Wireless Communications

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Lecture No.# 06

Interference and System Capacity

In today'slecture, we will talk about interference and system capacity. We will see that interference is a prime concernand has to be taken into consideration while designing cellular communications systems. The outline of today's lecture is as follows.

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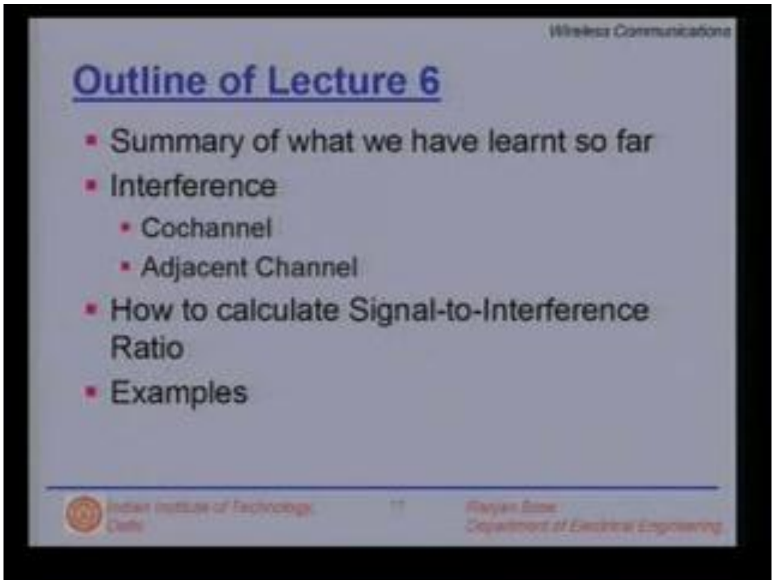

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Outline of Lecture 6

- Summary of what we have learnt so far
- Interference
  - Cochannel
  - Adjacent Channel
- How to calculate Signal-to-Interference Ratio
- Examples

We will first begin with summarizing what we have alreadylearnt.then we will talk about two important kinds of interference namely, the co-channel interference and the adjacent channel interference. We will then learn how to calculate the signal to interferenceratio which will have an impact on the number of users you can actually support.finally we will look at some examples.

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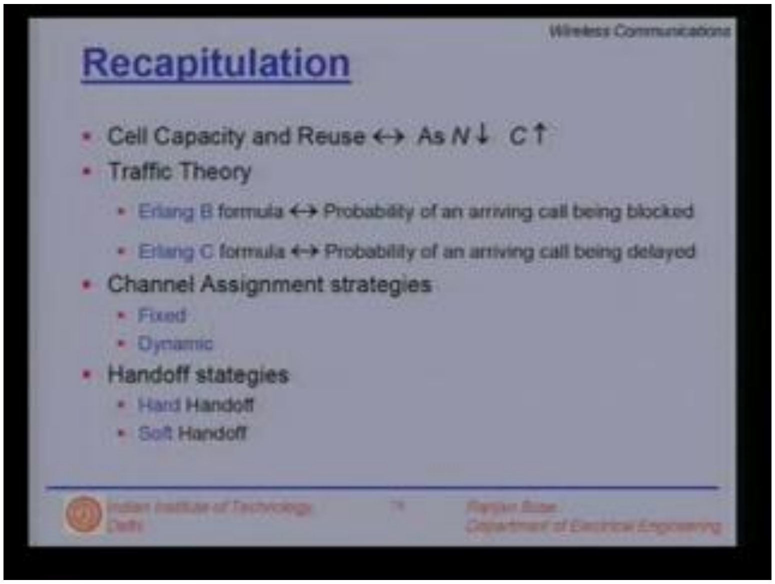

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Recapitulation

- Cell Capacity and Reuse ↔ As $N\downarrow$ $C\uparrow$
- Traffic Theory
  - Erlang B formula ↔ Probability of an arriving call being blocked
  - Erlang C formula ↔ Probability of an arriving call being delayed
- Channel Assignment strategies
  - Fixed
  - Dynamic
- Handoff stategies
  - Hard Handoff
  - Soft Handoff

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First let usrecapitulate.we learnt last time that the cell capacity and the reuse factor are interlinked.in fact if you look at the cluster size N, as N decreases the capacity of the system increases.last time we also learnt about traffic theory. We looked at the Erlang B formula which tells us how to calculate the probabilityof an arriving call being blocked. The Erlang C formula which tells us how to calculate theprobability of an arriving call being delayed beyond a certain time.we then looked at channel assignment strategies.there was a fixed channel assignment strategy and dynamic.finally we looked at handoff strategies which fell into the categories of hard handoff and soft handoff. Today we will focus on the other aspect which is interference, how to calculate it and what effect does interference has on the designing of cellular wireless communication systems.

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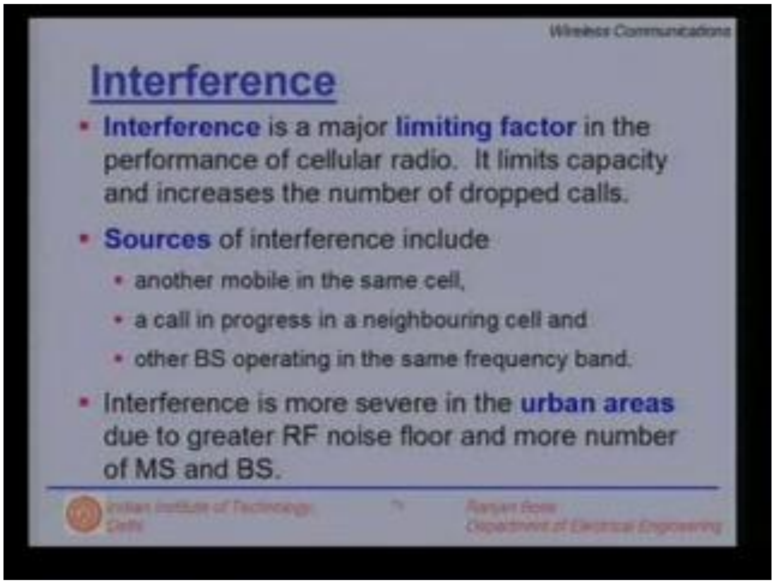

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Interference

- **Interference** is a major **limiting factor** in the performance of cellular radio. It limits capacity and increases the number of dropped calls.
- **Sources** of interference include
  - another mobile in the same cell,
  - a call in progress in a neighbouring cell and
  - other BS operating in the same frequency band.
- Interference is more severe in the **urban areas** due to greater RF noise floor and more number of MS and BS.

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Interference is a major limiting factor in the performance of cellular radio.it limits capacity and increases the number of dropped calls. we will see that interference has a direct correlation with the quality of service.these are the varioussources of interference.it could be another mobile in the same cell, it could be a call in progress in a neighboring cell and there could be other base stations operating in the same frequency band. All of these can cause interference.Interference is more severe in the urban areas due to greater RF- radio frequency noise floor and more number of mobile stations and base stations. However life is not all that bad.urban environment has anadvantage. the path loss exponent that is, how fast the signal strength decays as you move away from the transmitter is a bigger numberand the path loss exponent is usually close to 4 in urban areas which will lead to a decreased interference level.So they are both pros and cons for interference calculations within urban environments.

