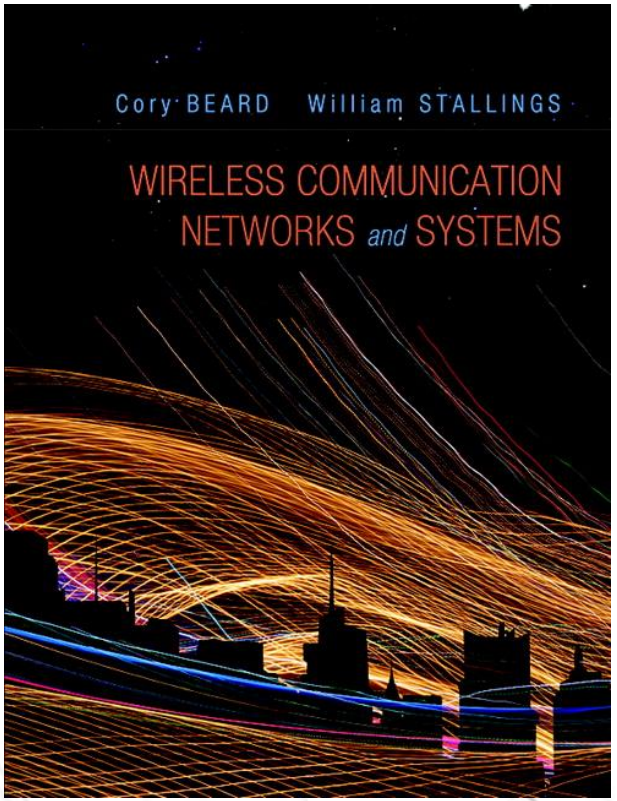
CHAPTER 13
CELLULAR WIRELESS NETWORKS



Wireless Communication Networks and Systems

1st edition

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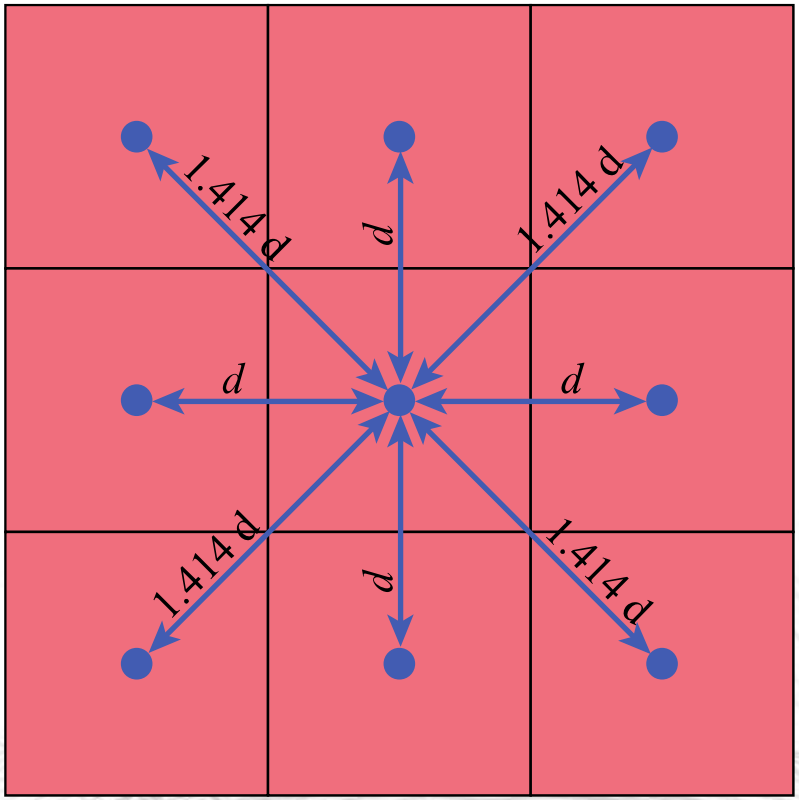
CELLULAR NETWORKS

