

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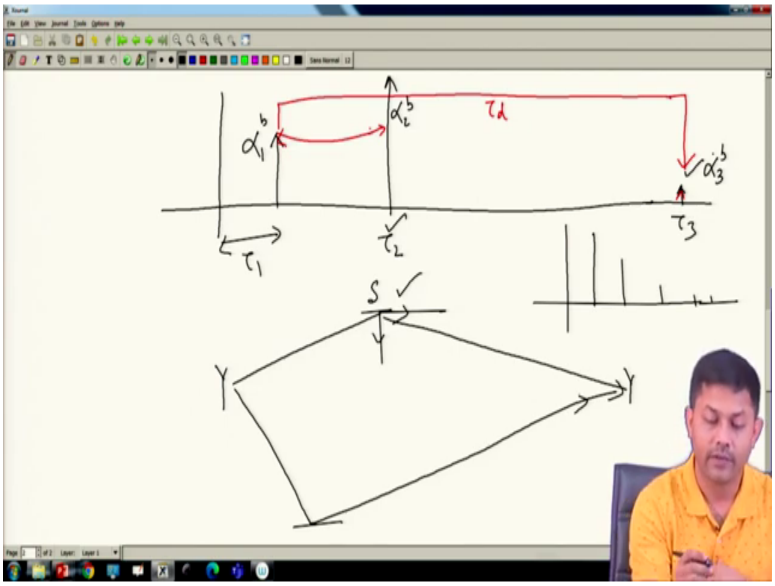

But think of a scenario where you have a channel like this, where you have some path here analog wise that is another path here. Now, have we noticed one thing that I have intentionally drawn a larger taps in the second case compared to the first case? So, why it is so? Never assume that the path which is coming at the beginning may always have the higher power though it is having a shorter delay.

Shorter delay does not mean that it always gives you the higher power, because it may happen that the fellow which may be a say scatterer and it has a very bad scattering. So, it scattered most of the power only a small fraction can just reach there right.

So, for example, you may have a transmitter here, you may have a transmitter here, and you have a reflectors say this is the first case you have say scatterer. And it scatter most of the power, but only a very small fraction can go here, but it is the shortest path. Whereas, I may have a larger reflector here just a sitting reflector which can have a larger delay which means larger path also.

Though it has larger path, so path meaning larger path loss will also be there, but because the scattering so high in the shorter path even with the path loss it still manages a higher power. So, point here is that never assume that a second or third path will always give you a less power.

So, what I am trying to say is that the if I draw a profile of the channel path instantaneous channel path, it will never happen like that, need not be. I am not saying it is not necessary that the profile will be like that it can be randomly effect, all depends on you know reflectors or scatterer.

Now, let us say I have one more path here coming back to the RMS concept; I have one more path here which is something like that. So, this is tau 1 delay; this is at tau 2 delay; this is a tau 3 delay. Now, apparently you may think that your you know your path delay or delay spread is very large. So, obviously, your coherence bandwidth will be small. But this gentleman has a very large, it does not have a very large contribution, it has a very small contribution.

Now, if it has a very small contribution why a bandwidth gets too much affected by the small contributory factor, it may not right because the contribution of this gentleman is very small. So, can I create some sort of a weightage some sort of a weightage?

That if somebody gives a more power that has a more weightage compared to the one which has some sort of a lesser power, and that is what that RMS comes into picture. So, this kind of diagram whatever I have just shown you, this coherence delay does not make much sense to us though by definition this is the coherence delay this is the delay spread, this is the complete delay spread.

So, this would be my tau d by definition. But the point here is that this path has so less contribution it is as if like the delay spread is something like that because a third fellow has a very small contribution ok. Now, how do I take care of such kind of things when you have a path, but contribution is almost negligible, and unnecessary in your calculation you may face some sort of a you know some sort of a lesser bandwidth which may not be the reality ok.