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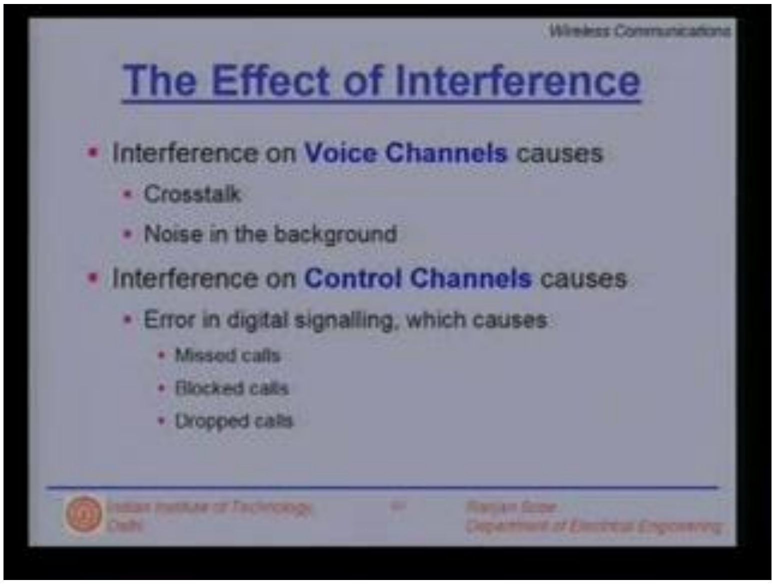

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The Effect of Interference

- Interference on **Voice Channels** causes
  - Crosstalk
  - Noise in the background
- Interference on **Control Channels** causes
  - Error in digital signalling, which causes
    - Missed calls
    - Blocked calls
    - Dropped calls

Let us now look at the effects of interference.what does it actually cause? Interference can occur both in voice channels and the control channels. It does not discriminate. Interference on voice channels can cause cross-talks and noise in the background.on the other hand, interference on control channels causes error in digital signaling which in turn causes either missed calls or blocked calls or even dropped calls. So you can see that interference will cause a decrease in the quality of service both either in the voice channels which are perceptibleas well as control channelswhich can lead to problematicissues like blocked calls. Clearly we have to do something about controlling interference.

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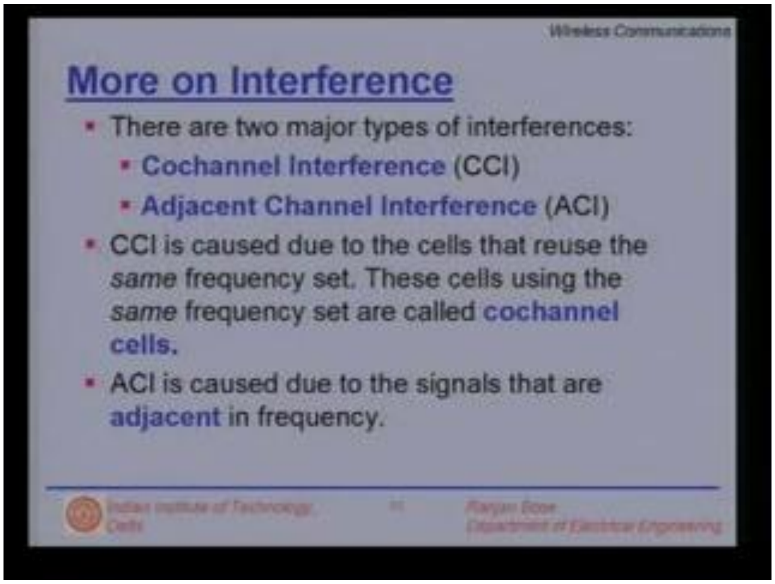

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More on Interference

- There are two major types of interferences:
  - **Cochannel Interference** (CCI)
  - **Adjacent Channel Interference** (ACI)
- CCI is caused due to the cells that reuse the *same* frequency set. These cells using the *same* frequency set are called **cochannel cells.**
- ACI is caused due to the signals that are **adjacent** in frequency.

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Now let us look at two major types of interferences.the first is the co-channel interference known as CCI and the second one isthe adjacent channel interference or ACI. Co-channel interference is causeddue to the cells that reuse the same frequency set.we have talked about thisearlier.these cells using the same frequency set are called co-channel cells. On the other hand adjacent channel interference is caused due to the signals that are adjacent in the frequency band.

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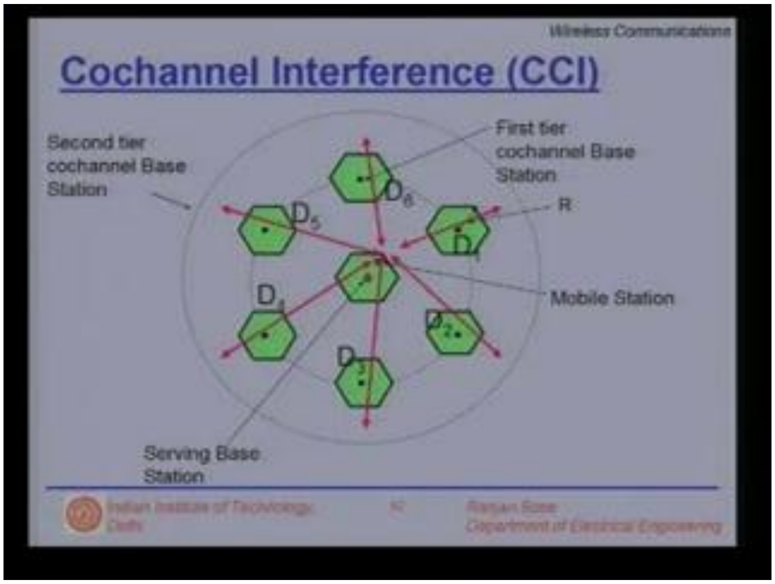

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Cochannel Interference (CCI)

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Let’s look at an example of how co-channel interference occurs.first let us look at a small cell with its own base station which is located at the center.for the sake of simplicity, we have taken a hexagonal cell.we all know that in real life cells are irregular in shape. Now since the frequency band is being reused, there would be several co-channel cells. Let’s put a mobile station first inside the cell.it is located at a certain position and is free to move around within the cell. The first co-channel cell is clearly located at a distance from the original cell. There is not just one co-channel cell but there should be several co-channel cells of radius R.

So let’s put 6 of them because of the hexagonal structure there will be 6co-channel cells in the first tier.clearly the location of the mobile will determine the exact distance of the mobile from the interfering base station. Here there are 6 distances from the 6 base stations radiating in the same frequency band. I have marked them as D 1 through D 6. They are all different. These can be said to be co-channel base stations within the first tier but please remember the hexagonal cellpattern is being repeated throughout the area of interest. So they will be second tier as well but clearly as the distance increases the interference levels wouldgo down. So the second tier would also contribute to some interference though less.

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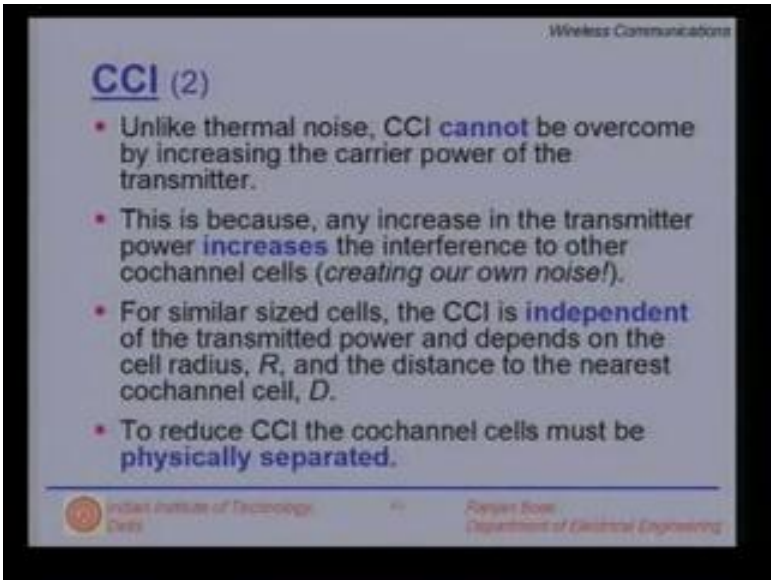

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CCI (2)

- Unlike thermal noise, CCI **cannot** be overcome by increasing the carrier power of the transmitter.
- This is because, any increase in the transmitter power **increases** the interference to other cochannel cells (*creating our own noise!*).
- For similar sized cells, the CCI is **independent** of the transmitted power and depends on the cell radius, *R*, and the distance to the nearest cochannel cell, *D*.
- To reduce CCI the cochannel cells must be **physically separated**.

