Introduction to Wireless and Cellular Communication
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Lecture – 10
Cellular System Design, Capacity, Handoff, and Outage
Cellular Geometry and System Design

Let me do a quick recap, because the hexagonal geometry is an important element of what we are talking about. We work with hexagons for the tessellation if you think about hexagon of dimension r, by dimension we look at the size side of the hexagon also happens to be the farthest distance from the centre of the hexagon to any of the vertex that also gives us the height of the equilateral triangle.

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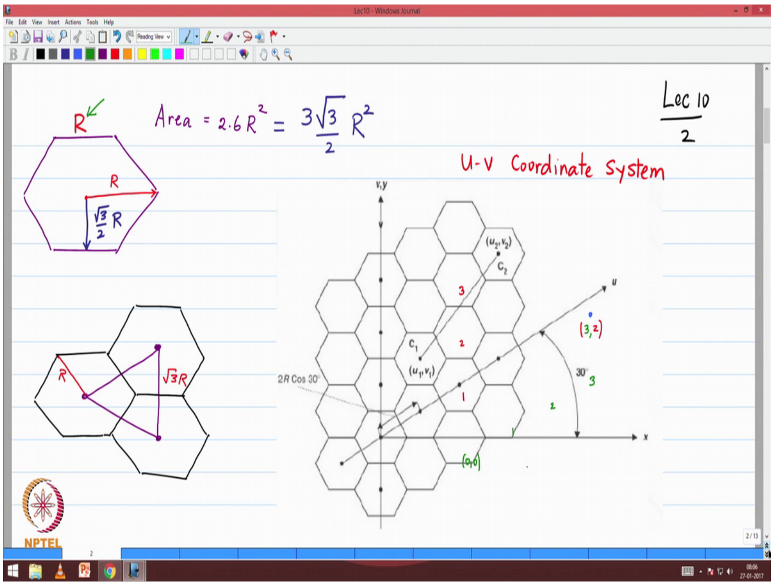

Is of the each 6 equilateral triangles as root 3 by 2 R and using that formula 6 times that area of an equilateral triangle, we get 3 root 3 by 2 R square. We also showed that these spacing between the centers of the hexagon is root 3 R and this also tells us the reason why we went to the option of using a normalized hexagonal scaling, where we choose R equal to 1 by root 3 that gives you a unit spacing between the centers.

Once we have that normalized hexagonal grid then the ability to locate a particular point requires us to have a the co ordinate system, and the coordinate system is a u v co ordinate system where the u and v axis are not at 90 degrees, but at angle of 60 degrees that imposes the only condition that when you calculate the distances you have to do it slightly differently and there was a question is to is that a obvious statement.

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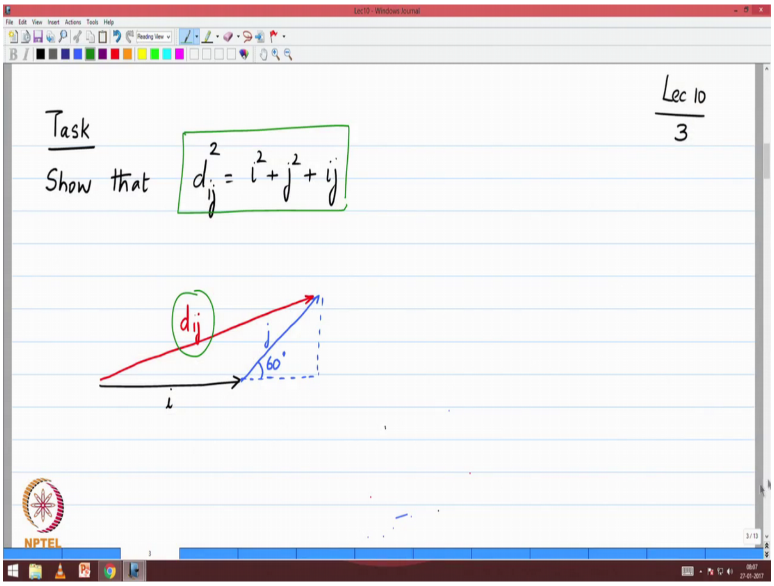

So, the easiest ways is let us do it I will leave this is an example. So, if I had a point which is at coordinates i comma j. So, I want to measure the distance from the origin 0 comma 0 to i j, I move I units along the u axis then rotate by 60 degrees that is the angle for the v the week v axis and then move j units across them.

So, now I am interested in the distance d i j. So, this is the parameter of interest again a simple resolution of components I am doing a Pythagoras theorem we will show that this is the formula that we should be using. So, d i j squared is the distance between the centers of 2 hexagons on these hexagonal grid and the i comma j are the coordinates of the second point the distance between them is i squared plus i j squared plus i j keep in mind it is on the normalized grid that we are talking about.

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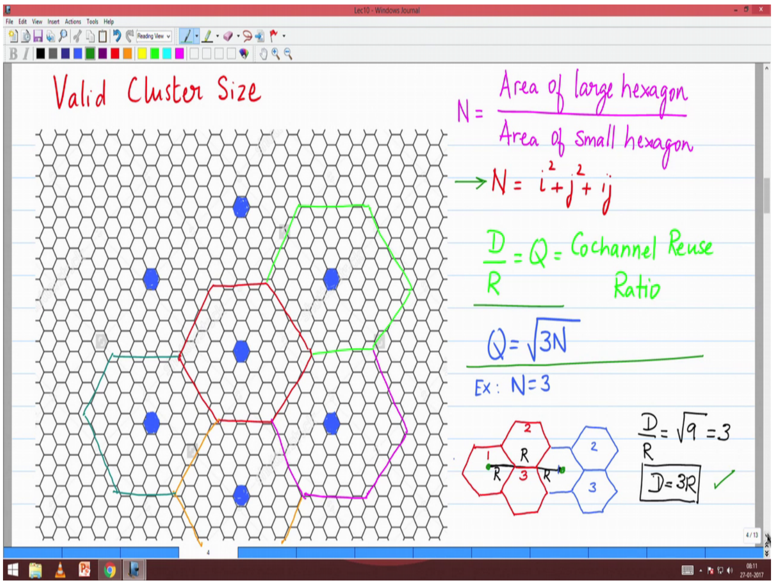

So, the next element that we discussed in the last lecture I hope you had a chance to review that was an argument which had 2 components. The first one said that the number of co channel interferers was calculated using a certain formula, that formula said that I will go I units along one along the one of the directions turned counter clock wise by j and then move that that basically puts you on a coordinate the u v coordinate system and basically you are you are shifting the u v coordinate system to get all the co channel interfering cells. So, we also gave the explanation that once you use this method the from a particular hexagon you can go out through one of the sides there are 6 sides, at most you will have 6 co channel interferes which are at tier 1; so given that sort of visualization.

