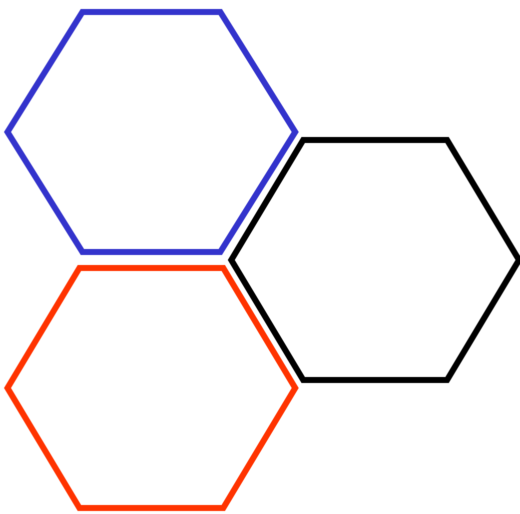
Resource Allocation in Cellular and Ad Hoc Networks



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Heuristic Methods for Optimization,
COMS 5722 , CEE 5290, ORIE 5340

Cellular Convergence

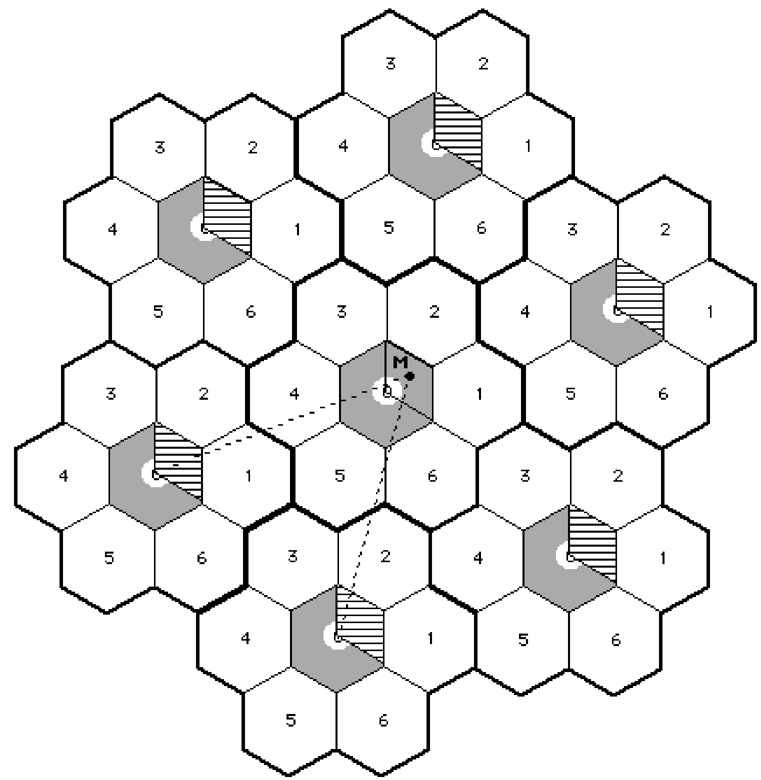
- 4.6 billion cell phones in use today.
- All major forms of modern electronic communication on one platform.
  - Texting (SMS), Email, Web-Browsing, iPod/Podcasts/Music, Games, Location-Based Services…
- Major platform for speech of all types.