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Unlike thermal noise, CCI cannot be overcome by increasing simply the carrier power of the transmitter.that is to say, if you are interestedin improving S to I, the signal to interference ratio, we cannot simply pump up the signal strengthand expect the signal to interference ratio to go up.this is because my signal is somebody else’s interference.i cannot do that. So we end up creatingour own noise by increasing the signal strength.so what is the solution we have only one way to decrease the signal to interference problemthat is, improve the S to I ratio that is by physically locating the cells far apart. So for similar sized cells, co-channel interference is independent of the transmitted power and depends on the cell radius R, the distance to the nearest co-channel cell D and in fact the ratioD to R. to reduce CCI, the co-channel cells must be physically separated.that is, we have to sacrifice a value of N and may be increase the value of N.

Please note that today you can use signal processing techniques to further reduce the interference effects.There's an emerging technology called multiple input multiple-output systems-MIMO which can also handle interference reduction issues. you can do coding to reduce interference as well that is you can use different kinds of codes in co-channel cells.similar to what CDMA does, the interference ofa co-channel cell may be rejected by your own cell. But if you do not want to carry out complicated signal processing techniques, you may as well increase the distance between co-channel cells.

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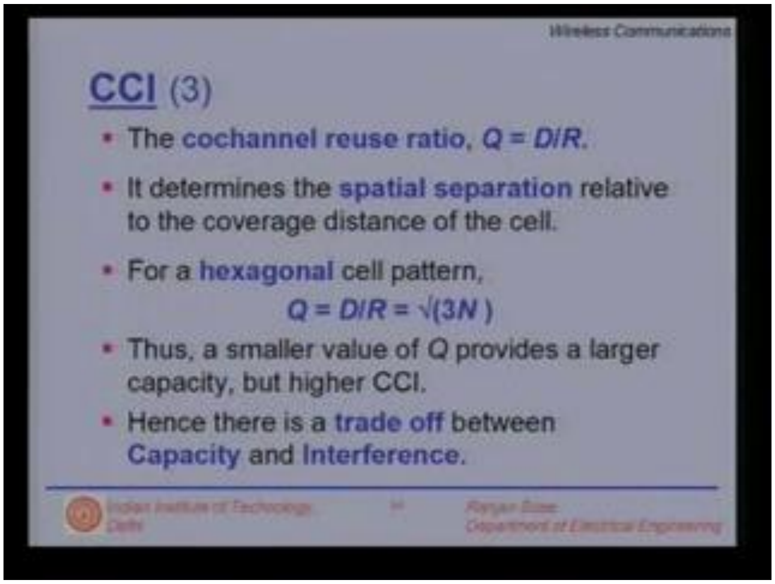

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CCI (3)

- The **cochannel reuse ratio**, $Q = D/R$.
- It determines the **spatial separation** relative to the coverage distance of the cell.
- For a **hexagonal** cell pattern,

$$Q = D/R = \sqrt{(3N)}$$

- Thus, a smaller value of Q provides a larger capacity, but higher CCI.
- Hence there is a **trade off** between **Capacity** and **Interference**.

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We know that the co-channel reuse ratio 'Q' is given by D over R where D represents the distance between co-channel base stations whereas R is the cell radius.so this is a normalized distance. Q determines the spatial separation relative to the coverage distance of the cell.for a hexagonal cell pattern we have seen that Qis nothing but under root 3 N. So it grows as the square root of the cluster size. Thus a smaller value of Q provides a larger capacity but a higher co-channel interference.the question is: what is the trade-off? How much do we gain it terms of capacity and lose in terms of co-channel interference? We will look at certain examples to clarify the issue.so we have to carefully understand and then design a system based on the tradeoff between capacity and interference.

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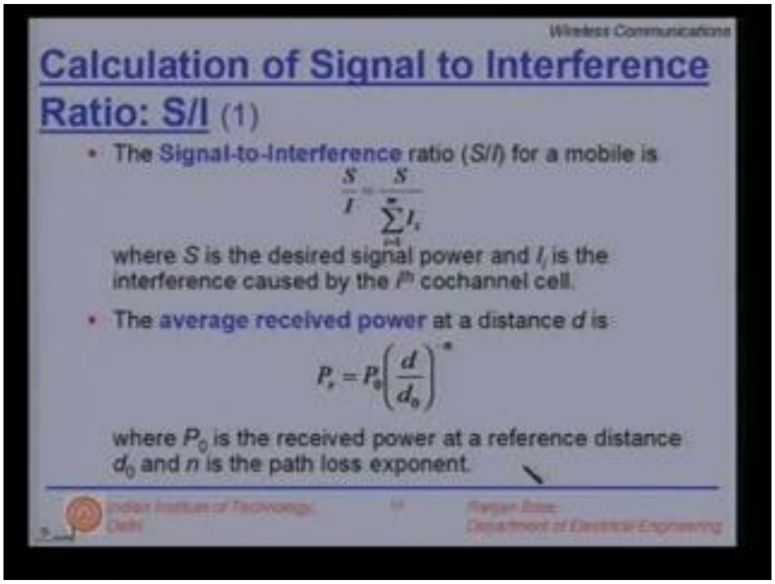

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Calculation of Signal to Interference Ratio: S/I (1)

- The **Signal-to-Interference** ratio (S/I) for a mobile is

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{m} I_i}$$

where S is the desired signal power and I_i is the interference caused by the i^{th} cochannel cell.

- The **average received power** at a distance d is

$$P_r = P_0\left(\frac{d}{d_0}\right)^{-n}$$

where P_0 is the received power at a reference distance d_0 and n is the path loss exponent.

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So the calculation of signal to interference ratio can be done as follows. The S to I ratio is given by the signal strength received at the mobile divided by all the power received from the interfering base stations. here on the numerator, I have put the signal strength received from the desired base station and in the denominator is the sum of various interferences from I =1 through m, where m could be the cells in the first tier, second tier or even beyond. This is a general formula. the average received power at a distance can be written as Pr the received power equal to the transmitted power P_0 at a distance d_0 and d is the received power at distance t. so this is a normalized power and n is the path loss exponent which can vary from afactor of 2 to 4 depending upon the scenario. Please note that there is an inverse law but it is not the inverse square law.it can be inverse cubedor inverse to the power four.

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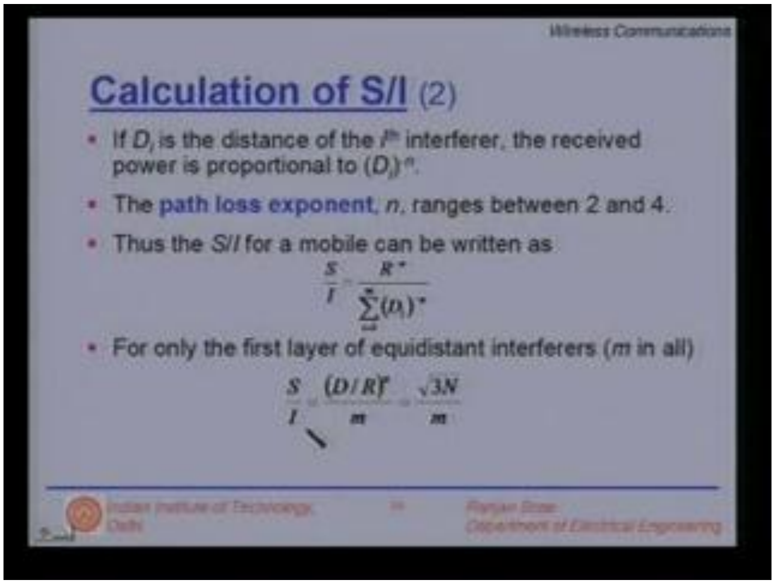

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Calculation of S/I (2)