So, basically if I start with the blue hexagon in the middle then I find the 6 co channel interferers. Now we also said that whatever cluster that I am using must have a must repeat itself around those 6 co channel cells that is a requirement because why that is how you tassel it. So, then in a broader sense you could visualizing whatever the cluster size is it should be approximately the area should be that of a hexagon because only then they will all fit together; though again there are some hexagons which are partly covered basically if you eventually resolve it should be an integer number of smaller hexagons.

So, given that understanding then we say that the cluster size should be area of the large hexagon by the small hexagon, we then showed that N is equal to d i j squared which is i squared plus j squared plus i j. So, basically we said that the cluster sizes that we could achieve would be constrained by the term that is given here and this would ensure that basically we would have a 6 co channel t r 1 interference there would be a tessellation of the of the cluster that is available to us.

Moving forward D by R is D is the distance between the co channel cells, R is the these dimension of the hexagonal of the of the individual cell of course, D is much larger than R assuming that you have a reasonable cluster size, D by R is a very useful parameter we call that as Q co channel reuse ratio and we showed that Q is equal to root 3 N and one example that we could verify again this is just so that we are all comfortable with this draw a 3 channel cluster. So, basically 1 2 3, 1 2 3 there is a red cluster and a blue cluster.

So, according to this formula that we have D by R is equal to root 3 N. N is equal to 3. So, D by R is equal to root 9 which is equal to 3 or d is equal to 3 R. So, it is says that in for a cluster size 3 the distance between the co channel cells is 3 times the size of the hexagon R of the hexagon and let us quickly verify. So, basically your traverse from cell the first cluster to the second cluster those are the co channel cells.

Basically I traverse 1 R going from the centre to the vertex, then one I go along the edge of hexagon that is also R and then again I go. So, that is verified that D is equal to 3 R and basically you can try it out for a slightly larger sizes and it is interesting to just get familiar with the hexagonal geometry.

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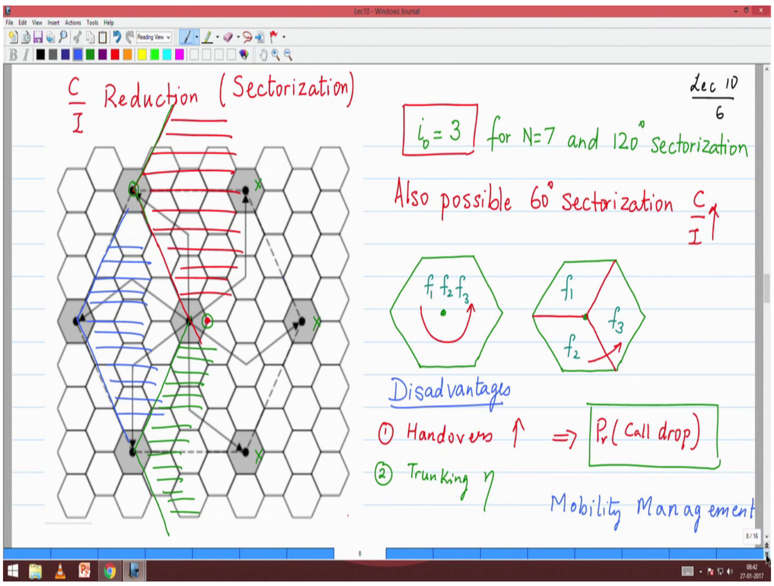

Now, I would like to move into a discussion of some of the other aspects that we had discussed in the last class. So, for that let me just refresh your memory that we did talk about the following scenario.

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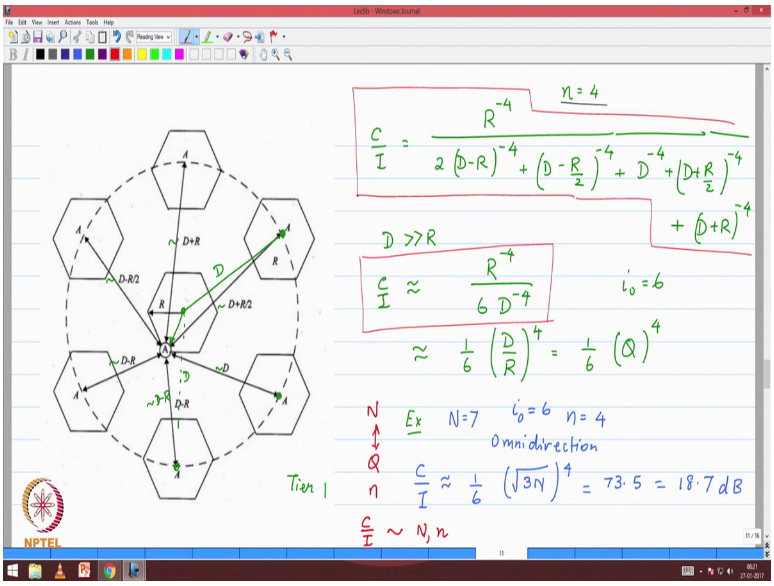

I have a cell in which I am interested in considering the interference looking at the tier one cells there are 6 of them, and we said that we would like to look at this particular C over I competition and as you recall from the last class.

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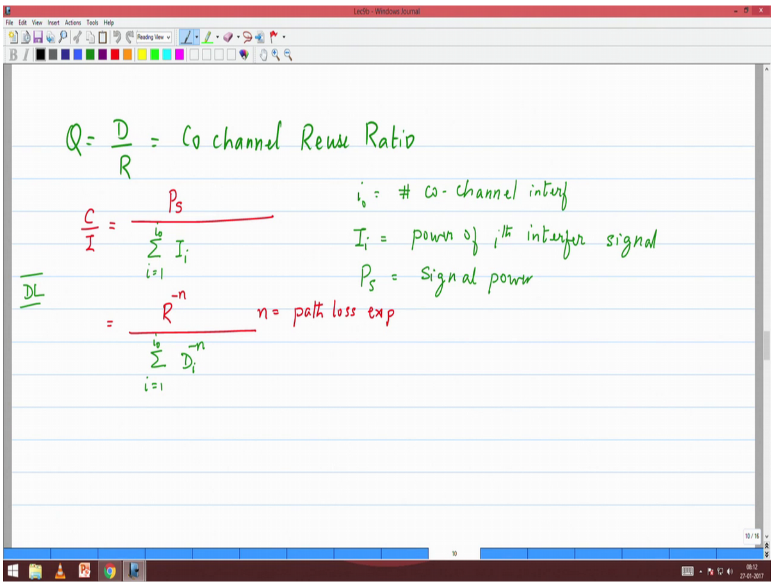

The C over I competition is measured it is given by the signal power divided by the sum of the interfering powers.

