Introduction to Wireless and Cellular Communication
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Lecture – 12
Cellular System Design, Capacity, Handoff, and Outage
Handoff & Mobility

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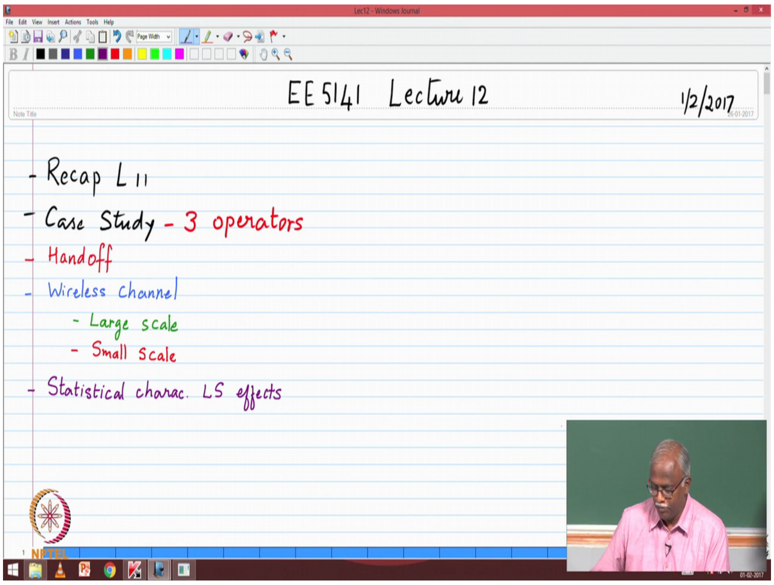

I think we will get started. Plan for lecture 12 is to do a quick a recap of what we have covered in the last class. We will spend some time on the case study as I mentioned this is something that I would like you to think about and see what are some of the implications of the system design concepts that is we have been talking about. Very specifically this today's lecture covers two aspects - one is the aspect of handoff, the second one is a more detailed understanding of the wireless channel. And in that context, we will talk about two types of effects - one of them called the large-scale effects and the one called the small-scale, and will describe each of those. We will begin by statically characterization of the large-scale effects and then leading into the small-scale effects, which is probably the most important element of our course in terms of understanding the wireless channel.

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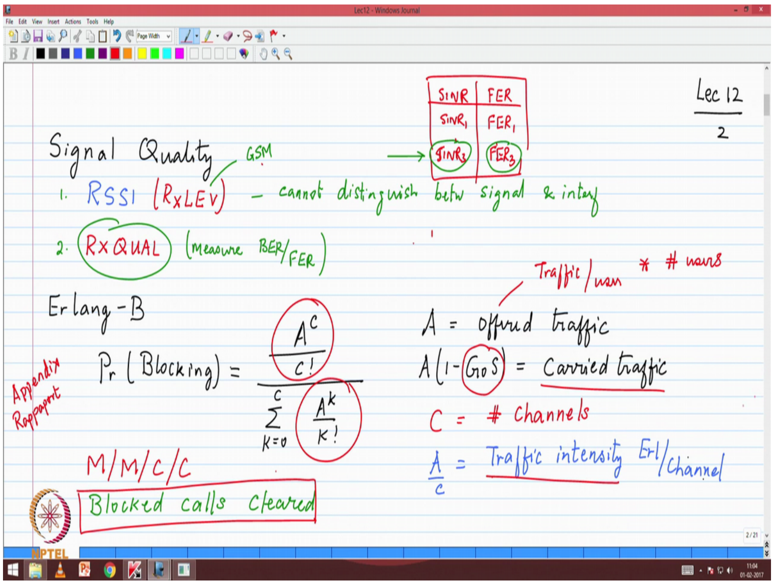

A quick recap of the concepts that we have introduced in the last class, we mentioned that there are two matrix that are commonly used in lot of the systems, one is measure of the signals strength received signal strength - RSSI in different cellular standards call it by different names. This is the name that is given in GSM for RSSI. Now, as we mentioned in the last class, the RSSI gives you only a total energy received. So, it cannot distinguish between signal and interference. So, this one just make a note that this cannot distinguish between a signal and interference, so it has its value it tells you if you are close to the base station or not, but again in a interference limited system this would not be the metric that you would rely on. Cannot distinguish between signal and signal meaning desired signal and the interference, so that is the point that we keep in mind.

So, which mean that RSSI we must be used in conjunction with another measure, which will tell you how good is the SINR. And in GSM again this quantity is called R x qual, it is a measure of the bit error rate slash frame error rate BER slash frame error rate. And it just tells you in a tries to mapping from the bit error rate or frame error rate to the received signal to interference noise ratio. So, from the BER, so for example, so if I have a table which says that for different values of SINR, what is the frame error rate for example. So, this is SINR 1, I have FER 1.

So, basically I have populated this table. I do an estimate of the frame error rate that is being achieved let us say this is SINR 3, FER 3. And if it turns out that my estimate of the of the frame error rate happens to be FER 3, then I report this as my R x qual. It is a very rough measure again we are not trying to do precise measurements this is only to know are you close to the base station or you at the cell boundary and it is a good way to keep in mind that when you think about it in the context of a system these two parameters are important.

Now, having understood that this is a important element making sure that we are understand the quality aspects, now we come into the capacity aspects. Now, the capacity aspect basically tells us that how do we estimate the capacity after you have designed the system and you have assigned number of channels to each of the cells, so that is the calculation that we did using the Erlang B formula. Again the if you are interested this is you can find it in the appendix in Rappaports book. So, the derivation is is available it basically goes into a Markov chain, where you say reaches if I have no user one user, two users and all the way up to capacity and all the possible transition the rate at which the transitions will happen and then as the result also. So, this is in a Rappaports book, if you would like to refer to it definitely a very useful information that you can get.

So, let me just complete this Rappaports book. Again depends on which addiction it is in the appendices you will find it. So, the Markov chain is a characterized in terms of memory less arrivals, memory less holding times the C channels being the number of channels available to serve customers and then C being the total allowed capacity, basically cC simultaneous calls. And cellular systems do have the design principle that if there is a call that does not get a channel then that call is removed from the system, we call it as blocked calls are cleared, basically they are not in a queue. So, therefore, Erlang B or not Erlang C is the formula that we use.

