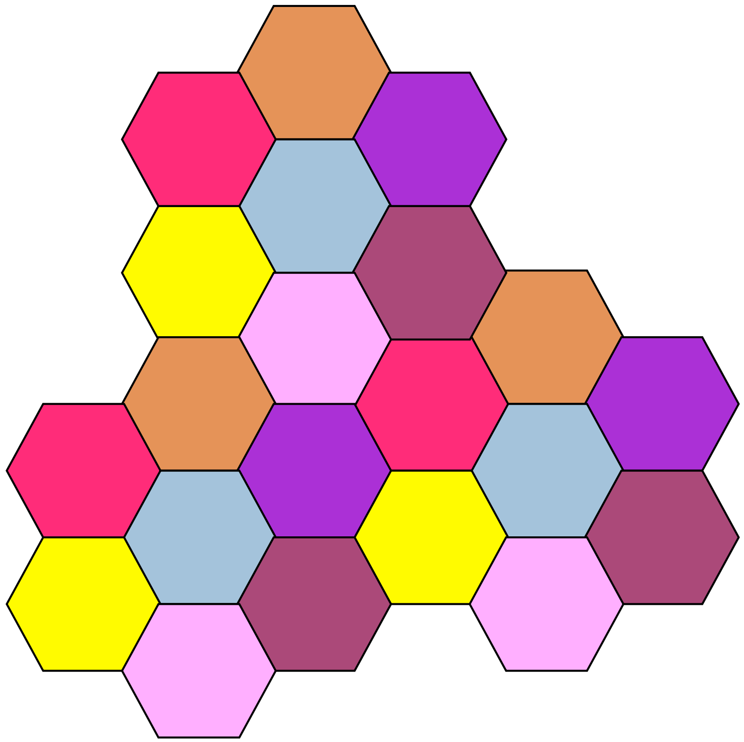
LECTURE 12

Deployment and Traffic Engineering

Cellular Concept

- Proposed by Bell Labs in 1971
- Geographic Service divided into smaller "cells"
- Neighboring cells do not use same set of frequencies to prevent interference
- Often approximate coverage area of a cell by an idealized hexagon
- Increase system capacity by frequency reuse



The Cellular Concept

- Deploy a large number of low-power transmitters (Base Stations) each having a limited coverage area
- Reuse the spectrum several times in the area to be covered to increase capacity
- Issues:
  - Capacity (traffic load) in a cell
    - One measure = number of *communication channels* that are available
  - Performance
    - Call blocking probability, handoff dropping probability, throughput etc.
  - Interference

Cellular Concept

- Why not a large radio tower and large service area?
  - Number of simultaneous users would be very limited (to total number of traffic channels *T*)
  - Mobile handset would have greater power requirement
- Cellular concept - small cells with frequency reuse
  - Advantages
    - Lower power handsets
    - Increases system capacity with frequency reuse
  - Drawbacks:
    - Cost of cells
    - Handoffs between cells must be supported
    - Need to track user to route incoming call/message

Communication Channel

- A frequency band allocated for voice or data communications
  - Simplest example: Frequency division multiple access (FDMA) with Frequency Division Duplexing (FDD)
    - 30 kHz bands are allocated for one conversation
    - Separate bands are allocated for uplink (MH to BS) and downlink (BS to MH)
- A set of time slots allocated for voice or data communications
- A set of spread-spectrum codes allocated for voice or data communications

Types of Interference

- TDMA/FDMA based systems
  - Co-channel interference
    - Interference from signals transmitted by another cell using the same radio spectrum
  - Adjacent channel interference
    - Interference from signals transmitted in the same cell with overlapping spectral sidelobes
- CDMA systems
  - Interference from within the cell
  - Interference from outside the cell

Clustering in TDMA/FDMA

- Adjacent cells CANNOT use the same channels
  - Co-channel interference will be too severe
- The available spectrum is divided into chunks (sub-bands) that are distributed among the cells
- Cells are grouped into clusters
  - Each cluster of cells employ the entire available radio spectrum
  - The spatial allocation of sub-bands has to be done to minimize interference

Cellular Concept (cont)

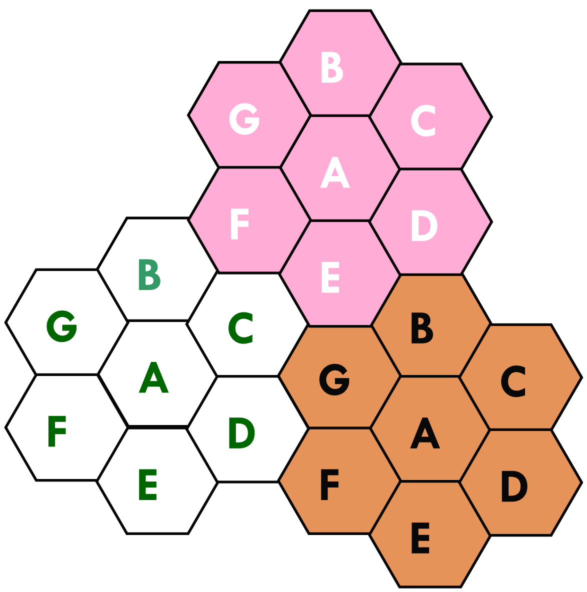
- Let T = total number of duplex channels

  K cells = size of cell cluster (typically 4, 7,9,12, 21)

  $N = T/K$ = number of channels per cell
- For a specific geographic area, if clusters are replicated M times, then total number of channels
  - System capacity = $M \times T$
  - Choice of K determines distance between cells using the same frequencies – termed co-channel cells
  - K depends on how much interference can be tolerated by mobile stations and path loss

Cell Design - Reuse Pattern

- Example: cell cluster size $K = 7$, frequency reuse factor $= 1/7$;
- Assume $T = 490$ total channels, $N = T/K = 70$ channels per cell



Assume T = 490 total channels, K = 7, N = 70 channels/cell

Clusters are replicated M=3 times

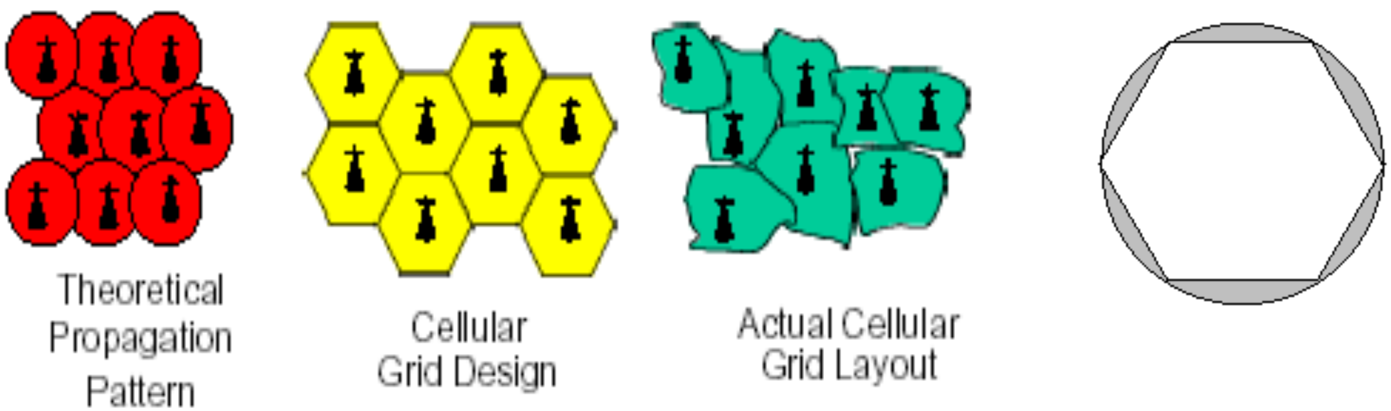
System capacity = 3x490 = 1470 total channels

Cellular Geometry

- Cells do not have a "nice" shape in reality
- A model is required for
  - Planning the architecture
  - Evaluating performance
  - Predict future requirements
- Simple Model:
  - All cells are identical
  - There are no ambiguous areas
  - There are no areas that are NOT covered by any cell

