Signal Processing for mmWave Communication for 5G and Beyond
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Module - 05
MmWave parameters
Lecture - 24
Angle of Arrival (AoA) and Angle of Departure (AoD)

Welcome, welcome to the Signal Processing for millimeter Wave Communications for 5 G and Beyond. So, now, for this module, we have started a new module and this is millimeter Wave parameter. Today is the lecture number 24, we will be discussing more on the Angle of Arrival and Angle of Departure of the millimeter wave.

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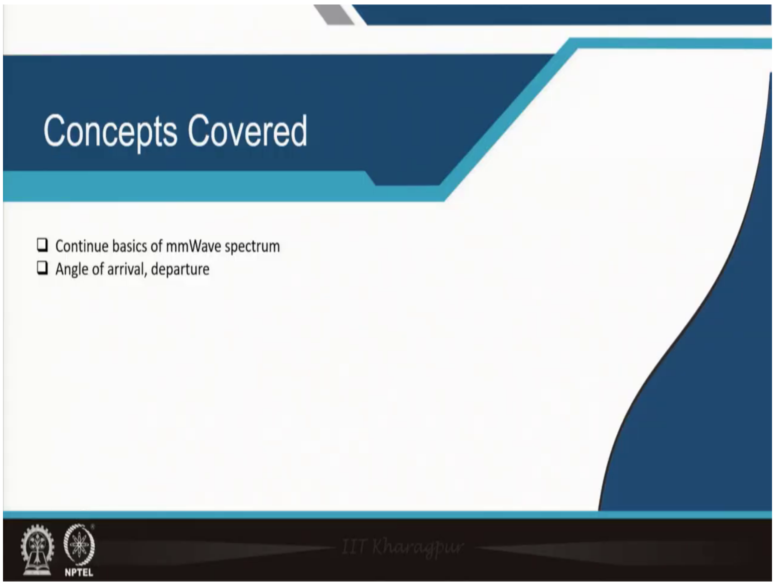

So, we will continue some more on the millimeter wave spectrum and millimeter wave activities and then we will give a concept of angle of arrival and angle of departure, ok.

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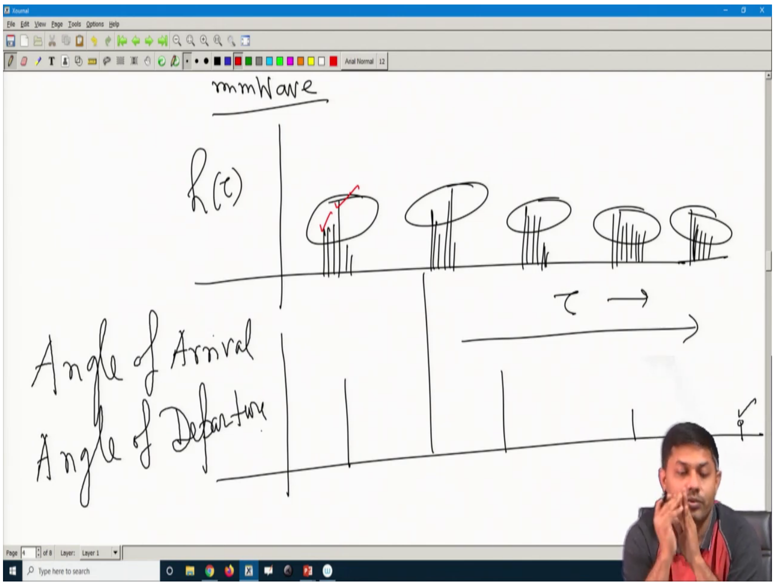

So, far what we have learnt, we have learnt that the h tau in millimeter wave. If I take the h tau, the h of tau was more of a clustered behaviour; it can be random, ok. There is one more difference you can see compared to 6 gigahertz ok, this individual lines can be random. So, their height can be random, because it depends on how the roughness is. But you can see that, you can observe that, as I use respect to tau.

As I go down my tau, it does not mean that the power of individual you know lines are actually going down. So, if I see the profile of a 6 gigahertz, it may be something like that of course, initially it can have higher power something like that; but as you go you know go down my tau, at least the last ones may have a smaller values, but that may not be the case in millimeter wave, because why it all again depends.

