

**Introduction to Wireless and Cellular Communication**  
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**Lecture – 13**  
**Cellular System Design, Capacity, Handoff, and Outage**  
**Handoff Part 2, Classification of Signal Variation**

Understanding the wireless channel, we will classify them as two types of effects one is what we refer to as large scale and small scale again we will describe and define those effects and then build our discussion around that. Shadowing is an example of a large scale effect.

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EE 5141 Lecture 13 2/2/2017

- Recap L 12
- Handoff
- Wireless channel
  - Large scale effects
  - Small scale effects
- Statistical charac. shadowing
- Multipath channels

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Reading Assignment ← Rappaport Propagation Article

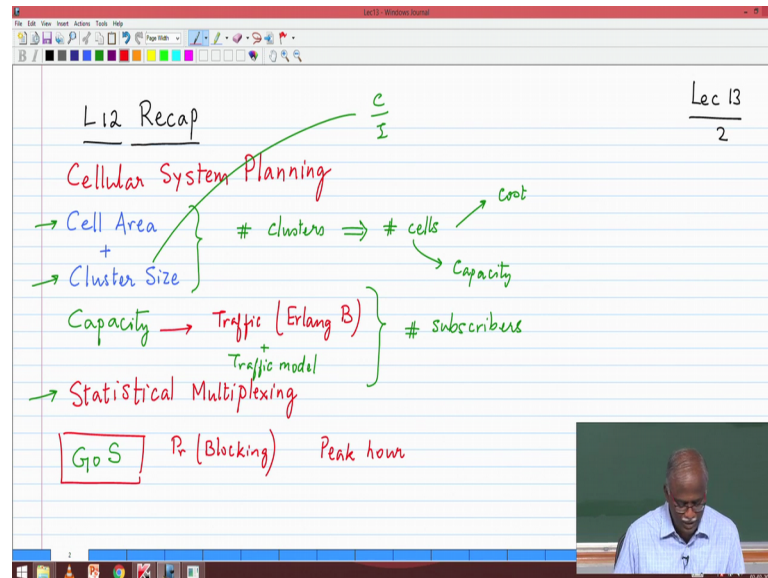
- W. Assignment 2 (Took on Tue 7/2)
- W. Assignment 3
- C. Assignment 2

So, we will begin by introducing the notion of how do we characterise these effects in a mathematical fashion in a mathematical framework that is the first part of today's lecture then we move into our characterisation of the small scale effects. Quick update or announcement regarding the written assignments written assignment number two has been uploaded we will have a test like you had for assignment test number one, next Tuesday written assignment tests assignment number 3 will be uploaded on Friday along with computer assignment number 2.

So, please do keep up with the assignments if you need help please do not hesitate to ask; reading assignments are being posted on a regular basis to keep track with our course it

would be very helpful if you are keeping up with the reading assignments, because that enriches your understanding of the entire picture ok.

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We move with a keep summary of what we have spoken about the cellular system planning. The cellular system planning requires us to fix few parameters; one of the things is the cell area that we have to decide ahead of time. The second one will be the cluster size now given that you can have a combination of these two then we have an idea of how many cluster and therefore, how many cells are going to be present. So, the combination of these two tells us how many clusters are going to be present that also tells us how many cells will be present. How many cells one of the offshoots will be the cost we do not look too much at the cost, our interest is primarily in terms of the capacity.

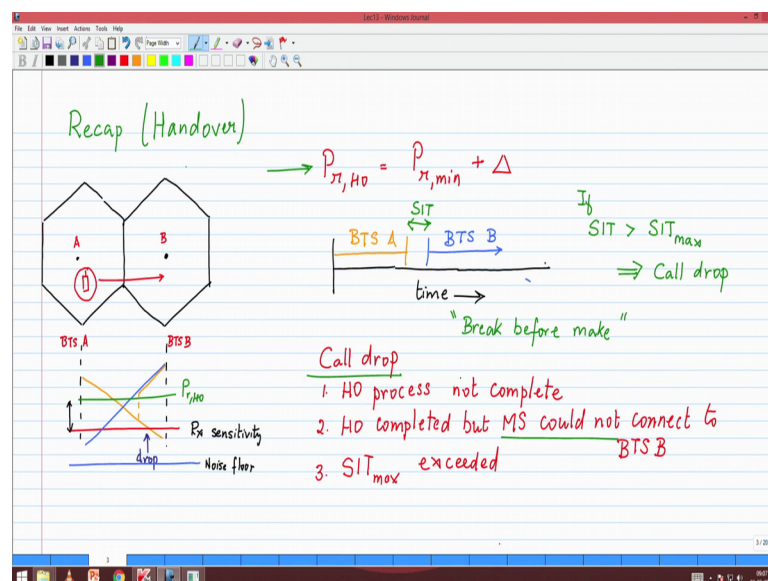
So, the capacity is what we focus on. So, once we have the number of channels available per cell, then we go back to our understanding of capacity and apply the traffic principles using the Erlang B formulation, cellular system is a blocking system. So, therefore, blocks calls are cleared we do not have queuing. So, therefore, we use the Erlang B analysis this coupled with a traffic model; traffic model has to say what is the approximate number of Erlangs each user will generate so that is what we mean by traffic model; and of course, you can have mixed models you can have some bodies

heavy user light user, but you must come up with some estimation of your total traffic based on the traffic model.

So, this then tells us the number of subscribers that we can support, and also the quality of service that will each of them will see based on the C over I that will be again determined by the cluster size. So, cluster size also has your an impact on the C over I that you will see and all of this we are exploiting the understanding of statistical multiplexing the fact that all users are not asking for service at the time and therefore, we are able to talk about a grade of service or a blocking probability in a statistical sense. So, this **is** probability of blocking and as I mentioned probability of blocking is measured at a peak hour. So, whichever is your peak traffic time that is when you measure blocking probability because there are times when there will be zero percent blocking.

So, again this is a quick summary as you try out some of the examples that will be there in assignment number three these concepts will get reinforced.

