Wireless Communications
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Lecture No. # 04
The Cellular Concept: System Design Issues

We shall now talk about the system design issues involved in cellular systems. First the basic concepts involved in a cellular system design.

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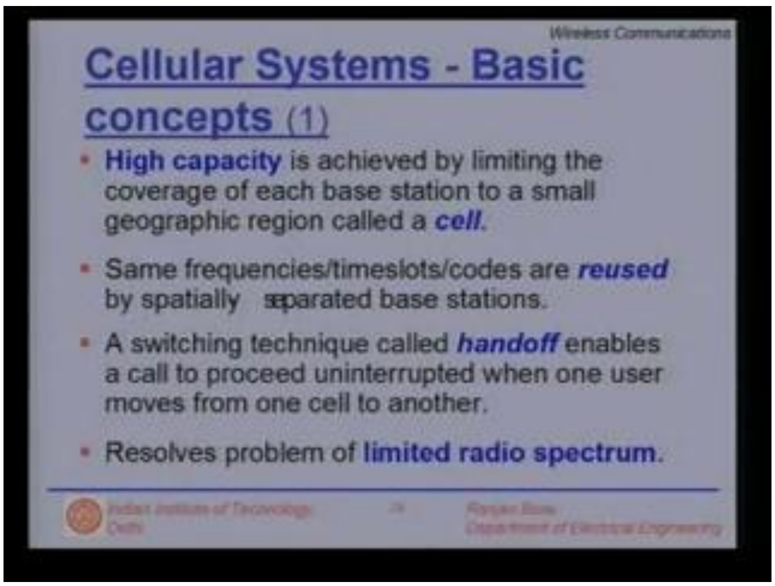

The basic requirement is of high capacity.High capacity is achieved by limiting the coverage of each base station to a small geographic region called a cell. This is different from the traditional radio transmitters which would cover the entire city and the whole city was one cell. This is a paradigm shift.In order to achieve higher capacity that is to support a larger number of users the city first must be divided into smaller cells and each cell must have a transmitting tower called the base station. The same frequencies or timeslots or codes are reused by spatially separating the base stations. So this factor of being able to reuse the frequencies actually allows you this high capacity.That means, a larger number of customers, more revenue and sustainability of the system.

However the movement we put more number of cells and at the same time promise the customers that they can move around because it is a mobile situation, we should have a mechanism to handoff the calls from one cell to another. So this is the price we have to pay in order to give enough mobility. This approach resolves the problem of limited radio spectrum.If we had the luxury of using infinite bandwidth, we don't need to reuse.Otherwise we will have to resolve to the techniques of frequency reuse.

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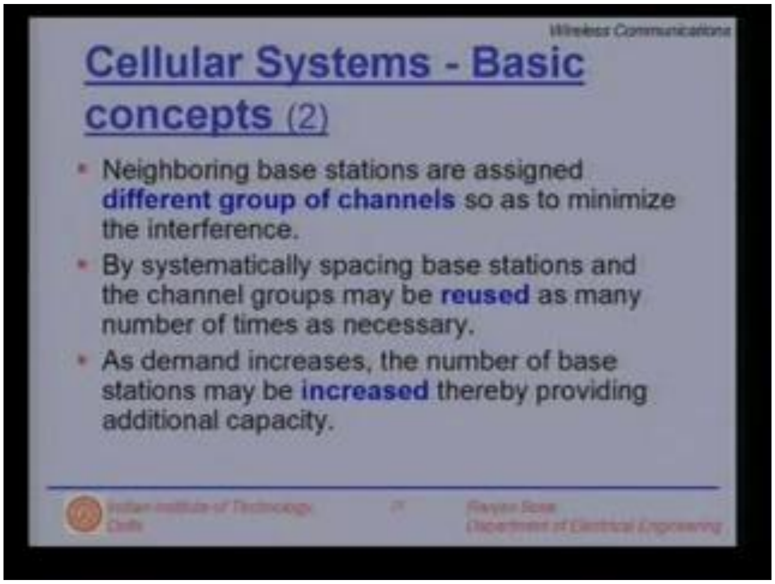

Let's look at some more basic concepts.Theneighboring base stations are assigned a different group of channels so as to minimize the interference. What do we mean by channels?As we saw earlier, we have certain frequencies or timeslots or codes and they form the channels. Since we have differentiated the entire regions and dividedit into sub cells, the neighboring cells must not use the same resources. But then we have to reuse it after sometime.So we have to come up with this notion of 'reuse distance' and 'frequency reuse planning'.If we do not plan well, at the end of the day, we will increase the overall interference.Interference will be an issue.We will also see certain mobile systems are interference limited. By systematically spacing base stations and the channel groups, we may reuse the recourses as mentioned before.

As the demand increases, the number of base stations may be increased thereby providing additional capacity. So there are ways and means today to expand your services.If your number of customers increases you can scale up your system. So this reuse factor and certain other advanced techniques will allow you to continue providing service to more and more number of stations even though you are not asking for extra bandwidth.This is the basic concept all. A very intuitive understanding is as follows.Just like the whole city has been divided into cells, each cell can be divided into sub cellsand further and further.So use smaller and smaller sub cells within the cell but keep in mind that the cell size can be reduced only if you reduce the power.Actually what determines the cell size and cell shape? We will discuss all these things. But clearly the transmitted power is a factor which will decide how big your cell is. So I can reuse and include more number of users provided I keep my emitted power under control. Nowlet's gradually buildup and understand how cellular network is laid out.

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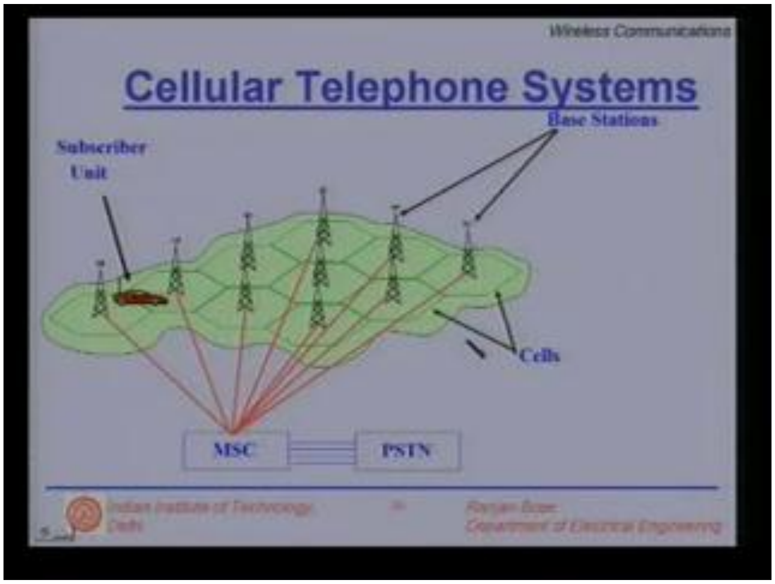

Suppose I have a base station here shown by a tower. There are transmitting antennas at the top and a transmitting unit may be at the bottom or at the top. It has a region of coverage. Here I have shown it as a hexagon.We will discuss why hexagons are traditionally used though in reality the real cell shapes have nothing to do with the hexagon.It's a concept which we will discuss. So every cell has a base station.Suppose we would like to provide coverage to an area, may be city 'x' using this cells, now I would like to put more number of cells to cover the region of coverage. So I have several cells. Here for the sake of simplicity, I have shown all cell sizes to be equal.Within the same geographical location most likely, all cells will not be of the same size.In fact, the terrain, the blockage, the density of people, traffic etc. Will determine how big or small the cells would be.

For example in Delhi, the cells near the Carnot place area which has high urban density will be much smaller.Hence we shall provide higher capacity. so cell size can be made smaller to do higher degree of reuse and hence provide much higher capacity.in outskirts of Delhi where the density of mobile phonesare not so high, we will have larger cells. So the entire city has been subdivided into cells with each base station put at the center of the cell. Now somehow, these base stations need to communicate with each other and also to the external world because the mobile system doesn't stand alone.It has to talk to the public switch telephone networks because I should be able to make a call from my mobile phone to a landline phone and vice versa. So the brain behind the cellular system lies in this MSC or the mobile switching center.

Clearly if I have to coordinate the activities of various cells, I need to put a line to all the base stations and connect them to the mobile switching center. So let's do that.so every base station is actually connected to the mobile switching center. Now let's put a customer, a mobile station, a car with a mobile phone in one of the cells and if this person wishes to establish a call from the mobile phone up to a public switched telephone network, I would like to have connectivity between the mobile switching center and PSTN or the public switched telephone network. We will talk about how the calls happen, what is the anatomy of a phone call, how to initiate a call from a mobile station to a landline phone or from a landline phone to a mobile phonelater.