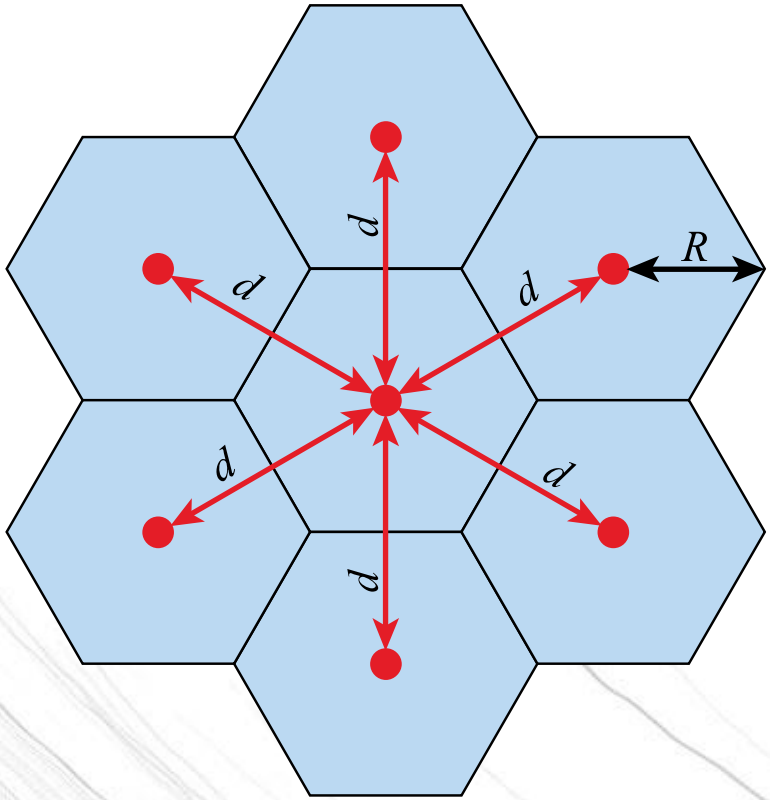
- Revolutionary development in data communications and telecommunications
- Foundation of mobile wireless
  - Telephones, smartphones, tablets, wireless Internet, wireless applications
- Supports locations not easily served by wireless networks or WLANs
- Five generations of standards
  - 1G: Analog
  - 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
  - 5G

CELLULAR NETWORK ORGANIZATION

- Use multiple low-power transmitters (100 W or less)
- 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)



(a) Square pattern



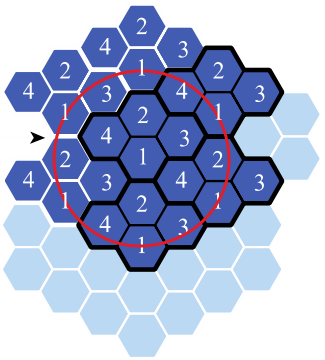
(b) Hexagonal pattern

$$d = \sqrt{3}R$$

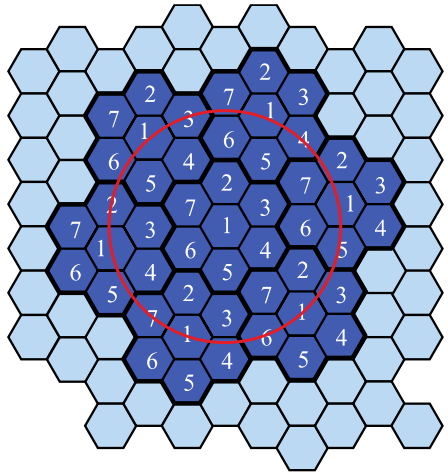
13.1 CELLULAR GEOMETRIES

FREQUENCY REUSE

- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Objective is to reuse frequency in nearby cells
  - 10 to 50 frequencies assigned to each cell
  - 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



