Introduction to Wireless and Cellular Communication
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Lecture - 08
Wireless Propagation and Cellular Concepts
Cellular Concept

Good evening, let us start the lecture. We started to address the aspect of the outage being a statistical phenomenon. So, by way of a recap I would like you to visualize our understanding of outage, outage is a statistical phenomenon, so we can talk about it in terms of a probability. We also said that given a environment over which we do not have any control, there is no notion of 100 present outage free scenario, you will always run into situations where there may be outage. So, the good design would be something that would in for 95 percent outage free or 98 percent outage free depending upon what your quality of service metric would be.

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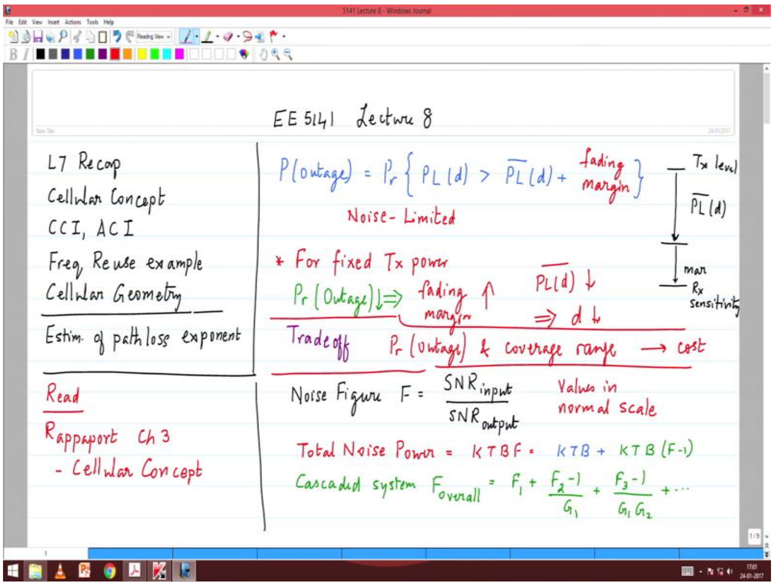

So, to visualize it, think of it as a transmit level that you have, let us assume that that is fixed, you have the receiver sensitivity in a non fading environment you would allow the entire difference between the transmit power to receiver sensitivity to be your path loss. In this case we allow a certain fading margin that is like a buffer and then on top of that whatever is remaining is what happens to be the path loss and because we have models we can talk about an average path loss. So, the line at the top basically denotes average path loss.

So, given that you have designed it using this underlying principle the probability of outage will be the probability that the actual path loss that you have encountered at a distance d is greater than the average path loss plus the margin basically you have exceeded the allowable margin and this is how we would visualize a noise limited system that is there is no other impairment other than the noise. So, to sort of reinforce that if I were to ask you now help me reduce the probability of outage. So, basically I want to reduce the probability of outage. So, if I say that I want to reduce the probability of outage, what do I have to do?

Student: Increase the fading margin.

Increase the fading margin. So, that would be the natural option because that is what protects you against the fading gives you that additional buffer. More than just the basic observation I just want to take it all the way through and see where the impact is going to be if I reduce the fading margin; obviously, if my transmit power is fixed average path loss is going to decrease average path loss decreasing; that means, path loss at a distance d the average has to decrease to accommodate the increased fading margin what does that imply that is present.

So, let me see if we can isolate the trade off part. The trade off is always between probability of outage probability of outage is one hand that is one that you want to manage and the coverage range basically if you say that no I cannot compromise on coverage range I still want to achieve the probability of outage, what are my only options?

Student: (Refer Time: 03:35).

Increase transmit power if you cannot do that I have to add more sites which means cost. So, basically eventually it will be a tradeoff between performance and cost and that is a classical engineering tradeoff that is what engineers are we try to find that right balance between the performance and the cost and optimize it to a point where the system is a performs acceptable. Very quickly the other points that we have discussed in the last class the noise figure our understanding is SNR at input divided by SNR at output we always talk about SNR in dB, but if somebody were to ask you to calculate the noise figure make sure that you keep in mind that these are when you write it as a ratio it has to be in the normal scale not in the dB scale, because if you wanted it in the dB scale you have write it as SNR input minus SNR output.

So, noise figure very often we when we work with noise figures we make the mistake going between dB scale and normal scale always the make sure that you know that you are consistent where they are talking about in the dB domain or the normal domain. A nice way to visualize the total noise power we know the basic formula is KTBF Boltzmann's constant, the ambient temperature, the bandwidth of there is AC filter and the noise figure always good to visualize it as 2 components one is the ambient noise KTB the other one is what your receiver added to it is KTBF minus 1. Taking this model and extending it to the cascaded system was what we did in the last class. So, if you had a cascaded system with the first stage having gain G 1 noise figure F 1 second stage gain G 2 noise figure F 2 G 3 F 3 then the overall cascaded noise figure would be given as F 1 plus F 2 minus 1 by G 1 F 3 minus 1 by G 1 G 2.

So, the noise figure of the latest segments or sections get down weighted by the gain of the first section and that is why we said the first stage is very critical and that is why we have a low noise amplifier and we also try to put the amplifier on the tower top there basically something called tower top amplifier you do not even want to have the cable loss because you want to pick up the improve the noise figure. So, that is our basic understanding.

