Lecture 10: Frequency Reuse Concepts

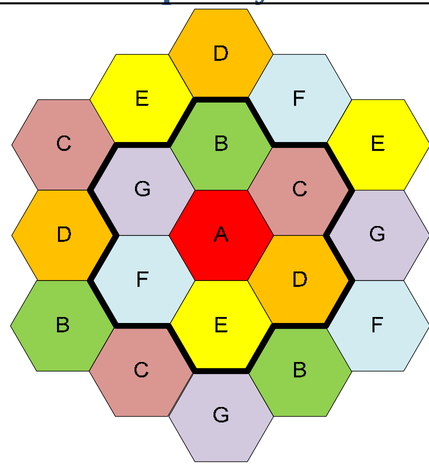
Improving Coverage and Capacity in Cellular Systems

When cellular service providers build their networks, their networks are designed to provide coverage to the area of desire with the expectation of possible increase in population in the near future. For example, a company may design a cellular network to cover a city of area 1000 km2 with population of 1,000,000 people today assuming that 15% of the population will subscribe to their cellular service, or 150,000 people. However, to accommodate possible increase in the percentage of subscribers or the same percentage of subscribers but an increase in population, the network designer may build the network to provide acceptable GOS for 200,000. Such move guarantees that the network will need any expansion for possibly 5 years.

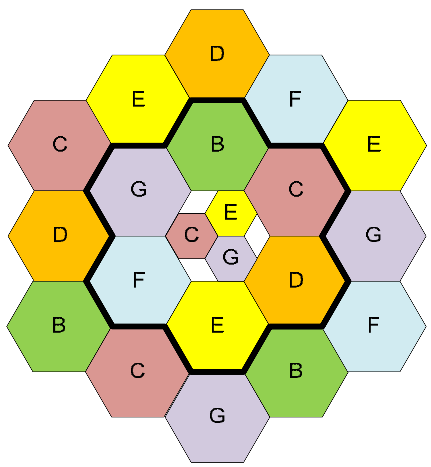
In some cases, it may be difficult to predict the need for network expansion or even when network expansion is predictable, the time for network expansion arrives. There are several techniques to expand an already existing network or to add more capacity to a network being built. In the following we discuss two techniques.

Cell Splitting

We have seen that reducing the size of cells of a cellular system keeps the SIR constant but results in an expansion of the network capacity because the smaller cells cover less area and therefore more cells would be required to cover the whole region which directly reflects on the network capacity. If the network is already functioning, it may be found that the network needs expansion only in specific regions and not network-wide expansion. In this case, a cell (or multiple cells) can be split into smaller cells and frequencies are redistributed in a way that does not cause additional interference. This is shown in the following figures. The first figure shows a cell that has reached it capacity and needs to be split. This cell is split into several cells. Since the area of a cell is proportional to R^2. So, reducing the cell readius to one half of its original value, for example, the area of the cell drops to one quarter of its original value. Therefore, theoretically, 4 of the smaller cells can fit into 1 of the large cells. However, since it is not possible to fit 4 quarter-size hexagonal cells completely into 1 full-size hexagonal cell, some regions will have to be covered by adjacent cells.



Original Cell Distribution



Cell Distribution following the splitting of the cell labeled A in the upper figure

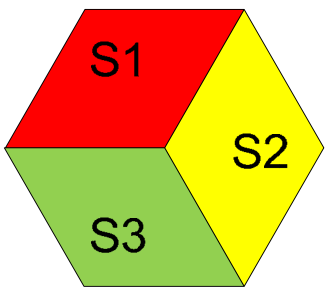
Note that following cell splitting, the new small cells are reassigned new frequencies that do not cause co-channel interference with adjacent cells as shown in the above figure. In addition, the power transmitted in the small cells is reduced compared to the power transmitted in the large cells as it would require much less power to cover the cell compared to the large cells. In fact the power has to be reduced by a factor of

$$\frac{P_{\text{Transmitted in Small Cell}}}{P_{\text{Transmitted in Large Cell}}} = \left(\frac{R_{\text{Small Cell}}}{R_{\text{Large Cell}}} \right)^n$$

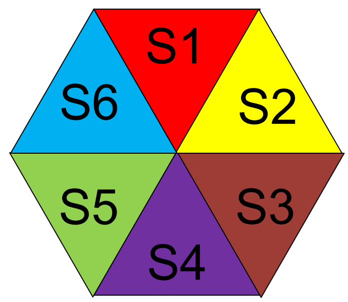
For example, if the cell radius of the small cells is half the radius of the large cell and the path loss exponent $n = 4$, the power transmitted by the tower of the small cell is only 1/16 that of the power transmitted by the tower of the large cell. In addition to the advantage of having a higher network capacity due to cell splitting, the reduced transmitted power, especially by the mobile phone, is another major advantages because it increases the battery life of these mobile phones. The main disadvantage of cell splitting is that it requires the construction of new towers, which is very costly.

