The Cellular Concept
Objectives of Wireless Systems

• Large Capacity
• Efficient use of Resources (Spectrum)
• Availability
• Adaptability to traffic density
• Service to mobile terminals
• Quality of Service
• Affordability
Introduction of Cellular Concept

• The need to operate and grow “indefinitely” within an allocation of hundred of channels has been the primary driving force behind the evolution of the cellular concept.

• The concept was developed in 1947 at AT&T Bell Laboratories. First tests were conducted in 1962 for commercial applications. FCC finally set aside new radio frequencies for land mobile communications in 1970. In 1970, AT&T proposed to build the first high capacity cellular phone system called “Advanced Mobile Phone Service (AMPS)”.
Definitions

- Mobile Station
- Base Station
- Mobile Switching Center
- Control Channel(s)
- Forward Channel
- Reverse Channel
- Full Duplex Systems
- Half Duplex
- Handoff
Evolution of Cellular Networks

• 1st Generation Cellular Networks: High power, high tower base stations, analog systems, FDMA. “The probability that a mobile will leave the coverage area during the course of a call was considered negligible”. Wireless was nothing but a mode of access to the fixed telecommunication network.

• 2nd Generation Cellular Networks: Digital systems… TDMA in North America (IS 54) and Europe (GSM) CDMA (IS-95) in North America

• 3rd generation: High bandwidth, service integration, high data rate
Basic Elements

• **Channel (Frequency) Reuse:**
  – Refers to the intelligent allocation and reuse of channels throughout different coverage areas which are separated from one another by sufficient distances so that co-channel interference is not objectionable.

• **Co-channel interference:**
  – Interference caused by transmissions on the same channel (e.g. same frequency)

• **Reuse distance:**
  – minimum distance between two cells using same channel for satisfactory signal to noise ratio
• Instead of covering the whole area with one transmitter (base station) of high power we deploy multiple base stations of moderate (lower) power. Each base station (cite) covers some specific area.

• Each base station is assigned a portion of the total number of channels, while neighboring base stations are assigned different groups of channels so that the interference between base stations (and mobile users) is minimized.

• Spacing the base stations systematically and allocating the channels appropriately results in minimizing the co-channel interference.
Hexagonal Structure

- Hexagons are usually used to depict the cells due to geometry considerations and calculation purposes (it closely approximates the circle, which is used as a coverage area by a base station that has transmission radius (range) R).
Consider that there are $S$ channels available (total in the system). If each cell is allocated $K$ channels ($K < S$) and if $S$ is divided among $N$ cells into unique and disjoint channel groups which have the same number of channels, then we have:

- $S = K \times N$
- The $N$ cells that collectively use all the available channels are called clusters, and $N$ is the cluster size. Typical values of $N$ is 4, 7, 12.
- If a cluster is replicated $M$ times within the system then the total number of users supported is given by:
  - $C = M \times K \times N = M \times S$
• \( C = M \times K \times N = M \times S \)

• For fixed service area if \( N \) decreases, while the cell size remains constant, more clusters are required to cover the area, and as a result \( M \) increases and therefore \( C \) increases.

• From a design point of view the smallest number of \( N \) is desired, so that \( M \) and thus \( C \) is maximized. However \( N \) represents how close cells that use the same channels are. Therefore smaller \( N \) corresponds to higher co-channel interference, while larger \( N \) corresponds to lower co-channel interference.

