## Lecture 5: Frequency Reuse Concepts

Interference from First-Tier and Second-Tier Co-Channel Cells

Theoretically, all cells with the same frequency group as a particular cell cause interference to the communication in that particular cell. However, due to the much further distance of the second and higher tiers of interfering cells, usually computations of interference of co-channels cells are computed for the first tier (the 6 cells with the same frequency that surround a particular cell). In this course, we will conceder interference due to first-tier co-channel cells only.

Consider for example, the cluster size $N = 7$ shown below. The central cell colored **RED** has the same frequency as the 6 first-tier co-channel cells colored **GREEN** and the 12 second-tier co-channel cells colored **BLUE**.
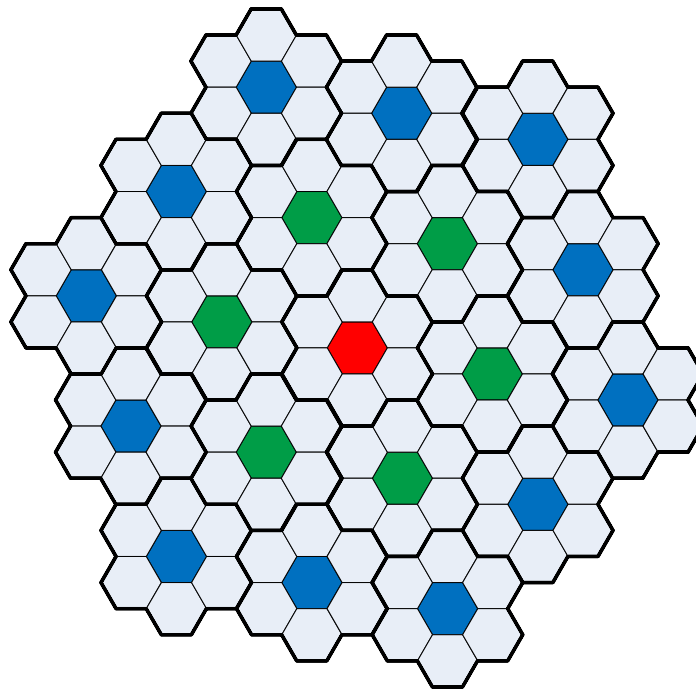
We see that there are 6 first-tier co-channel cells that are all at equal distance from the central red cell. Assume that the distance between any of the centers of the first-tier co-channel cells and the central cell is D. The second-tier co-channel cells are not all at equal distance from the central red cell. Of these, there are 6 that are located at distance $2D$ from the central cell and 6 other cells that are at distance $1.73D$ in this example. This will give an interference ratio of second-tier to first-tier co-channel cells that is equal to

$$\frac{\text{Interference of Second-Tier Co-Channel cells}}{\text{Interference of First-Tier Co-Channel cells}} = \frac{6\dfrac{1}{(2D)^n} + 6\dfrac{1}{(1.73D)^n}}{6\dfrac{1}{D^n}}$$

$$= \frac{1}{2^n} + \frac{1}{1.73^n}$$

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For values of $n = 2$, this ratio is equal to   0.584124

For values of $n = 2.5$,   this ratio is equal to   0.430807

For values of $n = 3$,   this ratio is equal to   0.318135

For values of $n = 3.5$,   this ratio is equal to   0.235226

For values of $n = 4$,   this ratio is equal to   0.174139

So, for practical values of n between 3 and 4, the ratio of the interference of second to first-tier co-channel is less than 1/3. Therefore, we will ignore it in this course.

Notes on Co-Channel Signal to Interference Ratio

We note the following important points about the co-channel signal to interference ratio (you may try the following conditions in the MS Excel sheet provided on WebCT and see the effect):

1. The radius of the cell has no effect on the SIR because as the radius of the cell increases, the distance of the cell increases, for example, the location of the corners of the cell move away by the same ratio that the co-channel cells move away.
2. The path loss exponent n has a profound effect on the SIR. The higher the value of n, the higher the SIR and vice versa. So, the fact that in urban regions the value of n is greater than the free space n of 2 is unexpectedly beneficial.
3. To get an acceptable value of the SIR around 18 dB or so, we need a cluster size of at least 7 and path loss exponent of around 4.
4. The distances between one of the corners of the central cell and the interfering co-channel towers become simpler to compute when i is equal to zero because of symmetry where each two cells will have the same distance to the corner at which the mobile phone is located.

