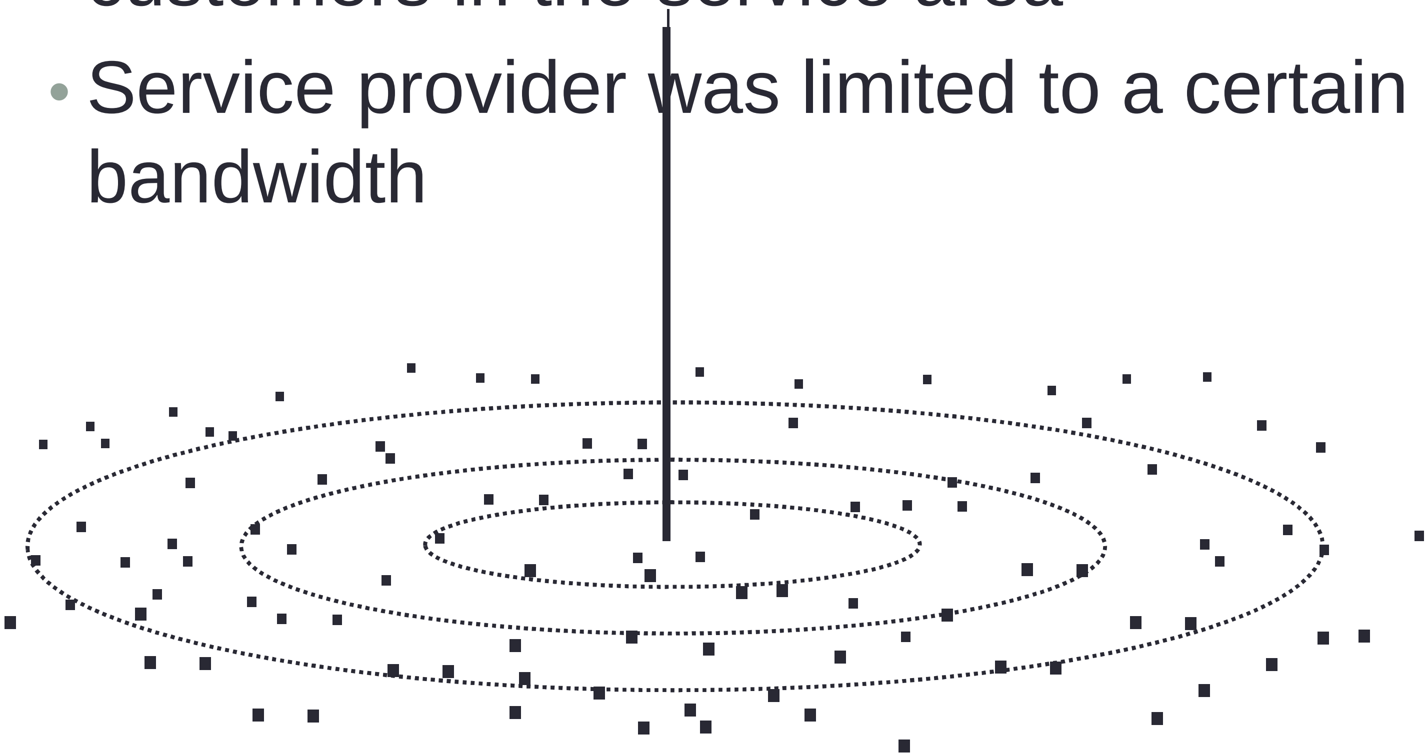
CELLULAR SYSTEMS

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

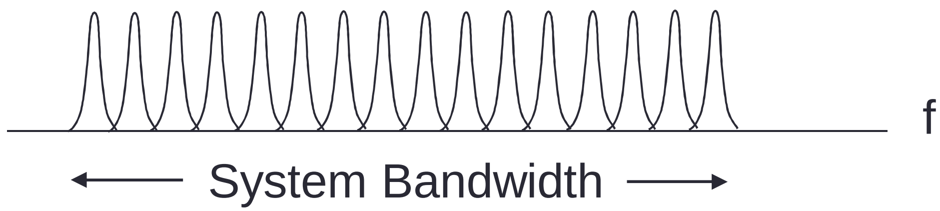
Before Cells…

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

