

# 無線網路多媒體系統

## Wireless Multimedia System

Lecture 5: Cellular Concepts

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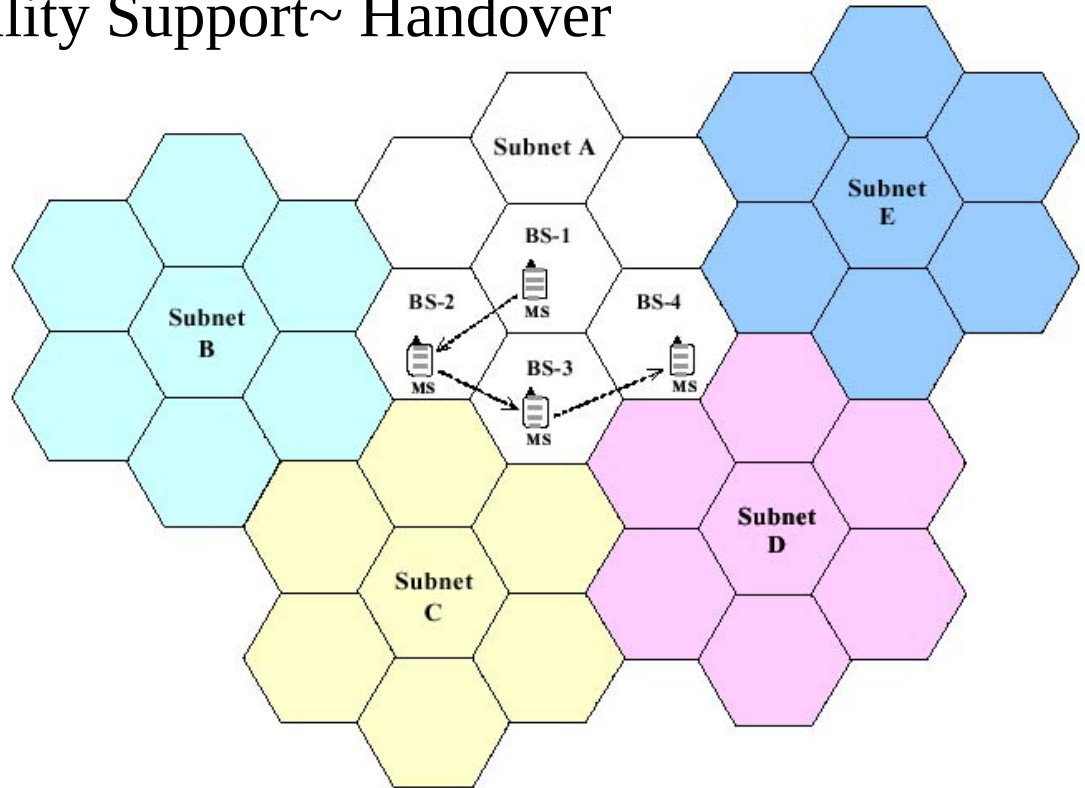
*<http://wmlab.csie.ncu.edu.tw/course/wms>*

We provide  
無線網路多媒體實驗室  
Wireless  
Wireless Network & Multimedia Laboratory  
Solution

# Mobility Support & Channel Reuse



Mobility Support~ Handover



Channel Allocations: Reuse



# Channel Assignment in Cellular System

- ◆ Fundamental Problem:
- ◆ Fixed Channel Assignment
- ◆ Dynamic Channel Assignment
- ◆ Hybrid Schemes
- ◆ Whole Channel Usage (CDMA)
- ◆ Reduce the Cell Size

# Hand-off in Cellular Networks

- ◆ Transfer of mobile to a new channel when it crosses cell boundary
- ◆ Handoff delay
- ◆ Prioritizing handoffs to reduce probability of dropped calls
- ◆ Handoff Strategies
  - ◆ Network Controlled handoff (NCHO)
  - ◆ Mobile assisted handoff (MAHO)
  - ◆ Mobile controlled handoff (MCHO)

# Agenda

- ◆ Cellular Concepts
- ◆ Channel Assignments
- ◆ Handover
- ◆ Next Lecture: 3G WCDMA design



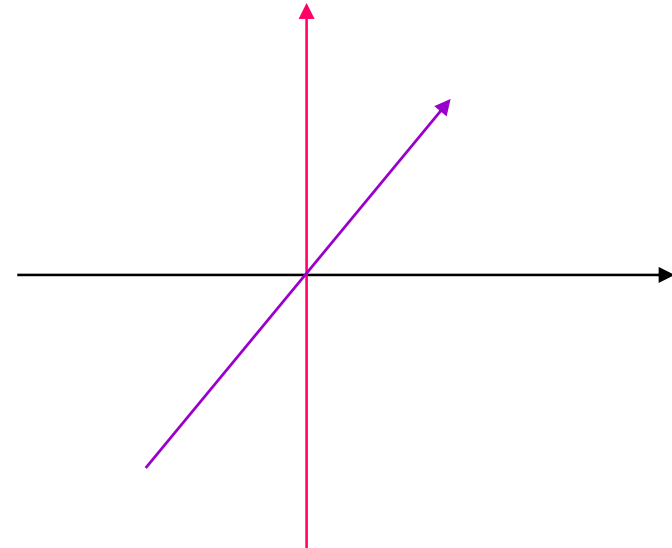
# Reading

- ◆ [Katzela96]Katzela, and M. Nahgshineh,"Channel assignment schemes for cellular mobile telecommunication systems: a comprehensive survey," IEEE Personal Communications, June 1996
- ◆ [Pollinin96], G.P. Pollini, "Trends in handover design, "IEEE Communications Magazine, March 1996.



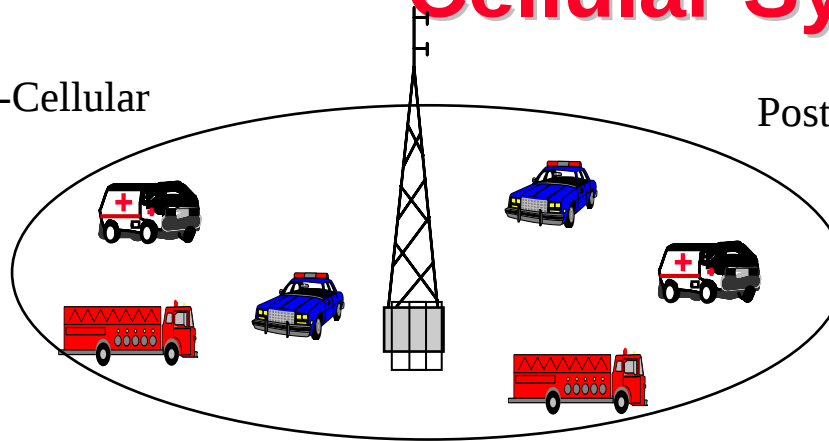
# Channel Allocation

- ◆ A given Channel Spectrum (or bandwidth) can be divided into a set of disjoint or non-interfering radio channel
  - Frequency Division
    - ◆ frequency band
  - Time Division
    - ◆ time slot
  - Code Division
    - ◆ modulation code

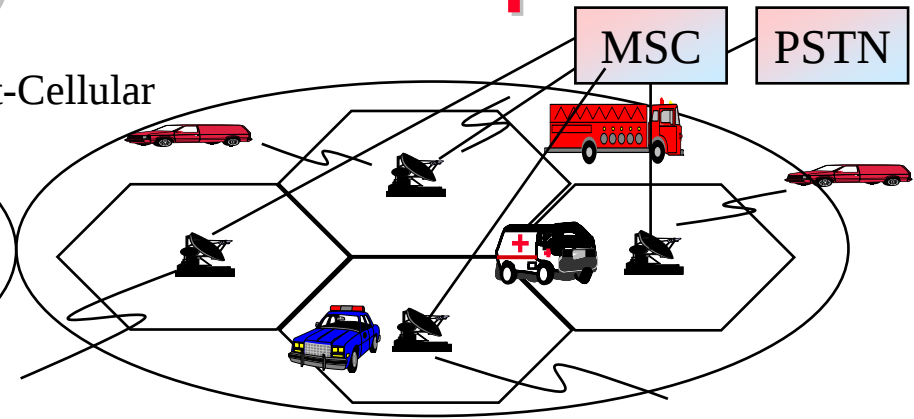


# Cellular System Concept

Pre-Cellular

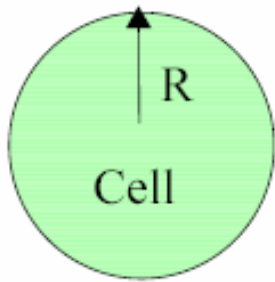


Post-Cellular



- ◆ Replace single high power transmitter covering the entire service area with low power
  - Mobiles in sufficiently distant base-stations may be assigned identical channel (frequency, time slot, & code)
  - System capacity may be increased without adding more spectrum
- ◆ Major conceptual breakthrough in spectra congestion & user capacity
  - Required relatively minor technological changes frequency reuse & co-channel interference, channel allocation, hand-offs

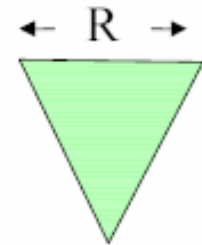
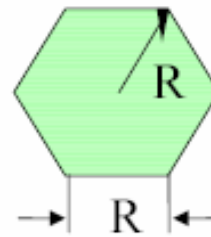
# Cell Shape