A is the offered traffic, offered traffic is looking at the users traffic generation pattern number of users that gives you the so this would be traffic per user into the number of users that would be within a cell most of these are looking at the capacity of at the cell level. So, this is the total offered traffic, but there is some blocking probability that is given by the grade of service. So, grade of service gives you the blocking probably. So, 1 minus the blocking probability is the probability that you are offered traffic is carried by the system, so which mean that your total or carried traffic is always less than the offered traffic by a small amount which is can related to the a grade of cells. C is the number of channels and the offered traffic by the number of channels are very important parameter for us traffic intensity which is Erlang per channel.

Now, will see that this, this A by C is a parameter that occurs in the blocking probability, so basically it occurs numerator and denominator, the numerator and denominator are you know denominator is larger than the numerator. So, it is a probability less than 1 as you have larger and larger number of Cs you can see that the blocking probability will reduce. So, this is something that we looked at maybe even looked at an example and a look at some numbers from the Erlang B graphs. The same information can be obtained from Erlang B tables also. Again those are available on the internet, available in appendix of Rappaports as well. So, either the graph over the table form, but make sure that you are doing accurate reading from the graph if you are doing because a small error in reading the graph can cause you a big deviation in terms of your estimate of capacity.

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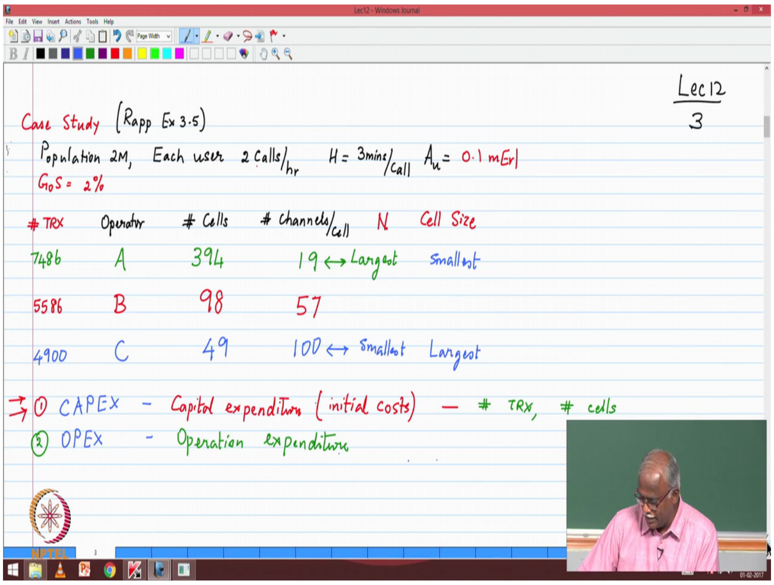

Now, we move to the case study, thus this is the interesting part. The population of the city or the area that we are trying to cover is 2 million a medium city a each user generates approximately one-tenth of a Erlang or 0.1 mille Erlang is the traffic is generated by the users. Now, for interesting discussion purposes, there are three operators each of them have designed their system using some criteria. Again we would like to be able to guess what their criteria are and so the information that is available us operator A, B and C each of them has use the corresponding number of cells and an each cell the operator has made these many channels available.

So, let me start with a very basic view of this. Typically for receiving one channel, you have to have what is called 1 T R x card basically at transmit receive card basically one board or card that processes both the transmit and receive for that particular channel at the base station you must have a T R x card. So, if I want to look at how many T R x s how many T R x cards operator A is going to require. So, can you tell me what is the total T R x cards is going to require 394 cells each of them 19 channels per cell which mean that the product of the two is a total number of T R x card across the system that the operator A is going to require.

So, do a calculation if you have your calculators with you, this is 7486, quickly do for the others other two operator B requires 5586; and operator C requires 4900. So, the cost of the of a system depends on how many cells you are creating and also how many T R x is your going to deploy that is all basically is a number of cells which means you have the towers that you will have to establish and the amount of processing cards. So, obviously, operator a has taken a route where he is willing to spend more upfront.

Now, whether he is justified or not we have to see, but this looks like operator C has played it safe, he is not invested too much in terms of. So, typically whenever you look at a project, there are two types of costs involved. The first one the being the capital expenditure, this is what you must invest in terms of the infrastructure and this is usually the initial cost that will be affected by that, so these are initial cost. And operators typically will want to keep CAPEX low at the beginning, because what otherwise what will happen they would have to spend a lot of money initially and that would mean that their cash flow issues would be there. So, this is related to initial cost.

So, typically you do not want to spend too much on CAPEX except if you have a very different strategy. When you want to come in and take over the market, you may say well you know I am going to take a risk, I am going to spend a lot of CAPEX in the hope that I am going to take a majority share of the market. Now, related to this is the second expenditure, which is operational expenses. Once you have deployed your network, what are the costs that you would have to worry about. Again in the design of a system OPEX is not a parameter that we focus too much on we would more or less focus primarily on the CAPEX part.

So, CAPEX is number of transmits receivers number of cells. So, this would be number of T R x s across the whole coverage area and the number of cells, and definitely operator A has taken the route of a high CAPEX option. Now, let us apply the things that we have studied in the context so far. Now, in the context of the number of channels per cell, A has only 19, C has 100, what is your feelings for the of the cell size?

Student: Cluster size.

Cluster size, whose got the smallest, whose got the largest? When your cluster size is increase, what will happen the number of channels per cell will decrease right cluster size increases, so that is again this is not given to us. You would infer from this that operator A has chosen the largest cluster size, because he has the smallest number of channels per cell. And again we would has that a guess that B obviously, has gone for the smallest because he has got the largest number of channels per cell. And B is somewhere in between. Now, given this and the fact that you just studied trunking efficiency who knows trunking the advantages of trunking better?

Student: C.

C because he is obviously, knows that if I put 100 channels per cell, I am going to get a lot of initial subscribers, but I am going to do it at the cost of quality, because I am created a very small cluster size, I am not deployed as many cells. But I am going to bank on getting more traffic. Now, cell size is also we can make an that is sort of obvious to C because he has they both have to all of them have to cover the entire city. So, which means that A has chosen the smallest cell size because he has got the largest number of cells and C has taken the largest cell size. So, given this scenario and B is somewhere in between in all the cases between is receive extreme seem to be A and, so tell me quickly what is operator A’s strategy, what do you think you operator a strategy? He is willing to spend maximum CAPEX.