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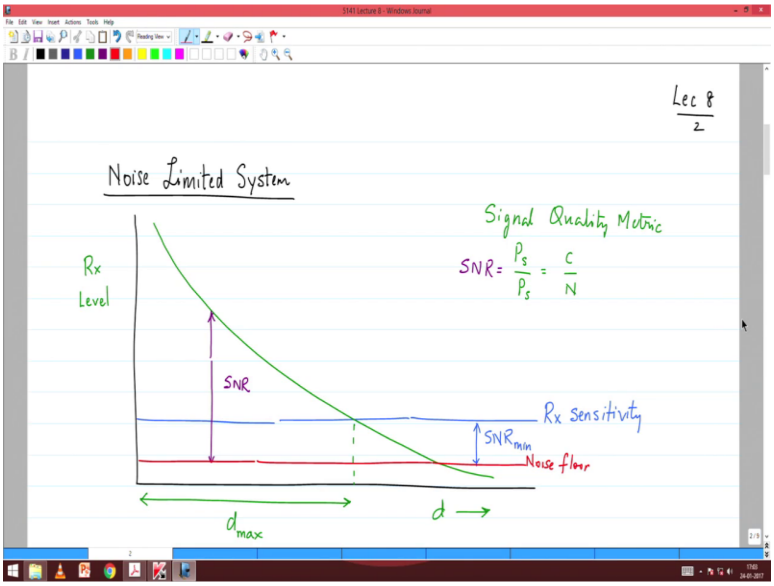

So, let is move on to the target of studying interference limited systems. So, before that one comment about the noise limited system. So, keep in mind that the picture that we have is a received signal power received, signal power will decay as a function of distance. So, that is based on the exponent. So, I basically shown it as an exponential decay, but in some exponential or it will decay the important point is where it crosses the received sensitivity threshold that will become my maximum allowable d max again notice in this figure I have not shown the fading margin if I allowed the fading margin the d max would decrease.

Now, the signal quality metric in theoretical when we talk about performance of a digital communication system we always talk about e B by naught, but in a practical system then talking about cellular and talked about deployment when you would talk about actually doing measurements in the field there is no notion of e B by n naught. So, they I can measure carrier power I can measure for your input power meter and measure for you the signal power. So, basically the signal quality metric for us is the carrier power or the signal power divided by the noise power P s by P n. So, that is the definition of the signal quality metric.

I would like to move from the noise limited system to the interference limited system.

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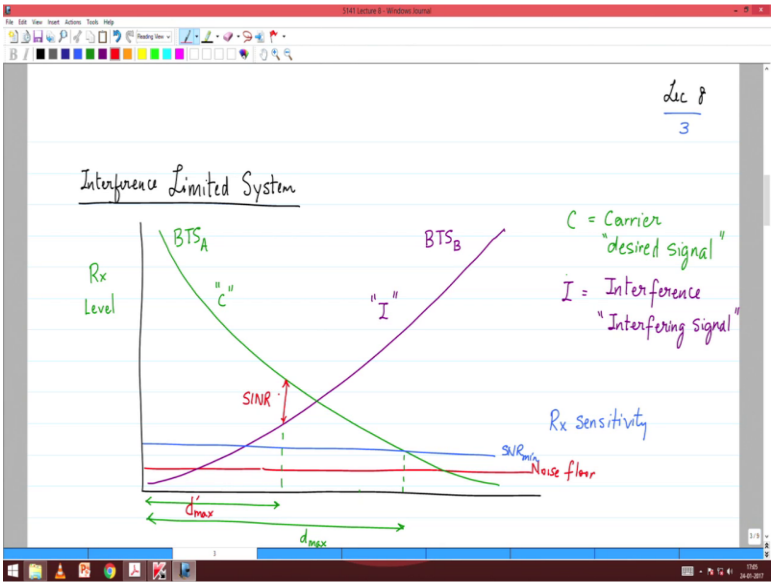

Again this is the figure that we already had a chance to look at, but I thought well I will pick it up from this point. So, the signal desired signal from base station A that is exactly as we have seen before the signal is decaying as a function of distance and there is a receiver sensitivity, but let us assume that there is a base station B which is also transmitting at the same frequency. Then it becomes a interfering signal we call it interference or interfering signal. Now the interfering signals strength the case as you move away from base station B. So, basically moving away from base station B, so if you are right at the middle point this midway between base station A and B we said that the signal power divided by interference power would be one both of them would be at equal power which means the impaired signal to impairment ratio is 0 dB most likely you will not be able to detect your signal at that point.

So, typically you would want to maintain a certain threshold for your signal quality. So, the question then becomes what is the signal quality metric in interference limited scenario.

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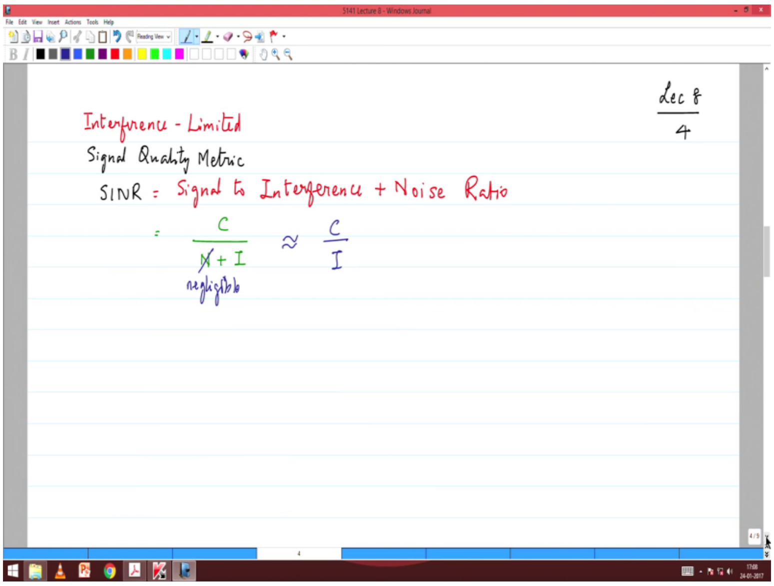

So, in a interference limited scenario the signal quality metric becomes is signal to interference plus noise, interferes noise is always present interference is what we have created interference plus noise, R stands for ratio the expression that we would typically write down for this would be C representing the signal N representing the noise plus the interfering signal.

Now, in the previous figure that we drew I would like you to pay notice to the following aspect that the interference is at a higher level than the noise. So, in some sense the interference dominates over the noise. So, indicate that by saying this is negligible the noise is negligible; that means, the interference is a more dominant term. So, this becomes approximately C over I carrier to interference ratio and most of our cellular systems C over I is the metric that we design for because the noise we are not noise limited, but we are interference limited. So, in interference limited environment I like to make one observation your transmitted signal power from your own base station of course, determines your range what else affects your range what else affect your range.