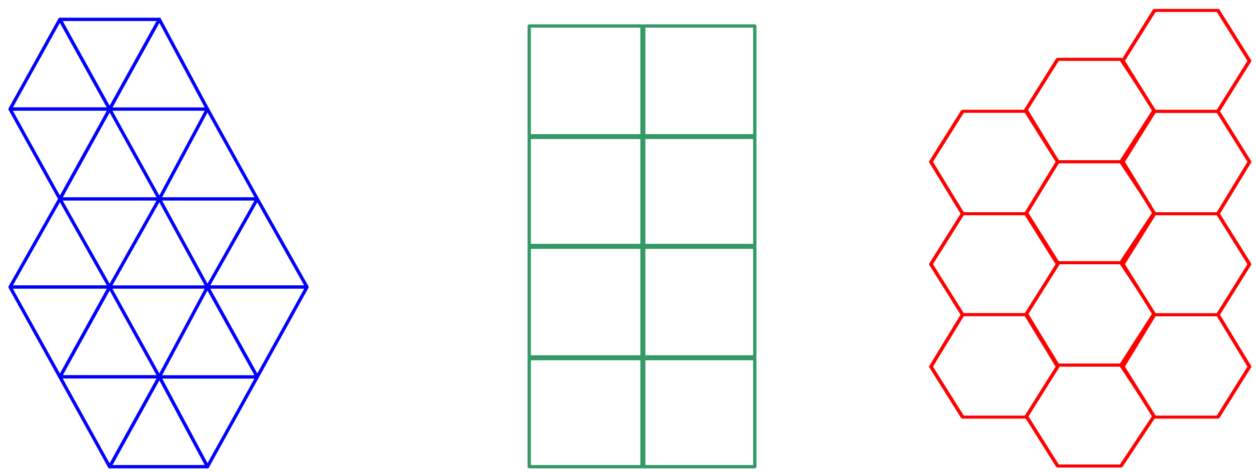
Cellular Geometry

- Propagation models represent cell as a circular area
- Approximate cell coverage with a hexagon - allows easier analysis
- Frequency assignment of *F* MHz for the system
- The multiple access techniques translates *F* to *T* traffic channels
- Cluster of cells *K* = group of adjacent cells which use all of the systems frequency assignment



Possibilities for cell geometry

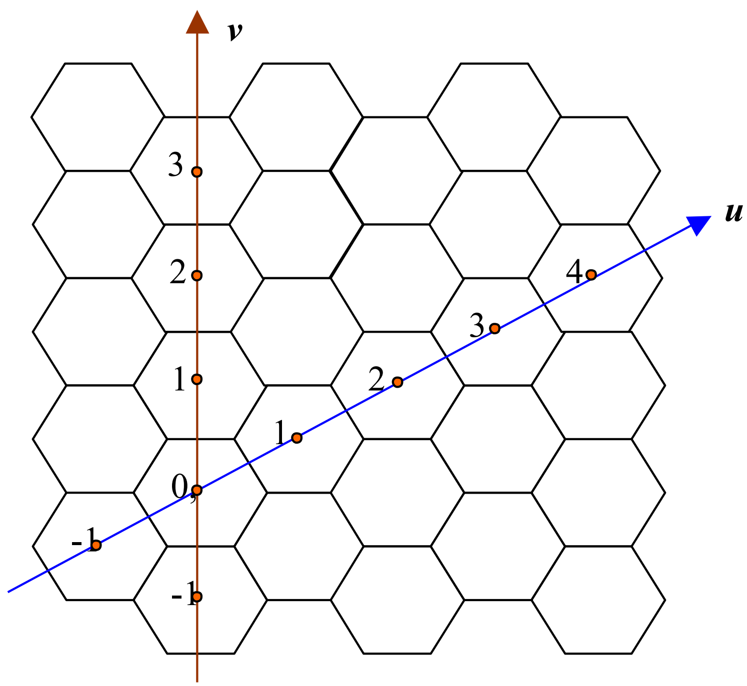
- Equilateral triangle, square or regular hexagon



Why hexagon?

- Among the three choices, the hexagon is the closest approximation to a circle
- For a given radius (largest possible distance from center of a polygon to its edge) a hexagon has the largest area
- A circle is sometimes used when continuous distributions are being considered

Determining co-channel cells and the reuse factor

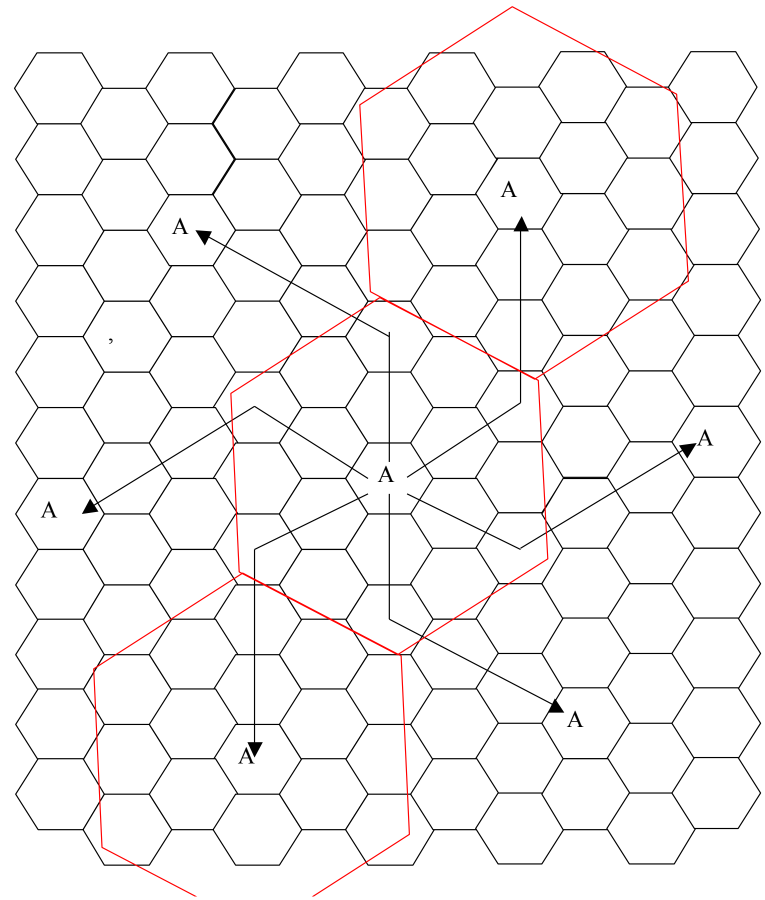


Cells are placed so that their centers have integer co-ordinates

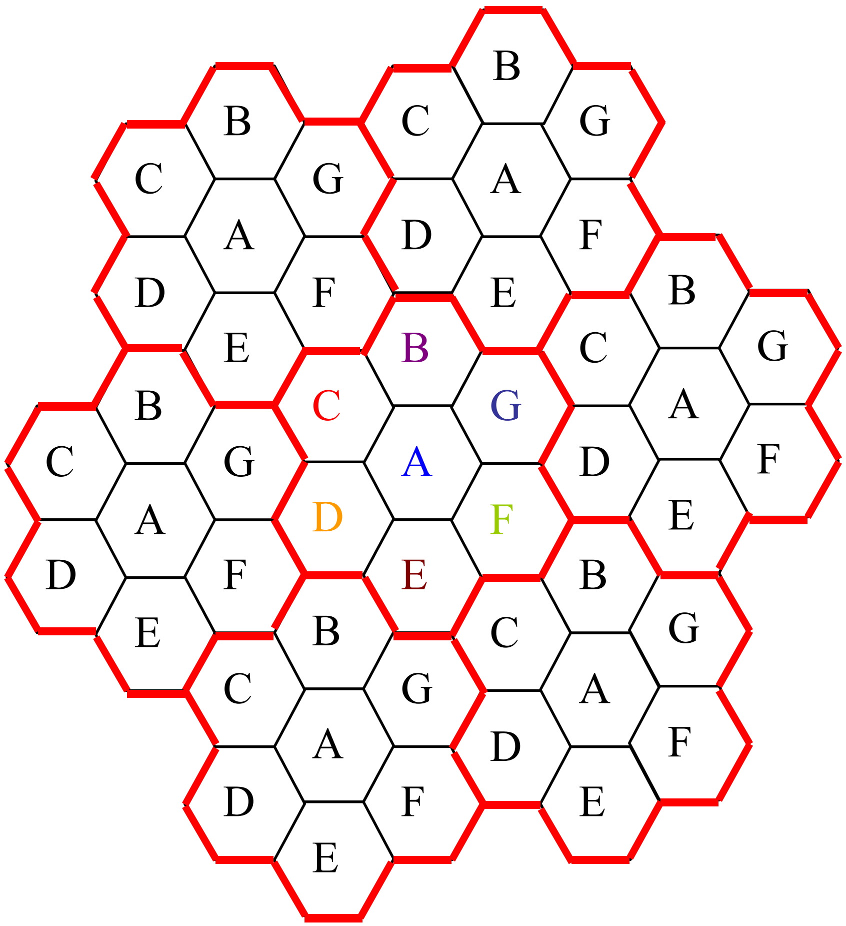
- Co-channel cells must be placed as far apart as possible for a *given cluster size*
- Hexagonal geometry has some properties that can be employed to determine the co-channel cell
- Co-ordinate system: u and v co-ordinates

