Signal Processing for mmWave Communication for 5G and Beyond
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Module - 10
MIMO-OFDM beamforming
Lecture - 54
MIMO OFDM decode and beam forming

Next, welcome; welcome to Signal Processing for millimeter Wave Communication for 5G and beyond. So far we have covered the MIMO OFDM structure, now today will be going to the MIMO OFDM decoding part and graduating to beam forming. So, what exactly the MIMO OFDM forming, ok and you will see that when you describe the MIMO OFDM beam forming that may be a very simple extension from your MIMO beam forming. We have learnt MIMO beam forming very extensively, but in the parameter estimation, but that will be the next modules activity.

But, at least the structure wise we know how exactly it is done, but so, we know MIMO beam forming we know MIMO OFDM, the only part is now left is just connecting the two dots ok and this will be the easiest task, ok. So, if you understand MIMO OFDM in depth if you understand MIMO beam forming in depth MIMO OFDM beam forming is just a one line or a few minutes statement ok.

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So, this is the content I mean concept that we will be covering it MIMO OFDM decode part which we left it in the last class, the structural we have decode. And then we have motivated what exactly the decoding should be and then we will be talking about the beam forming part ok.

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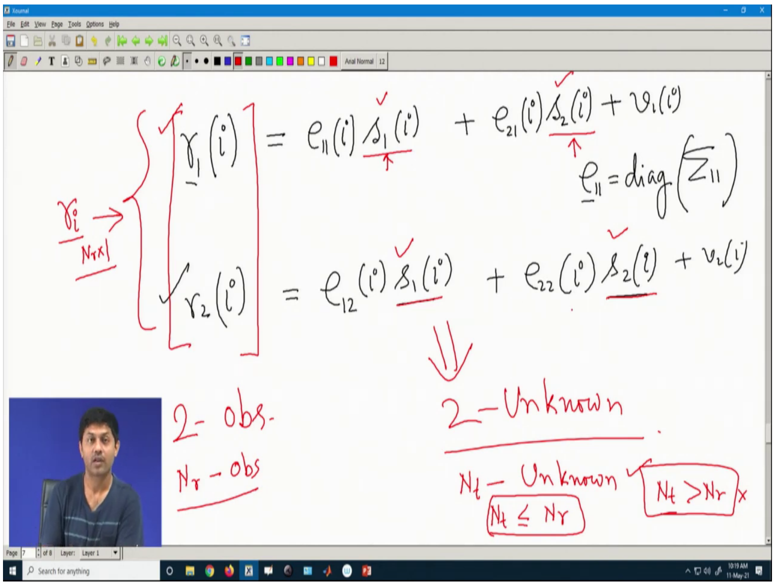

So, this is the place where we left in the last class, right. So, where we said if we have two observations or two antenna rather I am just considering two antenna in our case and this is the point where we left it where you say ok these are the two observation, but I see that individual observation has two unknowns and both the observations have the same unknown; so, which means that, if I have N number of observation, I have N number of unknowns ok.

So, instead of two observation if I say N r number of observation here should it be N r no it should not be N r it should be N t number of unknown ok that is the point we are trying to make it right because it is 2 cross 2. So, it will be two observation, two unknown, but obviously, when I generalize it I generalize the concept N r observation, but N t unknown.

So, naturally if N t greater than N r I think we have discussed in the normal MIMO case that such kind of systems performance should be very poor. We will do some tutorials and

MATLAB simulations and I am pretty sure that; that will make the points much clearer. So, these are the aspect. So, this is not a good condition.

So, we will assume that N t has to be less or equal to N r, then only the whole thing will works, right. That is a normal MIMO restriction because otherwise it will be a rank deficient and the performance should be very poor, ok. So, now let us look at these two scenario r 1 i and r 2 i ok. So, you have e 11, e 21, e 12, e 22. Now, if these two equations are given and you stack so, this you stack it call it r i call it r i or I should not say r i in this notation let me put it this way r i vector, ok. This is not a index rather it is more of a just pointer.

So, r i vector which contains the first antennas i-th element, the second antennas i-th element ok. If there are N r antennas probably you can generalize it N r cross 1 that is it I think you understand that part. So, if this is the case how do I put it in the matrix format? Obviously, because if this two unknowns are all same for all of them, so, I can put it this way.