- If D_i is the distance of the i^{th} interferer, the received power is proportional to $(D_i)^{-n}$.
- The **path loss exponent**, n, ranges between 2 and 4.
- Thus the S/I for a mobile can be written as

$$\frac{S}{I}=\frac{R^{-n}}{\sum_{i=1}^{m}(D_i)^{-n}}$$

- For only the first layer of equidistant interferers (m in all)

$$\frac{S}{I}=\frac{(D/R)^n}{m}=\frac{\sqrt{3N}}{m}$$

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Let us now look at the various calculations based on the distance.if DI is a distance of the Ith interferer and we know that all the interfering base stations may not be equidistant, then the received power is proportional to DI raised to the powerminus N. N is the path loss exponent which can range from 2 to 4. we can measure the value of N by carrying out the receivedpower measurements with respect to distance.thus the signal to interference ratiofor a mobile can be written as S over I equals R raised to power minus N. this is proportional to the received strength from the desired base station. R represents the cell radius.soyouare actually putting your mobile station at the edge of the cell.in the denominator,i have a summation for I = 1 through m DI where DI represent the distance from the I^{th} interferer again raised to the power minus m, the pathloss exponent. only for the first layer of equidistantinterferer,we can put this equation as Dover R raised to power ndivided by m. Just carry out the summationand assuming equidistant,so D 1 = D 2 = D 3 and so and so forth till D m. So you get an answer as under root 3N divided by m. This equation clearly gives a relationship between the signal to interference ratio and how it is related to N which determines the capacity. So as N increases, the capacity decreases but the signal to interference improves. So I can trade off the signal to interference which determinesthe quality of service verses the capacity of the overall system.

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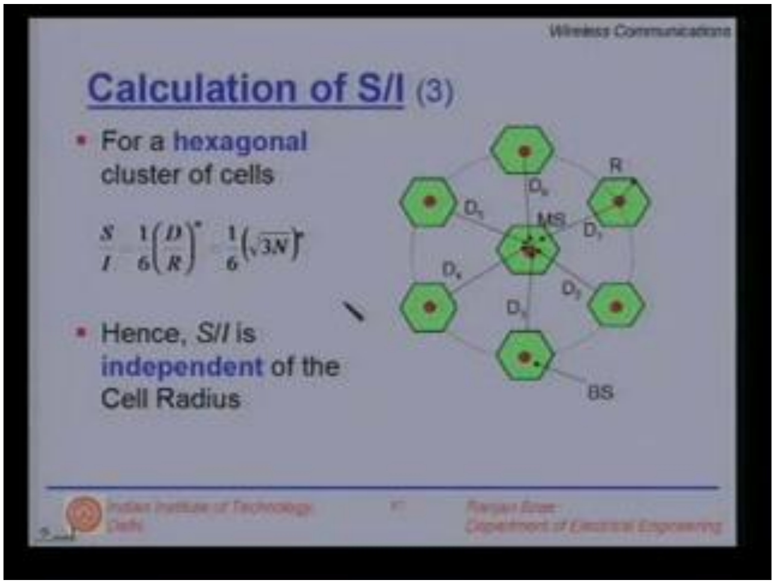

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Calculation of S/I (3)

- For a **hexagonal** cluster of cells

$$\frac{S}{I} = \frac{1}{6}\left(\frac{D}{R}\right)^n = \frac{1}{6}\left(\sqrt{3N}\right)^n$$

- Hence, *S/I* is **independent** of the Cell Radius

For a hexagonal cluster of cells, let’s look at one of the desired cellwith a base station marked asa red dot.we put the mobile station, this time close to the center of the cell. Then we put one of the interfering base station in the first tier, the second one, the third one and so and so forth till the 6th. Please note irrespective of the reuse factor and the cell cluster in the first tier, you have 6 interfering base stations.that is because of the hexagonal geometry. Here we have distances D 1 through D 6 to the mobile station. the cell radius is given by R. since we have assumed that approximately all the 6 interfering base stations areequidistantbecause of the shear position of the mobile cell station closer to the center of the cell, I can put D 1= D 2upto D 6 and so I equate it and I get 6 interfering stations contributing to 1 by 6(D over R raised to power N) which is nothing but 1 over 6 under root 3N whole raised to the power n.

Please note the signal to interference is clearly independent of the cell radius.as long asall the cells are equally large, my Rdoes not figure in.what figures in is ‘N’, the cluster size.

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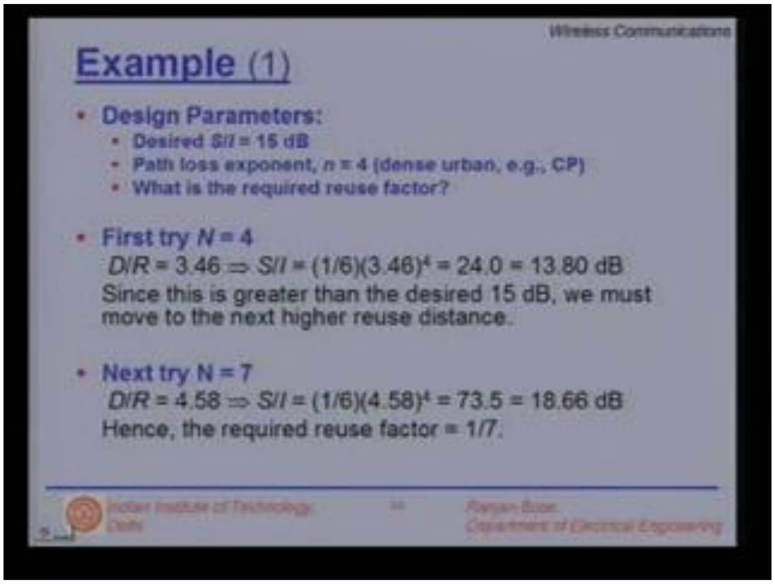

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Example (1)

- **Design Parameters:**
  - Desired S/I = 15 dB
  - Path loss exponent, n = 4 (dense urban, e.g., CP)
  - What is the required reuse factor?
- **First try $N = 4$**
  $D/R = 3.46 \Rightarrow S/I = (1/6)(3.46)^4 = 24.0 = 13.80$ dB
  Since this is greater than the desired 15 dB, we must move to the next higher reuse distance.
- **Next try N = 7**
  $D/R = 4.58 \Rightarrow S/I = (1/6)(4.58)^4 = 73.5 = 18.66$ dB
  Hence, the required reuse factor = 1/7.

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Let us now look at an example from designing a system. What are our design parameters?let's say the desiredsignalto inference is 15dB. Based on some trials and tests, suppose the service providers say a signal to interference ratioof 15 dB isadequate. However, the service has been provided in a dense urbanenvironment.here if you carry out measurements you will find that N is close to 4. So let us put N = 4 for our calculations.what we would like to know is based on these parameters, what is the required reuse factor? We are trying to link the signal to interference ratio requirements to the effect on the reuse factor,'M'. So let us try N =4.

Remember I cannot try any arbit value. N is given by I squared plus I j plus j squared where I and J are non-negative integers. So we know that for N = 4, the D to R ratio is given by 3.46. so by the simple formula of 1 by 6 under root 3N raised to power n, we have 1 by 6 times 3.46 raised to power of 4 which gives us 24 and in dB, it translate to 13.8dB.so if you are using a reuse cluster size of N =4, you end up having a signal to interference ratio of 13dB.this is less than 15dB.my interference values are much higher than mysystem can handle. So we must move to the next higher reuse ratio.so the next higher is not 5 or 6. The next higher N =7is the next feasible ratio. so we try N = 7.so these are the steps the system designer is doing while figuring out how to pick a correct value of N. for N =7, the D to R ratio is 4.58 which leads us to a S to I ratio of 73.5 when expressed indB is nothing but 18.66dB.our desired signal to interference ratio is 15 dB. So I am in business. I am actually doing much better.it's more than 3dB improvement in the required level. So I would use a reuse factor of 1 by 7.my clustersize is7.so in an area like Cannought with dense urban buildings I have a reuse factor N =7.