So, to avoid that, the RMS concept comes into picture. Now, what is the RMS delay, RMS delay spread definition? So, RMS delay spread definition is the following. Let us say I have a path gain say this is alpha 1, of course, the base band; this is say alpha 2, of course, in the baseband. And this would be say alpha 3 base band ok. So, that is the natural process, you have the gains.

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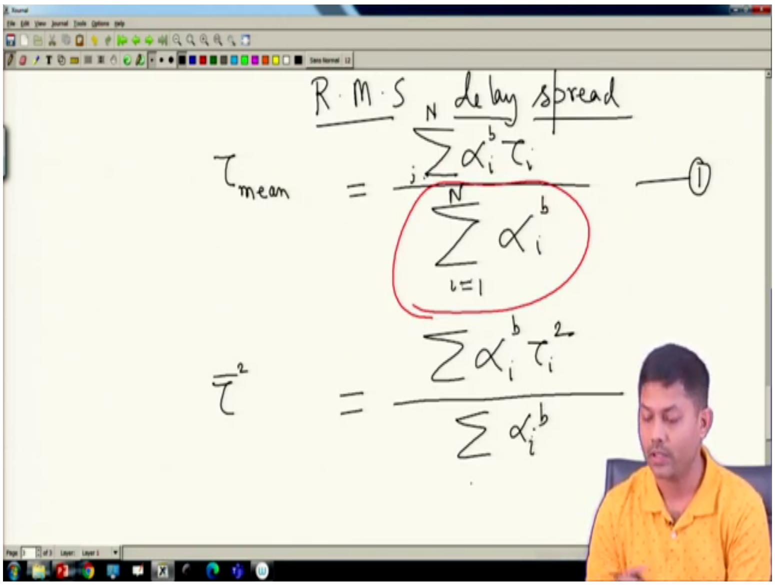

Now, what is the definition of RMS delay? So, I am just drawing now. It is basically the RMS delay spread instead of a non-multiple spread because this makes more sense for us compared to the normal delay spread because normal delays spread as I said if you have a last component that may not be contributory anymore, that may not have a huge contribution. So, why to consider so much on that?

So, RMS delay is defined as follows. Before that let us define a parameter called mean of the delay. So, let us call it mean tau mean. So, what is tau mean? Tau mean is basically the mean of all, it is not a general algebraic mean. The reason is that if you say tau 1, tau 2, the philosophy is the following; tau 1, tau 2, tau 3, if I say what is the mean?

You definitely say tau 1 tau 2 plus tau 3, and there can be a statistical mean you can have, or you can just have a; I mean if the system is a static you can just have a algebraic mean also that is not an issue. Or if you have a statistical thing, you can just create a if you know the you know if you know the PDF, you can create a expectation of that.

But the point here is that what we are not contributing what we are not considering is the magnitude of individual paths because that is the case right. It is not the value of tau 3; it is basically the magnitude of the channel path at that particular tau 3 that matter. So, the definition of tau mean is not just the algebraic or statistical mean it takes into account the path gain as well.

So, it is defined as summation of you know your alpha i b that is the thing and tau say i, i is equal to; i is equal to 1 to as many as path exist here. So, if you have n number of path i varies over there ok. Then summation of all your alpha i b i is equal to 1 to N. So, that is the definition.

So, here what I am doing is I am trying to do some sort of a normalization using this summation, at the same time I am multiplying it. So, now you see the tau i is multiplied with its magnitude of the gain, so that mean if the gain is small naturally that particular tau i may not have a very significant contribution to the delays pressure that is how the balancing act is done ok.

Let us define one more point called tau bar square. By definition it is called tau bar square ok. It is defined as follows. Same definition as in equation 1, but there is a slight change here. It is squared now; rest of the things remain same, rest of the things remains same ok. So, this is equation number 2.