Finding Co-channel cells (continued)

- Move a distance i along the u direction and a distance j along the v direction
- The cluster size $K = i^2 + ij + j^2$



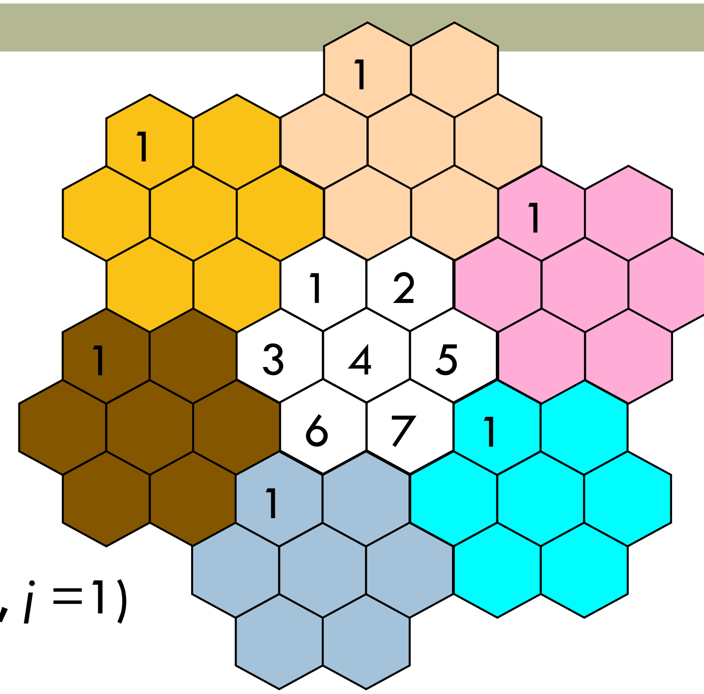
Example: i = 2, j = 1



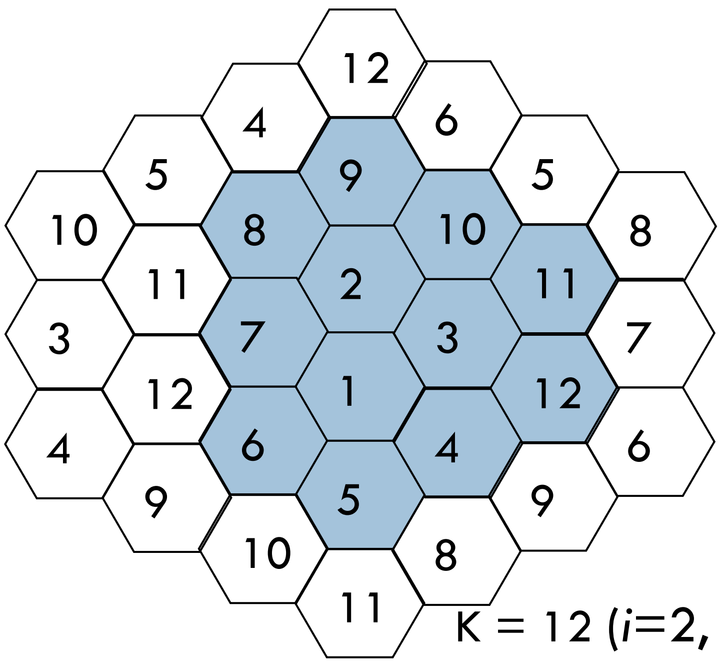
Cluster size
$K = 7$

Used in
Advanced Mobile
Phone Service (AMPS)

More Examples

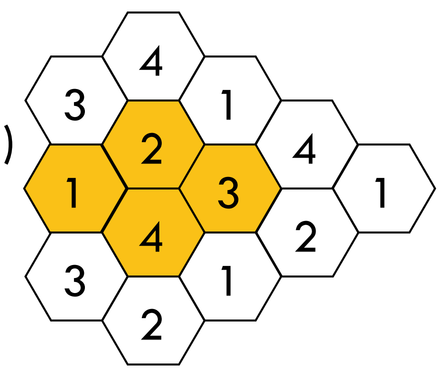


K = 7 (i =2, j =1)



K = 12 (i=2, j=2)

K = 4 (i =2, j=0)



Some results

- K = number of cells in a cluster
- R = radius of a cell
- D = distance between co-channel cells

$$\frac{D}{R} = \sqrt{3K}$$

- K can only take values that are of the form $i^2 + ij + j^2$; i, j are integers
- There are exactly six co-channel cells for a hexagonal geometry

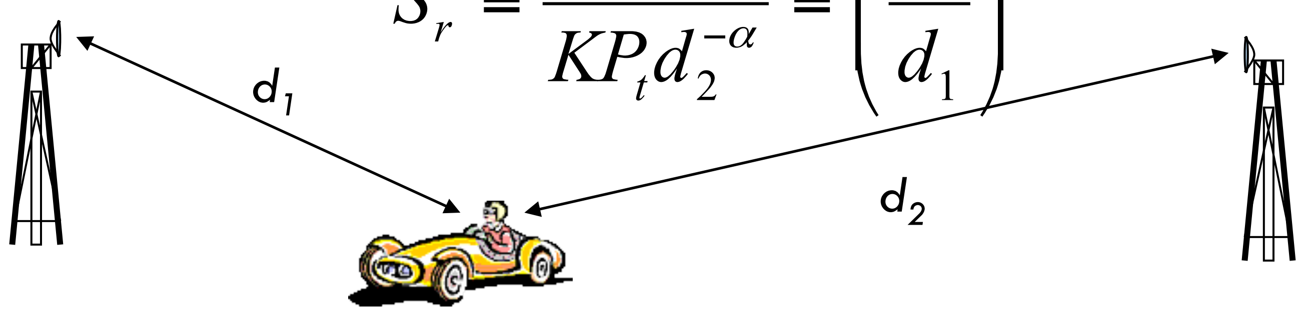
Issues Revisited

- Cluster size *K* determines
  - The co-channel interference
  - The number of channels allocated to a cell
  - Larger *K* is, smaller is the co-channel interference
  - Larger *K* is, smaller is the number of channels available for a given cell
    - Capacity reduces
- SIR or C/I

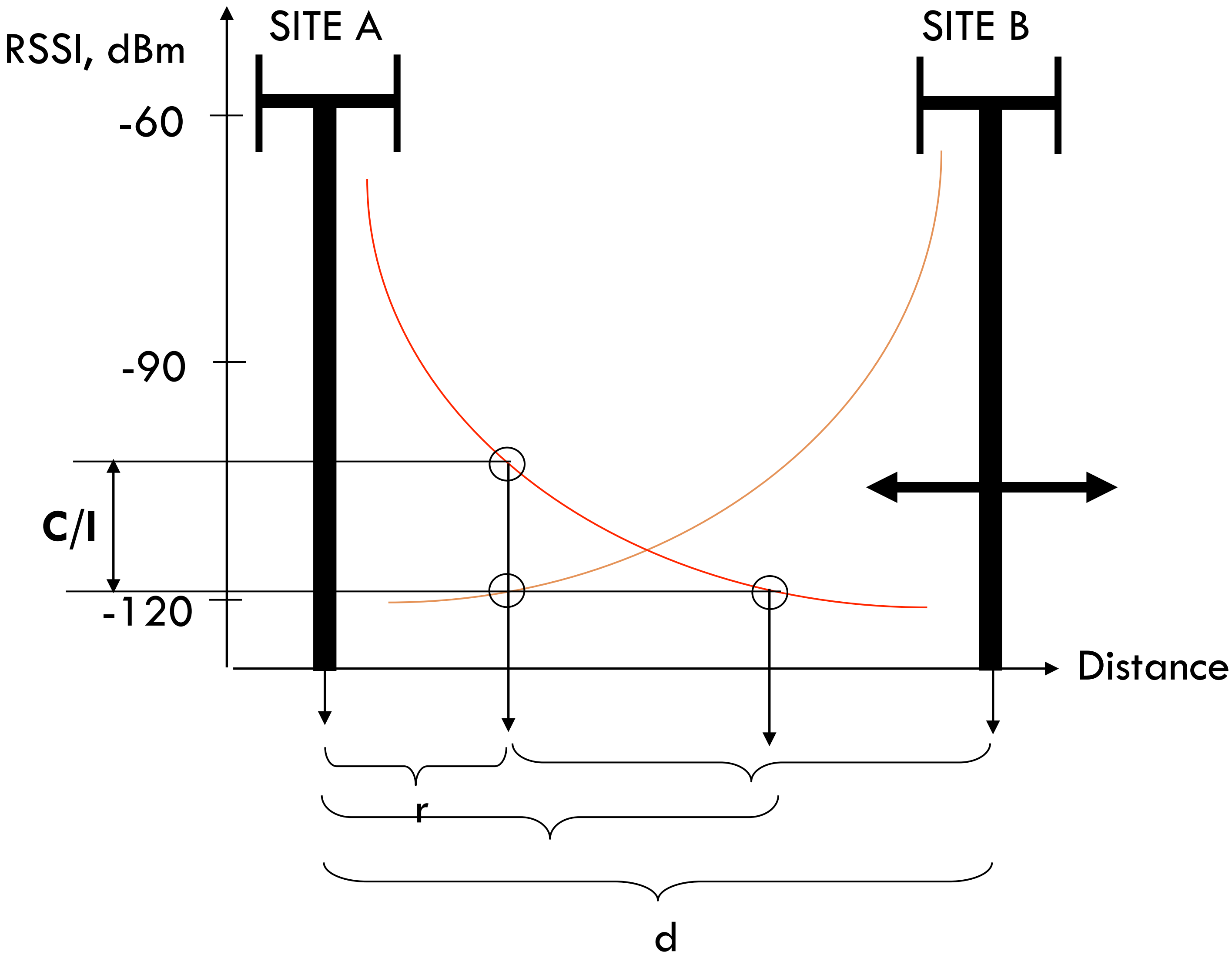
Signal to interference ratio calculation