The other thing that I mentioned is, suppose my user is truly mobile he loves to talk while driving.We should be able to provide some kind of a handoff as the mobile station moves from one cell to the other. We have to discuss these strategies.This slide gives you an overall picture of the cellular telephone systems. Remember this is a very simplistic model.In reality, cells are neither hexagonal nor equal in shape nor are they non-overlapping.In reality all the cells have a fair amount of overlap. Now talking about establishing a call from the mobile to the base station and from the base station to the mobile, we make use of channels.

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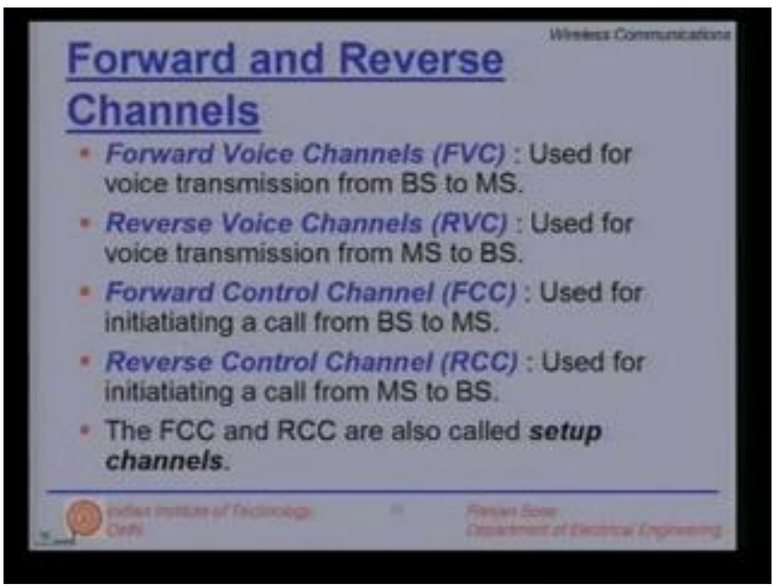

Most likely these channels are frequency bands or timeslots or codes.So the forward voice channel is used for voice transmission from the base station to the mobile station. The reverse voice channel is used for voice transmission from the mobile station to the base station. However, as we know voice channel can be only activated once the hand shaking has been done.So we required some kind of control channel. A forward control channel is used for initiating a call from the base station to the mobile station. A reverse control channel is used to initiate a call from the mobile station to the base station.Please remember the FCC and the RCC, the control channels are also called setup channels because of the nature of work they do. Needless to say the control channels are not used for sending voice but are used as overheads.They will take a percentage of the bandwidth, typically 5%.

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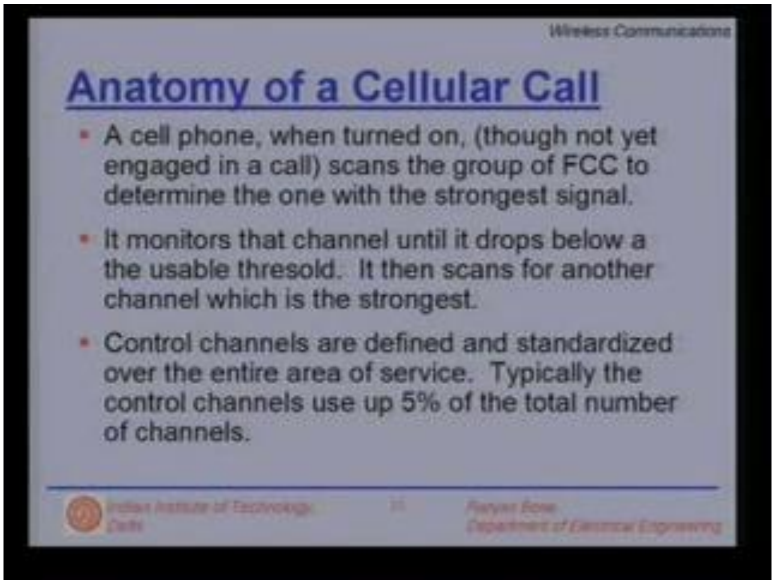

In this slide, let’s look at the anatomy of a cellular call.A cell phone when turned on but not engaged in a call scans the group of forward control channels to determine the one with the strongest signal. Please note even though you are not making a call, you are using a battery power.Therefore when you buy a phone, you have two kinds of time available; the talk time and the standby time. So your phone can get discharged over several days even though you don’t make a single call because it has to monitor and keep itself updated as to which cell it is talking to.

Therefore even though you don’t touch the phone, the display may change depending on which base station it is connected to. It is continuously monitoring the signal strength and knows at any time, at least one if not more, base stations with which it can communicate. So the mobile phone monitors the channel and keeps on monitoring because if the strength drops below a certain threshold, it scans for the next strongest. Control channels are defined and standardized throughout the service area.Typically the control channels use up to 5 % of the total number of channels.So5 % of your resources go into controlling setting up your calls.

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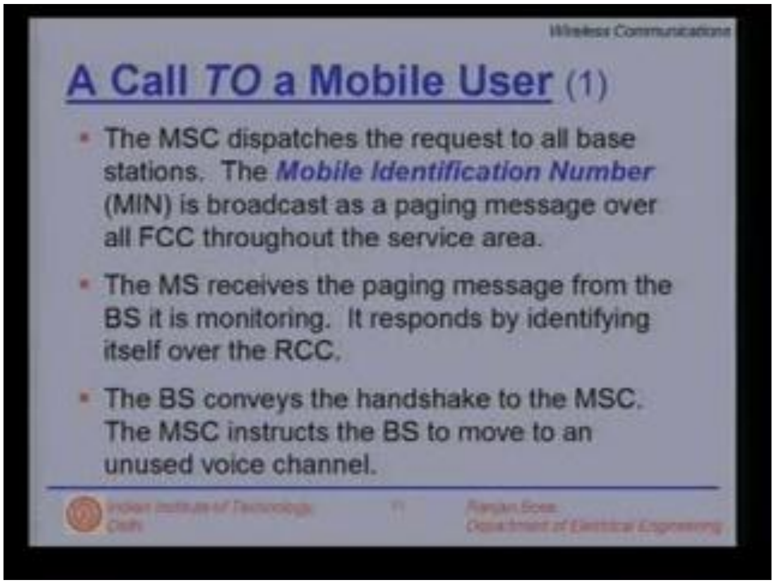

Let us now look at the case when you make a call to a mobile user.So imagine a scenario where a mobile station is somewhere in the geographical area.We have no clue and we try to make a call to a mobile user. So we dial this number 98182xyzpq and see what happens. so the moment you make this call, that is would dial this number which is pertaining to a mobile, the mobile switching center which is actually connected to the PSTN- public switched telephone network provided your making a call from the landline otherwise from one mobile to another mobile, the mobile switching center must come into the picture.It dispatches the request to all the base stations. Remember we are connected the mobile switching center to all base stations.Typically how do we have this connectivity? We can have a fiber we can have a point to point micro wavelength or any other way to connect the mobile switching center to the base stations. So once the mobile switching center dispatches the request to all the base stations, all the base stations send out a paging message. Now what is this message?

The mobile identification number which is a characteristic of that mobile station is being broadcast.It is unique to that mobile.This number may not be the same as the phone number. It’s another code. So mobile station receives the paging message from the base station it is monitoring because it was already in touch with one base station at least. So when that particular base station pages it that is, broadcast this mobile identification number, the mobile station must respond. it responds by identifying it but over the reverse control channel. The base station conveys the handshake to the mobile switching center.The mobile switching center instructs the base station to move to an unused voice channel. So it gives an instruction for the base station to look for an unused voice channel.It may be possible that that particular base station has run out of all the available voice channels. At that time they will not be the initiation of a call.

Student: Sir, you mentioned that mobile identification number and the mobile number are different. So where actually is the mobile identification number stored? Is it on the mobile itself or on the base station?

Professor: No. this is actually setup in a lookup table inside the mobile switching center.So there is a lookup table which has the phone numbers and these identification numbers. There is a host of other identification numbers also which can be used to ensure that legal calls are made. So for example, in GSM there is a provision that you can deactivate or label a phone as a stolen phone. So no phone call can be made from that phone which is labeled as a stolen phone because that number isblacklisted. Now what number will be blacklisted? Most likely the MIN will be blacklisted. So it stays with the mobile switching center.