If I am in a millimeter wave communication; what are the ranges, where are we actually, what are the ranges that millimeter wave can communicate? If it is 6 gigahertz, it will be kilometers. So, maybe 2 kilometer or 4 kilometer from one base station to the receiver right, but millimeter wave cannot go. If you do not do any directivity of the antenna or if you do not consider any beam forming, only few 100 meters probably maximum depends on your spectrum frequencies.

So, which means that, millimeter wave can be applied in a small geometry, small in the how small; it can be an indoor like office or maybe flats like a apartments I am talking or in a small locality, where the densed population is there, probably you can think of a circle of say 100, 200 meters. Those kind of small densed area, where millimeter wave is a very you know it is one of the good application; of course it has a outdoor applications, but this is one of the good applications where you can think of.

So, as the you know as the range is not so high, I am talking of an application; if it is an indoor what will happen. If it is indoor say for example, I am in a office; if it is office space, what is the maximum range of my office? It is like a floor right, floor could be like a 30, 40 meters that is all, right.

So, within that, everybody is acting as a scatterer and it would not make a much difference from the point if something is a closure or something is a 20 meter down the line. So, that is one of the reason, if it is an indoor kind of environment, you may not see a huge you know huge power fall as you move along the tau.

But you may see some power fall if you go to the outdoor case, but this is definitely a case for the 6 gigahertz. Now, we will be characterizing more on the cluster part. Now, what are the parameters that millimeter wave newly introduces? One whatever was there for 6 gigahertz, the same thing is there also; like for example, individual delay spread and so and so forth will be there. Is there anything else? Yes, there is one more thing that comes into picture.

This concept is called angle of arrival and another concept is called angle of departure, A o A and A o D. So, what is, why we should consider it first of all this two extra parameter, that is so prominent in millimeter wave or it was not there earlier, was it like that?

No, it was there; what is angle of arrival? Let us define it from a from signal processing point of view, which has nothing to do with what RF you are operating on. This angle of arrival is like you can see like it is an angle of arrival.

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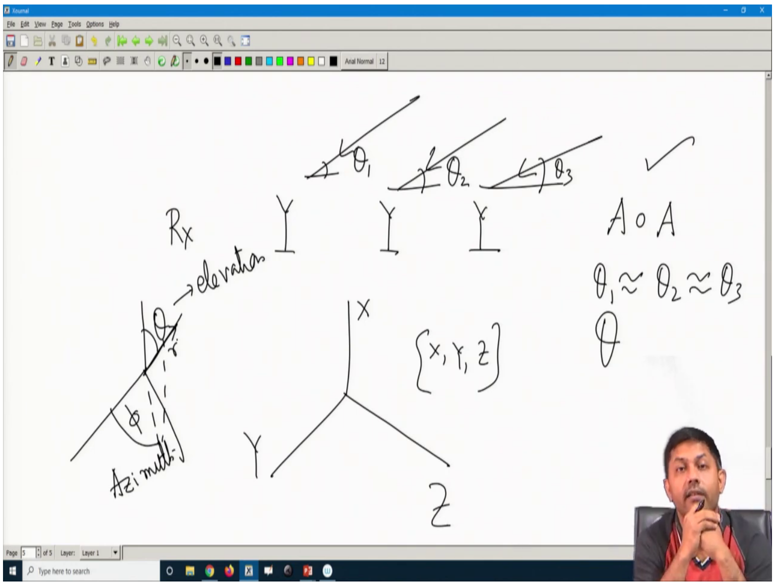

So, if you have a set of antennas, if you have a set of say receive antenna, ok. So, how exactly RF transmission happens, from somewhere it just comes here, right. So, it will be like this,

this comes here right, parallel it can come. But is it like a parallel it is coming? Well, may not be.

Because if the antenna distance is not so far; say for example, my T x and R X distance is just say 2 meters and I have say 10 R X antennas. So, this angle this, this rays may not just appear as a you know appear as a parallel ray; but say sufficiently I am assuming that they are in a larger distance, now how large depends, ok. So, it is large enough to make my ray's parallel assumption perfect, that is all.

