Wireless Mobile Communication

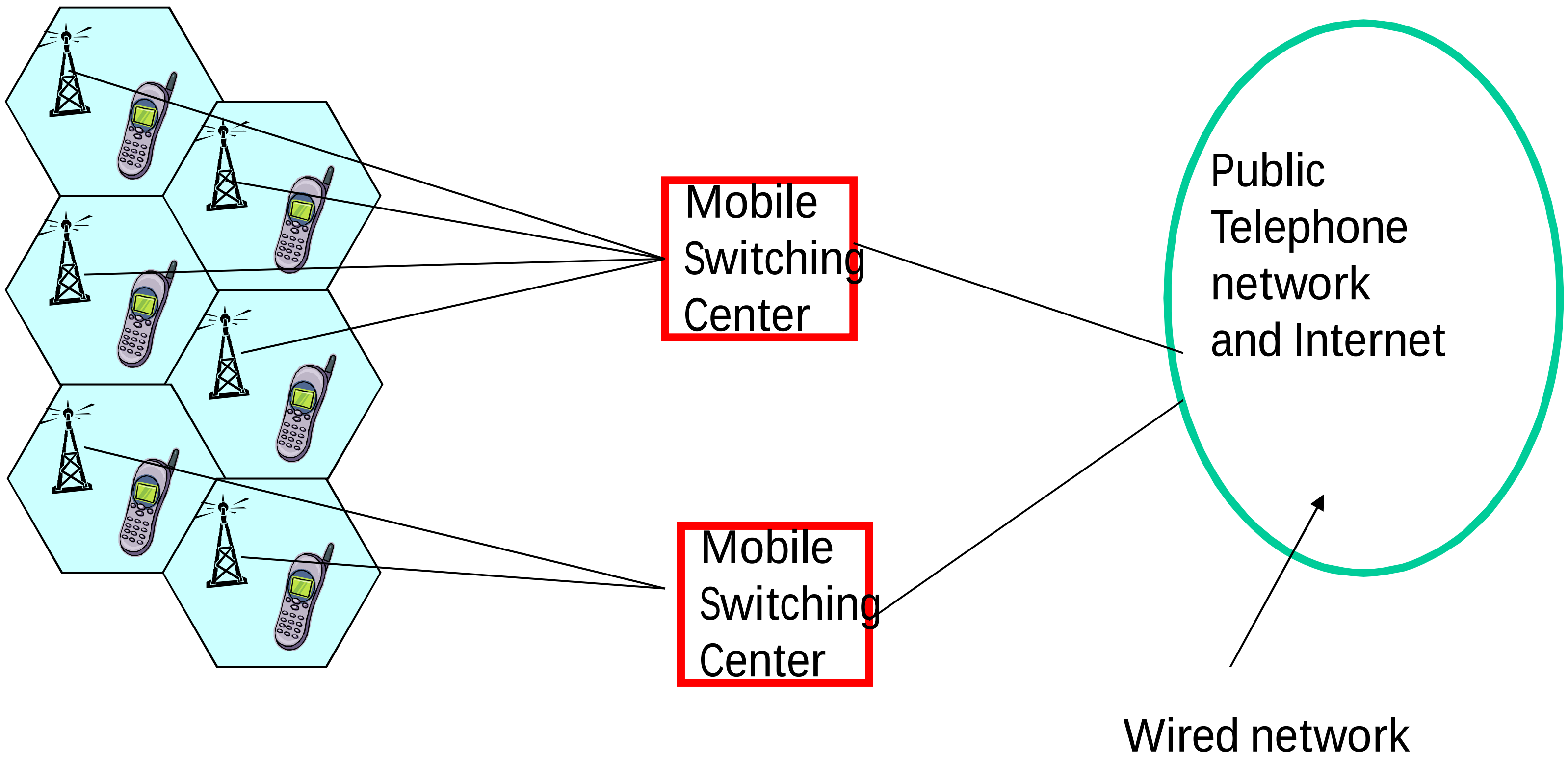
Lecture 17, 18, 19, 20

- Trunking and Grade of Service
- Handoff techniques

Topics to be covered

- Review
- Trunking and Grade of Service