Then there is something called as a location register.When we talk about GSM phones and basic protocols, we look at the home location register and the visitor location register where we will keep a lot of information about the mobile phones including the prepaid card details of whether the prepaid money is there, whether it has not defaulted and what are the call charges.In fact, before a call is established a lot of things are checked.The validity, the legality and other thingsand only then you initiate a call.

Student: sir, about what activities takes place in the handshake phenomenon?

Professor: so if we are talking about only the conceptual level we only verify whether a response comes from the mobile phone and that mobile phone is a valid phone with a valid SIM card. We are not talking about the physical activity about the voltage levels or the received single strength.So there are several numbers. The SIM card has a number.The hardware has a number and then there is a logical phone number. So it is possible to have a combination of valid numbers. SoMIN is the hardware number.Let’s look at a call to a mobile user now.

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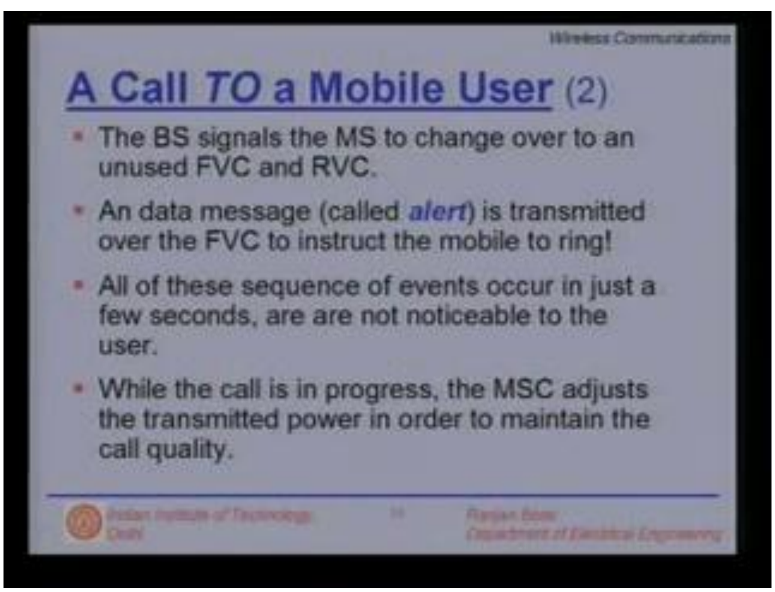

Actually we are continuing with the call to the mobile user having being paged and responded and being allocated an open frequency band. The base station signals the mobile station to change over towards unused forward voice channel and reverse voice channel. Please remember both these voice channels have to be available for the call to be initiated.The call has not yet been initiated.We are working on it. Next, a data message called the alert is transmitted over the forward voice channel to instruct the mobile to ring. Mobile so far has not run.

All these sequences of events have occurred just in a couple of seconds and are usually not noticeable to the user. You may here a series of beeps or a silence period of three seconds till you hear the ring.During this process this figuring out where the mobile is, checking out the identification numbers, allocating of frequency bands etc. takes place and then you hear the first ring. While the call is in progress, the mobile switching center adjusts the transmitted power in order to maintain the call quality. So lot of intelligence is built into the mobile switching center.However, things have gradually changed and in the modern base station, a lot of this activity takes place right at the base station.

The mobile switching center cannot really handle so much of traffic and the power control issues are taken care at the base station itself. As the handsets are becoming more and more microprocessor friendly and powerful microprocessor being built into handsets a lot of these power calculations are also done by the handset itself. So the idea is to distribute the computing so that the mobile switching center is not over loaded.The series of steps I have shown to you belong to the original GSM standard. Let’s now look at the other scenario where a call from a mobile user is being made.

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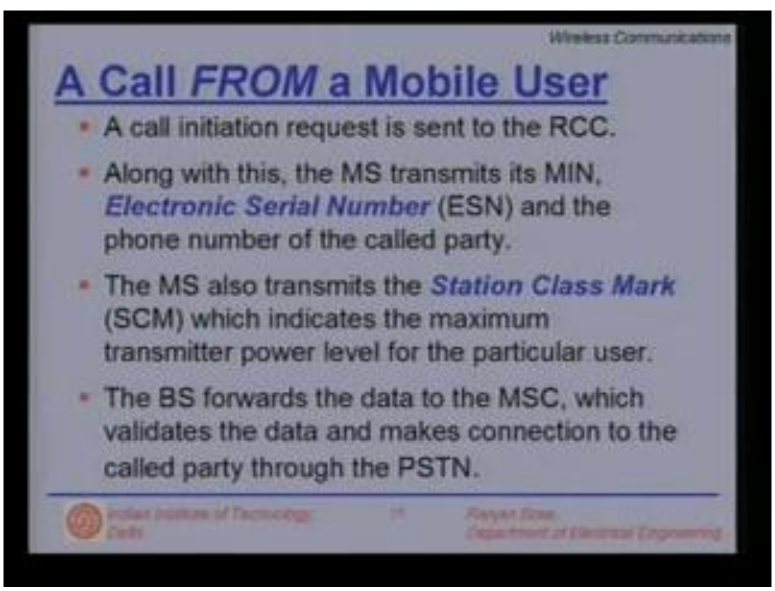

Remember at any time the mobile user is already in touch with at least one base station. So first, a call initiation request is sent to the reverse control channel.Remember the reverse channels are from the mobile to the base station.Along with this, the mobile station transmits its MIN. so it is in the hardware but it is also in the table of the mobile switching center.Along with this, another number called the electronic serial number and the phone number of the called party is also set. These different numbers have different utilities in terms of verification at different levels. The mobile station also transmits something called as a station class mark-SCM which indicates the maximum transmitted power level to the particular user. Basically this is a way to control the transmit power.

This request is sent to the base station which forwards the data to the mobile switching centerwhich in turn validates the data because it has the register locators.It has the data base.So it validates the data, makes the connection to the called party through the public switched telephone networkif it is to a landline number or to another mobile.But how to make a call to a mobile is already known to you. We will follow that procedure. Again you may hear a series of beeps or a silence period while all these activities are taking place until you hear the first ring.

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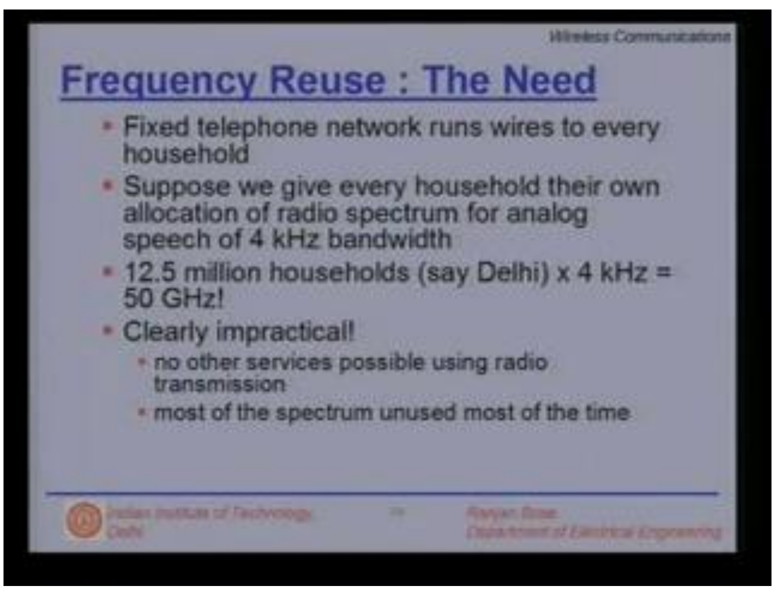

Next we come to a very fundamental concept of frequency reuse.i have already mentioned about it that the spectrum is limited.The only way out is to reuse the spectrum.What is the best way to do it? What is the most efficient way to do it?Before that let us look at an example to see the true need for frequency reuse. Suppose we had fixed telephone networks and they were running wires to every householdbut we are not talking about wire line truly.We have compared it to a wireless situation because we are looking at wireless cellular systems. Suppose we would like to give every household in Delhi a voice bandwidth.They can talk.So we need to give about 4 KHz of spectrumbut the number of households in Delhi is about 12.5 million.Suppose we get into a stage where we can actually give them 4KHz of bandwidth, we are talking about 50GHz of bandwidth.

Clearly we cannot allow this kind of outrage on a mobile phone network.We do not have the luxury to touch fifty GHz of bandwidth.We have to reuse our frequency. So clearly in practical, no other service is possible using radio transmission.Most of the spectrum unfortunately will remain unused most of the time. If I give a phone line connection, I cannot do adaptive reallocation.So clearly there is a need to do frequency reuse. This calculation has been done only for voice.If you have to provide additional data, allow them to check their emails over the phone, downloads stock codes and cricket commentary, we are out of business.