So, this was the explanation that we have given let me just build on that so that we can review the material for this class.

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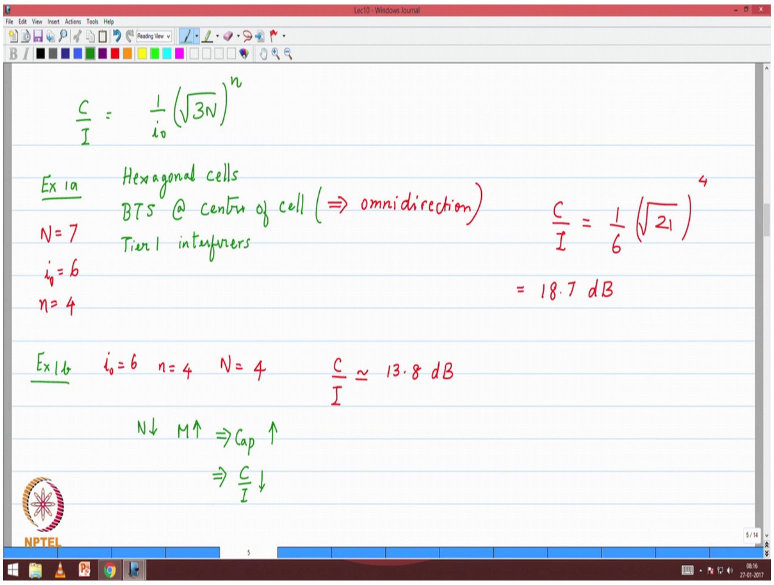

So, the ratio that we are primarily interested in is the C over I ratio, and the approximation that we had used again if you go back to this figure the approximation that we had used was to say that the in this particular case we showed that there are slight differences between the distances from the centers of the interfering base stations and the worst case location for the mobile. In some cases it is slightly less than D some cases it is slightly more than D, but we said if it is a large cluster size then this is going the difference differences in the D s are not going to be as significant. So, we are justified in the following expression.

So, basically it will be 1 by i naught root 3 N raised to the power n. So, what I would like to do is a series of very quick exam or calculations which I would like you to verify and make sure that you are comfortable with the results been presented; let us call this as example 1 a and the consideration that we are looking at hexagonal cells again more or less we would not have to change this for all assumptions it is hexagonal cells in our as for as our discussions are concerned. This next one is an important assumption the BTS at the centre of the cell that is not always true, but this for this example centre of the cell which basically implies that I am talking about omnidirectional antennas that is a observation that you sought of you should imply. Once I said that it is the centre of the self it has to be an omnidirectional antenna that will do the purpose and this one assumption is also important I am just saying that the tier one interferers they are the most dominant I want to consider only them at this instruction at this stage.

So, the for example, one is says that I want to look at this particular scenario for N equal to 7 and look at this competition. So, basically for this scenario C over I i naught happens to be equal to 6, because there are 6 co channel interferers basically this would be 1 by 6 root 21 raised to I have to give you the pathloss exponent n equal to 4 raised to the power 4. Again I think we probably wrote this down in the last class, but I thought I need to build on this for the point that I want to highlight. So, this would come out to be 18.7 Db; simple enough let us just build on this example 1 b I want to look at the following scenario.

So, I want to take the same conditions as before i naught equal to 6 which means it is tier one interferers 7 the path loss exponent n equal to 4, but I want to change the cluster size to 4, n equal to 4 again simple enough calculation, but the insights come as we compare these different results again notice it is an approximation. So, basically C over rise an approximate this says that 13.8 dB is the C over I that you would expect to have; this gives us very important in validation of the result that we had already expressed previously.

What happens when N reduces? N reduces that means; your cluster size has gone down. So, the cluster area has gone down. So, you need more repetitions of the clusters. So, M will increase M increases means capacity will increase let us not use C here capacity; capacity will increase but that is coming at the price of your quality going down because a co channel interferer has now become closer because of the reuse pattern. So, increase in the cluster size improves a over side decreasing the cluster size reduces it, but again we keep in mind the constraints and we work with that.

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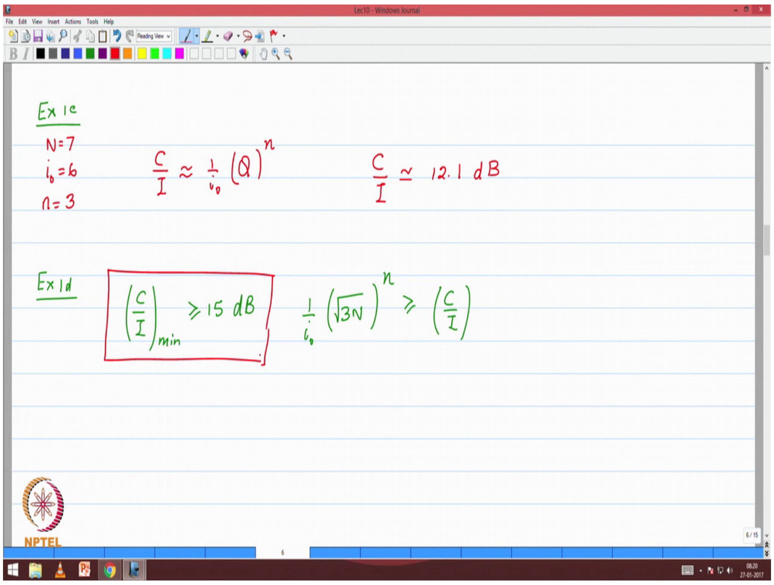

Let me build on it just a little bit more for completeness; let me call this as example 1 C building on this so going to go back to N equal to 7. So, let us say that I want to achieve a minimum of 15 dB for my C over I whatever system that I am going to design 15 dB is required. So obviously, 7 cluster size would work, but it is slightly on the higher side it is going to over satisfy and I wanted to see if it was possible to reduce it the next lower cluster size was 4 that is what is this calculation was and it is said no, most slightly it is not going to satisfy, it is going to give you only 13.8 dB. So, you are you have to look at other options. Now if I went back to the design process and I said N is equal to 7 is what I have to work with tier one interferers i naught equal to 6, I redo the calculation the measurement of the path loss exponent and I find out n equal to 3, the path loss is not n equal to 4.

