CHAPTER 7: Introduction to Cells

Cellular network concept

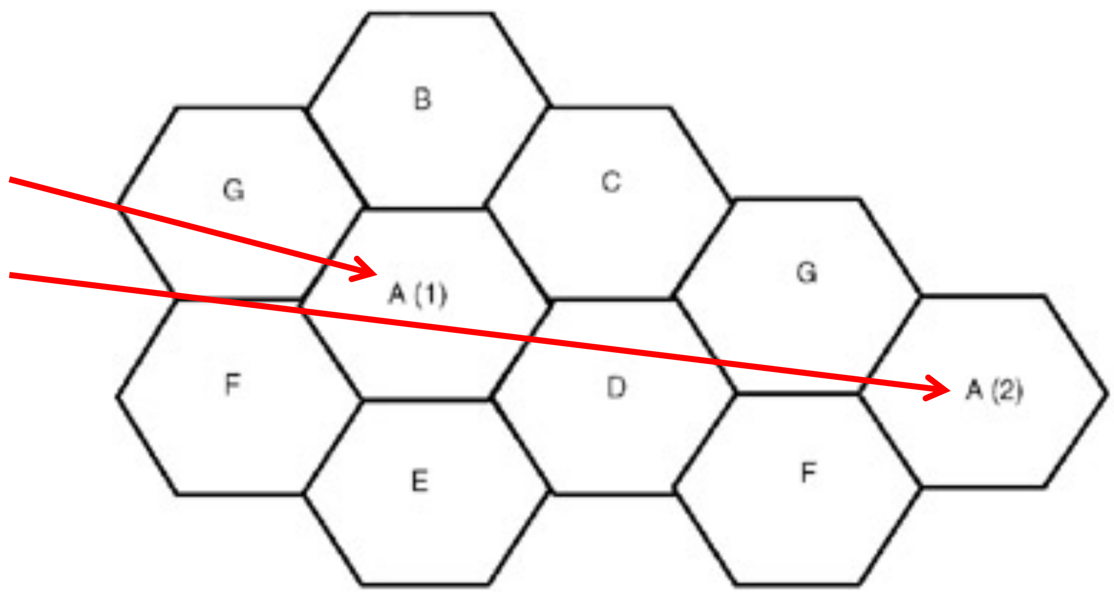
- In the first mobile network systems, the aim was to cover a very large area with a single high-power antenna.
  - max of 12 calls in New York City in 1970
- Cellular network concept
  - replace a high power transmitter with many low power transmitters
  - each base station gets a portion of all channels
- **Cellular network concept**

Cellular network concept

- **Principle:** As demand increases, increase the number of base stations and reduce their transmission power.
  - It serves a relatively large number of users by reusing a certain number of channels (channel reuse).
- The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning.

Cellular structure

- **Space division multiplexing** method is used
  - A base station covers a certain region (cell, cell)
  - Mobile stations only communicate with the base station



Cellular structure

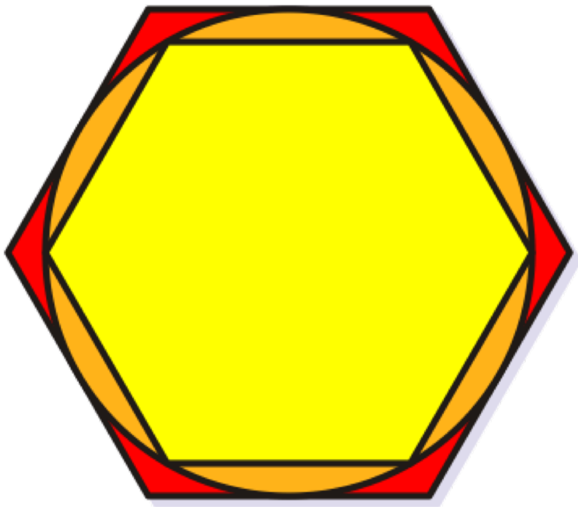
- Advantages of cell structures:
  - higher capacity, higher number of users
  - less transmission power needed
  - more robust, decentralized
  - base station deals with interference, transmission area etc. locally

Cellular structure

- Problems:
  - A complex infrastructure to connect all base stations
  - handover (changing from one cell to another) necessary
  - interference with other cells
- Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM)

Representation of Cells

- Footprint: the actual radio coverage of a cell circle
  - gaps and overlapping regions
- square; equilateral triangle; hexagon
- hexagon geometry allows the fewest number of cells to cover a geographic area