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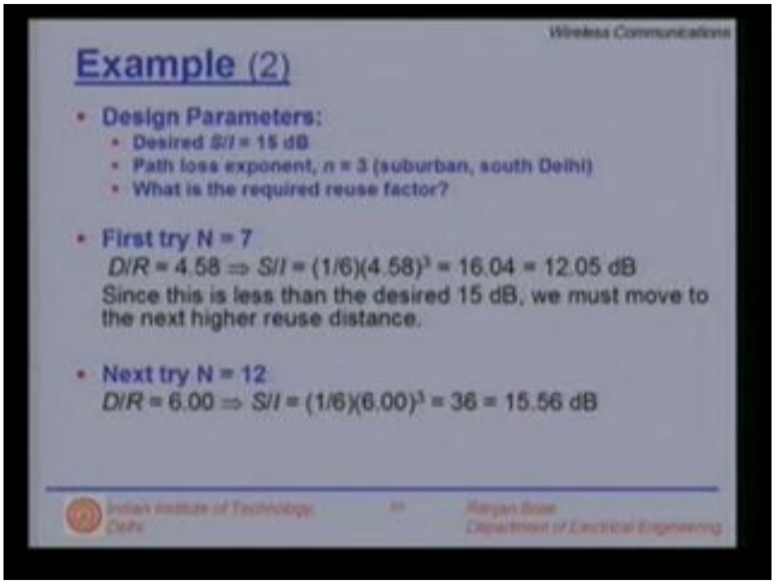

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Example (2)

- **Design Parameters:**
  - Desired $S/I = 15$ dB
  - Path loss exponent, $n = 3$ (suburban, south Delhi)
  - What is the required reuse factor?
- **First try N = 7**
  $D/R = 4.58 \Rightarrow S/I = (1/6)(4.58)^3 = 16.04 = 12.05$ dB
  Since this is less than the desired 15 dB, we must move to the next higher reuse distance.
- **Next try N = 12**
  $D/R = 6.00 \Rightarrow S/I = (1/6)(6.00)^3 = 36 = 15.56$ dB

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Let us now change the example a little bit and look at a slightly different scenario.i would like to look at the south Delhiregionwhich is more suburban.it's not a concrete jungle.there are buildings. There is foliage but not a very high density of concrete structures.again my desired signal to interference ratio is 15 dBbut the path loss exponent has gone down to N =3. The question again is: what is the required reuse factor? So my last example N =7 worked.let's see what happens if we put N =7. The D toR is the same 4.58.using the formula calculated before, S to I comes out to be16.04 which expressed in decibelsis nothing but 12 dBbelow the 15dB requirement.

So merely by changing the path loss exponent, I have been required to increase the value of N. so we must go to the next high reuse distancewhich is 12. So next try N = 12. for N =12, the D to R ratio is given by 6 and similar to interference, it comes out to be 36.when expressed in decibel,it's 15.56 just above what is required but we are still inbusinessbecause 15 dB is what is required. So in suburban Delhi, I have to use a reuse factor of 12.life is not all that bad because here probably, my capacityrequirements are less asopposed to the dense urban area where I have to support a larger number of people. So it is falling in trend.In higher concrete jungle density, we can handle more number of users. What will happen if we go down to N=2 which is truly our inverse square law -the free space propagation path loss exponent.so we look at another exampleto see what will happen if N =2.

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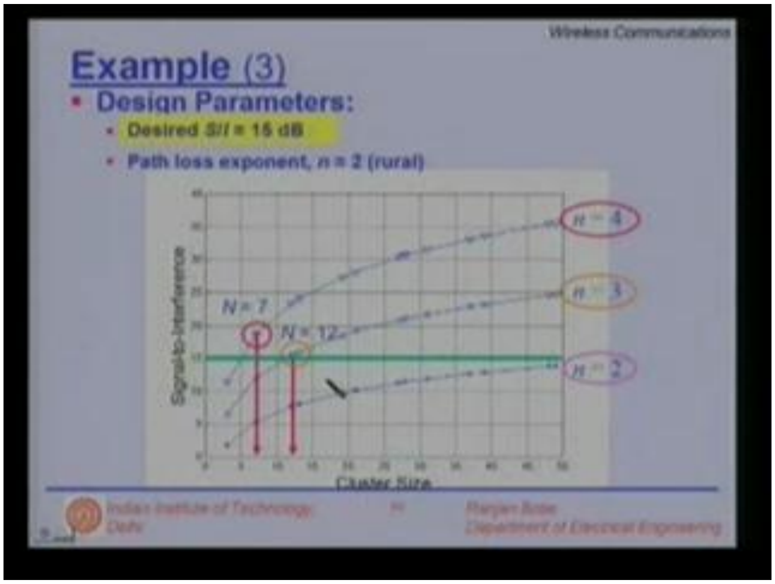

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Example (3)

- Design Parameters:
  - Desired S/I = 15 dB
  - Path loss exponent, n = 2 (rural)

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So in our design parameters this time, R is similar to interference. It’s15 dB again but it’s a rural environment where we can hope to have close to 2.first let us put in perspective what we have already acquired in terms of N =4 and N =3.i have a graph here. On the x axis is the cluster size and on the y axis is the signal to interference ratio dB. We are already familiar with the top most curve which has been plotted for path loss exponent N =4. Please note that the points that have been marked are at discrete values 3, 7, 12, 13 and so and so forth. What we have already seen is that for a 15 dB signal to interference ratio as desired, ifwe use N =4, the cluster size ‘N’=3 is not suitable.in fact what is above this 15 dB is cluster size N =7. The cluster sizeN =7 isrecommendedfor path loss exponent 4.

We also saw for the next level N =3.the path loss exponent N =3 forces us to go at a higher cluster size of 12. so we saw in the last example that N =12 is suitable very clearly from this.if we move this green line up or down, we can simply find out what is thesize of a cluster that you are required to use. So the next question is: what do we do for n =2? The rural areas here if we have to have the desired signal to interference ratio equal to 15, we search but we find that even if we go to a very high cluster size, we still do not reach 15. we have to do something else we have to use some kind of signal processing technique to do it because if we go to cluster size beyond 12, you are really not using the power of reuse factor.cluster size normally are not typically larger than 12 because we have to have enough number of customers in our the service area.

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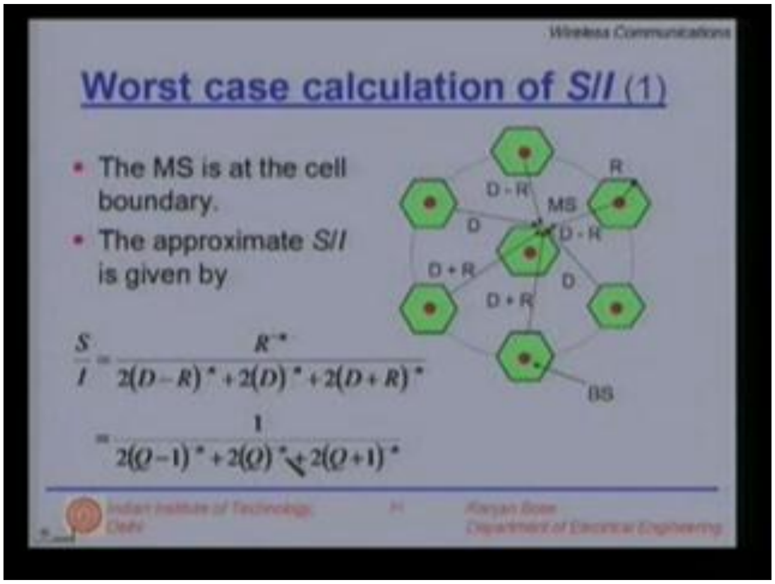

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Worst case calculation of *S/I* (1)

- The MS is at the cell boundary.
- The approximate *S/I* is given by

$$\frac{S}{I} = \frac{R^{-n}}{2(D-R)^{-n} + 2(D)^{-n} + 2(D+R)^{-n}}$$

$$= \frac{1}{2(Q-1)^{-n} + 2(Q)^{-n} + 2(Q+1)^{-n}}$$

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In the next slide we would like to talk about the worst case calculation of signal to interference.when does the worst case interference occur? The worst case interference will occur when the mobile station is at the cell boundary.why is it bad? Well I’m farthest from my own base station and may be much closer to an interfering base station. This will lead to a poorersignal to interference ratio. Diagrammatically, let’s put a desired base station here as a red dot. but this time I would like to place the mobile station at the very edge. So from the cluster of 6co-channel cells in the first tier, 2 co-channel cells are clearly closest to the mobile station.the two interfering base stationsare really much closer to the mobile station for example, as compare to two others which would be at a farther distance.