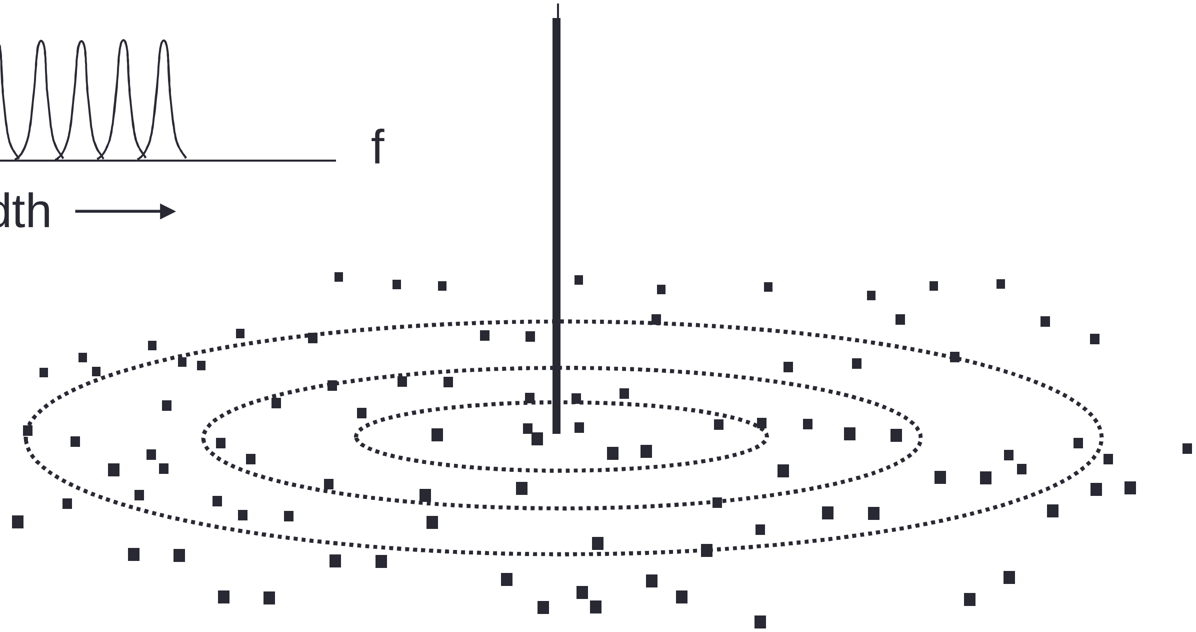


One Call per Channel

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



Only 16 users can be served with 16 channels