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Now, let us move onto our discussion on handover; yesterday we introduced the requirement or the necessity for a handover because of mobility. User is moving from base station A is moving over in A direction towards base station B at some point he is going to be the signal from base station A is going to be weak. Notice B is not a co channel cell because if B were a co channel cell it will actually be creating interference. So, B is an another is base station which is using an orthogonal resource and therefore,

there is no inference basically you are looking at transitioning from one resource to another and without them interfering with each other. The orange signal gives us the decay of the signal as you go from base station A towards base station B and there is a receiver sensitivity that receiver sensitivity level below which you will the call will drop that is the dropping point, but well before that you want to make sure that the handoff occur.

So, we define a parameter known as the handoff threshold, and using the handoff threshold  $p_r$  min plus the handoff threshold tells us when you have to start looking for candidate the base stations look for handoff to; and once you have confirmed that this is base station is consistently better than your own base station then you do the transition. So, that basically changes your signal to noise ratio from a being a poor to something that is provided by base station B and therefore, good condition signals are maintained. We mentioned that there is a speech interruption time; best way to visualise it is using this time line. So, if you think of this as time the time when you started moving away from base station A. So, there is some duration for which you are still under the coverage of base station A; and when you switch over to base station B that happens at this point at that point base station B picks up.

So, there is a gap between when you switch over from base station A to base station B that is what causes the interruption in your call since we are assuming it is a voice call it is referred to as speech interruption, but basically it is a break in your communication. So, this type of handover mechanism has got a specific name we break before make; you have to break the contact with one base station before you establish the next one break before make and it also tells us why there is risk of a call drop. One is you may not have finished the handoff process which means that you have not finished the measurements you have not given enough time for the network to figure out. So, basically the process is not over.

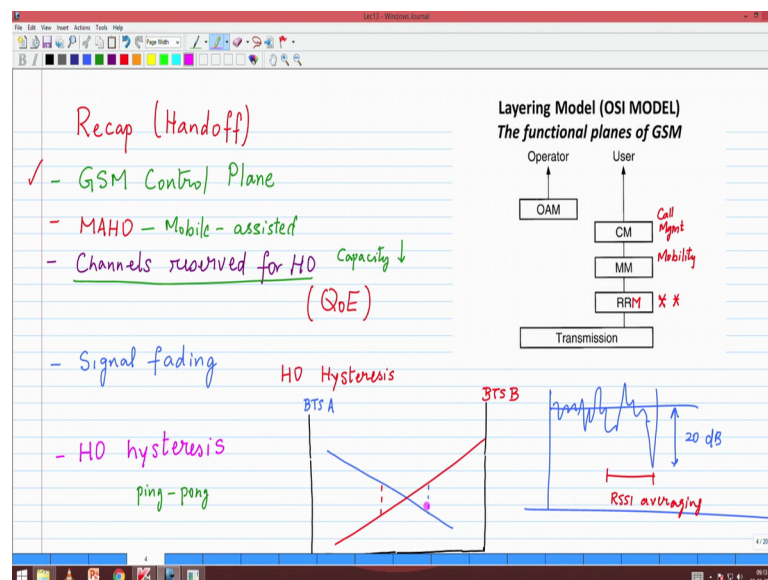
The second reason why a call drop can occur is that you have finished the process, the base station has told you now connect to base station B. Base station B tells you talk to me on frequency  $f_2$  time slot number 4, by the time you synchronise there is too much delay has happened basically mobile station there was a limitation on the mobile station the mobile station could not connect that also basically if the speech interruption time for



whatever reason you did not finish the measurements or you did not re synchronised base station B that will result in a call drop.

So, whatever the scenario if you have exceeded the maximum speech interruption time the phone itself will trigger basically you call drop, the network will then assume that you have you know terminated the call and then unfortunately you did not terminate you were actually in the wanting to handoff from one to the other. So, this is a process that we have to be very careful about and make sure that we do not lose the subscriber in the process.

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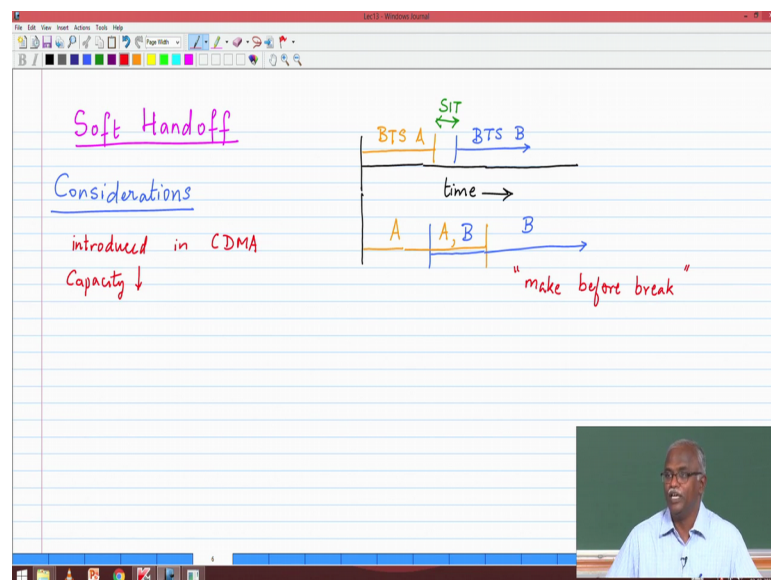
So, let us build on this understanding; yesterday we spent a few minutes on the GSM control plane again this is something that probably most of us never encounter, but from a understanding of the system it is good to know how the service is provided. Call management layer is like an ISDN it is just worries about establishing the call and terminating the call it does not know that it is GSM, it does not know that it is wireless all it says is connect me to this user.

Now, the layer that then figures out where this user is that is the mobility management layer; now mobility management layer does not worry about which base station which frequency which time slot that is not the worry of the mobility management layer, all it says is I have to reach this user I have to keep track of this user. So, therefore, I am monitoring the mobility of all the users in the network; may be more than million

millions of users I am constantly tracking. Then below that comes the GSM specific RF specific layer which is called the radio resource management layer. Now that is the layer that then decided which base station which frequency, which time slot all of that what power level to use when do you initiate a call when do you terminate a call all of that is managed by the radio resource management layer.