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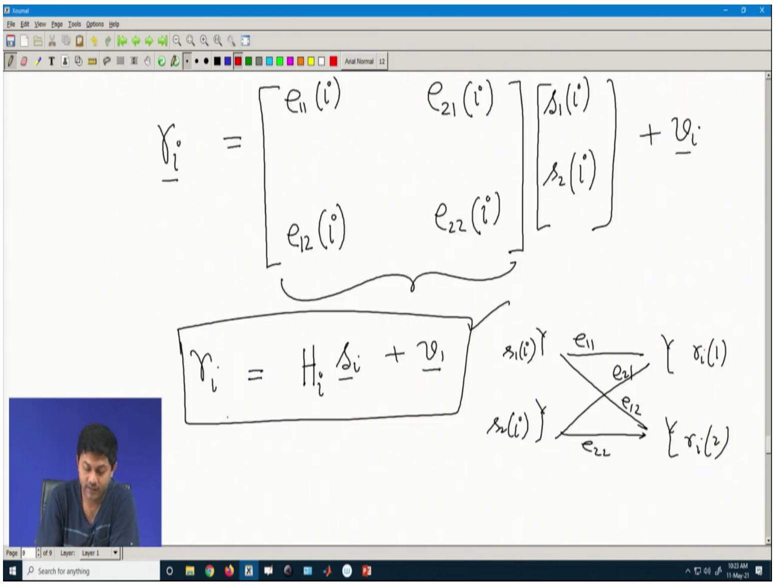

So, r i vector let me put it in different color r i vector. What is that? This will be e 11 i, then what was there e 21 ok and this will be e 12 i and this will be e 22 i, correct? Well, are there this is the s 1 vectors i-th term, this is the s 2 vectors i-th term that is all. And, then there is a constant, ok.

Now, can I call this my equivalent channel or well call it some channel H? As it is i-th, so, I call it i-th channel. It is just like a channel. I mean I can think of it is like a MIMO system, right. Think of it like a MIMO system and each and every antenna have been a single tap. So, that mean if it is as if like it is a two antenna system and the channel taps are single tap channel it will be like e 11 then it is e 21 sorry, this will be e 11 this will be e 21 this will be e 12 this will be e 22 this is s 1 i point it is s 2 i point.

This is r 1, this is r i's 1st element, this is r i's 2nd element. Can I think of it like that? Simple MIMO system with a single tap channel, that is all ok. Now, let us call it s i vector and v i vector. So, what am I getting? The simple MIMO system. So, I had started with MIMO OFDM system, now I am back to MIMO OFDM see MIMO system rather MIMO OFDM system, but there is a catcher. Catcher there are lot of pros and cons in this approach.

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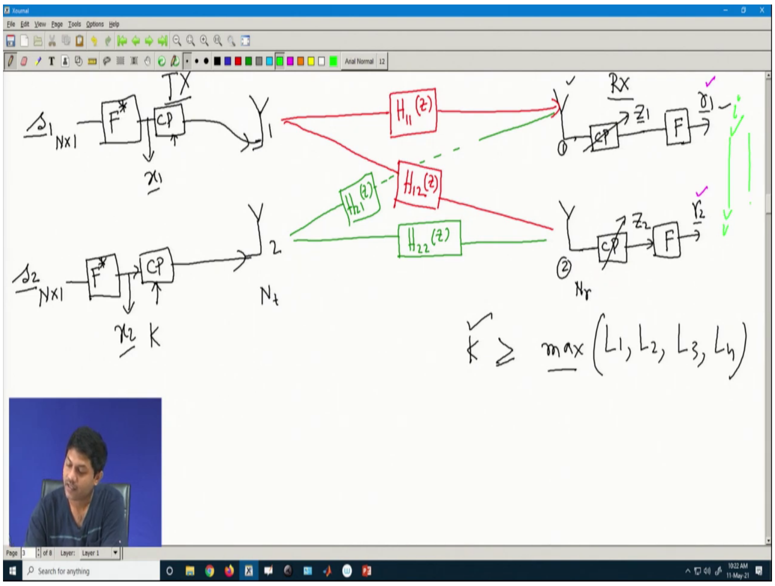

The pros and cons are how exactly my data's are. So, here you have the r 1 vector, you have the r 2 vector, right. Now, how am I decoding? When I decode it is like a I am observing vertically that is the point. So, that means, I am observing the i-th point which is I am taking the this point and this one vertically here also I am taking vertically.

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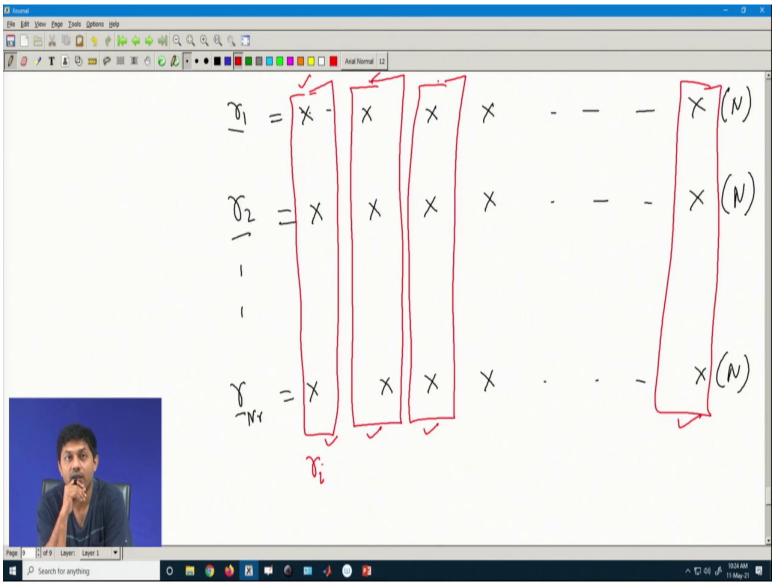

So, which means if I put it in a pictorial form let me put it in a pictorial form. So, I have r 1 vector and there are data's N number of data's I have r 2 vector and there are data's which is also N length and, similarly I have r N r vector and there are data's. So, when I decode it I am decoding what I am just taking the data vertically, I am stacking them vertically. So, I am taking this data first I call it r i vector if it is i-th, then I am taking them, then I am taking them, vertically I am considering it ok. So, that is how I put.