(a) Ideal cell

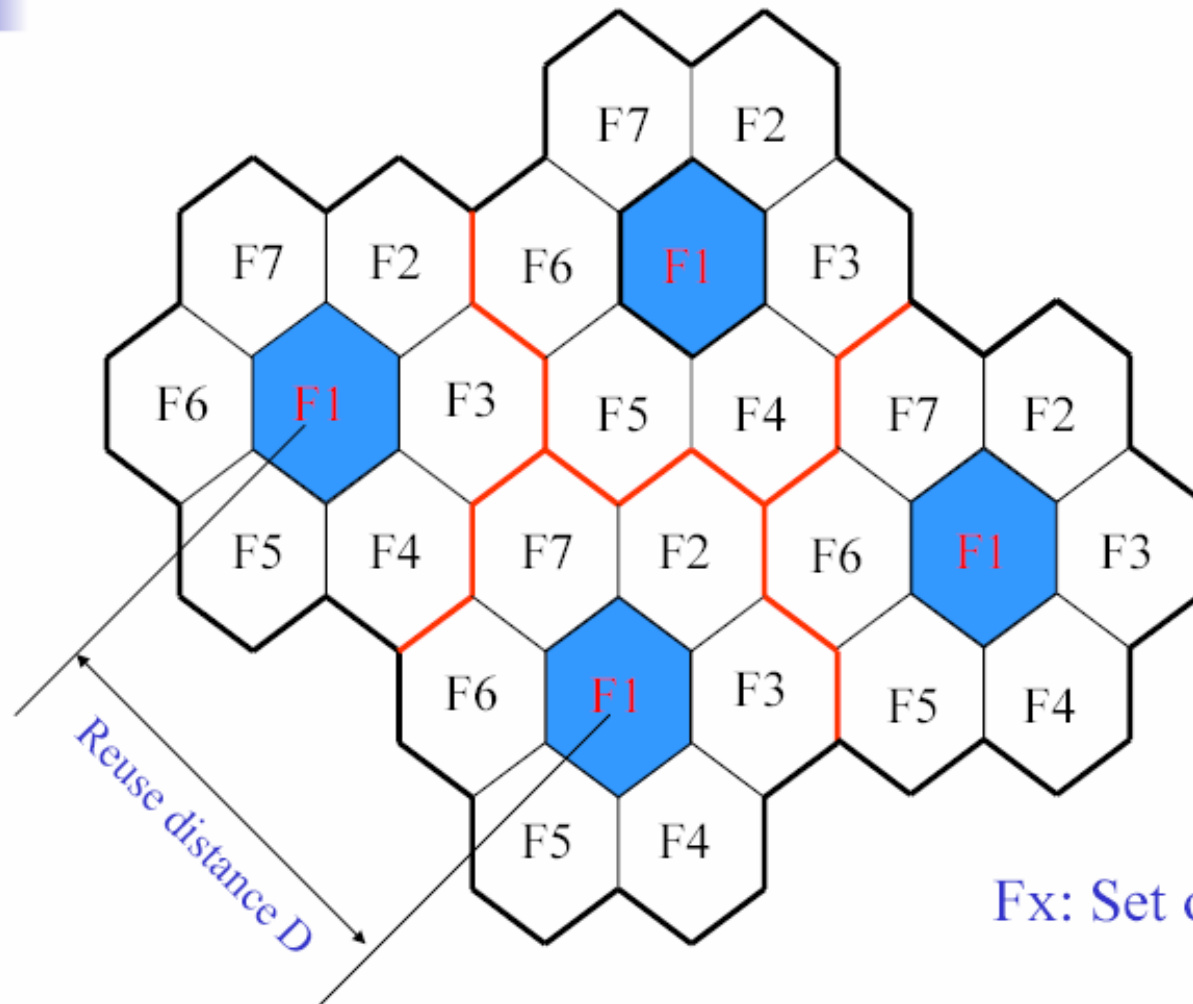


(b) Actual cell



(c) Different cell models

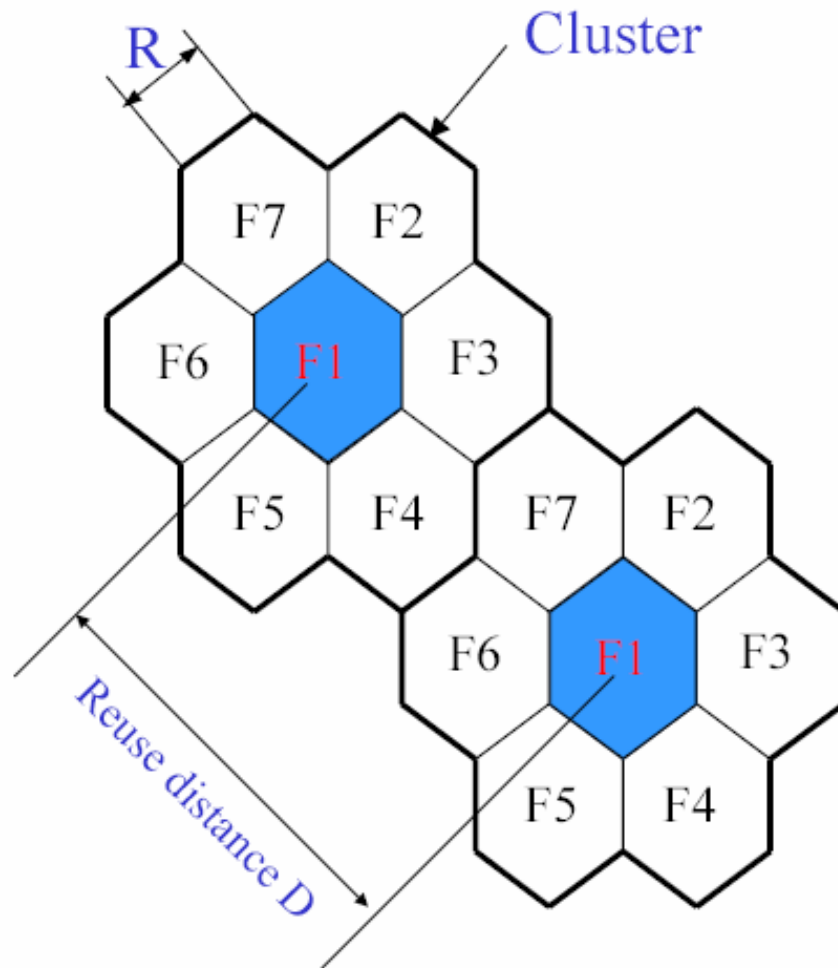
# Frequency Reuse



$F_x$ : Set of frequency

7 cell reuse cluster

# Reuse Distance



- For hexagonal cells, the reuse distance is given by

$$D = \sqrt{3NR}$$

where  $R$  is cell radius and  $N$  is the reuse pattern (the cluster size or the number of cells per cluster).

- Reuse factor is

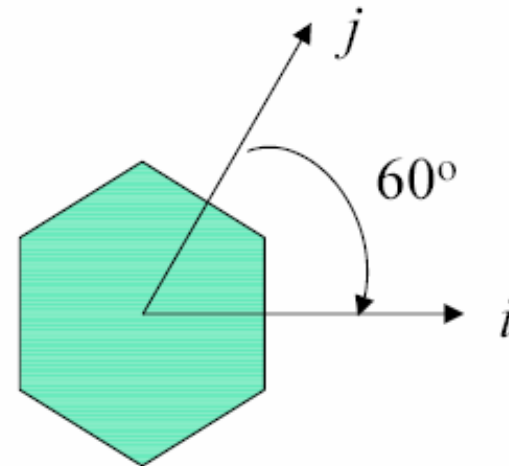
$$\frac{D}{R} = \sqrt{3N}$$

# Reuse Distance (Cont'd)

- The cluster size or the number of cells per cluster is given by

$$N = i^2 + ij + j^2$$

where  $i$  and  $j$  are integers.

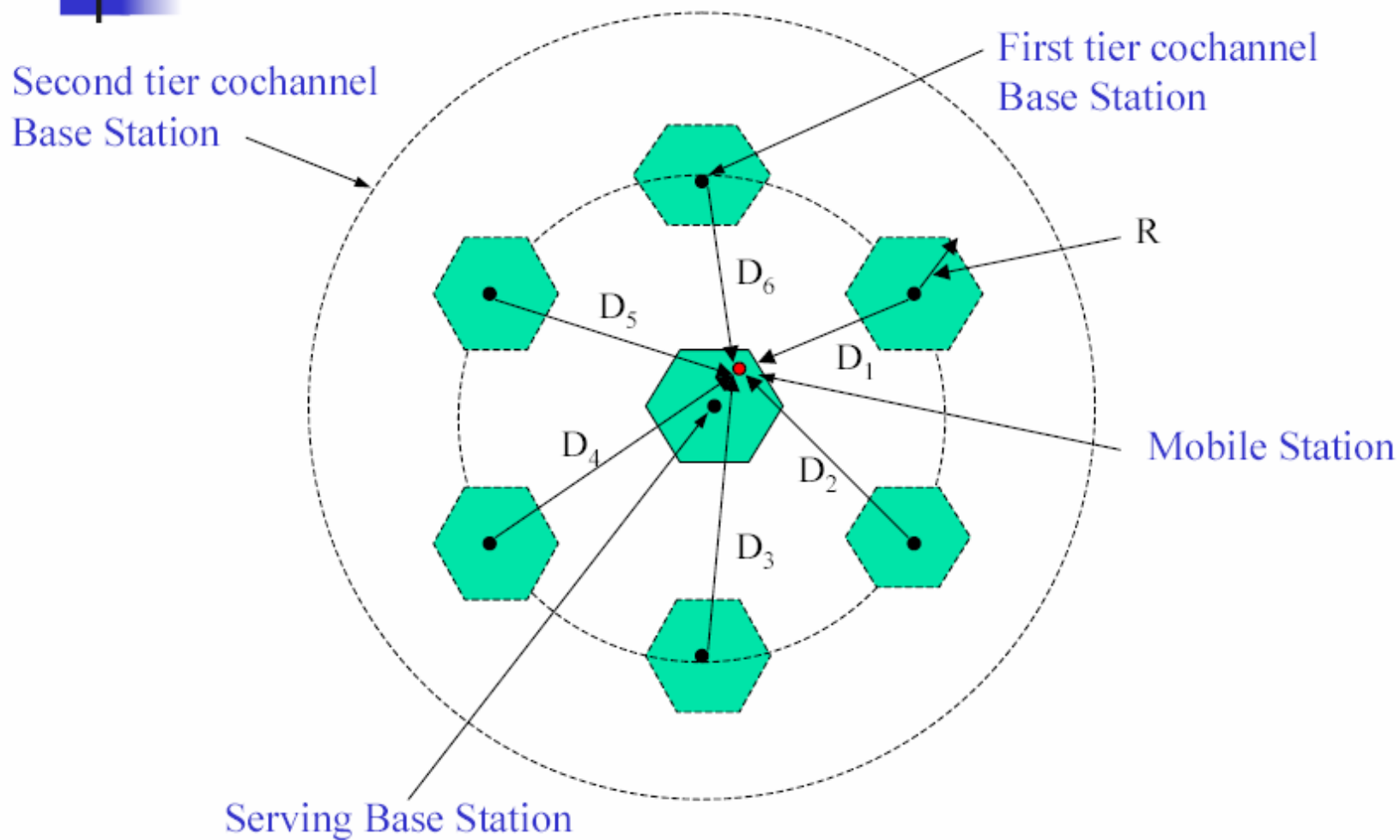


- $N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, \dots$ , etc.

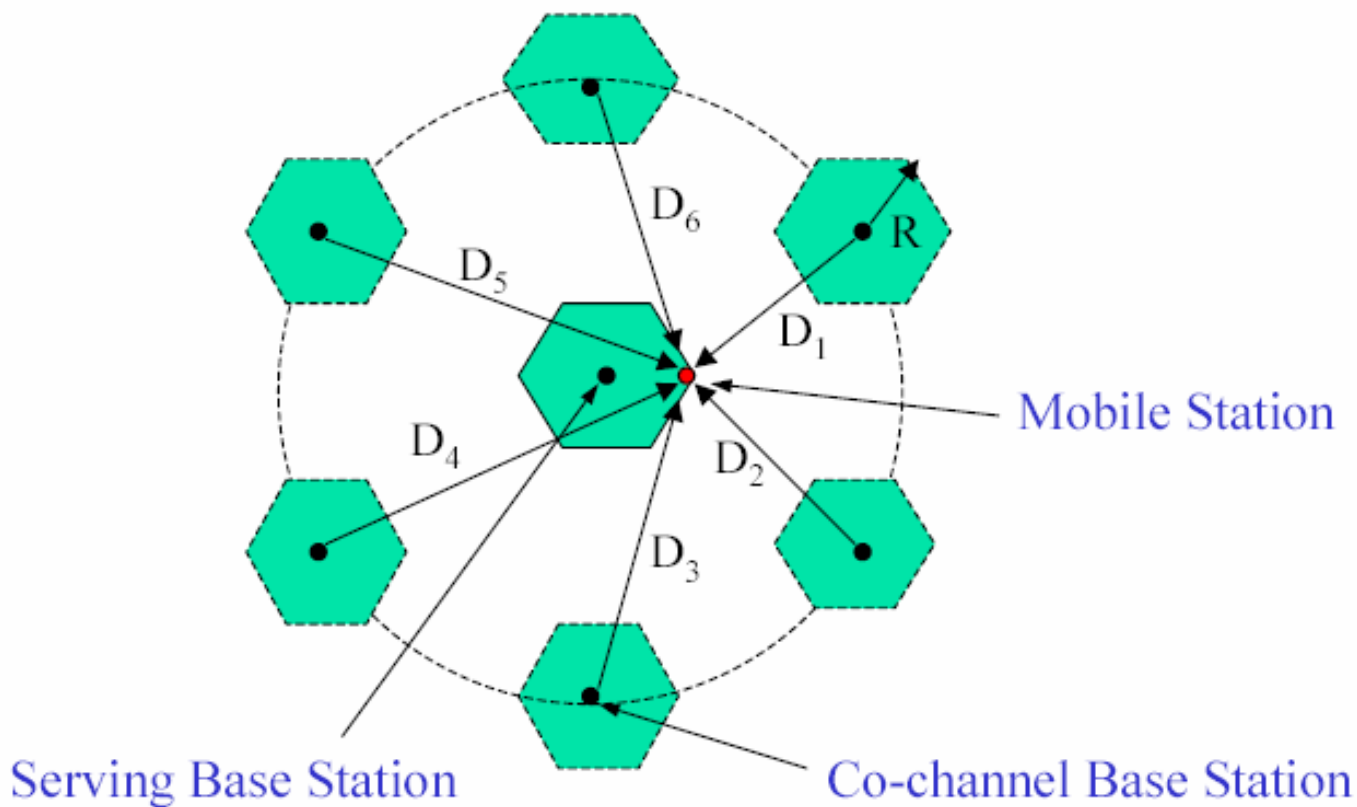
The popular value of  $N$  being 4 and 7.