So, the angle at which it is incident, angle at which it is incident, angle at which it is incident. So, this may be theta 1, this may be theta 2, this may be theta 3; so these are angle of arrival. So, this is basically your angle of arrival. Now, for our all for our all calculation, this may be the case, we will come to that point; but I am not making a crude assumption right away, we will make that assumption later.

But I can think of at every antenna, the incident angle at which the RF falls onto it is basically called the angle of arrival. Now, it has anything to do with RF speed RF frequency? Nothing, whether it is a 6 gigahertz or a 100 gigahertz, that incidence will always happens. Then why it becomes so prominent in millimeter wave, ok?

It is prominent or it comes into consideration rather, only when you are interested to know the geometry, geometrical positions or location of your receiver or transmitter or you know reflectors whatever comes into picture.

Whenever such kind of consideration come into picture; yes, then this is important, ok. Is it so in millimeter wave? Why suddenly in millimeter wave the locations or geometry becomes important; why not just we did that as we did in you know 6 gigahertz? We are not so worried about exactly in 3 dimension where this point is, right.

We are only worried about exactly what is the distance, not exactly where the position is. So, it was not of our consideration; but it may be of our consideration, if I am interested to look for it. For example, what if I am I want to know; suppose I am doing a transmission and I am there are many receivers or there are receivers and I want to track them. For example, you may see that on a particular screen, I want to know where my you know receiver is moving.

So, I can do that kind of consideration in my applications; see if my application demand that kind of scenarios, obviously I need to know what is the geometrical position, it could be a 2D position or it can be even be 3D. Today is the add a signal processing has come to such a level; you can exactly know where the, what is the geometrical location in 3 dimension, a particular receiver or a particular transmitter is.

So, when you have that kind of consideration; obviously you need to know what is the angle of arrivals, ok. But this consideration was there in 6 gigahertz or sub 6 gigahertz, just that we have been we it was not important for us; because there it was more of a you know how the channel behaves, how the channel taps behave, how the propagation comes into picture and what are the gains come into picture and what are the phase that come into picture.

But now a lot of indoor applications may require that kind of thing scenarios, where I really do not know where the position of the object is. Or later on we will also show you there is a concept called beam forming, where you really need to know what is the geometrical location, exact geometrical locations of that particular object; because you have to create or you have to orient the antenna towards that when.

See so far another issue was in 6 gigahertz, sub 6 gigahertz that, the antennas that we considered or the discussed so far was more of a omni direction. So, there you know geometrical location was not so important for us; because it is omni direction, every you know every direction the ray is radiated and the reception also can happen from any directions. So, it was not so important for us. But what if I want to transmit the power in a certain direction?

Suppose I am sitting in a room and I want to transmit the data in some 30 degree elevation, 40 degree azimuth that kind of some certain direction. Then, obviously this kind of things come into picture. See, even if you do not want to, even if you do not want your application to know where your geometry is; suppose I am not tracking any of the position related things, my application does not require it.

But because I am doing such kind of directivity in my antenna consideration; probably at that moment, angle of arrival and such things come into picture, because I need to know where the data is, where the particular object is present. This is important for us. So, this angle of arrival is defined as that.

So, let us call it theta, theta is my angle of arrival, ok. Now, is this angle of arrival just for a single angle or there are multiple such angle come into picture? Yes, there are two angle that come into picture here; one is that see its a geometry right, geometry if it is a polar coordinate, you need X, Y and Z, right. So, this is say X, Y and Z.

So, this is X coordinate, this is Y coordinate, this is Z coordinate. Now, to express any object in a geometry; I need X, I need Y, I need Z, all three together, right. Now, if it is a polar, I have the similar concept; just that it is not X, Y, Z anymore, rather it will be theta and how that object is pointed, this is it is a phi, ok. So, this is called the elevation angle and this is called azimuth angle.

So, you need theta and phi and of course, the distance r to denote any of this point in geometry in a polar coordinate. So, when I say angle of arrival, then if you say it is falling in a 30 degree angle, it is not very clear right; 30 degree is it elevation or is it in a azimuth space that is important to know, ok. So, angle of arrival it is not just one angle; it may have an elevation angle, it may have an azimuth angle.

