Cellular Systems

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A Finite Resource

- “Spectrum is like real estate—they just don’t make it anymore” [Webb '99]
- Cellular systems enable a service provider to serve more customers within a limited spectrum allocation

Before Cells...

- A single antenna would serve all the customers in the service area
- Service provider was limited to a certain bandwidth

One Call per Channel

- A different channel for every active call
- Even with trunking, demand quickly exceeded resources

Frequency Reuse

- Partition the service area into smaller cells
- One antenna (base station) serves each cell, transmitting lower power, using only a subset of the available channels
- Adjacent cell uses a mutually exclusive subset of channels
- Original channel subset used in a cell that is far away from the first cell

Cells

- Total number of channels, C, are used in one cluster
Reuse in Each Cluster
- The same C channels are used simultaneously in another cluster
- Max no. of users = C times no. of clusters

Co-channel Interference
- In the 4-cell cluster case, the nearest interfering signal comes from 2 cells over

Transmit Power Constraint
- The power transmitted by each base station needs to be large enough to cover its own cell, but small enough to not cause too much interference in the co-channel cells
- As cells get smaller, transmit power is reduced

Smaller Cells Serve More Users
- The cells can be made small enough to support any user density
  - Macrocells
  - Microcells
  - Picocells
- The cost is in more base stations and system complexity

Cluster Size, N
- $N$ only takes values $N = i^2 + ij + j^2$ where $i$ and $j$ are non-negative integers.
- Examples:
  - $i = 2, j = 0$: $N = 4$
  - $i = 2, j = 1$: $N = 7$

Location Rule
- To find the nearest co-channel cell, move $i$ cells along a chain of hexagons, turn 60 degrees counterclockwise and move $j$ cells
  - $i = 2, j = 1$: $N = 7$
Measures of Quality of the Received Signal

- Signal-to-noise ratio (SNR)
- Signal-to-interference ratio (SIR)

**SNR**

- Ratio of received desired signal power over the average noise power in the receiver
  \[ SNR = \frac{P_{\text{des}}}{P_{\text{noise}}} \]
- SNR can be improved by
  - Increasing the transmitted power
  - Decreasing the range
  - Using a better low noise amplifier (LNA)

**SIR**

- Ratio of received desired signal power over the received interference power
  \[ SIR = \frac{P_{\text{des}}}{\sum_{i=1}^{n_{\text{int}}} P_{\text{int},i}} \]
  - \( n_{\text{int}} \) is the number of interfering base stations
  - If all base stations increase their transmitted power by the same amount, the SIR doesn’t change

**Computing Received Power**

- Let
  - \( d_{\text{des}} \) be the distance to the desired transmitter
  - \( d_o \) be a reference distance (depends on antenna height)
  - \( P_o \) be the power received at the reference distance
  - \( n \) be the path loss exponent (3-to-4 for mobile cellular)
  \[ P_{\text{des}} = P_o \left( \frac{d_{\text{des}}}{d_o} \right)^{-n} \]

**Worst Case Interference**

- The SIR is worst for a mobile on the edge of a cell
  - If all base stations transmit equal power, SIR can be expressed
  \[ SIR = \frac{d_{\text{des}}^{-n}}{\sum_{i=1}^{n_{\text{int}}} d_{\text{int},i}^{-n}} \]
  - In this example, there are six interferers

**Co-channel Reuse Ratio**

- \( R= \) “major” radius of hexagonal cell
- \( D= \) distance between centers of nearest co-channel cells
- \( Q= \) \( D/R \)= Co-channel reuse ratio
  - Increasing \( Q \) decreases interference
  - \( Q= \sqrt[3]{N} \), where \( N= \) cluster size
Adjacent Channel Interference

- Even though the neighboring cells share no channels with the serving cell, the adjacent channels from those cells leak through the bandpass filter of the mobile.

Summary

- Cells allow a service provider to re-use frequencies so it can serve more customers.
- Smaller cells serve more customers.
- Co-channel and adjacent channel interference are important.

References