So, now remember the last comment that we made in the end of last lecture was that if the path loss exponent goes down in a noise limited you are very happy because range will increase, but in the case of a C over I system because this is given by 1 by i naught basically Q power n, Q is a factor that I is greater than 1 so therefore, the higher exponent the better the advantage. So, let us do a quick calculation just substitute in to this, this is even though you have I have used the cluster size of 7actually I am at a disadvantage because I actually can guarantee only 12.1 dB k.

So, basically now the question that often we would ask is next part example 1 d. So, what should be the cell size so that I get C over I minimum is greater than or equal to 15 Db. Now such a problem is quite common for us to address and try to solve and again this is something that you should definitely be comfortable in trying to address, again it is a it is a very straight forward one basically you would say root 3 n raised to the power n is greater than whatever is your C over I do not forget the 1over i naught. So, then I am sure you can take the logarithms and then and solve for the given this parameters you can come out with a value of n maybe if time permits we will do a simple calculation on that.

But let me sort of summarize by saying; cluster size is important to control the C over I you have to take in to account what is your path loss exponent because your path loss exponent actually is a key factor in the C over I discussion. So, very often the problem that we would try to we solving in a practical situation is the requirements would say design for me the C over I it will meet this requirement. Now I have to do a first in experiment to measure the path loss exponent then I have to calculate the cluster size, I also have to make sure that the i naught that I have used is the correct value. So, this is where I would like to spend a few more minutes in today’s lecture to highlight this very very important element and let me highlight it in the following fashion.

So, is everyone comfortable with this expression that we wrote down? Basically, n equal to 4 is the assumption, it can be any exponent basically what we have said is the desired signal; the desired signal is inversely proportional to R power minus 4, that will be the power n minus n that would be the path loss due to the for the desired signal and then for the each of the interfering signals you are comfortable with this expression.

Now, what is the big difference between this expression and the following expression where I have done an approximation? The difference is that in the second one I have assumed that these small variations around D are not as important I can approximate all of them to be D. So, now, that assumption is actually valid only in the context of a large cluster size. Now if I go to a smaller cluster size there is a impact that will come and I just want to highlight that in the in the following example.

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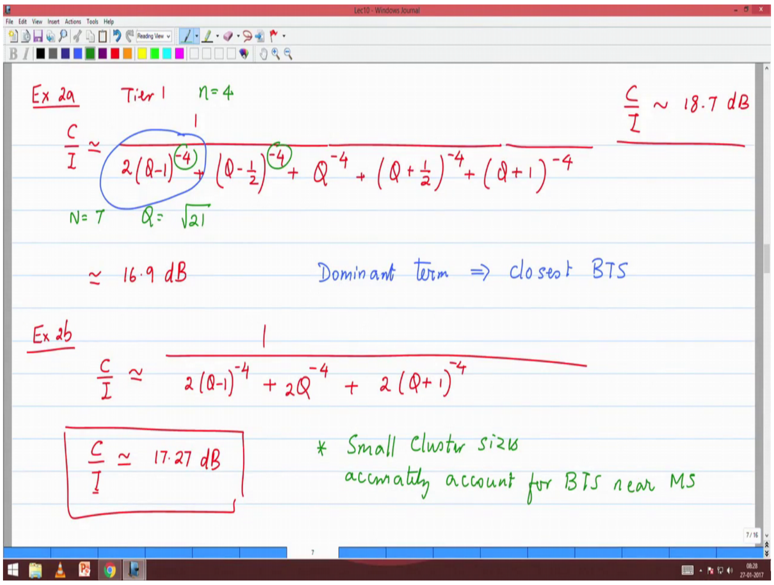

Basically, this is example 2 a, keep the earlier diagram in mind it is a hexagonal geometry I am looking at the tier one interferers. So, I want to look at the C over I expression.

C over I expression is a let me write it as approximately equal to for tier one interferers, tier one I am going to all of the remember I had R in the numerator and R in the denominator terms. So, if I divide numerator and denominator by R, I should get the following expression 2 times Q minus 1 raised to the power minus 4 plus Q minus half raise to the power minus 4 plus Q raise to the power minus 4 it is I just re write it in terms of a the Q term Q plus half raise to the power minus 4 plus Q plus 1 raise to the power minus 4. Just I just re written the equation the earlier equation notice that I have assumed the path loss exponent is the same as before that is why getting minus 4 everywhere in the numerator all of those are because the path loss exponent b.

Now, of course, I know that for n equal to 7, Q is equal to root 21, I want to substitute this expression and let see. So, previously if you notice the estimate that we had got me was C over I for this particular case was 18.17 dB, and we were quite happy we thought we had got a extra margin that is why we try to reduce the cluster size, but now substitute Q is equal to root 21 in to this expression and this expression comes out to be 16.9 dB 16.9 dB. Now I wanted to just quickly tell me what why did the C over l become worse than what I expect why what is the difference I mean I made a what seem like a very reasonable approximation and why did my C over I drop. First of all n equal to 7 is a very not a very cluster size that is the first thing.

The second one is which of these 5 terms is the most dominant one when it comes to C over I? Q minus one this is the guy who is the most important. So, Q is equal to root 21 is when you look at root 21 minus 1 it is actually quite a number that is different I mean raised to the power 4 will be different from root 21 root 10 to raised to the power 4. So, basically this is the culprit. So, what we need to be worried about is the dominant term. The dominant term is always the base station that is processed dominant term is means the closest base station those are the once that are likely to give you trouble, and we need to be very careful not to approximate them in a optimistic way because if I approximate this guy as Q power minus 4 then I have done it in my favor and then that is why I got a wrong expression.

Now, if you go back to this figure, and actually if you spend some time thinking about it you can actually make the following argument basically if you re rotate the geometry a little bit, you can now make the following statement. Instead of having 5 different distances actually I can work with 3 distances what are those 3 distances? So, this will be 2 b, C over I is approximately equal to 1 divided by 2 times Q minus 1 raise to the power minus 4 that is the dominant term I am not touch that the other terms I say this is approximately 2 times Q power minus 4, plus 2 times Q plus one raised to the power minus 4.

