EEEN3008J: Advance wireless communications

Cellular Wireless Networks

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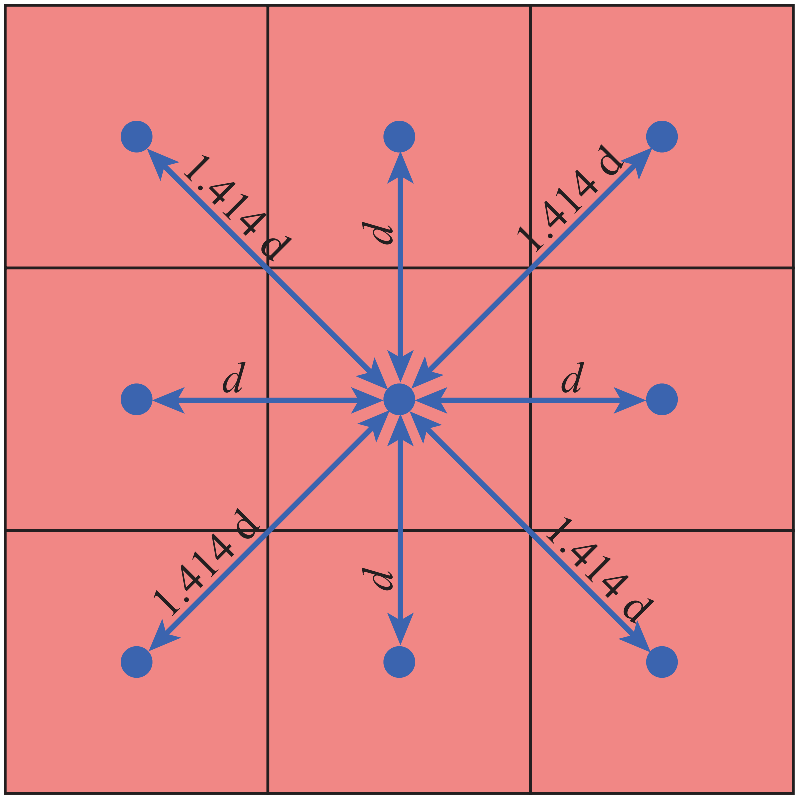
Cellular Networks

- Revolutionary development in data communications and telecommunications
- Foundation of mobile wireless
  - Telephones, smartphones, tablets, wireless Internet, wireless applications
- Supports locations not easily served by wireless networks or WLANs
- Four generations of standards
  - 1G: Analog
  - 2G: Still used to carry voice
  - 3G: First with sufficient speeds for data networking, packets only
  - 4G: Truly broadband mobile data up to 1 Gbps

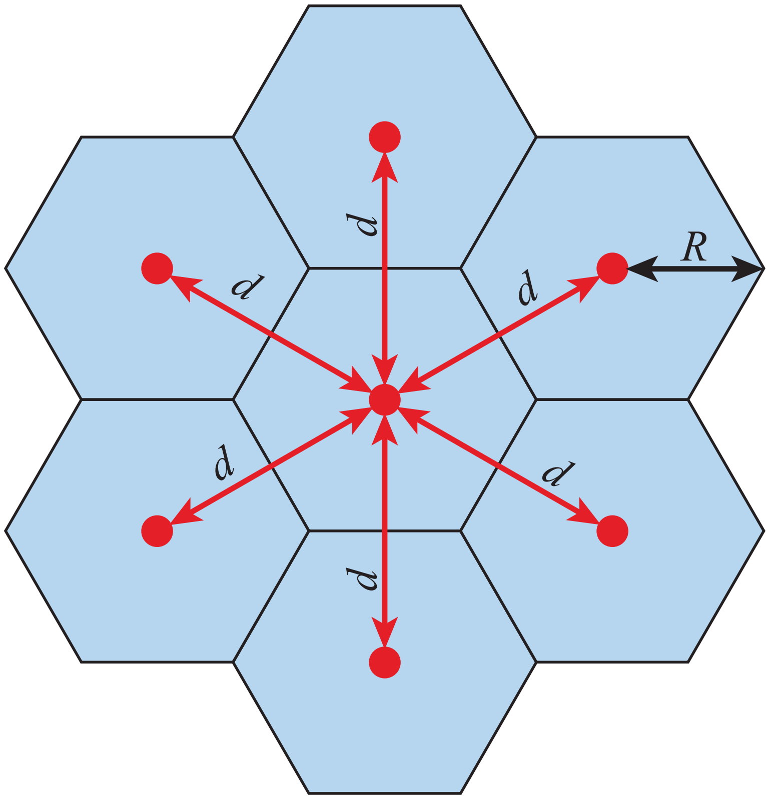
Cellular Network Organization

- Areas divided into cells
  - Each served by its own antenna
  - Served by base station consisting of transmitter, receiver, and control unit
  - Band of frequencies allocated
  - Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)