Cellular's Evolution

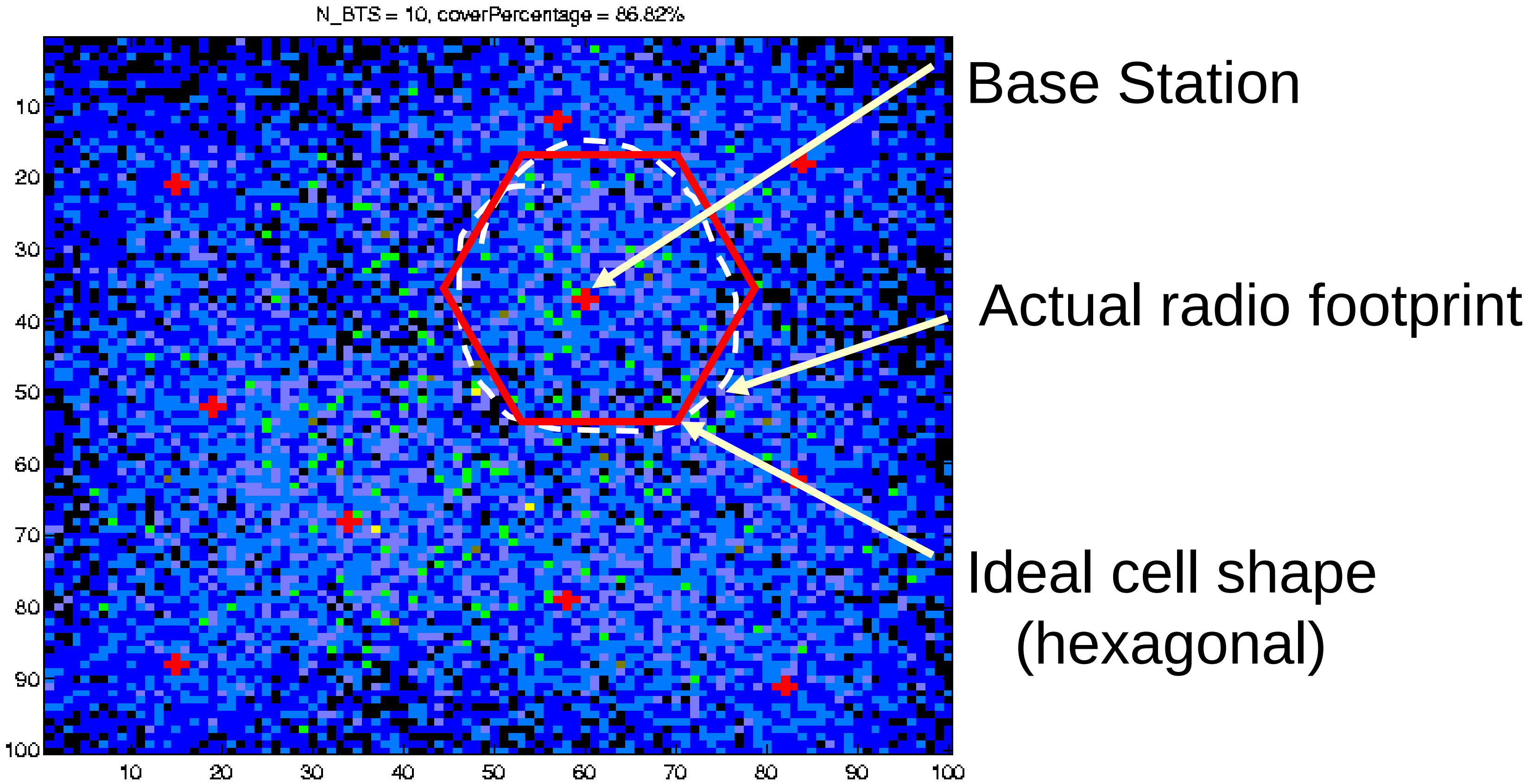
- Pre-Cellular (IMTS)
  - FCC allocation of 11 channels (VHF High)
  - 1976 - 545 customers in New York, 3700 on waiting list
- October 12, 1983 – 1st cellular system in Chicago
- 1985 – 204,000 subscribers in US
- 1988 – 1,600,000 subscribers in US
- 1990 – 2nd Generation Cellular in Europe
- 1999 – 3G (first release R99)
- 2012 – 4G

Reasons for Cellular Success

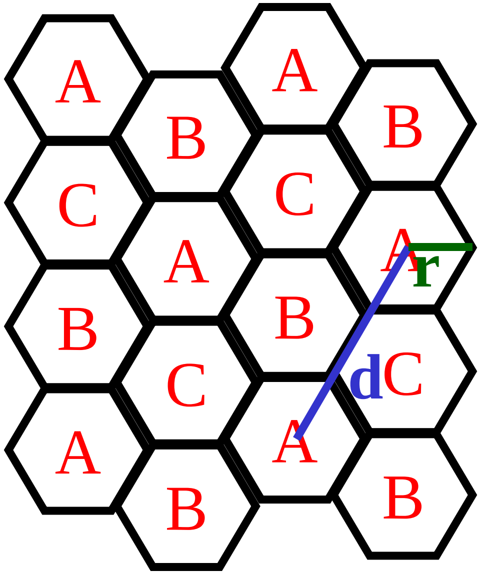
- Moore's law
- Distributed processing
- Frequency reuse…
  - Power control allows increased number of co-channel users per unit area.
- High national capacity
  - Keep transmission distances short
  - Higher (Bits/sec/Hz)/km^2



A Cell


N_BTS = 10, coverPercentage = 86.82%
Base Station
Actual radio footprint
Ideal cell shape
(hexagonal)