- Sectoring
- Microcell Zone Concept
- Roaming
- Call procedure

Cellular Network Architecture



Frequency reuse concept

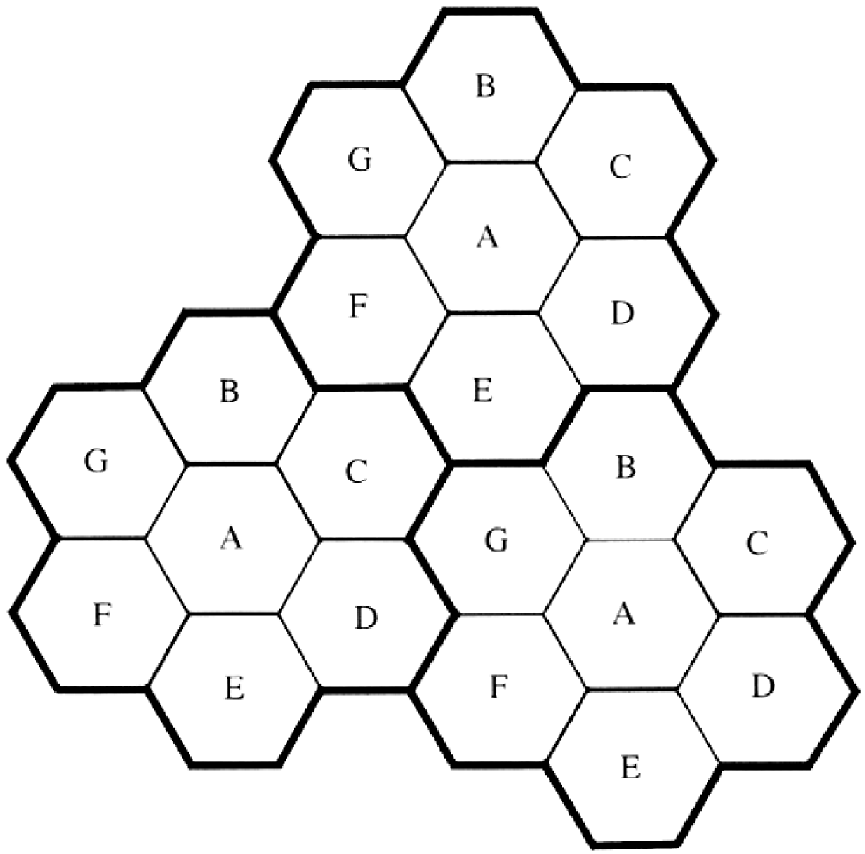
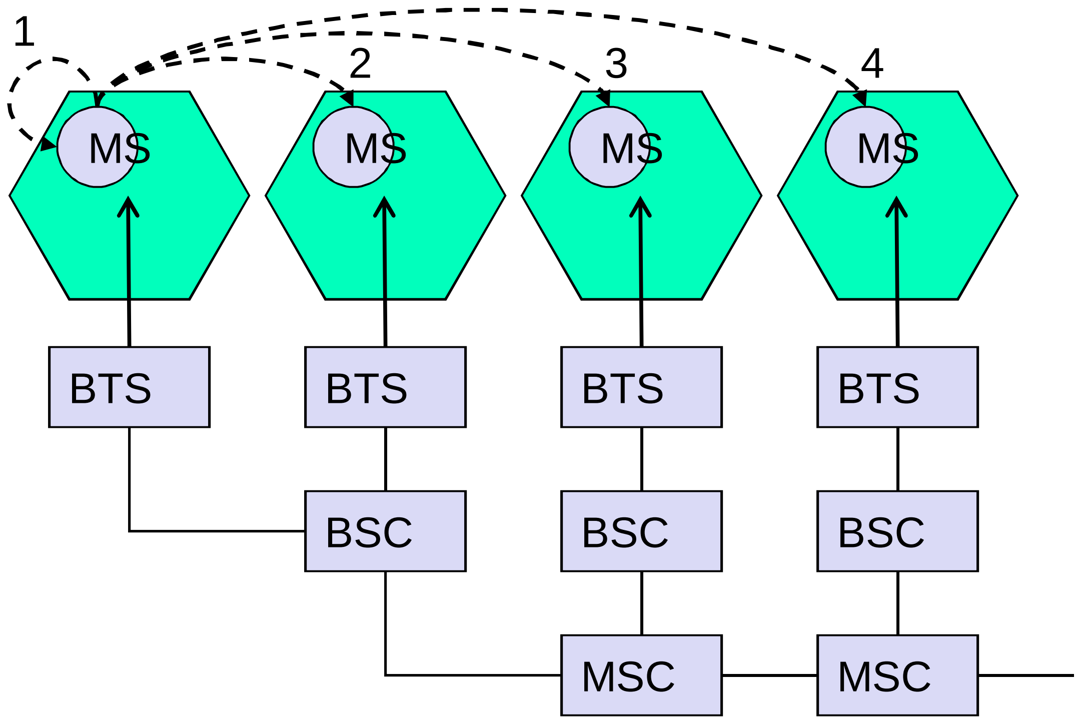