Cellular geometries



(a) Square pattern

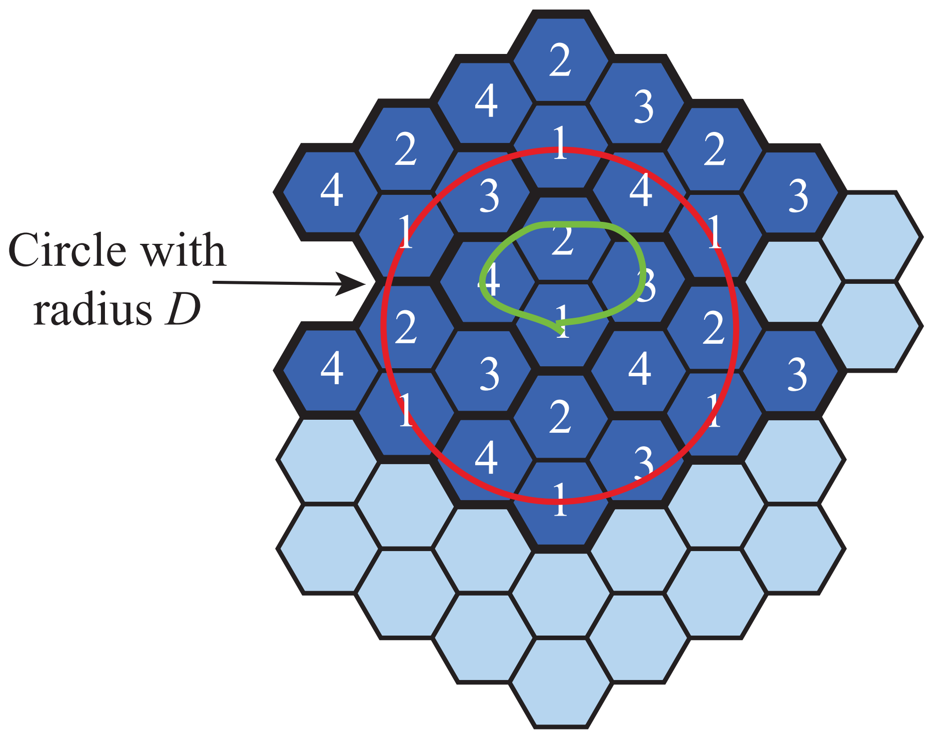


(b) Hexagonal pattern

Frequency Reuse

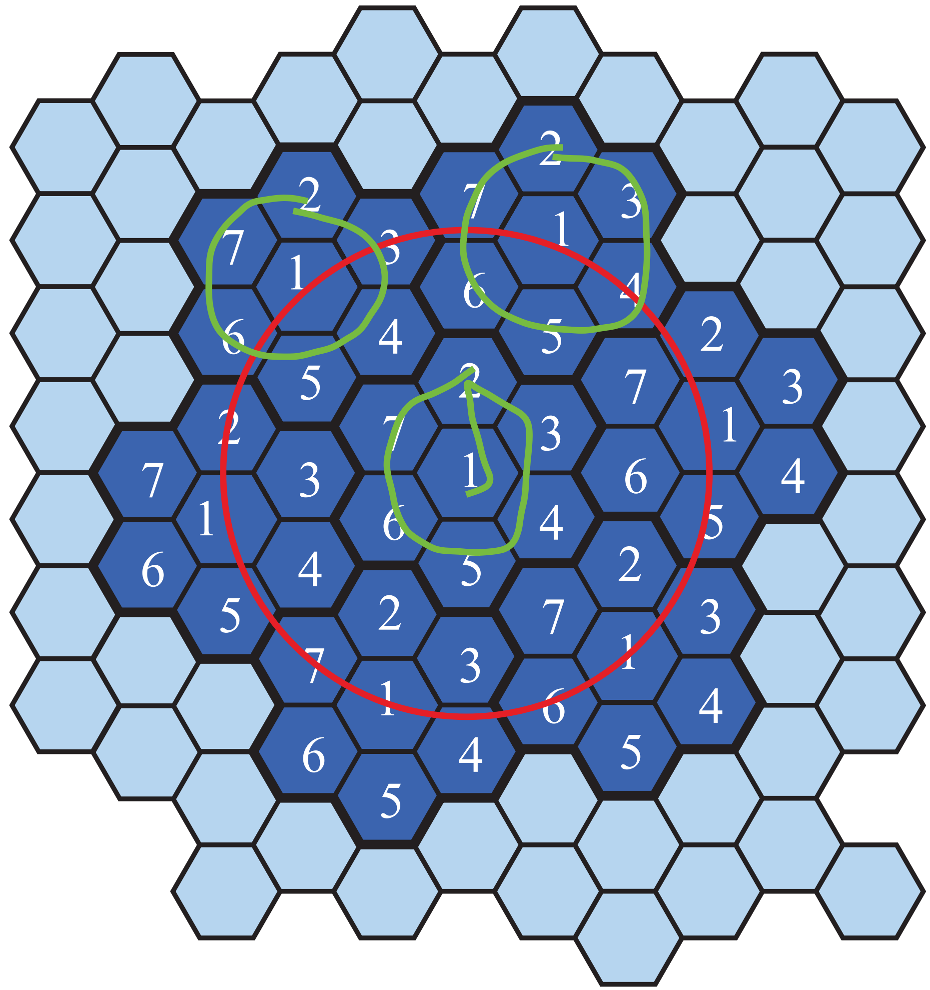
- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Objective is to reuse frequency in nearby cells
  - A set of *N* different frequencies $\{f_1, \ldots, f_N\}$ are used for each cluster of *N* adjacent cells
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells
  - The issue is to determine how many cells must intervene between two cells using the same frequency