So, that mean first I will take this vector this observation, this observation and finally, this observation. So, N number of observations I am taking vertically and that is the case which is represented here, is the i-th meaning it is a vertically if I consider just vertically see the first r 1, r 2, r 3 and so on so forth. This is how the things are got it. So, this is how I think now probably I put a different notation here.

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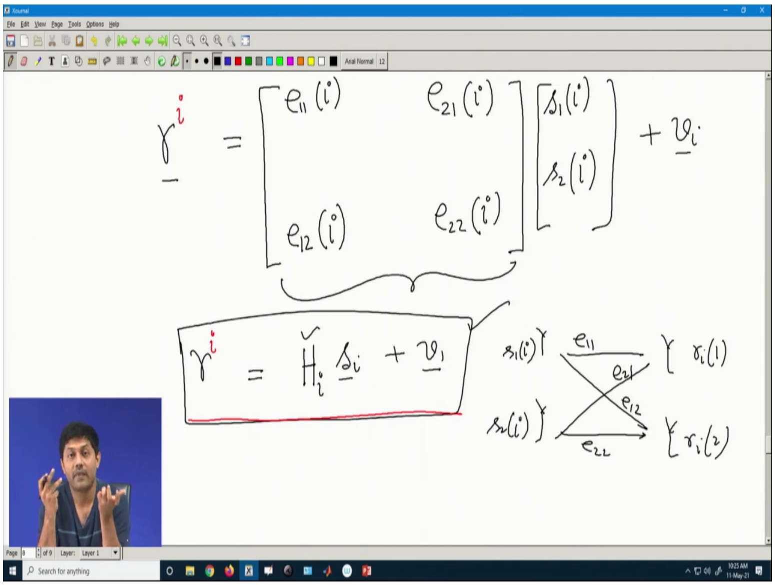

So, otherwise it will be confusing I put a r i here, because if it is r i in the below then it is go back to the, so, r i. So, just the notation here.

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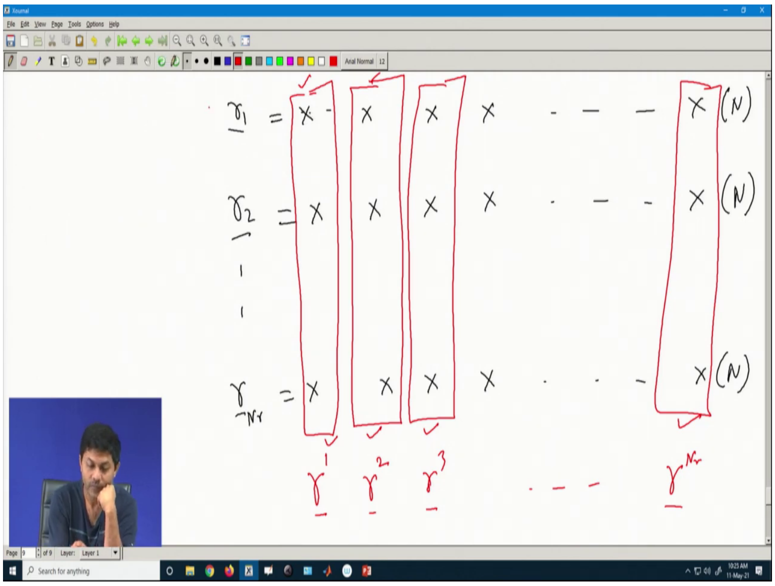

So, here I will call it r 1 vector, r 2 vector, r 3 vector and so on r. So, this will be the case r 2 for the r N r vector. This is how I because it is just a vertical concerns. Now, again I am back to the same problem which I wanted to avoid earlier ok. So, here what was the problem? Problem is that how do I decode it because it is again a matrix it is like a single tap matrix, right. So, how do I decode it? You develop equalizer, right. So, you can develop equalizer.