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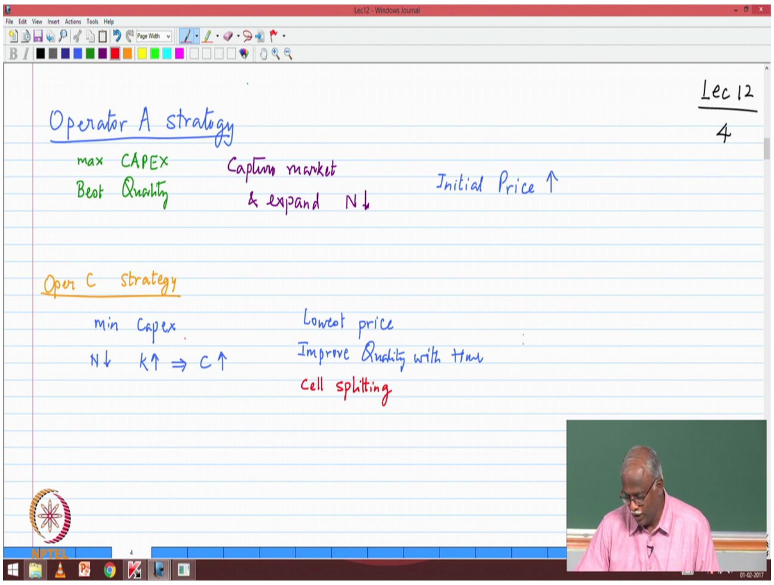

So, maximum investment in CAPEX which means is initial cost are high, but he is going to offer best quality and he is got large number of cells. So, therefore, presumably he is got ability to grow. And how will he grow, he is got large number of cells, he is using initially a large cluster size, if he starts reducing the cluster size number of channels available in each cluster will increase and therefore he is got lot of potential for growth.

So, basically we can summarize again I am not a business man, but what his market is capture the market using quality. Capture the market based on quality and then expand how will you expand reduce the cluster size basically reduce N and then he will have lots of capacity available, but what will his initial price at which you will have to basically he is running a business. So, therefore, his initial price is going to be higher than the other operators, because he has had more CAPEX. So, initial price will be higher again this is the true price, again he may offer a discounted price for a market reasons, but the initial cost he will have to break even he would even charge to a higher price, but with time he because his capacity is going to grow his price will decrease. So, again very good strategy if you want to take over the market and do better than the others.

Operator C strategy, so he says I am going to minimize the CAPEX I am going to create a very low cluster size. So, N is small. So, which means my C is large number of channels per channels per cell what alphabet it use for the that we just what was the number of channels per cell what was the symbol that was used. C? I do not think, it was C; C is for capacity

Student: (Refer Time: 16:00)

Now, N is a cluster size.

Student: K.

K. So, he has increased K by reducing cluster size and this automatically means that he will have at least based on Erlangs theory he should have much better initial capacity. And what will be his strategy, he says that you know offer the lowest price because he is invested the lowest cost capital expenditure basically capture the market and then keep making improvements to his network. And therefore, improve quality improve or make sure that you can make some changes to address this issue. So, improve quality with time interesting to see what with time.

So, what how will he how will he get capacity he is already deployed 100 cells, 100 channels per cell, but his cells are large. So, he has to go for cell splitting. So, he would have to do cell splitting if he wants to do capacity, but that is a very smart thing to do because that way he knows where the capacities are needed and he is going to increase capacity only in those areas. Whereas, operator A has taken a strategy where he has made lots of small cells not knowing where the traffic is going to be, so again very different ways of thinking, very different approaches to the market. And again B is somewhere in between these three these two extremes in that.

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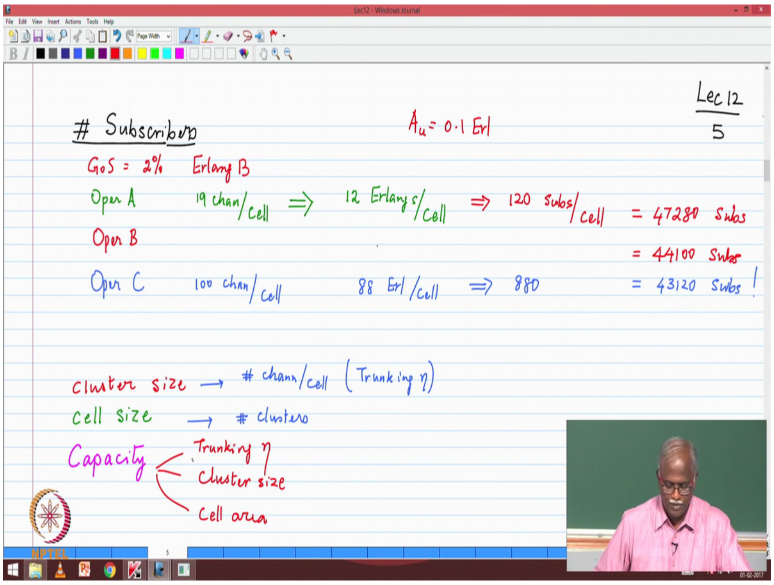

So, now we have given that we have got some amount of intrusion, let us go back to our capacity calculations. So, we have told that the grade of service is 2 percent, I know how to do Erlang B. So, Erlang B formula is what I used let us take operator A what colour did I used for operator A, operator was it was green operator A. I want to know how many subscribers can operator a handle and or how many users using his statistical multiplexing based on Erlang B. So, the number of channels per cell, number of channels is 19 channels per cell that is operator A's allocation based on Erlang B this tells me approximately 12 Erlangs per cell is what we can support that is a calculation that I used using the graph. Remember all the subscribers are using generating one mille Erlang one mille no 100 mille Erlangs, so it is 0.1 Erlang, 0.1 Erlang.