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, *N*, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels.

Four Types of Handoff



Handoff

- Δ=handoff thresh
Minimum acceptabl
signal to maintain tl
- Δ too small:
  - Insufficient time to complete handoi before call is lost
  - More call losses
- Δ too large:
  - Too many handoi
  - Burden for MSC

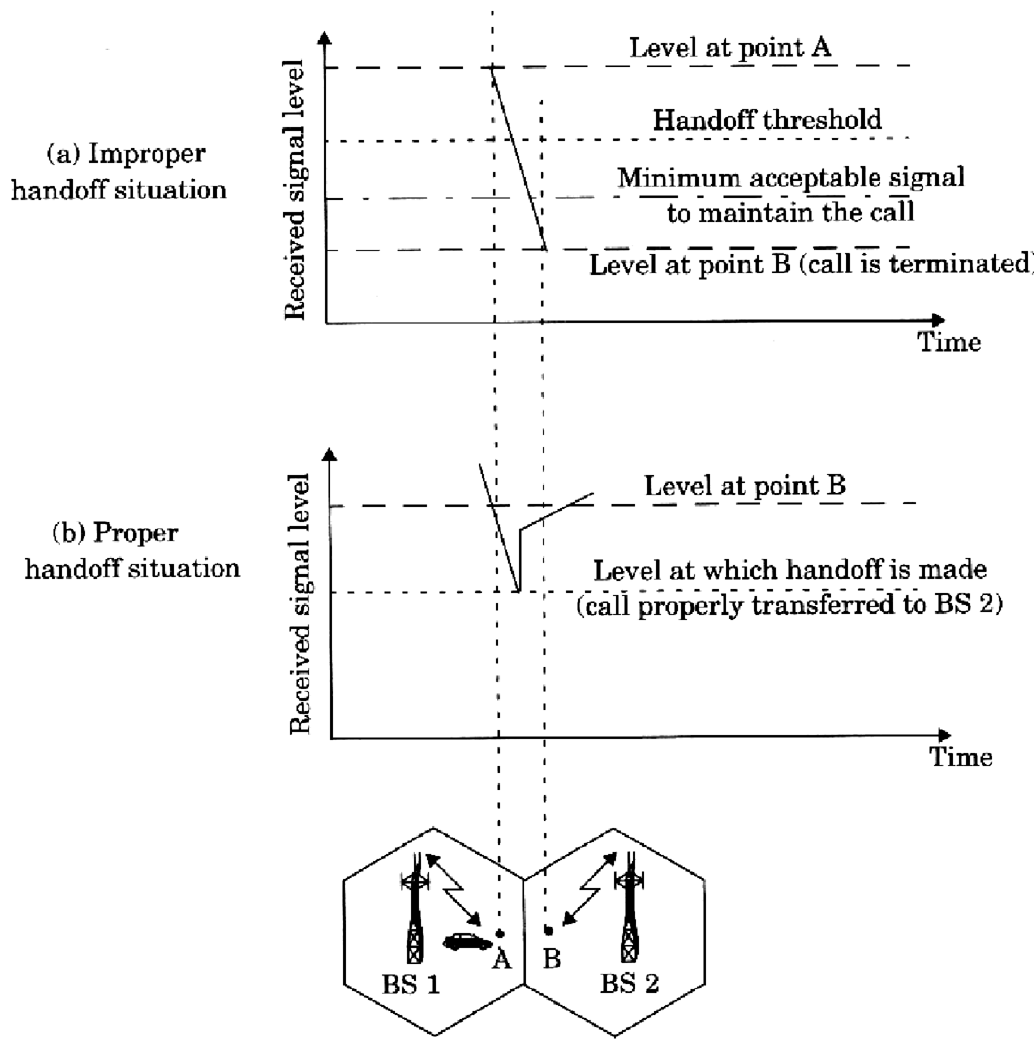


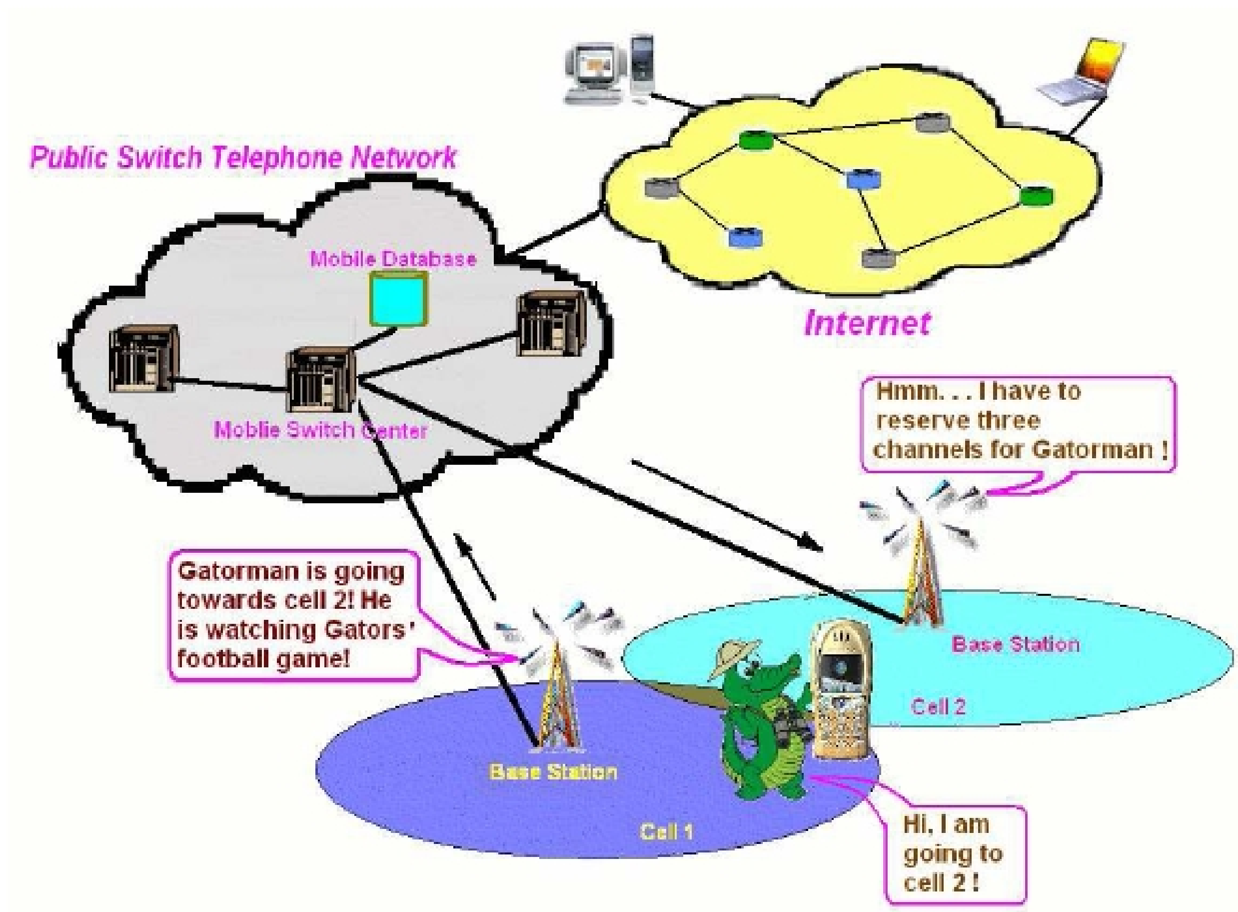
Figure 3.3 Illustration of a handoff scenario at cell boundary.

Styles of Handoff

- Network Controlled Handoff (NCHO)
  - in first generation cellular system, each base station constantly monitors signal strength from mobiles in its cell
  - based on the measures, MSC decides if handoff necessary
  - mobile plays passive role in process
  - burden on MSC
- Mobile Assisted Handoff (MAHO)
  - present in second generation systems
  - mobile measures received power from surrounding base stations and report to serving base station
  - handoff initiated when power received from a neighboring cell exceeds current value by a certain level or for a certain period of time
  - faster since measurements made by mobiles, MSC don't need monitor signal strength
- Mobile Controlled Handoff

Types of Handoff

- Hard handoff - (break before make)
  - FDMA, TDMA
  - mobile has radio link with only one BS at anytime
  - old BS connection is terminated before new BS connection is made.