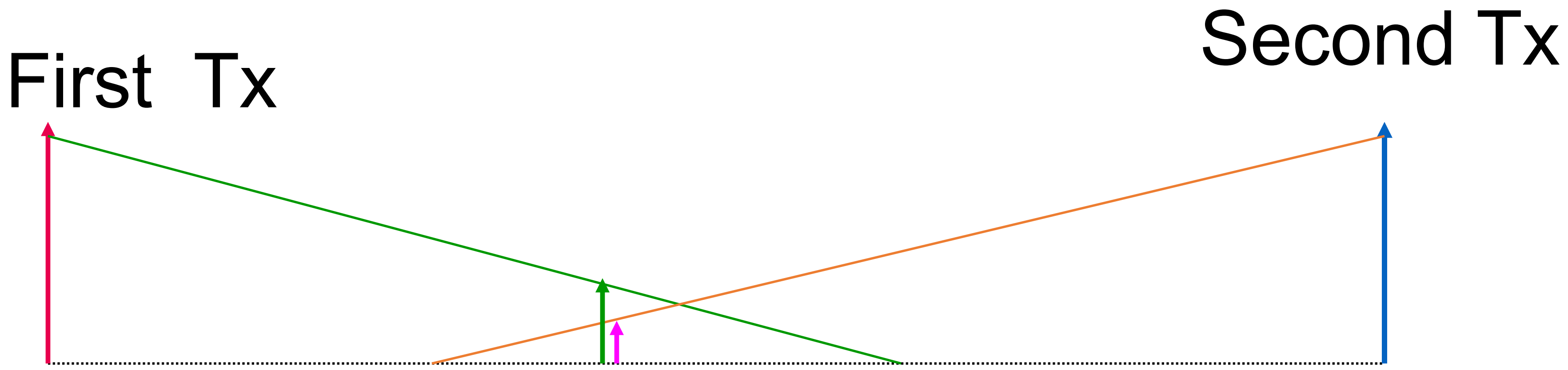


Channel definition

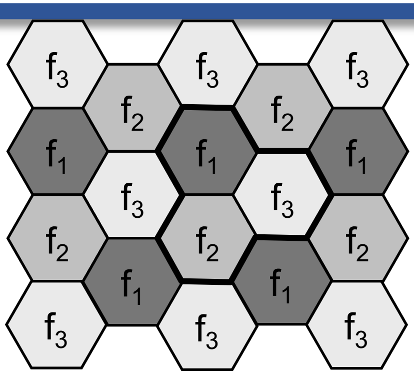
- A channel is characterized by a
  - frequency band in Frequency Division Multiplexing (FDM)
  - time slot in Time Division Multiplexing (TDM)
  - orthogonal modulating code in Code Division Multiplexing (CDM)
  - or, a combination of above

Channel reuse

- Channel reuse is possible if a second transmitter using the channel is ``far enough'' from the main transmitter so that the received energy from the main transmitter dominates the energy from the second transmitter.

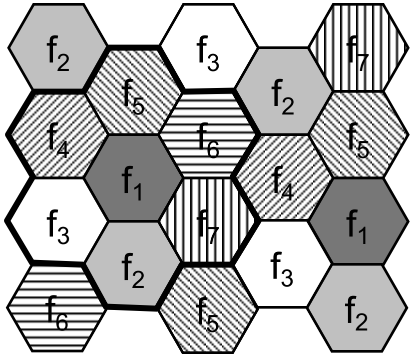


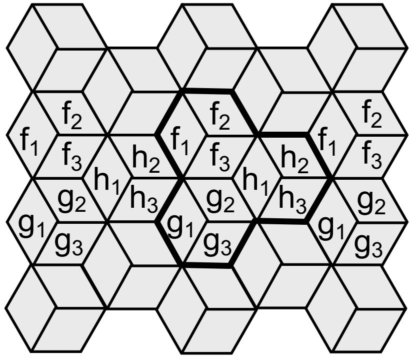
Frequency planning



3 cell cluster

7 cell cluster





3 cell cluster
with 3 sector antennas

Capacity and cluster

- N: number of cells in a group (i.e., cluster size)
- k: number of channels in each cell of a group
- S: number of duplex channels available for use in a group (cluster)
- $S = k N$
- The N cells is called a **cluster**.
- M: number of clusters and C: capacity
- $C = MkN = MS$
  - cluster size: 3, 4, 7, 12, …

Capacity and cluster

- the smallest possible value of N to maximize capacity C
  - interference
- The frequency (or channel) reuse factor of a cellular system is given by 1/N