- General: $$S_r = \frac{P_{desired}}{\sum_i P_{interference,i}}$$
- One desired signal and one interfering signal at distances d_1 and d_2

$$S_r = \frac{KP_t d_1^{-\alpha}}{KP_t d_2^{-\alpha}} = \left(\frac{d_2}{d_1}\right)^{\alpha}$$



SIR Calculation



S_r in a hexagonal architecture

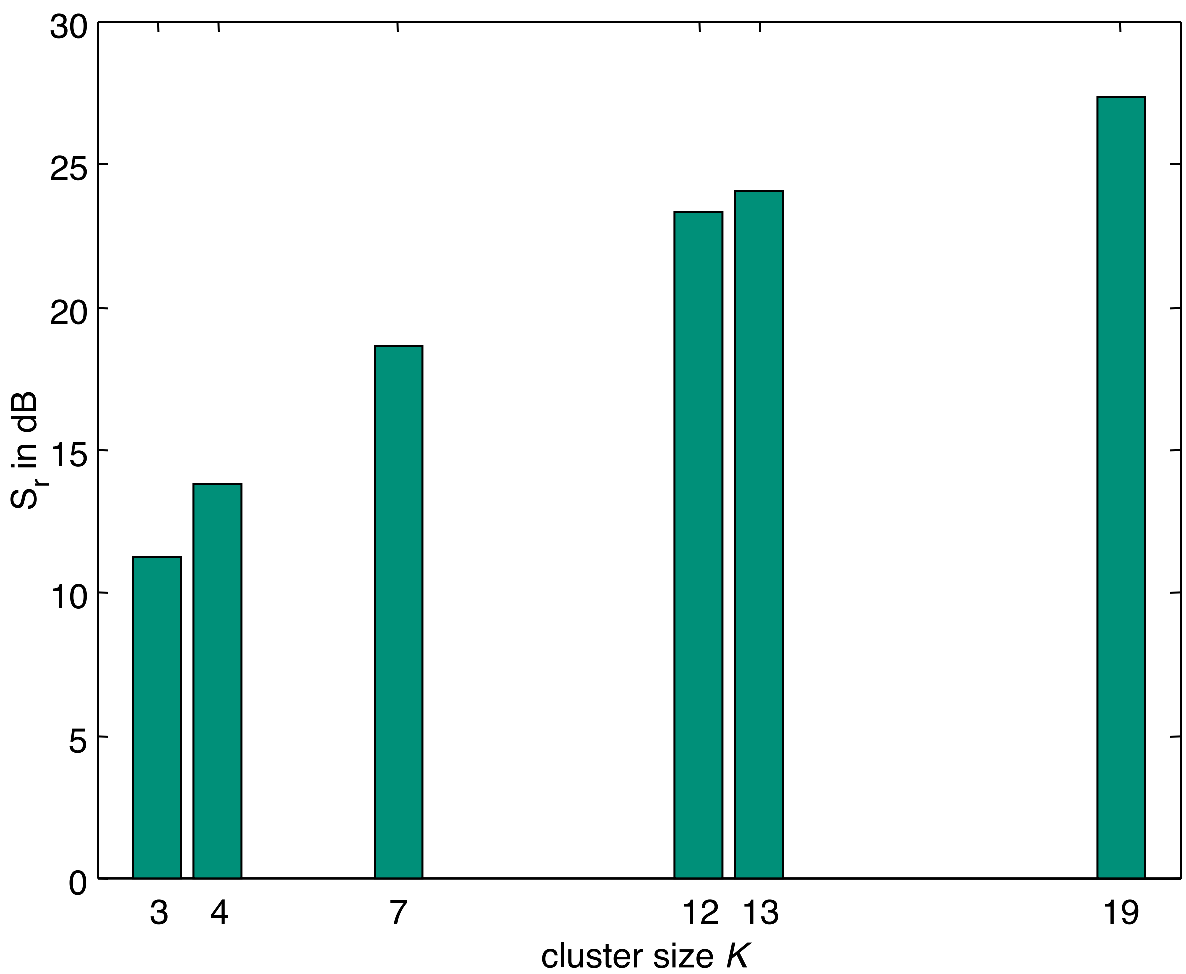
- With J_s interfering base stations

$$S_r = \frac{d_0^{\alpha}}{\sum_{n=1}^{J_s} d_n^{\alpha}}$$

  - $J_s = 6$ for a hexagonal architecture
  - $\alpha = 4$ for urban areas
- Maximum distance of the MS from a desired BS is *R*
- Approximate distance of the MS from each of the co-channel interferers is *D*
- The expression for S_r is:

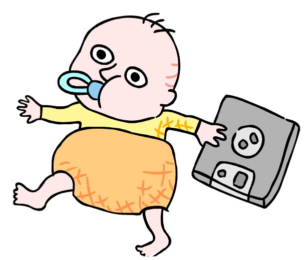
$$S_r \approx \frac{R^{-4}}{J_s D^{-4}} = \frac{R^{-4}}{6D^{-4}} = \frac{1}{6}\left(\frac{D}{R}\right)^4 = \frac{3}{2}K^2$$

S_r as a function of the cluster size



First Generation Cellular Systems

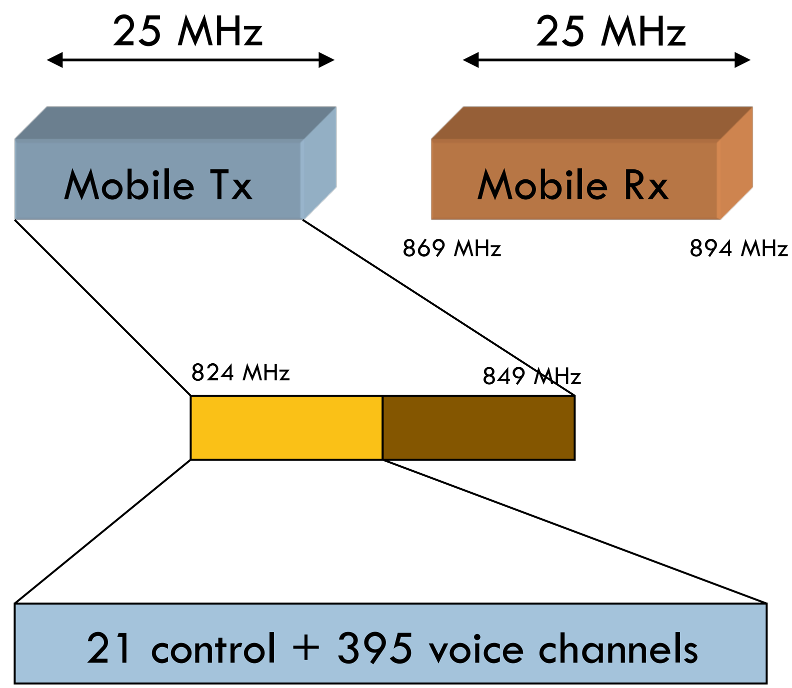
- Goal: Provide basic voice service to mobile users over large area
- 1 G Systems developed late 70's early 80's, deployed in 80's
  - Advanced Mobile Phone System (AMPS) - USA
  - Total Access Communications Systems (TACS) - UK
  - Nordic Mobile Telephone (NMT) System – Scandinavian PTTs
  - C450 - W. Germany
  - NTT System - Nippon Telephone & Telegraph (NTT) – Japan
- Incompatible systems using different frequencies!
  - Have similar characteristics though