Classical Design of Cellular Systems

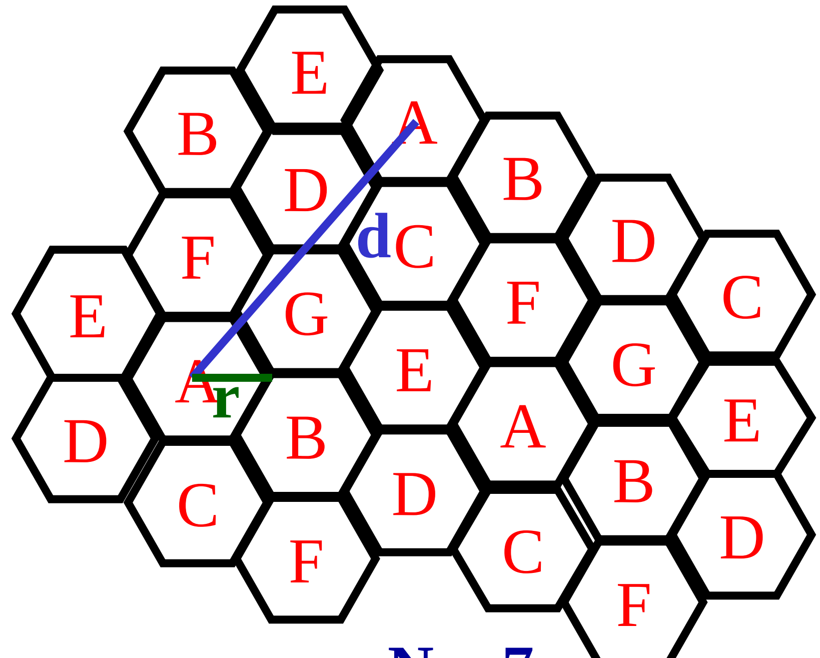


N = 3

r = Cell Radius   d = Co-channel Distance

For Hexagons: $Q = d/r = (3N)^{1/2}$,

N = Number of Cells per Cluster



N = 7

Interference-Capacity Tradeoff

- High Q => low interference, but
- High N => low capacity

Fixed Channel Allocation (FCA)

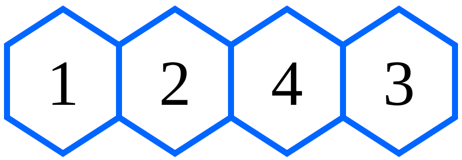
Sample channel allocation/occupancy table

Channels ⇒ ⇓ Cells	1	2 …	n-1	n	Cell User Traffic
A	1	0	1	0	33
B	0	1	1	0	26
C	0	1	1	1	5
D	0	0	0	1	49

- Traditional Approach: Equal number of channels allocated for each cell - this is not a good solution if user traffic is not uniform in all cells.

- A Better Approach: Take into account the average traffic in each cell, the known interference and bandwidth constraints and come up with the best allocation possible.

A Sample Channel Allocation Problem



Traffic Vector **T**:
1 1 1 3

Interference Matrix **I**:

$$\begin{pmatrix} 5 & 4 & 0 & 0 \\ 4 & 5 & 0 & 1 \\ 0 & 0 & 5 & 2 \\ 0 & 1 & 2 & 5 \end{pmatrix}$$

Co-channel constraint

Co-cell constraint

Sub-optimal Allocation **A** - 1 conflict, cost 1

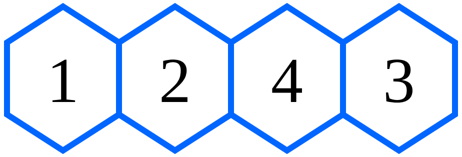
channels

cells

0	0	0	0	0	0	0	0	0	1	0
0	0	**1**	0	0	0	0	0	0	0	0
0	0	**1**	0	0	0	0	0	0	0	0
1	0	0	0	0	**1**	0	0	**1**	0	0

conflict

Sample Problem



Interference Matrix **I**:

$$\begin{pmatrix} 5 & 4 & 0 & 0 \\ 4 & 5 & 0 & 1 \\ 0 & 0 & 5 & 2 \\ 0 & 1 & 2 & 5 \end{pmatrix}$$

Traffic Vector **T**:

1 1 1 3

Optimal Allocation **A***- 0 conflicts, cost 0

channels →

cells ↓

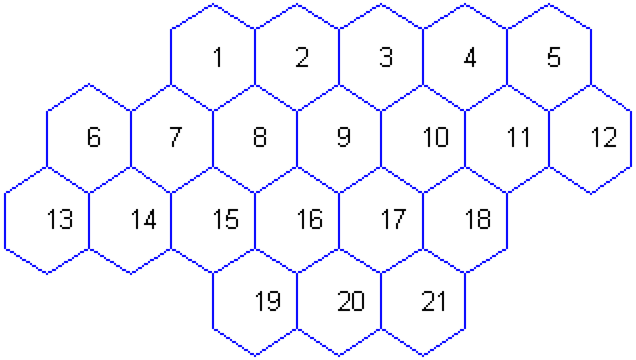
0	0	0	0	0	0	0	0	0	1	0
0	0	1	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0
1	0	0	0	0	1	0	0	0	0	1

Note: There may not always be a 0 cost assignment.

Still, fewer conflicts $\Rightarrow$ better call quality, lower call blocking rate.