# Cochannel Interference



# Worst Case of Cochannel Interference





# Cochannel Interference

- Cochannel interference ratio is given by

$$\frac{C}{I} = \frac{\text{Carrier}}{\text{Interference}} = \frac{C}{\sum_{k=1}^M I_k}$$

where  $I$  is co-channel interference and  $M$  is the maximum number of co-channel interfering cells.

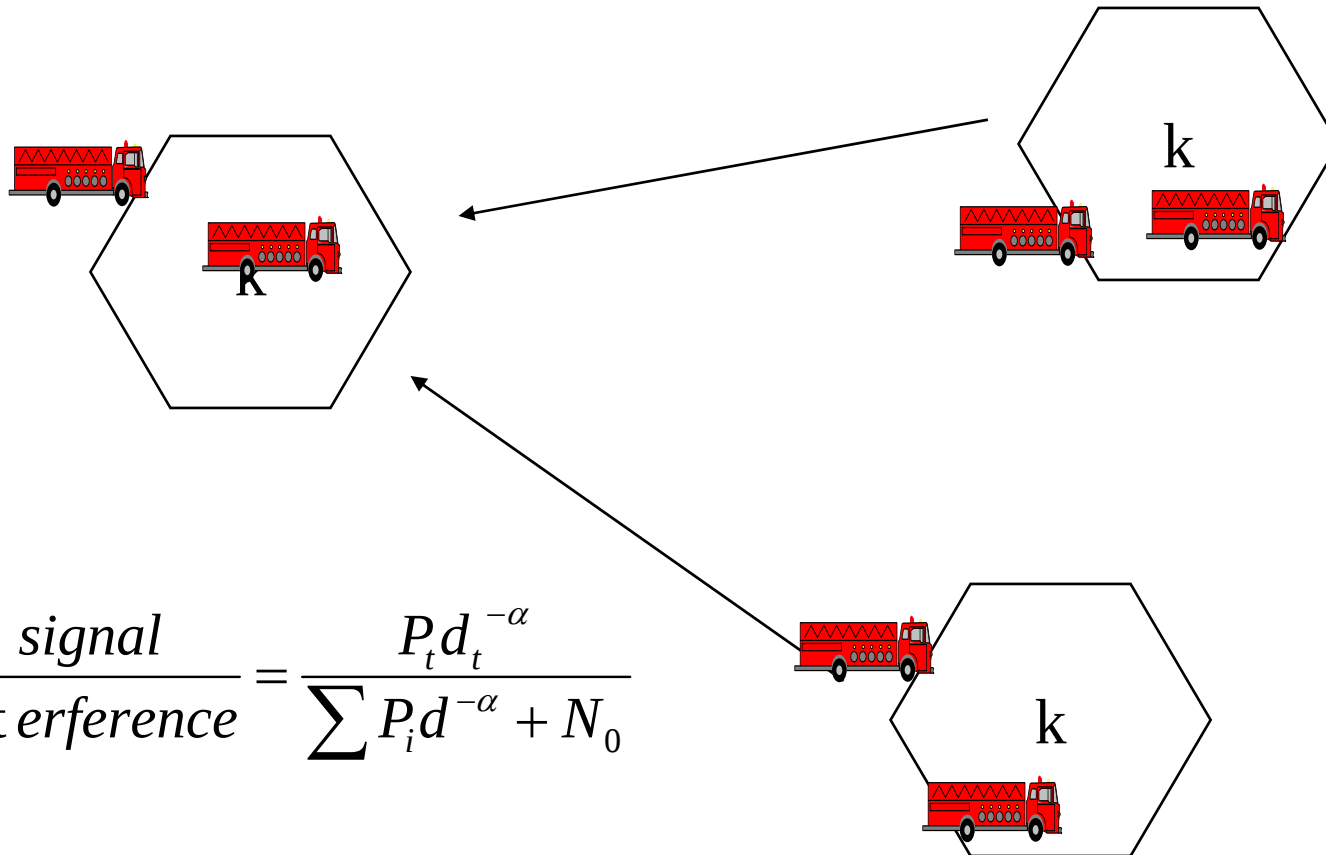
For  $M = 6$ ,  $C/I$  is given by

$$\frac{C}{I} = \frac{C}{\sum_{k=1}^6 \left( \frac{D_k}{R} \right)^\gamma}$$

where  $\gamma$  is the propagation path loss slope and  $\gamma = 2 \sim 5$ .

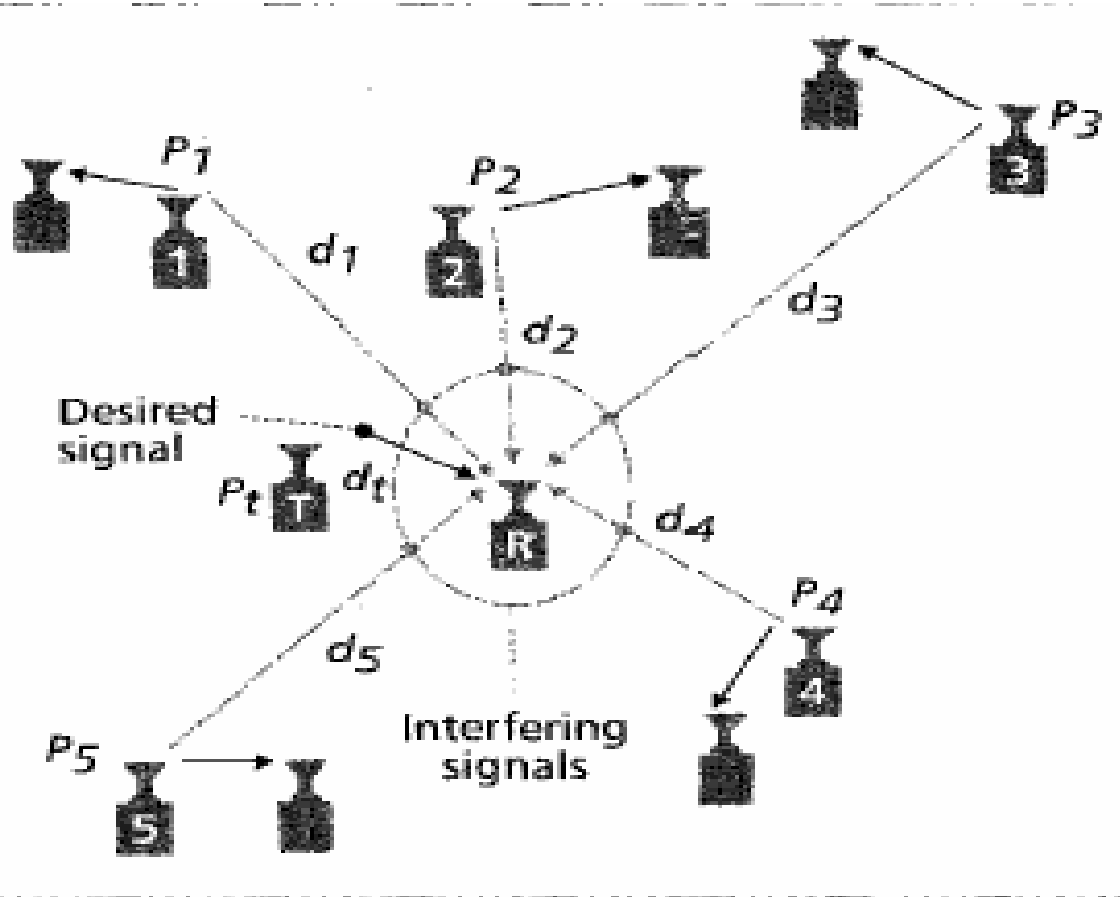
# Channel Reuse

- ◆ The same channel is reused simultaneously by other sets (Co-channel)



$$CIR = \frac{\text{signal}}{\text{interference}} = \frac{P_t d_t^{-\alpha}}{\sum P_i d_i^{-\alpha} + N_0}$$

# Interference



$$CIR = \frac{\text{signal}}{\text{interference}} = \frac{P_t d_t^{-\alpha}}{\sum_1^5 P_i d_i^{-\alpha} + N_0}$$



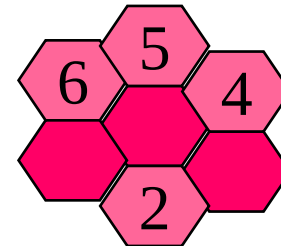
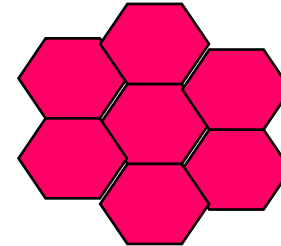
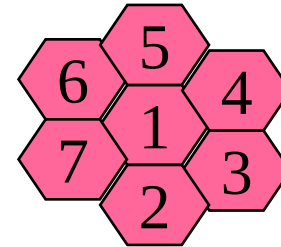
# How to improve CIR (Quality)

- ◆ Increase the transmitting power (Power Control)
- ◆ Increase the separating distance (Channel Reuse)

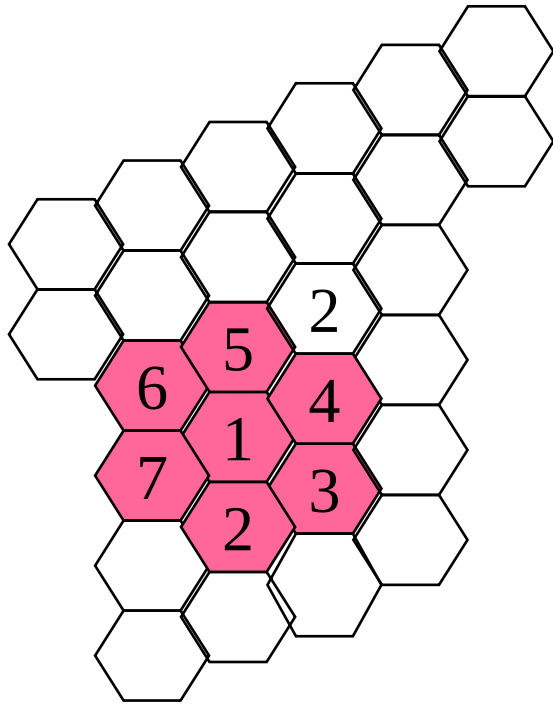
$$CIR = \frac{\text{signal}}{\text{int erference}} = \frac{P_t d_t^{-\alpha}}{\sum P_i d_i^{\alpha} N_0}$$

# Approaches

- ◆ Fixed      no flexibility
- ◆ Dynamic      complexity
- ◆ Hybrid      might be ok



# Frequency Reuse

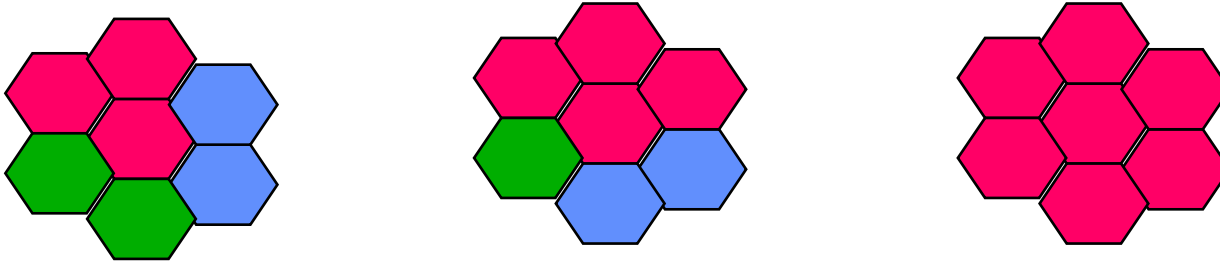


Idealized grid of  
Hexagonal cells

- ◆ Each BS is allocated a subset of carrier freqs
- ◆ Nearby BSs are allocated a different subset to avoid interference
- ◆ The total set is allocated to a small tessellating group of  $N$  neighboring BSs
  - Called “reuse cluster”
  - $1/N$  is the “reuse factor”
  - System capacity goes up by  $\frac{Area_{service}}{N \times Area_{cell}}$
- ◆ Used in FDMA & TDMA based systems
  - Not required in CDMA which has universal frequency reuse
- ◆ Cells idealized as hexagons
  - Real cell footprints are amorphous
  - Hexagon close to a circle
  - Not appropriate for micro-cells, highways etc.