Frequency reuse patterns



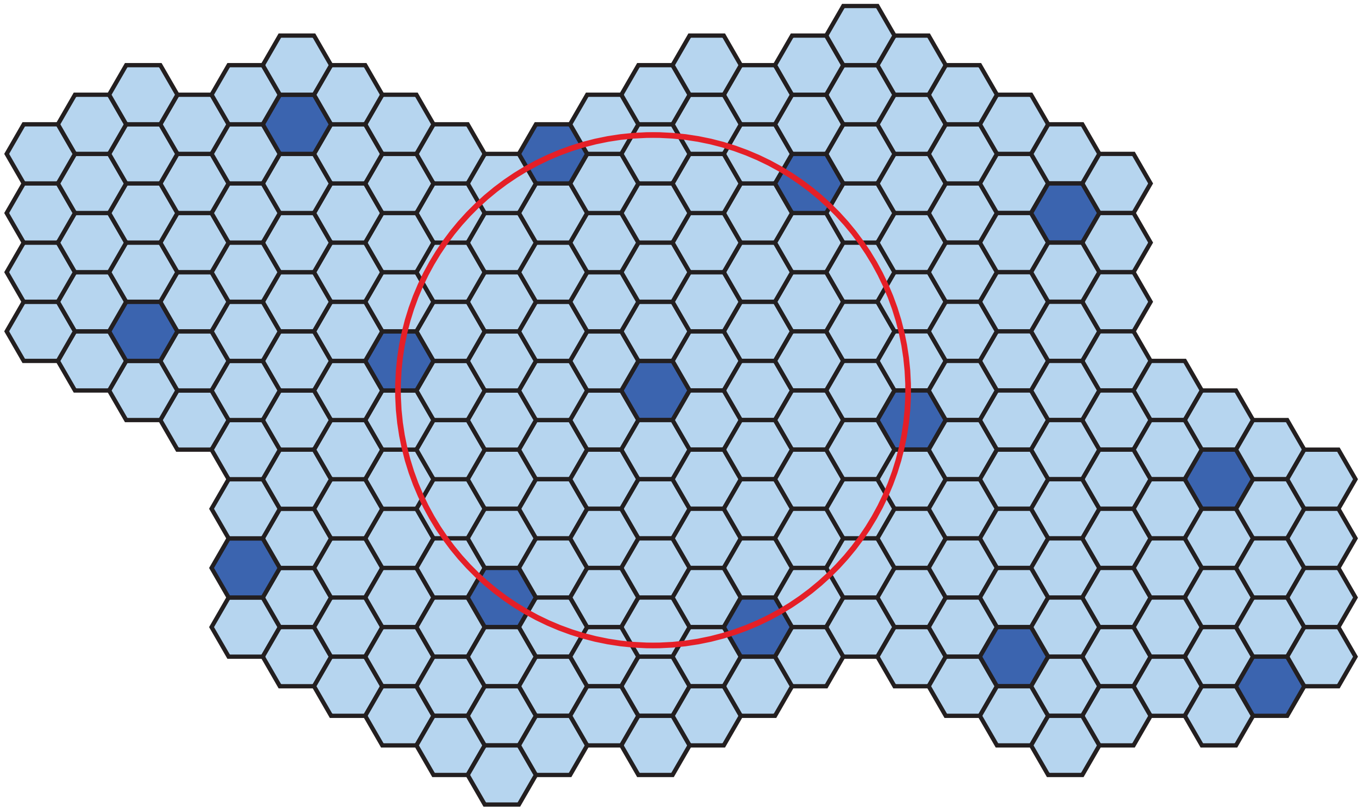
(a) Frequency reuse pattern for $N = 4$

Reuse patterns II



(b) Frequency reuse pattern for $N = 7$

Reuse patterns III



(c) Black cells indicate a frequency reuse for $N = 19$

Frequency Reuse: Parameters

D = minimum distance between centers of cells that use the same frequency band (called cochannels)

R = radius of a cell

d = distance between centers of adjacent cells $\left(d = \sqrt{3}R\right)$

N = number of cells in a repetitious pattern (each cell in the pattern uses a unique set of frequency bands), termed the **reuse factor**

In a hexagonal cell pattern, only the following values of N are possible:

$$N = I^2 + J^2 + (I \times J), \quad I, J = 0, 1, 2, 3, \ldots$$

Hence, possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, and so on. The following relationship holds:

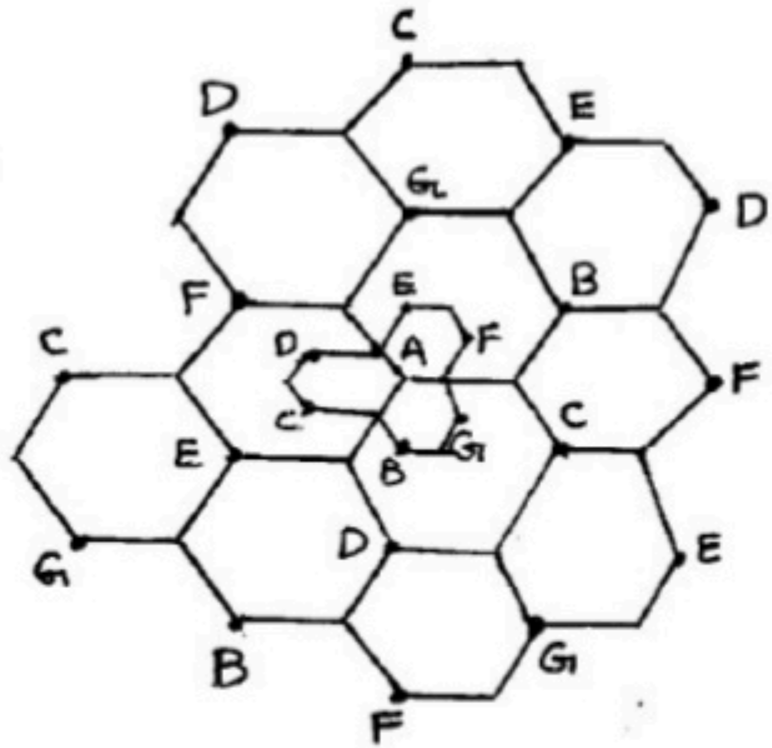
$$\frac{D}{R} = \sqrt{3N}$$

This can also be expressed as $D/d = \sqrt{N}$.