Adjacent Channel Interference (ACI)

Unfortunately, co-channel interference is not the only type of interference that mobile systems suffer from. Another type of interference is called adjacent channel interference. This type of interference occurs not because of mobile phones or cellular towers in different co-channel cells transmitting signals at the same frequency, but it occurs because of mobile phones in the same cell transmitting signals at different but close (adjacent) frequencies that the cellular tower has difficulty in filtering out the different channels from each other.

As stated before, we generally study co-channel interference that occurs in the forward channel received by the mobile unit. Although co-channel interference occurs in the reverse channel received by

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the tower, it is harder to study the co-channel interference in the reverse channel because of the difficulty of locating the mobile phones in the different co-channel cells.

Adjacent Channel interference is only a reverse channel problem. To illustrate why it occurs, consider first real signal filters. Real filters never have zero-width transition bands (the width of the region between the passband and the stopband is never equal to zero) and their stopband levels are never zero (the filters attenuate the undesired signals but not completely). Therefore, extracting a channel from a set of channels that are adjacent is never a perfect process because part of the undesired adjacent channels also passes through the filter in addition to the desired channel. Also, the closer the channels are to each other (the smaller the transition band is), the more difficult it is to construct the filter.

Now consider the following two scenarios in a cell:

1. All Mobile Phones are at Equal Distance from the Tower

Consider the case where there are 10 mobile phones that are communicating with a particular tower using channels consecutive channel.
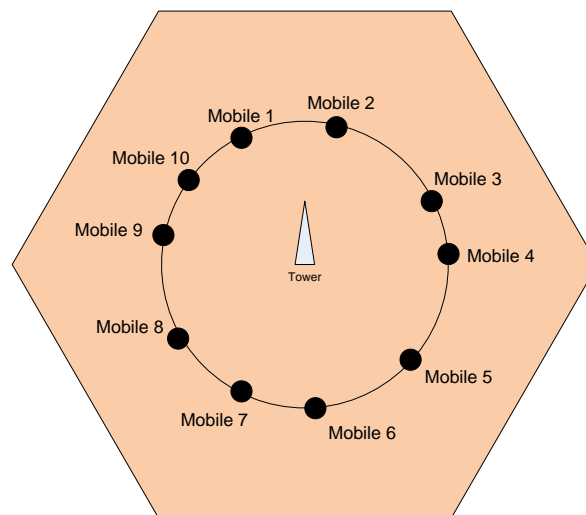

Because all mobile phones are located at equal distances from the tower, the power received at the tower due to each mobile is almost the same. The received signal at the tower may look like the following (assuming all channels are adjacent):
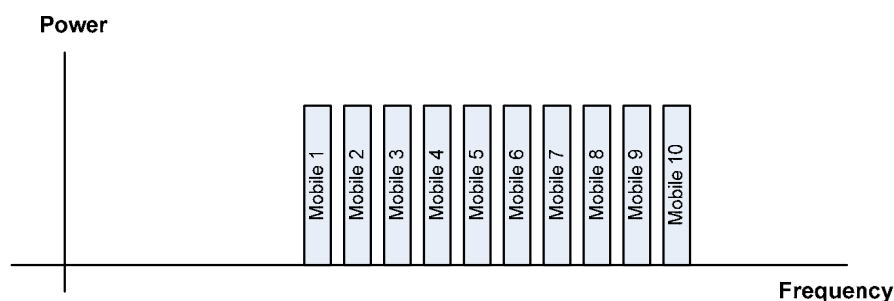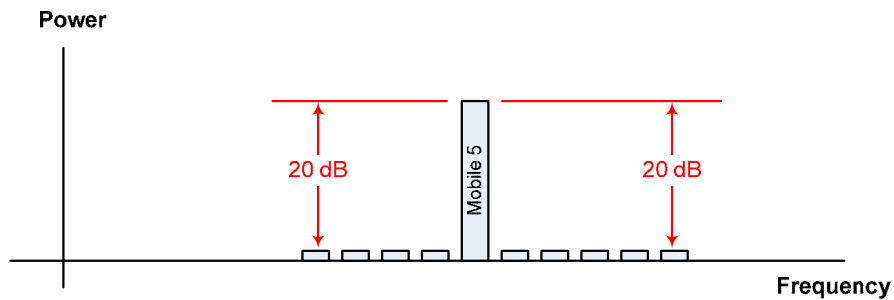