# Reuse Cluster For Hexagonal Cells

- ◆ A tessellating group of  $N$  hexagonal cells is possibly only iff



- ◆ Frequency Reuse Distance  $D$ 
  - minimum distance between centers of co-channel cells
    - ◆ Depends on # of nearby cochannel cells, terrain, antenna height, transmit power etc.
  - for hexagonal cells,  $D = R \sqrt{3N}$ 
    - ◆ Where,  $R$  is the radius of hexagon (center to vertices)
  - Increasing  $N$ , and therefore  $D$ , reduce co-channel interference (assuming  $R$  and transmit power are invariant)
  - $D/R$  is called the co-channel reuse ratio

# Determining Cluster Size

- ◆ If  $N$  is reduced while cell area is kept constant
  - more cluster needed to cover the service area
  - more channels per cell
  - more system capacity achieved
  - more co-channel interference co-channel cells are closer
- ◆ Goal is to maximize system capacity (or, capacity per unit area) subject to interference limitations
  - Minimum  $N$  such that carrier-to-interference ratio
    - ◆  $C/I \geq (C/I)_{\min}$
  - Reverse co-channel interference
    - ◆ Interference at a BS from co-channel MHs in other BSs
  - Forward co-channel interference
    - ◆ Interference at a MH from other co-channel BSs
  - Adjacent channel interference
    - ◆ From signals in adjacent channel due to imperfect filters
    - ◆ Don't assign adjacent frequencies to the same cell and if possible immediate neighbors

# Determining Cluster Size N

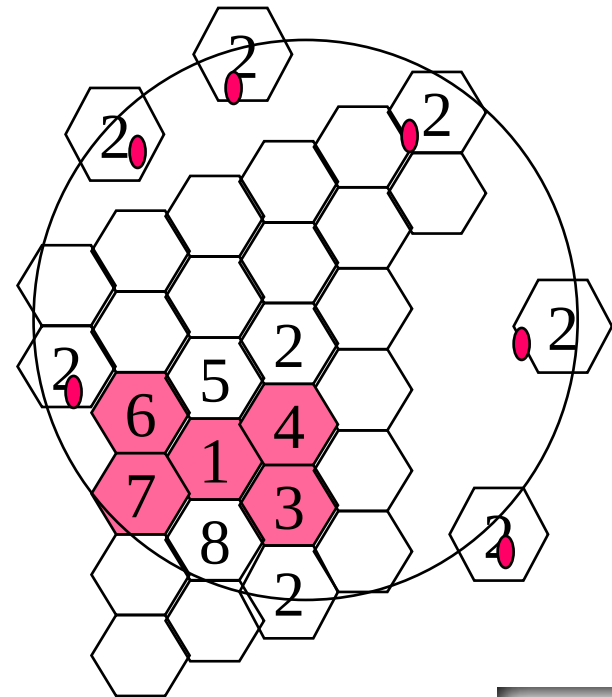
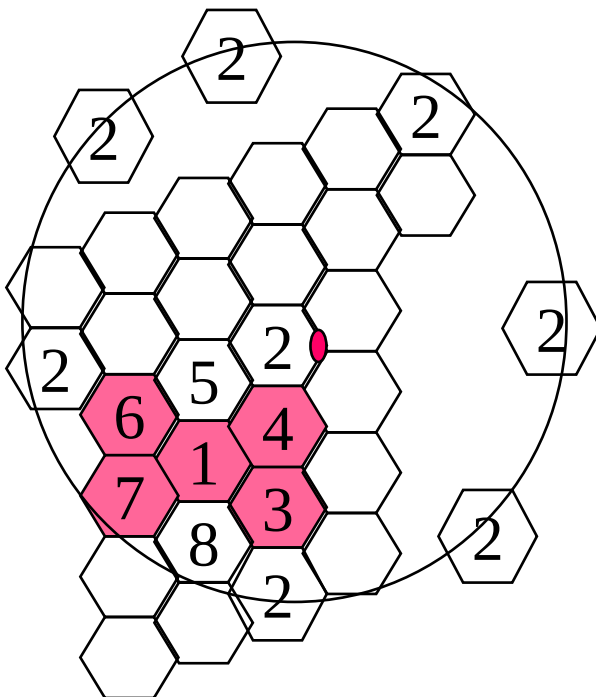
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  - minimum N such that carrier-to-interference ratio
    - ◆  $C/I \geq (C/I)_{\min}$
  - reverse co-channel interference
    - ◆ interference at BS from co-channel MHs in other BSs
  - forward co-channel interference
    - ◆ interference at a MH from other co-channel BSs
  - adjacent channel interference
    - ◆ from signals in adjacent channels due to imperfect filters

# Calculating C/I

- Let  $i_0$  be the number of co-interfering cells, and noise be negligible

- C/I = Carrier / All of the co-channel interference
- Where C is the desired carrier power and  $I_i$  is the signal power of i-th interferer

$$\frac{C}{I} = \frac{C}{\sum_{i=1}^{i_0} I_i}$$



# Calculating C/I

- ◆ Recall:  $P_r(d) = P_r(d_0) \left(\frac{d}{d_0}\right)^n$
- ◆ For equal transmit powers and path loss exponents:  $\frac{C}{I} = \frac{D_0^{-n}}{\sum_{i=1}^{i_0} D_i^{-n}}$
- ◆ Assume:
  - 1.  $n=4$
  - 2. worst case is at  $D_0 = R$  (when MH is at the fringe of its cell)
  - 3. only the six “first-tier” co-channel cells are considered
  - 4.  $D_1 = D_2 = D_3 = D_4 = D_5 = D_6 = D$
- ◆  $C/I \sim (D/R)^4 / 6$  depends only on the ratio  $D/R$

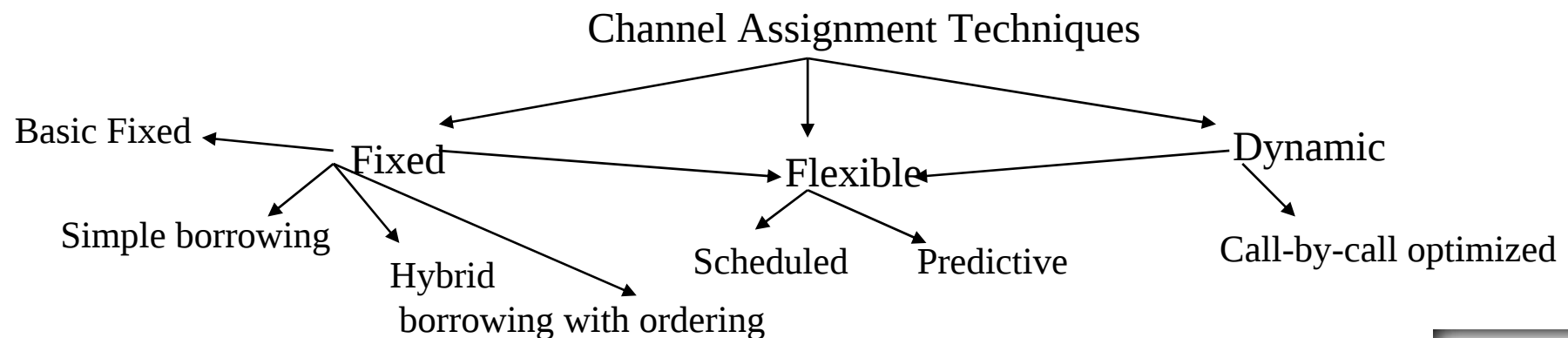
| system | $(C/I)_{\min}$ | $D/R$ | N |
|--------|----------------|-------|---|
| AMPS   | 18 dB          | 4.6   | 7 |
| GSM    | 11 dB          | 3.0   | 4 |

# Microcells-Reducing Cell Area

- ◆ IF cell area is reduced while  $N$  is kept constant
  - more clusters needed to cover the service area
  - $C/I$  is unchanged because  $D/R$  is unchanged
  - system capacity grows quadratically with radius scale factor
- ◆ Small cells need lower RF transmitted power
  - longer battery, smaller mobile end-points
- ◆ Small cells result in higher cell-boundary crossing
  - more signalling overhead
  - performance degradation (more disruption)

# Channel Assignment in Cellular System

- ◆ Fundamental Problem
  - How to assign channels to requesting call at a BS ?
- ◆ Goal: Maximum Spectral Efficiency for a specified grade of service and a given degree of computational complexity
  - probability of new call blocking
  - probability of forced termination
  - link quality
- ◆ Maybe a “new” connection, or a connection undergoing “handoff”



# Channel Assignment Techniques

- ◆ Fixed
  - Basic Fixed
  - Simple borrowing
  - Hybrid borrowing with ordering
- ◆ Flexible
  - scheduled
  - predictive
- ◆ Dynamic
  - call-by-call optimized

# Fixed Channel Assignment

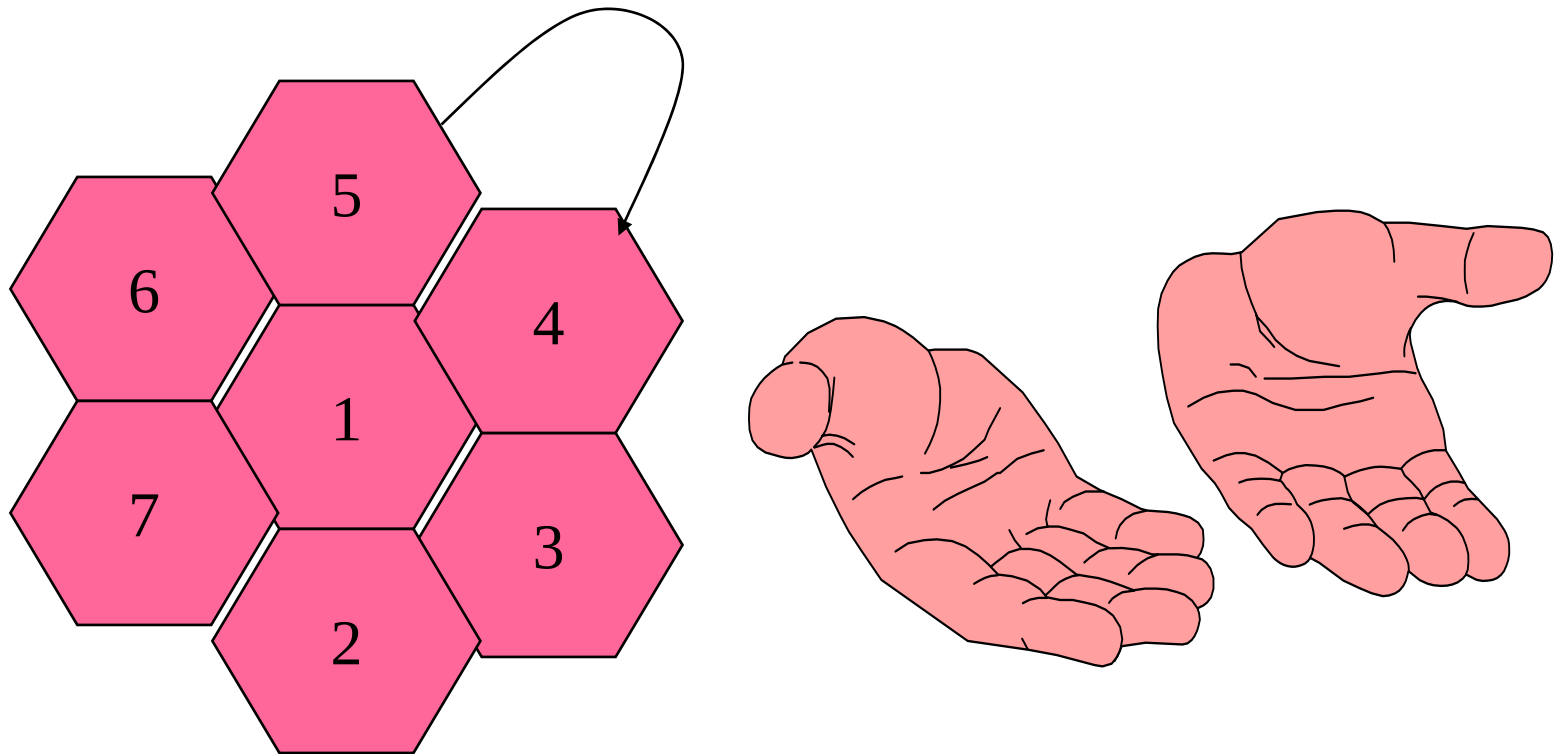
- ◆ Basic strategy
  - each cell is statically allocated a subset of channels
  - a requesting call in the cell can only use channel allocated to that cell
  - if no available channel in that cell, the call is blocked
  - MSC only informs new BS about hand-off, & keep track of serving channel