This is another approximation again it depending upon you know how you want to do it, you may say look I actually accounted for the most problematic term correctly the others are you know slight approximations of the other terms. Now this is yet another approximation which is not as good as the not as I accurate as 2 a, 2 b is better than the first approximation where you treated all the distances equally. So, again I can do calculate this do verify that C over I in this case comes out to be 17.57 dB. Again there is probably some other dominant term which now is Q minus half which you approximated as Q, which you know give you slightly more optimistic results. So, the key point to carry away from the discussion is be careful when you do the approximations because the approximations should not be misleading in terms of the results in it. So, the key point that may be we want to also take is far small cluster size be very careful in estimating the C over I.

So, for small clusters sizes account for those base stations near for the accurately account for the base stations which are near the mobile; account for the interference from BTSS near the mobile station that is a general guidelines it is a very useful one just that you keep this picture in mind. So, let us move quickly forward so that we can build on the concepts that we have what that we developed so far. So, the point sector are leading 2 from a practically discussion is first of all you better get your path loss exponent correct because you know because path loss exponent can mess up my entire design process. The other aspect that becomes very clear is our understanding that you know let us get the way is to reduce the interference. So, that is now we start thinking is I estimated my path loss correctly I brought the cluster size, now are there ways by which we can reduce the interference.

So, here is the aspect that I want you to consider, let us let us take a quick look at the elements. So, remember we are always saying that the down link is the more problematic situation and so we want to look at mobile in the worst case scenario. So, basically the mobile is that the red dot in the intermediate cell notice that let me just highlight for you the that is the desired mobile is sitting at edge of it is coverage, it is a seven cell hexagonal geometry. So, there are 6 co channel cells and we have drawn them basically this is a situation which would be a good for us to analyze. The point that we just wanted to make in this the situation is; if I do sectorization will it help me if I do sectorization will it help me and how much does it help.

So, the sectorization basically says that the base station now does not radiate in 360 degrees, but if you take base station number one notice at it is radiating in a 120 degree sector those are all this was the co channel cells all those be used are facing. So, like that I have I have shaded the red I have shaded the blue, the green, basically the east west facing sector for each of those co channel cells. So, from this point of you my mobile there are 3 base stations which are am not going to make a difference, these 3 are not going to difference because their radiating away from me. So, they are straight way I have reduce the amount of interference.

Now, the question is now what about blue; blue is going to hit directly, because it is light behind me it is going to radiate. Now red and green and kind of at edge of their coverage, so may be if I go little bit interior to the cell I may get in a more badly affected, but again to recognise that you know probably 3 base stations are going to cause interference for me. So, the understanding is that sectorization has reduced i naught from 6 to 3. Now again you have to look at geometry, you have to actually visualize thing which of these base stations are actually going to interfere with me and then try to do the estimation of I naught. Once you get encourage by at it 120 degree I reduced it by factor of 2 maybe I should do 60 degree sectorization may be something will be better. So, if I do 60 degree sectorization what will happen? C over I will improve further because more slightly you know 2 more base stations will get eliminated and therefore, then actually I am left with the C over I being better. Now is there price that we pay for this we need more antennas. So, that you can actually point the beam in that direction that is very good one what is the other one?

Student: (Refer Time: 26:30).

You need more sectors of course, yes. So, basically if you do 120 degree sectors, you need to have 3 sets of antennas if it has 60 degree sectors you will have to have 6 antennas on each base stations. Now so obviously, there is a cost factor that is involved is there any other an element or disadvantages that you see.

First or advantage or disadvantage is let us say the previously you had 3 frequencies available in the cell f 1 f 2 f 3; now if I do the sectorization and I do not want them interfere with each other I have to give each one different intermediate different cells. So, basically one takes f 1 other takes f 2 other take f 3. So, actually I am reducing my resources available for the, but you say well reduce the area. So, you know really it is not problem this is if I have a uniform distribution of users, but not if there is I am not so uniform, but that is really not the main disadvantage.

The main disadvantage that comes is previously I could mobile could go anywhere within the cell and still stay connected to this base station, but now the minute I cross over from you know in the same movement if I have, I may have to do at least one or possibly 2 hand over’s you know because and I am still connected to the base station same base station I did not change the base station, but because this cells are different I actually have to do more handovers. So, this basically means the disadvantage actually turns out to be a fairly significant one, the handovers will increase and the more you do sectorization the more the handovers will increase.

Now, keep in mind that handovers is a actually (Refer Time: 28:22) of the system. So, there is a possibility of call drop; there is a probability of call drop during a handover if for some reason the 2 the handover process does not happen the way it. So, basically there is a probability of call drop, and this is a vulnerability of the system the more times you ask user to have you do handover there is likelihood that the call will actually get disturbed because of this.

The second one which we will be able to appreciate by the end of the today's lecture is what is known as trunking efficiency, and we will highlight that in a very short time basically it says that whenever you have it is a problem in queuing theory, if you have some number of servers serving us some number of subscribers the best the best way to handle it to minimize the delay in serving these customers is by keeping them keeping all of the servers in a common pool and serving the customers in the following fashion may be small diagram would be helpful in this regard.

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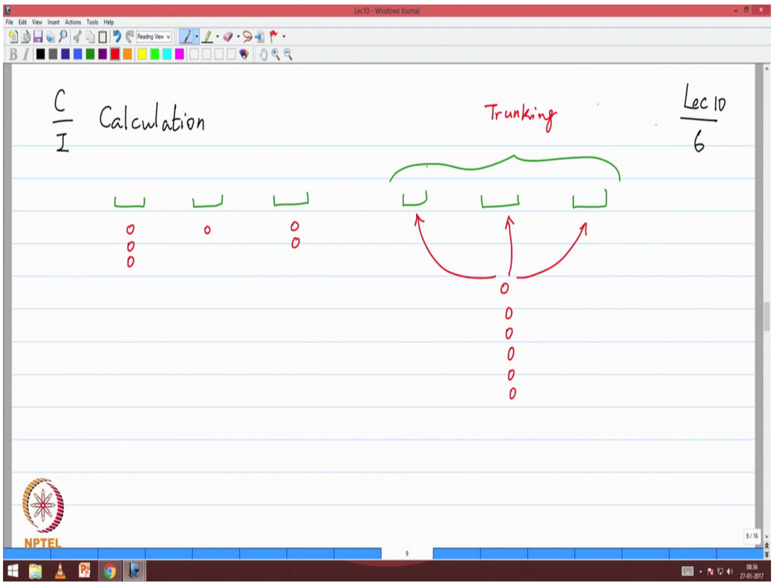

So, the scenario that we are looking at is I have let us say a ticket counter. I have 3 ticket counters which are serving users and then the users start lining up I am sure you have seen it in a checkout counters, you will always see the other lines seems to be moving faster and you want to move on to the other; that is because you know those counters are all you know separated and each of the serving different queue and there may be scenarios where one counter actually has no customers and, but still that the others are some delay you have to jump from here to here so that is a problem. The better scenario is if you had all of these users or the or the serving counters as a common resource, which means that then you say all of you line up same number of people whichever counter is free you go to that and this is shown to be a much more efficient system and it basically says whatever resources that you have to provide the service you have more flexibility if all of them are in a pool and are doing the same thing. So, this is what we call as trunking.