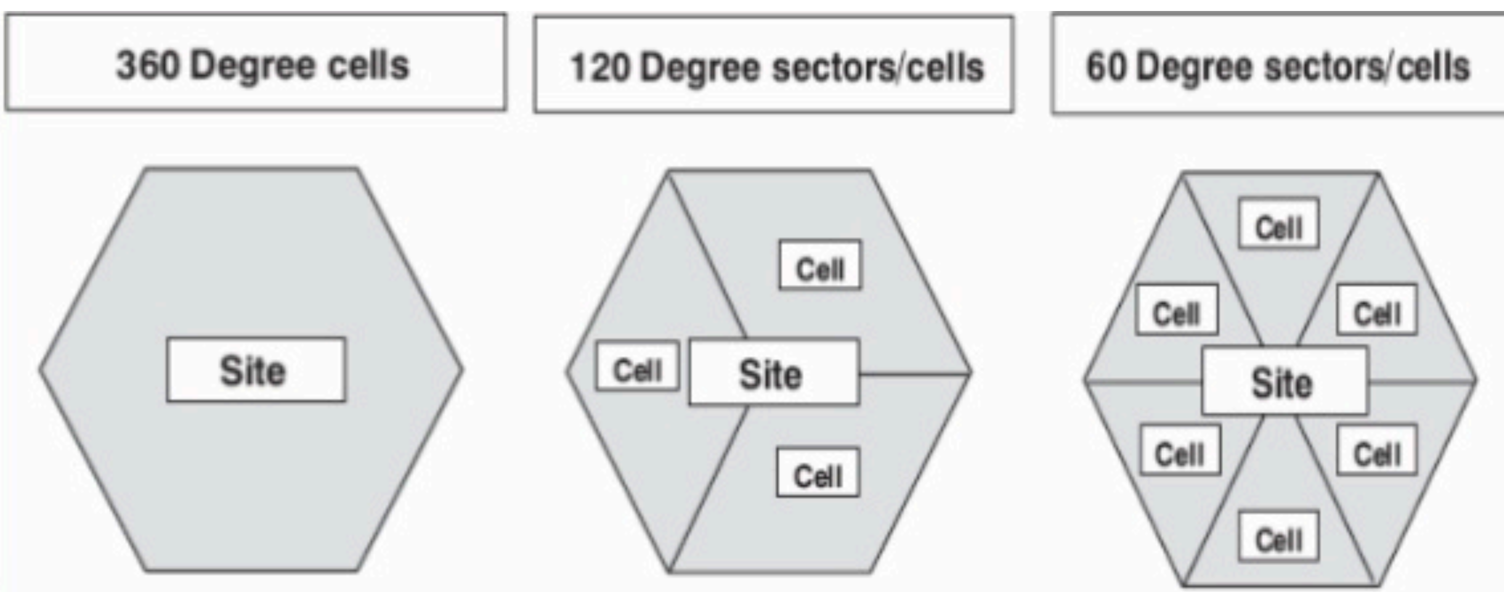
Approaches to Cope with Increasing Capacity

- Adding new channels
- 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
- Network densification – more cells and frequency reuse
  - Microcells – antennas move to buildings, hills, and lamp posts
  - Femtocells – antennas to create small cells in buildings
- Interference coordination – tighter control of interference so frequencies can be reused closer to other base stations
  - Inter-cell interference coordination (ICIC)
  - Coordinated multipoint transmission (CoMP)

Cell Splitting



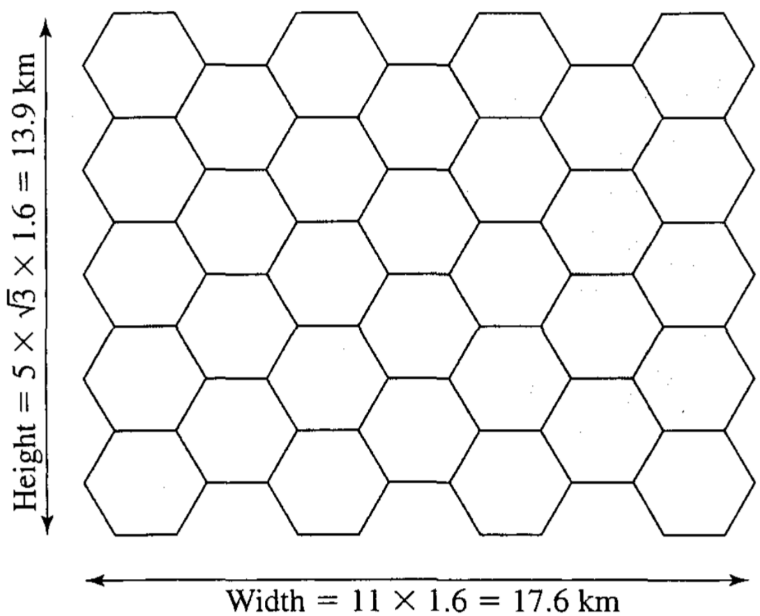
Sectoring



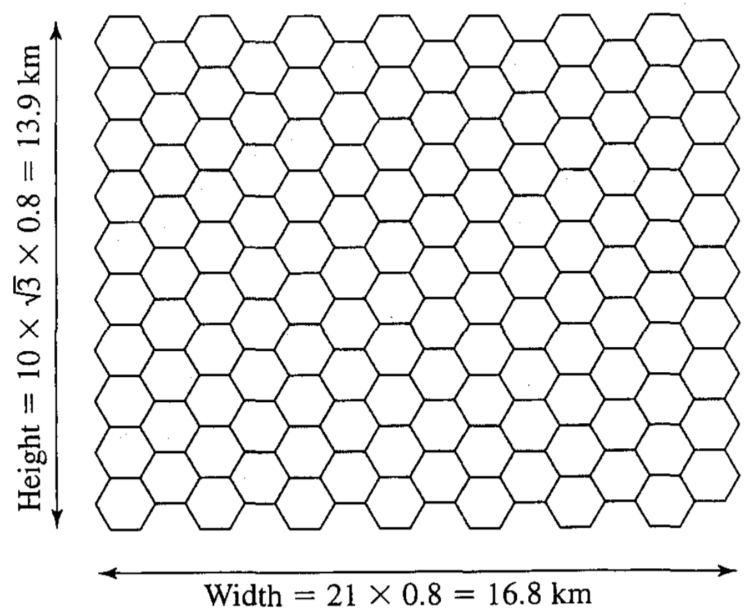
- If the pattern consists of N cells and each cell is assigned the same number of frequencies, each cell can have K/N frequencies, where K is the total number of frequencies allotted to the system.
- For AMPS, $K = 395$, and $N = 7$ is the smallest pattern that can provide sufficient isolation between two uses of the same frequency. This implies that there can be at most 57 frequencies per cell on average.