OR

Example: AMPS

- Voice channels occupy 30 kHz and use frequency modulation (FM)
- 25 MHz is allocated to the uplink and 25 MHz for the downlink
- 12.5 MHz is allocated to non-traditional telephone service providers (Block A)
- 12.5 MHz / 30 kHz = 416 channels
- 395 are dedicated for voice and 21 for control



Reuse in AMPS

- Subjective voice quality tests indicate that $S_r = 18$ dB is needed for good voice quality
- This implies $K = 7$
  - See next slide also
- Cells do not actually conform to a hexagonal shape and usually a reuse factor of $K = 12$ is needed

Frequency Reuse

Solving for D/R results in

$$\frac{D}{R} = \left(6\frac{C}{I}\right)^{1/\alpha}$$

Remember $D/R = \sqrt{3K}$,

which results in

$$K = \frac{1}{3}\left(6\frac{C}{I}\right)^{2/\alpha}$$

Example: Consider cellular system with

- C/I or S_r requirement of 18 dB
- Suburban propagation environment with α = 4.

Determine the minimum cluster size.

18 dB ➔ 18 = 10log(x) ➔
1.8 = log(x) ➔ $x = 10^{1.8}$ ➔
X = 63.0957,

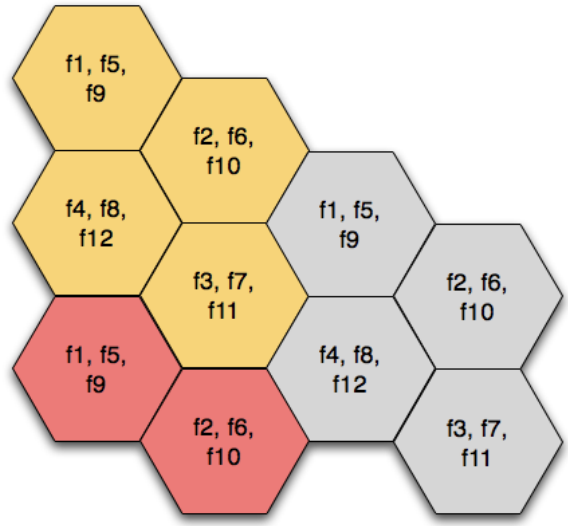
$K = 1/3 \times (6 \times 63.0957)^{0.5} = 6.4857$

Since K must be an integer, you round up to nearest feasible cluster size
=> $K = 7$

AMPS: Adjacent channel interference

- Cluster size is N = 7
- Consider the 395 voice channels
  - 1: 869.00 – 869.03 MHz
  - 2: 869.03 – 869.06 MHz …
- Cell A is allocated channels 1,8,15…
- Cell B is allocated channels 2,9,16…
- Channels within the cell have sufficient separation so that adjacent channel interference is minimized

Frequency Assignment



- Typical C/I values used in practice are 13-18 dB.
- Once the frequency reuse cluster size K is determined, frequencies must be assigned to cells
- Must maintain C/I pattern between clusters
- Within a cluster – seek to minimize adjacent channel interference
- Adjacent channel interference is interference from frequency adjacent in the spectrum

- Example: You are operating a cellular network with 25KHz NMT traffic channels 1 through 12.
  - Label the traffic channels as {f1, f2, f3, f4, f5, f6, f7, f8, f9, f10, f11, f12}
  - Place the traffic channels in the cells above such that a frequency reuse cluster size of 4 is used and adjacent channel interference is minimized

Capacity Expansion

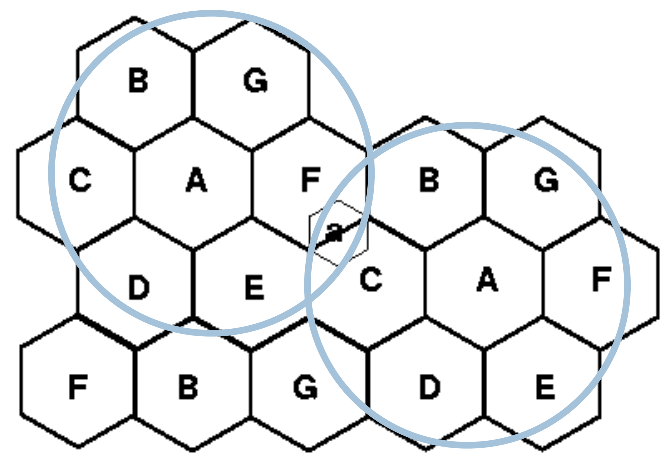
- Main investment in deploying a cellular network is the cost of infrastructure, land, base station equipment, switches installation, interconnection, etc.
- Income is proportional to subscriber base
- Initial installment may not be able to support increasing subscriber demand
- How can capacity be increased without replicating deployment?

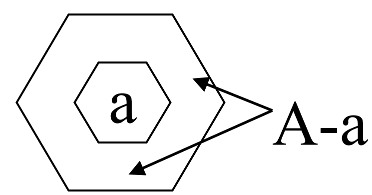
Techniques to expand capacity

- Additional spectrum
  - Very hard to obtain
  - 1900 MHz bands for PCS; 700 MHz bands from TV
- Architectural approaches
  - Cell splitting
  - Cell sectorization
  - Reuse partitioning
  - Lee's microcell zone technique
- Changing to digital – TDMA or CDMA
- Dynamic channel allocation

Cell Splitting

- Hotspots are created in certain areas
- Introduce a smaller cell of half the size midway between two co-channel cells
- Interference problems
- Channels must be split between the larger and smaller cells

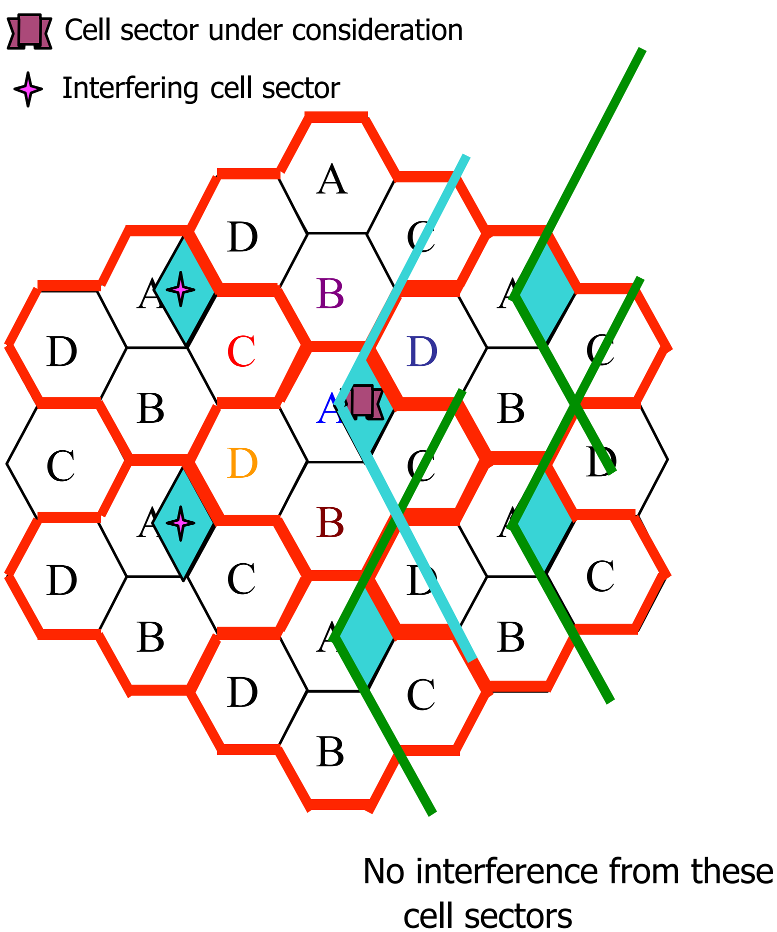




Cell Sectoring

- Use directional antennas to reduce interference
- Radio propagation is focused in certain directions
  - Antenna coverage is restricted to part of a cell called a sector
- By reducing interference, the cluster size can be reduced (J_s is reduced, and so we can reduce *N*)