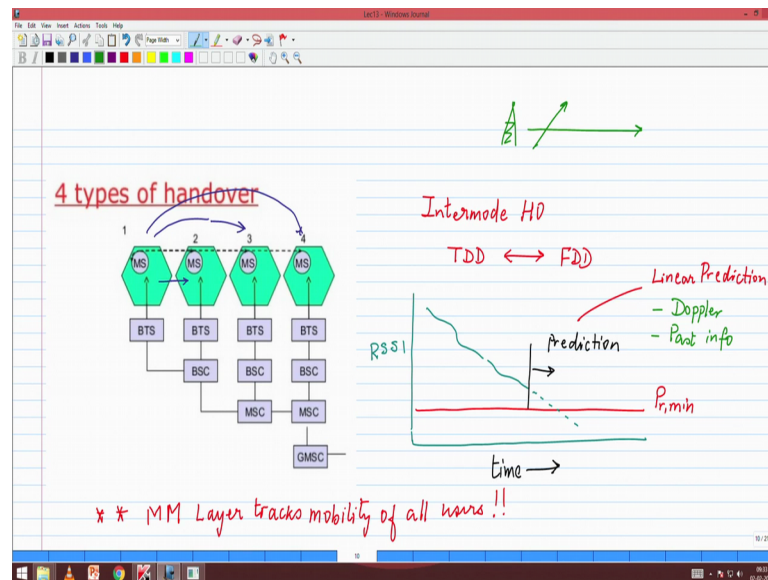
So, again you can see that how these functional layers work one with the other, each ones task is very well defined there are interfaces and therefore, the processing of a mobile is in a very very systematic fashion that is the mobile system.

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Now, the reason we introduce this was so that we could have an appreciation of the types of handoff that can occur in a in a GSM system.

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So basically we said that you could be changing from one base station to another base station under the same BSC or you could be changing from between BSCs or between MSC again there are different layers and please do keep in mind that the mobility management has to keep track of all the users in the system, because ultimately that is what enables you to design and implement a very efficient handoff mechanism.

So, our understanding of the GSM control plane very helpful again just to understand the big picture. Mobile assisted handoff as we saw there are several measurements that the mobile does to help the system decide when to do the handoff. So, mobile assisted this is a very key aspect of the handoff mechanism because the network depends on the mobiles to keep feeding that information and that is how we are able to make the decisions at the right time. We also said that there are channels that are reserved for handoff traffic that is coming, which means that you cannot do 100 percent loading of your own cell.

So, channels reserved for handoff there is an impact on capacity. So, there is a capacity will come down slightly and may be this question is obvious one. So, in a cellular system which is given higher priority is it an incoming call or handoff call.

Student: Handoff.

Handoff call because already I just now told you that there are channels reserved for it. So, if two handoff request and a new call comes in at the same time, the handoff will be given higher priority and the reason for that is.

Student: To minimise the call.

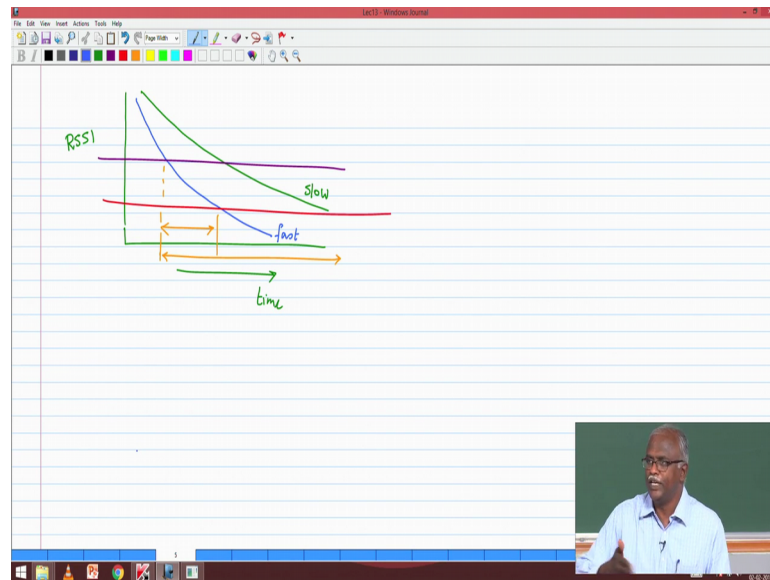
Yeah one is you want to minimise the call drops there is a psychological element to it because the cellular system is a blocked call cleared system; that means, if you get blocked user assumes oh this is the I will try again, but the quality of experience of the user is perturbed if the suddenly you are in the middle of a call and then the call drops. So, there is a quality of experience reason QoE and it has to with users and user perception. So, therefore, the handoff traffic is given a higher priority over the new traffic that is generated. The other element was that we did mention that there is a fluctuation of the signal we have not fully studied the signal fluctuation.

But we recognized that because of the special distribution of the nulls in the propagation channel there is a fluctuation especially if the mobile is moving. So, in order to avoid getting mislead and making a handoff when it is not needed you do RSSI averaging again the window over which you do the averaging again lot depends on what is your speed and this is something that the network will tell you how much averaging needs to be done.

Even on top of that we do not want a phenomenon known as ping pong handoffs. So, you do not want to sort of say handover me to b then again say no go I want to go back to a go back and forth. So, this ping pong handoff is something that we do not want to have and therefore, we have introduced a hysteresis. So, you do not handoff until you have established that a new base station is higher than by a threshold and only then you will do the handoff and likewise so you have decide to going back in the other direction you will handoff only when base station A becomes stronger. So, there is actually a region over which the handoffs occur and it will never be the point where you handoff in both the same point will not be where you will handoff in both directions where you handoff in one direction will be different from where you handoff in the other direction; and again this is something that you will we will do a practical experiment to verify that this is indeed the case that happens ok.

So, any questions on what we had covered in the last lecture this basically is a quick run through of the different elements, and the reason I repeated it was that it helps us build today's lecture. Now we move into the section that we wanted to devote for today, but may be before that let me just give one quick aspect I thought I would introduce.

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Now, the RSSI; RSSI as a function of let us say it is time the you are basically moving in this direction. So, you are moving from a to b, RSSI we know will decay right it has based on the propagation exponent it will decay.