In a noise limited system it would only B your transmitted signal power because nothing as affected and of course, the margin that you want to keep, but in this case the power level is which base station B is transmitting will also impact you know why is this is obvious from the figure you know why do we have to make a special mention of it the reason for that is we have cells of different sizes let us say you have deployed a Femto cell inside your home that is your this green level is transmitting let us say at 1 milli watt you may actually have a base station that is transmitting at thirty watts which is not too far away. So, which means at even though you are close to your base station you may actually get affected by the fact that there is a interfere whose at a much stronger level. So, the understanding of the signal quality is also an important element that we have to keep in mind the notion of the interfering signals interfering base stations power. So, keep this basic picture in mind.

So, what I would like to do is introduce for you the notion of the cellular concept using this framework.

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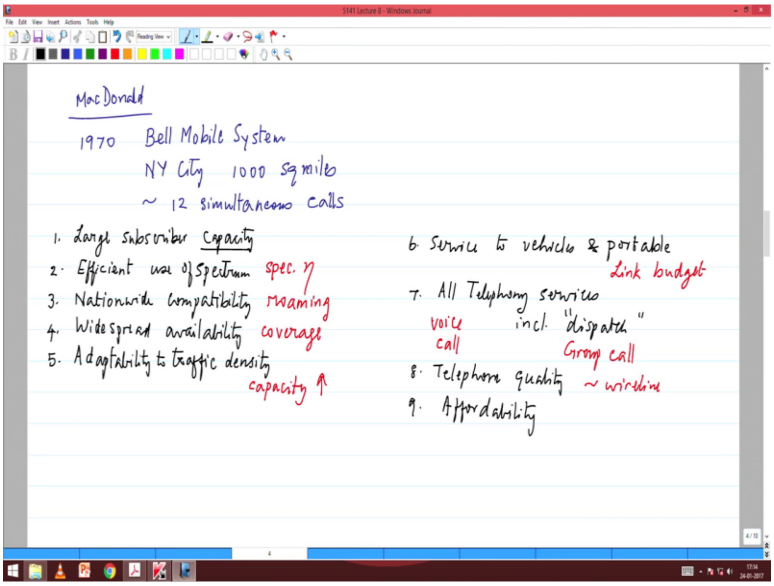

So, I trust you had an opportunity to read MacDonald’s paper, MacDonald’s paper was the foundation for the cellular concept and let me just mention where the origin came from. Basically in 1970, the Bell mobile system bell telephone system that was the telephone company equivalent of our landline service provided by BNSL this was the telephone company a bells telephone system was the telephone company and they also provided mobile service that was called Bell Mobile System.

So, basically bell mobile system provided mobile service in the year 1970 they had deployed a system in New York city population of more than 10 million people and approximately 1000 square miles you can convert it into square kilometers very large area and they could support a maximum of 12 simultaneous voice calls 12 simultaneous voice calls across the entire city and the reason was they had set up a very big transmitter very high power. So, to cover the 1000 square miles and of course, they had a spectrum available only for 12 simultaneous calls of course, they were not doing the very efficient method.

So, the basic premise of McDonalds work was based on 9 elements and I hope you would have read the document, but let me just highlight that. So, basically the first premise was you must have a large number or large subscriber capacity that was a requirement. So, this is what we would refer to as capacity that is in our term, so that was what he was trying to address as first stage efficient use of spectrum. So, whatever spectrum they had they were using fairly inefficiently because they were able to hold on his as 12 simultaneous calls efficient use of spectrum and this is something that in our terminology would be called as spectral efficiency, spectral efficiency and we will talk about that as we go forward he said that we should have the ability to have this system deployed nationwide compatibility.

The terminology was because remember that was it, they were the pre cellular days today what would you call this roaming. So, I should be able to go anywhere in the country and be able to use that this, the next requirement was widespread availability widespread availability that basically in availability is a term which says that when I want to access it the system must be able to accept me this would be in our terminology it would be coverage. Next point that he wanted to mention adaptability to traffic density, adaptability to traffic density again a good way to remember it is what was he thinking of if you design a system let us have designed and deployed the system let us say I have say I can make a 80 simultaneous calls you should never tell me 80 reached too bad I cannot do anymore.

So, basically if the traffic grows he wants to increase in capacity. So, somehow there should be a way to increase capacity as you go along do not tell me on day one to increase to deploy the capacity that I need ten years from now the item number 6 again as I mentioned 9 elements of this you wanted to service both vehicles and portables service to vehicles again car phones and portables again the thinking was that most of the phones would be vehicular and maybe a few portables would be there, but this would affect your link budget because portables would not have as much transmit power they would not have as much antenna gain, so you should have enough link budget.

Then number 7 again when you are reading the paper some of these may have puzzled you, but just thought I explain that, he said we should support all telephony services; that means, all everything like a normal telephone would provide and it also says including dispatch and in case you are wondering what this dispatches this is what we would call today as a group call. Group call is typically used by people like the police when they when the operator is talking every other mobile will listen it can listen at the same time it is not one to one its one too many. So, if anyone speaks all the others here that is what is called a group call as opposed to a voice call which would be a traditional telephony and last 2 very very important once telephone quality what did he have in mind basically you are saying that there your mobile phone should have the same as a wire line phone wire line quality voice quality and the last one was of course, the affordability or cost issue.

So, interesting that this was what he set out to solve and before we explore the elements let us look at what was his basic premise and how did he design it.

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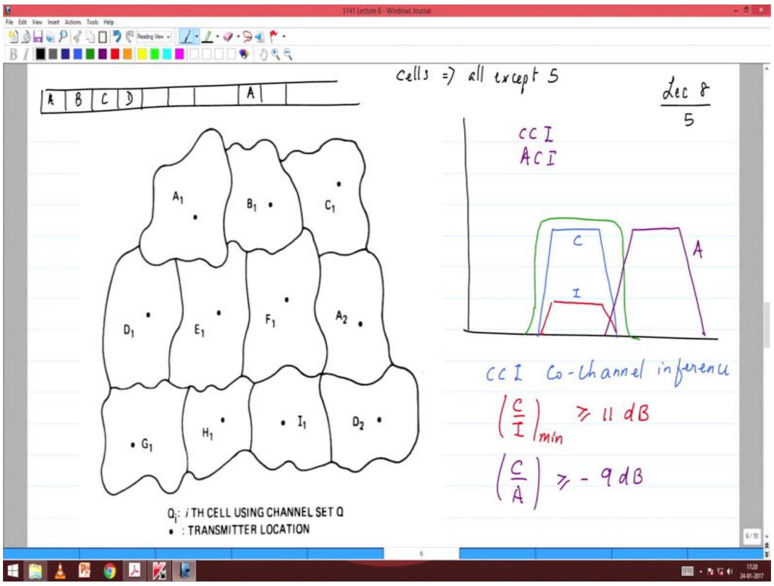

So, took a large geographical area he said I will create small cells basically I will put transmitters wherever the dots are I will give it some frequencies to operate A 1, B 1, C 1. So, if you notice it is gone all the way to I and then notice that there is an A 2; that means, basically I am going to use the same frequency a second time and so basically his concept was I will not create a single cell with large coverage, but I will create lots of cells with smaller coverage.