Trunking means you put all your resources in a pool and then take it as and when you need it. So, when we say trunking efficiency is affected that is because I took all of the user all the resources which were together in one cell and I sub divided it, and you know what is the price that we pay we will justify a in a moment we will justify a in a moment. But this is element that we keep in mind. So, C over I reduction is the goal we said sectorization is a good one for us to hang. Now what are the methods can we do for reducing the interference. So, the there is another method that is use for reducing interference let me just highlight that for you.

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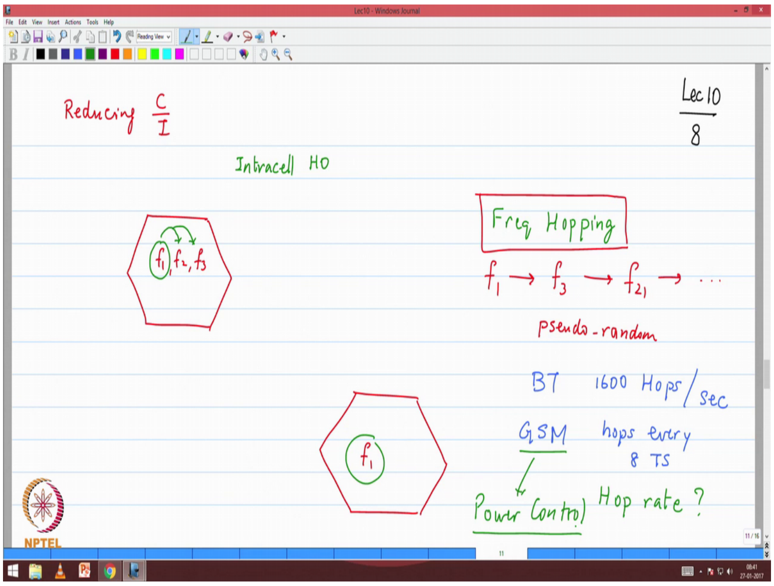

So, reducing C over I; so here is a cell again we will use the same frequencies f 1 f 2 f 3 are available to me, I have assigned f 1 to my user and let us assume that there is another co channel cell somewhere in the vicinity which also has a subscriber to whom f one has been assigned.

Now; obviously, there is interference between these 2 users. So, this particular user we could change the frequency from f 1 2 or f 3 this type is called a handover still it is called Intracell handover, and you are doing this handover not for because the mobile is move too far from you, but for interference purpose. So, Intracell handover because f 2 and f 3 probably are channels which are not having as much frequency or the interference; so therefore, it is an advantages for you to do that.

The second one that can be done is we do not know when such interferences will happen. So, what you do is what is called frequency hopping; frequency hopping says that my interference may come from any of my co channels and it may come on any frequency. So, what I do is I keep changing my hop my frequency deliberately. So, I start of with f 1 and then I will go to f 3 may be go to f 21, go to this is a pseudo random pattern. Now each of the co channel cells has got a different co random pattern. So, which means that yes there may be scenarios where 2 co channels collide, but very likely the next instant you will hop to different frequencies. So, this is a very very powerful method that I used to avoid interference because you do not know why the interference will come and therefore, you want to do that.

Examples of frequency hopping let me see quickly do recall Bluetooth does frequency hopping how many times per second? 1600 hops per second why because well I will ask let you answer the question hops per second. GSM we said well we know does GSM really have to do hopping yes does hopping; how many times per second does GSM do. So, basically it hops every eight time slots. So, in other words one frame you next you better to go the next frame it will be on a different frequency. So, first task one is please calculate the hop rate; please calculate the hop rate for GSM, it will come out to be much lower than a Bluetooth you can wait and verify that what is the hop rate for GSM. Now the question why should Bluetooth hop faster than GSM?

Student: Bluetooth is in (Refer Time: 34:44).

Exactly Bluetooth is in the unlicensed band you have no control over the other interfere whereas, GSM is in a controlled environment all the co channel interference is are actually uses of your own cell. So, there for what GSM does is actually do pseudo random patterns for each cell and they all hop in a coordinated manner so that the amount of interference that they cost each other is very very minimum. Therefore, GSM does not need to hop as much because the interference is coming from controlled environments and one more very important thing if there is one particular user whose causing a lot of power in GSM you have tool called power control, you can actually go in and tell that mobile reduce your power because I know you causing too much interference. So, that is a very very important element in the whole aspect.

Now, before we move into that domain remember I told you the issue of handovers; handovers also require 2 things, one is the mobile must inform the base station look my signal is getting weak please change me. So, there is a lot of signaling co happens between the mobile and the base station for a handover to occur. The second one is let us say that you are not in a call and you just moving from one side to the other now that also is a the situation that the mobile the system should know because if you remember the if there is an incoming call the system must know why to teach you. So, must actually inform the system where you are currently located. So, that element that aspect of it is called mobility management.

Mobility management is a requirement for all mobile systems because the users are constantly moving the more sectorization you do the more mobility management have becomes harder, because you know you constantly moving between sectors and the and the system needs to keep track of where you are currently located. So, those from user perspective we do not see too much of the impact, but from a system perspective there is a much harder problem in terms of mobility, in terms of handovers and a lot of the signaling that is going back and forth which is causing the things be more difficult. Any questions on what we have seen so far about sectorization, about the frequency, trunking efficiency and the issue of mobility if things are clear we move forward

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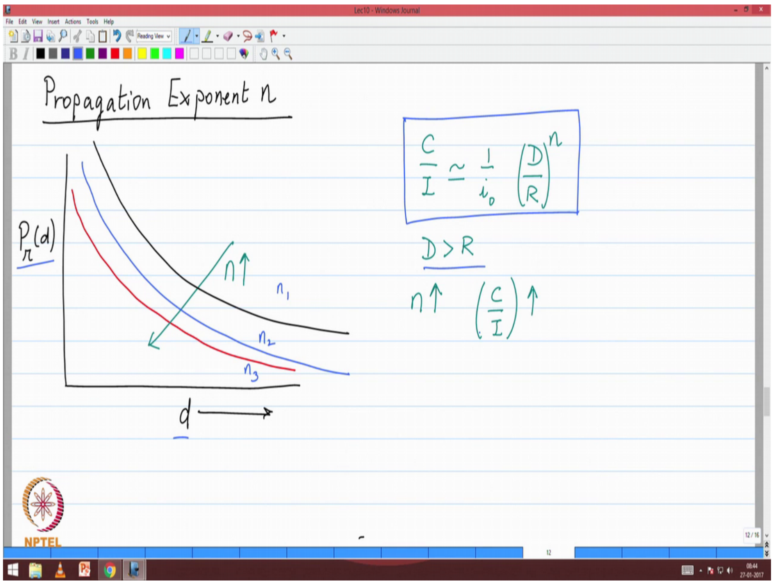