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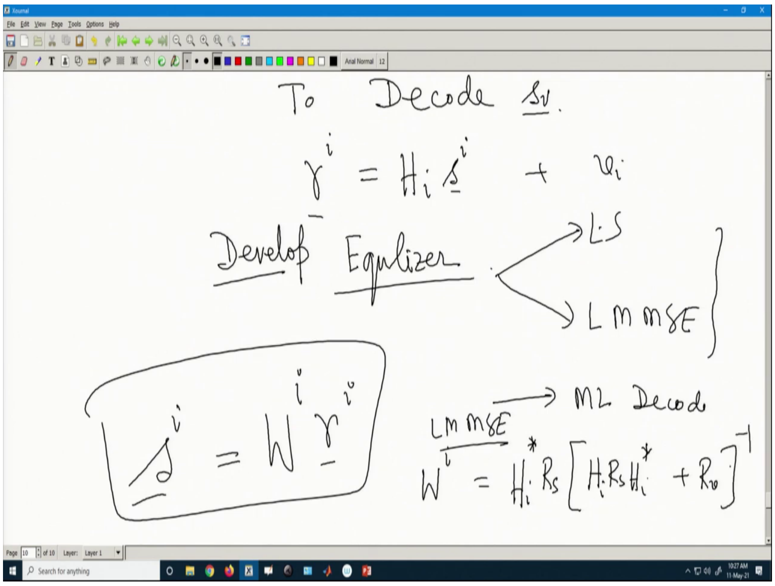

So, to decode s i vector, how do I decode that vector? To decode that vector what I do is this is my r i H i s i I will put it this way and then v i whatever. Now, to decode this s i you take the help of equalizer to develop equalizer because this is a matrix, right develop equalizer. What are the techniques of equalizer? I think we have extensively said that in the context of MIMO it may be least square maybe LMMSE.

Or you can even do ML, now this is not a equalizer. You can also do a ML decoding, but ML decoding might be tougher if the dimension of H matrix is larger, ML decode also you can do, but at least you can conveniently develop this elements equalizers. What that equalizer. So, it means that I will get my s i vector by developing a equalizer where I have to just multiply this one.

Now, what is this equalizer matrix? If it is LMMSE; for LMMSE I think we have extensively read it this was if you remember this was H i star then R of s then H of i R of s H star plus R of v inverse that was the LMMSE equalizer, right. You develop it you know everything, everything you just multiply you get a matrix, but again that is a problem. Problem here is that we are again coming back to the same inversion problem right that is the problem again.

So, MIMO OFDM when you go for MIMO OFDM I am back to the same problem ok that it is again giving me the equalizer. So, can I again do something to avoid the equalizer? Well, that is completely out of the scope of this course. But what I am trying to say I am back to the square one, but again it is not that back to the square one. It is just that I cannot avoid the inversion again if I take LMMSE decoding.

But, if I take some other decoding like ML decoding at least inversion is about it, but it then again a search problem will be larger ok. So, the problems still persist ok and that is a limitation ok it will be there if I have a MIMO OFDM because that is one of the decoding technique that you can think of it, ok. Can I have some other decoding technique which will reduce the complexity in huge way?

Well, you can. It is not that you cannot do, but again the complexity may or may not reduce. So, easily complexity will still remain as it is, ok. So, this is all about the MIMO OFDM part. Now, let us now come back to our beam forming case ok as I said we learnt about a beam forming, we learnt about MIMO beam forming, now we learnt about OFDM, we learnt about MIMO OFDM.

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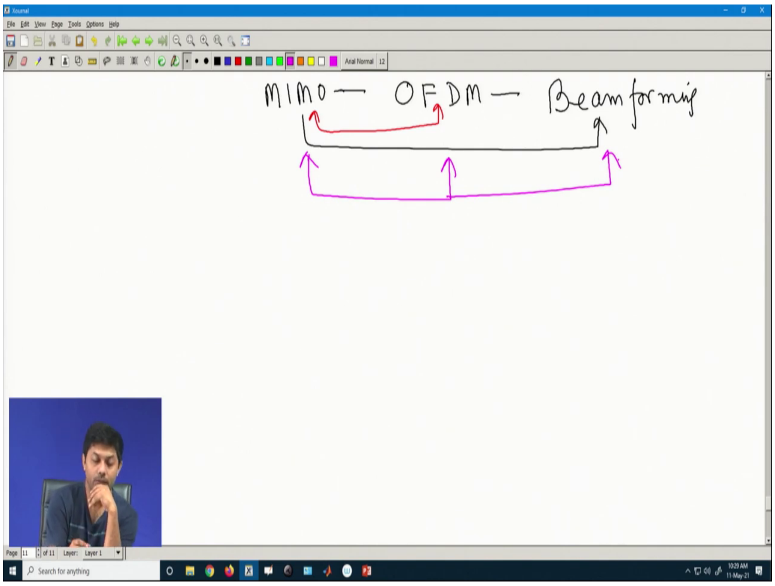

So, the only part remaining is that how do I combine these two together. So, we know extra parties OFDM. So, we have known this part MIMO OFDM, we have known this part, now the job is to know this part, this part and this part together ok. So, I will show you that it is just a simple extension of my structure ok. Now, so, how the structure would ok?