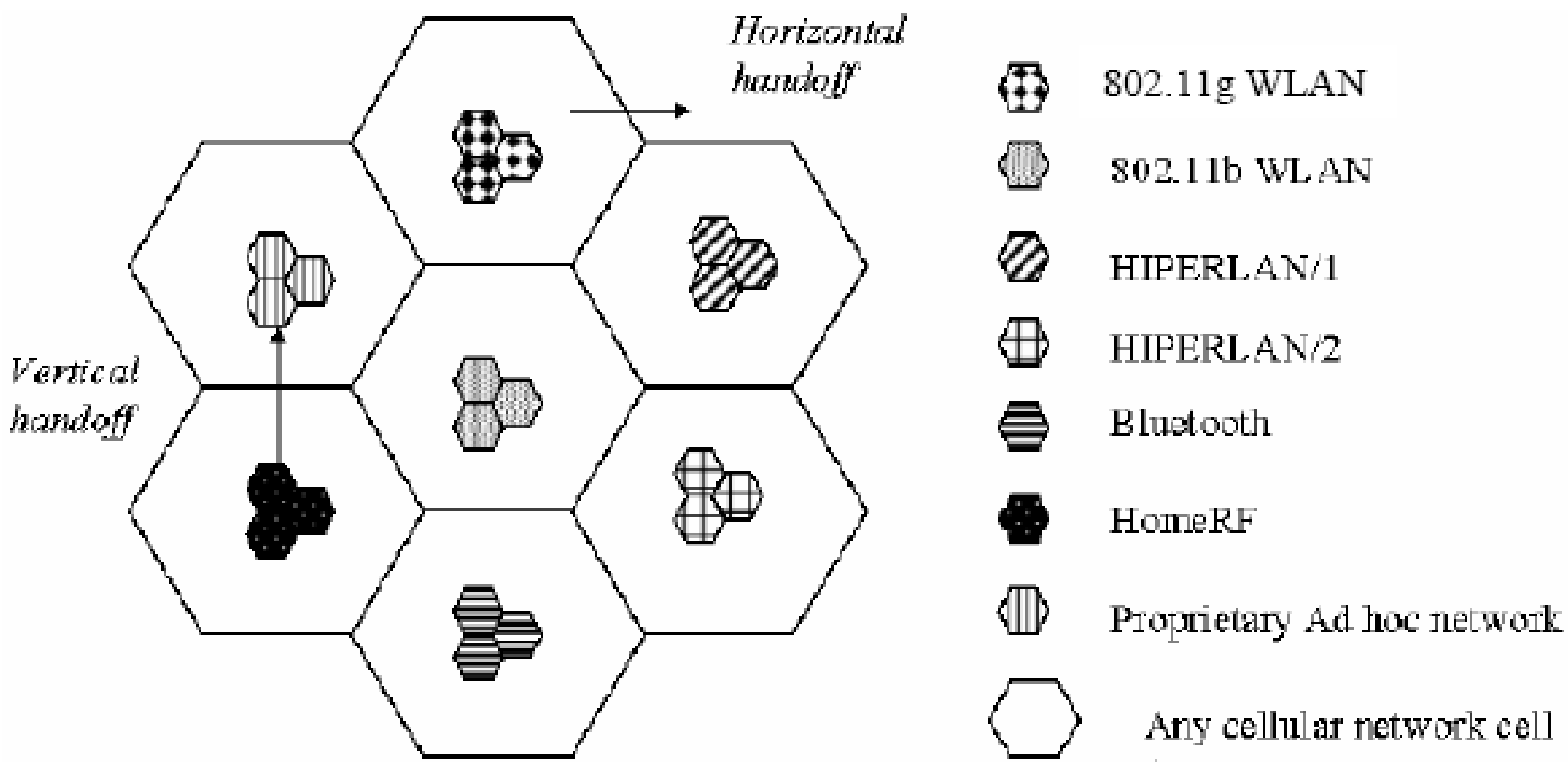
Types of Handoff

- Soft handoff (make before break)
  - CDMA systems
  - mobile has simultaneous radio link with more than one BS at any time
  - new BS connection is made before old BS connection is broken
  - mobile unit remains in this state until one base station clearly predominates

- http://www.youtube.com/watch?v=mYdk89hMyss

Types of Handoff

- Vertical handoff



Interference and System Capacity

- major limiting factor in performance of cellular radio systems
- sources of interference:
  - other mobiles in same cell
  - a call in progress in a neighboring cell
  - other base stations operating in the same frequency band
  - Non-cellular system leaking energy into the cellular frequency band
- effect of interference:
  - voice channel: cross talk
  - control channel: missed or blocked calls
- two main types:
  - co-channel interference
  - adjacent channel interference

Cochannel Interference

- SINR $$\frac{S}{I} = \frac{S}{\sigma^2 + \sum_{i=1}^{i_0} I_i}$$
- Power: propagation factor 2-6
  - Sun, nuclear bomb

$$P_r = P_t \left(\frac{d}{d_0} \right)^{-\alpha}$$

$$P_r(dBm) = P_t(dBm) - 10\alpha \log\left(\frac{d}{d_0} \right)$$

- Approximation

$$\frac{S}{I} = \frac{R^{-\alpha}}{\sum_{i=1}^{i_0} (D_i)^{-\alpha}} = \frac{(D/R)^{\alpha}}{i_0} = \frac{(\sqrt{3N})^{\alpha}}{i_0}$$

- AMPS example
  - α=4, S/I=18dB, N needs to be larger than 6.49.
  - Reuse factor 1/N small
- Relations: cochannel interference, link quality, reuse factor
- Example 3.2

Trunking

- Trunking: the channel is allocated on demand and recycle after usage
- Tradeoff between the number of channels and blocking probability
- Grade of service
  – Likelihood of a call is blocked or the delay greater than a threshold during the busiest time.
- Trunking theory
  – Erlang, a Danish Mathematician studied how a large population could be accommodated by a limited number of servers.
  – Erlang capacity: the percentage of line/channel occupied over time

Terms of Trunking Theory

Table 3.3 Definitions of Common Terms Used in Trunking Theory

Set-up Time: The time required to allocate a trunked radio channel to a requesting user.

Blocked Call: Call which cannot be completed at time of request, due to congestion. Also referred to as a *lost call*.

Holding Time: Average duration of a typical call. Denoted by H (in seconds).

Traffic Intensity: Measure of channel time utilization, which is the average channel occupancy measured in Erlangs. This is a dimensionless quantity and may be used to measure the time utilization of single or multiple channels. Denoted by A.

Load: Traffic intensity across the entire trunked radio system, measured in Erlangs.

Grade of Service (GOS): A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time (for Erlang C).

Request Rate: The average number of call requests per unit time. Denoted by λ seconds^{-1}.

Trunking Theory

- Each user generates a traffic intensity of Au Erlangs.
  - $A_u = \lambda H$, where H is the average duration of a call and λ is the average number of call requests per unit time for each user
  - $A = UA_u$, where U no. of users and A is the total offered traffic intensity
  - $A_c = UA_u/C$, where C is the number of channels
  - Offered traffic >= the traffic carried by the trunked system
- First type of trunked system
  - Blocked calls cleared: no queuing for call requests, no setup time
  - M/M/m/m: memory-less, Poisson arrival, exponential service, finite channels.
  - Erland B formula

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

Erlang B Example

Table 3.4 Capacity of an Erlang B System

Number of Channels *C*	Capacity (Erlangs) for GOS = 0.01	= 0.005	= 0.002	= 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