$$N = i^2 + i \cdot j + j^2$$

Example

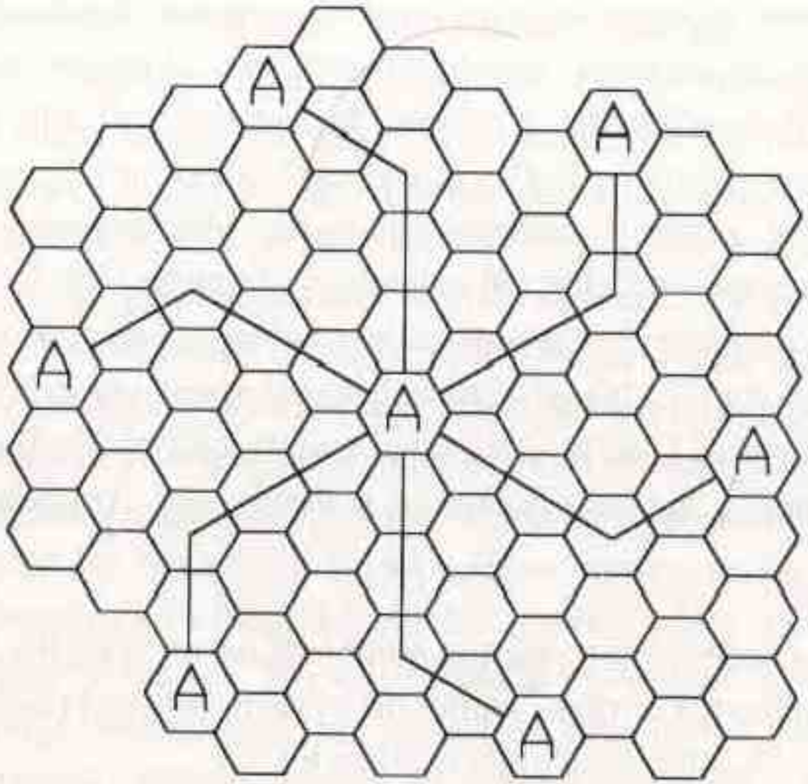


Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, $N = 19$ (i.e., $i = 3$, $j = 2$). (Adapted from [Oet83] © IEEE.)

Example

- If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute *k*, the number of channels per cell if N =4, N=7, and N=12.

- 33000/ (25 x 2) = 660 total number of channel
- 660 / 4 = 165 channel/cell
- 660 / 7 = 95 channel/cell
- 660 /12 = 55 channel/cell

Channel distribution strategies

- Fixed channel assignment:
  - certain frequencies are assigned to a certain cell
  - problem: different traffic load in different cells
  - blocking: if all channels in a cell are occupied, a new call is blocked
- Strategies to overcome the effects of non-uniform loading
  - non-uniform channel allocation: the number of channels assigned to each cell depends on the expected load

Channel distribution strategies

- Fixed channel assignment:
- channel borrowing schemes: borrow a channel from a neighboring cell if the interference constraints are fulfilled; borrowed channels are returned once calls are completed
- channel locking: when a channel is borrowed, several other cells are prohibited from using it

Channel distribution strategies

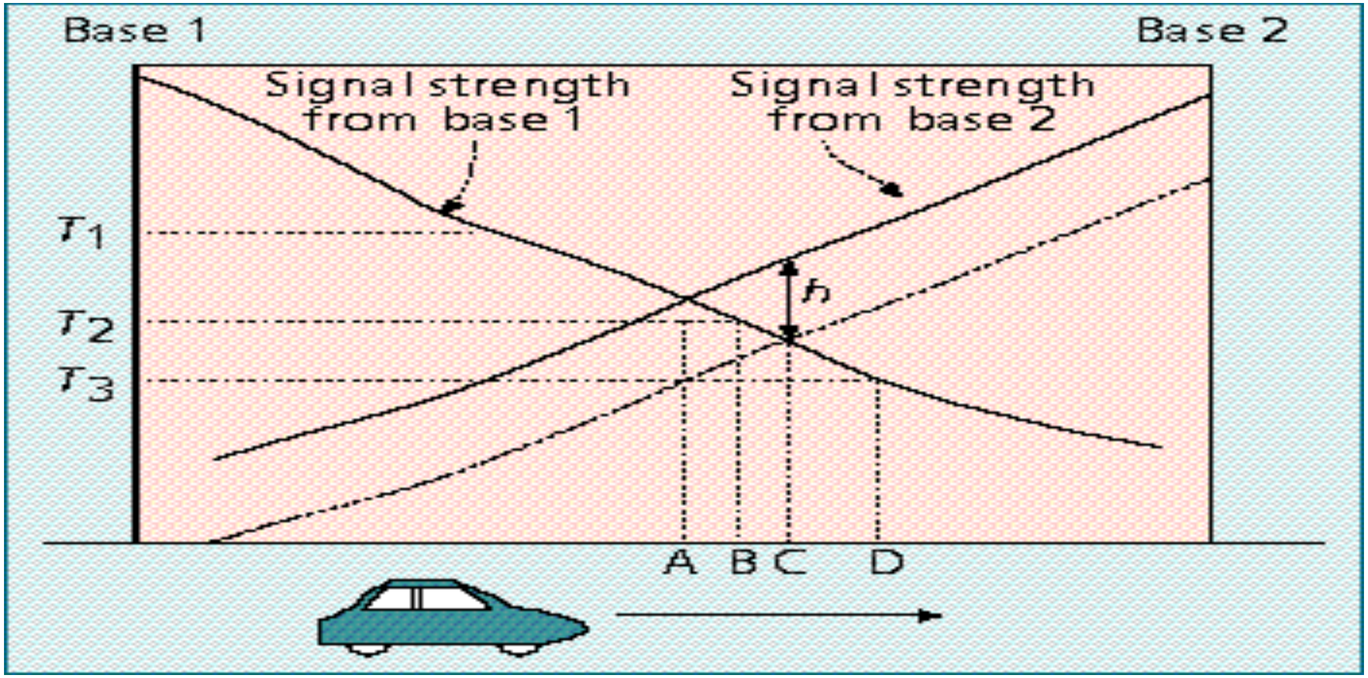
- Dynamic channel assignment (DCA):
  - channels are assigned according to traffic
  - Mobile switching center (MSC) chooses frequencies depending on the frequencies already used in neighbor cells
  - more capacity in cells with more traffic
  - MSC collects real-time data on channel occupancy, traffic distribution, etc.
- DCA Strategies
  - Centralized DCA: centralized controller or centralized pool
  - Distributed DCA