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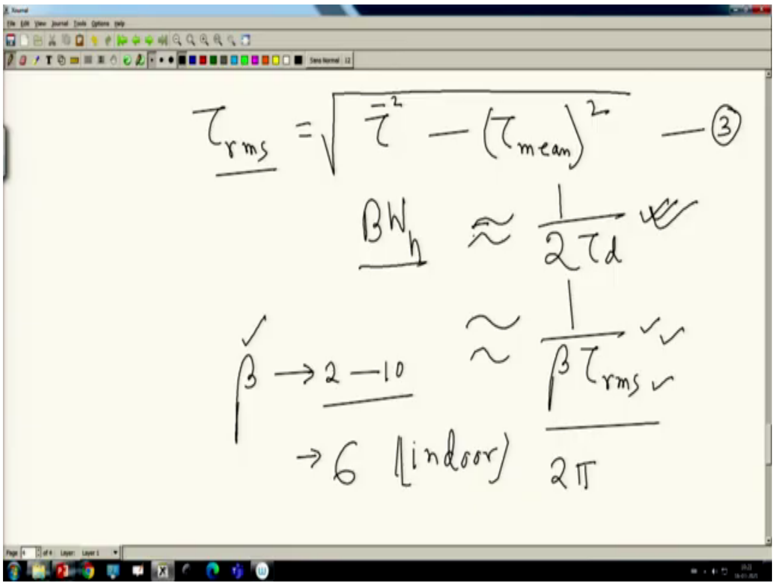

Then next finally, the RMS – Root Mean Square. So, this is that bar square whatever we have defined equation number 2 divided by tau mean whatever we have defined in equation number 1, square it. So, that is the definition of my tau RMS ok. Now, this makes much more sense than the you know the exact delay spread. Delay spread is delay spread. There is no question on the delay spread. Delay spread defined is minimum to the maximum point.

But taking delay spread into the bandwidth consideration may have that issue whatever I have explained. So, now, instead of delay spread and bandwidth coherence bandwidth relationship whatever we have sent that is your bandwidth of h coherence bandwidth, we have defined it right tentatively 1 by 2 of tau d. Instead of that what we define now is more of this definition. Some function say some factor called beta into tau RMS.

This is more appropriate definition of the coherence bandwidth between the tau RMS. So, this is the relationship between tau RMS and bandwidth. Now, this is ok, this only assumption here is that the first case assumption is that the even the last fellow, the last you know the last delays point is also contributing significantly, but this makes the balancing act.

See if that fellow does not contribute significantly, it will create some sort of balancing. Now, this is more appropriate you know relationship. Now, the what is this beta factor? This beta factor can vary. It can be between 2 to 10 depends on it depending on where the channel model is concerned. For example, if it is indoor, indoor it will be approximately 6, approximately ok. So, this will be approximately 6 if it is indoor.

Like that there will be various way of defining the channel. If it is outdoor, if it is rural, this beta can vary. This beta can vary; sometime it could be 2 pi, sometime it could be 7s, 8, different, I mean there are lot of measurement related works happened already in the last decade where beta is defined.

So, this is the relationship between coherence bandwidth and the RMS bandwidth, RMS delay part delay spread of the RMS. Now, this is more appropriate way of defining. But in case the last tau or the last reflectors or the highest I mean last reflector also contributes significantly, this works fine whatever we have defined earlier ok.

Now, next point is so we have defined what? We have defined bandwidth, we have defined coherence bandwidth, we have defined delay spread, we have defined the relationship between delay spread and coherence bandwidth, and then we have modified our definition of coherence bandwidth with the with respect to the RMS value of the delay spread.

And we have defined the RMS value of the delay spread. And we are trying to we have tried to you know create the relationship between that. And then we said it is not a very you know it is not a very exact relationship because there is a factor beta coming into picture, and that depends on the channel environment from any value it can take from 2 to 10 kind of thing, and it all depends on the environment to choose. So, this is the kind of parameters that we have defined for channel.

Now, so far what we have assumed is that channel is just static ok, but that is not the case because your real environment of say 5G, 4G, 2G, 3G whatever you know wireless system you can consider, there will be mobility. Mobility does not mean that only receiver will be moving, mobility can be at the transmitter also, mobility can be the reflector, scatterer those things also.