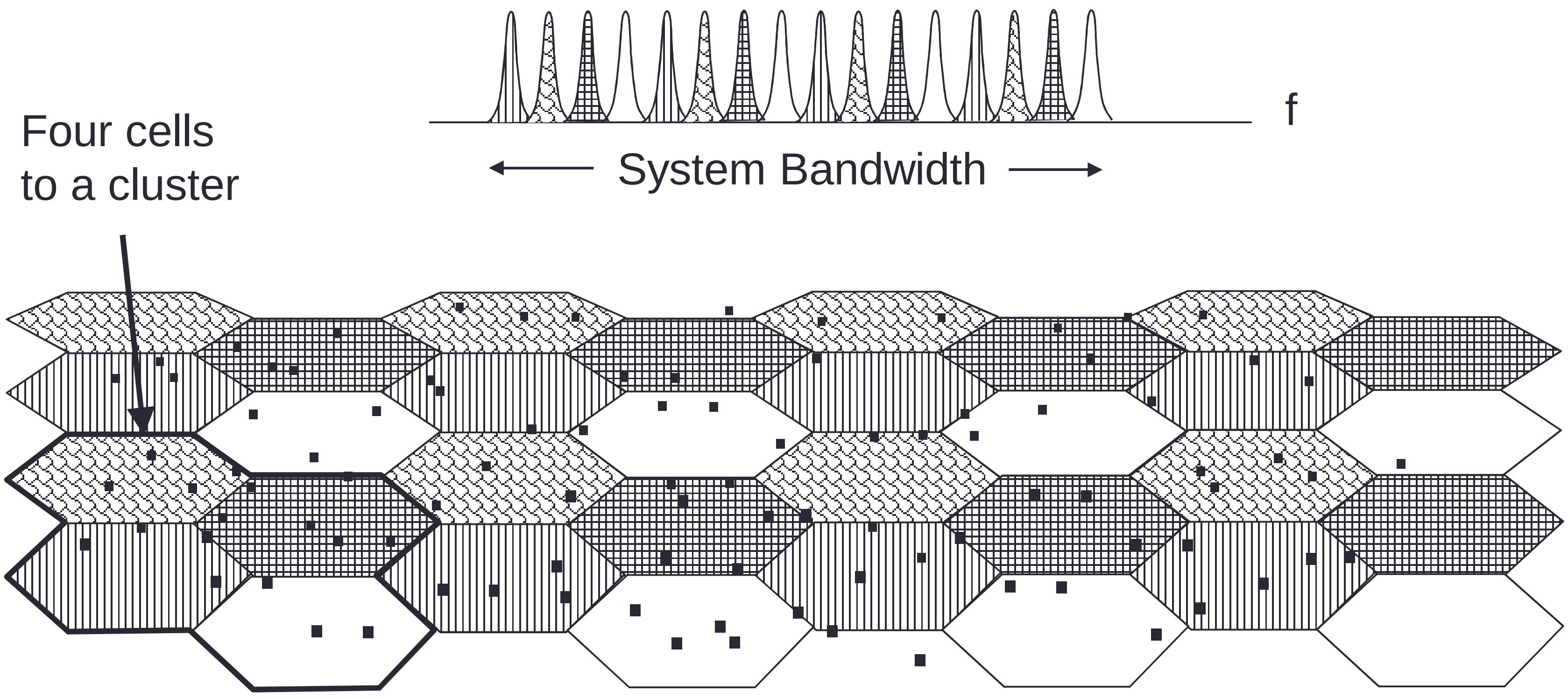


Frequency Reuse

- 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

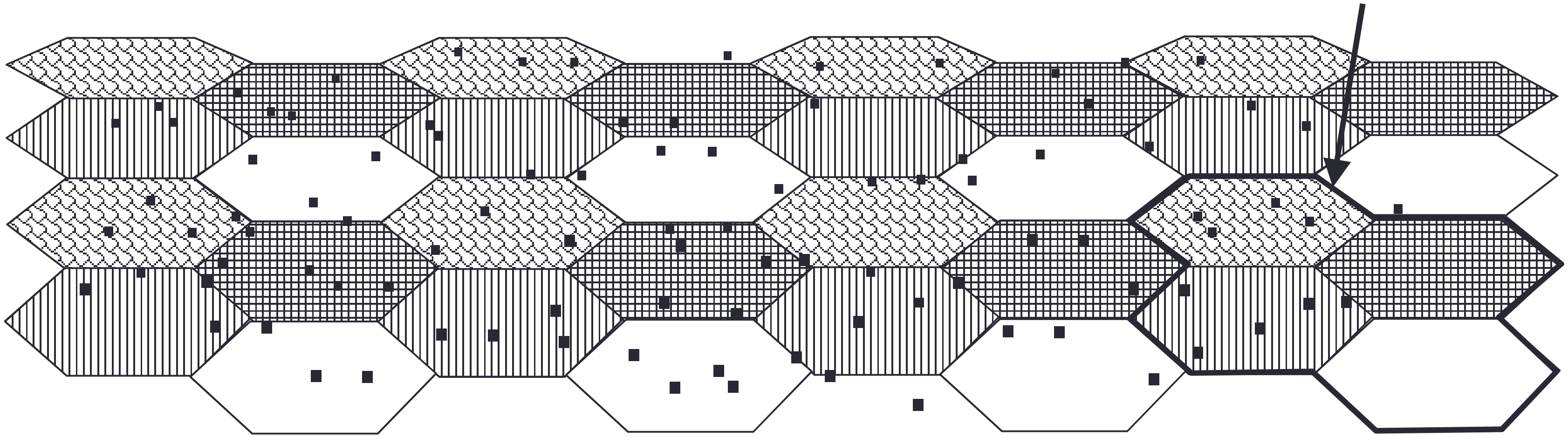
- Total number of channels, C, are used in one cluster