Channel distribution strategies

- Hybrid channel assignment (HCA):
- the total set of channels is divided into two subsets
  - the first subset of channels is assigned to cells by FCA
  - the second subset is kept in a central pool and assigned dynamically to cells on demand

Handoff (or Handover)

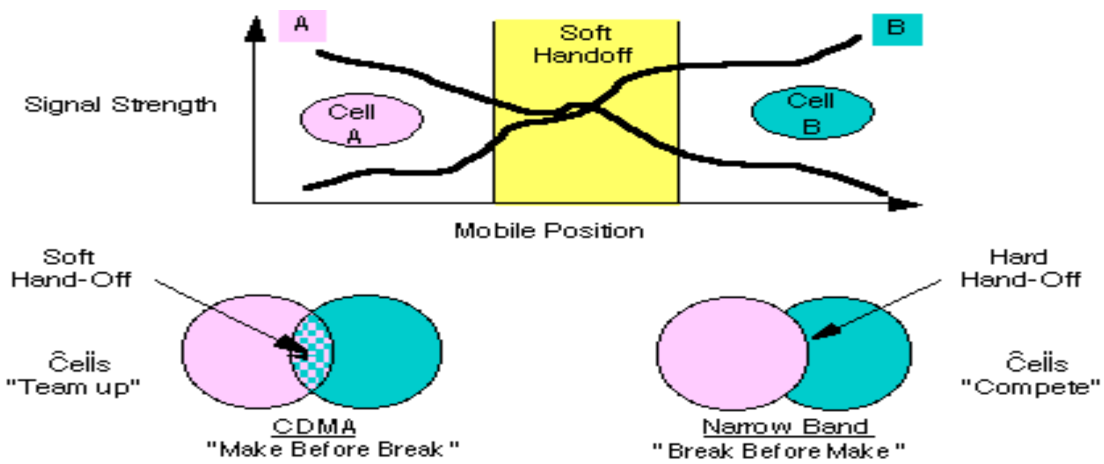
- Handoff (or handover): an ongoing call is transferred from one cell to another cell as a user moves



As user moves, signal strength of base 1 and base 2 decreases and increases, respectively (Source: G.P. Pollini, “Trends in Handover Design”, IEEE Communications Mag., March 1996, vol.34, no.3.)

Hard and soft handoff

- hard handover: mobile drops a channel before picking up the next channel (in TDMA systems)
- soft handover: mobile station receives signals from two or more base stations, compares them and picks out the best signal (in CDMA systems)
- Softer handoff: occurs between sectors of cell



Handoff priority

- ongoing calls versus new calls
  - QoS
    - call blocking rate
    - call dropping rate
  - Prioritizing Handoffs
    - guard channel concept
    - queuing of handoff requests

Interference in cellular networks

- Interference is a major limiting factor in wireless cellular systems
  - Interference is a major bottleneck in increasing capacity and is responsible for dropped calls
    - co-channel interference
    - adjacent channel interference
- co-channel cells: cells that use the same set of frequencies
  - interference between these cells are called co-channel interference
  - co-channel cells must be separated by a minimum distance

Channel reuse rate

- reuse distance: D (the distance between centers of the nearest co-channel cells)
- R: radius of cell
- channel reuse ratio: $$Q = \frac{D}{R} = \sqrt{3N}$$
  - small value of Q provides larger capacity since N is small
  - large value of Q means better QoS (larger D)

SIR and SNR

- SIR: Signal-to-Interference Ratio
- SNR: Signal-to-Noise Ratio

- S: Signal Avg Power
- I : Avg. Interference (or Noise) Power

Channel reuse rate

Co-channel reuse ratio: $Q = \frac{D}{R} = \sqrt{3N}$

Low Q → High capacity (C)