Three-sector cells and a cluster size of $K = 4$

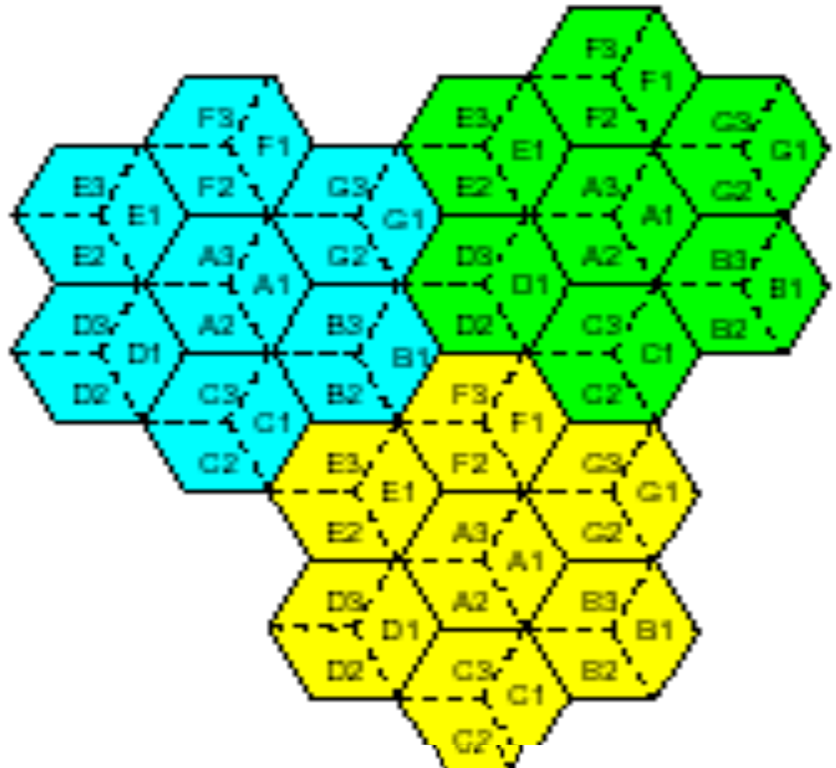


- 120° directional antennas are employed
- Channels allocated to a cell are further divided into three parts
- Without directional antennas, S_r = 13.8 dB which is inadequate
- With directional antennas, S_r = 18.5 dB

$$S_r \approx \frac{R^{-4}}{J_s D^{-4}} = \frac{R^{-4}}{2D^{-4}} = \frac{1}{2}\left(\frac{D}{R}\right)^4 = \frac{9}{2}K^2$$

Sectored Frequency Planning

- Example: Allocate frequencies for a GSM operator in U.S. PCS B-block who uses a 7 cell frequency reuse pattern with 3 sectors per cell
- Use a Frequency Chart – available from FCC web site
- Groups frequencies into 21 categories Cells A-G and sectors 1-3 in each cell



Frequency Chart . 612-685 represent B-block frequencies for GSM

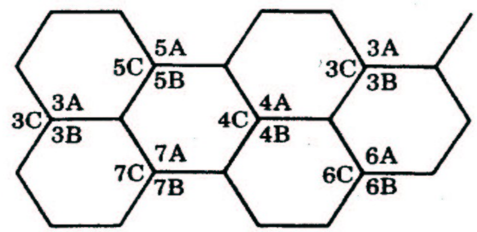
A1	B1	C1	D1	E1	F1	G1	A2	B2	C2	D2	E2	F2	G2	A3	B3	C3	D3	E3	F3	G3
612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632
633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653
654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674
675	676	677	678	679	680	681	682	683	684	685										

Sectored Frequency Planning

- Example: Allocate frequencies for an AMPS operator in cellular B-block who uses a 7 cell frequency reuse pattern with 3 sectors per cell
- Use a Frequency Chart – available from FCC web site
  - Groups frequencies into 21 categories Cells 1-7 and sectors A-B-C in each cell

Block B

1A	2A	3A	4A	5A	6A	7A	1B	2B	3B	4B	5B	6B	7B	1C	2C	3C	4C	5C	6C	7C
334	**335**	**336**	**337**	**338**	**339**	**340**	**341**	**342**	**343**	**344**	**345**	**346**	**347**	**348**	**349**	**350**	**351**	**352**	**353**	**354**
355	356	357	358	359	360	361														375
376	377	378	379	380	381	382														396
397	398	399	400	401	402	403														417
418	419	420	421	422	423	424														438
439	440	441	442	443	444	445														459
460	461	462	463	464	465	466														480
481	482	483	484	485	486	487														501
502	503	504	505	506	507	508														522
523	524	525	526	527	528	529														543
544	545	546	547	548	549	550														564
565	566	567	568	569	570	571														585
586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606
607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627
628	628	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648
649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	717	718	719
720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740
741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761
762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782
783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799				

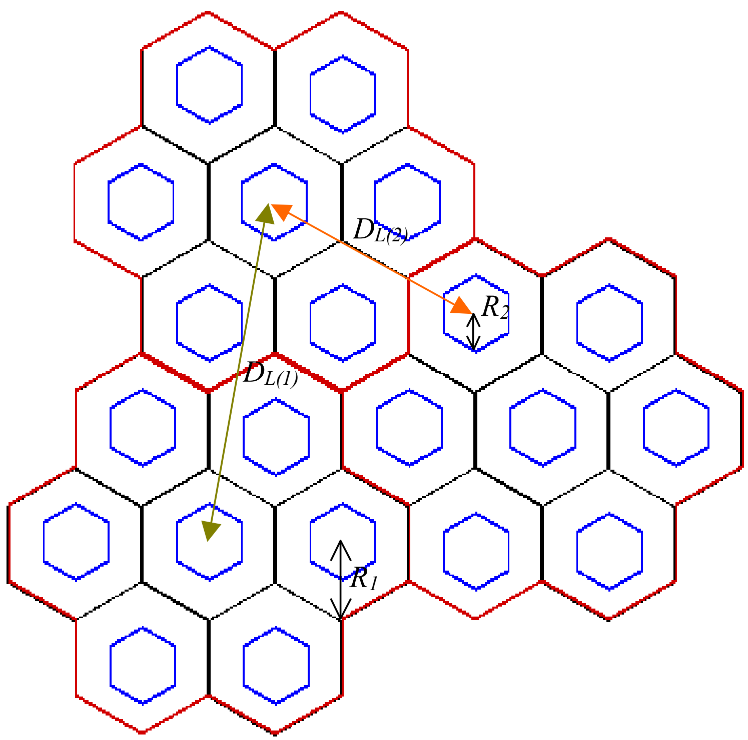


*Boldface numbers indicate 21 control channels for Block A and Block B respectively.

Summary: Cell sectoring

- The cluster size can be reduced by employing directional antennas
- Sectoring is better than splitting
  - No new base station has to be set up
  - No new planning efforts are needed to maintain interference levels
- Sectoring leads to handoff between sectors which increased signaling load and loss of quality
- A cell cannot be ideally sectored and the signal to interference values obtained here are optimistic

The Overlaid Cell Concept



- Channels are divided between a larger macro-cell that co-exists with a smaller micro-cell that is completely contained within the macro-cell
- D_2/R_2 is larger than D_1/R_1
- Split-band analog systems
- Reuse partitioning

Split band analog systems

- Use 15 kHz voice channels instead of 30 kHz voice channels
- 15 kHz channels need S_r of 24 dB which is 6 dB larger
  - In FM, the bandwidth is proportional to the required SNR
- Suppose $R_2 = (1/\sqrt{2})\, R_1$ (is S_r satisfied?)
  - Area of the micro-cell is ½ area of the macro-cell
  - Same number of channels for micro and macro cells
- If the number of channels in a cluster per overlay is M, then:
  - M(15 + 30) = 395 x 30
    - Recall – AMPS has 395 Voice can accommodate 395 voice channels each 30 kHz wide.
  - M = 263 => there are 526 channels per cluster
    - 263 15 kHz channels + 263 30 kHz channels
  - Capacity gain of 33%