That mean the complete environment can be in a mobile things ok. Suppose, you are in a train and you are getting a WiFi hotspot. So, here transmitter is also moving, you know receiver is also moving, every reflectors are also moving, all things I mean. Now, whether they have really movement with respect to each other that is a secondary question, but there is a mobility ok, and that is what the reality.

Now, if that is the case, what happens to the channel, we need to understand that. So, moment that becomes a reality where that is like a mobility the channel becomes a time varying, and we try to model that how exactly the time varying nature comes into picture into the channel based on my mobility.

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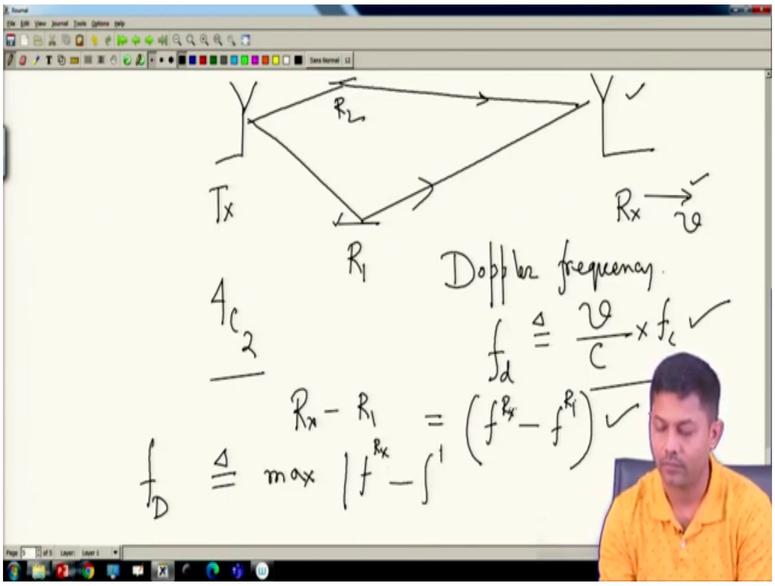

So, let us take again the simple model. Let us take the now it will be straight forward and kind of an extension to whatever we have defined so far. So, this is my original case. This cell is this is my transmitter; this is my receiver. And let us assume I have one reflector here; I have one reflector here. And I may have another reflector that is ok – reflector number 2 ok.

Now, let us say this R 1 and R 2 the reflectors are fixed, but whereas the receiver is moving at a speed of velocity v ok in the direction in the parallel direction, in the direction I have shown it here. So, let us say everything is a two dimension concept here. And I am looking at the whole thing on a plane, and the receiver is moving in the plane in the this direction ok.

So, if that is the case, there is a concept called Doppler frequency. What is Doppler frequency? Doppler frequency is basically the relative frequency that something is happening relative because it is a relative velocity with respect to that, there is a relative frequency comes into picture. It is defined like this D sometime people some books define it as an f also.

So, let me just stick to that notation f d. This is defined as if the velocity is v divided by speed of light multiplied by whatever frequency of RF operation is going on, so that is the definition of a Doppler frequency. So, that means, if the v is there non-zero there will be a Doppler frequency. And what is the impact we will just know that. So, this is just a definition ok. So, let us understand what is its impact, ok.

So, now, there are few more definitions, the definitions are the following. Just like your delay spread what we did is that you have delay between every two element, and we took the difference between the two element, and we took the maximum of it right. So, here also we create some every similar kind of definition here. And we will we gradually define these variables and their impact on the channel model ok. So, this is the first definition.

A second definition is the Doppler frequency difference between two elements. So, here how many elements are there? You have actually four elements – you have two reflectors, you have one T X, and one R X. So, you have several four elements are there. Just like the earlier case we can create 4 C 2 number of Doppler frequency difference between two elements.

So, what does it mean? Let us take the difference between R 1 and R 2 ok. Now, here if I look from the outside, I see R 1 and R 2 are fixed, T X is fixed, but R X is moving right. So, I am say I am observing the whole thing from the outside. So, what does it mean? It means that for R 1 there is no Doppler frequency because it is not moving. For R X, there is a Doppler frequency; for R 2, there is no Doppler frequency; for T X, there is no Doppler frequency.