# Fixed Channel Assignment

- ◆ Variation
  - borrow channel from neighboring BSs if all channels busy at BS under MSC supervision, and only if does not cause interference borrowed channels are “locked”
  - hybrid channel assignment
    - ◆ two groups of channels: fixed and borrowable
    - ◆ ratio determined a priori depending on traffic estimate
  - borrow-with-channel-ordering
    - ◆ fixed-to-borrowable channel ration varied on changing traffic condition
    - ◆ channels are rank ordered

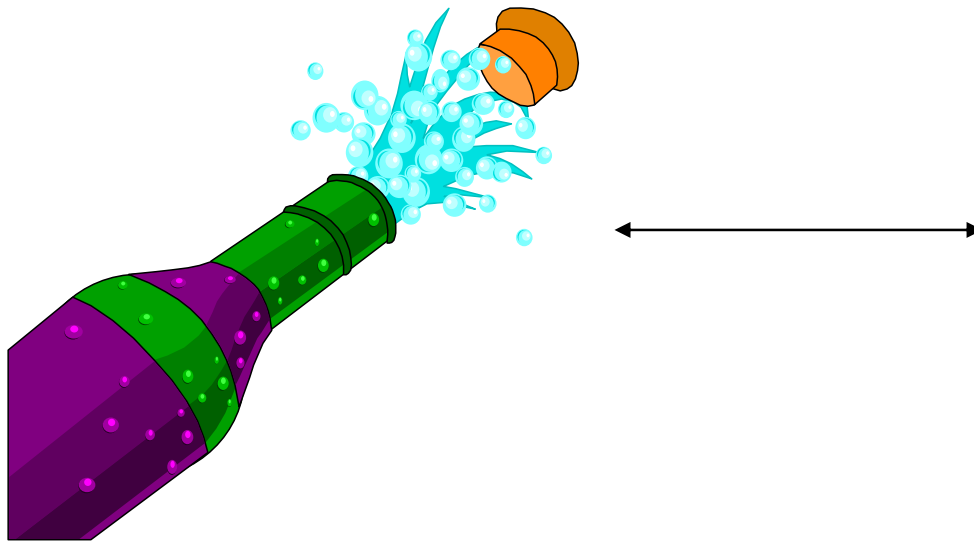
# Fixed Channel Assignment

- ◆ We might borrow from neighboring cells



# Traffic & Resource

- ◆ Uniform Distribution

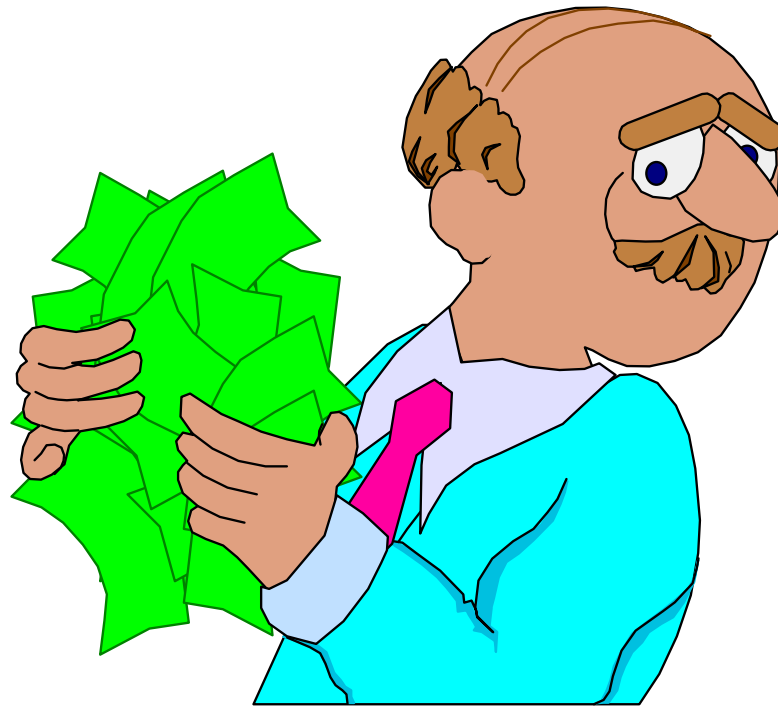


Channel Resource

User Demanding

# Dynamic & Assignment

- ◆ Maybe I should assign you based on current condition



# Issues to consider



- ◆ Selected Cost
- ◆ Blocking Probability
- ◆ Reuse Distance
- ◆ CIR
- ◆ QoS (Quality of Service)
  - current value
  - handoff value

# Dynamic Channel Assignment (DCA)

## ◆ Basic Features

- channels not allocated to cells permanently
- MSC allocated channel to a call from the global pool taking into account
- Advantage: channel assignment may be retained across hand-off
- Disadvantage: interruptions, deadlocks, instability

# Dynamic Channel Assignment

- ◆ DCA algorithms differ in distribution of control among BSs and MSC
  - Centralized DCA
    - ◆ can do a globally optimized channel assignment and call rearrangement BSs need to communicate with MSC e.g. Maximum Packing
  - Decentralized & Fully Decentralized DCA
    - ◆ rely only on local monitoring to make channel assignments
    - ◆ require limited local communication among cluster of BSs

# Flexible Channel Assignment

- ◆ Combine aspects of FCA and DCA
- ◆ Each cell is assigned a fixed set of channel
- ◆ Plus, a pool of channels is reserved for flexible assignment
  - MSC assigns these channels
- ◆ Flexible assignment strategies
  - Scheduled assignment: rely on known foreseeable changes in traffic pattern
  - Predictive assignment: based on measured traffic load at every BS

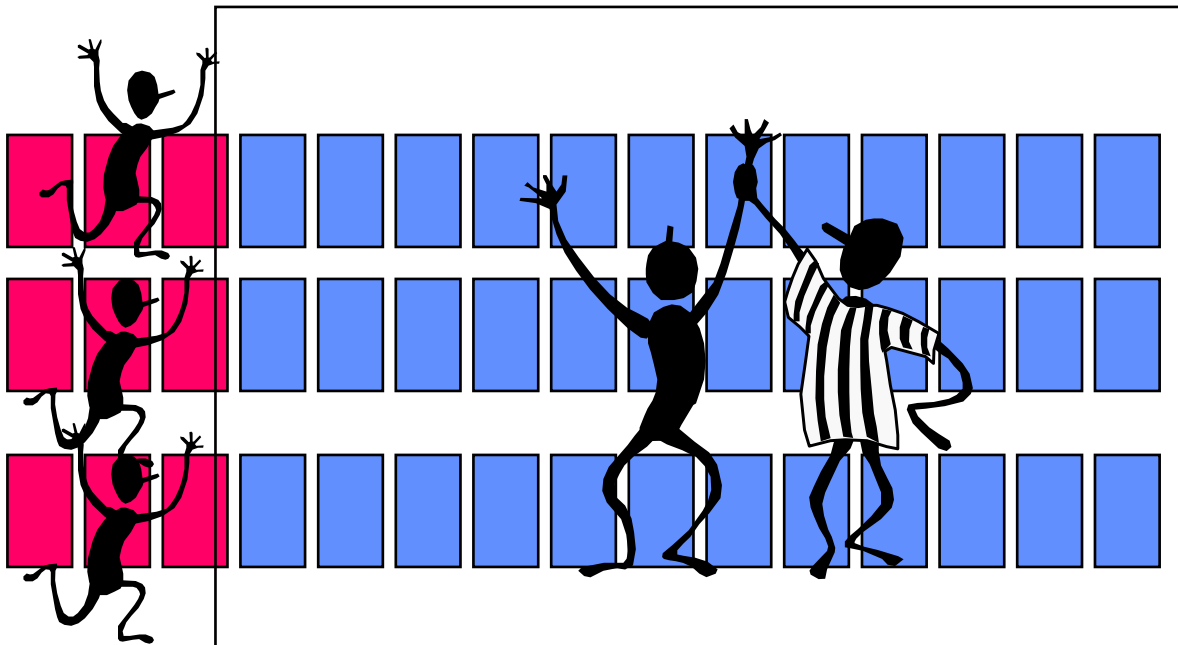
# MSC will pick up one for MH

- ◆ Here you go !



# Flexible Channel Assignment

- ◆ Assign some of channel for minimum traffic requirement
- ◆ Keep all of the others in a service pool



# Handoff Handling

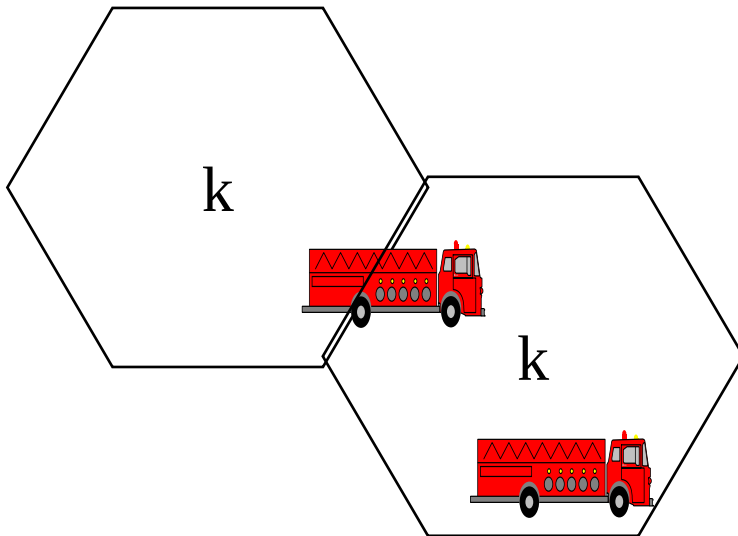


Keep the QoS while the user moves

# Handling Handoffs

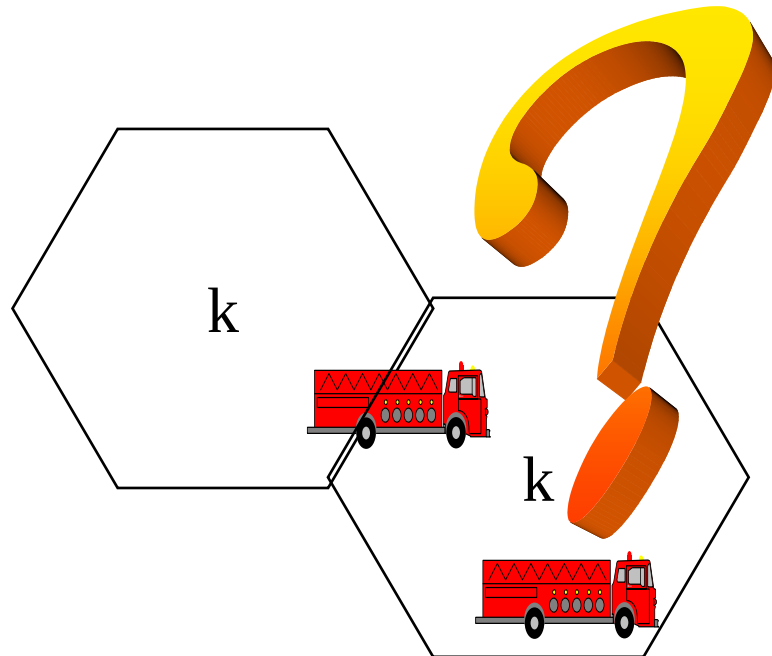
## ◆ Handoff

- change the radio channel
  - ◆ the same base station
  - ◆ the new base station
- due to
  - ◆ the radio link degradation
  - ◆ channel reorder



# What is going to happen ?

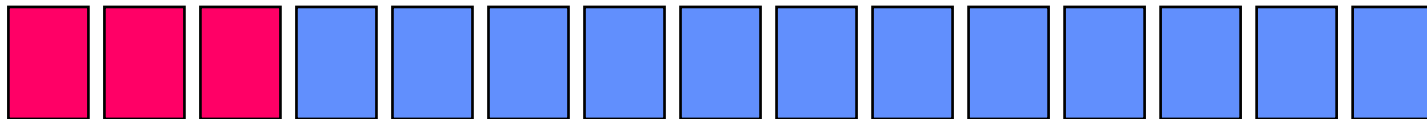
- ◆ The new cell must assign new channel
- ◆ We must reserve some hand off channel
- ◆ Some connection must be blocked !!