Traffic Engineering

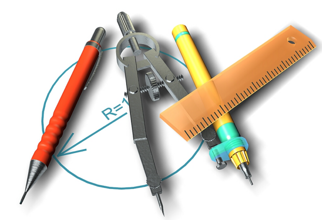
- Cells - deploy a large number of low-power base stations - each having a limited coverage area
- Reuse the spectrum several times in the area to be covered to increase capacity
- Issues:
  - Capacity (traffic load) in a cell
    - One measure = number of ***communication channels*** that are available
  - Performance
    - Call blocking probability, handoff dropping probability, throughput etc.
  - Interference

Traffic Engineering (2)

- Questions:
  - If I want to place a call, what is the probability that I will NOT get a communication channel?
    - "New call admission"
  - If I am moving from cell to cell, what is the probability that during a call, I will NOT find a communication channel in the new cell to continue my call?
    - "Handoff call admission"

Grade of Service

- Grade of service
  - Usually 2% blocking probability during busy hour
  - Busy hour may be
    1. Busy hour at busiest cell
    2. System busy hour
    3. System average over all hours



- Given $c = T/K$ traffic channels per cell – what is the grade of service (GoS)?
  - How many users can be supported for a specific GoS?
- Basic analysis called *Traffic Engineering or Trunking*
  - Same as circuit switched telephony
  - Use Erlang B and Erlang C Models

Erlangs - 1

- Let there be $c = T/K$ channels per cell
- In a given time period, suppose there are Q *active* users
  - If $Q = c$, any new call will be blocked with probability 1
  - If $Q < c$, then your call may get a channel
- How do we quantify this better?
  - Erlangs

Erlangs - 2

- How do you estimate traffic distribution?
  - Traffic intensity is measured in Erlangs
  - One Erlang = completely occupied channel for 60 minutes
- Examples
  - 30 kHz voice channel occupied for 30 min/hour carries 0.5 Erlangs
  - 100 calls in one hour each lasting 3 minutes = 100 calls/hour × 3/60 = 5 Erlangs

- Agner Krarup Erlang
- Scientist with the Copenhagen Telephone Company
- Studied data from a village's telephone calls to arrive at his conclusions

More on Erlangs

- Traffic intensity per user A_u
  - A_u = average call request rate × average holding time = $\lambda \times t_h$
- Total traffic intensity = traffic intensity per user × number of users = $A_u \times n_u$
- Example:
  - 100 subscribers in a cell
  - 20 make 1 call/hour for 6 min => 20 × 1 × 6/60 = 2E
  - 20 make 3 calls/hour for ½ min => 20 × 3 × .5/60 = 0.5E
  - 60 make 1 call/hour for 1 min => 60 × 1 × 1/60 = 1E
  - 100 users produce 3.5 E load or 35 mE per user

Notation associated with queues

- Written as P/Q/R/S
  - P: Description of arriving traffic
  - Q: Description of service rates or times
  - R: Number of servers
  - S: Number of users that can be in the system (includes those being served and those waiting)
- M => Markov (Poisson arrival times, exponential service times)
  - Commonly used as it is tractable and it fits voice calls
- If the number of users that can be in the system (S) is infinite, it is dropped from the notation

Erlang B Model: M/M/c/c queue

- To estimate the performance of a trunked system use the Erlang B queueing model
- The system has a finite capacity of size c
  - Customers arriving when all servers busy are dropped
- *Blocked calls cleared model (BCC)* (no buffer)
- Assumptions
  - c identical servers process customers in parallel
  - Customers arrive according to a Poisson process (average of λ calls/s)
  - Customer service times exponentially distributed (average of $1/\mu$ seconds per call)
- The offered traffic intensity is $a = \lambda / \mu$ in Erlangs

Erlang B Formula or Blocking Formula

- Probability of a call being blocked *B*(*c*,*a*)

$$B(c,a) = \frac{\frac{a^c}{c!}}{\sum_{n=0}^{c} \frac{a^n}{n!}}$$

- Erlang B formula can be computed from the recursive formula

$$B(c,a) = \frac{a \cdot B(c-1,a)}{c + a \cdot B(c-1,a)}$$

- Usually determined from table or charts

Example of Erlang B Calculation

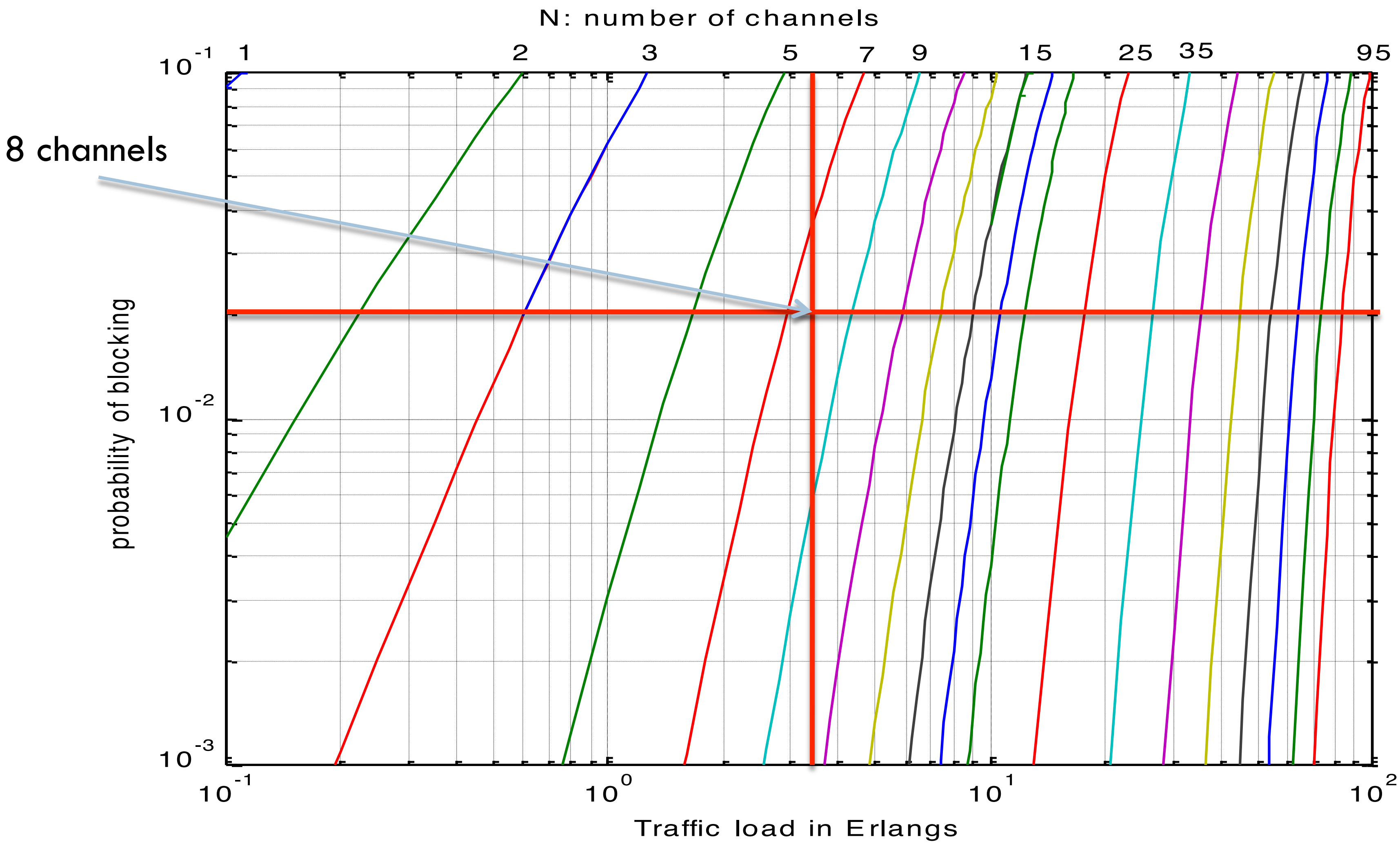
- For 100 users with a traffic load of 3.5 E, how many channels are need in a cell to support 2% call blocking ?
  - Use Erlang B tables or charts
  - With a 2% call blocking, we need 8 channels

Sample Erlang B table

(Erlang *B*)