Now, you may ask you know why these frequencies are not the same for example, why a one and a one and b one are different frequencies and that that is an important concept which is explained as follows. So, let us take a quick look at the notion of what is the type of interference that we are, so if this is your desired signal blue is your desired signal whatever is your desired and if somebody else in this say in a geographical is away from you is using the same spectrum same frequency. That means, there is another person whose got this red signal and what does your receive filter would do, the receive filter always tries to filter out the desired portion of the signal that is the function of the receive filter it throws out everything else, but notice it cannot do anything against this red signal because it is a interfere who is within your band. So, if this is denoted as c this would be denoted as your s interference and we would actually call it as CCI co-channel interference.

Now, your receive filter is powerless against co-channel interference because the co-channel interfere lies within your own bank. So, the only way you can manage co-channel interference is by saying what is the minimum C over I; C over I minimum and I will just give you the number that was given for a GSM for cellular design it said that you must design your cellular network to ensure that minimum of 11 dB is maintained. So, this is your equivalent of receiver sensitivity, but in a interference limited environment there is no more talk about receiver sensitivity it just says you whatever you do in terms of creating additional cells make sure that my code channel interference will never exceed 11 dB.

Now, what happens if b 1 is your immediate neighboring frequency? So, basically if that was a neighboring frequency that would be your this would be called a adjacent cell not a co-channel, but an adjacent channel set and notice your receive filter is doing a pretty good job of suppressing most of your of the adjacent channel. So, what is the ratio of C over A that you can tolerate in a typical system assuming your filter has done a good job you can actually GSM system is designed to have minus 9 dB, how do you interpret it? My adjacent channel can be 9 dB stronger than my desired signal, not a problem my receive filter will knock off most of it and whatever leaks in I can say I can live with that.

So, the difference between CCI and ACI, ACI stands for adjacent channel interference CCI; co-channel interference now what happens if you have a frequency that is beyond a? What happens?

Student: (Refer Time: 21:21).

Your orthogonal; your orthogonal. So, you do not have worry about that channel at all because that is not going to affect you your receive filter will kill it completely. So, you are most worried about those interferers that are in your own band and on either side of you that that is your adjacent channel that we are looking at now McDonalds basic premise was you take your spectrum take your spectrum let us say that I have a my spectrum I divide it into the different channels FDMA concept I call the first one as a second one as B C D, those frequencies I assign it to those cells then eventually when I finish assigning to all the cells I will start reusing a again that becomes. So, all those with designated as a will be used in this cell and any other cell that is designated as a. So, this is the frequency reuse concept.

What MacDonald basically said was small cells I cannot afford to use the you know the same frequency in my own self. So, basically I will make sure that there is some separation between the points that or the geographical location that used the same frequency, but my neighboring cells I will make sure that they are given frequency that will not interfere with me design my receive filter. So, that the adjacent channel interference criterion is met. So, McDonald’s concept number one was the notion of cells small cells. So, cell was the concept that he was designing out of the 9 items which items did he fulfill with this concept please go back and verify that he did satisfy sorry.

Student: (Refer Time: 23:12).

Everything except one all except 5 and 5 was the traffic density because in this design mechanism if the capacity if every cell has got a certain capacity, but if that geographical region says I want more capacity your; he does not this scenario does not address that. So, all except 5 condition number 5 were met with this and his solution also gave us what is called cell splitting.

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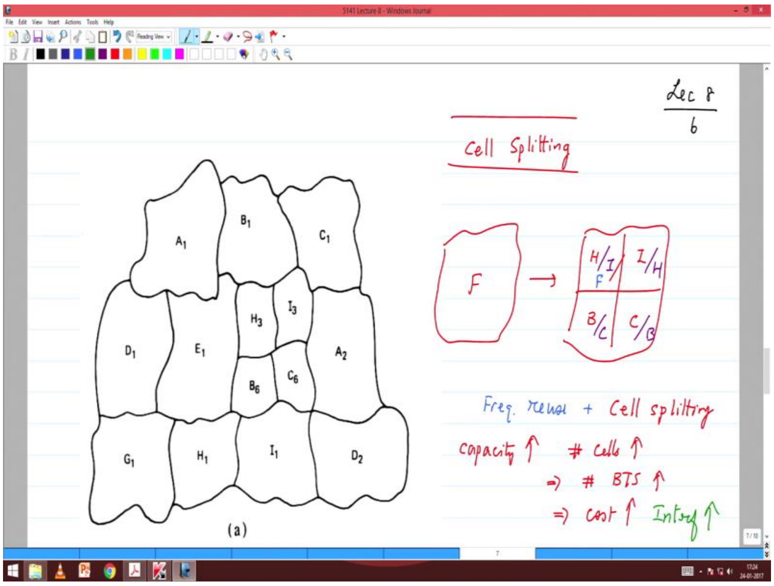

So, frequency reuse cells plus cells cell splitting are the main contributions of McDonalds paper pretty much what this; what made cellular today and what was cell splitting.

Let us say the cell which was given the frequency F had excess capacity that needed excess capacity what he would do is leave the other cells alone just go in and subdivide these the cell f into let us say 4 or 5 regions now you have to allocate. So, what previously was one self denoted as f now became a cell with 4 regions and basically he is reusing H why is he able to reuse h because there is some distance away from there. So, he is reusing H, he is reusing I in this one because again there is a geographic separation notice b is being used in the bottom and C.