• Therefore minimum value of \( N \) should be obtained (desired), such that the co-channel interference can be tolerated. The value \( N \) is called reuse factor. (Some books define \( 1/N \) as the reuse factor).
Graph Coloring equivalent problem

- The problem of determining N and assigning channels to the cells under the above considerations is equivalent to the graph coloring problem, as follows. Consider a graph obtained by representing each cell by a vertex, with an edge joining two vertices if the corresponding cells can not use the same channel (due to co-channel interference). Then the problem is to find the minimum number of colors required, so that there are no two vertices that are connected with an edge that are assigned the same color. In general this is NP hard problem.
N=3 – reuse pattern

One channel can be (re)used in all cells of the same color
N = 7 – reuse pattern
Properties and Fundamentals of the Cellular Geometry

- Let Radius of each cell = \( R \)
- Let Distance between center of adjacent cells = \( d \)
- Let Distance between centers of Co-channel Cells = \( D \)
- **Step-1**
- **To find the relation between radius of cell (\( R \)) and distance \( d \)**

From the above figure,

\[ CI = \frac{R}{2}; \quad OI = \frac{d}{2}; \quad OC = R; \]

By Pythagoras theorem

\[ OC^2 = OI^2 + CI^2 \]

\[ R^2 = (d/2)^2 + (R/2)^2 \]

\[ d = \sqrt{3} \times R \quad \text{_____________ (1)} \]
• The figure below shows the most convenient set of coordinates for hexagonal geometry. The positive halves of the two axes intersect at a 60-degree angle, and the unit distance along any of the axis equals \( \sqrt{3} \) times the cell radius.

• The radius is defined as the distance from the center of a cell to any of its vertices. Based on this, the center of each cell falls on a point specified by a pair of integer coordinates.
The first thing to note is that in this coordinate system the distance \( d_{12} \) between two points \((u_1,v_1)\) and \((u_2,v_2)\) respectively is:

\[
d_{12}^2 = (v_2-v_1)^2 + (u_2-u_1)^2 + 2(u_2-u_1)(v_2-v_1)\cos(60^\circ) = \\
= (v_2-v_1)^2 + (u_2-u_1)^2 + (u_2-u_1)(v_2-v_1) \\
\]

Therefore:

\[
d_{12} = \sqrt{(v_2-v_1)^2 + (u_2-u_1)^2 + (u_2-u_1)(v_2-v_1)} \\
\]

Using this we can easily verify that the distance between the centers of adjacent cells is unity and the length of a cell radius \( R \) is: \( R=1/(\text{sqr}(3)) \). In general, as we showed before if the distance between the centers of adjacent cells is \( d \), then: \( R=d/(\text{sqr}(3)) \).
• **Step-2**
  • To find the distance between the centers of large Clusters (D)

  Let us have a cell at (0,0)
  Let us have Co-channel Cell at (I, J)
  By using Distance formula between two cells (as described before and assuming the previous coordinate system)
  • $D^2 = ((I-0)^2 + (J-0)^2 + I*J)$
  • $D = \sqrt{(I^2 + J^2 + I*J)}$  \hspace{1cm} (2)

• **Step-3**
  • To find the radius of the cluster (Rc)

  • $Rc = D/\sqrt{3}$  \hspace{1cm} (3)
  • $Rc = \sqrt{(I^2 + J^2 + I*J)/\sqrt{3}}$  \hspace{1cm} (3)
Step-4
To find the number of cells in a cluster (N) (i.e. cluster size)
N = Cluster Area/Cell Area ______(4)
Single Cell Area = 6 * (Area of 1 triangle with equal edges R) = 6*
[(1/2) * R *(d/2)]
From (1) we have that d = sqrt(3) * R. Therefore:
Single Cell Area = 6 * [(1/2) * R * (1/2) * sqrt(3) * R] = 3 * Sqrt(3)/2 *
R^2 ______ (5)
Following similar reasoning the cluster area is:
Cluster Area = 3 * Sqrt(3)/2 * Rc^2 ______ (6)
Substituting equation (5) and (6) in (4)
We get,
N = Rc^2/R^2
By substituting (3) and (1) and using that (assuming unit distance
d=1) we get:
N = I^2 + J^2 + I*J ____________ (7)
Step-5
To find Co-channel Reuse Ratio (Q)

- \( Q = \frac{D}{R} \) \hspace{1cm} (8)
- Substituting equation (7), (2) and (1) in (8) and also taking unit distance (i.e. \( d = 1 \))
- We get,
- \( Q = \sqrt{N \times 3} \)