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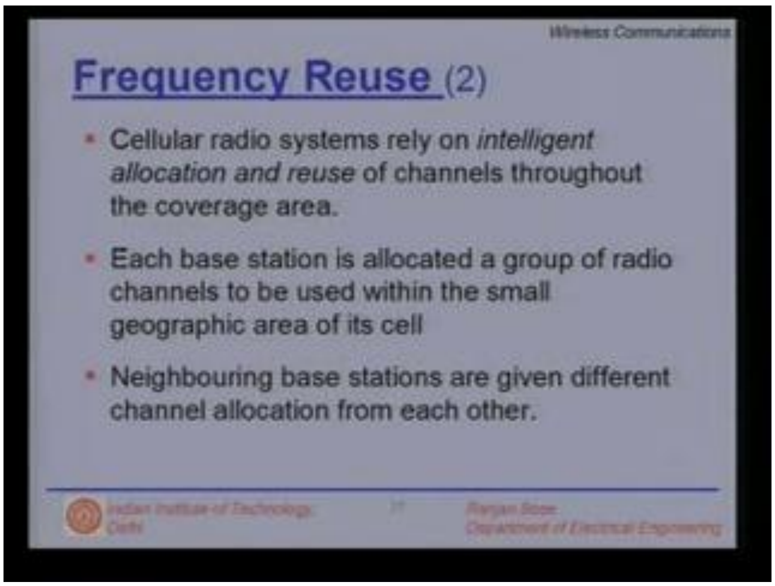

Cellular radio systems rely on intelligent allocation and reuse of channels throughout the coverage area.We need to emphasize this point because this forms the crux of the matter. Each base station is allocated a group of radio channels to be used within the small geographic area which we have already defined as a cell.Soit is not just a frequency but a frequency band. Neighboring base stations are given different channel allocation from each other because we would like to avoid interference. The biggest problem with frequency reuse is manmade noise or interference. If I am going to reuse the same frequency for transmitting data at a distance, I will definitely get some stray interfering signals. Theyare exactly in the same band.You cannot use a filter to filter it out because your data is also in the same band. That also makes a point that I cannot improve my performance by simply increasing the signal to noise ratio. If I increase my signal strength to beat the noise, I'll also create more interference for my friend because the frequency is being reused. Cellular networks must have an efficient power control mechanism. It's very important.In fact your GSM phone monitors the transmit power level 800 times/ sec.

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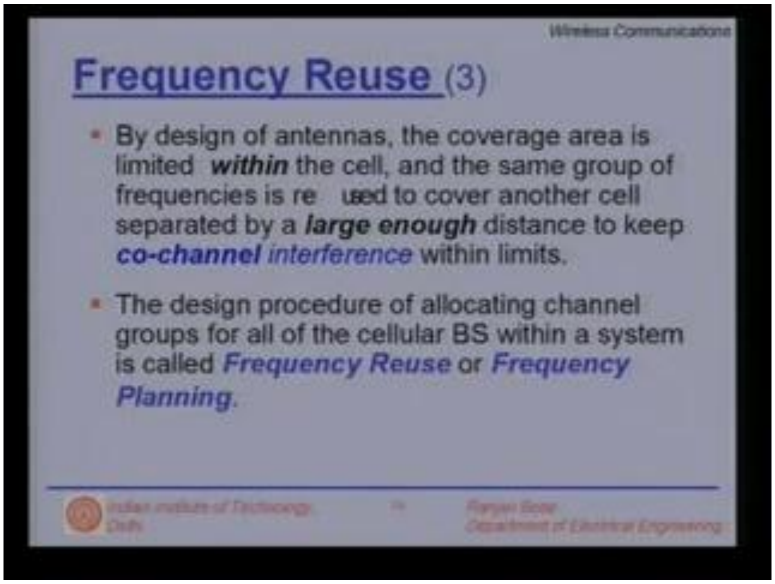

Now by the design of antennas and regulating the transmit power, the coverage area within the cell is limited. The same group of frequencies are reused to cover another cell separated by quote-unquote“a large enough distance”. Why a large enough distance because you want to keep this co-channel interference which is generated by cells using the same frequency band under control. Clearly I would like this co-channel interfering cell to be as far as possible because of the inverse square law that will take place. However the farther we put the co-channel cell, the less frequently I reuse the frequency, the less capacity I can have. so that is the tradeoff between how much capacity I can pack in in terms of closely putting the reuse factors and then we can go ahead and reuse the frequency as and when it is desired.

The design procedure for allocating cells for the cellular base station within a system is called the frequency reuse or frequency planning. Frequency planning should not be very complicated because at the end, we have to ensure that certain base stations are using certain bandsand the other base stations are using another band. So we cannot really come up with a very complicated scheme also frequency reuse is done in terms of a cluster. So you have a cluster of cells where you reuse the frequency bands and then you replicate that cluster over the entire geographical area. Let’s look at an example of a frequency reuse over a certain geographical area say, Delhi.So here we have an approximate outline of the city of Delhi.

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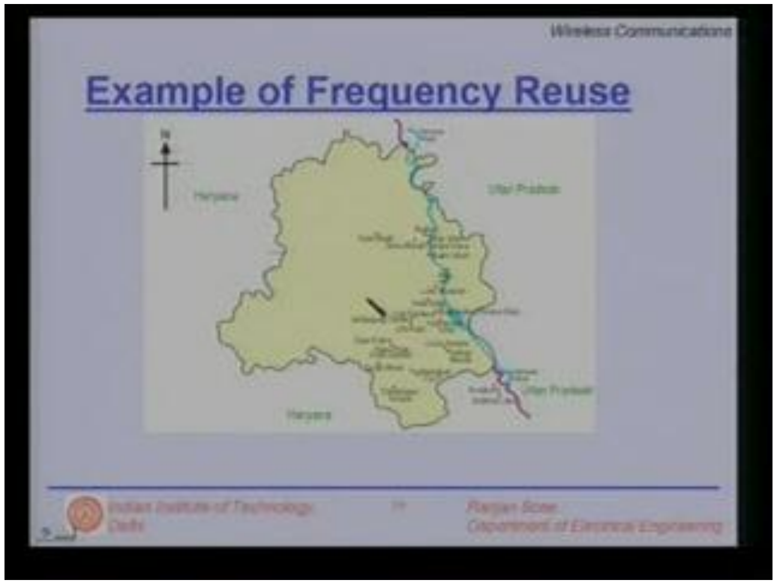

We have the neighboring states.We can see the river flowing by.Our job is to setup a frequency reuse pattern in this city of Delhi. So we first start with a cell.Typically, a cell will be of a radius of 3km -5 km in a city which is urban.

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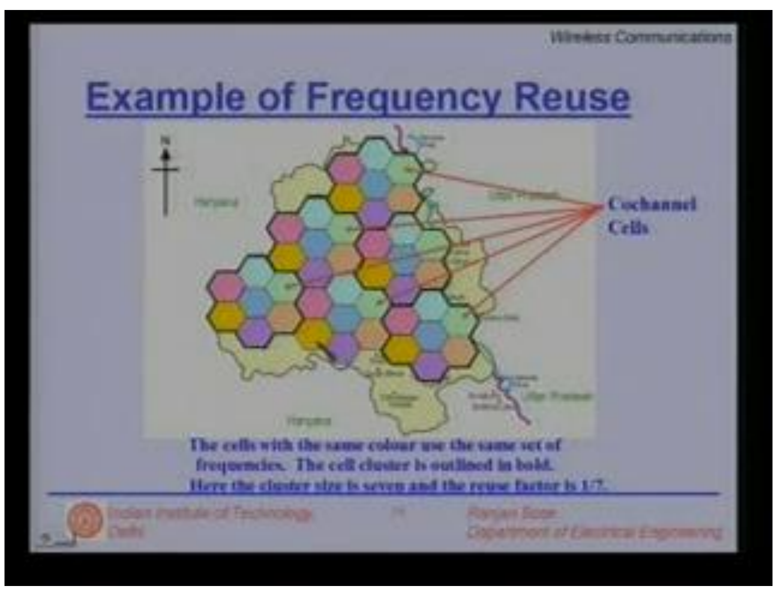

I have put in a hexagonal shape just for the sake of clarity.it is put in blue indicating a certain frequency band being used. I have another cell which is using another frequency band denoted by light blue in the slide. It's another hexagonal cell.i am not showing an overlap.in reality, there will be overlap.I'm going to fill up the space by adding more hexagonal cells. So I have put up a cluster of 7 cells here, each one represented by a different color and each color represents a different frequency band. Clearly, the user of adjacent cells are not interfering because they are using different frequency bands and are not going to interfere. I like this cluster (Refer Slide Time: 32:34) and I would like to replicate this cluster all over the geographical area. So I put exactly this cluster of 7 cells nearby (Refer Slide Time: 32:46). note that the deep blue one which I started off with is being repeated herebut the distance between this blue and this blue is the same as light green with this light green (Refer Slide Time: 33:00).So the reuse distance is the same. It is interesting to note that you cannot have any random number of cells in your cluster. I cannot have for example, a cluster of 5 cells which can have this uniform repeat pattern. We will look at what are the possible cluster sizes.