So, this tells me that this user this operator can support 120 basically 12 Erlangs divided by 0.1, 120 subscribers per cell and he has got a total of 394 cells. So, presumably on day one, this operator can handle 47 to 80 subscribers hope you saw the flow. Operator has done the design and says I have 19 channels per cell available you look up Erlang B formula and say he is got approximately 12 Erlangs capacity per cell with 0.1 Erlang Being the traffic generated by subscriber that is based on statistical multiplexing. I can support 120 subscribers per cell upper limit and that would correspond to 47 to 80.

Now, what would we have what we would expect is that now C is going to have much better capacity because of his design. Let us take a look at operator C, operator C what colour did I choose, operator C is blue. So, operator C again this is something that you can do I will just give you the quick summary 100 channels per cell that corresponds to 88 Erlangs per cell. This corresponds to 880 subscribers per cell and comes out to be 43120 subscribers. What happened? He took advantage of statistical multiplexing trunking efficiency, but he ended up with less subscriber, I thought his strategy was get more subscribers. What happened?

Student: (Refer Time: 21:06) number of cells.

Number of cells he did not deploy enough number of cells to of course, he can now do cells and increases capacity, but the key point is not to the he is definitely taken full advantage of trunking efficiency, but he is not created enough number of cells. But that is again part of the strategy that operator c has chosen. Operator B is somewhere in between again it you can please verify that for operator B, what colour did I have – red Operator B, go through this simple exercise you should get forty 44100. So, operator B has done a pretty reasonable job overall middle way in terms of costs everywhere he is in terms of capacity also, he is done the reasonable size.

So, what are some of the key take away from this discussion cluster size will affect, what number of carriers per cell number of channels per cell, channels per cell that is a very important one for trunking efficiency. So, this is directly going to affect my trunking efficiency. So, I have to be careful with my cluster size, keep it small to the extent that is possible. Now, when I go to cell size, creating large cells versus small cells, this is going to affect number of clusters I am going to have number of clusters. And more number of clusters I have basically my cell size is small, I am going to have more overall capacity in the system. So, we saw how operator A though he did not have much capacity per cell he made up it for a by deploying large number of cells. So, this is another aspect.

So, when I come to overall or comments about capacity I need to worry about trunking efficiency that is an important element not to forget that. The cluster size is also important because that is to going to tell me how many channels I have available to do the trunking. And cell area also important because that is going to tell me how many clusters are going to be there it for my overall capacity. So, all three play a part in this in this discussion. So, again do some spend time thinking about this example, it is a interesting very real life example and you can learn a lot of things about system design from this discussion.

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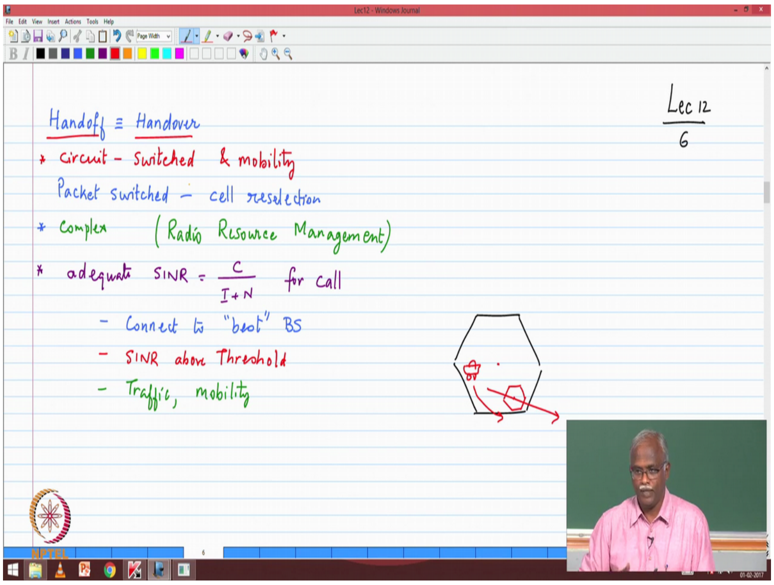

The next topic that we wanted to expose or cover as far as part of the course would be called as handoff. In some technical documents you call it see it as a handover both mean one. And the same thing this is you mobile changing from one base station to another base station, again we will talk about the different aspects of handoffs. Now, the notion of handoff comes primarily from circuit switched application. Why, because you have a call that is in progress and you must make a seamless transition from one base station to another especially if the user is moving. So, this is for circuit switched systems with mobility handoff is absolutely crucial, if you have circuit switched and mobility.

So, the mobility is what makes handoffs necessary and now the question is is this is needed for package switch no; obviously, even in package switch network if you move from one location to another you must connect to the new base stations. So, packets switch also has a notion of handover, but it is not called handover because to keep the concepts separate, it is referred to a cell reselection basically it is like access point selection instead of A you choose to B. So, packets switch also has a notion of mobility and fact that you must now connect to a different system it is called cell reselection.

But many of the things that we will talk about are relevant in both context and cell reselection is the term that is commonly used. Again once you have done cell reselection there will be a rerouting of packets. In the case of a circuit switch hand over has occurred the call itself will rerouted basically all the voice information will gets. So, in both cases, there is rerouting of information. This is one of the most complex parts of a cellular system. It as users take it for granted this is a very complex operation and that is one of the reason why I just wanted to expose it to you, so that you have an appreciation for it it is a in concept it is very straight forward. I want to connect it to one base station I need to connect it to another base station, but in the course of today's lecture you will see that there are several elements that are associated with that this is a functionality that is called or referred to as radio resource management.

The base stations and the channels are all radio resource. And you are using resources from base station A and then switching over to base station B, radio resource management is the name that is given to this type of function within the cellular network and we will talk little bit more about that. Now, one of the criteria that we have to make sure is maintain is that there is adequate SINR, when you do the handoff. You cannot do a handoff and then the call the call quality suddenly degrades. So, adequate SINR must be maintained through the handoff process. So, this would be C over I plus N, again N may be negligible if it is a interference limited system made it to retain to sustain the call. And the element of handoff always says that you must connect to the best base station.

Now, best we may think is best is SINR right that is obviously, the interpretation from a users perspective, but from a system perspective that is not may not be the best. The one with the lowest traffic may be the best option; the one, which has got the resources to serve you or may not be the best in terms of SINR. So, it is actually counter intuitive because the system is designed such that there is a method called maintain SINR above a threshold, it is not the best this threshold is gives you good voice quality if you talking about voice applications. As long as your SINR is above the threshold, the system will not ask you to do handoff will not allow you to do a handoff even if you say no I can see a better base station. Again a lot of time decisions to do handoff or not do handoff is based on traffic which also means that availability of channels it also can sometimes mean based on mobility.