Erlang B

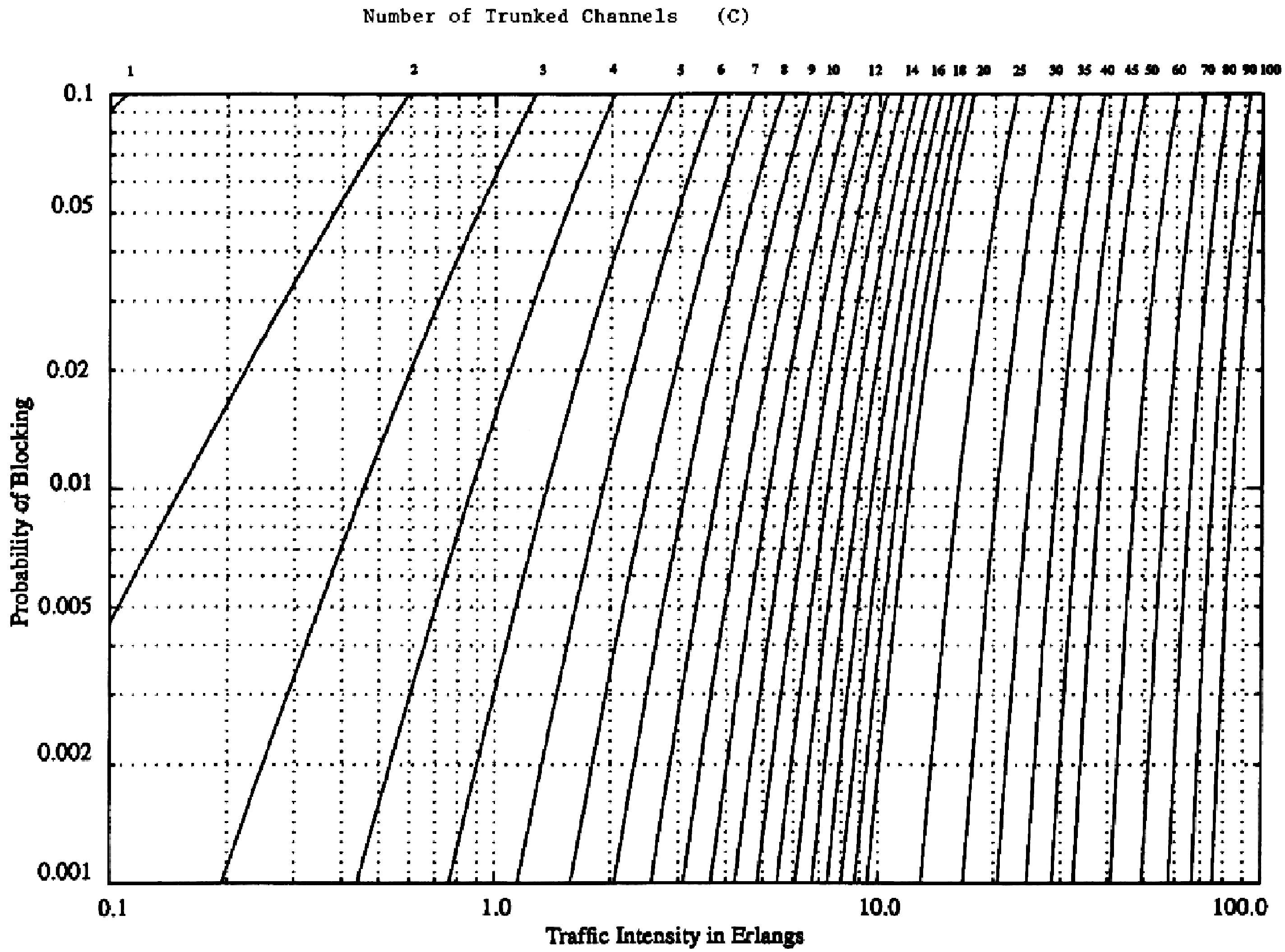


Figure 3.6 The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

Blocked Calls Delayed

- Blocking calls are delayed until channels are available, queuing
- Erlang C $$\Pr(delay > 0) = \frac{A^C}{A^C + C!(1-\frac{A}{C})\sum_{k=0}^{C-1}\frac{A^k}{k!}}$$

- Probability of delay lager than t
  - Exponential service distributions
  - Pr[delay>t]=Pr[delay>0]Pr[delay>t|delay>0]
    =Pr[delay>0]exp(-(C-A)t/H)
- The average delay D
  - D=Pr[delay>0]H/(C-A)

Erlang C

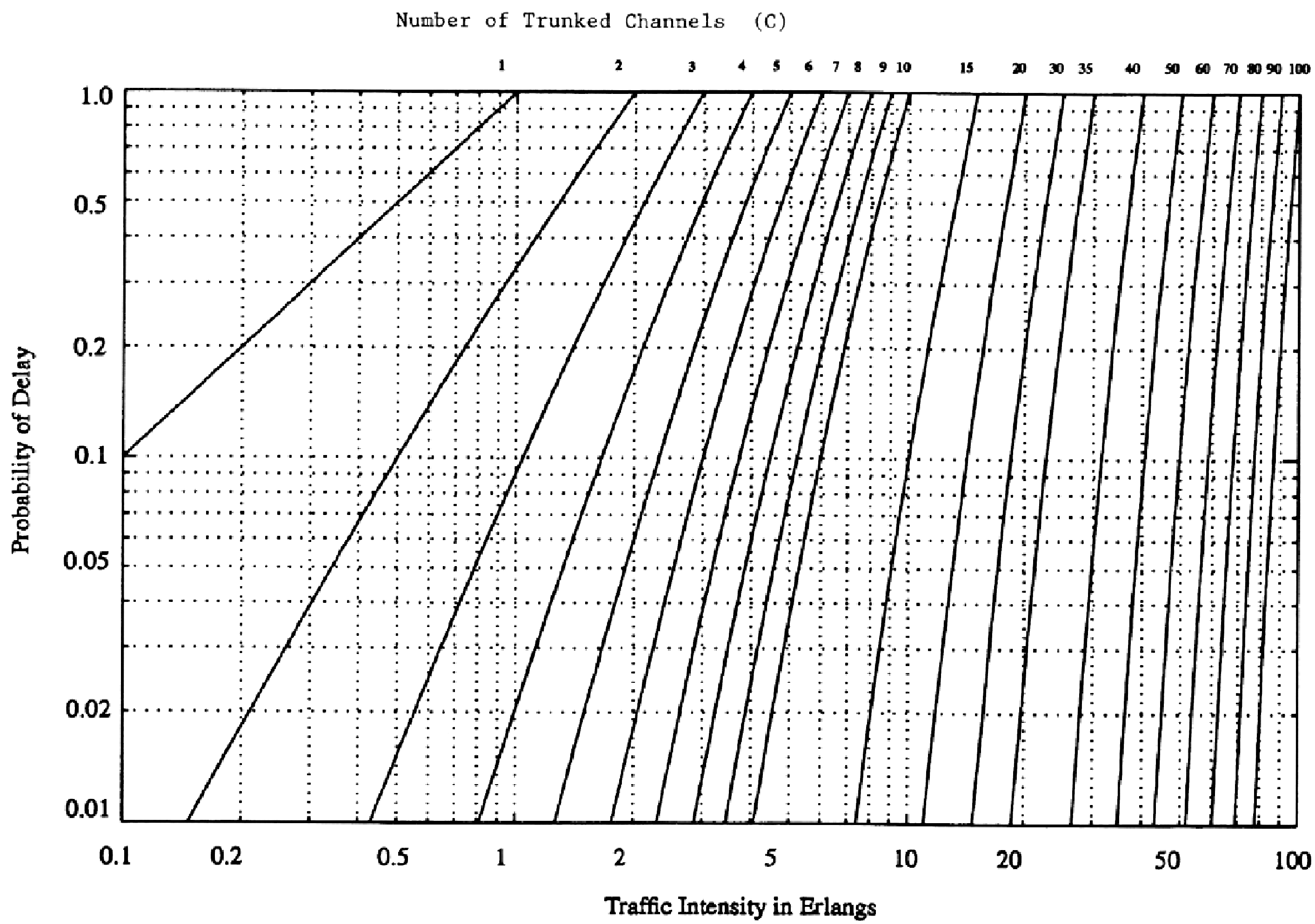


Figure 3.7 The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

Examples

- Example 3.4
- Example 3.5
- Example 3.6
- Example 3.7

Approaches to Increasing Capacity

- Frequency borrowing
  - frequencies are taken from adjacent cells by congested cells
- Cell splitting
  - cells in areas of high usage can be split into smaller cells
- Cell sectoring
  - cells are divided into a number of wedge-shaped sectors, each with their own set of channels
- Microcells
  - antennas move to buildings, hills, and lamp posts

Cell Splitting

- subdivide a congested cell into smaller cells
- each with its own base sta

reduction in antenna and transmitter power

- more cells ➔ more cluste
  ➔ higher capacity
- achieves capacity

improvement by essentially rescaling the system.