High Q → High QoS

i_o= the number of co-channel interfering cells

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_o} I_i}$$

S: Desired signal power

I_i: The interference power caused by the i^{th} interfering co-channel base station

Channel reuse rate

- n: the path loss exponent
- $P_r = P_o \left(\frac{d}{d_0}\right)^{-n}$
- P_r: received power at a distance d from the transmitting antenna
- P_0: received power at a small distance d_0 from the transmitting antenna
- The received power at agiven mobile due to the ith interfering cell is I_i if D_i is the distance of the ith interferer from the mobile
- $I_i = S\left(\frac{D_i}{R}\right)^{-n}$
- By substituting this in the above equation for S/I, we get

Channel reuse rate

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_o}(D_i)^{-n}}$$

If all the interfering base stations are equidistant from the base station, we obtain

$$\frac{S}{I} = \frac{R^{-n}}{i_0 \times D^{-n}} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$$

US AMPS requires $\frac{S}{I} \geq 18\ dB$

Example

- If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system,
- **what is the frequency reuse factor (1/N) and cluster size (N) that should be used for maximum capacity if the path loss exponent is (a) n= 4, (b) n=3?**
- Assume that there are **6 co-channels** cells in the first tier, and all of them are at the same distance from the mobile.

Solution

n=4

N=6 hücreli bir sistem olduğunu kabul edelim (i=1,j=2)

6 tane interfering hücre var

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(\sqrt{3\times6})^4}{6} = 54 = 17{,}32dB$$

Elde edilen değer 15 dB den büyük olduğu için kullanılabilir.

n=3

N=6 hücreli bir sistem olduğunu kabul edelim (i=1,j=2)

6 tane interfering hücre var

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0} = \frac{(\sqrt{3\times6})^3}{6} = 12{,}72 = 11{,}04dB$$

Elde edilen değer 15 dB den küçük olduğu için kullanılamaz.

N değeri artırılmalıdır (i=2,j=2 → N=12)

Trunking, GoS, Cell Sector

Trunking

- trunking allows users to share a pool of channels
- trunking theory determine the number of users that can be supported in a network
- if no channel is available, then
  - blocking
  - queueing

Traffic Intensity

- (traffic intensity)

=(arrival rate of calls) X (average call duration)

=(# of calls / hour) X (average call duration in hours)

Earlang

- 1 Erlang represents the amount of traffic intensity carried by a channel that is completely occupied (1 call-hour per hour or 1 call-minute per minute)
- Example: a radio channel that is occupied for 30 minutes during an hour carries 0.5 Erlangs of traffic.

Grade of Service (GoS)

- GoS is a measure of the ability of a user to access a trunked system during the busiest hour.
- For a given GoS, the job of wireless designer is to estimate the maximum required capacity and allocate the proper number of channels.
- GoS is usually given as the likelihood that a call is blocked or delayed

Total Traffic Intensity

- Each user generates a traffic intensity of A_u Erlangs
  - $A_u = \lambda H$
  - where
  - H is the average duration of call
  - λ is the average number of call
  - requests per unit time
- U: number of all users
  - $A = U A_u$

Total Traffic Intensity

- traffic intensity per channel, $A_{c,}$ is given by
  - $A_c = U A_u / C$

- AMPS is designed for a GOS of 2% blocking.
  - During the busiest hour, only 2 calls out of 100 calls can be blocked at most

Trunked Systems

- There are two types of trunked systems:
  - Blocked Calls Cleared
    - no queuing
    - Erlang B formula
  - Blocked Calls Delayed
    - Erlang C formula

Erlang B

- Erlang B determines the probability that a call is blocked.

$$Pr\{blocking\} = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS$$

Erlang C

- The likelihood of a call not having an immediate access to a channel is determined by the Erlang C formula.

$$Pr[delay > 0] = \frac{A^C}{A^C + C!\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C-1}\frac{A^k}{k!}}$$

Erlang C

- The probability that the delayed call is forced to wait more than *t* seconds is given by the probability that a call is delayed, multiplied by the conditional probability that the delay is greater than *t* seconds

$$
\begin{aligned}
Pr[delay > t] &= Pr[delay > 0]Pr[delay > t | delay > 0] \\
&= Pr[delay > 0]\exp(-(C-A)t/H)
\end{aligned}
$$

The average delay D for all calls in a queued system is given by

$$D = Pr[delay > 0]\frac{H}{C-A}$$

where the average delay for those calls which are queued is given by $H/(C-A)$.

Erlang B - Example

- How many users can be supported for 0.5%=0.005 blocking probability for the following number of trunked channels in a blocked calls cleared system? (a) 5, (b) 10, (c) 20, (d) 100. Assume each user generates 0.1 Erlangs of traffic.