Reuse in Each Cluster

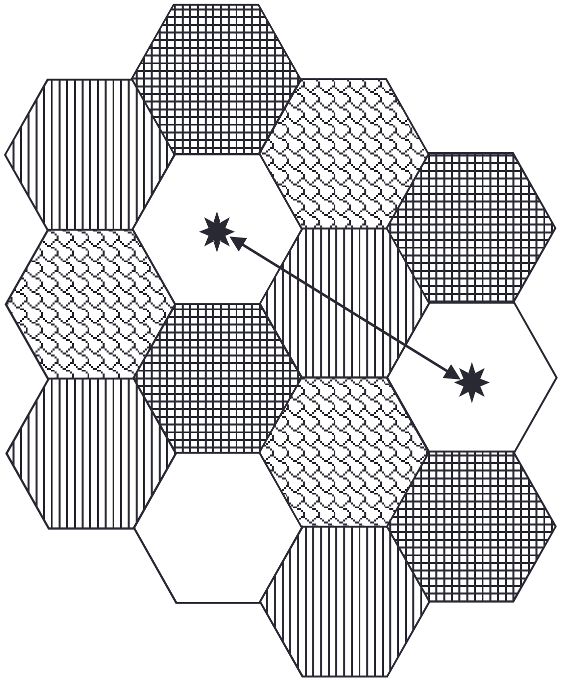
- The same C channels are used simultaneously in another cluster
- Max no. of users = C times no. of clusters