So, it all depends on whether you really want to consider a 2 dimensional space or a you know single dimensions single, dimension you know single dimension antennas; like for example, the antennas are like a it is a strip kind of thing. If you want to consider that kind of thing, what angle I need?

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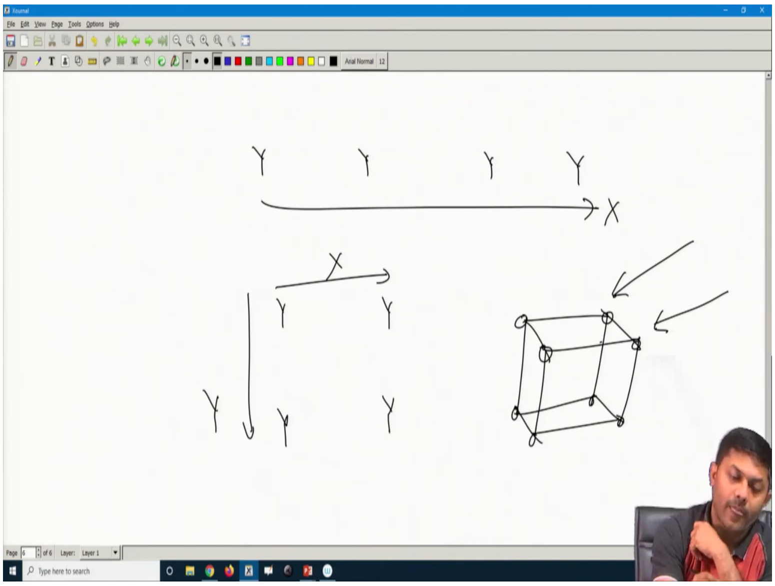

If I have say for example, this receive antennas are like this, it was in a straight line; what angle of arrival I need to consider? Versus a case where I have these scenarios, same for antennas I am placing on this plane in a 2 dimensions case.

So, this is my X coordinate and this is my Y coordinate, this is my X coordinate, ok. I can have even a 3D case; for example, there are cases where I can have just like a box. So, for example, my and I have antennas at every boxes corner. So, this is my receiver structure, this is receivers antennas are placed like that.

So, a ray is incident on them, ok. So, then how I should consider the angle of arrival then in that case. So, such things will now come into picture in our mind right, ok. So, when I say I want to create a geometrical positions, mainly it will be angle of arrival and angle of departure; but it will be elevation angle and with respect to the azimuth angle. Similarly if it is not a receiver, if it is in a transmitter side, say I am in a transmitter side.

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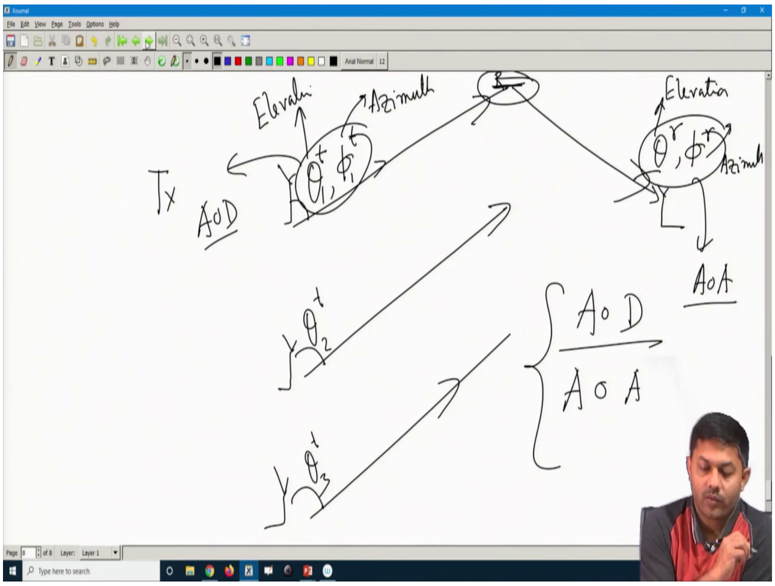

So, I have antenna here, I have one more antenna here, I have one more antenna; just three antennas ok. And let us say these antennas are I would say they may be isotropic, but overall let us say their beams are or rather let it be not I mean isotropic; let it be isotropic antenna, suppose there is a reflectors here sitting there. So, the ray is going and then comes back like that, ok.