So, for rest of the three, it is zero Doppler frequency, but R X is having some Doppler frequency. Now, it is just a definition ok. And how many such you know points I can get? If I take the pair – any two pair, I will get 4 C 2 times of pairs I will get it. So, that means, if I take R 1 versus the R X. So, let us say R X versus R 1 ok. So, what is the Doppler frequency difference?

It is the individual frequency difference. So, I may have a say f of R X minus f of say R 1, so that is the Doppler frequency I am talking of. So, it need not be positive because the difference can be positive and negative. So, I should not write a mod here predominantly. So, I should write because it can be negative as well because you do not know how the difference is right. So, I will define it like that, is just the difference between the Doppler frequencies ok.

So, now the Doppler so naturally just like your delay spread, I can also define some sort of a Doppler spread ok. So, the Doppler spread f of capital D i if I denote it Doppler spread is defined as the you know the maximum of mod of every individual. So, absolute value of your difference.

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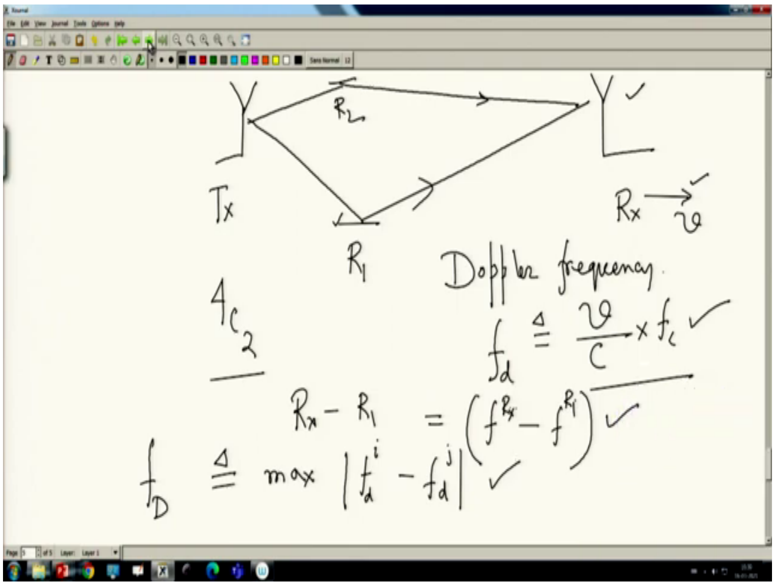

Now, I should not write R X, I simply write it is a d between ith node minus jth node, I write it like that, so that is the definition of my Doppler spread. So, what does the Doppler spread indicate?

Its indicate, it is the maximum Doppler frequency difference between any two nodes ok. So, you take any two node, see what is the difference of the Doppler frequency comes into picture, and take the maximum of that absolute value, so that is my Doppler spread.

Now, these are all definition. I still have not gone into the time varying nature of my channel. Now, we are kind of you know intuit that, because everything is moving in time there will be some sort of a time varying nature coming into picture. Now, this is not the tau domain. Tau meaning it is not the delay spread domain. It is more in the t domain because we have already defined two time notions for channel.

One is a tau, another is t. t is basically the time of progression where you will have the like how you observe the data like t 1 time, t 2 time that time progression I am talking of. And the tau 1 was basically the difference of the you know the delay part. So, there are two time notions that we have seen here.

And when the system is static, the only time domain that appears in the channel is the tau domain not the t domain. Now, the here the t domain comes into picture because now channel becomes time varying. Delay spread is one aspect. Now, the time varying nature how it exactly appears that we need to analyse it.