Now, let me just make one comment about mobility why does mobility have to come into the picture, when I am doing a handoffs. So, very quickly, supposing I have a large cell and inside that I have a micro cell. I have a vehicle that is my vehicle got and it is moving away from the base station and it is going away. So, a very soon itself and my signal is getting weak and it says by the way I can see micro cell which is giving good signal quality. Vehicle moving at high speed will cross this before we know, before you done the handoff it will ask for handoff again. So, mobility is the very important. See you want to make sure that you will you have some idea about the mobility of the user before handoffs are given. So, traffic mobility those are elements to keep in mind. Now, I want to ask the question why not allow the best SINR, why now allow best SINR, what is wrong in allowing best SINR?

Student: (Refer Time: 29:59)

I am doing measurements, and I am find that I am connected to base station A, base station B is going to give me a better SINR. Why not I move to best?

Student: because base station B might already have some traffic.

That is one reason, that is assumed scenario that base station B has enough capacity to take me on.

Student: (Refer Time: 30:21)

Exactly that is the very, very key term. So, this if I allow everybody to say go connect to the best base station, there is a phenomenon called greedy behaviour. Everybody says I want the best SINR. So, the minute one user changes that will change the equilibrium and everybody else will start doing handoffs because each one wants to connect to. And then every time there is some perturbation of the system, you will see that there is a large number of handoffs occurring for no reasons, they all are happy communicating. But because somebody made a change either a call ended or a call new call came in there is going to be a, it is somewhat unstable of course, there are equilibrium for these types of behaviour, but you know cellular system has to operate in a much faster time scales. So, we cannot allow network with a million users to settle for a solution in a greedy fashion.

So, basically avoid greedy behaviour may be that is just the principle that we keep, so that is why we say this is to avoid greedy behaviour. I am assuming you are familiar with the notion what greedy is you just want to want to best for yourself you do not care about the others. And therefore, each of the users each of the users will start asking for handoffs. Some more elements of the handover, handover must be seem less user must not have to do anything must not know that the handover has occurred that is very, very important and always we must make sure that SINR is of sufficient quality which we have already mentioned.

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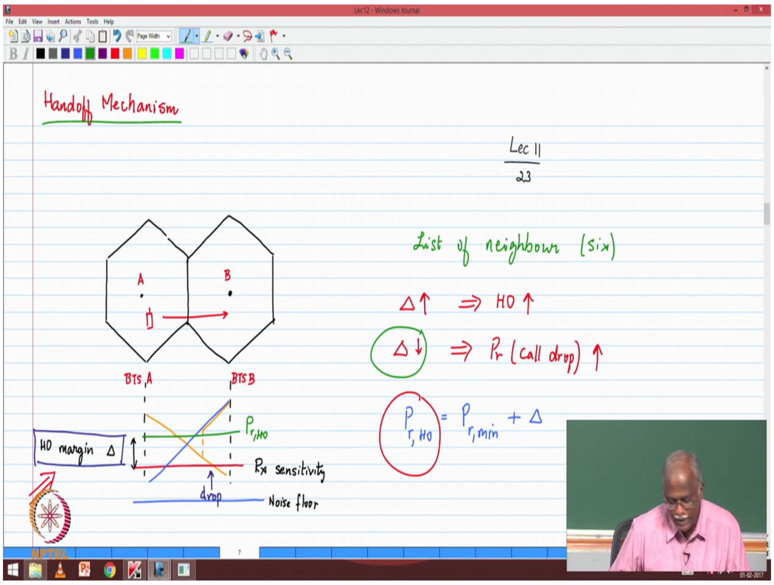

Now, concept that you need to keep in mind is the following in terms of the handoff mechanism. Let us say that I have a user who is going from base station A to base station B. So, base station A, base station B, I am going I am starting off from close to base station A I am going to move to base station B. My signal strength I have shown as a something like decays as I am move away from that my orange line. So, there is a receiver sensitivity level below which a call drop will occur. If I have not done anything at this point, I will have a call drop. This is a point where call drop will occur why because I have gone below receiver sensitivity, I cannot receive signal anymore. So, this is place where the call drop will occur.

So, before I hit that call drop point, I must do something to connect to a better base station. So, obviously, there is a base station B and I have and I have to connect and what is the mechanism that is used to do that. So, basically from receiver sensitivity, you would decide something referred to as handoff margin that is your buffer time to find another base station. So, anytime a user reports signal strength has gone below that margin, below the green line, you are not that handoff level you are not at call drop point, but you are within that margin of the of the call drop level, you start looking for other base stations

So, the typical way is that network tells you the list of neighbours. It says here are some neighbouring base stations how does the network know, the network knows you are cell connected to tells you the neighbours. Typically 6 is a good number of neighbours that the system will ask you to measure because it does not know which side of the cell your oriented, therefore, ask you to measure six and then gives the give the information. Based on that let us say it finds a B is the best option, but you still moving. So, and while this measurement reporting decision mechanism is happening, you are still moving, your signal is still dropping hopefully it has not hit the call drop point, but before that if you are given handover to cell B. Then your signal strength instead of decaying further will suddenly jump, and then you will start getting better signal strength, and as you go closer to B, it will get better and better, so this is the basic mechanism that is present.

So, what is the key element that needs to be decided by the operator it is this handoff margin. If I put my handoff margin very large, what will happen, lots of people will start doing measurements and start reporting and asking for handoff, because they will think that they are close to the boundary. So, this will lead to large number of handoffs, it is a safe method that way nobody will get call drop, but the issue is that there will be lot of people who are asking for handoffs. And handoffs as I mentioned there is a risk that the call will get dropped in the process of transfer. So, there is you do not want to do the handoffs unnecessarily.

Now, what happens if I do not set this large enough then there is a probability that the call drop will increase, probability that call drop which is also not good for me. This will increase and that will lead of user dissatisfaction. Now, this is also a problem for high velocity users because that basically tells me from the time they cross the green line to the cross red line, the time available is very less because they are moving fast, and they could be moving directly away from the base station. And therefore, these are potentially uses have to do my handoff decisions very, very fast.