Erlang B Chart

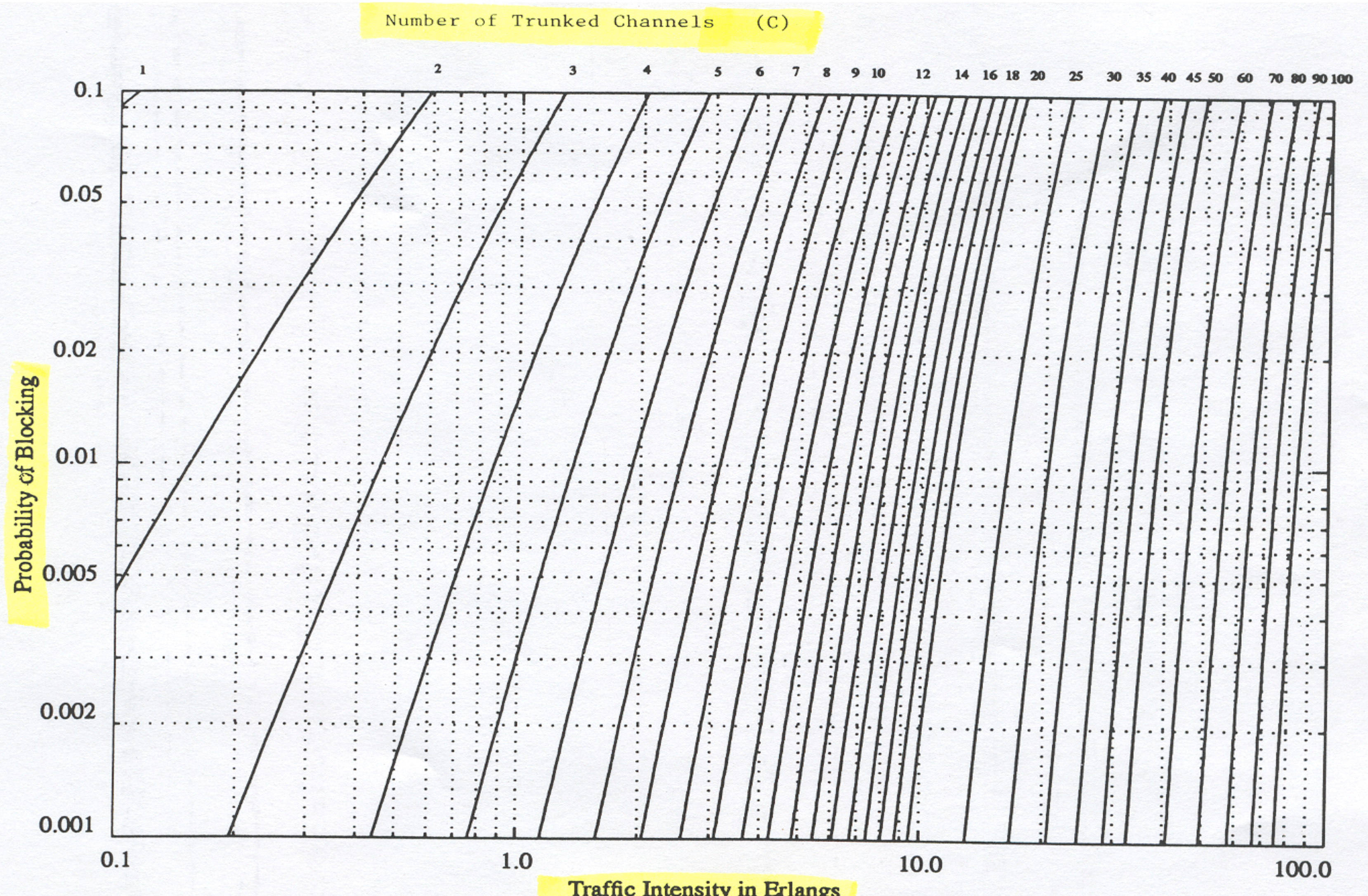


Figure 2.6

Erlang B System Capacity

Table 2.4 Capacity of an Erlang B System

Number of Channels C	Capacity (Erlangs) for GOS			
	GOS = 0.01	GOS = 0.005	GOS = 0.002	GOS = 0.001
2	0.153	0.105	0.065	0.046
4	0.869	0.701	0.535	0.439
5	1.36	1.13	0.900	0.762
10	4.46	3.96	3.43	3.09
20	12.0	11.1	10.1	9.41
24	15.3	14.2	13.0	12.2
40	29.0	27.3	25.7	24.5
70	56.1	53.7	51.0	49.2
100	84.1	80.9	77.4	75.2

Capacity $\le$ A

" $\le$ total offered traffic intensity

Capacity (Erlangs) = total traffic intensity = A (in Erlang)

Erlang C - Example

- A hexagonal cell within a 4-cell system has a radius of 1.387 km. A total of 60 channels are used within the entire system. If the load per user is 0.029 Erlangs compute the following for an Erlang C system that has 5% probability of a delayed call:

  How many users per square kilometer will this system support?