Now, just as a thought exercise I could have assigned I here could I not basically I would also work instead of I could have given H, here I could have given C, here I could have given B, here all I need to make sure if there is sufficient separation from any other cell that is using the same frequency I could have also have assigned F to any of those notice F was there I do not need to leave off using those frequencies I could use F in one of these not in more than one any one of them could have been given S and then I could have to find 3 so, but the concept is very very you know it has a huge impact it says I will split the cell and assign frequencies that are non interfering or that will satisfy the c over I criteria. So, basically with these 2 McDonalds concept they said that all the nine requirements of a cellular system can be met.

So, that is the significance of the contribution. So, it is the frequency reuse, frequency reuse concept plus the cell splitting concept is the essence of the cellular design as we know it today. So, let me ask you a question what is the capacity of a cellular system that is designed in this fashion its infinity, but I can go on subdividing right I can go on dividing into smaller and smaller cells where is the price that I pay for that I will increase the number of base stations. So, if I keep increasing capacity if I keep increasing capacity the number of cells will keep increasing which means the number of base stations will keep increasing am I right and that eventually means cost. Again it comes down to a cost versus performance trade off and engineers we will find the right one also I heard somebody mention it the more base stations you deploy the more difficult it is going to be for you to find a non interfering frequency allocation.

So, frequency interference management is going to become a challenge maybe just add to this number of base stations will increase cost will increase and maybe very important interference will also increase we should never forget that that is a important element that we want to keep in mind. So, let us move to a example that I hope will make these concepts very easy for us to visualize and make it concrete. So, an example on frequency reuse, frequency reuse and the whole notion of cellular design.

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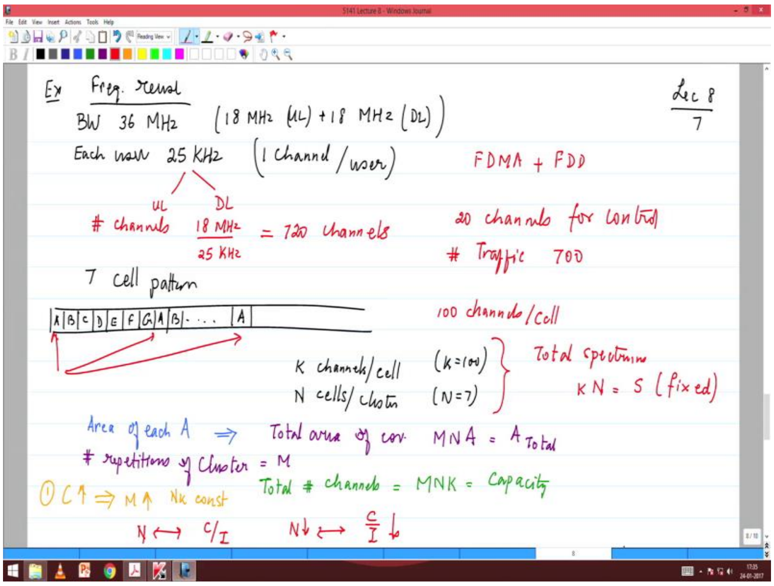

So, let us assume that the total bandwidth that has been allocated for the particular operator for whom you are designing the system let us say they have been allotted mega hertz it very generous allocation, but that is this is a problem. So, 36 mega hertz is 18 mega hertz on the uplink and 18 mega hertz on the downlink the total allocation has to be taken into account at the part of it one half of it is uplink other half of it. So, this is a frequency division duplex system.

Now, each user is, each user is using 25 kilohertz and basically one channel per user is what we are doing, one channel per user such a system would be called what type of multiple access am I using FDMA, it is an FDMA FDD system. So, maybe just make a note of that it is an FDMA FDD system, but whatever we talk about it is going to be perfectly applicable to any other multiple access system it is just for us to visualize. So, a number of channels notice I need 25 megahertz for uplink and I need 25 megahertz for downlink because uplink one user a is talking to B downlink B taking and both require 25 megahertz. So, if I were to ask you to tell me the number of channels available channels would be available would be 18 megahertz divided by 25 kilohertz; 25 kilo hertz which is 720 channels.

Now, if you remember when we talked we talked about a cellular system there are certain channels which are only reserved for control information this is not for traffic it only carries. So, let us assume that in this entire region 20 channels will be dedicated for control twenty channels for control information. So, what is available for traffic would be 700, traffic is 700, now I want to use a 7 cell pattern, 7 cell pattern and let me show you how to visualize a seven cell pattern - basically we will let me see if I have a figure that that will make it easier.

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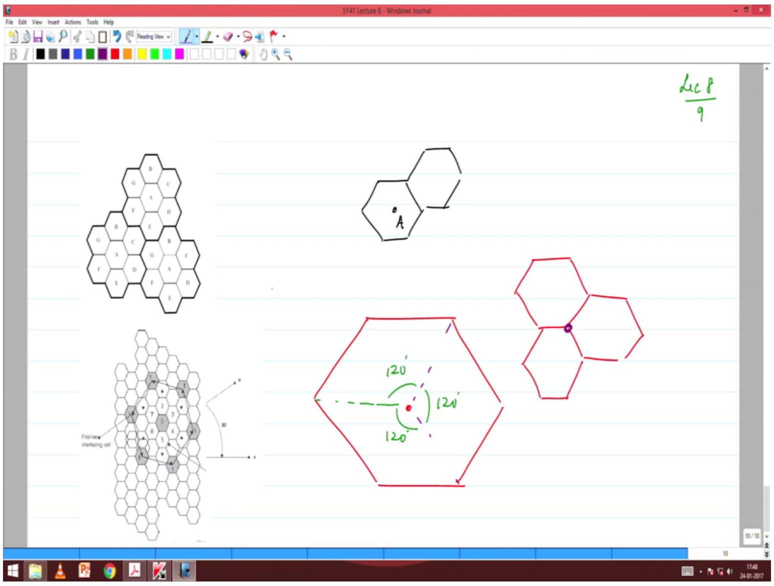

Just think of the just a one cluster alone. So, basically I have a cell base the base station is sitting at the middle then I have a neighbor let me call this as the cell A then notice I can then visualize B C D E F G then again the pattern repeats. So, I am basically in such a scenario I am working with a seventh cell cluster and so going back to the example that we are working with I would have to do my frequency planning in the following fashion. I have take the first frequency a assign it to sell a then B C D E F G why am I not giving A A A because; that means, I will get adjacent channel interference I do not want that. So, A B C, so the adjacent the next frequency that is used in cell A it comes here. So, this is also going to A then this B you can see how the pattern will repeat.