So, very important element is that I must decide on the threshold. So, the key phenomenon or the key point that is this P receive handoff that is the point at which I start to make the decision, so that will be the P r min that is my receiver sensitivity plus delta. So, this is the level this is the green level that green line that we have shown. So, may be just write that here. So, this is the P r h o level, once I across that call below that I know that I must start looking for the handoff mechanism to work.

Student: can you repeat the question.

The mobile has gone below P r h o. So, should you respond to fading? Because fading is an phenomenon that will happen for milliseconds of duration. So, if you make a measurement. So, the very good I am glad you ask that example. So, what would you do you would have to one of the metrics that you would be looking at is RSSI and the mobile is reporting RSSI measurements. So, to avoid responding to fading maybe the point at which you did the measurement, the signal was in a fade and then you report that in the system, the system says oh my goodness, you are already in call drop mode let me do a handoff for you. You change the new base station and then you report saying no no, my original base station was actually better in hand me back, thus called a pink pomp handoff that you definitely do not want to do.

So, what you do is what is called RSSI averaging. So, when a mobile reports that you have gone below P r h o in the base station actually ask to do measure again measure again because it is doing some averaging and say. If you keep reporting that if your continuously gone below the signal level and you are decreasing further then the base station knows it has to act fast in order to help you with the power handoff mechanism

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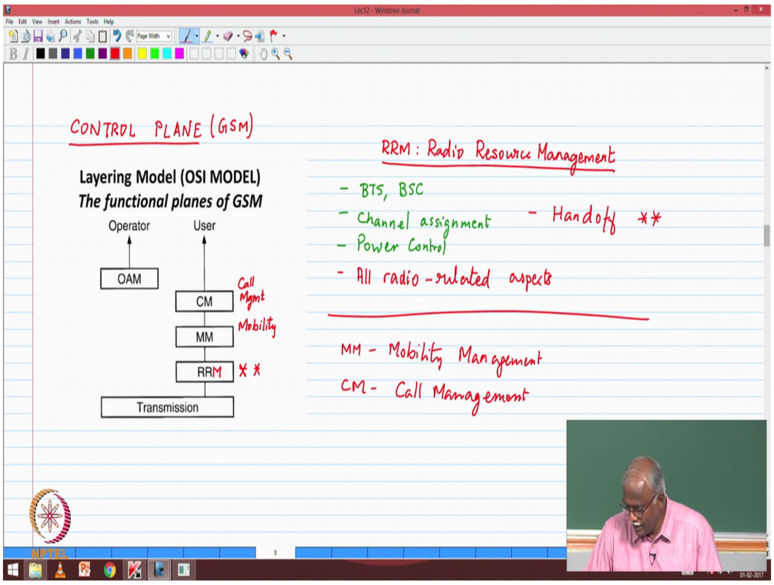

Let us move on now. This is a part that normally is not really taught in text books, but I feel is absolutely important that you have a good feel for this, this is called the control plane of any cellular system what we have showed in the control plane of GSM. Now, the radio resources are the parts associated with the radio resources are one is the BTS, the other one is the base station controller of course, the mobile from the network side it is the BTS and the and the base station. Now, radio resource management remember I told you handoff is part of the radio resource management. What does it do it controls everything of the BTS and the BSC.

For example, it would a talk about the channel assignment which frequency, which time slots all of that would be decided by this layer of the control software. It also does power control if you are transmitting with two little power or too much power, it will tell you that. And this is also where the handoff is handled, because it has to coordinate between one base station and another base station, and there are radio resources of both bases stations are involved it has to be managed. And therefore, the handoff one of the crucial functions of the radio resource management is in this box.

Now, about the radio resource management is a layer of a software; basically this is the layered architecture. So, we can summarise it by saying this is all the radio related all the r f or radio related aspects are controlled by radio resource management radio aspects. Now, above the radio resource management is layer called MM - mobility management, and then above that is layer called the call management - CM. So, I want to explain it you. So, that you can appreciate how the cellular system has been designed keeping these three layers in place. Now, if you remember in first one of the introductive lectures we made a diagram of landline network calling a mobile or a phone what was the first step. The first step was an incoming call that came in and said establish a connection with the mobile.

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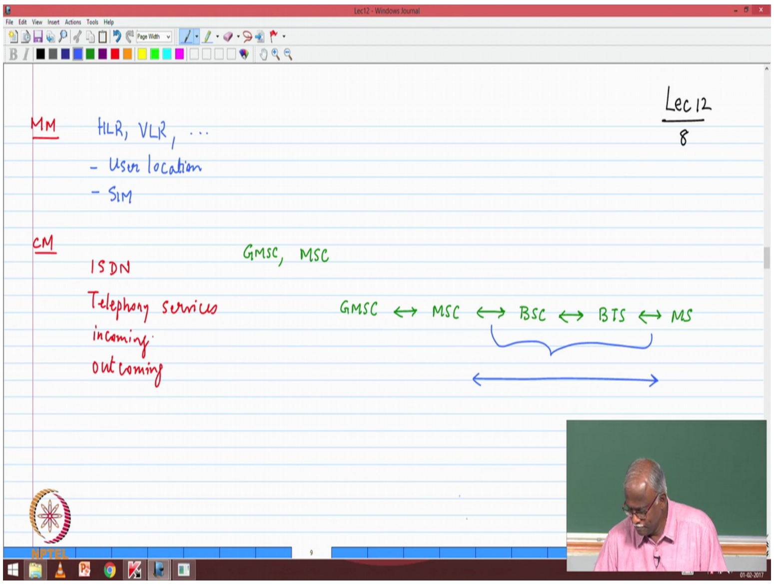

Now, the call management layer call management layer is basically a layer that is taken from ISDN, it provides the telephony type of functions all the telephony functions or telecom related functions, all the telephony services are provided by this layer. So, what would be some of the this thing would be establish an incoming call, establish an outgoing call all of those are the functions of the call management layer. Now, the actual flow of information who controls incoming outgoing typically this would be the gate way MSC or in some cases it would be the MSC, if you within your own network you do not need to go to the gate way MSC. So, typically what would be the link that you would have you would have gate way MSC talking to an MSC talking to a base station controller which talks to a BTS which then talks to the mobile station, so that is the flow of information.