Erlang C Chart

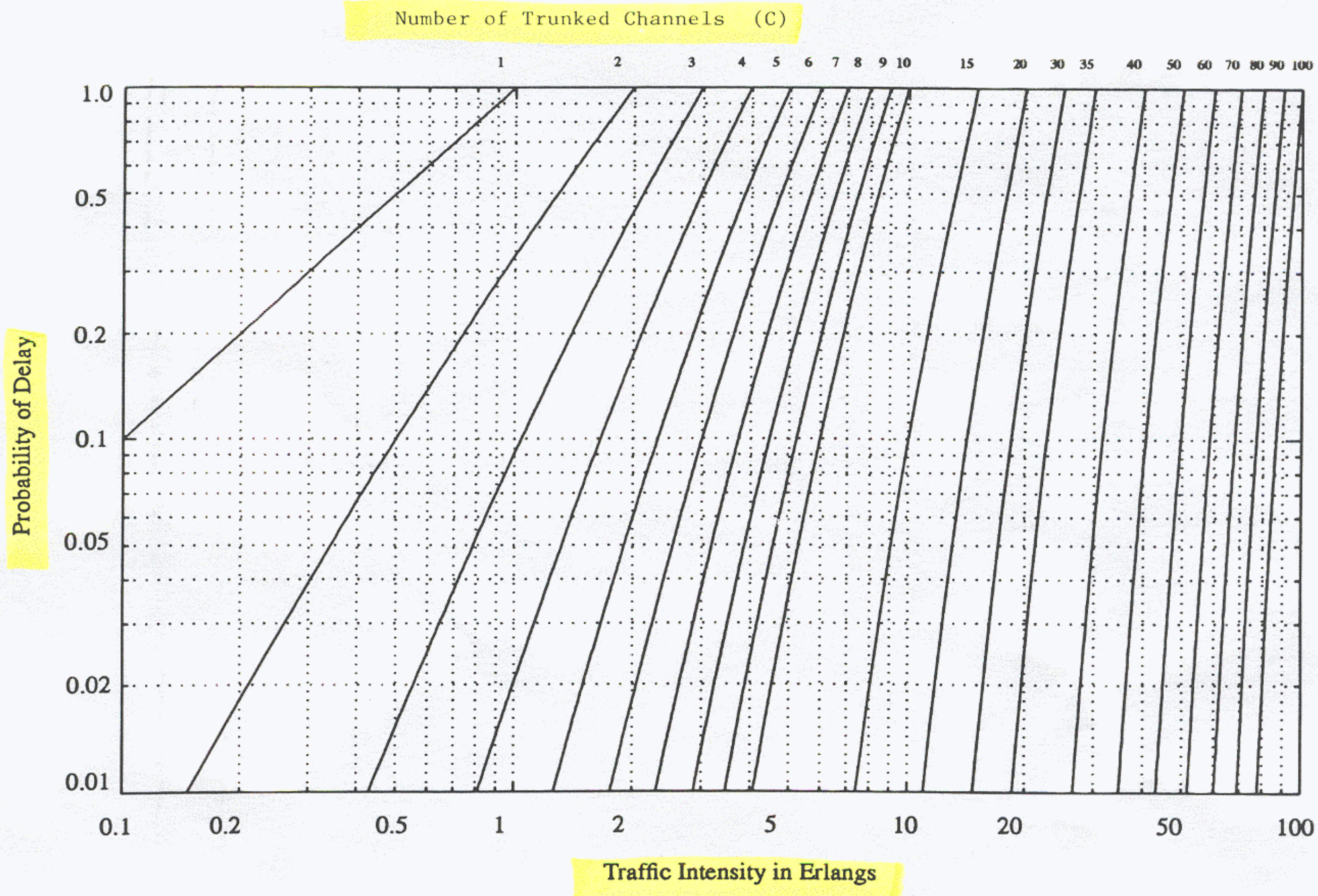
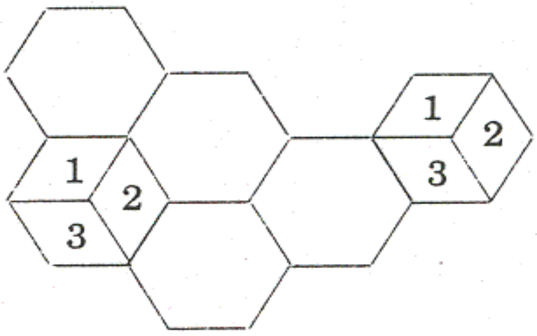