So all four so far areco-channel cells but the first two cells are much closer to the mobile station than these two (Refer Slide Time: 28:20). so approximately I can say that from the first two co-channel cells, the distance from the mobile to the interfering base station is roughly D – Rwhere D is a distance between the base stations and R is the cell radius.on the other hand, the next two interfering base stations are at a distance approximately D from the mobile station. But that’s not the end of the story.we have two more co-channel cells.but by the mere position of the mobile station, these two interfering base stations are almost at a distance D + R (Refer Slide Time: 28:00). So in the 6co-channel cells, the base stations there are differently placed with respect to the mobile stations.the distances are differentso the interference must be different.

The approximate signal to interference ratio in this worst caseanalysisis given by S to I is, in the numerator we have R raised to power minus n, again ‘minus n’ represents the path loss exponent. R is thedistance of the mobile station from itsown base station. so the numerator is proportional to the signal strength received by the mobile station.in the denominator, we have 3 factors.the first factor is 2 times D - R raised to power minus N. this correspondence to two base stationswhose distances are D - R with respect to the mobile station. There are 2 of them. So I have put a factor of 2 here. Then there are 2 other co-channel cells whose base stations are located approximately D distance apart. so 2D raised to power minus n and similarly for the farthestapart base stations which are at a distance D + R. now if we represent the factor D over R as Q, so take the R down into the denominatorand you can write itas 1/2 Q -1 raised to power -n +2times Q raised to power - n +2timesQ +1 raised to power-n. Please note that Q typically is not a very large number with respect to 1.so we cannot neglect the one with respect to Q. You will not have theminus one and plus one. If you are doing the average case analysis where in, the mobile station is located somewhere within the cell, not necessarily at the boundary. In that case, you will have 1/6 Q raised to the power minus n. sothere are two cases: the worst case and the average case.

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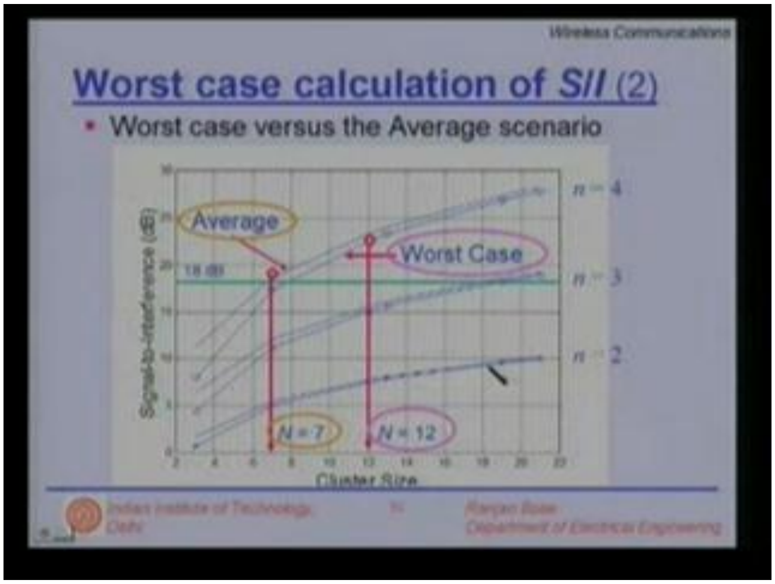

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Worst case calculation of *S/I* (2)

- Worst case versus the Average scenario

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The worst case verses average case scenariocan be seen in the current slide.here in this graph, on the x axis I have plotted the cluster size on the y axis I have the signal to interference ratio in dB. the top most curve corresponds to a path loss exponent of N =4. The next one is N =3 and then the next one N =2. What we want tosee from this curve is how much doesthe worst case analysis differ with respect to the average interference calculations. so the average is given by this continuous curve without the triangles whereas the lower curve within N =4 is the worst case analysis.as expected the curve for the worst case must be below the average case scenariobecause on the y axis you have signal to interference ratio.the worst case interference is larger.so signal to interference ratio is lower. The question is: how much? So if you can see for the case of n =4, the difference is large for small cluster size.remember small cluster size is what is actually used. Anything below 12 is of importance. Cluster size larger than 12 is usually of academic interest. So wherever our interestlies, yes there is a differencebetween the average case and the worst case for N =4. Interestingly, when you have N = 3, the difference reduces and the trend continuous.when we look at the free path loss exponent, N =2, the free space propagation, the difference is barely enough that is, there is hardly any difference between the worst case and the average case scenario.in reality, N =4 would be used for a city like Delhi. So let us now look at another design problem.here we have to design, a system for signal to interference ratio =18dB.we have made our requirements more stringent. about 3 dB more stringentthan the 15 dB requirement in the previous example.

So the objective is as follows.we would like to know the cluster size for signal to interference ratio =18dB.we have of course the average case analysis and the worst case analysis. now for the average case analysis, the closest cluster size which goes above the 18 dB mark is N =7. Clearly 18 dB requirement can be met in the average casescenario if the cluster size N =7.please note that N =7 is not sufficient.in the worst case scenario, it has dropped below this one. so for the average case even though N =7 suffices, for the worst case I must go the next higher level which is nothing but N =12. So for the worst case I am bound to take N =12.now what will the service provider do? Either he has to think about all his customers who are at the edge of the cell or the worst case analysis really applies to them. so either he is nice and considers all those customers who are sitting on the fringe, then for them and themalone, he designs the cluster size equal to N =12 or if he forgets about those people sitting on the cluster edge and just takes the average case scenario and puts N =7, what will he do? Well, if he has to make money, the ratio 7 : 12 is too much to lose out. If he can support more than one and a half times a number of customers if he goes from N =12 to N =7. So he will forgot about those sitting on the edge of the cell and really do the calculation for the average case scenario. Please note that yes, these exact calculation of the average case and the worst case forces you to change the entre design. The effect will not be so prominent if I am working at n =3 and hardly makes a difference when n =2. so a service provider in Delhi must take this worst case situation into analysis intoconsideration in Delhi but not so much in smaller towns like Jaipur and Lucknow and definitely not in the outskirts where n =2 is required.

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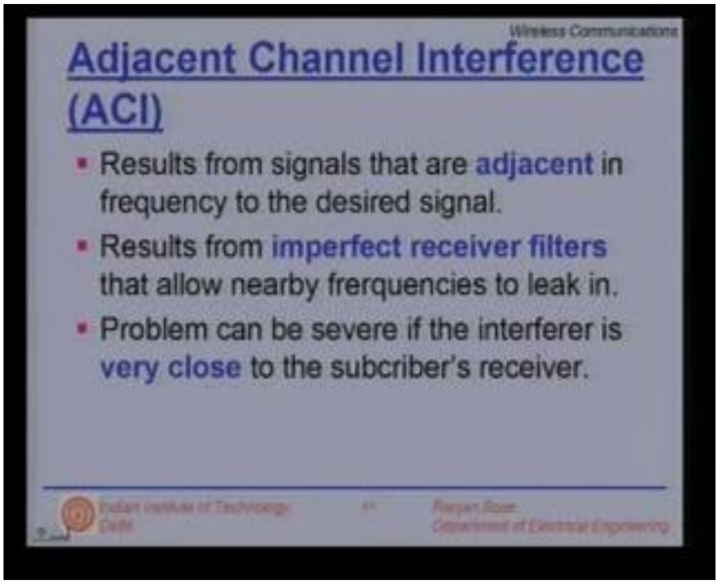

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Adjacent Channel Interference (ACI)

- Results from signals that are **adjacent** in frequency to the desired signal.
- Results from **imperfect receiver filters** that allow nearby frerquencies to leak in.
- Problem can be severe if the interferer is **very close** to the subcriber's receiver.