Now, if you were moving at a faster speed now that basically tells you that you are going to go your signal is going to decay faster. So, this is your minimum level where call drop will occur, this is your threshold for starting the handoff notice that the time available for handoff is much less. So, this is a time available for a fast user whereas, you have much more time available for a slow user and so there is a need to keep track of the. So, this is a slow user the green line represents a slow user, the blue line represents a fast user fast in terms of mobility.

So, again keep in mind that handoff is not just a single mechanism that is implemented that works under all situation, it is actually a quite a complex one as I mentioned we have just sort of given you a flavour of the different elements that are present. Now we want to move into another very very important concept and this comes from going back to saying what is wrong with the handoff mechanism as we have defined it. So, when we go back

and look at what are the weakness of this handoff mechanism basically it is this particular interruption that occurs because if that interruption increases then the call drops.

So, the question that arises is can I have a scenario where rather than having a break before make can I have a system that does make before break; that means, you establish the contact with base station B before you break the link with base station A; very valid question however, remember I mentioned right at the beginning these are orthogonal resources; that means, in a TDMA system base station A is talking to you on a different frequency base station B is talking to you on a different frequency, time slots may be different. In fact, both may ask you to use the same time slot both now how does a mobile talk to two on two different resources the only way it can do it if it has two receivers. So, this is not a trivial from the implementation point of view.

But it turns out in a CDMA system CDMA systems are single cell reused systems, the same resources spreading codes are used in both systems. So, this is actually possible in a CDMA system because one receiver can receive both the base station signal because both are transmitting in the same frequency. So, that is a possibility for CDMA. So, this actually came was introduced in the context of CDMA introduced in CDMA and it became one of the main reasons why CDMA over took TDMA as the third generation system was because you could do this soft handoff.

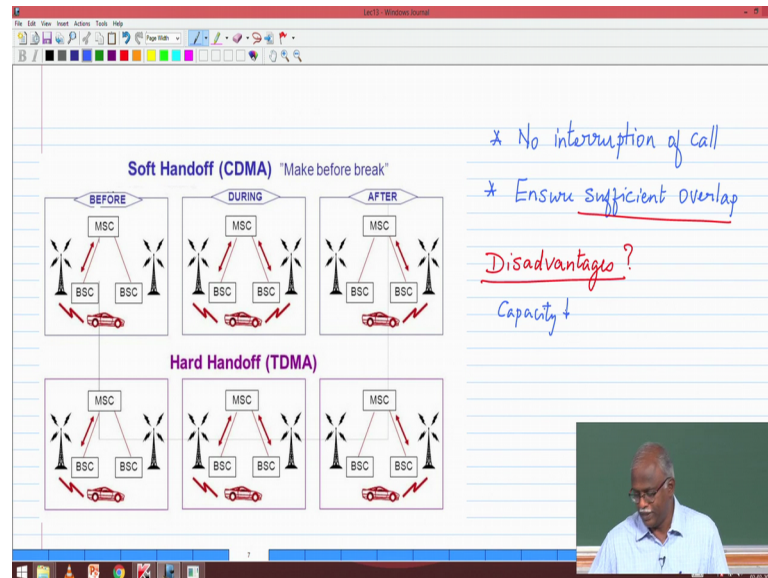
Soft handoff basically says that you can overlap the users you do not have to break one of them and you can decide when to do the breaking of the system. So, again this a useful visualisation it is a useful concept now what is the of course, it is a huge advantage because now there is no issue with call drop you can decide when to terminate base station B, now what is the price that you pay for this does it come for free.

Student: (Refer Time: 18:35) we using more.

As long as you are in that hand handoff region you are using double the resources. So, there is introduction reduction in capacity; and just like human beings mobiles also very greedy they are very happy to be in soft handoff, they like because they get more better signal to noise ratio and actually mobiles left left they will actually be in soft handoff longer than they need to be. So, again there is a price that you pay in terms of the soft capacity. So, and you also keep in mind that there is coordination needed between the

two base stations because you know two different base stations are talking with this system.

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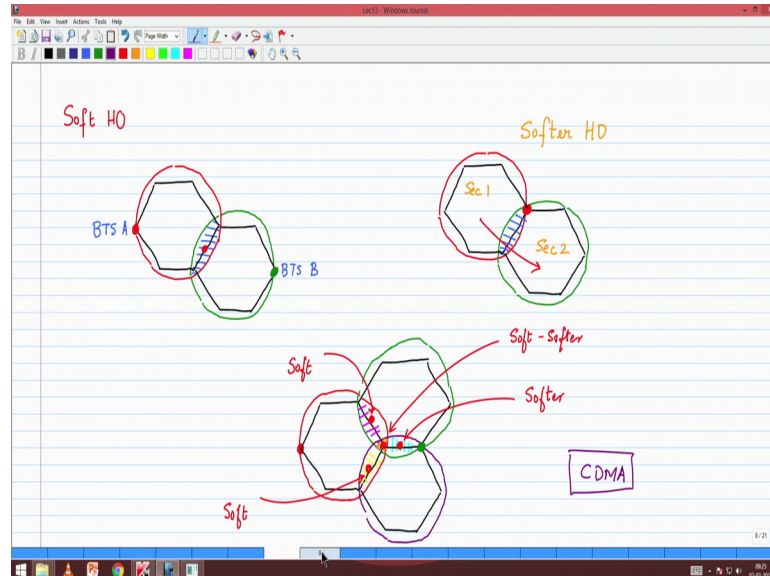
So, here is a visualisation of the mechanism that we talked about, look at the bottom part of the picture where we introduced the hard handoff you are connected to base station A with base station controller. Then as you are moving away at some point the information is given to the other base station controller you have to take over and the base station B starts to communicate, but there is a time gap between when you end with base station A and then you start with base station B; this is basically the hard handoff that is the understanding of why speech interruption comes in and why there is a possibility of a call drop.

Now, soft handoff on the other hand basically says you are talking to base station A moving towards base station B there is some point where both are communicating with you in the meaningful way they are not causing interference to each other they are both giving you useful signal and then when you sufficiently are connected to the base station B you disconnect. And of course, the disadvantage is that capacity will go in order to have a efficient soft handoff mechanism we must ensure that there is sufficient overlap in terms of the special overlap of the coverage of the two cells the disadvantage would be the reduction in capacity.