- Cell Splitting from

radius R to R/2

- Table 3.4 example

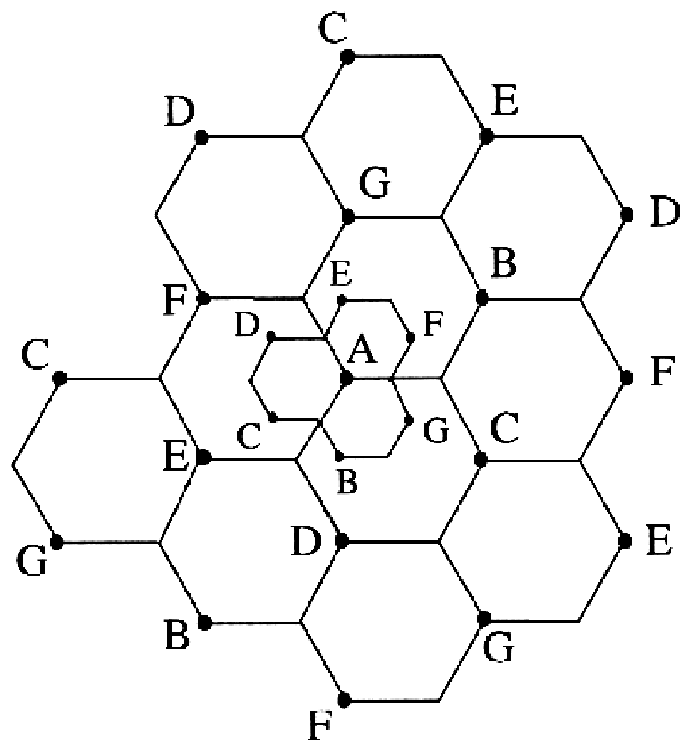


Figure 3.8 Illustration of cell splitting.

Cell Splitting Example

- Power reduction is 16 times and 12 dB for half cell radius for propagation factor is 4.
- antenna downtilting
- Umbrella cell
- Example 3.8

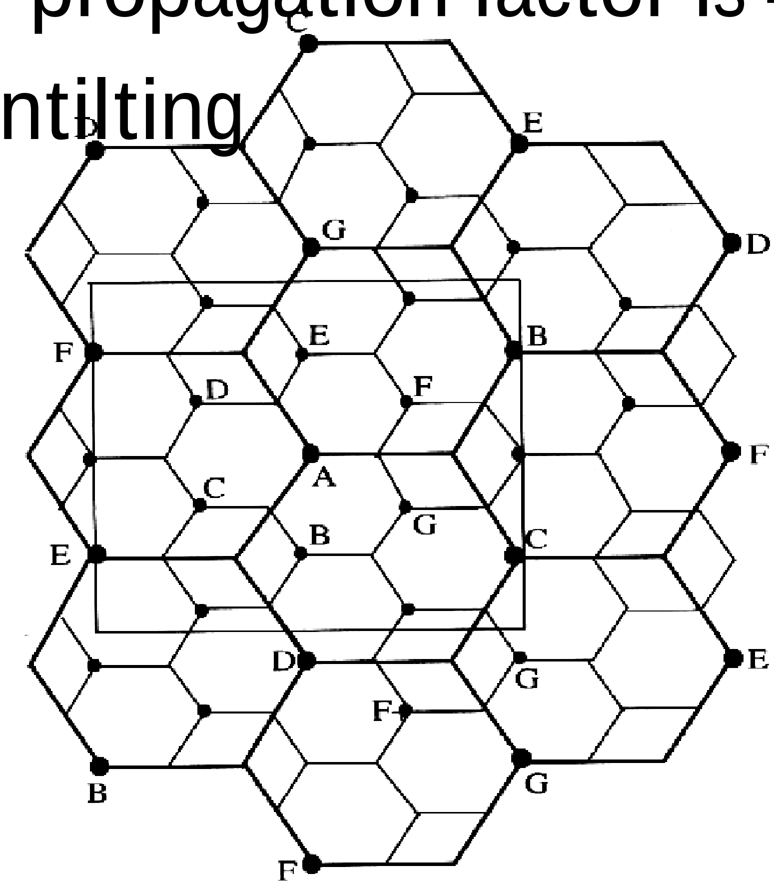


Figure 3.9 Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

Sectoring

- In basic form, antennas are omnidirectional
- Replacing a single omni-directional antenna at base station with several directional antennas, each radiating within a specified sector.
- achieves capacity improvement by essentially rescaling the system.
- less co-channel interference, number of cells in a cluster can be reduced
- Larger frequency reuse factor, larger capacity

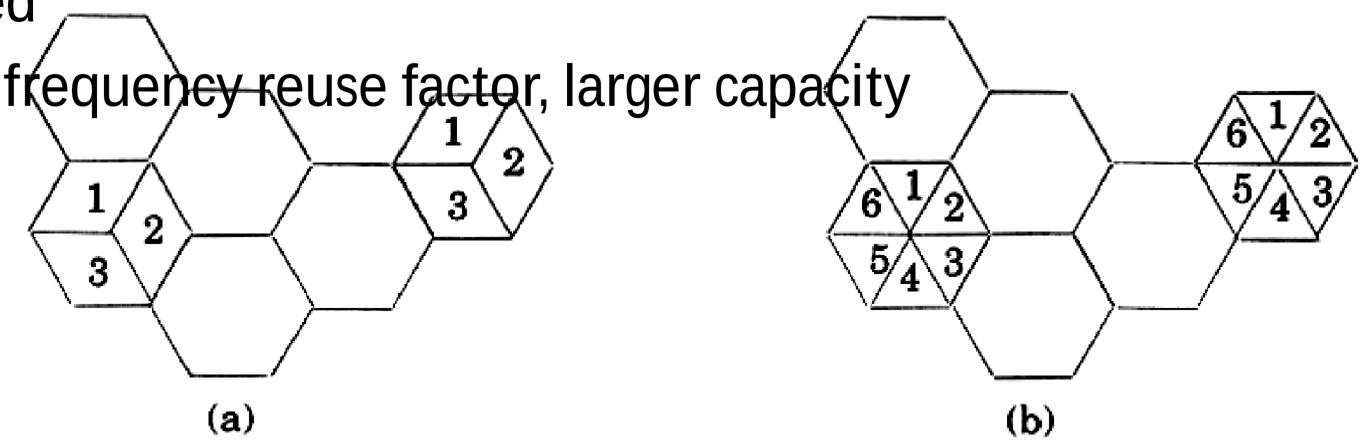


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

Sectoring Examples

- Only two cochannel cell
- S/I improvement 7.2dB
- Capacity 12/7
- First type handoff
- Trunking efficiency low
- Urban area not good
- Example 3.9