To extract any of the channels (for example the channel of Mobile 5), and reject all other channels by attenuating them by around 20 dB, for example, a simple filter can be used in the following form:

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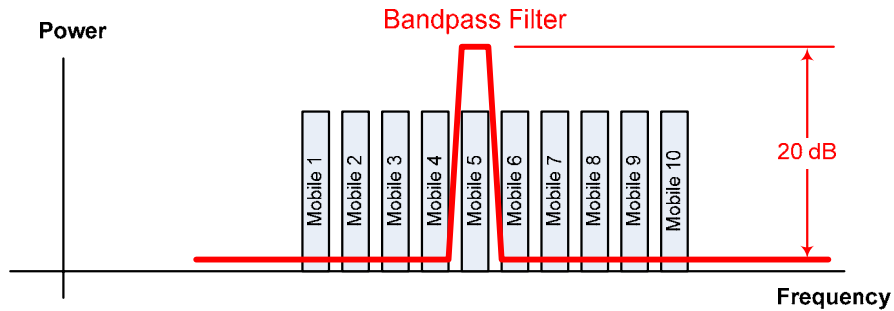
The resulting signal at the output of the filter will be:

An attenuation of 20 dB of the adjacent channel compared to the desired channel is generally acceptable and means that the filtering process was successful.