So, given that we are willing to take this reduction in capacity what are the some of the other aspects that we need to look into?

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The other aspects is the fact that let us take the situation where you have base station A there is base station B let us label them this is base station A this is base station B, they want to provide a coverage for a mobile who is in the overlap zone that is when you would actually be able to do soft handoff; both base stations must receive in this case the voice information because that has to be encoded. So, that there has to be a coordination and they must both transmit so that the base station the mobile in the middle gets the benefit of the soft handoff. So, there is coordination between base station A and base station B.

Now, it could happen that the two sectors or cells if you want to think about it are actually to the two cells that you are going from one cell to the other the two cells are actually two sectors of the same base station that can happen because if this was the base station that was serving both you moved from this cell to this one it turns out that this is base station sector one this sector 1 this is sector 2.

So, basically this is sector 1 of the base station this is sector 2 of the base station and you are basically moving from sector 1 to sector 2. Now intuitively and from an engineering sense this one should be an easier scenario because there is only one base station involved all it needs to do is instead of radiating on this beam I switch over to radiating

another beam. So, this type of handoff where you are actually doing going from one beam of base station or one sector of a base station to another one is actually called softer handoff.

Now, are we limited to soft handoff between only two base stations? The answer is no because you could actually be in a location where 3 may be sometimes even 4 5 base stations can provide meaningful coverage. So, in those scenarios a CDMA system can actually do soft handoff with multiple more than two base stations. So, you could visualise the situation where you know there are three base stations, you are sitting the mobile is sitting in the middle over here and it says oh I am very happy because I am getting signal from multiple people, but I am using more resources than I can mobile does not worry about that you have to worry about it mobile is very happy is taking.

So, but notice that in this case two base stations and three sectors are involved; if your mobile was in this point it would be a soft handoff, because that is between two different base stations two sectors of two different base stations. Now if your mobile was in this region that would be a softer handoff because there was a two sectors of the same base station now mobile in this point is soft or softer.

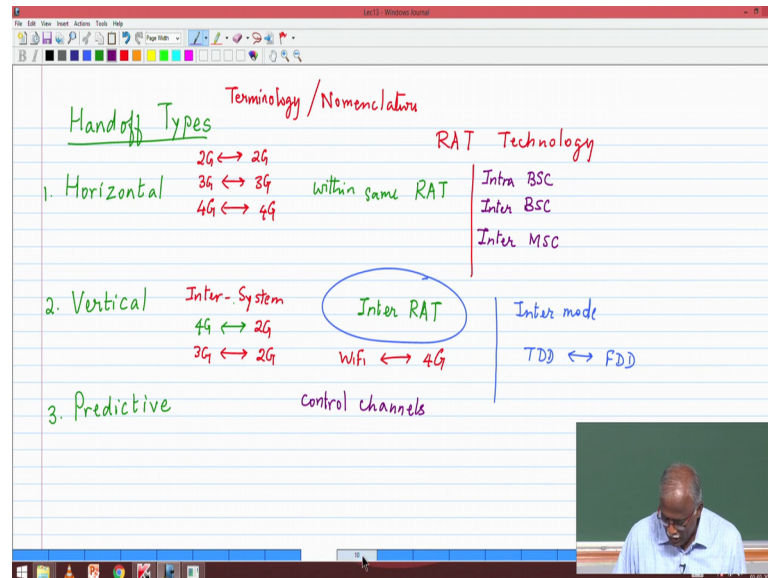
Student: Soft.

Soft again and mobile in the middle is actually is a combination of soft and softer. So, basically it is called soft softer handoff; that means, there are if you just say soft handoff; that means, all are different base station if you say soft and softer; that means, there are some transmissions that are coming from the same base station again it is the reason I mentioned this is one is terminology, if you learnt soft handoff in the class and then you read softer and you wondering you know what happened what is the difference you know. So, there is a reason why it is called softer handoff, but more important it is just that when you design it at a system and start and you start appreciating what are some of the nice elements about the system, and keep in mind that this is not easy with non CDMA systems.

So, this is all of this actually comes from the world of CDMA. So, TDMA actually cannot do this, what about OFDM? You answer me at the end of the course it is a very interesting question it is possible that you can do from the neighbouring base stations,

but this notion of soft handoff is actually not very common even in o f d m, but you think about and then explain that.

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Now, I would like to just quickly introduce little bit of terminology or nomenclature. So, that you are familiar with the usage of these terms. We have basically covered whatever we need to cover from an basic understanding of the handoff mechanism, sometimes you will hear the word horizontal handover (Refer Time: 25:46) base station is up there I have to do something now I cannot do anything horizontal, no that is not what horizontal is horizontal basically means that you are handling off within the same system 2G to 2G, 3G to 3G, 4G to 4G ok.

So, when you do not say anything it is assumed that it is a horizontal handoff; the reason you have even introduced the fact that is called something as horizontal because there is something which is also bit different from this that is a vertical handoff. So, vertical handoff is a inter system handoff. Another common terminology that you will find is radio access technology horizontal handoff happens within the same RAT; this is within same RAT that means, if you are in 2G you handoff to another 2G cell now the inter RAT is what a vertical handoff is; inter RAT from one radio access technology to another one.

What are some common handoffs that we can see you are probably connected to a 4Gsystem you go outside the coverage it may drop you to GSM. So, you may actually handoff your voice from 4G to 2G or from 3G to 2G this is very common especially

when you move on a train outside of city metro coverage most likely you have been handed off to a 2G system. So, that is an inter RAT, but what is becoming increasingly important from a data perspective is another form of inter RAT transfer that is from Wi-Fi to cellular Wi-Fi to 4G for example.

Now, that is also an inter radio access technology because those are two very different systems, they also form the elements that. So, this is another aspect in the context of horizontal handoff remember there were several types that we characterised in the last class also mentioned it today it is intra BTS you can have that well intra BTS is not correct intra BSE. Intra BSE within the same two different BTSS then inter BSE then you can inter MSE. Again those are all nomenclature that you encounter horizontal handoff inter MSE; that means, you know exactly what is happening I am going from 2G to 2G, I am connecting between two locations that are being controlled by two different NSEs.