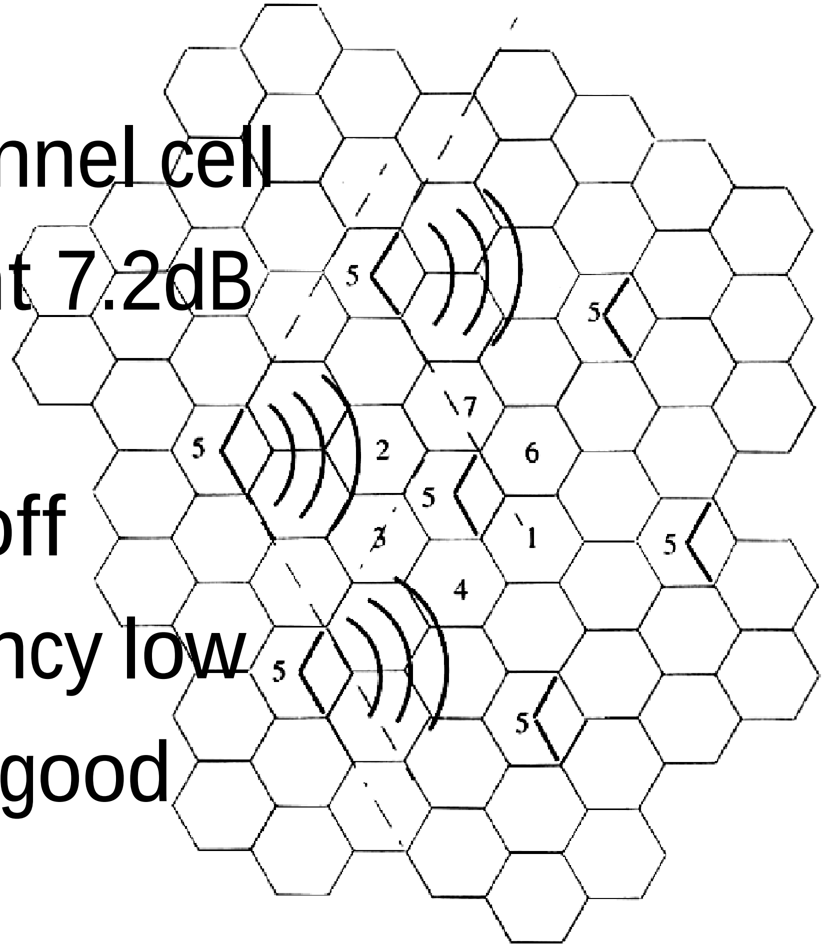


Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

Repeater

- Extend coverage range
- Directional antenna or distributed antenna systems

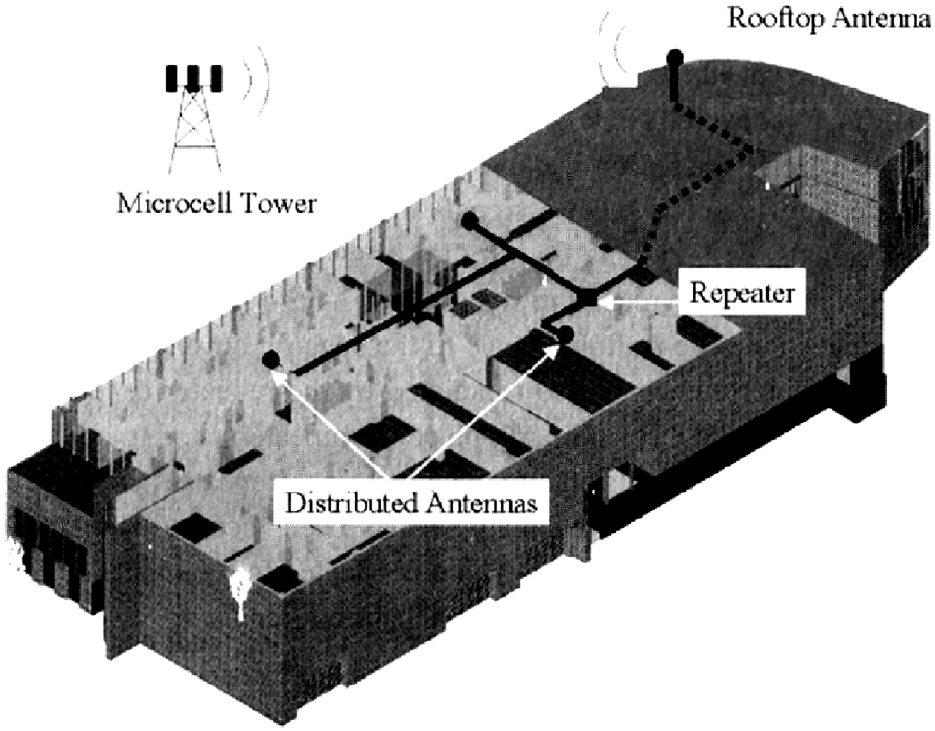


Figure 3.12 Illustration of how a distributed antenna system (DAS) may be used inside a building. Figure produced in SitePlanner®. (Courtesy of Wireless Valley Communications Inc.)

Micro Cell Zone

- Superior to sectoring, any base station channel may be assigned to any zone by the base station
- Same channel
- No handoff
- Only the active zone