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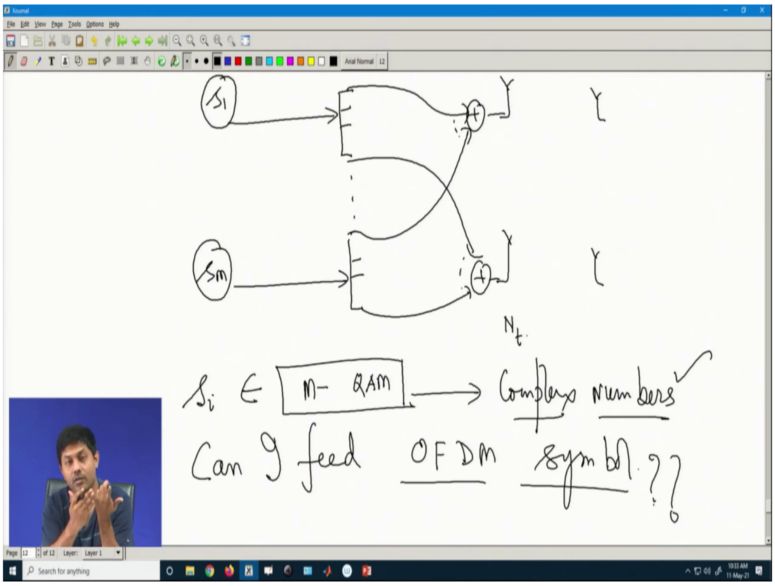

So, if you remember how exactly a MIMO OFDM, MIMO beam forming structure was that this was the; if you remember this was the data strive s 1 data strive s 1 data and then you have s m data, ok. And, then it was going through if you remember then it was going through some phase shifter and so on so forth. This will also go through some phase shifter then finally; it will go through N t number of antennas, right.

And, here if you remember there are some addition that the first will be here and this first will be here and for this one the last will be here, this last will be here and in between whosoever last everything is there, right. So, in between I will put it like this. This is what this is what we have discussed it, right. So, I let me put the structure here and in the receiver side what we have done a reverse operation, we have done it, right.

So, now, from the MIMO OFDM beam forming point of view what extra addition that is comes into picture? As I said the beam forming has nothing to do with OFDM why beam forming has nothing to do with OFDM because beam forming is more of a you know creating a beam and steering the beams. So, it really does not matter what value of s 1 and s 2 comes into picture really does not matter and that is what we have learnt it also, ok.

So, it is not s 1 and s m that matters to me it is basically the phase and the distance among the t x antenna that matters to me to create a beam and to create a steering, ok. So, how does it matter what is s 1 and s 2? What was the earlier case for s 1 and s 2? In the earlier case, s 1 and s 2 where some constellation data. Say for example, you may have M-QAM data.

So, your s i can come from any M QAM data or it can be m p s k data whatever constellation you choose, it may come from that ok, but was there is restriction that it should be so and so always? No, it is the normal it is any complex number. So, in a end of the day this is some complex number in a very general sense. Now, I hope you can guess how MIMO OFDM beam forming structure will be there.

This just some complex numbers, ok. If that is the complex number can I feed the question is can I feed can I feed OFDM symbol? Naturally, I can feed OFDM symbol because it is just a complex number. We have (Refer Time: 18:03) is also some complex number that is it the story ends here, so, which means that s 1 and s 2 what if they are just OFDMs number. So, which means instead of this let me remove this part intentionally, ok.

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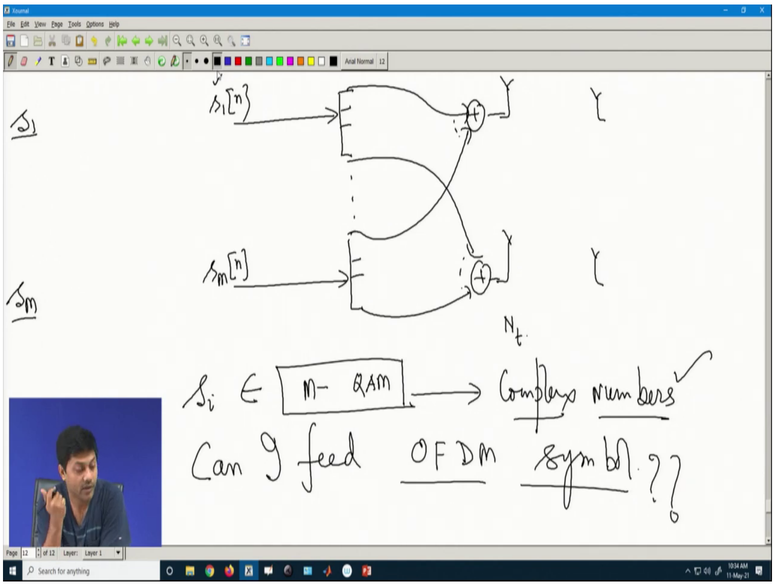

So, how I draw it? What should I do? This will be my s 1 vector, ok. This is my s m vector, but now it is a vector because I am feeding it serially. So, this is the only extra change in the earlier notion, what will happen is that it is just one point story, right. At a one point that mean at the nth point this is the beam, this is the steering. But, now n itself is now varying up to capital N. So, earlier what happens?