Now, the last part that inter radio access technology also has something known as an inter mode handoff; now that is a very tricky one inter mode because that means, I am changing over from TDD to FDD of course, I cannot do anything soft here it has to be hard, but the. So, the landscape of handoffs is actually quite broad there is a lot of complexity involved in it, but at a conceptual level it is good for us to have this broad you know painting where we now the landscape of handoffs. Keep in mind that if you want to do for example, an inter rat handoff; the mobile has to do a lot of work because if you are basically on one radio access technology using one particular receiver chain at the same time the mobile the infrastructure is saying go and do measurements on a 4G system, which means that you have to change your receiver in a sense because your bandwidth will change your sampling rates will change, lots of things will change you have to change all of those do the measurements come back to your old system and then report.

So, again you not only have to do measurements on two different channels you also have to listen to two different control channels. Remember all information from the network comes from on control channels. So, you have to listen to two different control channels you have to listen to the control channels of the origin radio access technology, you also have to look at the control channel of the target radio access technology. So, again listening to two control channels doing lots of measurements in between your current

operations is non trivial. So, therefore, the any type of handoff actually makes the mobile little bit more complex and therefore, you know more impact in terms of the design and the implementation.

Now, the last part is we must do something to help the mobile poor mobile in a sense asking you to do so many measurements, you are asking to do the changes what is it that the network can do to help the mobile. So, that is where we look at the help that it can give. So, the network is constantly monitoring the received signal strength from the mobile. So, long before you even get into the handoff zone that you before trigger saying I am I am near my threshold, the mobile says let me look at that trajectory of the RSSI that you are reporting.; it is going down down and I know the rate at which it is going. So, I can anticipate that you are going to ask for handoff.

So, again the network sort of does predictive preparations for the. So, there is a prediction. So, there is a signal passing technique called linear prediction those of you work with speech you know that looking at the past you can actually predict some things in the future what the signal will look like. So, one of the things that you would want to use in this information is how fast the user is moving. So, that would be a measure of Doppler because that tells you how fast the signal will change. It also tells you what has been happening in the past. So, one is Doppler, one is past information why is in Doppler alone not enough is a tricky situation.

If this is the base station and you are moving directly away from the base station then your Doppler will tell you the full story. But if you are going at some you know angle where your Doppler with respect to the base station you are moving in a direction where the Doppler does not look very high, but you may still be moving fast. So, that is the tricky situation because you know Doppler may be you may be (Refer Time: 32:42) this probably somebody is moving slow, but actually you are you are going to cross the handover boundary very fast. So, there is a notion of Doppler gives you an idea how fast you are moving, but you may be Doppler measurement may say that you are not very fast because there is a angle with respect to the base station direction and you just have to be cognisant of that.

So, if you look at the rate at rate of change then you know no no this guy has got low Doppler, but things are changing pretty fast. So, therefore, you want to keep frank and as

I mentioned again mobility management has to take care of all of this the monitoring of all of these parameters are done by the radio resource management, and when you think that there is some you know anticipatory need for handoff you trigger the mobility management layer saying hey you know what I need to I need resources in an another base station. So, therefore, make sure the handoff happens smoothly. So, this is the broad landscape of handoffs and I will just pause to answer any questions that you may have; because I recognise that this is probably the first time some of these terms may be somewhat new any questions on what we have spoken so far.

Student: Sir, that angle is parameter for more than Doppler (Refer Time: 34:02) direction.

Correct.

Student: Because we will have (Refer Time: 35:05).

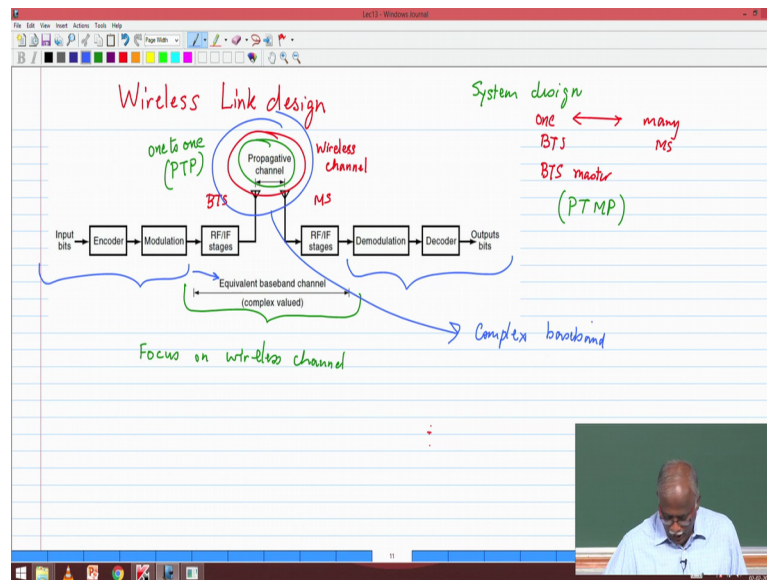
Yes yes exactly. So, that there is a velocity  $\cos \theta$  which is what is velocity two velocities what we need for handoff, but  $v \cos \theta$  is what we will measure in terms of the Doppler.

Student: But if we know the angle we can know the (Refer Time: 34:19).

So, the question is do I know the angle of movement sometimes not because unless you start looking at the location of the user you do not know, all you know is this persons RSSI is dropping very fast and by looking at the signal that I receive from this user I can guess the Doppler information we will study about how Doppler can be computed from the received signal. So, from the received signal I measure the Doppler, I do not know what  $\cos \theta$  is I just assume that you know you are moving slowly because so, but that may not be the correct assumption. So, Doppler alone does not give me the full picture good.

Let us now move into the next element, we have so far been talking a lot about system design. So, system design as opposed to what we are going to be studying now; system design is for a base station and large number of users.

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So, it is a one to many system. So, one BTS to many mobile stations in one cell and then there are lots of the cells. So, therefore, what we are looking at a large scenario large perspective and this is a scenario where you make several assumptions and one of the assumption is that the BTS is the master, and it is a many to one to many communication.