Example

- Assume a system of 32 cells with a cell radius of 1.6 km, a total of 32 cells, a total frequency bandwidth that supports 336 traffic channels, and a reuse factor of N = 7. If there are 32 total cells, what geographic area is covered, how many channels. are there per cell, and what is the total number of concurrent calls that can be handled? Repeat for a cell radius of 0.8 km and 128 cells.



(a) Cell radius = 1.6 km

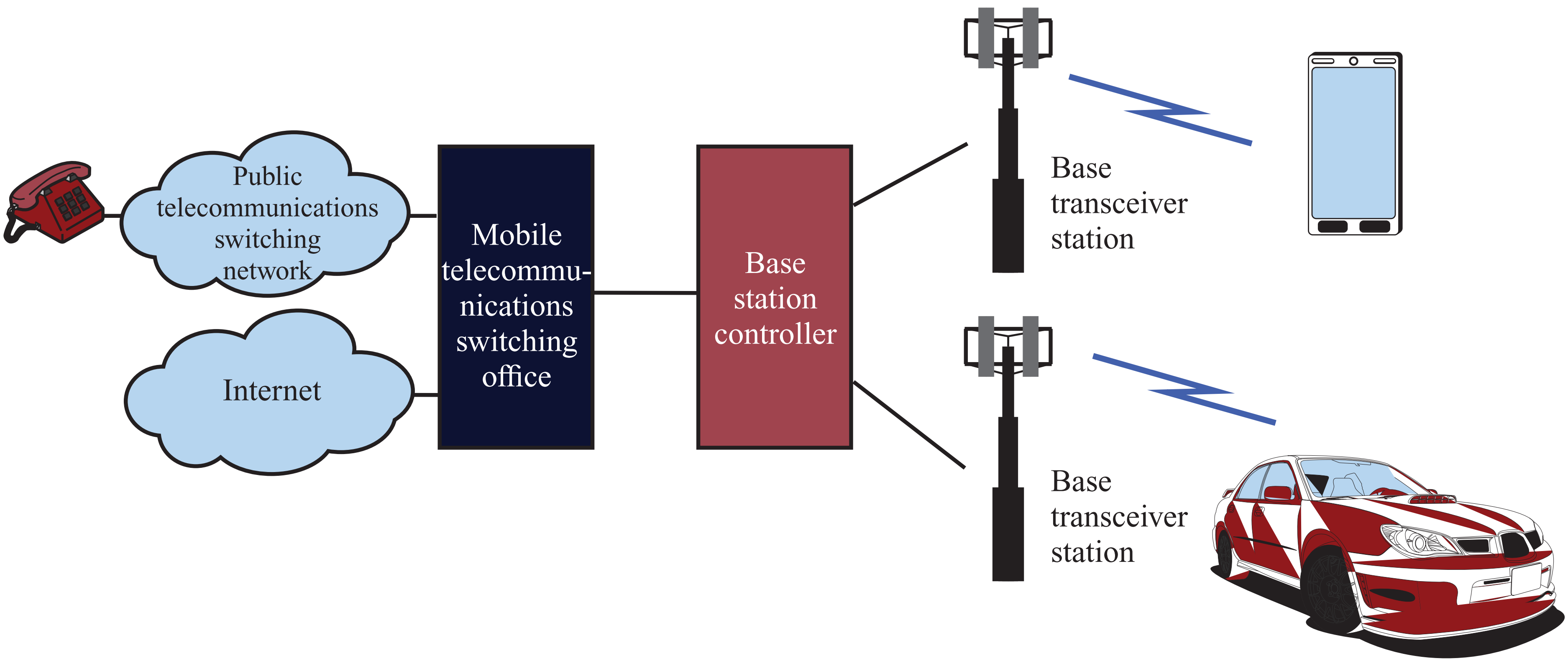


(b) Cell radius = 0.8 km

Cellular Systems Terms

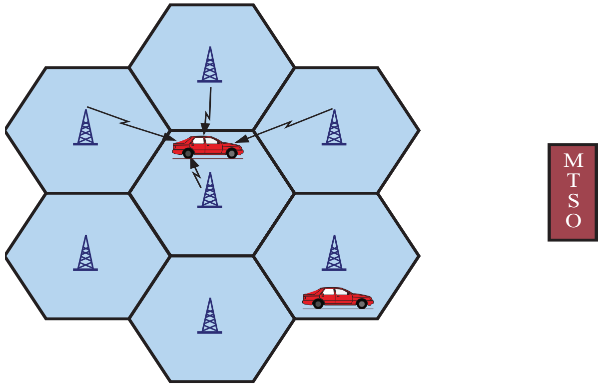
- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - Control channels – used to exchange information having to do with setting up and maintaining calls
  - Traffic channels – carry voice or data connection between users

Overview of a cellular system

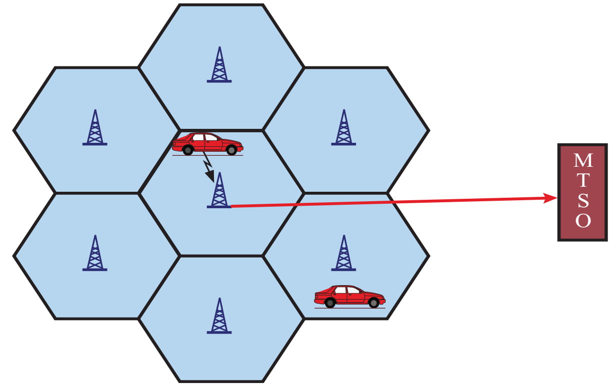


Steps in an MTSO Controlled Call between Mobile Users

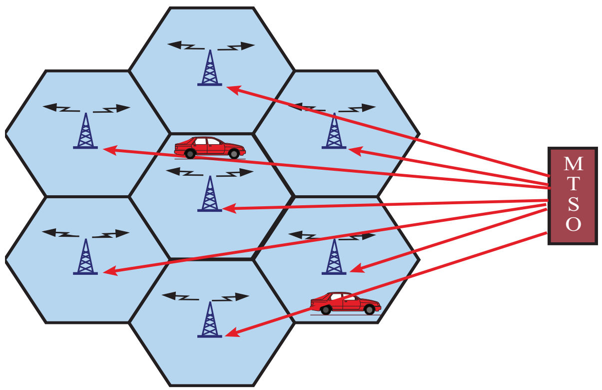
- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff



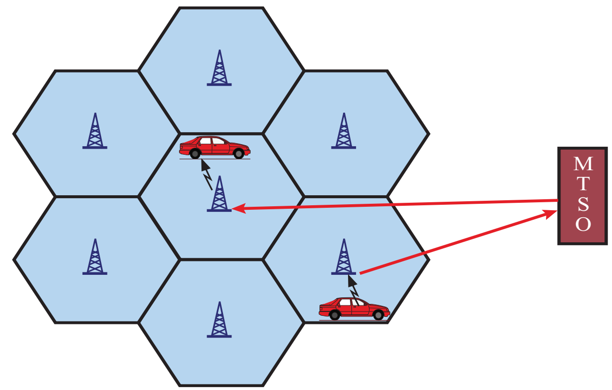
(a) Monitor for strongest signal



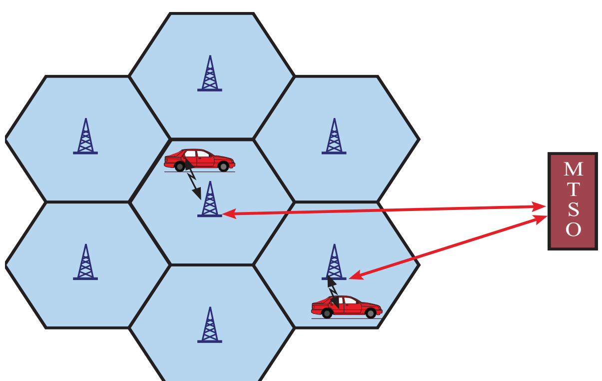
(b) Request for connection



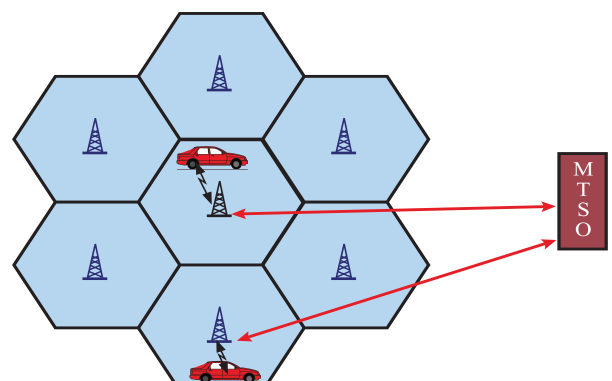
(c) Paging



(d) Call accepted



(e) Ongoing call



(f) Handoff

Additional Functions in an MTSO Controlled Call

- Call blocking
- Call termination
- Call drop
- Calls to/from fixed and remote mobile subscriber

Mobile Radio Propagation Effects

- Signal strength
  - Must be strong enough between base station and mobile unit to maintain signal quality at the receiver
  - Must not be so strong as to create too much co-channel interference with channels in another cell using the same frequency band
- Fading
  - Signal propagation effects may disrupt the signal and cause errors

Mobile Radio Propagation Effects

Path Loss Model

$$\boxed{\begin{aligned} L_{\mathrm{dB}} &= 69.55 + 26.16 \log f_c - 13.82 \log h_t - \mathrm{A}(h_r) \\ &\quad + (44.9 - 6.55 \log h_t) \log d \end{aligned}}$$

where

$$\begin{aligned} f_c &= \text{carrier frequency in MHz from 150 to 1500 MHz} \\ h_t &= \text{height of transmitting antenna (base station) in m, from 30 to 300 m} \\ h_r &= \text{height of receiving antenna (mobile unit) in m, from 1 to 10 m} \\ d &= \text{propagation distance between antennas in km, from 1 to 20 km} \\ \mathrm{A}(h_r) &= \text{correction factor for mobile unit antenna height} \end{aligned}$$

For a small or medium sized city, the correction factor is given by

$$\mathrm{A}(h_r) = (1.1 \log f_c - 0.7) h_r - (1.56 \log f_c - 0.8) \text{ dB}$$

And for a large city it is given by

$$\begin{aligned} A(h_r) &= 8.29[\log(1.54\, h_r)]^2 - 1.1 \text{ dB} \qquad \text{for } f_c \leq 300 \text{ MHz} \\ A(h_r) &= 3.2[\log(11.75\, h_r)]^2 - 4.97 \text{ dB} \qquad \text{for } f_c \geq 300 \text{ MHz} \end{aligned}$$

$$L_{\mathrm{dB}}(\text{suburban}) = L_{\mathrm{dB}}(\text{urban}) - 2[\log(f_c/28)]^2 - 5.4$$

$$L_{\mathrm{dB}}(\text{open}) = L_{\mathrm{dB}}(\text{urban}) - 4.78(\log f_c)^2 - 18.733(\log f_c) - 40.98$$

Example

Let $f_c = 900$ MHz, $h_t = 40$ m, $h_r = 5$ m, and $d = 10$ km. Estimate the path loss for a medium-size city.

$$\begin{aligned} A(h_r) &= (1.1 \log 900 - 0.7)5 - (1.56 \log 900 - 0.8) \text{ dB} \\ &= 12.75 - 3.8 = 8.95 \text{ dB} \\ L_{\text{dB}} &= 69.55 + 26.16 \log 900 - 13.82 \log 40 - 8.95 + (44.9 - 6.55 \log 40) \log 10 \\ &= 69.55 + 77.28 - 22.14 - 8.95 + 34.4 = 150.14 \text{ dB} \end{aligned}$$