Now, call management basically says that I do not know anything about the existence of anything that is related to the radio, I am totally blind to that. What I am like an ISDN function provider which says connect me to the base station which thinks that the base the MSC talking to the mobile station it does not know anything about channel power control base station nothing it does not know anything it just says connect me to this mobile station. So, it is one of those layers where it has no notion that the underlined link have got you know base station base station controller, it just says it treats this as a link between the MSC and the mobile station providing all of the ISDN functionality.

Now, the layer sitting in between says when this one says connect me to this particular mobile the mobility management is one that comes in. And typically these it is the home location register, the visitor location register plus there are some several other nodes which are part of the system these are the one that are keep in track of where the user location is the phone turned on what services are currently being offered to the user. So, basically all of the information with respect to the SIM, you know where the user is located all of that.

So, now let us go back to this layer the previous picture. So, if the incoming call comes in, the call management says establish a connection with this mobile does not care about anything else, and passes that information down to the next layer. The mobility management says you want to talk to this, by this is user is now currently in Bangalore and he is in this particular location, so then that information is passed down to the corresponding base stations in Bangalore it says range for this particular mobile. So, you can see how these three layers actually work together to form the handoff.

Now, I am a mobile who says I am going to go out of coverage of one base station who will I reported to I will report it to the RRM base station controller and the BTS. But the BTS and the BSC by themselves cannot take decision, they may have to report it to the higher layer and say by the way this user is moving away, what do I do and then there is an information that is given and based on that appropriate action is taken.

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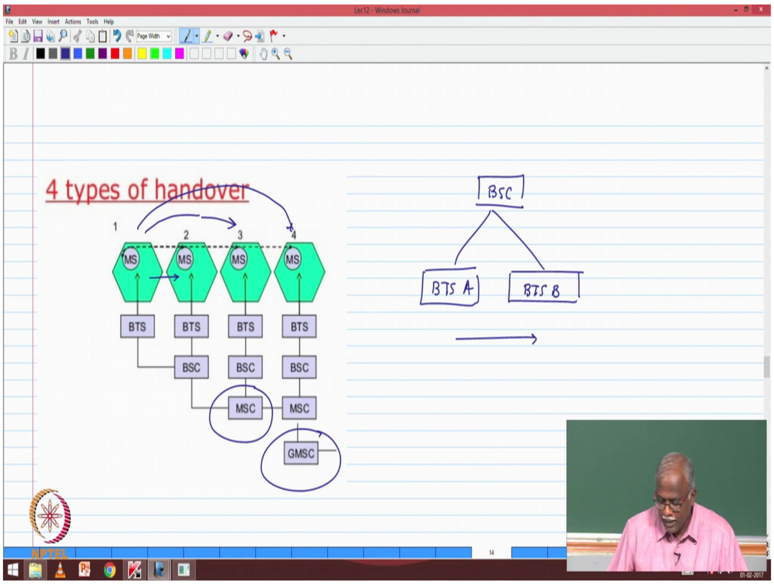

So, let me just explain this aspect a little bit more using a following diagram. So, supposing I am connected to the architecture of the network is that there is a BSC, and it is connected to BTS A and to BTS B, usually one base station controller can handle several BTSs. And let us say that you are going to move from A to B, this is something that the base station controller can do. So, basically you are moving from two base stations, you are between two base stations which are connected to the same BSCs. So, this is a BSC level handover, basically the BSC will reroute the calls, it does not have to inform the MSC because MSC is still point the traffic towards the corresponding BSC and the BSC says instead of routing this base station, I will route it somewhere else.

Now, if you happened to be going from a base station which is connected to two different BSCs that is a next level of complexity that is going from one to three. You are going from one cell to another it is so happens that the bases station of cell one is connected to BSC one base station of cell three is connected to this. This is the case where the two BSC s have to coordinate, so which means that the MSC has to get involved, so MSC level coordination.

Now, vocationally you may have this is very, very rare if you actually are going to two cells connected to two different MSCs that means, it is a very large city one northern part of the city is connected to MSC 1, is southern part of the city is connected to MSC 2. And then you have to get the so basically if you are doing this type of a system then the gate way has to come into play, because the routing to the MSC it has to change. So, again its not a though it seems like a its a somewhat you know trivial thing, but actually when you come to look at it is a very complex mechanism of measurements, reporting, decision and all of this has to happen very, very fast to support. And to the extent that we have talked about today we have only touched the tip of the ice berg in terms of the complexity.

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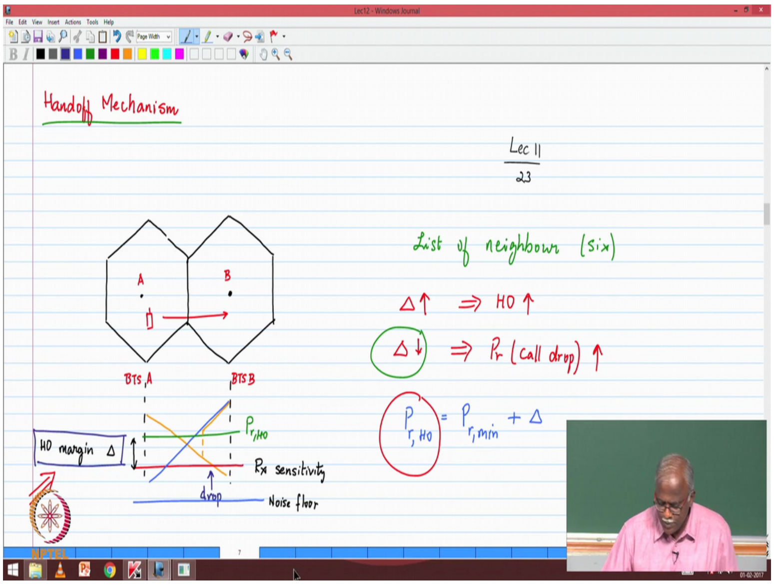

Maybe just take a few minutes to explain to you few more elements of the aspects that.