Let's take this example forward by putting another cluster. Again note that the distance between the green cells here are the co-channel cells. It is the same between this cluster and this cluster this cluster and this cluster (Refer Slide Time: 33:42). No frequency band is being discriminate.All frequency bands are going to suffer through the same co-channel interference levels. We are excited about this plan.So we keep adding clusters and we are happy that we have been able to cover most of the region by these cells. This pictorial figure gives where we use what frequency.

Conversation between student and professor: The question being asked is: whyshould the distance be same? The answer is the following.Suppose you take this cell, rotate it and keep it, then certain cells will have more distance and certain cells will have less distance.Certain group of cells will have poor quality of service because of interference because distance will attenuate the radiations coming from a co-channel cell. If the distance is fixed and pre-calculated, then we know how much interference we are dealing with. Therefore I am saying the distance should be same to guarantee a certain level of affordable co-channel interference. If we have this cluster size smaller, say a cluster of 4, then the reuse distance will go down and the capacity will go up. Therefore you will have to tradeoff between the co channel interference and the reuse distance. So cells with the same color in this diagram reflect same frequencies.In this example we have used a reuse factor of 1/7.

Conversation between student and professor: The question being asked is: when we switch on a mobile phone and we want to initiate a call which frequency do we choose? Suppose my mobile phone is in this light green cell and it is switched on, it has only a set of frequencies with which it can communicate to this base station. The mobile has a possibility to use any of the frequencies in all the cells.But which particular reverse channel will it use will be dictated by the base station and eventually through the mobile switching center. But the base station in this region would communicate using a frequency band represented by green and tomorrow if the base station wishes to move to the purple cell or to the orange cell; it will choose the frequency sub-band accordingly.

Student: Sir, patterns depending on the channel available or frequencies allocatedto the mobile center?

Professor: That’s right. depending upon the channels available, the frequencies available and allocated and suppose a base station can only support these green frequencies while the mobile station moves from green to the purple cell, a handover will take place not only to the base station but a new channel will be given which is nothing but a new frequency. So explicitly I have put arrows to all the light green cells which form the co-channel cells.Similarly all the purple cells are co-channel cells and will interfere.

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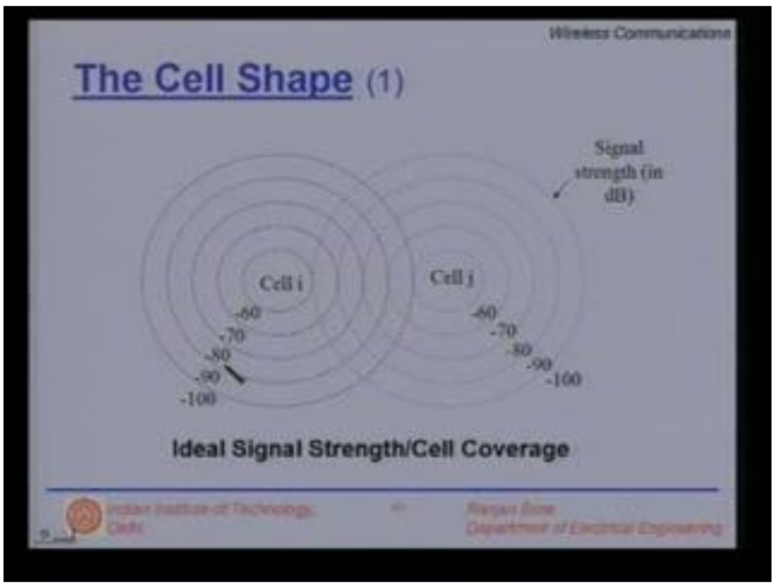

In the next couple of slides, let’s look at the shape of the cells.what determines the shape of the cells and how can we regulated if at all. Consider cell i and cell j which are co channel cells.Assuming the base station is located at the center of the cell and it’s an omnidirectional base station.it radiates circularly in all directions. As we move away, the received strength falls.so just for the sake of this example, let’s assume the received power is in dBm with respect to 1 mW. So it’s at -60 dbm,-70 dBm and so and so forth as you move away from this cell. same is the case with cell j.

The question is: how much you would like to separate the cell so that the received power by cell i coming from cell j is below a certain level.if your handset can handle interferences below 80 but not more than that, I need to decide a certain reuse distance.so who decides the reuse distance because the reuse distance can be changed it can be as low as 1, I don’t reuse at all.in the sense that, every neighboring cell uses the same frequency 2,3 or change to 4 or 7 or 12.These are the certain possible reuse numbers. We will talk about which one to choose for your application depends upon, how much interference you can tolerate. sometimes you can have interference mitigation techniques by signal processing which will allow you to handle larger interference.

Then your reuse distance can actually go down.so by signal processing you can make the capacity of the system higher. In reality, the cell shapes would look like this.

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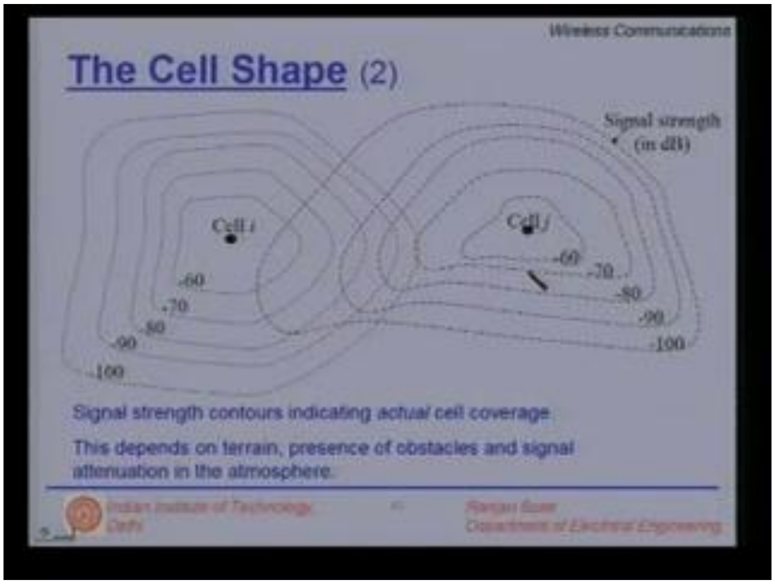

Why is there a dent here (Refer Slide Time: 40:10)? Possibly there is a building here.Why is there a big dip here? Possibly there is a forest area or foliage which is attenuating the signals. Remember these contours represent the received signal strength.note2 things.not only the cells and the received contours are irregular; they are also not equally spaced any more. In this region this the radiations are going through a medium which is attenuating it differently.most likely is going through a concrete jungle here so that it is falling much faster. So the cell shapes in reality look like this and these pictures should be taken into consideration to actually decide the reuse distance. Signal strength contours are indicating actual cell coverage. This depends on the terrain whether its rocky, foliage, water bodies, presences of obstacles, buildings, towers and the attenuation in the atmosphere like rain, fog, dust, smog and other factors. All these factors will determine the received signal strength and hence the shape of the cell. As a system planner you must considered all these factors before you say “i would like to have a reuse factor of 7”.