So, the frequencies that are assigned to cell A are this one this one and then once we go past this repetition again there will be another A that will also be assigned to cell A. So, all of these together are given to that cell marked as a similarly to B to C and then any cell that is marked A any cell that is marked as A has the same set of frequencies. So, keep in mind your co-channel interference you are going to worry only about co-channel interference is going to come from any other cell that is marked A, they are not near you and this hexagonal geometry again we will talk a little bit more about it ensures that there is sufficient separation between cells that are using the same frequency.

So, let us go back and complete our numerical calculation. So, the 7 cell cluster basically means that I have 100 cells; 100 channels per cell 100 channels per cell now here comes the formal frequency planning element of it. So, the notation that we will follow is K channels per cell assuming that I have K channels per cell in this case K equal to 100 K equal to 100, the next term that we introduce is an number of cells per cluster cells per cluster in this case we are looking at N equal to 7.

This already tells us a very important parameter the total number of channels per cell and total number of cells per cluster and that cluster is now going to repeat. So, what is the total spectrum that I have for traffic total spectrum that I have for traffic will be K times N and that is a fixed number I cannot I cannot vary that lets call that as S and make sure that we will never we cannot violate that because if I increase if I have to if I out increase K have to reduce N and what are the implications we will talk about, but again K times N is the total spectrum that is available that is used within one cluster and every cluster is going use the complete spectrum that is available to us.

The next one that we are we are always in interested in is covering a geographical area. So, let us assume that the area of each cell area of each cell is a area of each cell is a. So, this tells me another parameter that is a fixed quantity there are a fixed number that. So, I need to keep in mind the total area of coverage. So, total area of coverage or before that I need to also indicate how many times the cluster is repeated number of repetitions of the cluster to cover the whole area repetitions of the cluster we will denote it by the letter M. So, total area that is being covered area of each cell, which means the total area of coverage area of coverage is that there are M clusters into N cells per cluster into MNA, MNA is the total area of coverage and again assuming that you are covering a certain city this is also more or less 6 you may you know coverage may extend a little bit outside, but by and large that this is what we are working.

Now, within this entire geographical area what is the total number of channels that you have, total number of channels? So, at any given time what is the total capacity how many simultaneous voice calls can you carry number of channels that you can carry this also is related to the number of clusters that you are using and within each how many cells per cluster and within each cell how many channels are available. So, this is your capacity.

So, given a spectrum you divide it into channels you say that I am going to have the size of the cluster is determined and based on that the number of channels per cell becomes a fixed the area of the cell that you want to design that will determine how much transmit power you want to use that will tell you how many times the cluster has to be repeated to cover the whole area that is MNA. And once you have designed the number of repetitions it also tells you how many channels are there available to you for working with the capacity.

So, here comes the application part. So, the first question as always is I want to increase capacity I want to increase capacity I want to increase the number of channels. So, what do I do? Obviously, capacity is M N K and K times N is a fixed quantity I cannot ask for more spectrum. So, the only option I have is increase M. So, this basically says go ahead and try to increase your M because if I say increase K; that means, I or increase or K or N; that means, I am going to ask for a number of increase more spectrum. So, keep in mind that N K is a constant N K is a constant.

Now, of course, there is a certain reason for choosing N at to be of a certain size and as I mentioned to you the fundamental reason for choosing N is based on what will be your C over I that will that will result what will be the minimum C over that will happen because of co-channel interference. Now if you push me to increase capacity then the only option that I have is I will say go ahead and decrease N decrease the decrease the visit is it N that I am supposed to do yeah it decreases the number of clusters per cell because, but then you say well you know that did not help me because N and K will compensate each other N K is a is a constant.

So, now the key element that that we suffer when I reduce n is that my C over I is going to reduce my C over I is going to reduce. Now notice that if N has reduced in the total area what will happen M has to increase because that you have to cover the total area cluster size has reduced a size of the cell remains the same if I; that means, number of repetitions the minute I increase M capacity will increase. So, reducing N I pay a price, but it will give me indirectly capacity. So, what I need you to make sure that you are comfortable with this the number of channels per cell is one parameter number of cells per cluster, the area, the cluster, size the impact of C over I on these there are several interesting interdependencies I would like you to be familiar and comfortable with these with these aspects any questions on what we have talked about maybe there is some element that you want to clarify. I will notions of frequency reuse are you comfortable with that, yeah.

Student: (Refer Time: 39:07) he said that (Refer Time: 39:10) over come by cells (Refer Time: 39:14) but what if the graphic is dynamic mean graphic will be dynamic and so how can we go in the middle and (Refer Time: 39:22).

Correct. So, again keep in mind that this is that the document which basically gave you the concept of cellular. So, they are not visual did not quite visualize there is a cricket match going on. So, if you know all the people have gone to chip hawk and then after that that is you know everybody's got the phoenix mode. So, this movement of users was not visualized as much. So, the notion that that would that would result in for the example what that would be would have to be done in McDonalds design would that let us say you know this cell when he did the splitting was one area where there is a likelihood of high traffic density and G was another area of high traffic density you would have to do cell splitting in both those areas.

Now, if you tell me that it is going to move around that I have no idea to predict ahead of time what is what is going to happen now that is even our 3 G systems cannot handle that. So, the best that they can do is if this cell starts overflowing they will ask the neighboring cell a take this call take this call they will try to what is called offloading of traffic, but the ideal scenario is for you to be able to dynamically create capacity now how do you do that how do you do that.

Student: (Refer Time: 40:46).