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



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

$$N = I^2 + J^2 + (I \times J)$$
$$st\ I, J = 0, 1, 2, etc.$$

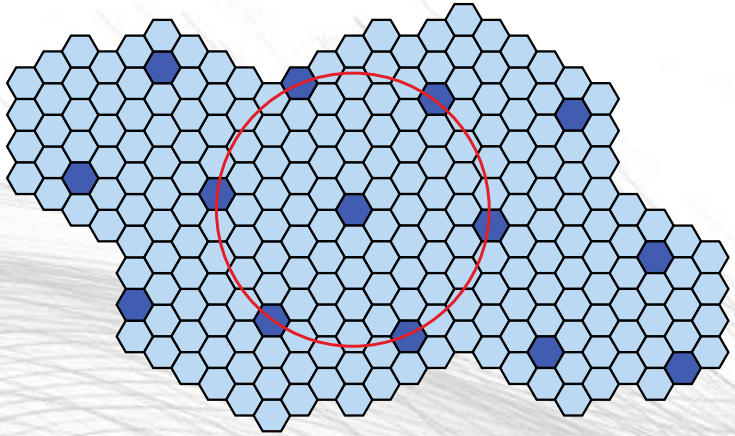
$$\frac{D}{R} = \sqrt{3N}$$

D is minimum frequency reuse distance

R is the cell radius

N is the number of cells in a cluster

1/N is the reuse factor



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

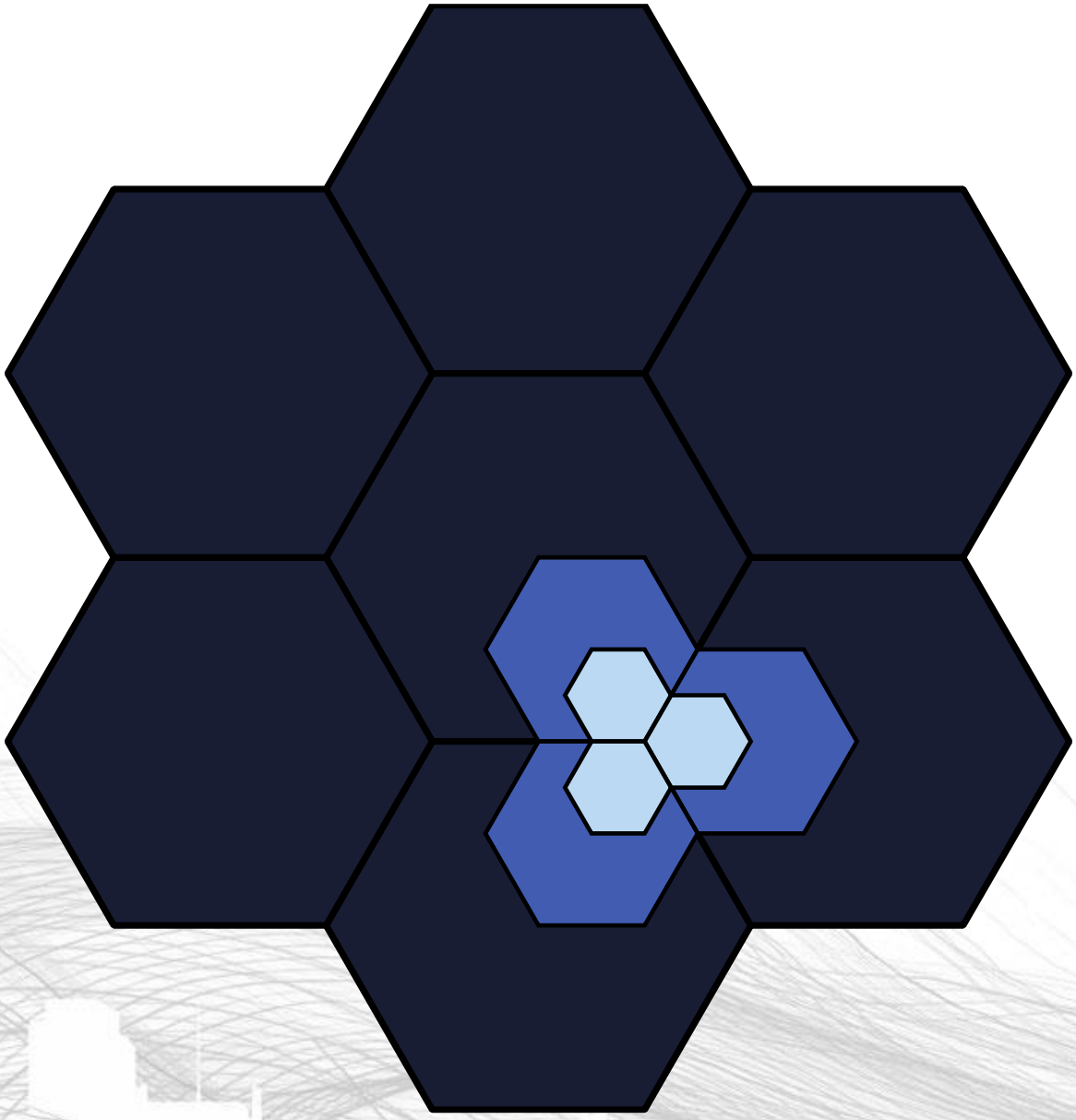
By the Law of Cosines:

$$D^2 =$$
$$= d^2 I^2 + d^2 J^2$$
$$- 2(dI \times dJ)\cos(120º)$$
$$= d^2\left(I^2 + J^2 + (I \times J)\right)$$
$$= 3R^2\left(I^2 + J^2 + (I \times J)\right)$$