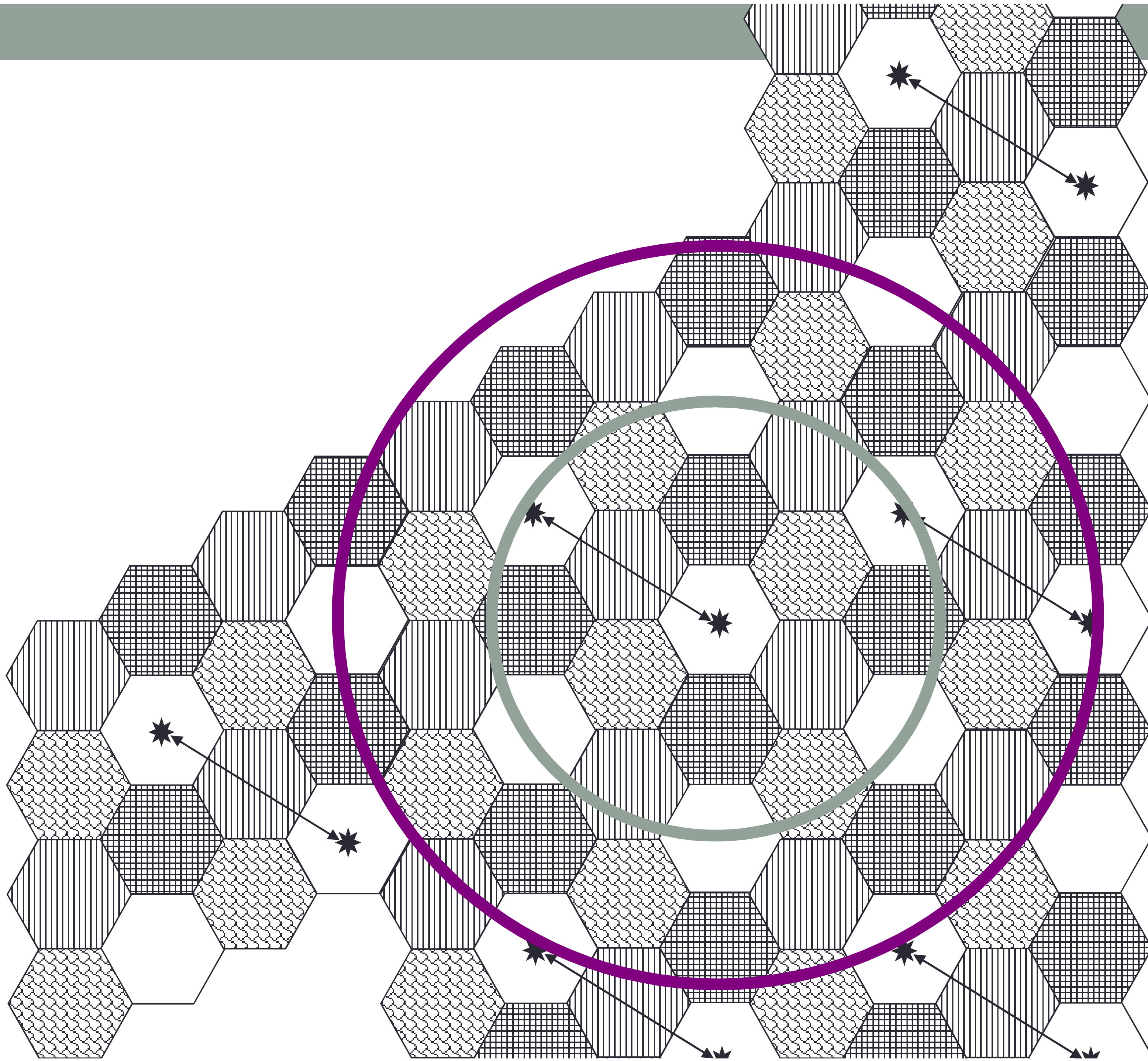
Another cluster



Co-channel Interference

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



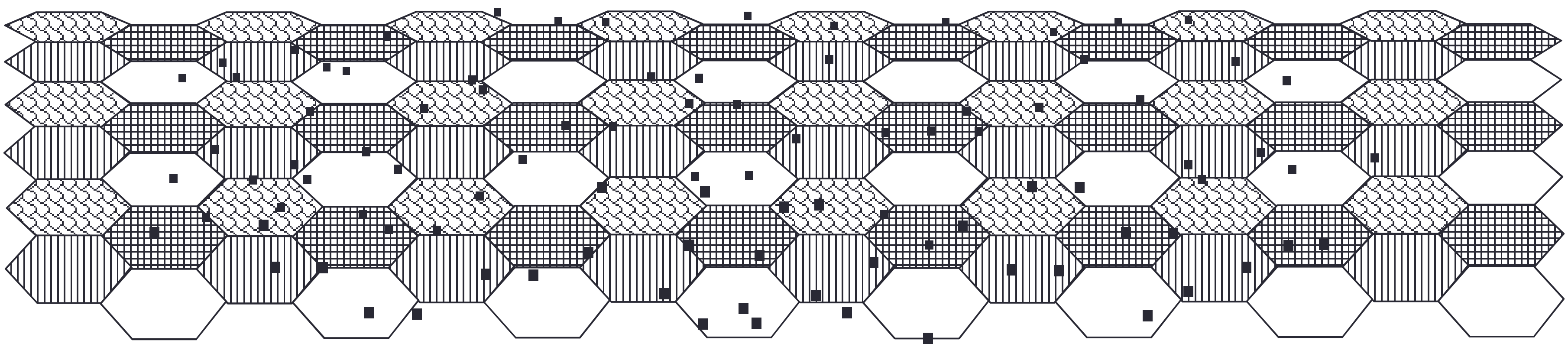


Transmit Power Constraint

- 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

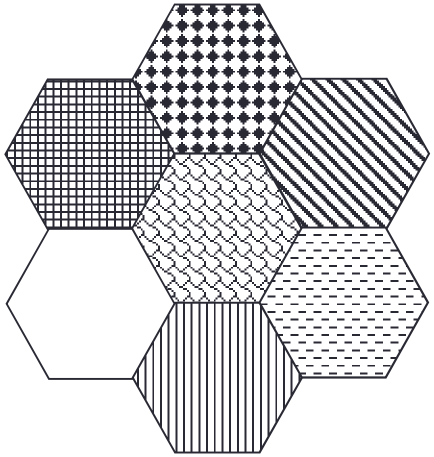
Smaller Cells Serve More Users

- 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

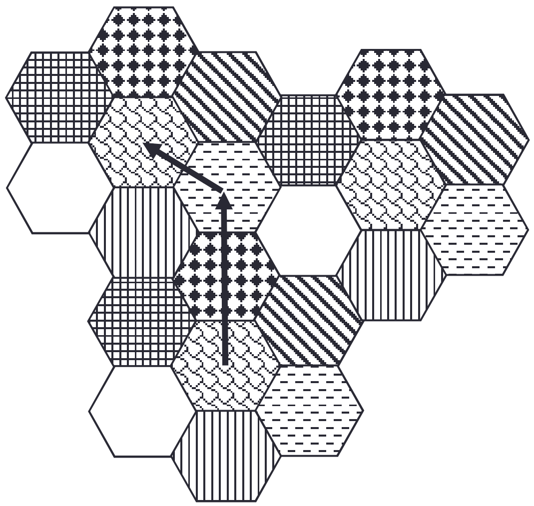
- N only takes values $N = i^2 + ij + j^2$ where i and j are non-negative integers.