Handoff Performance Metrics

- Cell blocking probability – probability of a new call being blocked
- Call dropping probability – probability that a call is terminated due to a handoff
- Call completion probability – probability that an admitted call is not dropped before it terminates
- Probability of unsuccessful handoff – probability that a handoff is executed while the reception conditions are inadequate

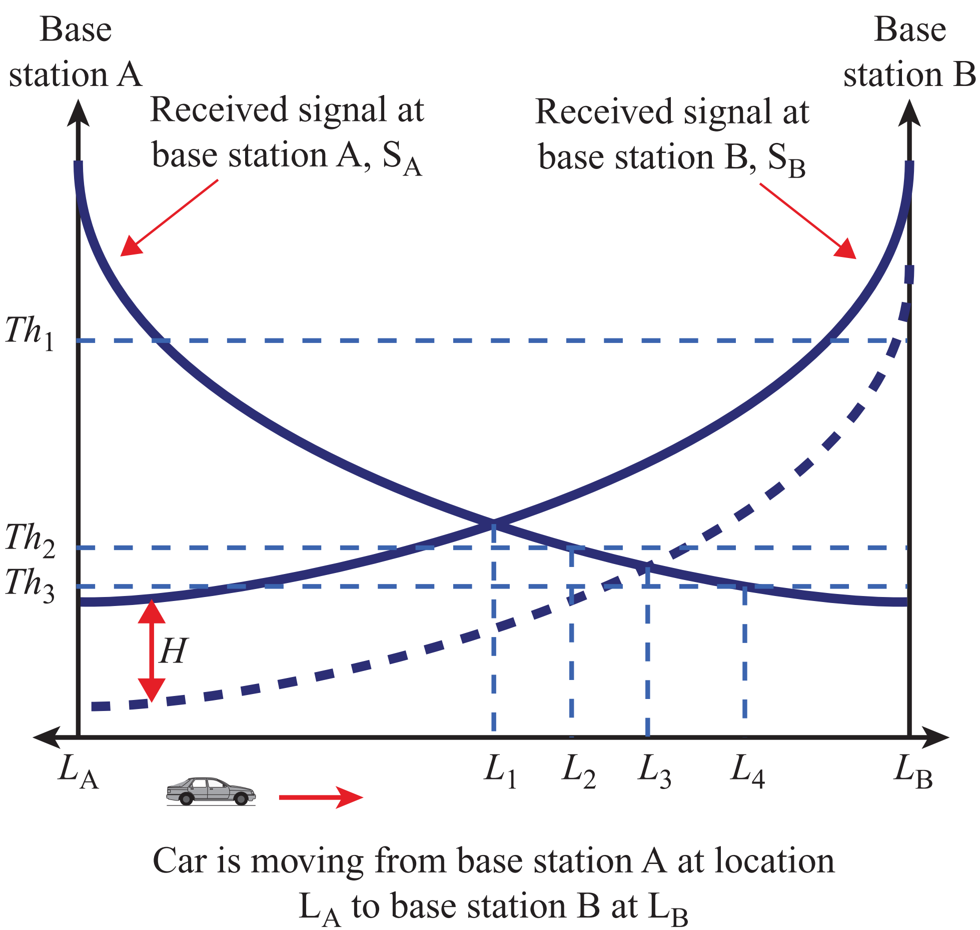
Handoff Performance Metrics

- Handoff blocking probability – probability that a handoff cannot be successfully completed
- Handoff probability – probability that a handoff occurs before call termination
- Rate of handoff – number of handoffs per unit time
- Interruption duration – duration of time during a handoff in which a mobile is not connected to either base station
- Handoff delay – distance the mobile moves from the point at which the handoff should occur to the point at which it does occur

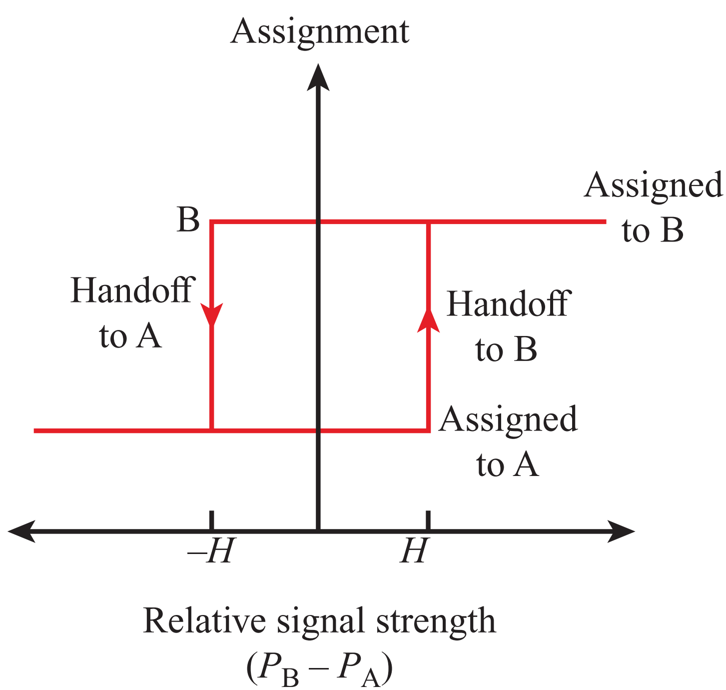
Handoff Strategies Used to Determine Instant of Handoff

- Relative signal strength
- Relative signal strength with threshold
- Relative signal strength with hysteresis
- Relative signal strength with hysteresis and threshold
- Prediction techniques

Handoff between two cells



(a) Handoff decision as a function of handoff scheme



(b) Hysteresis mechanism

Power Control

- Reasons to include dynamic power control in a cellular system
  - Received power must be sufficiently above the background noise for effective communication
  - Desirable to minimize power in the transmitted signal from the mobile
    - Reduce co-channel interference, alleviate health concerns, save battery power
  - In Spread Spectrum systems using CDMA, it's necessary to equalize the received power level from all mobile units at the BS