So, on the other hand the bulk of this course that we are going to be once we have this systems perspective reasonably well understood what we are going to be focusing on is the actually physical communication between the base station and the mobile. So, this could be the base station side, this could be the mobile side, what is sitting in between is the wireless channel, and at this point it is not a one to many system it is a one to one system.

So, one to one system you are not talking about base station talking to hundred mobiles, you are talking about one base station talking one mobile what happens to the signal that was transmitted by the base station what happens what is the affect on that. So, at this point it is a O to P point to point link is what we are looking at as opposed to point to multi point was what previously the picture that we had in terms of I am making sure that everybody has got good signal to noise ratio at this point you are saying no I want to know what is my signal to noise ratio how can I improve my signal to noise ratio how do I do that.



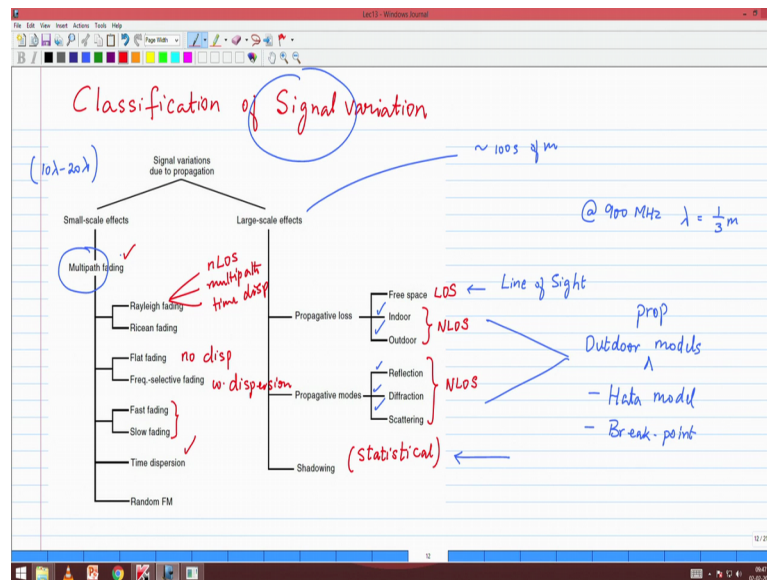
So, the focus on the channel is the primary take away from this course. So, the focus will shift from system to a very narrow part of the entire communications chain. So, focus on the wireless channel. Now if you were to say RF portion of the communication system it would mean the following RF is there in the transmitter there is RF in the mobile. So, the RF portion actually is this whole thing.

Now, what we when you say RF it is that, but when RF channel I am not worried about the power amplifier I am not about the filters I am worried about what is happening in this particular space. So, the focus of the course is not broadly RF yes it is RF, but it is RF channel not the RF impairments that is caused by the power amplifier and other things. So, again let us be very specific now what is difference between this what we are going to study and what we have studied in digital communications what we did for the most part in digital communications was we took the transmit portion this is the transmitted portion. And we said that I am going to represent signal in terms of a complex base band signal then we moved over to the receive side and said I now have the complex baseband of the signal with some impairment noise fading whatever it was. So, you basically skipped from transmitter to receiver using complex baseband as your representation.

So, again it is very different what we are going to focus on this course is not so much on the representation at the transmitter and receiver it is what happens in the middle and again keeping mind that the RF portion is a modulated signal. So, it is a real signal, but it is going on quadrature carriers. So, what we would represent is this portion of the signal or what is happening in that in complex baseband. So, though it is not baseband it is not complex, but for us to get a full understanding what we would represent is a complex baseband representation of what happens in the RF channel.

So, again I hope the nomenclature the difference between what the digital communication scores and the wireless communication scores, why are both talking about complex baseband. And what is the difference between the complex? I have written it wrong baseband; complex baseband is representation is what we will picking up in today's class any questions on this terminology or nomenclature.

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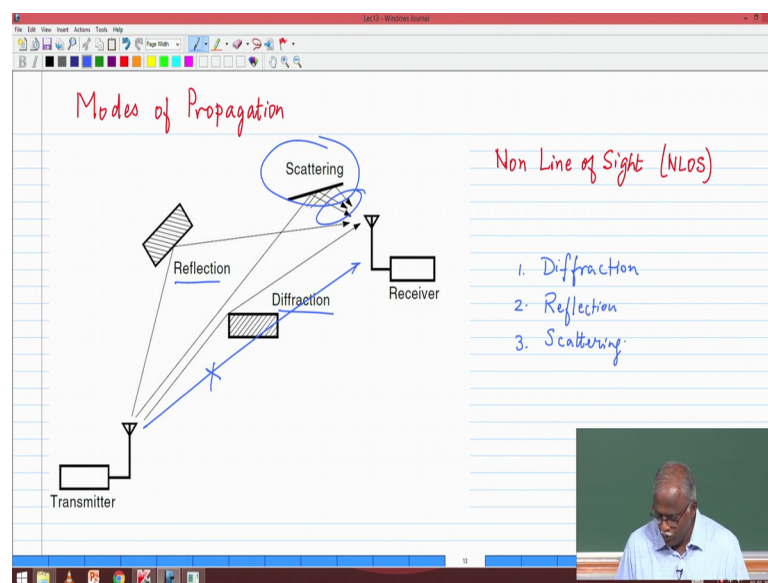
Now, let us quickly look at the what all do we study in this context of what happens between antenna to antenna. So, what are all the aspects that will impact the signal quality signal propagation?

So, first and foremost we go in and say that in this big picture there is one thing that we already have looked at that is shadowing because there can be a physical obstruction that is that is affecting it, and we have also made some references to this multipath propagation we said that signal goes in multiple paths. So, what we will see are two types of effects the first one are what we call as large scale effects; when you move hundreds of meters, hundreds of meters that is the large scale effects. So, typically shadowing is large scale effect, on the other hand small scale effects are those that happen when I move from 20 lambda to 10 lambda to 20 lambda in that order in that range of so the ranges are very different. Small movements if I move from this end of the table to the other end of the table my shadowing will not change, but there are parameters that will change and that those the change with small perturbations of your position are referred to as small scale effects.