	A, erlangs												
	B												
N	1.0%	1.2%	1.5%	2%	3%	5%	7%	10%	15%	20%	30%	40%	50%
1	.0101	.0121	.0152	.0204	.0309	.0526	.0753	.111	.176	.250	.429	.667	1.00
2	.153	.168	.190	.223	.282	.381	.470	.595	.796	1.00	1.45	2.00	2.73
3	.455	.489	.535	.602	.715	.899	1.06	1.27	1.60	1.93	2.63	3.48	4.59
4	.869	.922	.992	1.09	1.26	1.52	1.75	2.05	2.50	2.95	3.39	5.02	6.50
5	1.36	1.43	1.52	1.66	1.88	2.22	2.50	2.88	3.45	4.01	5.19	6.60	8.44
6	1.91	2.00	2.11	2.28	2.54	2.96	3.30	3.76	4.44	5.11	6.51	8.19	10.4
7	2.50	2.60	2.74	2.94	3.25	3.74	4.14	4.67	5.46	6.23	7.86	9.80	12.4
8	3.13	3.25	3.40	3.63	3.99	4.54	5.00	5.60	6.50	7.37	9.21	11.4	14.3
9	3.78	3.92	4.09	4.34	4.75	5.37	5.88	6.55	7.55	8.52	10.6	13.0	16.3
10	4.46	4.61	4.81	5.08	5.53	6.22	6.78	7.51	8.62	9.68	12.0	14.7	18.3
11	5.16	5.32	5.54	5.84	6.33	7.08	7.69	8.49	9.69	10.9	13.3	16.3	20.3
12	5.88	6.05	6.29	6.61	7.14	7.95	8.61	9.47	10.8	12.0	14.7	18.0	22.2
13	6.61	6.80	7.05	7.40	7.97	8.83	9.54	10.5	11.9	13.2	16.1	19.6	24.2
14	7.35	7.56	7.82	8.20	8.80	9.73	10.5	11.5	13.0	14.4	17.5	21.2	26.2
15	8.11	8.33	8.61	9.01	9.65	10.6	11.4	12.5	14.1	15.6	18.9	22.9	28.2
16	8.88	9.11	9.41	9.83	10.5	11.5	12.4	13.5	15.2	16.8	20.3	24.5	30.2
17	9.65	9.89	10.2	10.7	11.4	12.5	13.4	14.5	16.3	18.0	21.7	26.2	32.2
18	10.4	10.7	11.0	11.5	12.2	13.4	14.3	15.5	17.4	19.2	23.1	27.8	34.2
19	11.2	11.5	11.8	12.3	13.1	14.3	15.3	16.6	18.5	20.4	24.5	29.5	36.2
20	12.0	12.3	12.7	13.2	14.0	15.2	16.3	17.6	19.6	21.6	25.9	31.2	38.2

Erlang B Chart



Example: Using Erlang B for traffic engineering

- Consider a single analog cell tower with 56 traffic channels
  - When all channels are busy, calls are blocked
  - Calls arrive according to a Poisson process at an average rate of 1 call per active user per hour
  - During the busy hour ¾ of the users are active
  - The call holding time is exponentially distributed with a mean of 120 seconds

Example: Continued

- What is the maximum load the cell can support while providing 2% call blocking?
  - From the Erlang B table with c= 56 channels and 2% call blocking, the maximum load = 45.9 Erlangs
- What is the maximum number of users supported by the cell during the busy hour?
  - Load per active user = (1 call/3600 s) × (120 s/call) = 33.3 mErlangs
  - Number of active users = 45.9/(0.0333) = 1377
  - Total number of users = 4/3 number active users = 1836

Another Example

- Consider an AMPS system with 30 kHz channels, 4 sectors/cell, frequency reuse of $K = 9$, and 12.5 MHz of bandwidth.
  - Number of channels = $12.5 \times 10^6 / 30 \times 10^3 = 416$ channels
  - Say 20 are control channels => total number of voice channels = 396
  - Number of channels/cell = 396/9 = 44
  - Number of channels/sector = 44/4 = 11

Example (Continued)

- For a 2% blocking probability, from the Erlang B tables, the maximum traffic load is
  - For AMPS: 5.84 E
- If the average call duration is 3 minutes, and each call is 3/60 = 0.05 E
  - AMPS can support 116 calls/hour/sector

Handoff and Mobility

- A call will occupy a channel as long as a user is in the cell
  - If we assume cell residence time is exponential, then the channel occupancy = min(call holding time, cell residency time)
  - Also exponentially distributed
- Similar calculations can be done, but we ignore mobility and handoff here

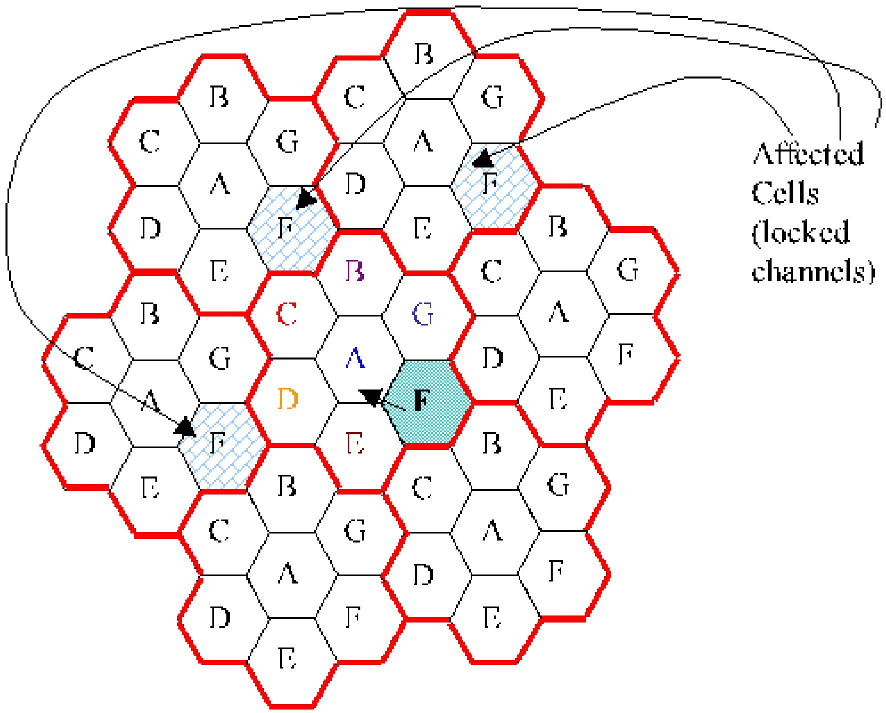
Channel Allocation Techniques

- Idea:
  - During the day on weekdays, downtown areas have a lot of demand for wireless channels
  - In weekends and evenings, suburban areas have a larger demand and downtown areas have very little demand
  - Instead of allocating channels statically to cells, allocate channels ***on demand*** while maintaining signal-to-interference ratio requirements
- The (voice) user does not care how the channels are allocated as long as
  - He/she gets access to the channel whenever required
  - The quality of the signal is acceptable

Channel Allocation Techniques (2)

- Fixed channel allocation (FCA)
  - Channel borrowing
- Dynamic channel allocation (DCA)
  - Centralized DCA
  - Distributed DCA
    - Cell-based
    - Measurement-based
- Hybrid channel allocation (HCA)

Channel borrowing



- Idea: Borrow channels from low loaded cells and return them whenever required
  - Temporary channel borrowing
    - Return channel after call is completed
    - Locks channel in co-channel cells
  - Static channel borrowing
    - Distribute channels non-uniformly but change them in a predictable way

Dynamic Channel Allocation

- All channels are placed in a pool
  - When a new call comes in, a channel is selected based on the overall SIR in the cell
  - Selection of the channel in this way is costly
    - Needs a search and computation of SIR values
- Centralized
  - A central entity selects channels for use and returns it to the pool after completion of calls
- Distributed
  - Base stations locally compute the channels that can be used
    - Cell-based – BSs communicate with each other on the wired backbone to determine the best way to select channels
    - Measurement-based – BSs measure RSS or receive RSS reports from MSs that they use in their decisions

Comparison of FCA and DCA

Attribute	Fixed Channel Allocation	Dynamic Channel Allocation
Traffic Load	Better under heavy traffic load	Better under light/moderate traffic load
Flexibility in channel allocation	Low	High
Reusability of channels	Maximum possible	Limited
Temporal and spatial changes	Very sensitive	Insensitive
Grade of service	Fluctuating	Stable
Forced Call Termination	Large probability	Low/moderate probability
Suitability of cell size	Macro-cellular	Micro-cellular
Radio equipment	Covers only the channels allocated to the cell	Has to cover all possible channels that could be assigned to the cell
Computational effort	Low	High
Call set up delay	Low	Moderate/High
Implementation complexity	Low	Moderate/High
Frequency planning	Laborious and complex	None
Signaling load	Low	Moderate/High
Control	Centralized	Centralized, decentralized or distributed