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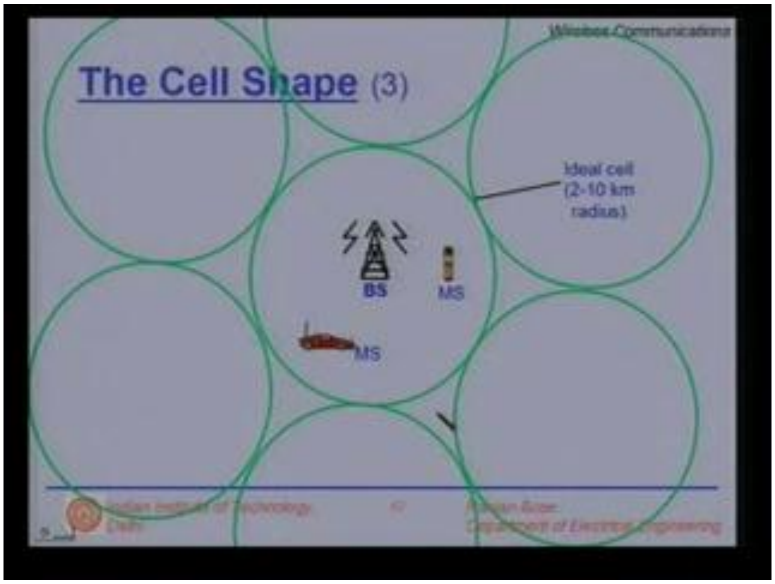

So let us now see the applicability of the hexagonal cell shapes. Why are we using this hexagonal shape? Why is it of importance even academically? So we have a base station which will radiate.now if it is in omnidirectional radiation, we would have a circular cell.it's ideal.in reality we would not like to have it for several reasons. Suppose the ideal cell is of radius 2 – 10 km. who decides this 2 – 10 km radius? It starts with the radiated power and then the obstacles that may be encountered in the cell. Let us put up one mobile station here and another mobile phone in a car so that they are very much contained in this circular cell. I would like to do system planning and cover my entire area of interest using circular cells. I can do so but the problem with putting circular cells for coverage is that you are left with these empty spaces where I cannot predict any coverage. It's clearly a bad modeling as a mobile system service provided I must be able to give 99.99 % coverage if not 100 % because my competitor will. I cannot have frequency planning done based on cell shapes which leave out by design some of the areas.so what do I do?

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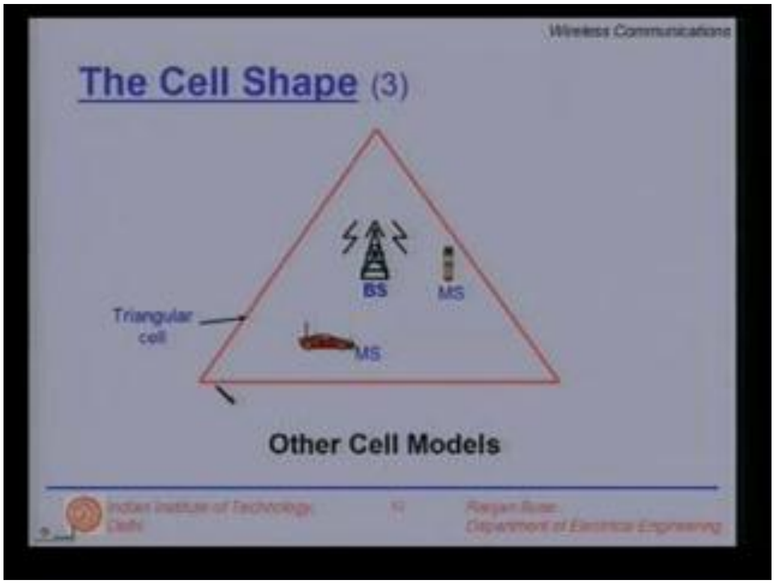

I have to try and come up with other cell models which can approximate the circular shape but not leave out sections. So one of the simplest shapes that allow me to cover the entire space by placing cells next to each other is the triangular cell. I can cover the entire area with triangular cells without leaving any place.

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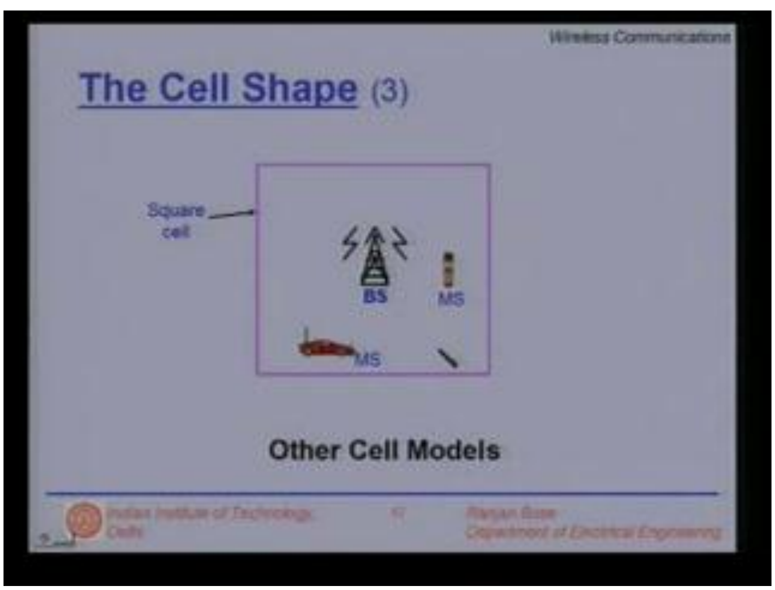

Clearly, triangle is a poor approximation of a circle. So in order to maintain close contact with reality I come up with another cell shape called the square cell.it also has a property to cover the entire geographical region without leaving open spaces. It also approximates the circle but in a poor manner.in reality we do not actually use the cell except in certain cases for example, the LMDS–"local to multi point distribution service" which is based on the IEEE 802.16 which by designed uses square cells. But we are not going to discuss that at this moment in time. So in a quest to come up with a cell shape which approximates the circular ideal shape but is not completely counter intuitive, we go to the next possible shape which is the hexagonal cell.

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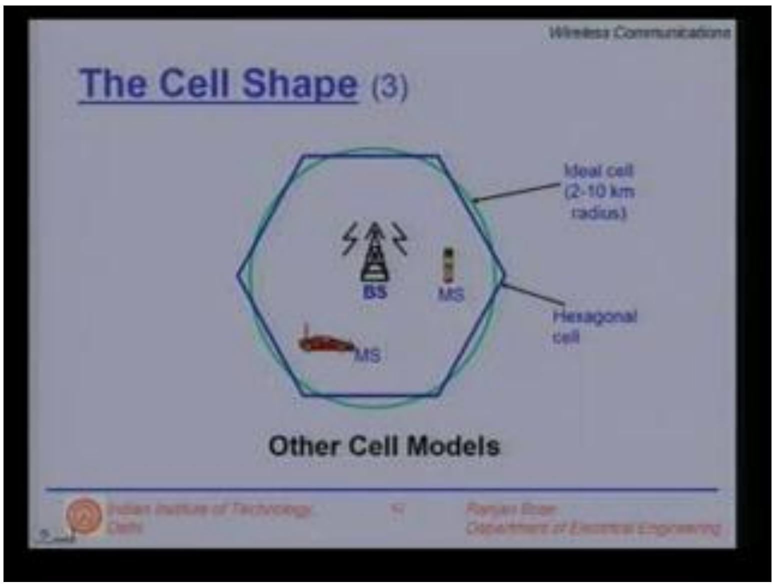

Clearly it is closer to the circular ideal shapeand it also covers the entire space without leaving blank spaces.hence hexagonal cell is used as an approximation to the circular pattern and thus what we will use and will look at the hexagonal geometry and see how we determine the reuse distance, how much co-channel interference we will get in terms of hexagonal cell pattern.so please remember hexagonal cells are conceptual.

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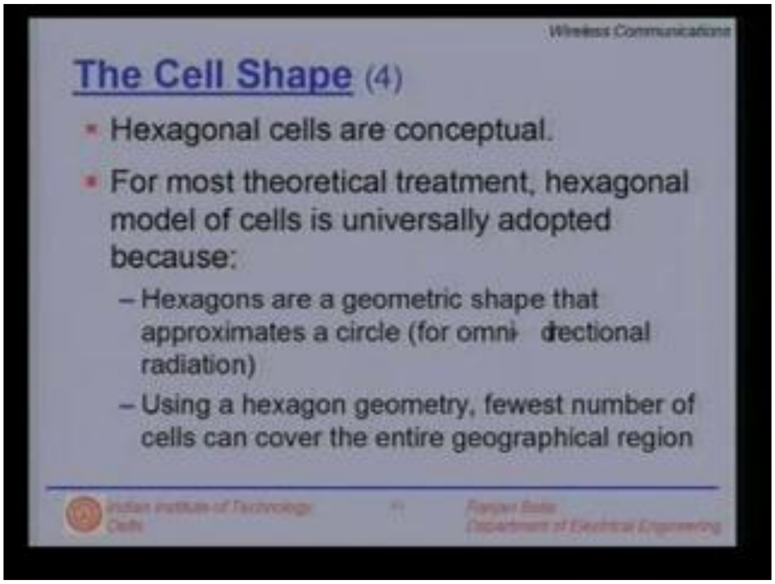

For most theoretical treatment, hexagonal model of cells is adopted because they are shapes that approximates a circle. Using a hexagonal geometry, fewest numbers of cells can cover the entire geographical region as opposedto square cell or a triangle cell. So let's stick with hexagonal cells and you will find it in most textbooks and research papers that they are using hexagonal cells.