Sectoring

The sectoring technique increases the capacity via a different strategy. In this method, a cell has the same coverage space but instead of using a single omni-directional antenna that transmits in all directions, either 3 or 6 directional antennas are used such that each of these antennas provides coverage to a sector of the hexagon. When 3 directional antennas are used, 120° sectoring is achieved (each antenna covers 120°), and when 6 directional antennas are used, 60° sectoring is achieved (each antenna covers 60°).



120° Cell Sectoring



60° Cell Sectoring

Dividing the cells into sectors actually reduces the network capacity because the channels allocated to a cell are now divided among the different sectors. In fact, handoff takes place when a cell phone moves from one sector to another in the same cell. The gain in network capacity is achieved by reducing the number of interfering co-channel cells. If sectoring is done in a way that channels assigned to a particular sector are always at the same direction in the different cells (i.e., group A of channels is assigned to the sector to the left of the tower in all cells, and group B of channels is assigned to the sector at the top of all cells, and so on), each sector causes interference to the cells that are in its transmission angle only. Unlike the case of no sectoring where 6 interfering co-channel cells from the first-tier co-channels cells cause interference, with 120° sectoring, 2 or 3 co-channel cells cause interference and with 60° sectoring, 1 or 2 co-channel cells cause interference. The number of co-channel interfering cells depends on the cluster shape and size. By having less than 6 interfering first-tier co-channel cells causing interference, the SIR is increased for the same cluster size. This allows us to reduce the cluster size and achieve the same original SIR, which directly increases the network capacity.

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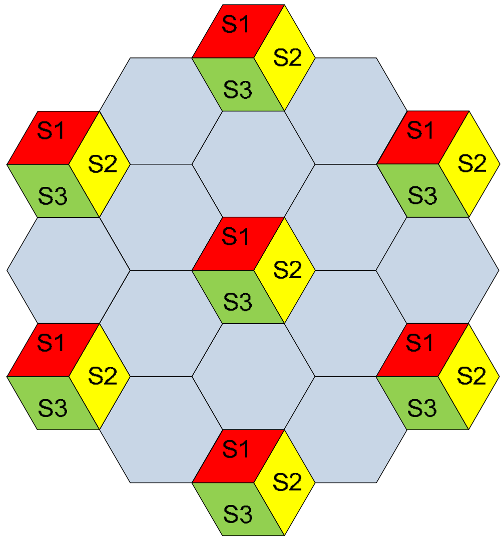
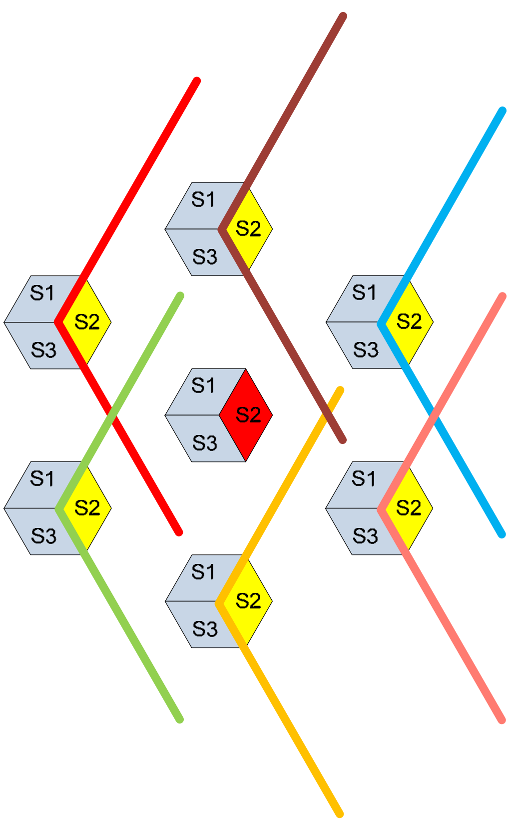
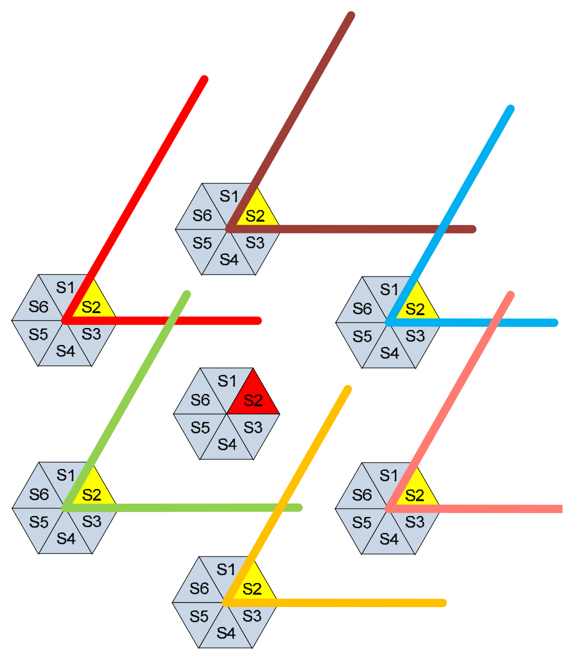


As seen in the figures below, for the case of cluster size of $N = 4$, only 2 of the 6 co-channel cells cause interference to the middle cell for the sector labeled S2 in the case of 120° cell sectoring (the cells with radiation sectors colored red and green). The other 4 cells, although they are radiating at the same frequencies cause no interference because the middle cell is not in their radiation angles. For the case of 60° cell sectoring, only one cell causes interference (the cell with radiation sectors colored green).