# Solutions for handoff

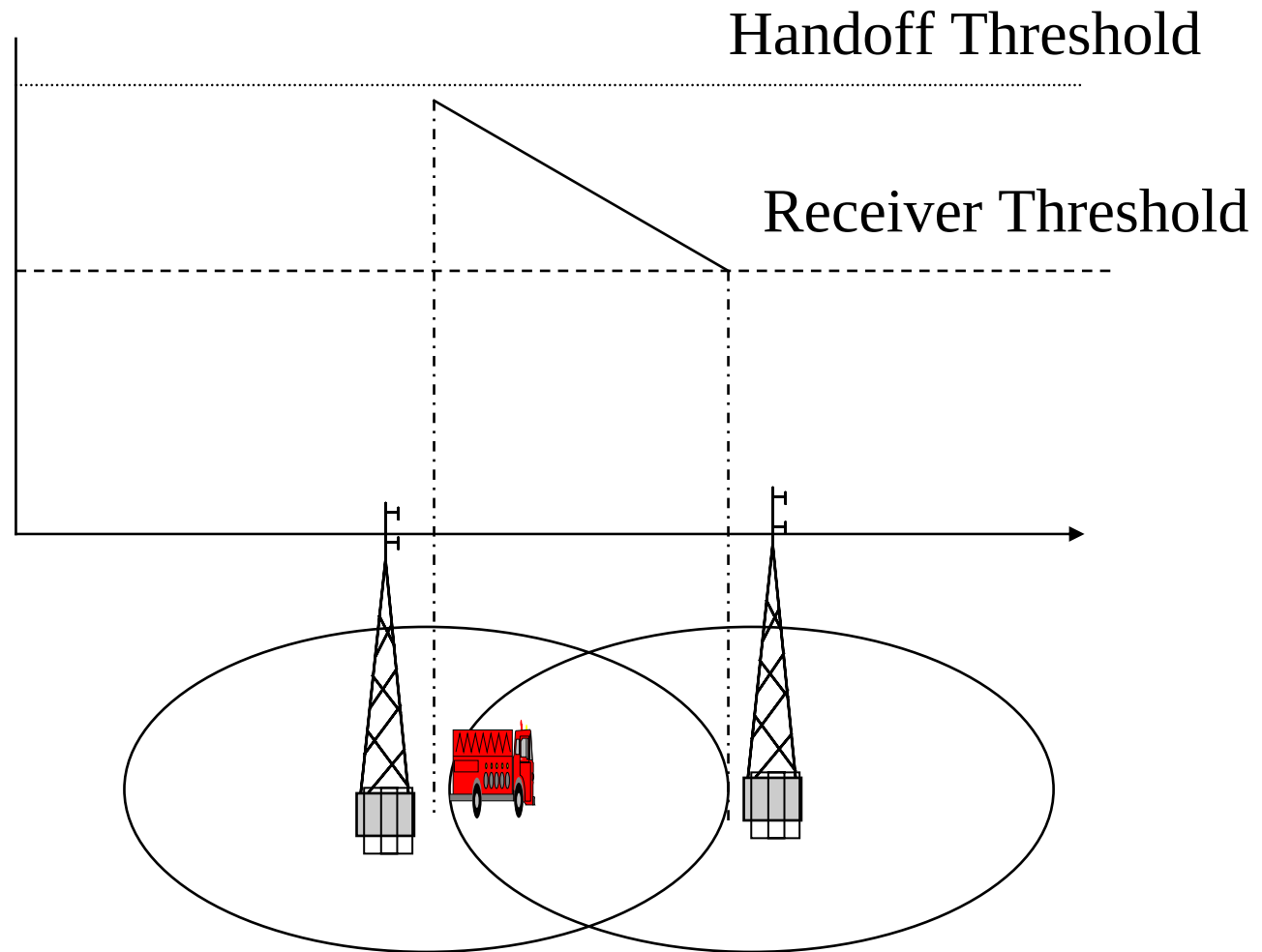
- ◆ Handoff Priority
  - guard channel for handoff
  - how much, inefficiency
- ◆ Queueing of Handoff request
  - take a seat for future handoff

# Guard Channel



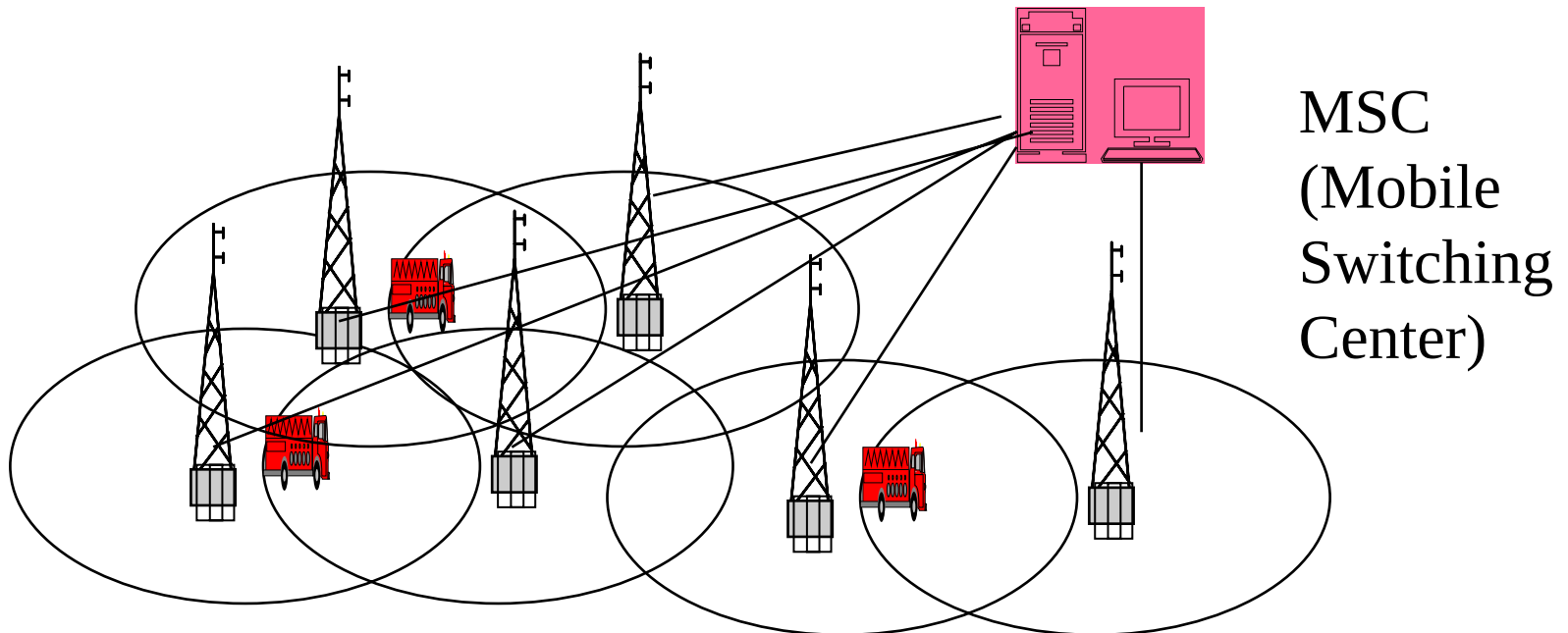
Reserved for Handoff

# Thresholds



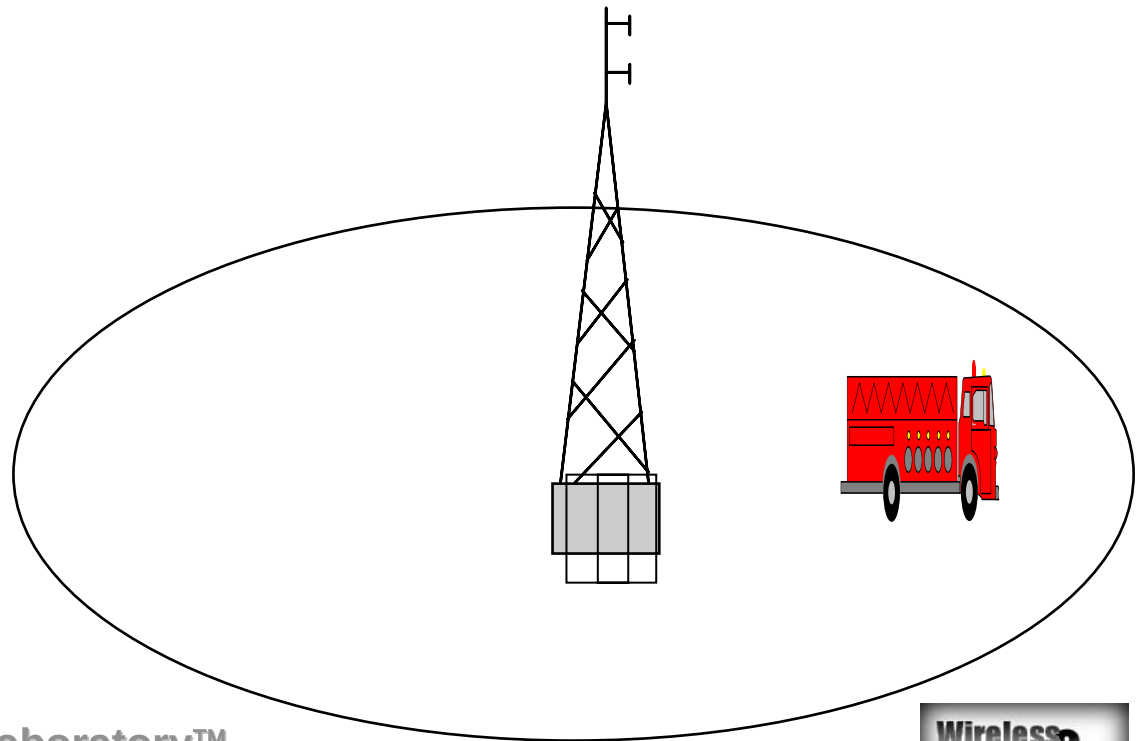
# Who is going to take over Handoff

- ◆ Yourself (Mobile Users)
- ◆ Infrastructure Network
  - Base Station
  - Mobile Switching Center



# Negotiating Procedure

- ◆ Base Station
  - detect the receiving signal from MH
  - send a measurement order
- ◆ Mobile Host
  - measure on demand
  - measure all the time