13.2 FREQUENCY REUSE PATTERNS

APPROACHES TO COPE WITH INCREASING CAPACITY

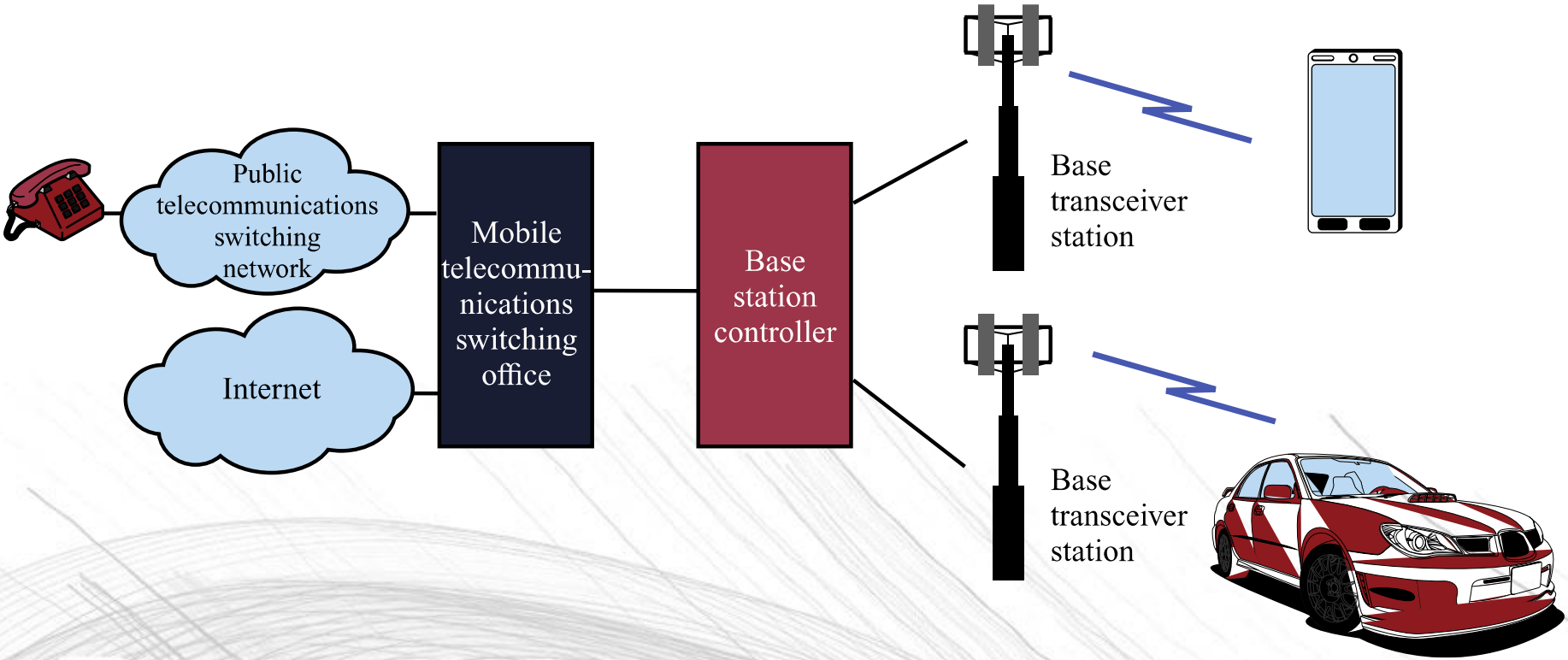
- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels
- 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)