The Philadelphia Problem

Known to take at least 258 channels to get conflict free assignment!
Size of search space: $({}^{5418}C_{470})$



Interference Matrix:

5	2	1	0	0	1	2	2	1	0	0	0	0	1	1	1	0	0	0	0	0
2	5	2	1	0	0	1	2	2	1	0	0	0	0	1	1	1	0	0	0	0
1	2	5	2	1	0	0	1	2	2	1	0	0	0	0	1	1	1	0	0	0
0	1	2	5	2	0	0	0	1	2	2	1	0	0	0	0	1	1	0	0	0
0	0	1	2	5	0	0	0	0	1	2	2	0	0	0	0	0	1	0	0	0
1	0	0	0	0	5	2	1	0	0	0	0	2	2	1	0	0	0	0	0	0
2	1	0	0	0	2	5	2	1	0	0	0	1	2	2	1	0	0	1	0	0
2	2	1	0	0	1	2	5	2	1	0	0	0	1	2	2	1	0	1	1	0
1	2	2	1	0	0	1	2	5	2	1	0	0	0	1	2	2	1	1	1	1
0	1	2	2	1	0	0	1	2	5	2	1	0	0	0	1	2	2	0	1	1
0	0	1	2	2	0	0	0	1	2	5	2	0	0	0	0	1	2	0	0	1
0	0	0	1	2	0	0	0	0	1	2	5	0	0	0	0	0	1	0	0	0
0	0	0	0	0	2	1	0	0	0	0	0	5	2	1	0	0	0	0	0	0
1	0	0	0	0	2	2	1	0	0	0	0	2	5	2	1	0	0	1	0	0
1	1	0	0	0	1	2	2	1	0	0	0	1	2	5	2	1	0	2	1	0
1	1	1	0	0	0	1	2	2	1	0	0	0	1	2	5	2	1	2	2	1
0	1	1	1	0	0	0	1	2	2	1	0	0	0	1	2	5	2	1	2	2
0	0	1	1	1	0	0	0	1	2	2	1	0	0	0	1	2	5	0	1	2
0	0	0	0	0	0	1	1	1	0	0	0	0	1	2	2	1	0	5	2	1
0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	2	2	1	2	5	2
0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	2	2	1	2	5

Traffic Vector: 5 5 5 8 12 25 30 25 30 40 40 45 20 30 25 15 15 30 20 20 25

Using Heuristic Search

- The Channel Allocation Problem is known to be NP-complete
- Problem representation:
  - Treat **A** matrix as a row vector
  - Cost function: Given **A,** the number of "conflicts" (interference constraint violations) is the cost.
  - Neighborhoods for Simulated Annealing, Taboo Search, Genetic Algorithms : must preserve the number of 1s in each row of **A**

Using Heuristic Search

- Possible neighborhoods for SA, GS / Mutation for GA:
  1. Pick a 0 bit in one of the rows of A and invert it. Also pick a 1 bit in the same row and invert at the same time.
  2. With probability P_m mutate a given bit, if inverting from 0 to 1, pick some other 1-bit at random and invert it to 0 and vice-versa

- Crossover for GA: Perform crossover points at ends of rows. In other words, treat all allocations for a single cell as one indivisible unit/gene.

Neighborhood Schemes

Representation of decision variables

A

0	0	1	0
1	1	0	0
0	0	0	1

→ 0 0 1 0 1 1 0 0 0 0 0 1

Possible neighbor for SA, TS or mutation for GA

0 0 1 0 1 1 0 0 0 0 0 1 → 0 0 1 0 1 0 0 1 0 0 0 1

Crossover for GA

0 0 1 0 | 0 0 1 1 0 1 0 0

1 0 0 0 | 1 0 0 1 0 0 0 1

0 0 1 0 1 0 0 1 0 0 0 1

1 0 0 0 0 0 1 1 0 1 0 0

Crossover point (only at end of a row in **A**)

Ad Hoc Networks

- An ad hoc network is a network of nodes in which routing and other network layer functionality resides primarily in the nodes, as opposed to a dedicated infrastructure. [Goldsmith/Wicker 2002]

- We allocate channels to users instead of base stations.

- Problem
  - Interference matrix?
  - Traffic vector?
  - Allocation vector?

Suggested References

- Bhaskar Krishnamachari and Stephen B. Wicker, "Global Search Techniques for Problems in Mobile Communications,“ in *Telecommunications Optimization: Adaptive and Heuristic Approaches*, Eds. David Corne et al., John Wiley & Sons Publishers, October 2000.
- Andrea Goldsmith And Stephen B. Wicker, "Design Challenges For Energy-Constrained Ad Hoc Wireless Networks," *IEEE Wireless Communications Magazine*, August, 2002.
- Stephen B. Wicker, “Digital Telephony and the Question of Privacy,” *Communications of the ACM,* Vol. 54, No. 7, July, 2011, pp. 88 – 98.