So, the angle at which it is incident upon on a particular reflectors, usually angle of departure. So, with respect to that you know transmitter. So, what is my angle of departure? It is the angle at which he is transmitting ok; say for example, he is transmitting at an angle of phi or rather say theta r, I would theta t let us say, this may be reflecting or this may be transmitting with some angle say theta t.

This may be reflecting theta t may be theta 1, theta 2, theta 3 like that. So, these are all angle of departure. So, what it departs from a particular transmitting antenna; so this is called A o D angle of departure. And now we have angle of arrival, these two concepts are very prominent for the millimeter wave. So, it means that, let us let us understand that.

So, it means for every reflector. So, let us say how do, ok. So, now, we understand the definition of angle of arrival, angle of departure. So, it is basically the angle at which ray is incident on a set of receiver antenna angle of arrival, angle of departure the ray at which the set of rays come out from the transmitting antennas and falls on other objects. So, that is the angle of departure.

Now, why am I interested to know that we have already explained; but is there a case while angle of arrival and angle of departure will be different for an object?

Because if I say transmit at a particular direction 30 degree; why it should be falling on a 60 degree on other case? It is not logically correct right ok; will there be a case where it is really that, that we need to understand. See why angle of arrival and angle of departure may be different, because you have a reflectors in between.

If there is no reflector, suppose you are in a free space and you are directing your data or directing your ray at a particular direction. Suppose I have a dipole antenna, it is directing or pointing the ray in a particular direction say 45 degree angle, it is radiating.

So, if there is a receiver in that path as there is no other reflector, he also receive at the same angle right, I mean there is no difference. So, angle of arrival, angle of departure will be the same in that case. But then why it will be different angle of arrival, angle of departure? Because if there is a reflector; suppose I am on a ground, if there is a reflector.

So, this fellow, you can look at this fellow will be transmitting in a particular direction; but when it comes to another receiver, it is not the same angle right, because you do not know how the reflectors will reflect the data. So, here when it is coming up here.

So, the angle of arrival in the receiver side may not be the same. So, angle of departure with respect to the first antenna, compared to the angle of arrival with respect to the second first receiver antenna may not be the same; because there is a reflector sitting inside it ok.

Now, when I say theta r, naturally there is a phi r; because both the angles are required to define the angle of arrival or angle of departure. It is not one angle, because you require elevation and (Refer Time: 19:15) azimuth. So, here also I have phi, ok. So, both the angles will be, it is a set. So, when I say angle of arrival, it is actually a set of angles that is coming into picture there.

Now, if it is a 2, it is a single dimension case, naturally one of the azimuth or one of the things may not be coming into picture. But in general if I consider a 3D geometry or a 2D geometry, both the angles will be coming into picture; one is a elevation angle, one is your azimuth angle, here also this is say elevation angle, this is basically your azimuth angle, ok.

Azimuth angle and this whole set constitute is angle of departure, whole set constitute angle of arrival ok; it is like a set, these are two tuples point. So, it is whole two angles are required to define the exact position, because you need to know both of them together, ok. So, now, let us go back to our millimeter wave system, how exactly I define my angle of arrival and angle of departure.

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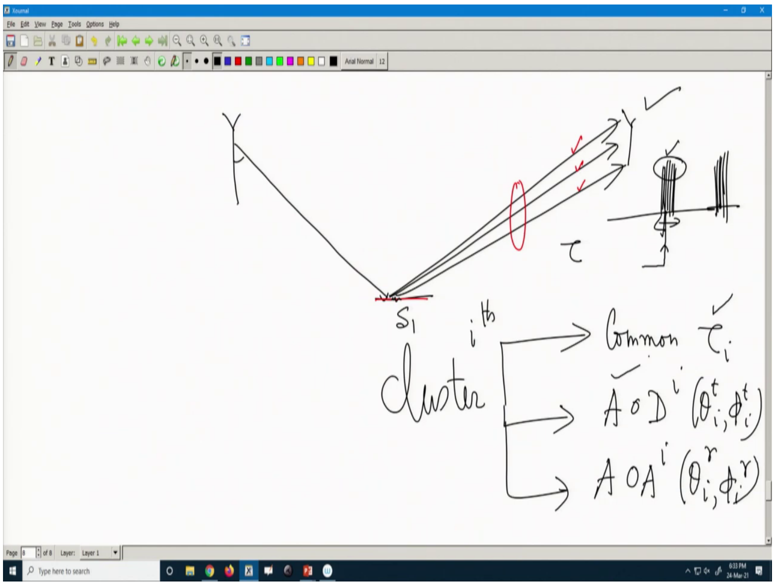

