Lecture 4: 1.4 Explain concept of cluster

Fundamental of Cellular Communication

DI05011011: Mobile Communication

Agenda for Today

- 1. The Frequency Allocation Problem
- 2. What is a Cluster?
- 3. Characteristics of a Cluster
- 4. Determining Cluster Size (N)
- 5. The Magic Numbers of Cellular Design
- 6. Concept of Co-channel Cells
- 7. Visualizing a Cluster
- 8. Summary

The Frequency Allocation Problem

- A network operator (like AT&T or Vodafone) buys a limited block of radio spectrum from the government.
- This spectrum is divided into a finite number of voice/data channels (denoted as 'S').
- **The Problem:** If two adjacent cells use the exact same frequency channel, their signals will collide, causing severe interference.
- **The Solution:** We must distribute these 'S' channels among a group of cells in such a way that neighboring cells never use the same frequency.

What is a Cluster?

- A **Cluster** is a group of adjacent cells that collectively use the entire allocated frequency spectrum.
- If a cluster has 'N' cells, the total available channels (S) are divided among these N cells.
- Channels per cell (k) = S / N.
- Inside a single cluster, no two cells share the same frequency. This ensures zero interference within the cluster.

Characteristics of a Cluster

- **1. Completeness:** A cluster contains all the frequency channels available to the system.
- **2. Uniqueness:** Frequencies are not repeated within a single cluster.
- **3. Tesselation:** Clusters must interlock perfectly with other clusters of the same size to cover a large geographic area without gaps.
- **4. Size (N):** The number of cells in a cluster is denoted by N. Common sizes are 3, 4, 7, 12, etc.

Determining Cluster Size (N)

- Because cells are modeled as hexagons, we cannot just arbitrarily choose a cluster size (N).
- To ensure that clusters fit together without gaps, N must satisfy the following geometric equation:
- $\mathbf{N = i^2 + ij + j^2}$
- Where:
- - 'i' and 'j' are non-negative integers (0, 1, 2, 3...).
- - They represent the number of steps taken along the hexagonal grid to find the next nearest co-channel cell.

The 'Magic Numbers' of Cellular Design

- Let's calculate possible cluster sizes using $N = i^2 + ij + j^2$:
- - If i=1, j=1: $N = (1)^2 + (1)(1) + (1)^2 = 1 + 1 + 1 = \mathbf{3}$
- - If i=2, j=0: $N = (2)^2 + (2)(0) + (0)^2 = \mathbf{4}$
- - If i=2, j=1: $N = (2)^2 + (2)(1) + (1)^2 = 4 + 2 + 1 = \mathbf{7}$
- - If i=3, j=0: $N = (3)^2 + (3)(0) + (0)^2 = \mathbf{9}$
- - If i=2, j=2: $N = (2)^2 + (2)(2) + (2)^2 = 4 + 4 + 4 = \mathbf{12}$
- Therefore, valid cluster sizes (N) are: 3, 4, 7, 9, 12, 19, etc.

Concept of Co-channel Cells

- Once a cluster uses all the frequencies, the pattern is repeated geographically.
- A cell in Cluster 1 that uses 'Frequency Group A' will have a counterpart in Cluster 2 that also uses 'Frequency Group A'.
- These two cells are called **Co-channel Cells**.
- The design goal is to ensure that the distance between co-channel cells is large enough so their radio waves don't interfere with each other.

How to Locate Co-channel Cells

- To find a co-channel cell in a neighboring cluster using the 'i' and 'j' parameters:
- 1. Start at the center of the original cell.
- 2. Move 'i' cells across the centers of adjacent hexagons.
- 3. Turn 60 degrees counter-clockwise.
- 4. Move 'j' cells forward.
- You have now landed exactly on the nearest co-channel cell!

Visualizing a 7-Cell Cluster

- - Imagine a central hexagon (Cell A).
- - It is completely surrounded by 6 other hexagons (Cells B, C, D, E, F, G).
- - This forms a relatively circular block of 7 cells.
- - This block can seamlessly connect with another identical 7-cell block, covering a city map like perfectly laid floor tiles.
- - Frequency 'A' in the first block is physically separated from Frequency 'A' in the second block by at least two other cells.

Trade-offs in Cluster Size (N)

- **Small Cluster Size (e.g., N = 3 or 4):**
- - **Pros:** High capacity. The total spectrum 'S' is divided into fewer groups, so each cell gets more channels.
- - **Cons:** Co-channel cells are physically closer together, increasing interference.
-
- **Large Cluster Size (e.g., N = 7 or 12):**
- - **Pros:** Co-channel cells are farther apart, meaning less interference and better call quality.
- - **Cons:** Lower capacity. The spectrum 'S' is divided into many groups, so each cell gets fewer channels.

Lecture Summary

- A cluster is a group of 'N' cells that collectively use the entire frequency spectrum available to the operator.
- Frequencies are unique within a cluster (no interference).
- Cluster sizes are determined by the equation $N = i^2 + ij + j^2$.
- Valid cluster sizes include 3, 4, 7, 9, and 12.
- Cells in different clusters using the same frequencies are called Co-channel cells.
- Cluster size dictates the trade-off between network capacity and interference.

Next Lecture Preview

- Now that we know how frequencies are grouped into clusters, how do we reuse them across a whole city to increase capacity?
- In the next lecture, we will cover:
- **1.5 Frequency reuse and system capacity**
- - The core concept of frequency reuse.
- - Mathematical formulas to calculate total system capacity (C).
- - How frequency reuse makes cellular networks scalable.