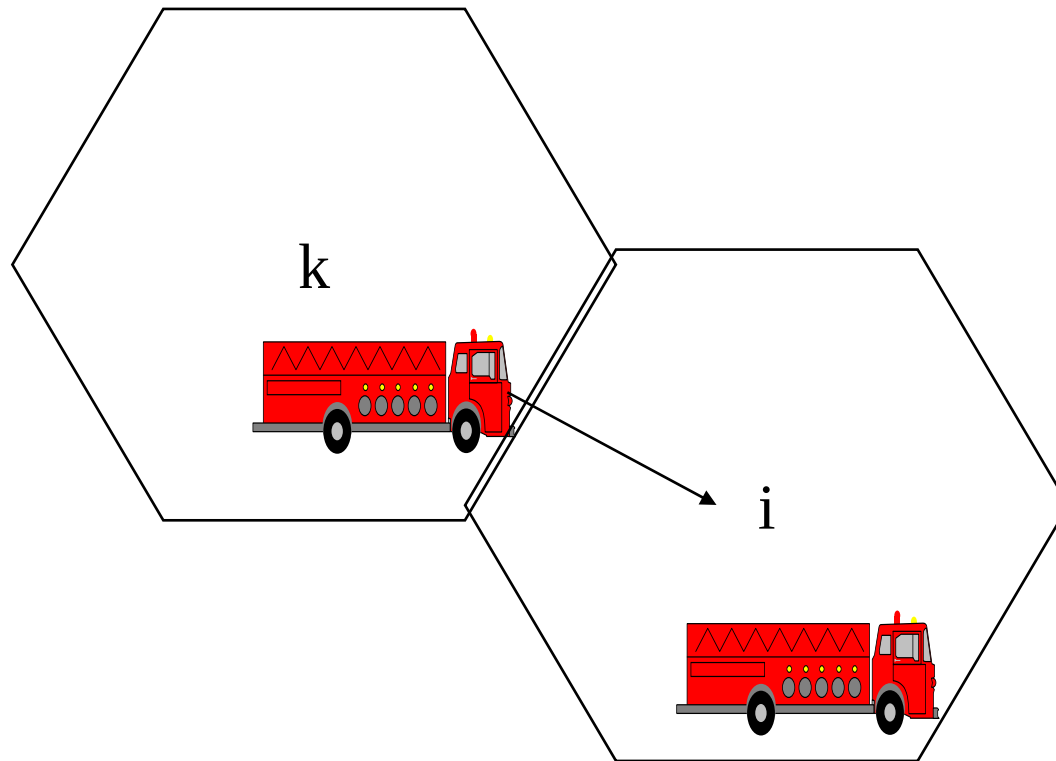


# Hand off Procedure

- ◆ Decide the New Base Station
  - MSC picks the best for MH
  - MSC picks the candidate MH specify
- ◆ New Base Station decides to accept or not ?

# Call Queueing Scheme

- ◆ Queue for a channel, handoff threshold, receiver threshold

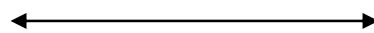


# Trends in Hand over Design

- ◆ Hand over and Hand off are the same
- ◆ Small cells -> more hand over
  - allocate network resource to reroute the call to the new base station
  - if not quick enough, QoS will drop dramatically



QoS

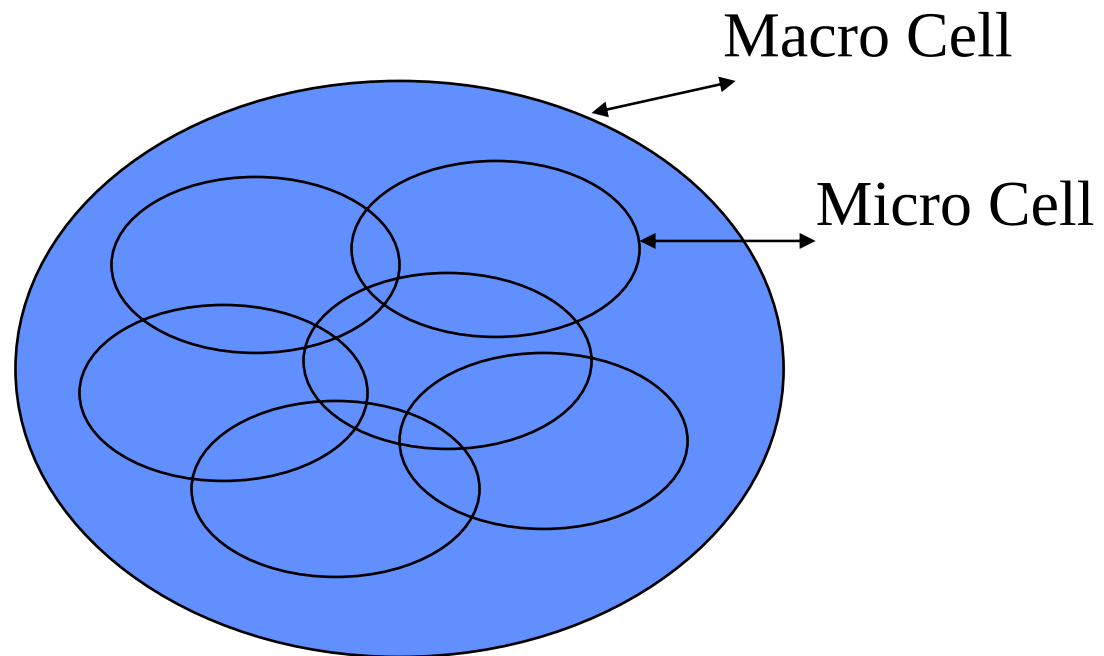


Hand off



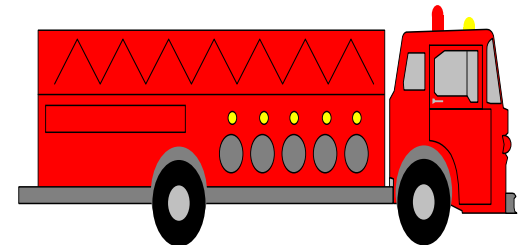
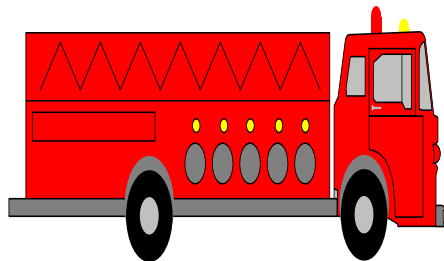
# Mobility Solution

- ◆ Multi-tiers
  - micro-cell and macro-cell
  - based on the speed
  - different schemes



# Velocity Estimation

- ◆ Doppler Frequency is known -> Estimation of the velocity of the mobile users
- ◆ Mobility is estimated from the time spent in a cell



# Handoff in Cellular Networks

- ◆ Transfer of mobile to a new channel when it crosses cell boundary
  - identify new base station, assign new channel
  - hand-off initiated at a carefully chosen signal level
  - avoid triggering handoff due to momentary fades

# Hand-off

- ◆ Handoff delay & interruption
  - dropped (or on hold) connection if signal too low before handoff processed
  - performance degradation (disruption) in data stream
- ◆ Prioritizing handoffs to reduce probability of dropped call
  - connection dropped if no spare channels in new cell
  - guard channel : subset of channels reserved for handoff requests works well with DCA
  - handoff queuing : time interval between handoff trigger & connection drop  
cell overlap, speed of mobile

# Handoff in Cellular Networks

- ◆ Probability of unnecessary Handoffs
- ◆ Hard vs. Soft handoff
- ◆ Hand off rate
- ◆ Handoff also triggers rerouting in the network layer
- ◆ Handoff is tightly coupled to DCA, MAC, and Networking Routing

# Handoff Strategies (I)

- ◆ Network controlled handoff (NCHO)
  - used in first generation analog cellular systems
  - link quality is only monitored by the serving BS and surrounding BS
  - handoff decision is made by the network (typically central agent)
  - handoff delays of several seconds (10) and infrequent link quality updates



# Handoff Strategies (II)

- ◆ Mobile assisted handoff
  - used in second generation digital cellular system
  - both the mobile and the serving BS measure link quality
  - only mobile measures link quality of alternate BSs
  - mobile periodically sends the link quality measurements to serving BS
  - handoff decision is made by the network
  - handoff delays of few seconds (1-2) and frequent link quality updates

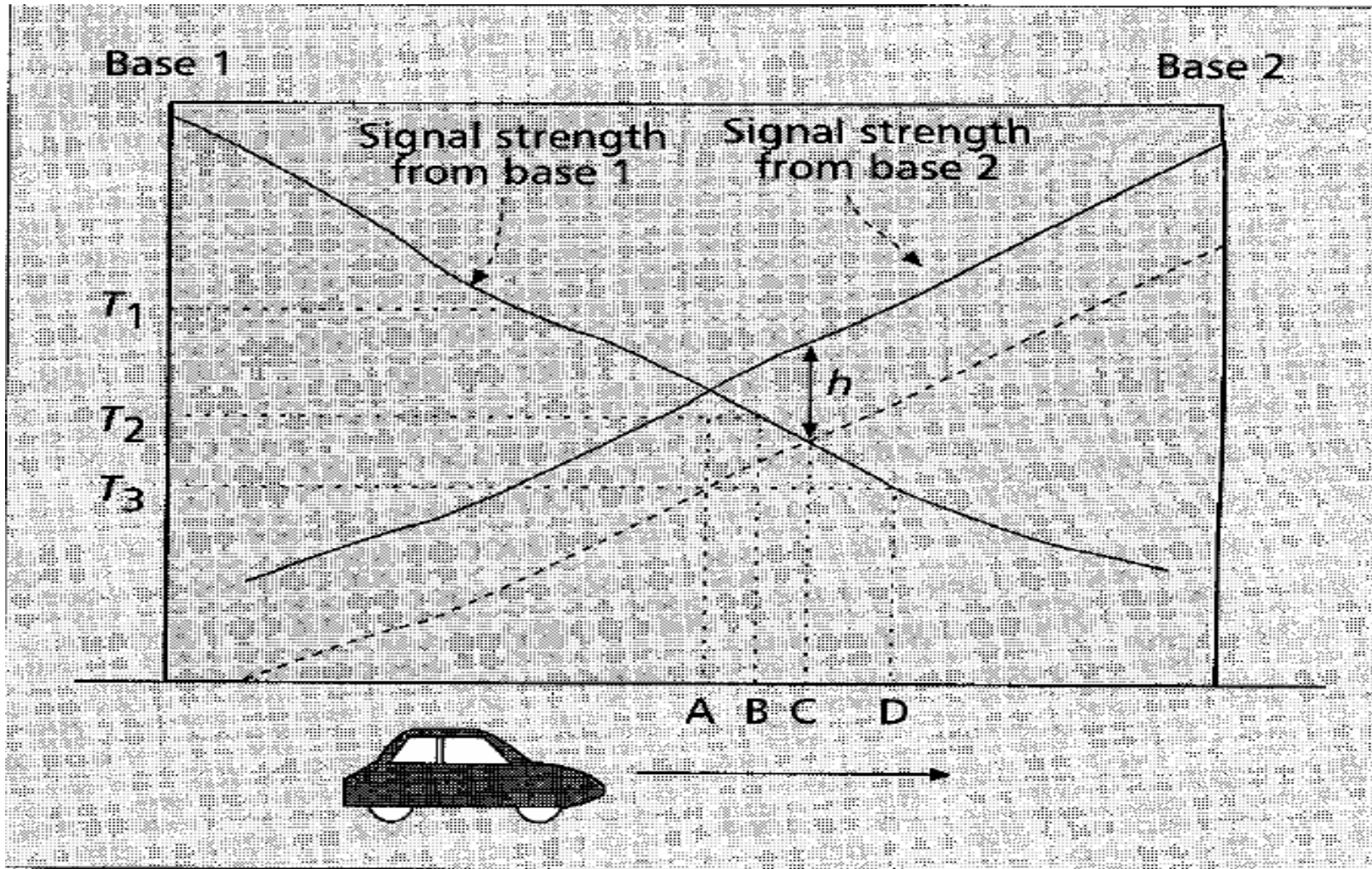


# Handoff Strategies (III)

- ◆ Mobile controlled hand off
  - used in some new digital cellular systems
  - link quality measurements as in MAHO
  - serving BS relays link quality measurements to mobile
  - handoff decision is made by the mobile
  - handoff delays of about 100 ms