- Examples:
  - i =2, j =0: N =4
  - i =2, j =1: N =7



A 7-cell cluster

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

$$SNR = \frac{P_{des}}{P_{noise}}$$

- 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

$$SIR = \frac{P_{des}}{\sum_{i=1}^{n_i} P_{\mathrm{int},i}}$$

n_i 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_{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)

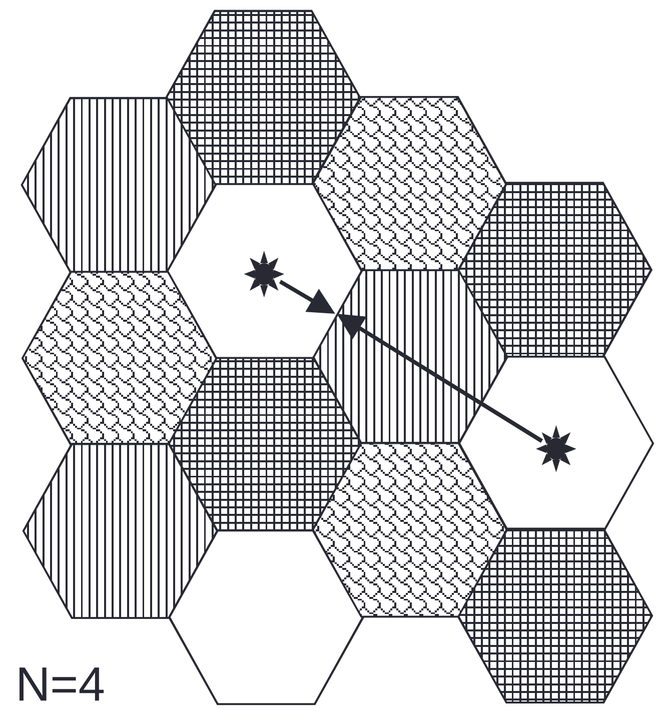
$$P_{des} = P_o \left(\frac{d_{des}}{d_o} \right)^{-n}$$