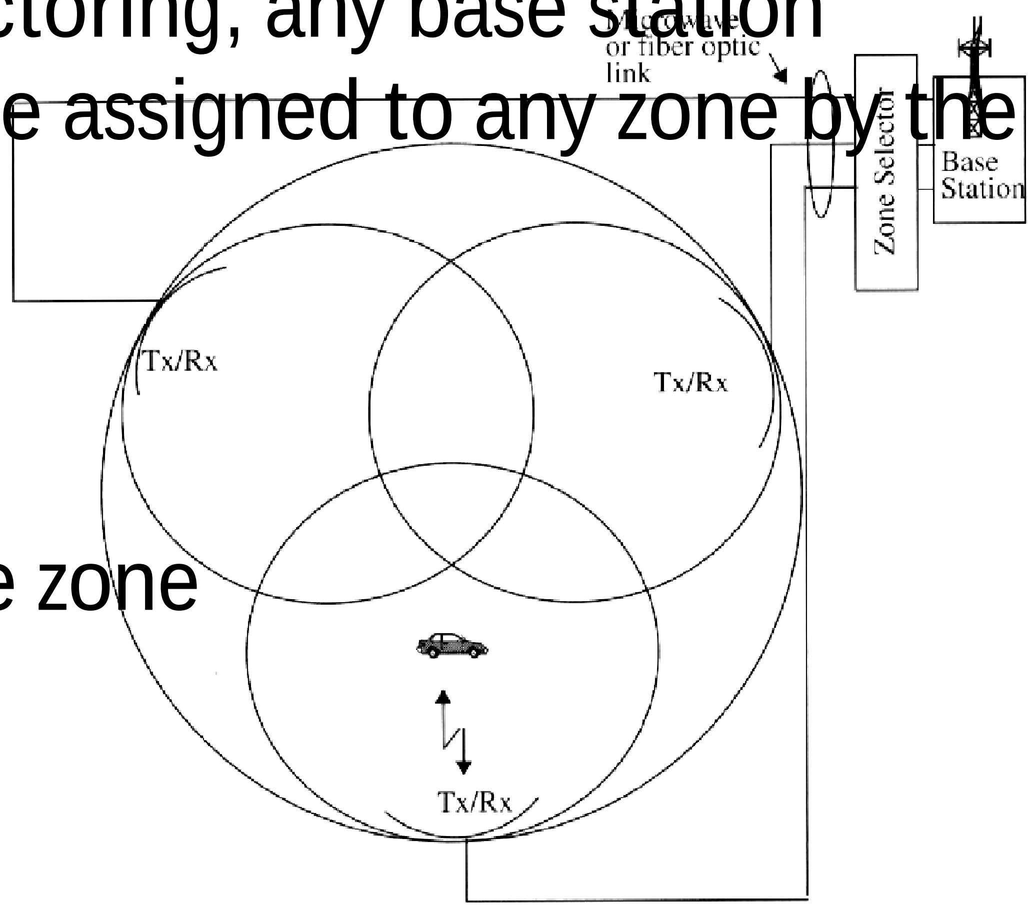


Figure 3.13 The microcell concept [adapted from [Lee91b] © IEEE].

Micro Cell Zone Concept

- Large control base station is replaced by several lower powered transmitters on the edge of the cell.
- The mobile retains the same channel and the base station simply switches the channel to a different zone site and the mobile moves from zone to zone.
- Since a given channel is active only in a particular zone in which mobile is traveling, base station radiation is localized and interference is reduced.

Example

- Dz/Rz=7, but D/R is 3.
- 2.33 times

capacity gain

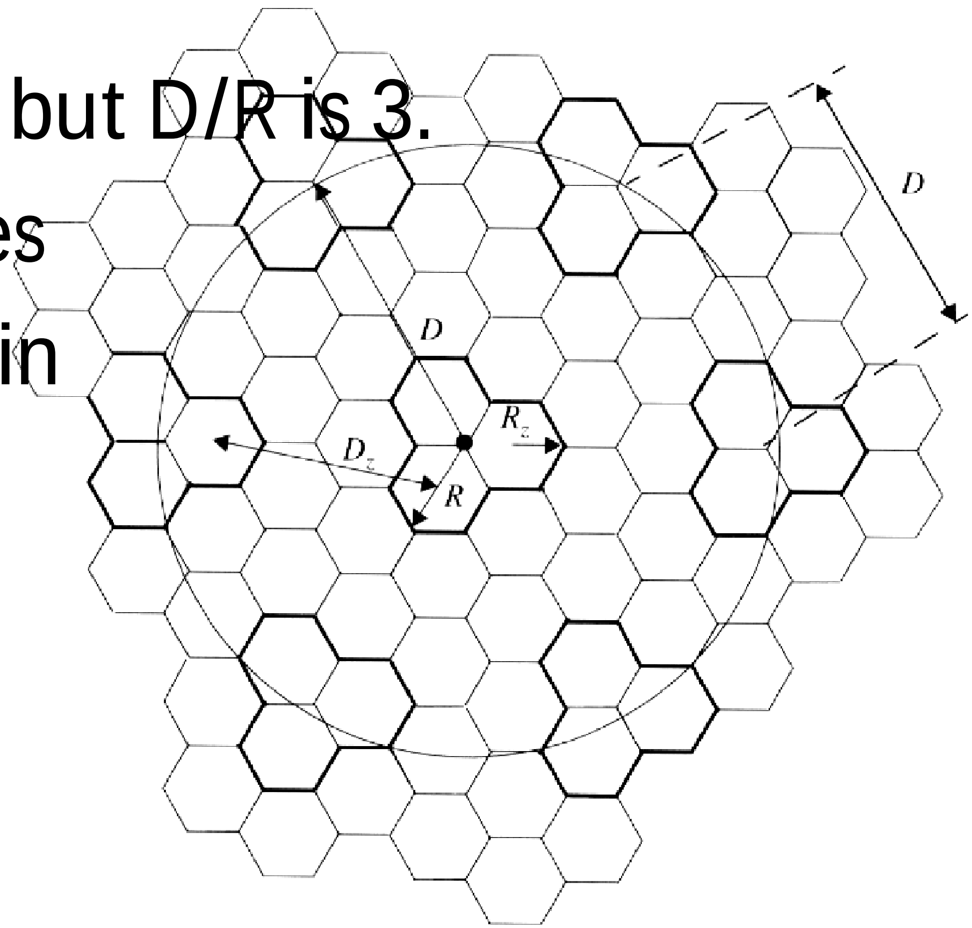


Figure 3.14 Define D, D_z, R, and R_z for a microcell architecture with $N = 7$. The smaller hexagons form zones and three hexagons (outlined in bold) together form a cell. Six nearest co-channel cells are shown.

Brief Outline of Cellular Process

- Telephone call to mobile user
  - Step 1 – The incoming telephone call to Mobile X is received at the MSC.
  - Step 2 – The MSC dispatches the request to all base stations in the cellular system.
  - Step 3 – The base stations broadcast the Mobile Identification Number (MIN), telephone number of Mobile X, as a paging message over the FCC throughout the cellular system.
  - Step 4 – The mobile receives the paging message sent by the base station it monitors and responds by identifying itself over the reverse control channel.
  - Step 5 – The base station relays the acknowledgement sent by the mobile and informs the MSC of the handshake.
  - Step 6 – The MSC instructs the base station to move the call to an issued voice channel within in the cell.
  - Step 7 – The base station signals the mobile to change frequencies to an unused forward and reverse voice channel pair.
  - At the same time, another data message (alert) is transmitted over the forward voice channel to instruct the mobile to ring.

Telephone Call Placed by Mobile

- Step 1 – When a mobile originates a call, it sends the base station its telephone number (MIN), electronic serial number (ESN), and telephone number of called party. It also transmits a station class mark (SCM) which indicates what the maximum power level is for the particular user.
- Step 2 – The cell base station receives the data and sends it to the MSC.
- Step 3 – The MSC validates the request, makes connection to the called party through the PSTN and validates the base station and mobile user to move to an unused forward and reverse channel pair to allow the conversation to begin.

Roaming

- All cellular systems provide a service called roaming. This allows subscribers to operate in service areas other than the one from which service is subscribed.
- When a mobile enters a city or geographic area that is different from its home service area, it is registered as a roamer in the new service area.
- Registration
  - MSC polls for unregistered mobiles
  - Mobiles respond with MINs
  - MSC queries mobile’s home for billing info
- Calls
  - MSC controls call and bills mobile’s home