Let us say I have an antenna ok, I have a receive antenna here and I have just one reflectors or a scatterer, whatever you think of. Let us say I have a ray here and let us not assume any lowest path; you can have a lowest path, that is not a big issue. And there are this is how it will be reached here right or at least a bunch of ray go there, that is how we have defined it. I have drawn a bunch of goes going like that, but in fact it will be slightly, it depends on that how the roughness.

So, you can understand. So, this is one of the scatterer. So, let us call it S 1 scatterer, ok. So, what is the angle of arrival now and angle of departure now? Because if you notice angle of arrival or rather angle of departure for the transmit antenna is more or less one angle; whereas the angle of departure at the R X side there are many, sorry angle of arrival at the R X side is many.

Many rays are coming right and there is no guarantee that they will all come at the same angle right, they may have their own point. Now, question is that, will there be so much different if the ray comes from one scatterer, ok? If you think carefully how the spectrum was, how the sorry; not spectrum, how is the channel taps look like it is like a cluster clusters clusters.

Each and every ray has its own angle of arrival and has its own angle of departure right; because this particular say I am thinking of say first one, first one, it has its own angle of arrival and own angle of departure, this also has its own angle of arrival angle of and so on so forth. So, if there are thousand such tiny points, each and every point has its own angle of arrival, angle of departure, ok.

Now, if somebody wants to know in which direction my rays are you know received at a particular antenna, he will be confused. Why, it is virtually not possible to even estimate; if there are thousand such paths, tiny paths are there and it is not virtually possible to estimate so many angle of departure and arrivals. So, can I do some approximation? So, this is how a millimeter wave, signal processings first approach of approximation.

So, what I do here is that, whenever you have this scenarios, that it comes from one bunch; can I have a common angle of arrival and angle of departure for all this bunch? Is it possible? If yes, how do I even get that? It is very much possible, ok. So, the weight you can define is that, I can have one of the one common angle of departure; because for each and every ray, the angle of departure will be slightly different, but it is not so high, because they are all come from the same scatterer.

So, it will not be huge, it will not be huge; why because it is very tiny, look at the difference in the tau domain, very small tau domain difference. So, can I have and also if not, it is not just the angle of arrival; what about my delay spread, delay? See if it is a bunch, if it is a bunch, if it is a bunch; every bunch every you know every tiny fellow, every tiny reflection is also having its own delays delay point.

That mean can I have, can I have. So, can I have just like your angle of arrival or angle of departure, can I have a common a delay point? Because this spread may not be so high, this spread is not so high; it is very densed, because it is coming from the same reflector just the roughness. So, can I have one common delay number, just like your sub 6 gigahertz, can I have it?

Yes it is absolutely possible, because they are all like a nearby point. So, when I go for such kind of engineering consideration; because now I have to do all these signal processings and so and so forth, so lot of estimations and all things will come into picture. So, I try to reduce the number of variables in my case. So, when you have this kind of cluster, cluster; what I will have it is that, cluster will have one common, one common.

See if it is a ith cluster, I will have a common tau i; it will have common A o D, that mean one set of theta i, one set of phi t i. It will also have a common set of angles, instead of each and every tiny angles, I can have common. So, how do I define that? So, can I have some sort of an average? So, one way is that, well can I have some sort of an average; that mean probably in the midpoint if I take it, the guy who is sitting in the mid.