Here is a intuitive way to understand why C over I improved in the case of an increasing path loss exponent. So, the traditional graph that we do was to look at the received signal power as a function of distance you basically plotted may be at break point model or one of those some from by which was it decreasing. So, you got the black for n 1 this one for n 2 n 3 and if you compare; obviously, as n increases the received signal power is lower. So, the higher the path loss exponent the lower will be the received power signal. So that is basically saying that you know when you are in a noise limited system higher path loss exponent is to your disadvantage.

On the other hand, because I have a situation where my C over I depends on the d over R ratio raised to the power n, and since the d is greater than R I always stand to gain by doing this a in this scenario, but there was a very interesting question than I can keep increasing n in because then I can get better and better C over I what is the answer to that? N is not in my control really n is not in my control and by the way n becoming larger is not I mean yes in a, for a comparison this is, but if I take n equal to 6. That means, my signal itself will not travel very power, that is my cell is will decrease and I have to deploy a lot more cells yes my interference becomes less of a problem it looks more like a noise limited system, but the cost of the system increases. So, 2 things one is I do not have n, I do not have the ledger of choosing n that is natures gift to us. So, we do not get to manipulate that, but at least we so.

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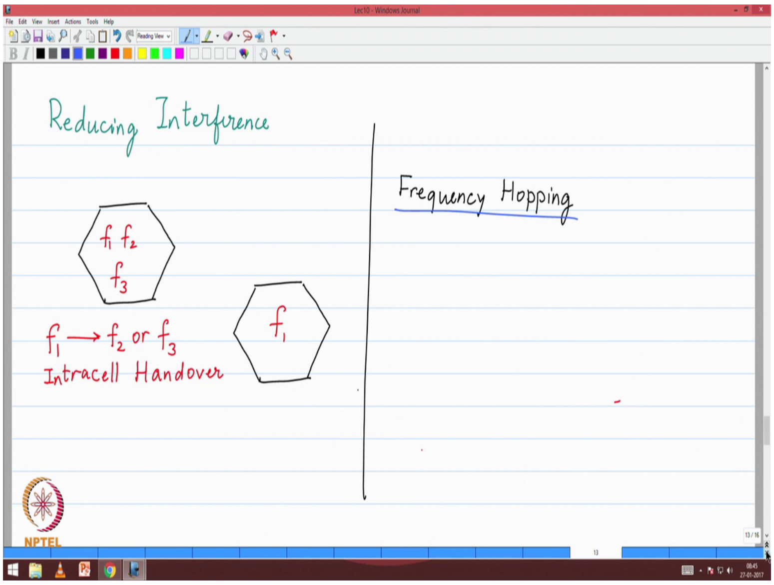

And reducing interference remembers we talked about intra cell handover, frequencies hopping these are our tools for reducing interference and let us move on to the next element this whole issue of capacity.

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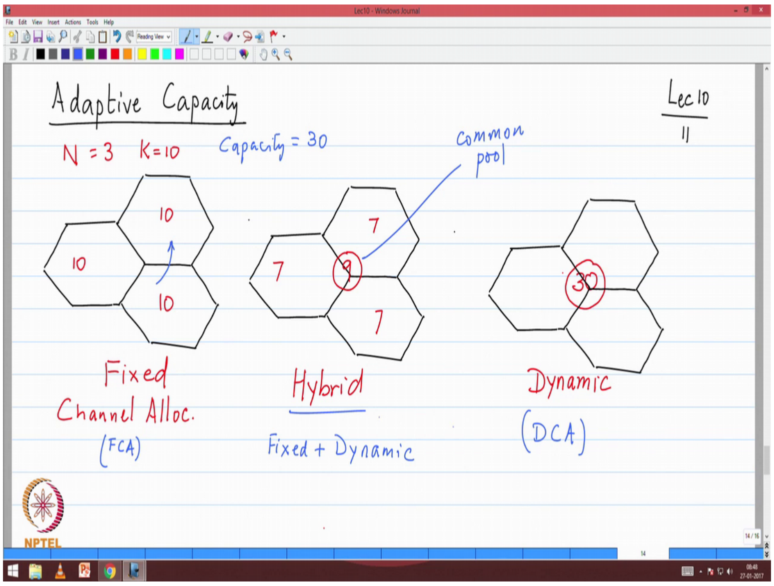

Now, capacity as we mentioned is a very important element and this notion of creating sectors actually a causes a reduction in capacity. So, what we are primarily going to look at is; what are the ways in which we can handle that capacity issue. So, let us take 3 cell clusters; there are total of 30 channels available because 10 channels per channel per cell cluster size 3. So, total capacity is equal to 30. So, capacity equal to 30 the traditional way of assigning the resource was to give 10 to each of them, and if there is a user who is crossing over from one side to the other you have to do a handover. So, basically you treat them as that is what we call as the fixed channel allocation this gives you a clear capacity for each cell I can say I got 10 channels what is the capacity I can I can calculate.

Now, the next level where you want to have some flexibility, where you say that well you know sometimes there may be more capacity needed in one cell. So, rather than assigning them in a fixed manner you out of the 10 channels available each cell 7 is pre assigned, but 9 of them are in a common pool. So, this is a common pool. So, depending upon which cell needs more traffic at the end of the day still 30 channels is what you have, but you are doing a little bit more flexibility. So, this is a hybrid channel allocation method this partly fixed partly dynamic. So, this fixed plus dynamic and that is why we call it as the hybrid model.

Now, the fixed one is easy you do it once then you do not have to interfere with the working of the system, but on the other hand a dynamic one constantly each of the cells has to keep reporting what is the current traffic condition. So, there is a lot more control that happens in the case of a hybrid system. Now to take it to the to the maximum efficiency you would have say I am not going to any allocation, I am going to do it very dynamically all channels are in a common pool remember trunking efficiency where you try to keep the all the counters in a common pool, this is basically moving towards that this is called dynamic channel allocation.