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

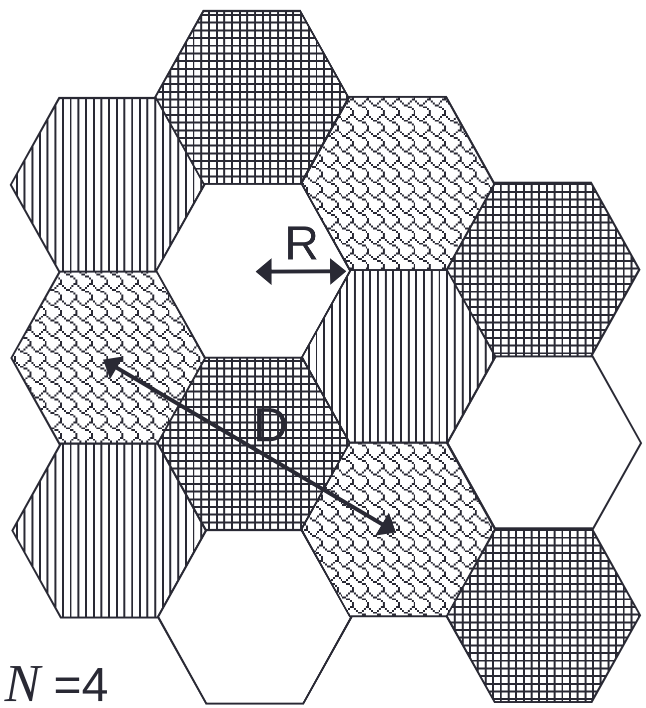
$$SIR = \frac{d_{des}^{-n}}{\sum_{i=1}^{n_i} d_{\text{int},i}^{-n}}$$

- In this example, there are six interferers



Co-channel Reuse Ratio

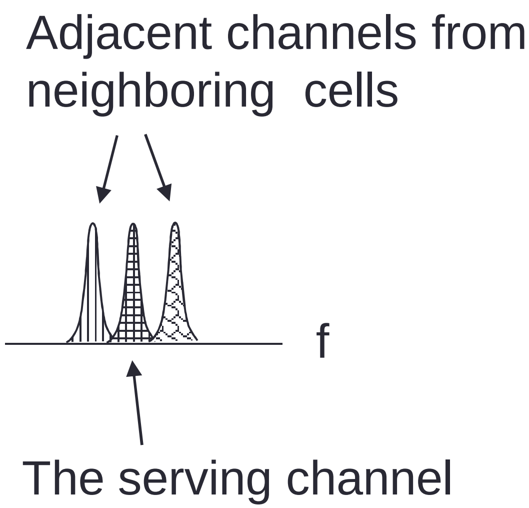
- R="major" radius of hexagonal cell
- D=distance between centers of nearest co-channel cells
- Q=D/R=Co-channel reuse ratio
- Increasing Q decreases interference
- Q=$\sqrt{3N}$, where N=cluster size

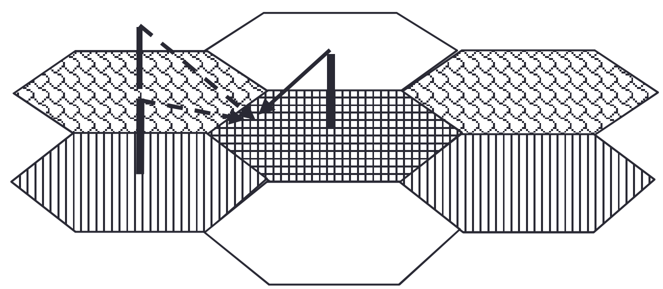


N =4

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