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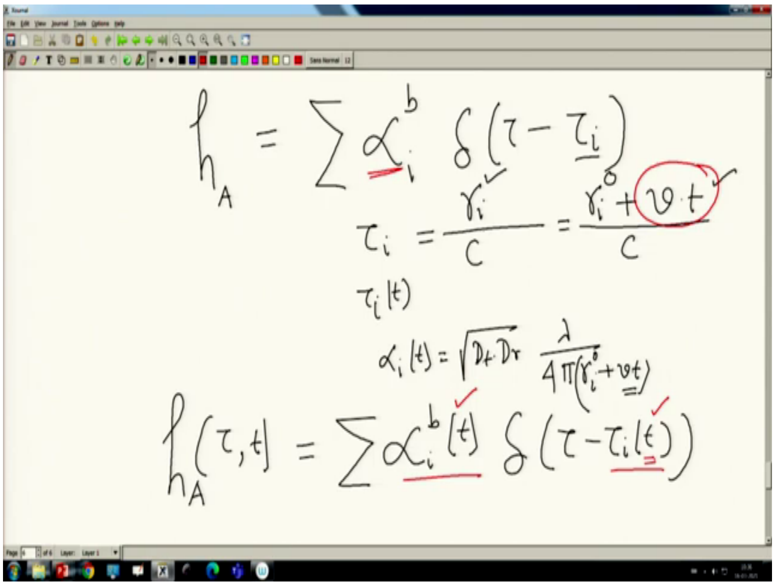

Let us go back our go back to our original channel model. If you look at h say RF for analog. What was the case? That was alpha b i Dirac function of tau minus tau i right. So, that was the; that was the case we have defined it ok. But now what about this tau? What is this tau? Tau is nothing but the distance of that ith reflector, T X to it is basically the distance between the T X to R X through that particular reflector ith reflector that is the time, that is the tau divided by speed of light.

So, let us say that distance is r i divided by C that was the definition now. Now, it is time varying. Why it is time varying? Because r will not be constant anymore for that ith reflector, it may be; it may be varying. So, let us say r i whatever its initial value ok plus velocity if the if something is moving at the speed of you know speed of v that velocity I am talking, and C. This is what it is coming into picture.

Now, does it mean that this velocity will be associated with the ith reflectors? No, it is associated with the ith, not ith it is associated with the receiver because finally it is a receiver that is facing the effect. Whether receiver is moving or reflector is moving, that makes no difference here as long as the r is you know r itself, this r i itself changes. Because if the reflector moves, r i changes; if the R X move, the receiver moves R X changes, or if the T X move for that also R X changes ok.

So, this is what coming because now this is the new you know after t time that is what the data will be coming into picture. So, which means that this tau i is now becomes a function of time because of this fellow v into t fellow that is the only difference coming into picture here ok.

Now, how do I integrate it in our system? Is there any other things that can vary? Yes, what about the alpha? Alpha also varies. Why alpha varies? Because alpha if you look at alpha has three component, one is a path loss component that comes from the Friis equation, another is an absorption component, another is a phenomena dependent component right. We have defined it already.

Now, phenomenon and absorption, they may not change too much based on time because the environment does not suddenly change its nature of material so that the absorption will be so different; more or less with the small time more or less that remains same.

But what about the Friis part, the path loss part? Yes that will be different. Why, what was the path loss gain? Path loss gain was root over of you know D t D r into lambda by 4 pi r i. Now, r i is the time varying.

So, now it will be instead of r i, I will say r i plus you know v t that will be coming into picture. So, alpha also change. Now, this alpha that also becomes a time varying thing that also becomes a time varying because of this t ok. So, as a whole can I say this h A which is the analog channel now that will be of course, it was a tau initially now that would be t also ok. Now, this would be now this will be the case this will be the case. These two components now it becomes a time varying nature ok.

Can I model such things straight forward? Probably, no. Why? Because this is time varying, its time varying. So, the way we the philosophy of modelling is that you treat tau and t, two separately, two separable components, not separable, two separate components. So, first you treat that as a tau given a constant time, and then do something in the t domain, so that is how the philosophy is.

So, in a summary, first you do a tau processing, and then you do a t domain processing. Now, in next class, we will explain more on the modeling of the channel with respect to the time now ok, this t how the modeling can be when I am in a t domain.