So, when I say s 1 I did not consider any n. So, probably I can write n I can write it. So, which we at the n-th point of my data transmission what is my beam and what is my steering that was the only part which we were considering it I did not consider any vector aspect of s 1 and s m individually. Now, that is the only big change which will be appearing, but does it make my whole beam forming different? No, it does not make my beam forming different because beam forming has nothing to do with s 1 and s m.

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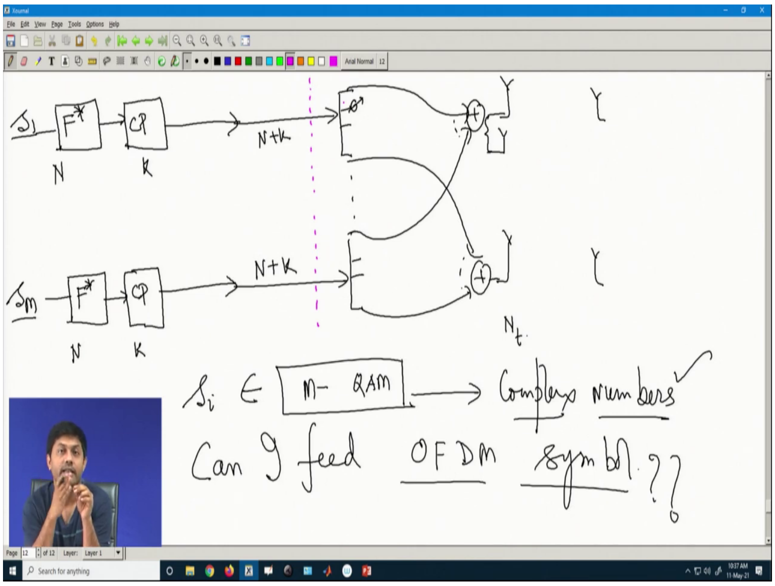

The beam is formed by the distance between the antennas and the steering happens how exactly I feed my face here, that is my beam and this is the beam steering part. It really does not matter what I am feeding s 1 and s m. It is absolutely material to think about it ok. So, here that is the main point here. So, here s m what I will do? I will put IFFT matrix. I will put an a IFFT matrix here, ok.

Then what should I do? I will add a C P, this I will feed it similar thing this I will feed, but students. So, it means you have N number of data here, K number of data here; here also N number of data here, K number of data. So, here N plus K CLE data will be fed here also N plus K CLE data will be fed here ok.

So, now the point here is let me just put it this one just think of the right side think of the left side. Does the right side K are how many what data is being shift or what data you being fed no and does it does the configuration of my steering vector change for N plus K data? Will it be constant? Will it be different? It will be constant. Why should it be different? Because when you say I am steering a data towards the transmitter or a receiver I have to continuously feed the data in the same direction ok.

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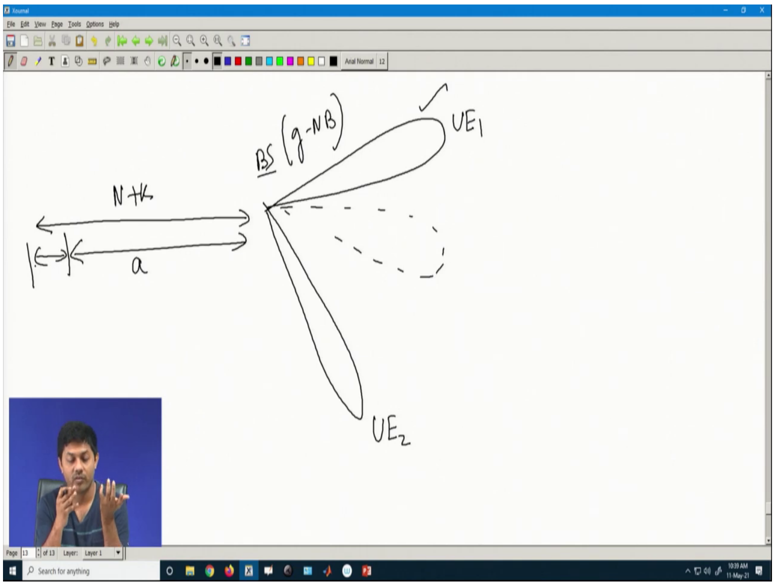

So, what I am trying to say here is that suppose I have created a beam like this because it is a minor. So, I can create multiple such beams ok. So, this is say UE 1, this is say UE 2 ok and this is my base station or g-NB ok and this is how the beams are created. So, let us say I am just having two beams I have created. Now, this entire beam is not for nth time it is for the complete you know OFDM structure.