Now, when you read books like rappaport or mulish, you can you can see how they have given the trade hours between a fixed channel allocation versus the dynamic channel allocation and you know how to do look at the whole spectrum of the challenge that are ahead of us.

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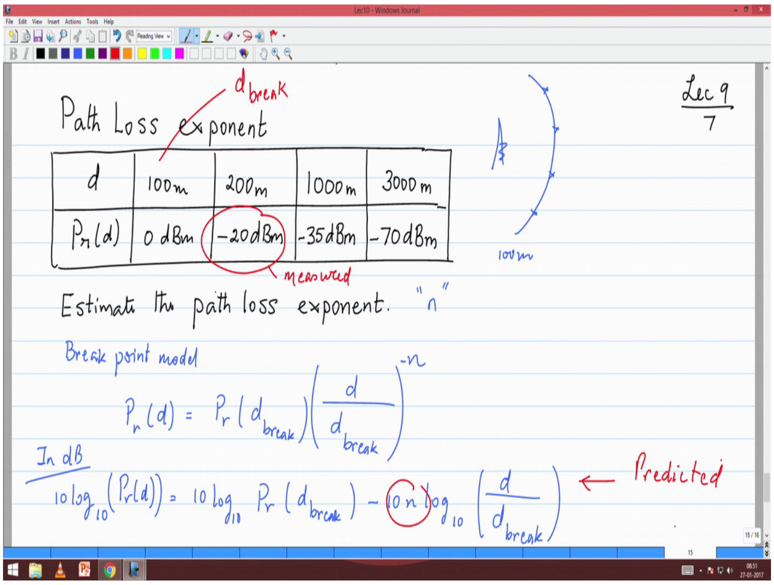

Now, comes the last part of the calculation path loss exponent being an important factor in the discussion that that we have had so far and let us quickly make sure that we can solve this problem.

So, here is a experiment that has been conducted; 4 sets of data where given to you basically it was done by lots of averaging if you remember the figure that we drew this is the base station this is 100 meters you take that measurement of that 100 meters and then. So, this is at 100 meters and then you have the average 0 dBm at 200 meters minus 20,000 meters minus 35 dBm and 3000 meters. So, I want to find the best path loss exponent m and use the notion of least squares. So, basically there is a curve to be fitted I want to look at. So, let us quickly look at the break point model, the break point model is what we would like use for this calculation.

The break point model basically says that the received signal power at a distance d is given by the received signal power at a break point, at a break point then d by d break raised to the power n that is my break point model that is available to us. Now writing it in dB is helpful. So, basically this is p R in dB. So, it will be 10 log base 10 of P r of d is equal to 10 log 10 of P r at d break that is the and then minus this d by d break raised to the power no received signal power should be minus n correct path loss will be d by d break to the power n. So, this would be minus 10 n log base 10 d by d break.

So, basically notice it if I write it in a log form, the term n becomes like a linear parameter that I need to estimate and then now I would like to do least squares fit, but the problem is I do not have a d break by nobody told me what d break was. So, by d point we say this is going to be might d break; where I can given that you have to solve this problem and hundred meters is not a bad assumption because that is usually what d break will be if you have an outdoor scenario.

So, given this what is the calculation that we have to do? So, this is the measured signal power this is measured. So, I want to reduce the mean squared error between the measured and the predicted. So, the prediction will come from this equation gives me the predicted value, this equation these numbers give me the actual value and therefore, I am able to do a least squared fit to this. So, let us just do the following calculation.

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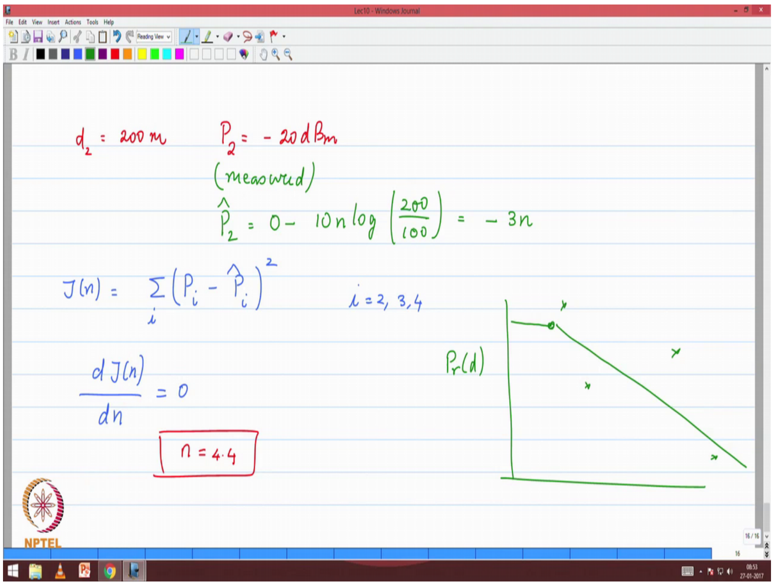

So, let us take the second distance which was at a distance of 200 meters the measured value P 2 is minus 20 dBm that is measured this is the measured value.

On the other hand the predictor value by the model let me call that as P 2 hat; the predicted model basically says I have to look at the path loss at the break point in dBminus 10 n times this expression. So, please substitute the path power at the break point is 0 dBm minus 10 n log of the ratio of the distances 200 by 100 that is equal to minus 3 m. So, P 2 is minus 20 dBm, P 2 hat is minus 3 n. So, if you were to now write down the objective function as the minimum squared error J of n this will be summation over the all the measurements that you have P i minus P i hat whole square. So, basically you will write down the equation for 2 3 and 4 because those are the P i equal to one becomes your reference point.

So, once you write down this expression, then what you do is differentiate J of n with respect to n set it equal to 0 that basically gives you the (Refer Time: 47:11) value and for this particular you will have the 3 terms you differentiate that and then solve the equation you should get n is equal to 4.4. So, in a nutshell what is the problem that was solved I have received signal power at different distances I got some measurements at different values, and then I have found I found the best least squared estimate that that passes through this and in mind that my break point was somewhere there and so before that it would have been a certain slope and this slope that we have calculated is for that part after the break point model.

So, again it is a simple problem, but it is a very very practical so that you can actually do such experiments and verify. So, it is very a useful tool. So, we have address how to carefully estimate the path loss exponent; also address how to do estimate C over I cluster size what happens when you do a increased sectrorization what is the impact of in terms of the capacity, what is the impact in terms of the quality we will pick it up here in the next class.

Thank you.