2. Some Mobile Phones are Very Close to Tower and Some are Very Far

Consider now the second case where the same 10 mobile phones that are communicating with a particular tower, but 9 of these phones are located at equal distance and very close from the tower while one of them is located at a very far away point from the tower such that the ratio of power received from the nearby phones to the power received by the far away phone is 60 dB due to the huge difference between the distances of the 9 mobile phones compared with the single faraway mobile phone.
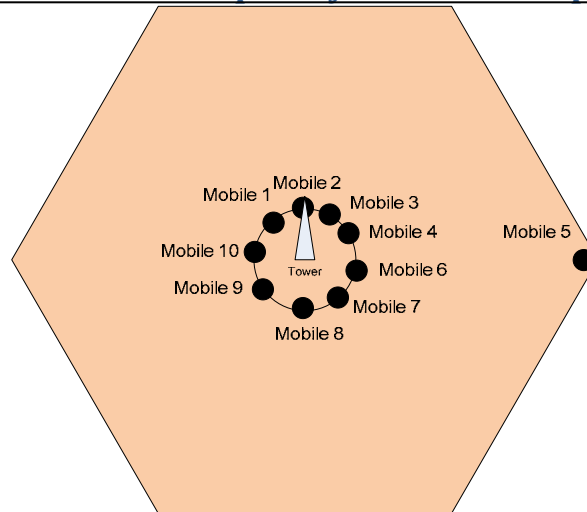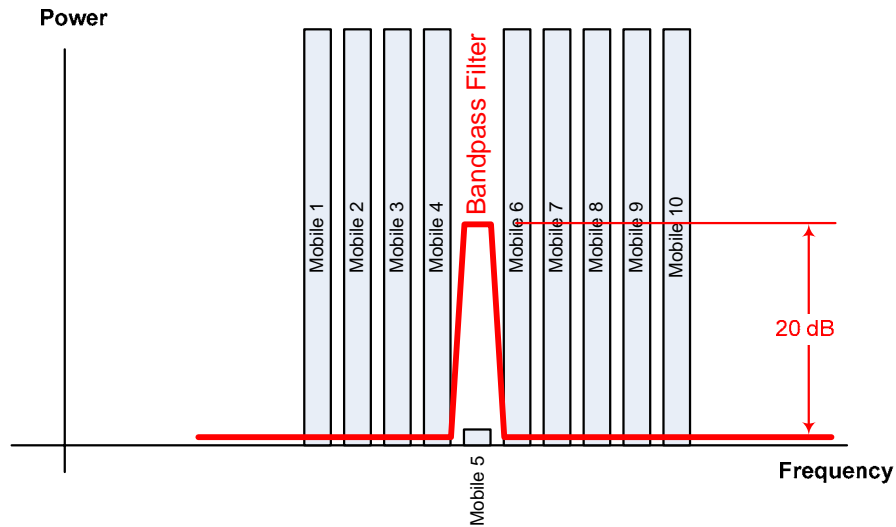
This situation produces a phenomenon called the near-far effect where the powers received at the tower for different channels varies significantly. The received signal at the tower in our above example may look like the following (assuming all channels are adjacent):
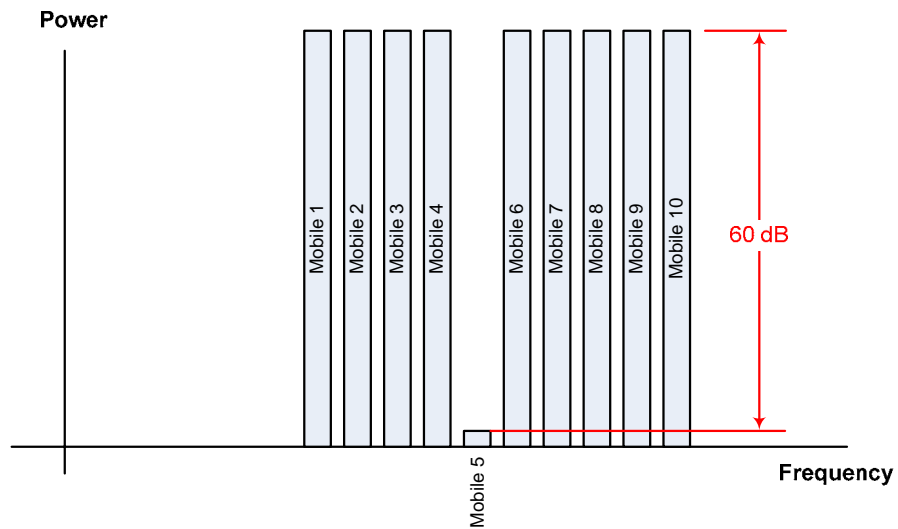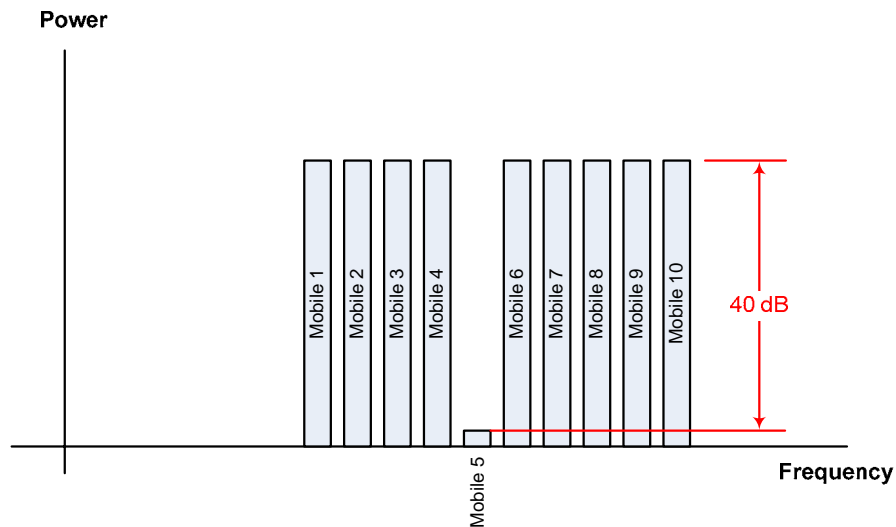