So, which means that if I feed here so, this is the only difference between MIMO OFDM and MIMO beam forming and MIMO OFDM beam forming. In MIMO beam forming technically from every N I can change my beam, though it is not possible so fast because it means that at every sample time I change my beam structure.

Practically it is not done, otherwise because it has to have a very strong you know computational power that within such a small time you readjust your steering that is not possible practically, but theoretically it is possible. But, here the restriction is that for the entire N plus K transmission.

I have the ensure my beam is in the same direction, otherwise it is not possible right because if say up to say up to a number of data I steer the I keep the beam like that, but for rest of the data I suddenly change my steering will the system works will not work right. Because these data's are disconnected to the e v and the whole OFDM will crash. The OFDM will work only if it is between N plus K.

So, that is the only change here ok. So, this is the restriction that for the entire N plus K, I have to keep my beam in the same direction ok. So, that is the big restriction. I should not say it is a big restriction. It is attentatively a restriction, ok. Now, you may ask a question what happens to the Doppler then?

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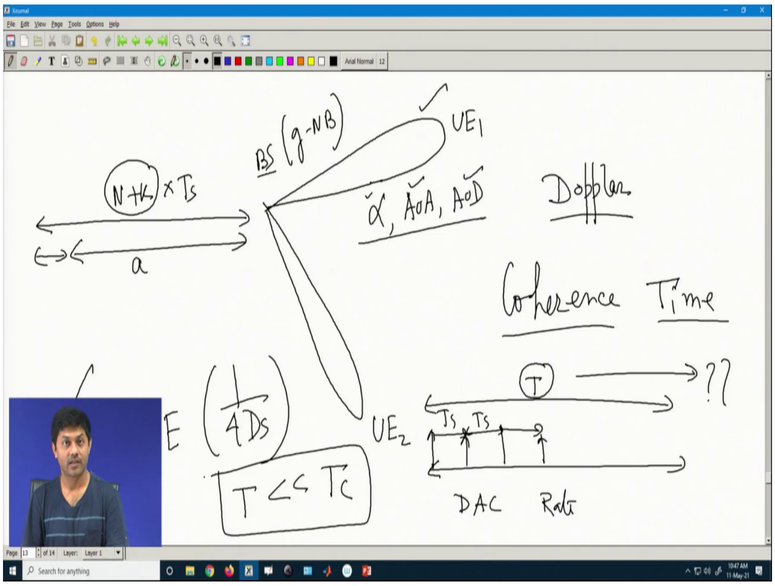

Suppose, I have a Doppler though I have not touched upon the Doppler part, yet in the context of a beam forming so, there is something called an adaptive beam. So, how adaptively you change your beams here in this case. So, here it is a more of a static environment and we are tentatively going for the static environment cases where I am not really going for the Doppler, but what if there is a Doppler, even if there is a Doppler I would not change the direction of beam for the N plus K.

So, I am assuming that for the N plus K my channel do not change if it changes you gone the whole OFDM things will not work. So, the for the entire OFDM frame my channel has to be constant. Why? I think that part I have not discussed it. So, if you notice it so, let me put it this way, why the if there is a Doppler the whole scheme will fail?

Your beam forming will fail your OFDM will also fail because what was the power of the OFDM? So, power of OFDM is that it basically converts ISI channel if you take from a matrix point of view that creates a to a pledge matrix, then it converts to the circular channel matrix, right.

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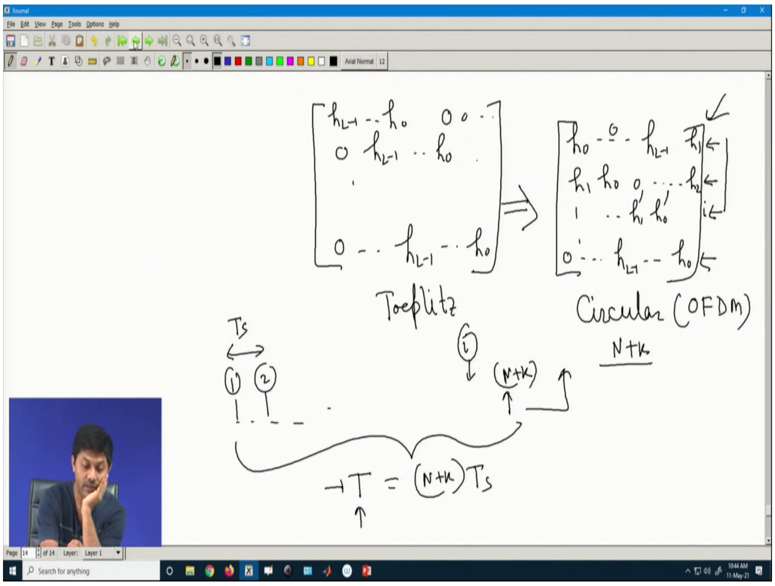

So, which means that originally the channel was something like h L minus 1 h L dot dot h 0 then 0 h L minus 1 if there is no OFDM, right. So, finally, it will be like that. So, this is what we have learnt it when you are discussing the OFDM initially that this will be the case if it is a it is a Toeplitz matrix.