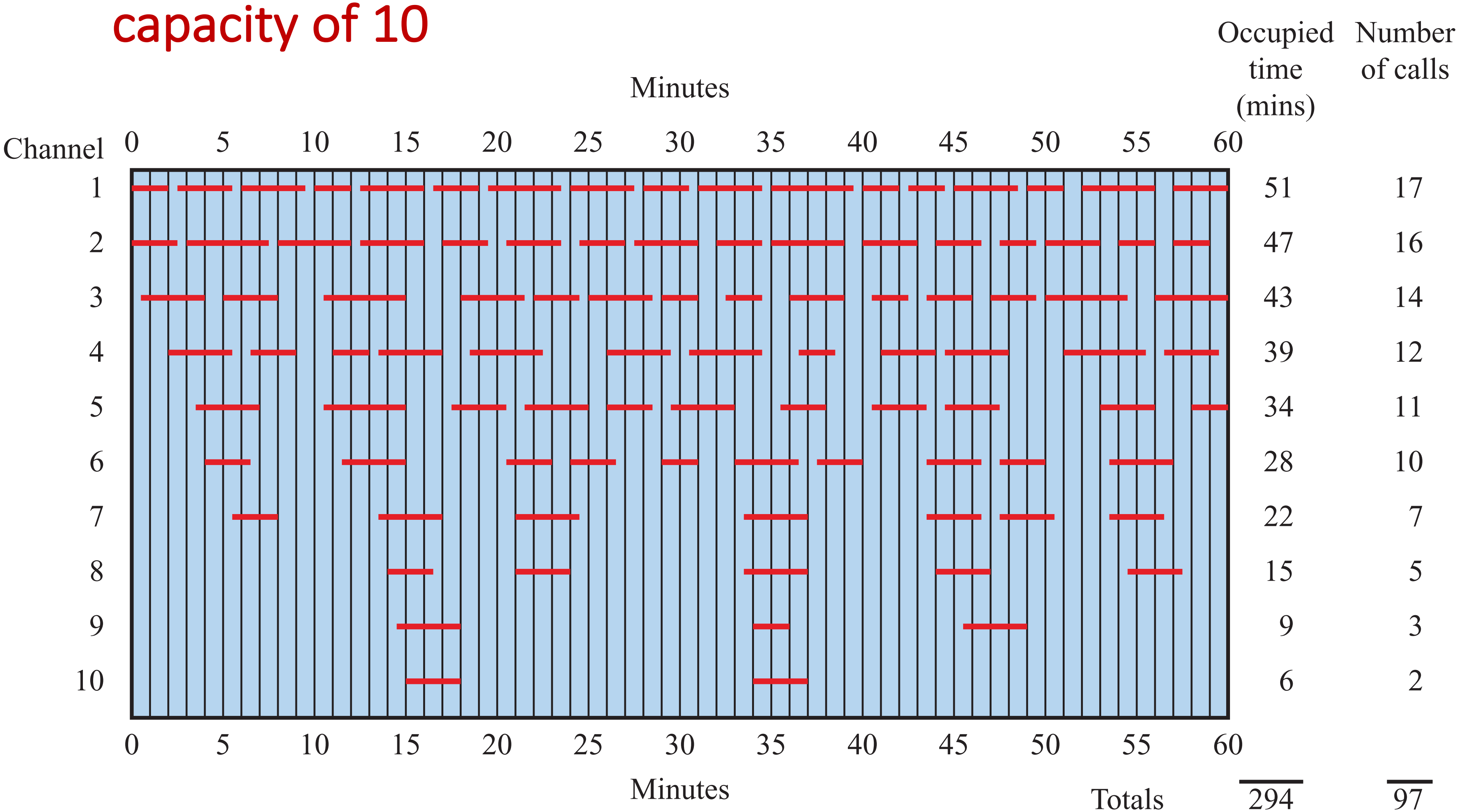
Types of Power Control

- Open-loop power control
  - Depends solely on mobile unit
  - No feedback from BS
  - Not as accurate as closed-loop, but can react quicker to fluctuations in signal strength
- Closed-loop power control
  - Adjusts signal strength in reverse channel based on metric of performance
  - BS makes power adjustment decision and communicates to mobile on control channel

Traffic Engineering

- Ideally, available channels would equal number of subscribers active at one time
- In practice, not feasible to have capacity handle all possible load
- For *N* simultaneous user capacity and *L* subscribers
  - $L < N$ – nonblocking system
  - $L > N$ – blocking system

Example of distribution of traffic in a cell with capacity of 10



Note: horizontal lines indicate occupied periods to the nearest 1/2 minute

Blocking System Performance Questions

- Probability that call request is blocked?
- What capacity is needed to achieve a certain upper bound on probability of blocking?
- What is the average delay?
- What capacity is needed to achieve a certain average delay?

Traffic Intensity

- Load presented to a system:

$$A = \lambda h$$

  - λ = mean rate of calls attempted per unit time
  - h = mean holding time per successful call
  - A = average number of calls arriving during average holding period, for normalized λ

Factors that Determine the Nature of the Traffic Model

- Manner in which blocked calls are handled
  - Lost calls delayed (LCD) – blocked calls put in a queue awaiting a free channel
  - Blocked calls rejected and dropped
    - Lost calls cleared (LCC) – user waits before another attempt
    - Lost calls held (LCH) – user repeatedly attempts calling
- Number of traffic sources
  - Whether number of users is assumed to be finite or infinite

Factors that Determine the Nature of the Traffic Model

- For infinite source, LCC system

$$P = \frac{\frac{A^N}{N!}}{\sum_{x=0}^{N} \frac{A^x}{x!}}$$

where

A = offered traffic, erlangs

N = number of servers

P = probability of blocking (grade of service)