That is another solution you can say basically D E and H, I am going to take some channels from you and give it to G temporary now that is that is also that is what is called dynamic frequency planning. So, basically depending on where there is capacity you sort of allocate more cells that is a very good solution that is one way by which we can do that any and you think of anything which is very very futuristic. Actually it still in the research stage we hope to be able to demonstrate that some time very soon here at IIT, Madras basically it is a base station that is flying on a drone.

So, you just let the drone go where the capacity is and then take care of the capacity and, but you have to make sure that the drone does not interfere with the others and there are a lot of technology issues that are being worked out, but the latest proposal is you can create capacity wherever you want you can create it in a very very flexible manner, but the existing mechanisms would be take your resources and redistribute that is the best that you can do second is offload your traffic to neighboring cells because most of these can easily accommodate users from the neighboring cells. So, you can do offloading of traffic reallocation of resources those are the basic elements that that we have other than you know something where you can dynamically bring in a base station, but very good very good question any other, yeah.

Student: (Refer Time: 42:23) base station repeater or what.

It is a base station; it is a regular base station. So, it actually is connected to the network and people who are connected to the mobile base station do not know that it is a drone basically they think that it is a regular base station that I am talking to.

Student: (Refer Time: 42:42).

This would be through microwave backhaul. So, it would be a wireless connectivity to the rest of the network, so today; even today if you deploy a base station in a remote location in fact, if you go we did not allow the operators to lay fiber. So, most of our cell phone towers in the in the campus all have microwave backhaul. So, you will see a small dish which is doing the microwave connectivity. So, it is not difficult for us to do a wireless backhaul for a mobile base station yeah, but obviously, the connectivity to the core network is very very important because base station actually hands a large amount of data any other question I want to start you thinking on a couple of things and the first one is the notion of cellular geometric again the best reference for this is Rappaport’s book chapter 3 cellular geometry.

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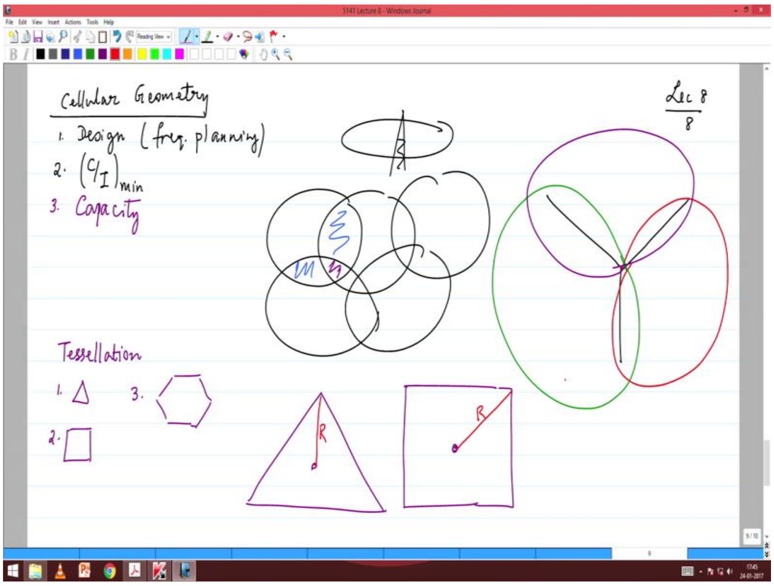

What we are trying to understand is how do we design a system how do we estimate the C over I. So, the aspects are I want to know the design.

So, then I can do the frequency planning frequency planning the second element that I need to worry about is what is my C over I and I am always worried about that c over I am in I should make sure that I meet this requirement otherwise I will have an outage scenario. Now in an interference limited environment you have to worry about fading – yes, no, that is only for noise limited or is it something here also very much here because in let us say that you have an interfering base station and your signal and you go behind a building what happens - your signal has dropped interference signal is still present outage. So, absolutely fading margins have to be figured in into this as well. So, the whole whatever we have learnt as far as noise limited systems actually carries in except the only thing is now instead of thermal noise it is some manmade signal that is setting your threshold and based on that you have to design your system.

So, these are the 2 basic elements that we have we have to worry about. So, the in terms of cellular geometry we already talked about the notion that there can be omni directional radiation. If you had omni directional radiation what the way you would your cells would start to look at is it would start having this type of a pattern and the reason you would have to have coverage overlap of coverage is because you do not want to have coverage gaps. So, this would be a way by which you would have to worry about.

Now, we also said that we would like to have one twenty degree sectaries radiation. If I tell you that that is the preferred design of Sonora principle then the question would be what is the shape that you would have to have for your cell and it turns out that that is not very different because that still starts to look like a circular shape is what we will end up having.

So, the elements that we want to incorporate into our design is that it is you should not constrain me to say you have to do omni directional or sectaries antenna, I should be able to do if flexibly I should be able to decide on that I will do my analysis based on omni directional, but I may deploy it when I comes to the in this field as something that is in a sectaries antennas I in terms of self planning one of the things that would be problematic is you know there is so many of these areas that are overlap of 1 or 2 cells and then there are some which are overlapped by multiple cells those are problematic areas in the sensor now to which cell do I assign that user and it becomes always a confusion. So, preferably I would like to have non overlapping cells right, so that I can then design my system.

Again when practice it is going to look like this, but when I design my system on paper I can then talk about capacity per cell because that is one thing that is very very important. So, maybe add a third item I am also interested in the capacity that we will achieve. So, the question is what shapes can you use what is this method of designing such a system this method of designing is called tessellation it you take a shape and keep repeating it until you cover the entire area and it obviously, it has to be a regular shape equilateral triangle a square or a regular hexagon. So, basically you are looking at different possible of. So, one is a triangle 2 is a square of course, pentagon is also possible, but you notice that you know there are some limitations in terms of desolation. So, the next shape that actually gives us good geometry is a hexagon.

Now, of course, between these 3 you know you can go to higher order, but again the complexity of the tessellation you know increases to keep a simple tessellation pattern and to do these are the 3 basic shapes its talked about in McDonalds paper. So, his proposal was let us look at a common how do you compare a triangle to a square. So, he said let us look at a common element of the distance of the farthest point from the base station to be a fixed quantity. So, if I were to design a triangle shaped cells I have got a base station sitting in the middle I am going to define the maximum distance. So, this is the point that the maximum distance that is going to be R. So, by the same token if I were to design it using a square the base station is in the middle the point of maximum distance is going to be R that is going to be the end of course, for a hexagon.