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Now we will look at the next type of interference which is the adjacent channel interference.this results from signals that are adjacent in the frequency to the desired signal. this results from imperfectreceiver filters that allow nearby frequencies to leak in. please remember your handset prices go down because the hardware put in there is cheaper and the filters that we put in there also do not have two stringentrequirements.that is, the sharp cut off donot exist.

Clearly if youhave cheap filters, you will let in more adjacent channel interference.but we really cannot do much with the cost of the handsets.they must keep going down. So what is typically done is to use expensive, very well designed filters at the base station.in fact, the cost of the base station is being shared byso many numbers of users. So adjacent channel interference is actually handled more at the base stations but also at the handsets level.the problem can be severe if the interferer is very close to the subscriber's receiver. So if my friend and I are going in the same car and by whatever coincidence we both are assigned adjacent channels, then we will have crosstalk or if the interference is in a channel which is used for control, then one of the calls might get dropped or some other problems might occur.

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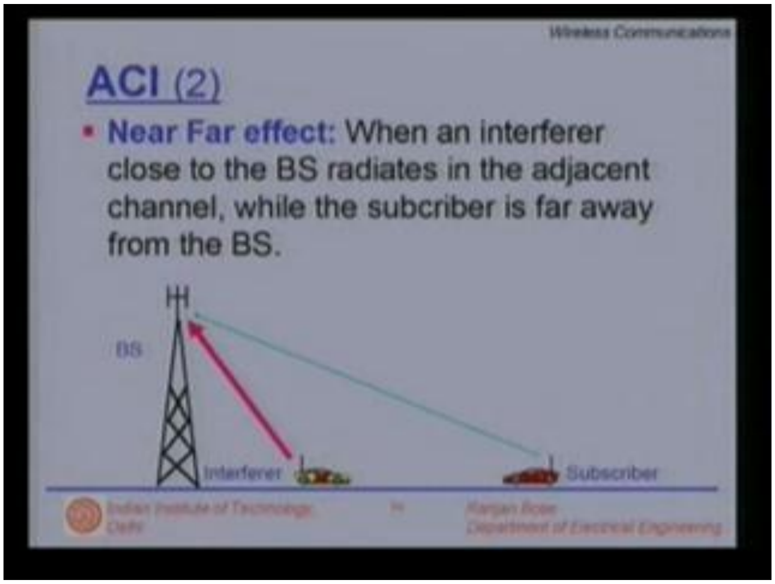

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ACI (2)

- **Near Far effect:** When an interferer close to the BS radiates in the adjacent channel, while the subcriber is far away from the BS.

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Another effect of adjacent channel interference is called the near far effect.what is the near far effect?when an interferer close to the base station radiatesin the adjacent channel while the subscriber is actually far away from the base station. Please remember the path loss exponent is close to four.the signal strength goes down very fastto the power of four of the distance. So if my interfering handset is close to the base station, whereasi am, as a subscriber far away from the base station, my signal will get a lot of interference at the base station. Let us look at it from an example.let us first put a base station and the subscriber.sothe subscriber is mobile and he is located at a certain distance from the base station. But there are lot of uses and let us have an interfering handset sitting inside a car which happens to be closer to the base station. As bad luck would have it, the interferer is radiating in an adjacent frequency band. So even though the subscriber is trying to communicate with the base station, by the time the signal reaches the base station, it is fairly weak. The path loss exponent is prettyhigh.so what is being received at the base station is a low signal level but still it can be handled. It is within the threshold. on the other hand, for the interferer which happens to be located much closer to the base station, it is radiating in the adjacent band and because of the imperfect filters, a lot of energy is leaking in. butit's a lot high energy.in fact in the next slide we'll see what could be the relative strength of the interfering signals with respect to the desired signal.

So what should the base station do? It should invest in making much sharper band pass filters.that's wherewe have to work.

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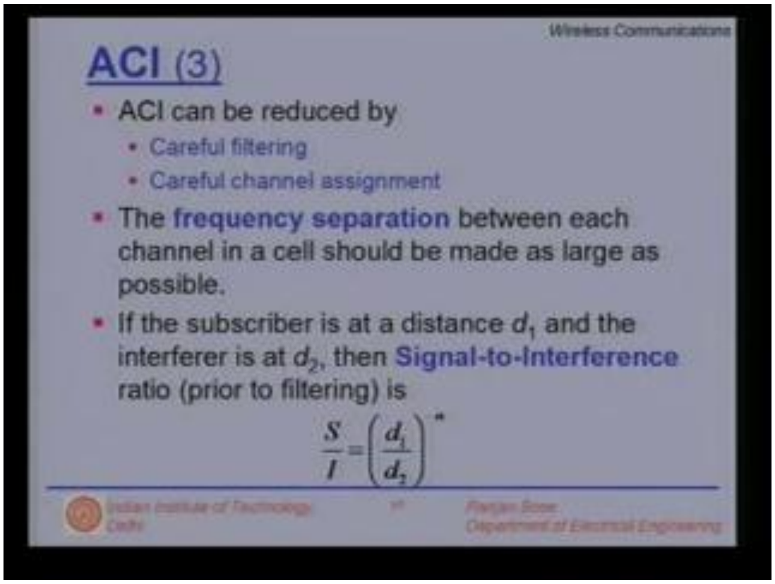

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ACI (3)

- ACI can be reduced by
  - Careful filtering
  - Careful channel assignment
- The **frequency separation** between each channel in a cell should be made as large as possible.
- If the subscriber is at a distance d_1 and the interferer is at d_2, then **Signal-to-Interference** ratio (prior to filtering) is

$$\frac{S}{I}=\left(\frac{d_1}{d_2}\right)^{-n}$$

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So the adjacent channel interference can be reduced by careful filtering which means more expensive filters and then of course, attacking the problem at the root which is careful channel assignment. The frequency separation between each channel in a cell should be made as large as possible. if a subscriber is at a distance d 1 and the interferer is at a distance d 2,then the interference value will be determined by d 1 and d 2 and the signal to interference ratioprior to filtering is given by S to I is equal d 1 over d 2 raised to power minus n. With the samephilosophy, the path loss exponent works inverselywith respect to the distance.

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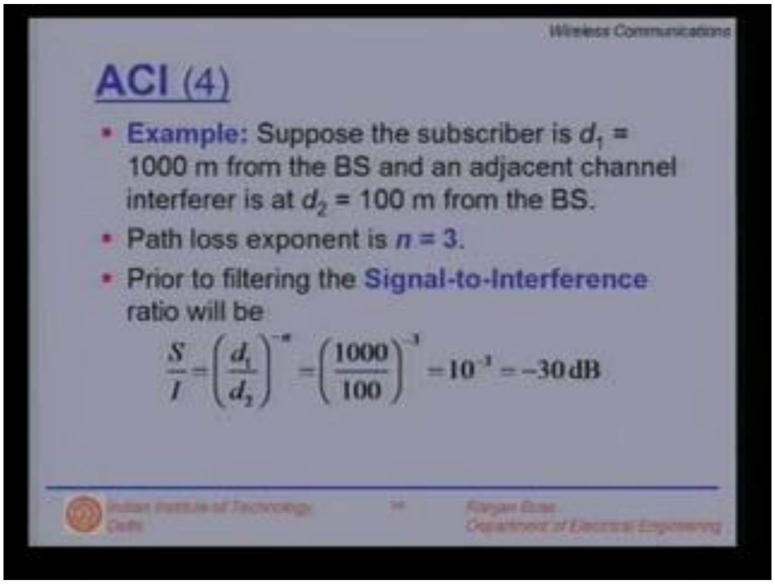

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ACI (4)

- **Example:** Suppose the subscriber is d_1 = 1000 m from the BS and an adjacent channel interferer is at d_2 = 100 m from the BS.
- Path loss exponent is $n = 3$.
- Prior to filtering the **Signal-to-Interference** ratio will be

$$\frac{S}{I}=\left(\frac{d_1}{d_2}\right)^{-n}=\left(\frac{1000}{100}\right)^{-3}=10^{-3}=-30\,\mathrm{dB}$$

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Let’s look at an example how good or bad the adjacent channel interference can be.suppose the subscriber which is radiating and we are talking about the desired signal, the subscriber is at a distance of 1000 m from the base station, typical base stations can have a radius of 5 km. Now today because of higher capacity requirements, the cell sizes are much smaller. suppose the subscribe is located at a distance of a kilometer from the base station whereas, another mobile which is using anadjacent channel is unfortunately at a distance of only 100 m from the base station. Let us say that they are in South Delhiwhere the path loss exponent is close to 3. Prior to filtering, the signal to interference ratio can be calculated as S over I is equal to d 1 over to d 2 raised to powerminus n. This is nothing but 10 to the powerminus 3.in terms of dB, it is minus 30dB. So my desired signal is actually drowned out.thenear-far effect.somethinghas to be done about it. In fact, what should be the sharpness ofthe filter? How fast should the filter roll off factor be? It should bedeterminedbased on what is the signal to interference ratio. Based on the roll off factor of the filter, we can find out what is the minimum channel separation in terms of frequency bands requiredso that the signal to interference level is at a certain desired level.