Then using OFDM this whole matrix is changed to a circular channel matrix where it will be h 0 2 h L minus 1 h 1 in between this will be all 0's then this will be h 0 h 1 and so on. Finally, it will be h 0, h l minus 1, this will be 0, this will be 0, h 2 and so on. So, this is how the structure. So, this is a circular matrix and this is where the OFDM comes into picture. So, that is the only job OFDM does it.

So, converts the Toeplitz matrix to a circular channel matrix, but what is the key assumption here? Key assumption here is that your channel coefficient do not change for the entire N plus K transmission for the entire N plus K certain I mean I am serially transmitting this is my first data, this is my second data with C P and then this is my N plus K-th data serially I am transmitting it right through the antenna.

So, for the entire you know the time domain so, if there is a if sample to sample time is T S that mean my DAC sampling rate is T S and there are N plus K. So, N plus K multiplied by T S. So, let us call it total time T. So, this is one OFDM frame length frame timings right that one N plus K samples constitute the one OFDM frame.

So, that complete entire during that entire T times my channel do not change why because if any point suppose at this point. So, at this point my suddenly my channel changes say at say i-th position my channel suddenly changes. So, here also what will be reflected this i-th position instead of h 1 h 0 somewhere this h 0 becomes h dash h 1 becomes h 1 dash and so on so forth because the channel changes so, this will also be changed here, ok.

Then will it be a circular channel anymore it would not because one of the element changes meaning it breaks the complete circularness. So, the assumption here is that N plus K total T and total T times this whole circular things.

So, those whole channel do not change ok how do I ensure how do I ensure that my whole t times my channels do not change ok. So, this is one of the interesting point even in the context of beam forming because if that changes everything is gone. So, what does it mean in the context of beam forming?

Channel do not change what does it mean it means if you remember those coefficient of the channel, we were dealing with alpha the gain, then AOA, angle of departure. These three components do not change throughout my N plus k multiplied by my T S time T S is my sampling time at the DAC.

So, that mean every time my DAC is sending one by one, one by one the sample stack if there are say N plus K samples what will do? The DAC will take the first sample, then after T S time it will send the second sample, after T S time it will give you the this is my DAC rate third sample, T S time fourth sample and so on and so forth. So, total time is T. So, throughout this time I have ensure my alpha, AOA and AOD all remain same.

How do ensure? It may have a Doppler. Because you cannot stop Doppler because your environment is moving some little breeze is coming and you also may be you know by you also you know you may be walking little bit. So, Doppler will be there. You cannot say that whole thing is just static that that does not happen in wireless communication, but the question is that is that Doppler tolerable enough such that it does not change the time within this steam and how do I ensure that alpha, AOA and AOD do not change?

What restriction what is the technical parameter that should be honored in my design aspect such that none of them changes? I think if you can guess I would have said a parameter called coherence time. In the context of channel 6 gigahertz channel if you remember what is that coherence time? Coherence time is the time for which my channel do not change significantly. What how you define that if you remember T c was approximately expectation of 1 by 4 into Doppler spread, right.

If D s is the Doppler spread one by 4 this approximately expected value is kind of a T c ok this one definition was there. So, as long as your now if you see if your Doppler spread is 0 your T c is almost infinite that mean channel never changes. If there is a small Doppler and D s becomes larger and larger T c, T c also becoming smaller and smaller. So, that is basically the design parameter that you need to consider.

So, which means that your T time in your beam forming in that OFDM context your T time can I say it has to be very very less than my Tc that mean if I know Tc I have to ensure my T is very very less than T c. Then only this whole system will work otherwise it will. So, in the next class I will be talking more on that angle how do ensure your T is less or very very less than T c and how do you determine your T s how determine your N and how Doppler comes into picture in the beam forming will be explaining in the next few classes ok.

So, with this I just give an introduction in this class regarding the MIMO OFDM beam forming and will talk more on that. It is constituted by probably 20 – 30 papers. So, putting references for all 20 – 30 paper will be very confusing for me. So, it is a gist of those 20 – 30 papers. So, probably what I said is important, ok. Thank you.

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I hope I covered MIMO OFDM decoding part, then I covered MIMO OFDM beam farming structural part and then I gave some introductory part on how what are the parameters that would come into picture and how do you choose basically the motivation is that for the next class how do you choose your T the OFDM timing and also how do choose your sampling timing, how do you choose your the length N, those are the aspect which will also be coming into picture for the beam forming angle.

So, because for the beam forming alpha, AOA, and AOD estimations are very crucial. So, we have den sure that all this parameter remain constant throughout my OFDM because this is one of the restriction when you go for MIMO OFDM system. This was not there for MIMO beam forming case, ok. This is more coming from the OFDM perspective.

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So, with this I these are some of the reference, I am not putting in extra specific references because there are plenty of works done in this context. So, this is if you just go to the I triple E explorer you will find lot of such works present there ok so.