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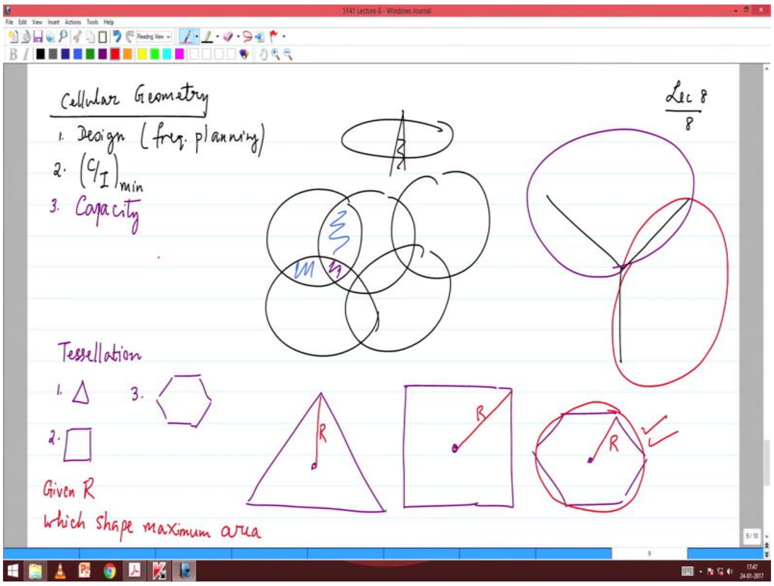

Let me just highlight that the base station is in the center again the distance of the furthest point is going to be R.

Now, given that now you are comparing apples to apples the question that the question that would be asked is which of these tessellation patterns gives you the minimum number of cells because that is going to. So, for a given R, given R which shape maximizes the area which shape maximizes area wide why is that a constraint because that will tell me how many cell size I have 2 maximum has maximum my area maximum area and it turns out that the hexagon will win you can do a simple calculation and understand that this is the and we will basically assume that you are comfortable with this conclusion that the hexagon is a regular shape gives you a very nice tessellation it also maximizes the area for a given distance between the base station and the furthers point and also easy to see that it is a reasonably good approximation to a circle which will be the radiation pattern if you were to do omni directional radiation.

Now, you may ask now what about if I did sectaries radiation, not a problem let me see if I can quickly draw a hexagonal cell, hexagonal cell I am at the middle I want to do 120 degrees radiation, now the most common we do is 120 degrees radiation then I say here is cell number 1, second one is cell number 2 basically you have inherently you have 120 degree sectors inside a hexagon 3 of them very nicely it fits in and the shapes are still regular.

The other way to implement a 120 degree sector also another elegant solution and you may you may almost say that this is the reason why we have chosen a hexagonal pattern is to move the base station from the center of the hexagon to a vertex automatically you get 120 degree sectorization. So, again for many reasons hexagons are the preferred choice and we will basically in the next lecture we will introduce for you the elements of a hexagonal cell geometry base design. So, before I conclude today's lecture I want to pose a certain problem to you.

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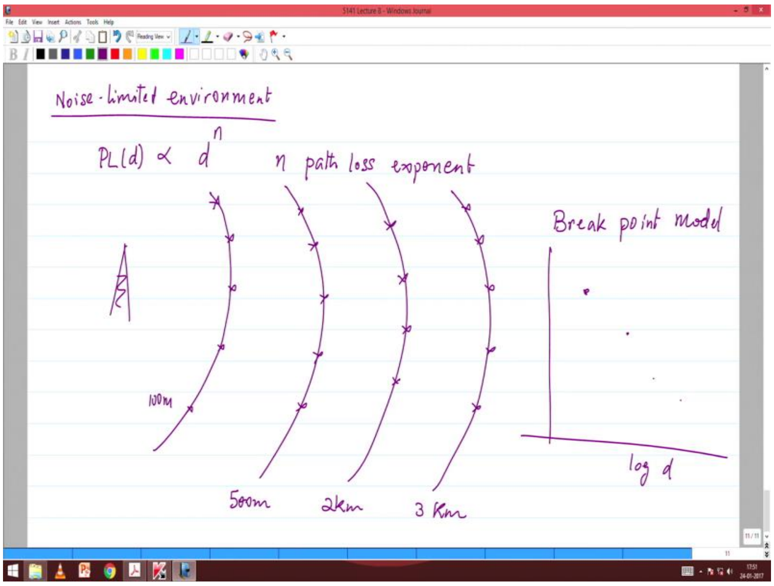

So, this goes back to our noise limited environment noise limited environment. Now in the noise limited environment what you are always looking for is the range that you can you can cover with a certain transmitted power. Now the range path loss at a distance d is proportional to the distance raised to the power n, n is the path loss exponent path loss exponent. Now if you were given the task of deploying a wireless system inside our campus go ahead and design the system you know put the base stations and then estimate how many base stations you will need.

So, this is what you will do you will set up your transmitter somewhere and then at a radius an arc of let us say 100 meters you will measure the power levels at different points then you repeated for at different points and you will then try to do a curve fitting which will then tell you what is the path loss exponent. Now I want you to think about how would you do the curve fitting given that I want to work with the breakpoint model.

So, I will give you a set of measurements it will be let us say at 100 meters, 500 meters, 2 kilometers, maybe 3 kilometer, some sets of values I do a bunch of measurements. So, basically each of them will be a set of measurements and then I give you those average readings and then say figure out the path loss exponent and this is a very very practical exercise because you know you actually have to do that this will be uploaded as a basically something for you to work out I will explain it in class, but then in the next lecture, but this is something I want you to think about. Again it is a very very interesting problem how do I estimate the path loss exponent just by you know given these measurements how do I do that.

So, start thinking about it basically what you would do is receive signal power as a function of log d you are getting some average values and I need to find the slope. But think about it, it is a very interesting problem very practical problem we will address it, but that important thing for next lecture is hexagonal geometry. Please do read Rapoport chapter 3 because that will enable us to quickly go through the key results in cellular concept.

Thank you.