Conversation between student and professor: the question being asked is: is the signal to interference at alldependent on the power of transmission? Is the transmitted power coming into the picture? So the answer is no. the transmitter power is the same for both the desired and the interfering mobile station. So even for adjacent channel interference, assuming both the handsets are identical, theirpeak and average transmitpowers are the same. The received strength depends only on the distance between the transmitter.in general, neither co-channel interference nor adjacent channel interference can be reduced by playing with the transmitted power. So let us comeback to this example where wehave found out that this signal to interference ratio is actually minus 30dB.i can barely extractout mysignal unless I have a good filter.

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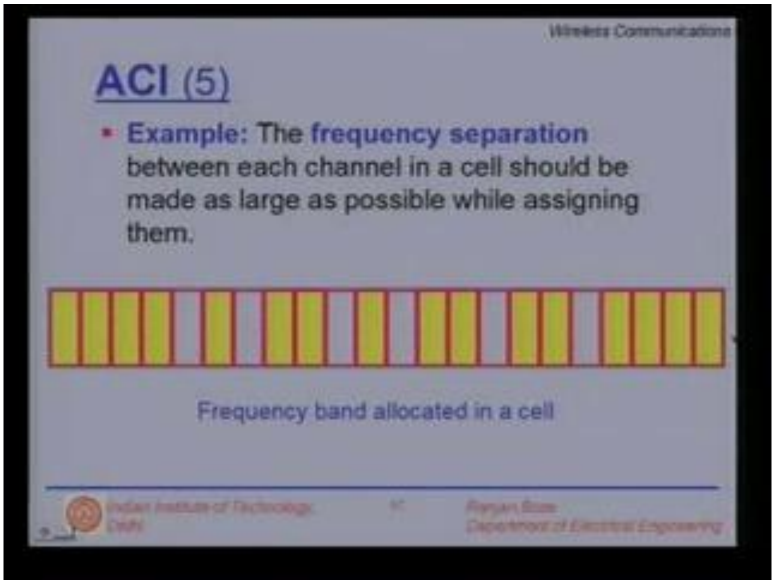

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ACI (5)

- **Example:** The **frequency separation** between each channel in a cell should be made as large as possible while assigning them.

Frequency band allocated in a cell

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The other method to reduce the adjacent channel interference is by smart frequency separation.that is, you have a frequency band which has sub-bands to be allocated to different users calledchannels. Now clearly as and when thedemand arises, you have to assign the frequency bands.but you should not start with the first band and then the next band and then the next band. In fact you should have maximum separation.there could be several algorithms. Let's take an example.suppose these are a set of frequency sub bandsallocated to a single cell and my jobis to allocate these frequency bands. But the objective is to ensure that the frequency separation between each channel is maximized. Now it is early in the morning and the first userrequests for a channel. So I as a person who is trying to assign different channel gives say, the first channel.it could be anyone of the channel and I have picked up the first channel. Clearly whensecond request comes, I should not give the second band here neither the third band.in fact, I should give the most farthest apart. So I'll give the second user the second band which is the farthest apart.

Clearly the demand is increasing and so a third user requests for a channel and I give a channel which is almost equally spaced.i could have given this channel as well but for the sake of an example, I have assigned this channel. Then the next user requests a channel.i have to put it which is maximallyapart and so andso forth. So you get the picture as to how the channel assignments have to be done in order to maximize the frequency separation. The next user requests and clearly you see the pattern.iam trying to fill the gaps in such a manner that the frequency separation is maintained. Now at this stage, I have been able to assign 9 channels and I stop at this location because the 10th user, when requests, a channel has to be put adjacent to some other channel.i have run out of gaps. Please note initially there were 22 slotsto fill but I have run out of slots by the time I have reached 9 users. I have not done a good job. In fact, had I put alternate frequency separation bands, I could have handled 11channels and still had the same level of adjacent channel interference. Please remember, even though these channels are separated, they still will be adjacent channel interference.it depends on how sharp yourfilteris.

Please remember your adjacent channel strength could be 30 dB higher.1000 times higher than your desired signal.

So even though your frequency band pass filter is trying to cut offthe filters, fair amount of power can actually leak in. These Red Guard bands do exist but they barely solve much of the problem. Then the 10th user requests.i put in the 10th user here as thefirst guywho gets actually channel adjacent to one of the existent channel buti had no choice. I cannot deny the service and then the next request comes. I fill it more and so and so forth. So as a request comes in, I keep on assigning channels and I am filling it up. So the moment I fill up, all these people are having a hard time. Here I have not differentiated between a voice channel and a control channel. The adjacent channel interference as well as the co-channel interference can cause not only crosstalk or background noise in voice channels.it can cause a call to drop or a call to be blocked. so I am filling up more and more.i have two more slots available and finally the last slot and I cannot give service to any more people and the service that I am giving may not be of the best quality also. if another person requests, I can either borrow a voicechannel as we have seenearlier or we can say,“sorry, all lines are busy.please call after some time.” so at this point, let us conclude today’s talk by summarizing what we have learned today.

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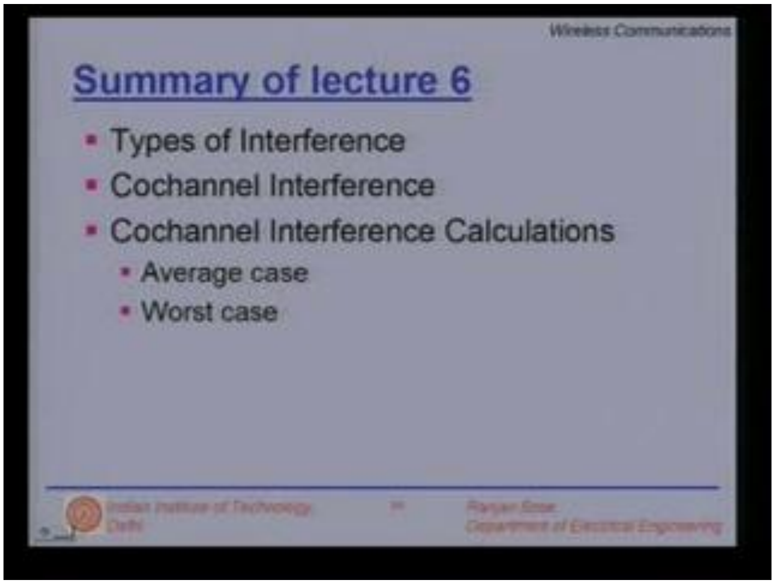

Summary of lecture 6

- Types of Interference
- Cochannel Interference
- Cochannel Interference Calculations
    - Average case
    - Worst case

We have looked at the different kinds of interferences namely the co-channel and the adjacent channel interference. we looked at the co-channel interference in greaterdetail because it is ofbig concern.we looked at how to calculate the co-channel interference values.Specifically, the average case as well as the worst case analysis.we learnt that these two cases have a direct relationship with the path loss exponent being used. Then we lookedat the adjacent channel interference. Let us conclude our talk and next time, we will talk about power control to reduce interference. Thank you!