Now, how small are the perturbations I think we did simple calculation last time, but let us do that again if I am talking about 900 mega hertz, my lambda is one third of a meter we are talking about 20 lambda; that means, around 6 meters so small variations that up outer limit that is small scale variations.

Now, on this one you are talking about variations over one kilometre 200 300 meters quite a big difference in that. Now let us start by understanding what these parameters tell us, free space propagation it is a large scale you can have free scale propagation over long distances, but free scale propagation happens line of sight right there are no obstructions between the transmitter and receiver line of sight. Now in cellular we never assumed that there is line of sight and so more or less everything else is non line of sight NLOS is non line of sight, non line of sight could be indoor propagation could be outdoor propagation both these are valid environments.

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Now, what are the ways in which the signal propagates when you do not have line of sight. Again I am sure you would have seen it in physics, but I thought I would just mention it this is described in the propagation article. So, if I have transmitter and receiver I do not have line of sight. So, basically this path is obstructed. So, therefore, the only ways in which it can propagate is the most important one is diffraction that is the bending of electromagnetic waves around the edges of objects, again I am sure you have done physics experiments in diffraction this is exactly the same thing. So, there is the bending and this has do with Huygens principle.

Now, the other type of mechanism by which the signal propagates is if you have very smooth surfaces which can then actually reflect the rays so; that means, you are basically changing the using the laws of reflection angle of incidence is equal to angle of

reflection. So, therefore, it can do a complete change of diffraction is just the bending this is a and of course, there is curved mechanism which is also important because reflection and diffraction alone do not account for all the signal that we receive, then you go back and look at there are objects that are in your vicinity large objects which are not very smooth so, therefore, they are not reflecting it in uniform directions, but basically they are scattering the signals some of which are beneficial to you and they reach.

So, the three modes of propagation, diffraction or diffraction second is reflection and scattering all three have a role to play, all three have different roles to play whether you are talking about outdoor or indoor and again what type environment that you are in all of these. So, when you go back and look at it all of these have to be accounted for depending upon whether you are indoor or outdoor they impact you differently. So, the combination of these two gives you outdoor propagation models.

Outdoor propagation models any outdoor propagation model that you have heard off?

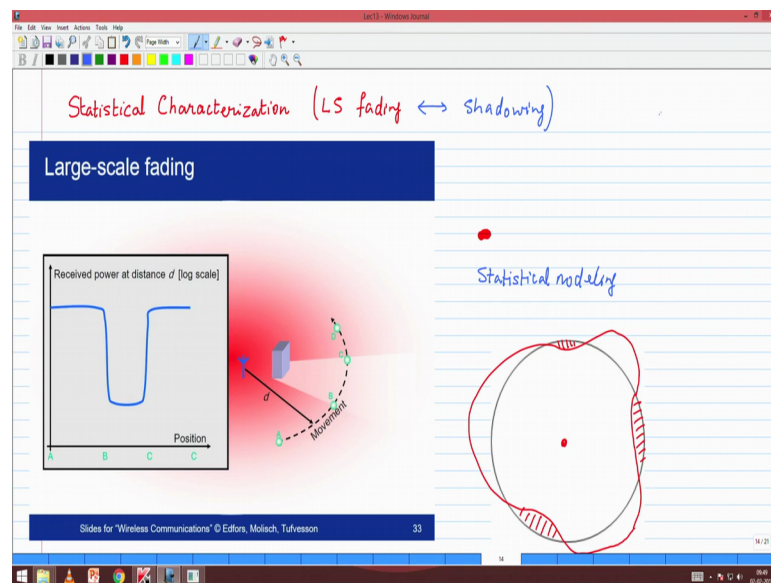
Student: Hata.

Hata model. So, there may be just an name at this point, but the let me just that down Hata model like Hata model. So, outdoor models these are propagation models example Hata model and by the way the break point model also fits into this because it is a non line of sight propagation mechanism, and may be you can write it down here break point model and the actually models that are used for outdoor propagation are fairly involved they have lots of parameters they are characterised, but at the end of the day these are large scale effects. So, now, moving over to the other sight, we now say that now I know that multipath happens what are the ways in which multipath which manifests itself. First of all it is going to manifest itself as fading that is number one, second it is going to manifest itself as time dispersion; the fading itself can be either fast or slow that is two variation where depends on your Doppler direction of which you are moving.

Now, can is the fading occurring along with time dispersion. So, flat fading means that there is multipath there is there is no dispersion, this is adding is occurring multipath is there, but there is no time dispersion this is with time dispersion and again leads to different types of environments one of the most common that we see is what is known as Rayleigh fading. So, this is non line of sight it has got multipath present, multipath it can have time dispersion it can have time dispersion as well time dispersion.

So, Ricean fading has got a small line of sight component it is not no line of sight there is a. So, again the bigger scheme of things we have large scale effects small scale effects; large scale effects deal with shadowing and basic propagation, and the small scale effects are caused by the different reflections or the different paths that are arriving what is the phase difference between them I am they are adding constructively or destructively is there a time dispersion between these two mechanism.

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So, this is a picture that sort of gives us a broad perspective and what we will do now is to build on this perspective. So, the first thing that we are going to take up is how do we proceed with this mechanism. So, the first one that we would like to do is statistical characterisation of large scale fading caused by shadowing.

Again this is just to introduce us to the notation the mathematical framework so that we start to think along these lines. So, as we saw in the first lecture the shadowing basically happens because there is a obstruction in the line of my signal path. So, if I am at position A I get a goods signal, if I am in position B and C there is a there is drop because of the obstruction. We also said that this can be visualised in terms of a circle of coverage because of obstructions your coverage may reduce in some places in some places you may actually go beyond the circle and that is what we said is the realistic scenario that will happen on the ground this is what we said we will capture in terms of a statistical model of shadowing.

So, statistical model of shadowing and this is what we would develop first, get a feel for what the how we go about this and then move over from the large scale the shadowing modelling of shadowing to the small scale effects. So, that is our plan. If you can read ahead this is, I will suggest the appropriate reading portions. Please do start looking at the shadowing part then we will move into the effects of small scale fading.

Thank you.