Trying to extract the channel of Mobile 5 (which is the weak signal) using the same filter above with the 20 dB passband to stopband attenuation ratio shown below:

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Power

Mobile 1 Mobile 2 Mobile 3 Mobile 4 Bandpass Filter Mobile 6 Mobile 7 Mobile 8 Mobile 9 Mobile 10

20 dB

Mobile 5

Frequency

will give the following signal:

Power

Mobile 1 Mobile 2 Mobile 3 Mobile 4 Mobile 6 Mobile 7 Mobile 8 Mobile 9 Mobile 10

40 dB

Mobile 5

Frequency

Clearly, the filter failed to extract the channel of the faraway mobile (Mobile 5) because the adjacent channels are much stronger than it. We would need several similar filters (3 more similar filters making a total of 4 filters) to extract the channel of Mobile 5. This results in a complicated filter and therefore a complicated mobile system.

Solving Adjacent Channel Interference

If you noticed, in the above two cases, we showed the problem of ACI assuming that the channels used by all mobile phones to communicate with a specific tower are all ADJACENT to each other. The solution to the problem of ACI is to insure that non of the channels assigned to a specific cell are adjacent. For a cluster size of $N = 7$, for example, distribute the channels of the system among different cells in the cluster such that the following channels are allocated to the different cells:

Cell 1 gets Channels 1, 8, 15, 22, 29, 36, …

Cell 2 gets Channels 2, 9, 16, 23, 30, 37, …
Cell 3 gets Channels 3, 10, 17, 24, 31, 38, …
Cell 4 gets Channels 4, 11, 18, 25, 32, 39, …
Cell 5 gets Channels 5, 12, 19, 26, 33, 40, …
Cell 6 gets Channels 6, 13, 20, 27, 34, 41, …
Cell 1 gets Channels 7, 14, 21, 28, 35, 42, …

By doing this, we guarantee that even if the near-far effect occurred for the signals received by a specific tower, the channels received by the tower will be separated by what appears to be wide guard bands (the bands assigned to channels of other cells). For example, if the channel of Cell 1 above suffer from the near-far effect, the band assigned to channels 2, 3, 4, 5, 6, and 7 represent one of the guard bands around channel 8 and the band assigned to channels 9, 10, 11, 12, 13, and 14 represents the other guard band. Therefore a very simple filter with very wide guard bands can be used to provide attenuations of 70 or 80 dB to combat the near-far effect without a problem. This is seen in the following example.
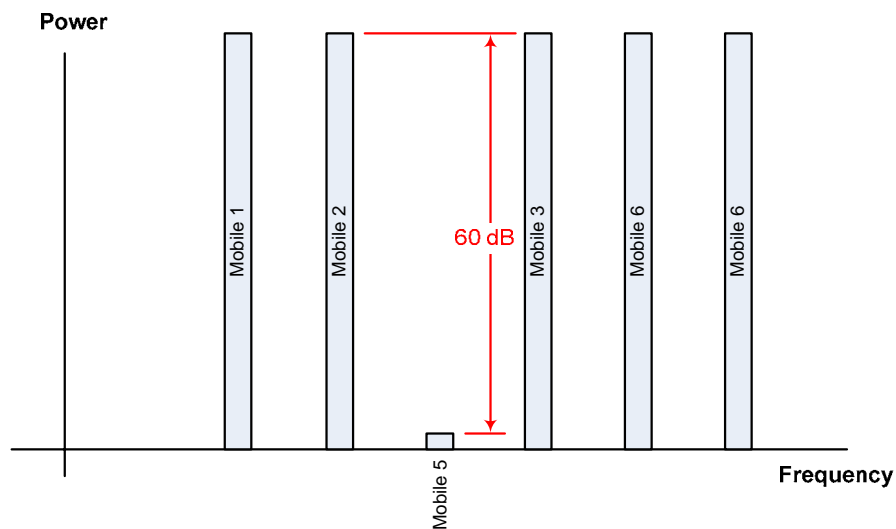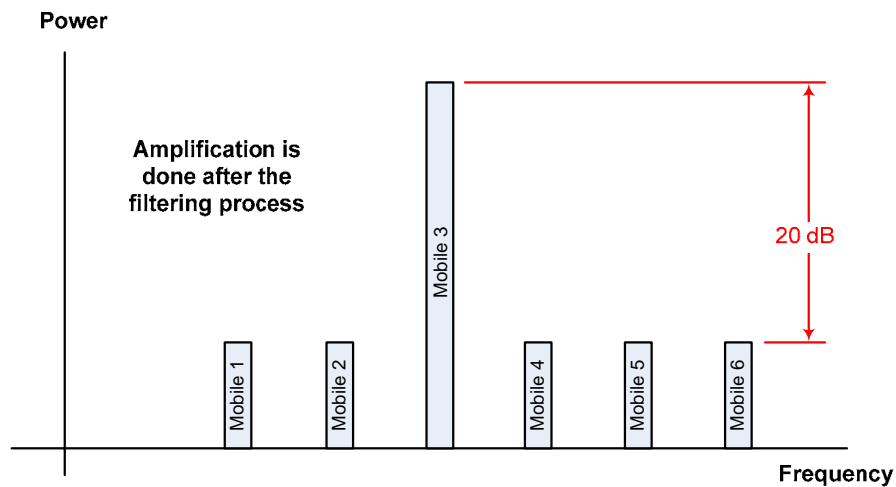