120° Cell Sectoring



60° Cell Sectoring

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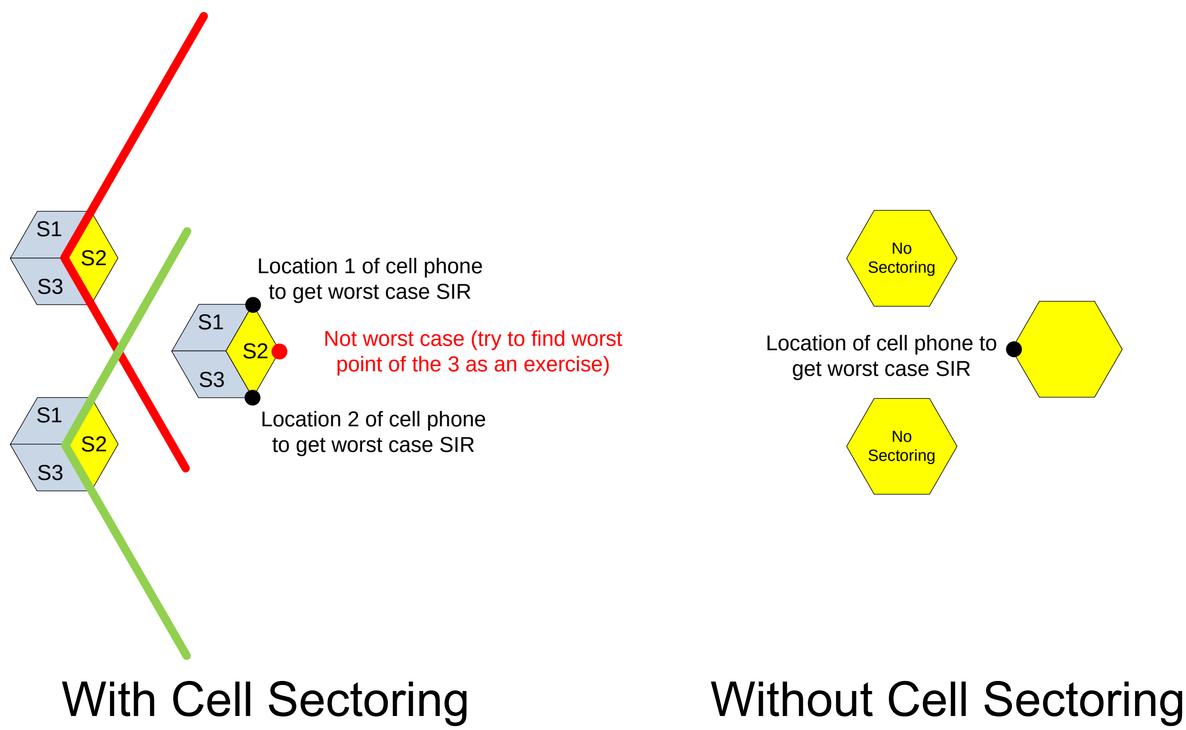
In addition to the reduced number of interfering towers that sectoring produces, the SIR is reduced due to another reason. Since interfering tower always fall behind the tower (i.e., if a sector is radiating to the Right, for example, the interfering cells must be to its Left). Therefore, the worst case SIR occurs when the mobile phone being served by that sector is located at a relatively far corner with respect to the interfering cells. This means that among the 6 interfering co-channel cells in a non-sectored system, the sectored system gets rid of some of the worst interfering cells (the cells closest to the corner at which the mobile phone is located).



Exercise 1:

A cellular system uses a frequency reuse factor $N = 4$ ($i = 0,\ j = 2$). If the path loss exponent $n = 4$, and cell radius $R = 5\ \text{km}$. Find in dB the following quantities:

a. The SIR for the system with no cell sectoring.

b. The SIR for the system when 120° cell sectoring is used (note that worst case occurs when mobile phone is at the furthest point from the interfering towers).

c. The SIR for the system when 60° cell sectoring is used (note that worst case occurs when mobile phone is at the furthest point from the interfering towers).

Exercise 2:

A region with area of 10,000 km^2 has an evenly distributed population of 2.5 million people. A percentage of 30% of the population is subscribed to a cellular service that queues blocked calls, has a total of 420 full duplex voice channels per cluster, has cells of radius 3.06 km, and uses a 12 cell frequency reuse. Assume that each user makes 1 call each 3 hours with average call duration of 2 minutes per call. Find:

a) The number of channels per cell.
b) The total number of channels in the system.
c) Traffic intensity per cell.
d) The probability of a call being delayed any amount of time.
e) The probability of a call being delayed more than 10 seconds.
f) Maximum carried traffic for the whole system.
g) The average delay of the system (in seconds).
h) Repeat parts (a) – (g) when 120° cell sectoring is used.
i) Repeat parts (a) – (g) when 60° cell sectoring is used.