Figure 2.7
The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

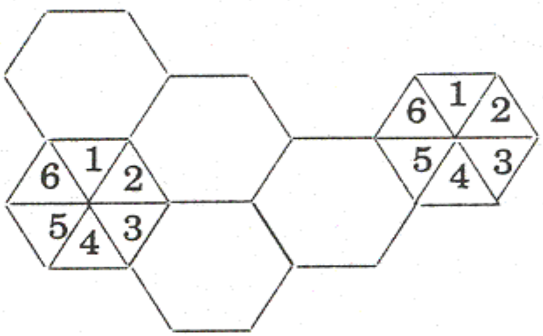
Trunking Efficiency

- Trunking efficiency is a measure of number of users which can be offered a particular GoS with a particular configuration of fixed channels

Sectoring



(a)



(b)

Figure 2.10
(a) 120° sectoring.
(b) 60° sectoring.

Sectoring

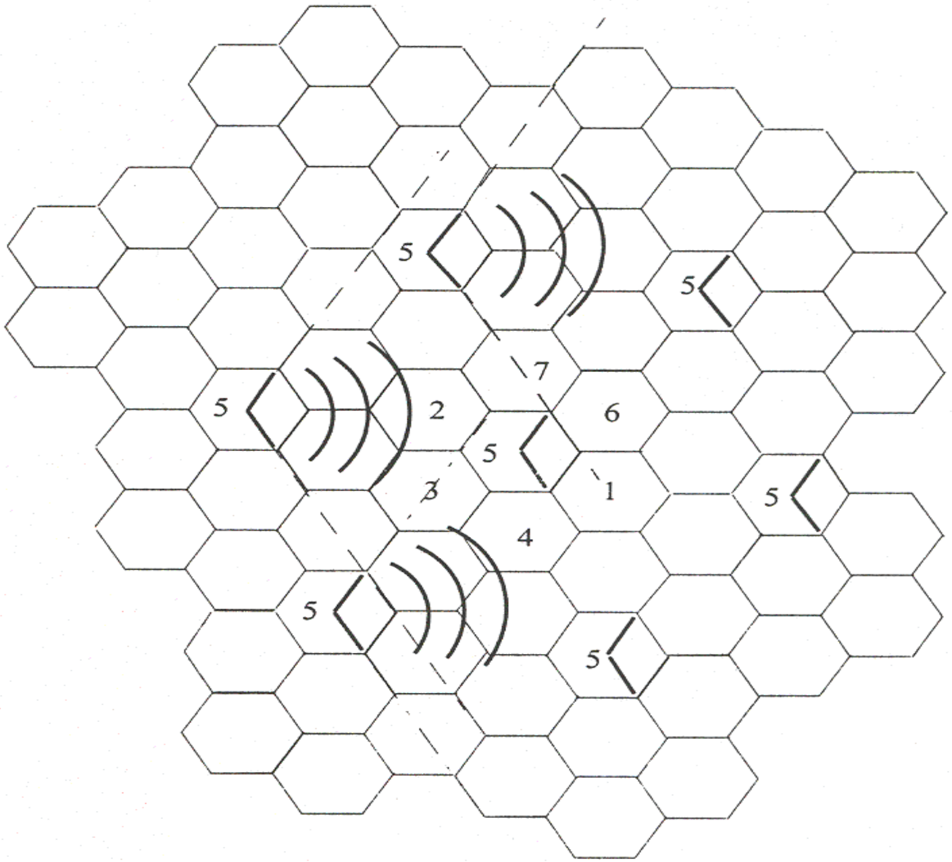


Figure 2.11
Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only 2 of them interfere with the center cell. If omni-directional antennas were used at each base station, all 6 co-channel cells would interfere with the center cell.

Facts for sectoring in a 7-cell reuse system

- Sectoring reduces interference by reducing the number of interferers in the first tier. Therefore, sectoring improves the S/I for each user in the system
- Sectoring decreases the trunking efficiency. That is, unsectoring may handle more total traffic intensity in Erlangs (or more number of calls per hour) than sectoring
  – because the channels allocated to a cell are now divided among the different sectors.

Example

- Consider a cellular system in which:
- An average call lasts 2 minutes, the probability of blocking is to be no more than 1%. Assume that every subscriber makes 1 call per hour, on average.
- If there are a total of 395 traffic channels for a 7-cell reuse system, there will be about 57 traffic channels per cell.
- Assume that blocked calls are cleared so the blocking is described by the Erlang B distribution. From the Erlang B distribution, it can be found that **the unsectored system may handle 44.2 Erlangs or 1326 calls per hour.**

Example

- Now employing **120° sectoring, there are only 19 channels per antenna sector (57/3 antennas).**
- For the same probability of blocking and average call length, it can be found from the Erlang B distribution that each sector can handle **11.2 Erlangs or 336 calls per hour.**

Thank You..