Using a simple filter with low order (because of the wide guardbands) allows us to extract the desired signal as shown below:

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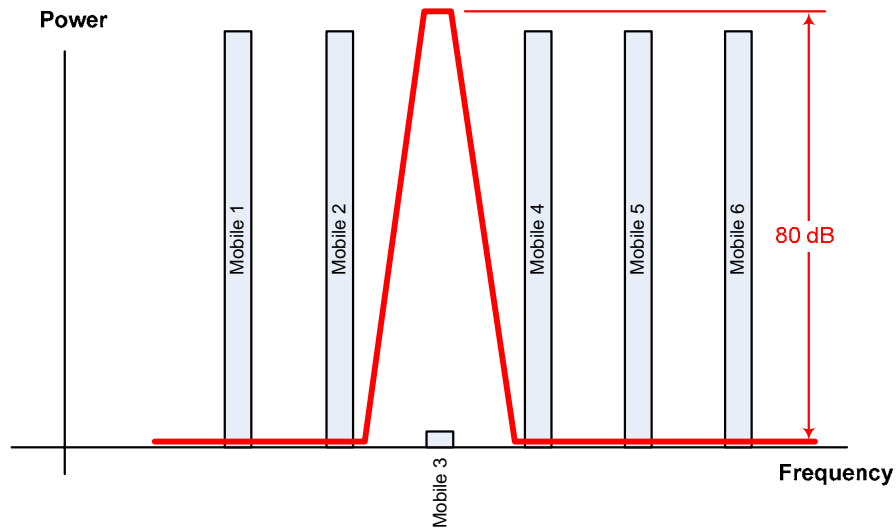
The result of the filtering process would be:

In this case, although there was a 60 dB difference in power between the near channels and far channel, the wide guardband between the channels allowed us to use a simple filter (low order) that has a very high passband to stopband attenuation ratio of 80 dB to extract the very weak signal and reject the very strong signals.

Note that even if the transmission of a mobile phone in another cell reaches the tower and causes ACI, because the mobile phone is located in another cell, its power would certainly be limited and would not cause significant ACI.

Therefore, to solve the ACI problem, the channels of a cellular system are always distributed such that no adjacent channels are assigned to the same cell.