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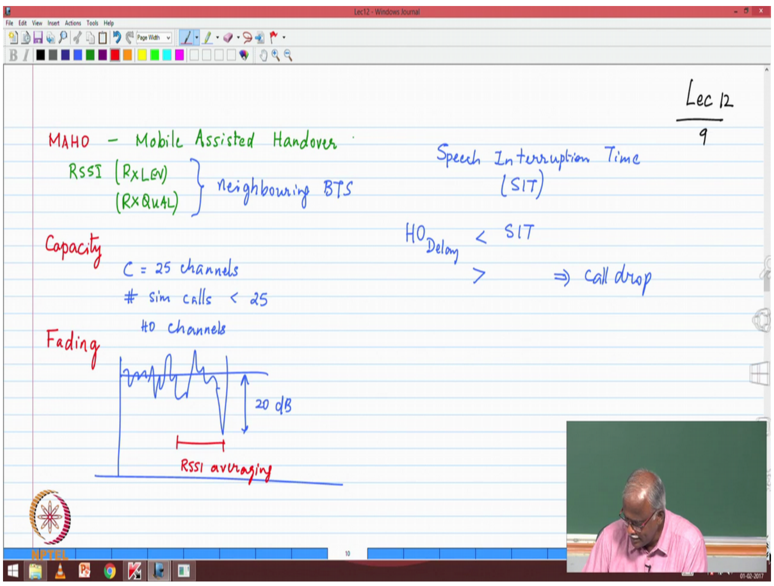

So, the first element that I would like to highlight is that the mobile is very actively involved. So, we call it as mobile assisted handoff. Whatever handoff mechanism we do the mobile has to help the base station vocationally the base station may take unilateral decision saying ok, you just have to change, but almost always there is some input that is coming from that it is not like that do you want to handoff base station never ask is that ok. Tell me the readings and I will tell you when to change and the base station is the boss. So, mobile assisted handover.

Now, what is the mobile reporting typically it will report RSSI or RXLEV it will also report RX QUAL, it is already reporting for its current base station, now it will report it for the neighbouring base stations neighbouring base stations. And the list of neighbours provided by the by the base station, so the neighbouring BTSs. So, once this information is given then the network then decides there is parameter which is called speech interruption time especially when you talk about speech interruption time.

There is some time window after which the speech quality significantly degrads. So, whatever time that you do for the decision for handoff, this has to be kept in mind. So, SIT is a very important parameter. So, whatever happens in terms of the handoff delay - H O delay must be less than the SIT speech interruption time that is which that you can because if it is greater than that will lead to call drop. Because the once the speech interruption time becomes too large the mobile thinks that the network thinks that the handoff is failed and therefore, the call drop will happen. So, if it is greater than then implies call drop. So, you want to avoid that. So, therefore, the mobile has to play an important role and the speech intrusion time is parameter that you are constantly observing.

Now, handoffs as I mentioned also have an impact on capacity. So, supposing you had c equal to 25 channels, and I have allowed 25 users to be active on my in my cell then suddenly there is a request for handoff then call drop will occur. So, the capacity or the number of simultaneous calls has to be less than 25, it cannot be 25 less than capacity because otherwise there will be handoff traffic cannot be handled. So, this is called the what we call as handoff channels or the capacity that is reserved for handoff. Unfortunately, it is something that you can you have to provide which will affect your own capacity traffic carrying capacity, but you must make sure that handoff traffic is not dropped. So, this is an important element that is that.

Then the issue of fading I think that was already brought up let me just highlight that. This is your average received signal power fading basically says that you will see something like this the it can have a fading dip can be as much as 20 dB. We will be studying this is a lot of detail, but that can pretty much tell you that you are very close to the call drop level. So, you do not want to respond to this. So, you introduce the RSSI averaging window. So, RSSI averaging ensures that you what you report will be verified that you are really not close to call drop just happened to be momentary fade.

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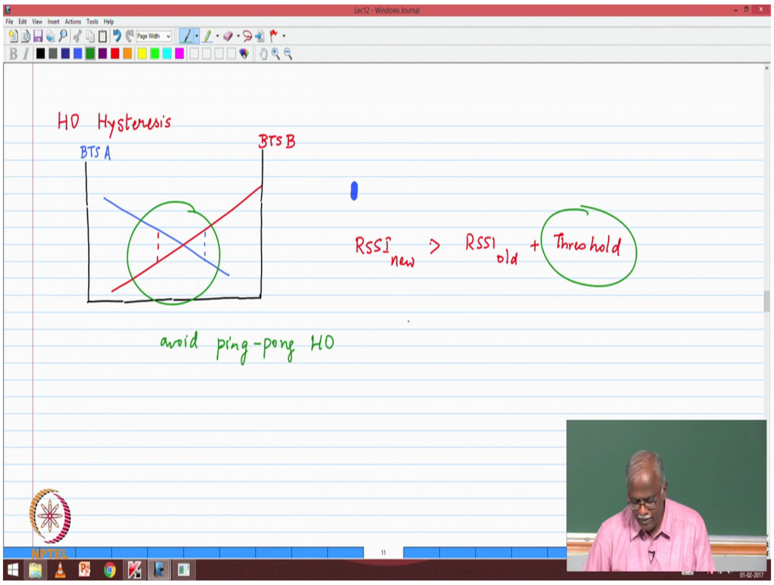

And the last one that I want to explain is the notion of a hysteresis this notion of a ping pong effect not having the ping pong effect. So, let us say I am moving from base station A to base station B, the handover point when I go from A to B will be different from when I go from B to A. And why is that because you know if you are happened to be exactly at the boundary then you will going back and forth between the two base stations. So, the network says that you know keep measuring the RSSI of base station B, if it is constantly better than yours and above a certain threshold only then you can change over.

So, basically what it says is the RSSI of the new base station must be greater than the RSSI of old RSSI of old plus some threshold. Now, if you insist on this threshold being non zero that means, when I go in the other direction you will wait till the base station A becomes efficiently stronger. So, this basically avoids the ping pong effect avoid the ping pong handover because this is not good and also it you mind up dropping calls and disturbing the traffic.

So, in a nutshell, the key elements are that handoffs are very, very crucial; mobile plays a very important role it affects capacity, you should not respond to fading. Handoff is not to take care of fading, but handoff is for when the scenario is that your signal level average signal level is falling close to the call drop point. And the last element is that hysteresis must be maintained, so that you get stable handoff mechanism within the system. We will stop here.

Thank you.