13.3 CELL SPLITTING

CELLULAR SYSTEMS TERMS

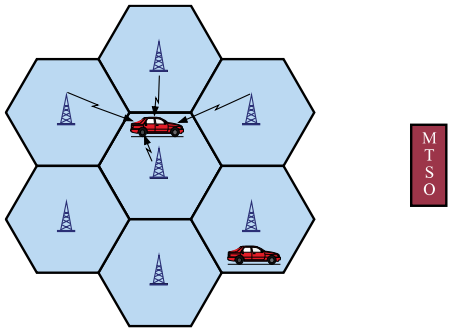
- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - Control channels – used to exchange information having to do with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



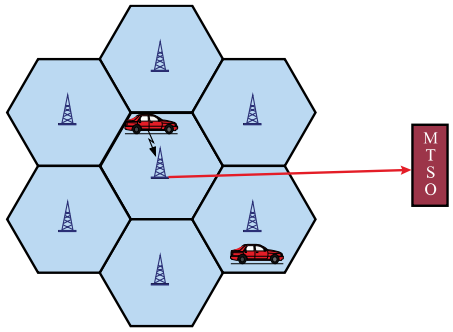
13.5 OVERVIEW OF CELLULAR SYSTEM

STEPS IN AN MTSO CONTROLLED CALL BETWEEN MOBILE USERS

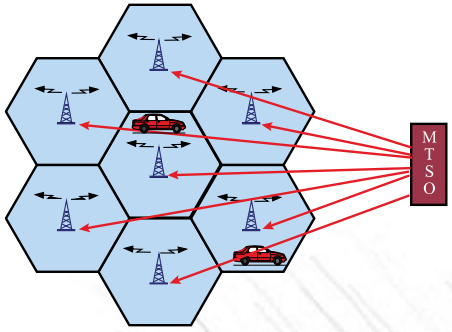
- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff



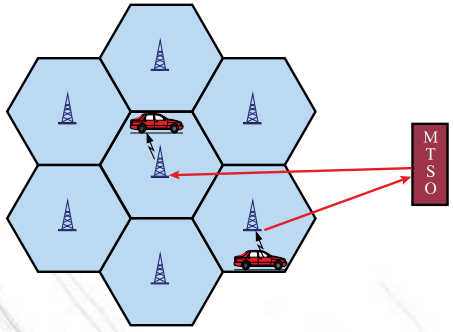
(a) Monitor for strongest signal



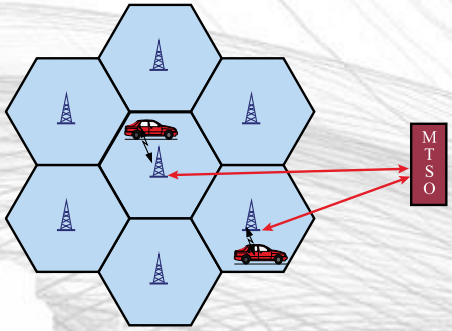
(b) Request for connection



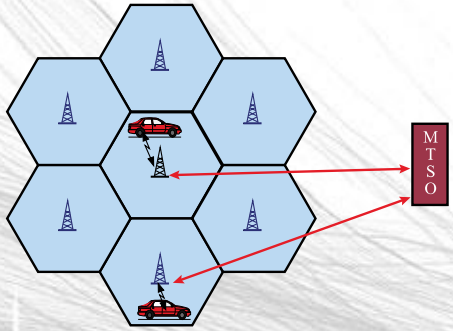
(c) Paging



(d) Call accepted



(e) Ongoing call



(f) Handoff

13.6 EXAMPLE OF MOBILE CELLULAR CALL

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

HANDOFF PERFORMANCE METRICS

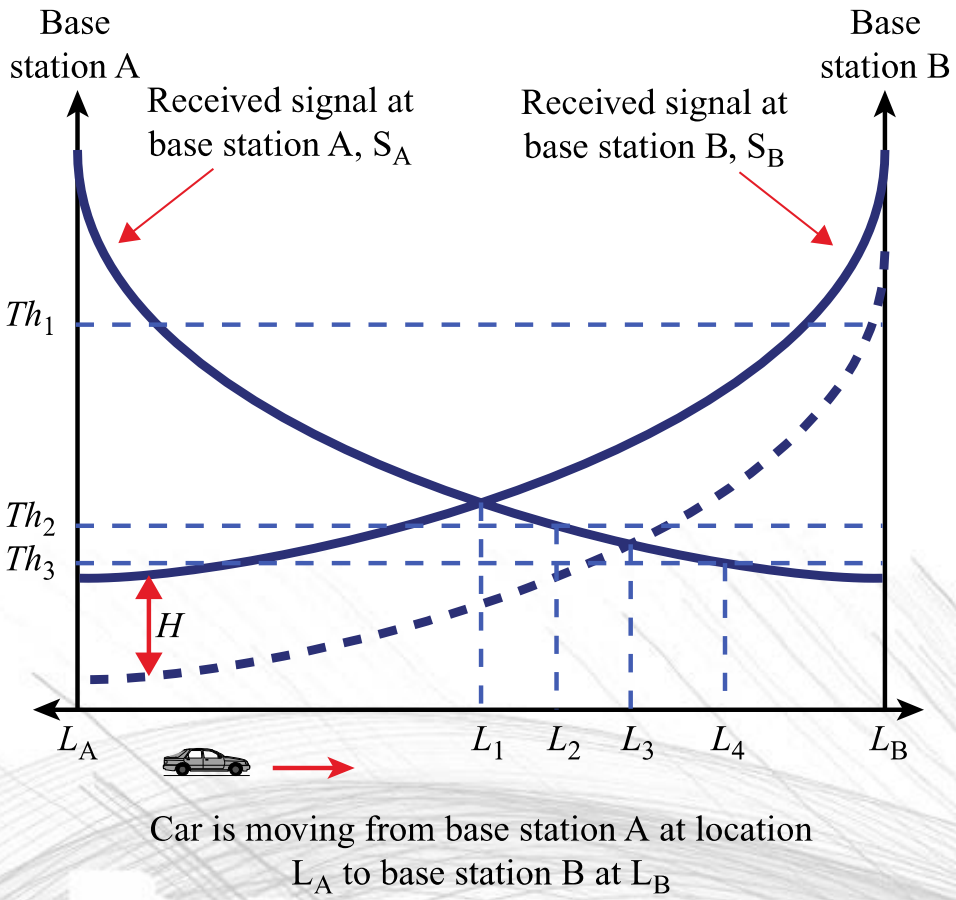
- Call blocking probability – probability of a new call being blocked
- Call dropping probability – probability that a call is terminated due to a handoff
- Call completion probability – probability that an admitted call is not dropped before it terminates
- Probability of unsuccessful handoff – probability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

HANDOFF PERFORMANCE METRICS

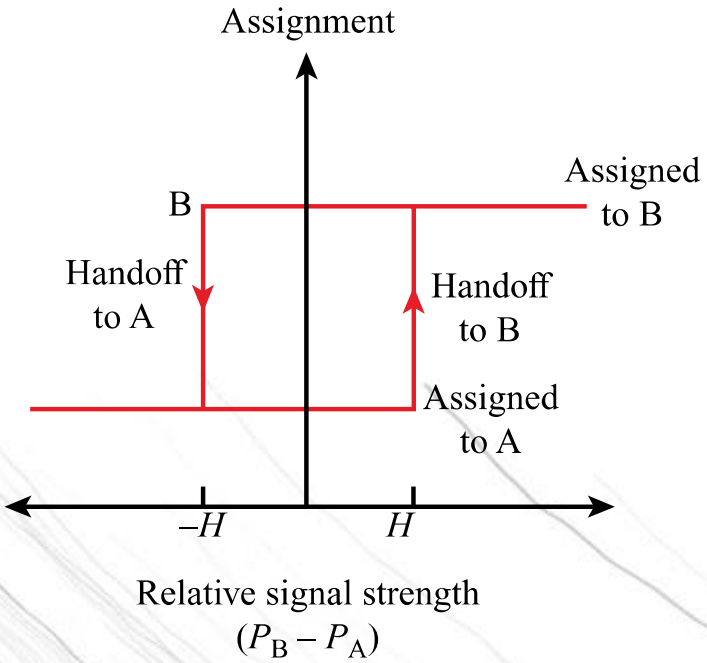
- Handoff blocking probability – probability that a handoff cannot be successfully completed
- Handoff probability – probability that a handoff occurs before call termination
- Rate of handoff – number of handoffs per unit time
- Interruption duration – duration of time during a handoff in which a mobile 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



(a) Handoff decision as a function of handoff scheme



(b) Hysteresis mechanism

13.7 HANDOFF BETWEEN TWO CELLS

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 SS 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