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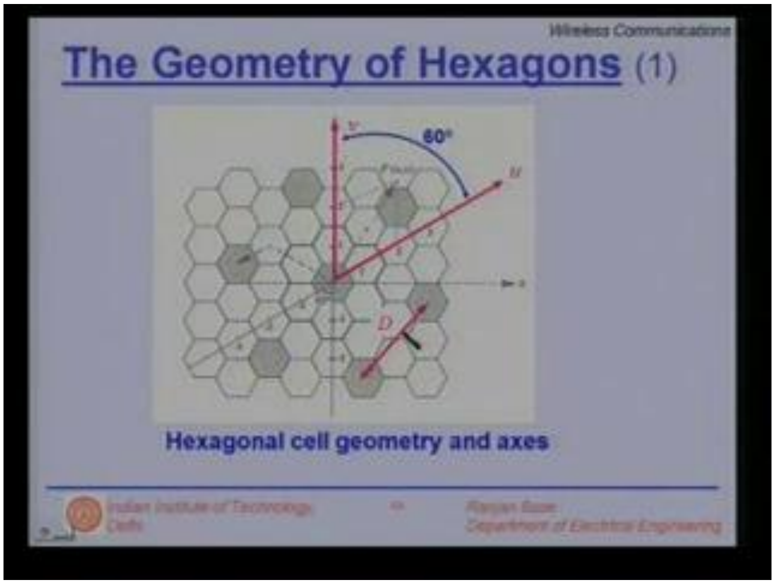

Next a few slides on the geometry of hexagons.the regular Cartesian coordinates of x and y which are orthogonal are not completely appropriate. So consider the x axis and the y axis and I have placed a lot of hexagons which are closely spaced and here if you look carefully with a slightly darker shade I have outlined a cluster.a cluster of seven cells we had seen earlier. we have also repeated the cluster so that there is a reuse distance. but we are not comfortable with this hexagonal cells because the moment I go along this x axis, I sometimes start with a complete cell, then go through it, cut in the middle and I don't like this geometry. what if I look at this (Refer Slide Time: 47:31) axis which is at a diagonal but touches the centers of each of the hexagons kept in this way and we put another axis which touches the centers of all the hexagons along this axis.

In that case, we don't have to count fractional amounts of hexagons as we go along any axis. So let us define this funny U-V axis which are actually separated by 60 degrees.isthe logic clear? We would like to count hexagons after what is a reuse distance. we would like to quantify that number in terms of the cell radius. So the cell radius R is the same as the length of a side of a hexagon. I would like to count the distance in terms of the cell radius. How many units are there? How many radii do I move from one cell to other? So it will be a normalized unit. If I would like to measure the distance between two co-channel cells D, I want to quote it in terms of this number R which is the cell radius and the length of the side of a cell.

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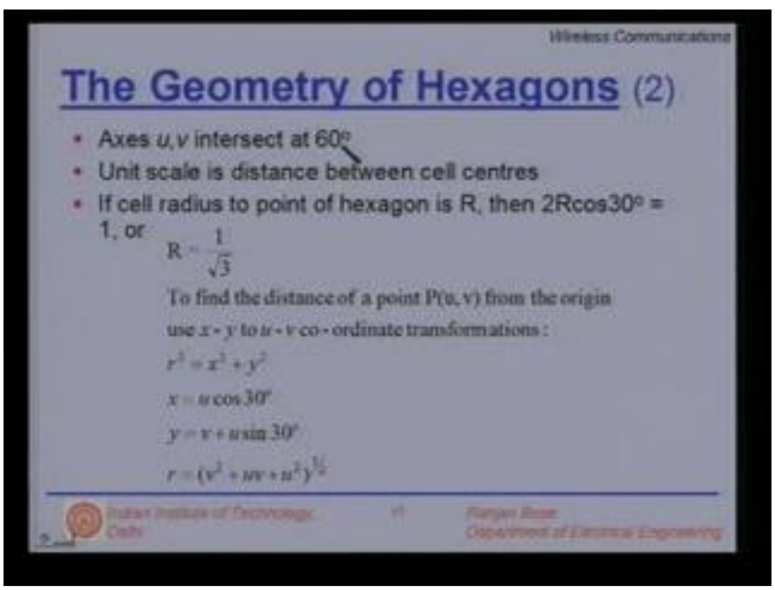

So the axes U and V intersect at 60 degrees as you have seen because hexagons have great affinity to this 60 degree angle.unit scale is distance between cell centers. If a cell radius of a point in the hexagon from the distance on the center to one of the corners is R, then 2R cos30 is 1 or R can be written as 1 over root 3 normalized. If you do the basic mathematics, you will come to the equation that r = square root of v squared + u squared+uv, coming from simple geometry if you go back. So what it means is we can represent our distance ‘r’ in terms of units on the uv axes. The u-v axes are special because they are separated by 60 degrees.

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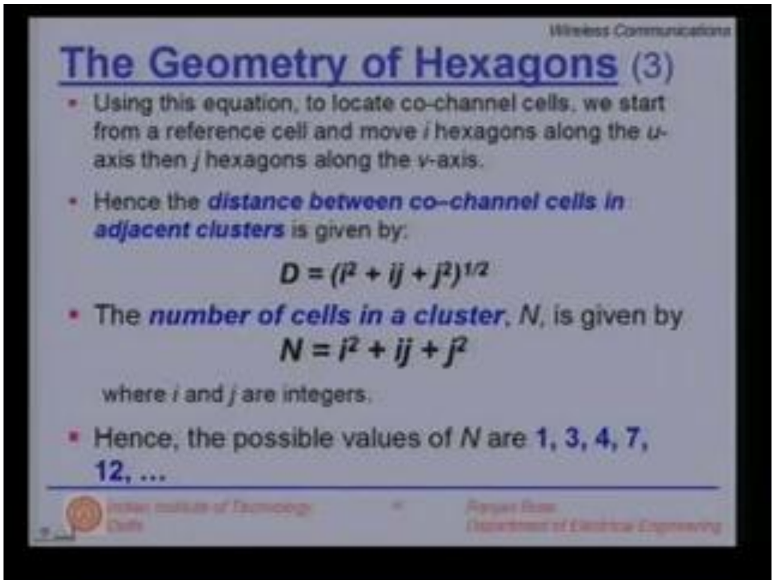

S o that equation written here as a distance is nothing but I units that you move along the u axis, j units that you move along the v axis.so i squared + v squared +uv. Square root of that is the distance. And what happens after this distance? After this distance you reuse the frequency.so D is the frequency reuse distance. N is a number which is found by substituting only integer values for i and jand that tells us after how many cells I reuse the frequency. That is, how many cells are in my clusterbecause after we run out of the cells in the cluster, we reuse it.from the hexagonal geometry alone we have that not all integer values of capital N are possible. In fact, if you use integers for i and j, the possible values are 1, 3, 4, 7, 12, …

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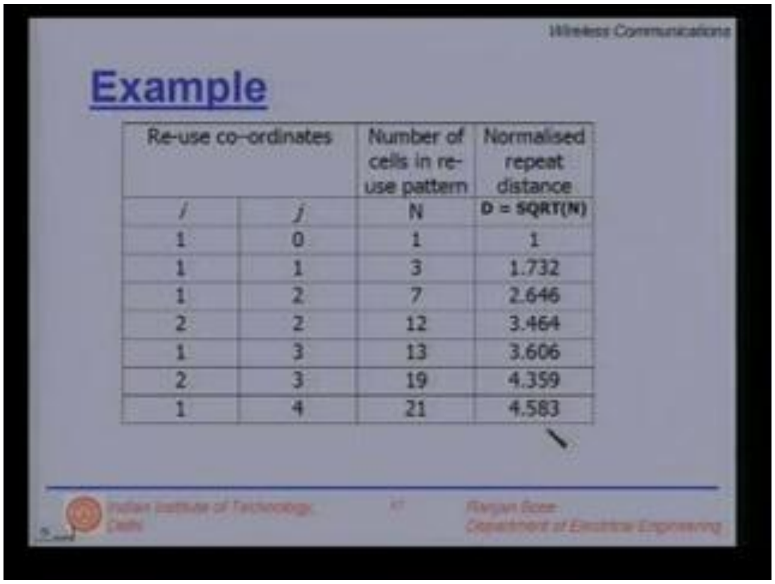

Re-use co-ordinates		Number of cells in re-use pattern	Normalised repeat distance
i	*j*	N	D = SQRT(N)
1	0	1	1
1	1	3	1.732
1	2	7	2.646
2	2	12	3.464
1	3	13	3.606
2	3	19	4.359
1	4	21	4.583

In fact if you look at a table for integer values of i and j, we come up with 1, 3, 7, 12, … and if you calculate the distance which is the reuse distance in terms of the normalized radius, you get a certain figure. This will tell you how far must your co channel cells would be and whether you can tolerate the interference.