And what is it so straight forward, or there are some complicacy arising because of this t domain nature ok. So, with this I conclude the session this particular class. We have just started the Doppler.

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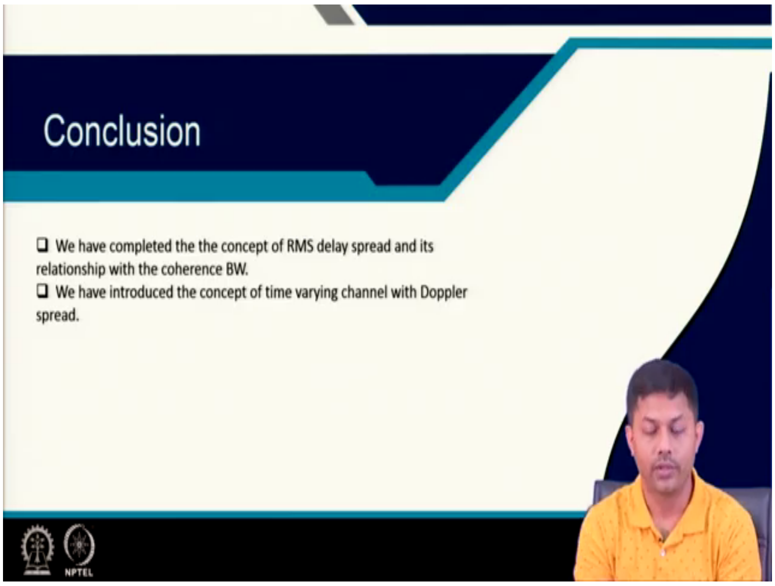

And so in conclusion we have kind of completed the concept of RMS delay, delay spread, and its relationship with the coherence bandwidth. We will give you some assignments definitely regarding this RMS delay spread and the coherence bandwidth case. And we have just introduced the concept of time varying channel with respect to the Doppler spread. So, we will continue this part in the next class.

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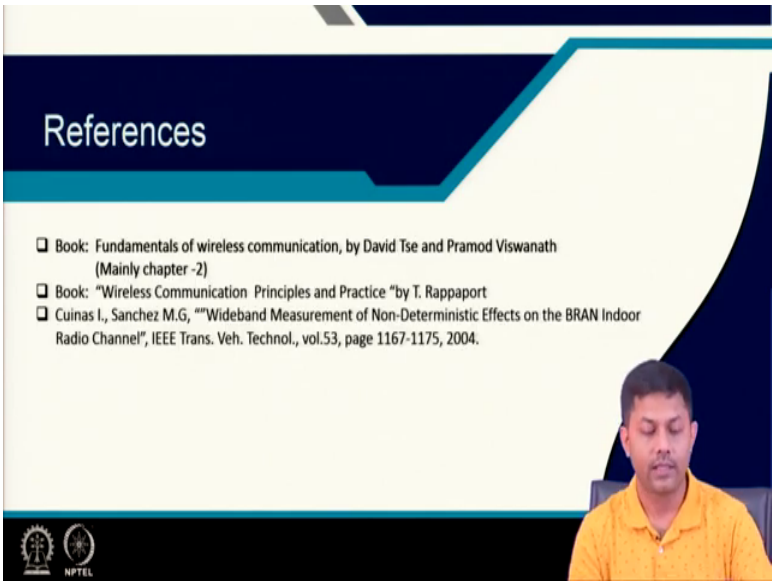

So, these are the references that I follow here. The earlier book by David Tse and Pramod Viswanath, but the second book is very important where the RMS delay part is very well-defined Wireless Communication Principle and Practice by Rappaport. And third paper, I really like this paper because that basically brings the relationship between the RMS tau RMS with respect to the coherence bandwidth for different type of channel model.

It, in this particular case it has taken some indoor models and there are some other models it has taken. So, that I mean how do you find the beta this particular third paper gives that guideline ok.

Thank you.