Whatever its delay is, I will say in the whole bunch it is almost the same; whatever that midpoint is having A o D and A o A, everybody is having almost the same one. Is the better, is there a better way? Yes, you can have your better way; you can say this is more of an average, that mean each and every individual tau i or A o D you can you can have it and then you can just average it.

So, it is a common practice that for a cluster, I will not definitely consider such kind of multiple points, multiple variables for each and every clusters, it will be a common cluster. So, it could be either a common RMS for all of them, it could be even a common A o D for all of them, it could be even a common A o A all of them; because otherwise you cannot handle so many variables in your system, ok.

So, in summary what we covered today, we just gave a very brief description about what is the angle of arrival, what is the angle of departure and then how exactly in a cluster, you have a common tau, you have a common A o D and A o A.

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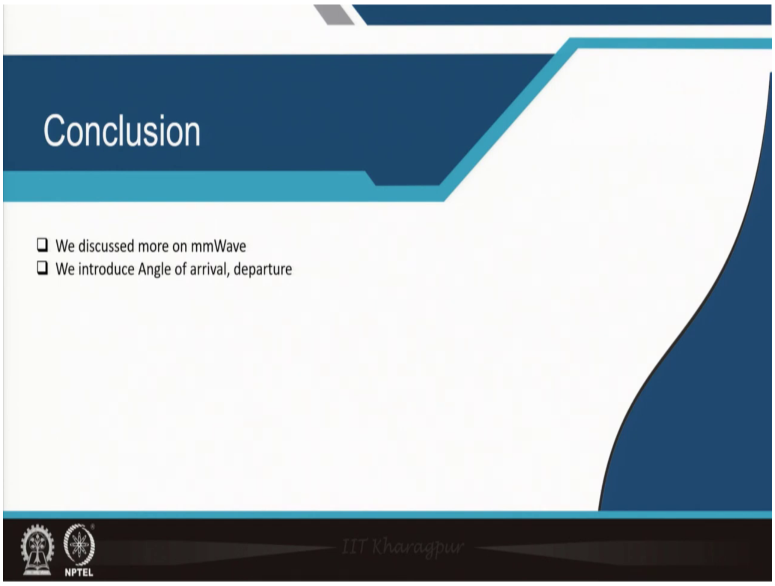

So, if you come to the conclusion of this class; I would say we just discussed more on the millimeter wave obviously, and then we introduced the concept of angle of arrival and departure and little bit on the 3D side. Now, we will discuss more on the 3D side; how do you really get a conversion between x, y, z and 3D, we will now talk about more on that.

And we will also talk about what are the different geometries, at which you can transmit the data's at which you can receive the data's. Now, antenna geometry will now come into picture, which was not even a consideration in the earlier case.

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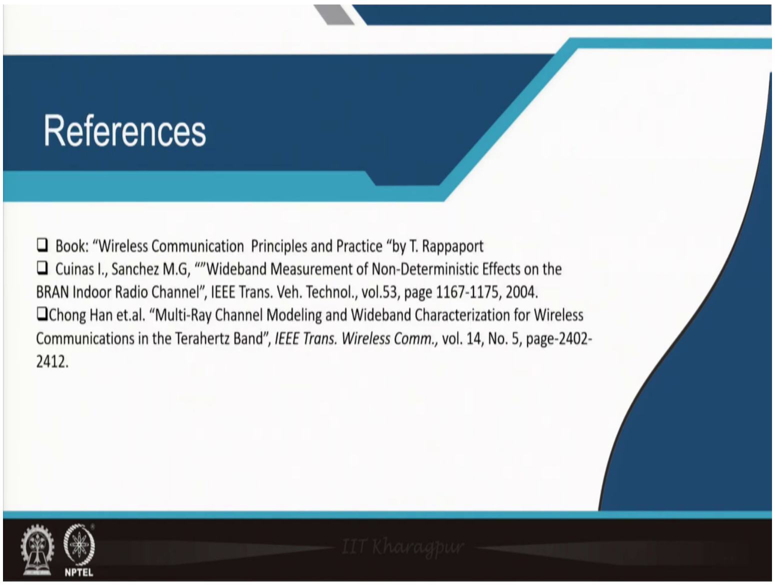

So, with this I conclude the session the references are the same and.