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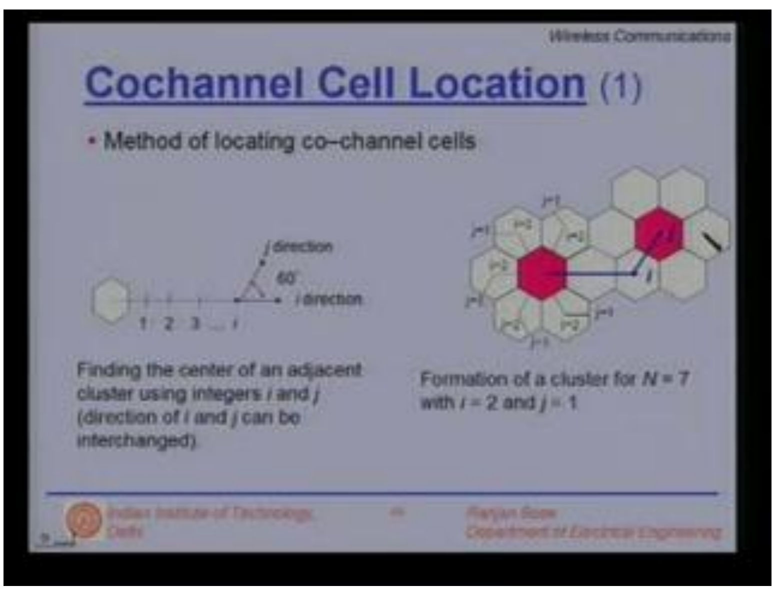

Let us look at a few quick examples. How to look at a co-channel cell, because co-channel is clearly going to limit the performance of the system.This is your typical 7 cell reuse pattern. You can see 7 cells here and we have seen this structure before. So I would like to find out after what distance will this cell repeat. Now for N = 7, using that formula i squared + j squared +ij, i =2, and j =1 gives you N =7.2 squared is4 + 1 squared is 5 +1 into 2 is 2.That gives us 7. So all it means is that if I move 2 units along the i axis and 1 unit along the j axis, I should be able to get a co-channel cell that uses the same frequency.

So let's translate this cell 2 units along the i axis which is at favorite U axis and 1 unit along the j axis which is the V axis and see where we go.So if we go along the y axis, we move 1 unit and we will use another unit. So the original cell as now we moved 2 units along the i axis. Weare only half way through because we have to move it 1 unit along the V axis which is at60 degrees. So let's do that along this j axis.So this original cell has not translated here and the co-channel cells are actually shown in red. So if we complete the picture, let's put in the cluster and you see that these 2 cells which are the co-channel cells indeed have the own clusters and repeat. This logic is true for every cell in the cluster. So I have several cells. So take the total band, suppose it is 700 MHz, you divide it into 100 MHz each, put each 100 MHz sub band into the cells and repeat it.

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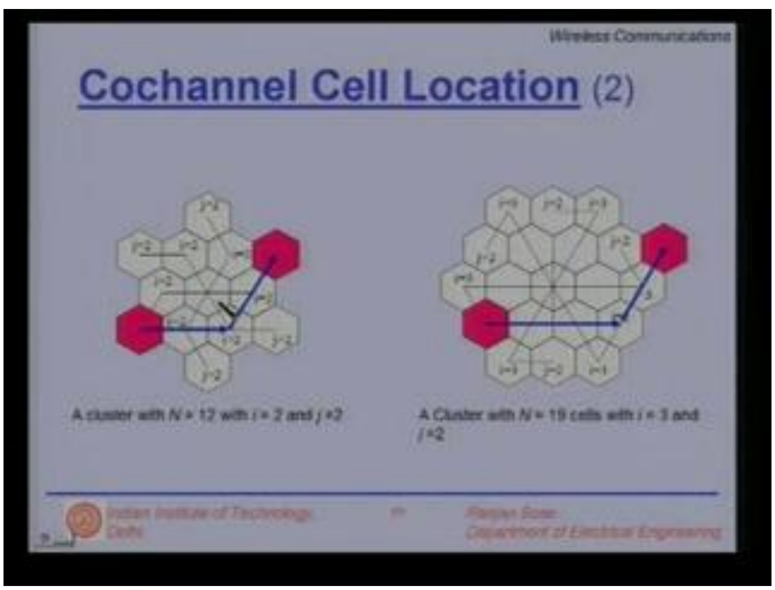

Let's look at two quick examples.This is a cluster size with 12 cells and this number N =12 comes from the same formula i squared + j squared +ij with i =2 & j =2. So in this case, these are the two co channel cells (Refer Slide Time: 55:00). If you move 1 unit & 2 units along the i axis and then move 1 unit & 2 units along the V axis, you get the co-channel cells.

Student: Is N =12the number of cells?

Professor: N =12 is the number of cells inside the cluster and N = 12 has been found by using integer value i = 2 and j = 2 in the formula.

Student: Is the whole thing a cluster?

Professor: Yes.

Student: Are there 13 in it?

Professor: Yes because the 13th cell is a reuse cellbecause in the cluster I cannot repeat.

Let's look at the next larger cluster size of N =19. Suppose I have to provide service where my system is extremely sensitive to interference I cannot reuse frequencies very frequently.i must increase the reuse distance. I'll go to larger cluster size.Again for i =3 & j =2, you can have these two (Refer Slide Time: 56:18) cluster co channel cells. If you move along the i axis, you have 1, 2 & 3 units.Along i 1 unit,2 along the j again at 60 degrees and you are with the co-channel cell. Please note distance here is less than the distance here (Refer Slide Time: 56:41). This scenario has less interference whereas clearly, this scenario has more interference, much more than the N =7 (Refer Slide Time: 56:49). In GSM we use N = 7 and sometimes N =4 and if I am very ambitious, you can also use N = 3.

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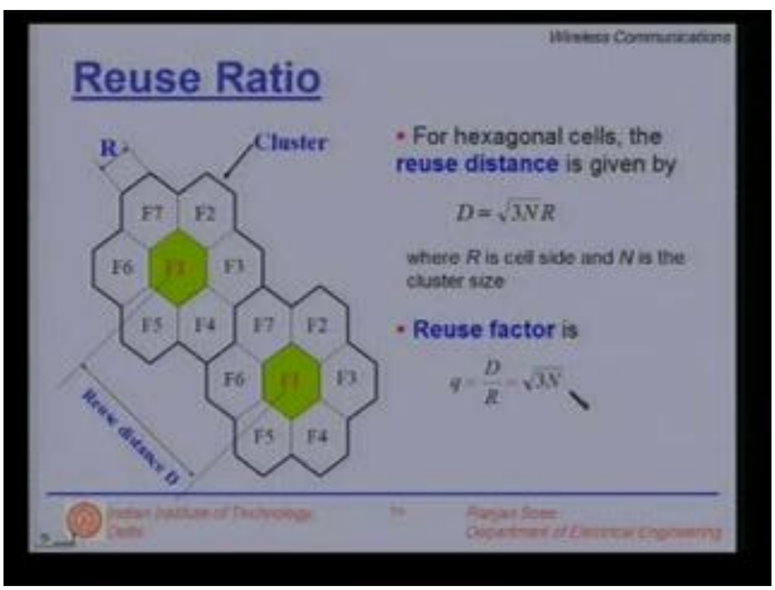

Here we summarize in the sense that I have drawn two clusters for N =7.You have F 1 to F7 in the first cluster. I am not using color coding here and similarly for the second segment. F 1 and F 1 are co-channel cellsseparated by something called is a reuse distance from the formula that we have done earlier and if you substitute in terms of NR and D, you get the reuse distance. This is D as under root 3 N times Rwhere R is the side of a cell also the cell radius.Clearly, the distance increases as you increase the cluster size. the reuse factor is defined as D over R. it’s a normalized distance with respect to the radius and it is nothing but under root 3 N. We will conclude at this point and will take cell capacity and reuse distances in the next class.