# Handoff Scenario

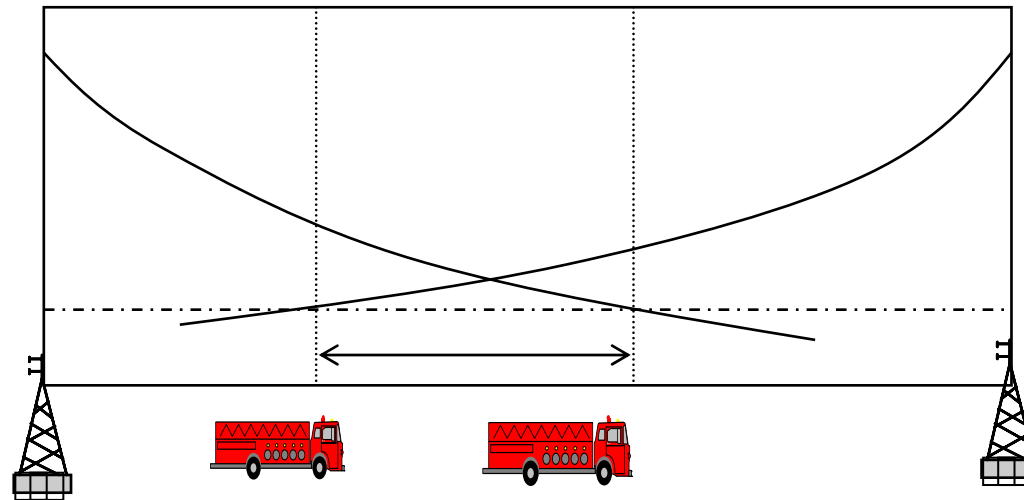


# Handoff Initiation Strategies

- ◆ Relative signal strength
  - Always choose the strongest received BS
  - Too many unnecessary hand-offs
- ◆ Relative signal strength with threshold
  - Current signal  $<$  threshold,, and other BS is stronger
  - May let MH stray too far into other cell; overlapping cell coverage
  - Effectiveness depends on knowledge of cross-over signal
- ◆ Relative signal strength with hysteresis (plus optionally dwell timer)
  - Hand-off only if new BS's signal is stronger by a hysteresis margin
  - Prevents ping-pong effect from rapid fluctuations
- ◆ Relative signal strength with hysteresis & Threshold
  - Hand-off only if current BS's signal below a threshold, and new BS's signal is stronger by the hysteresis margin
- ◆ Prediction techniques
  - Decide based on expected future value of received signal strength

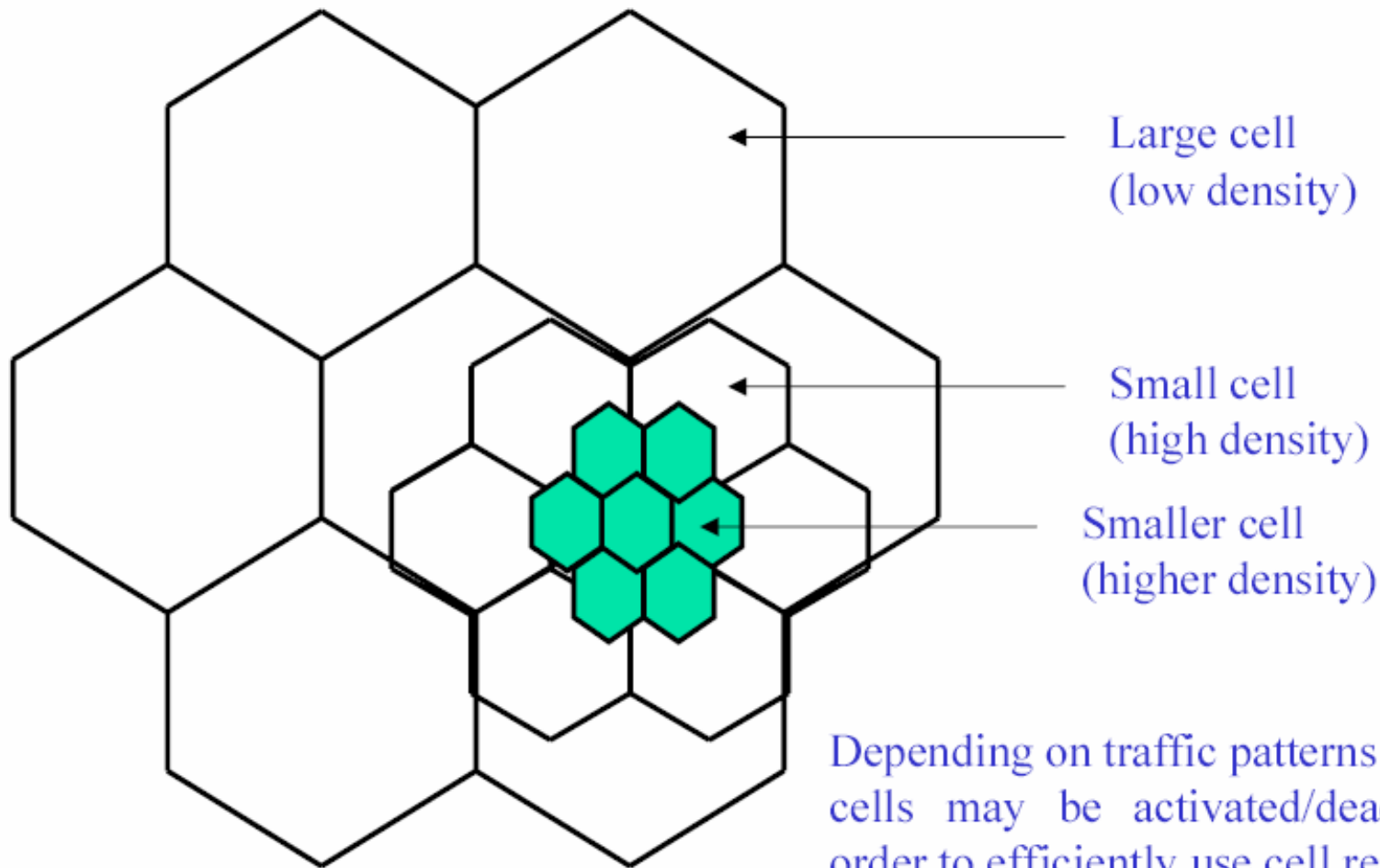
# Handoff Queueing

- ◆ Goal is to reduce handoff failure probability
  - Better to block a new call than to drop an existing one
  - Exploits overlap between cells to queue hand-off request in advance



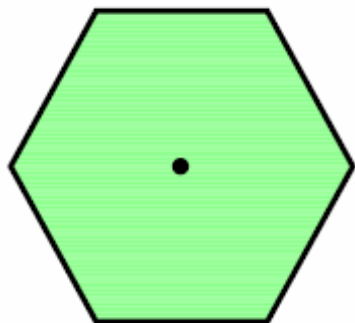
- ◆ Handoff request is issued according to handoff initiation strategy
  - Request is queued
  - Decision must be made (handoff or failure) while MH still in handoff interval

# Cell Splitting

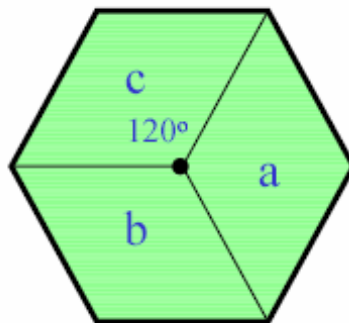




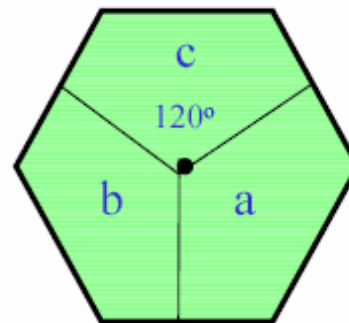
# Cell Sectoring by Antenna Design



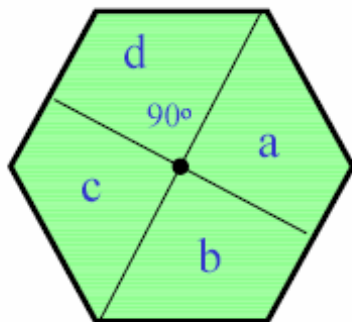
(a). Omni



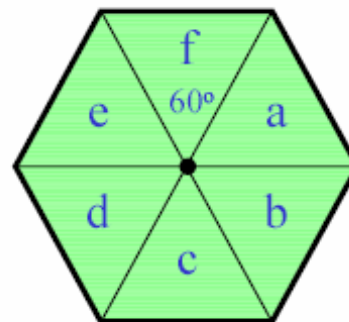
(b). 120° sector



(c). 120° sector (alternate)



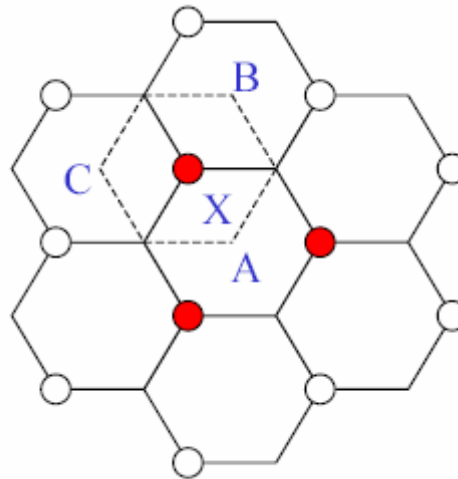
(d). 90° sector



(e). 60° sector

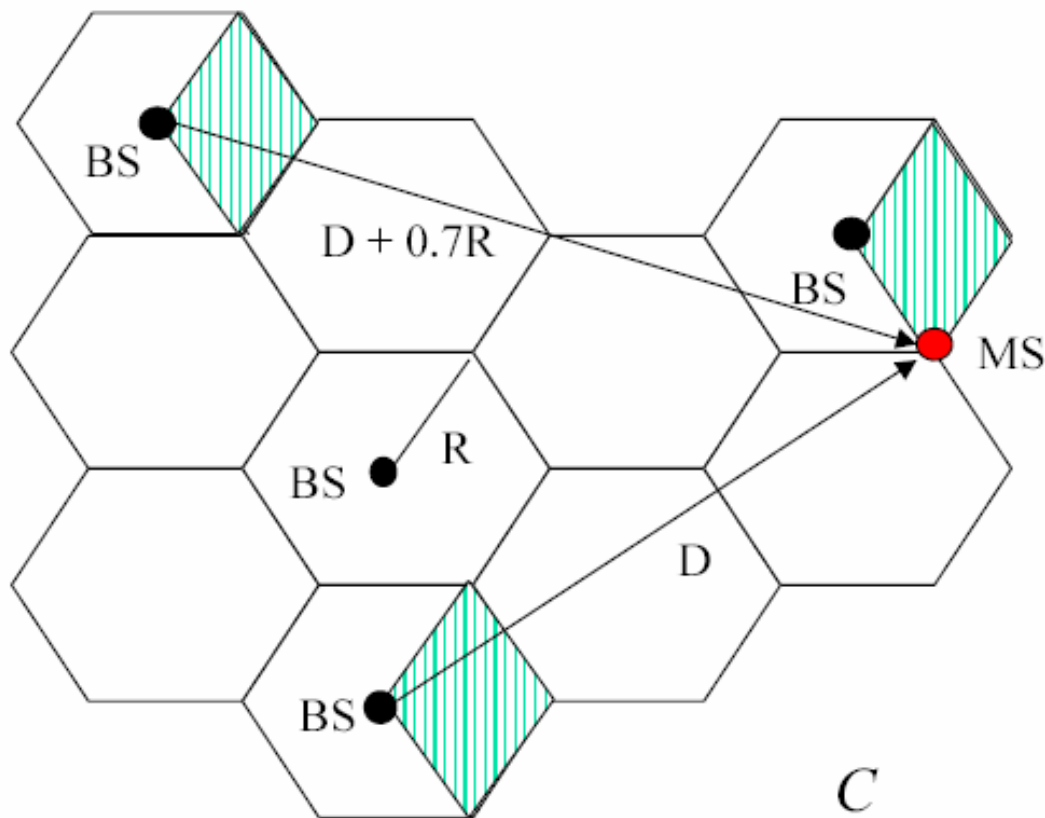
# Cell Sectoring by Antenna Design

- Placing directional transmitters at corners where three adjacent cells meet



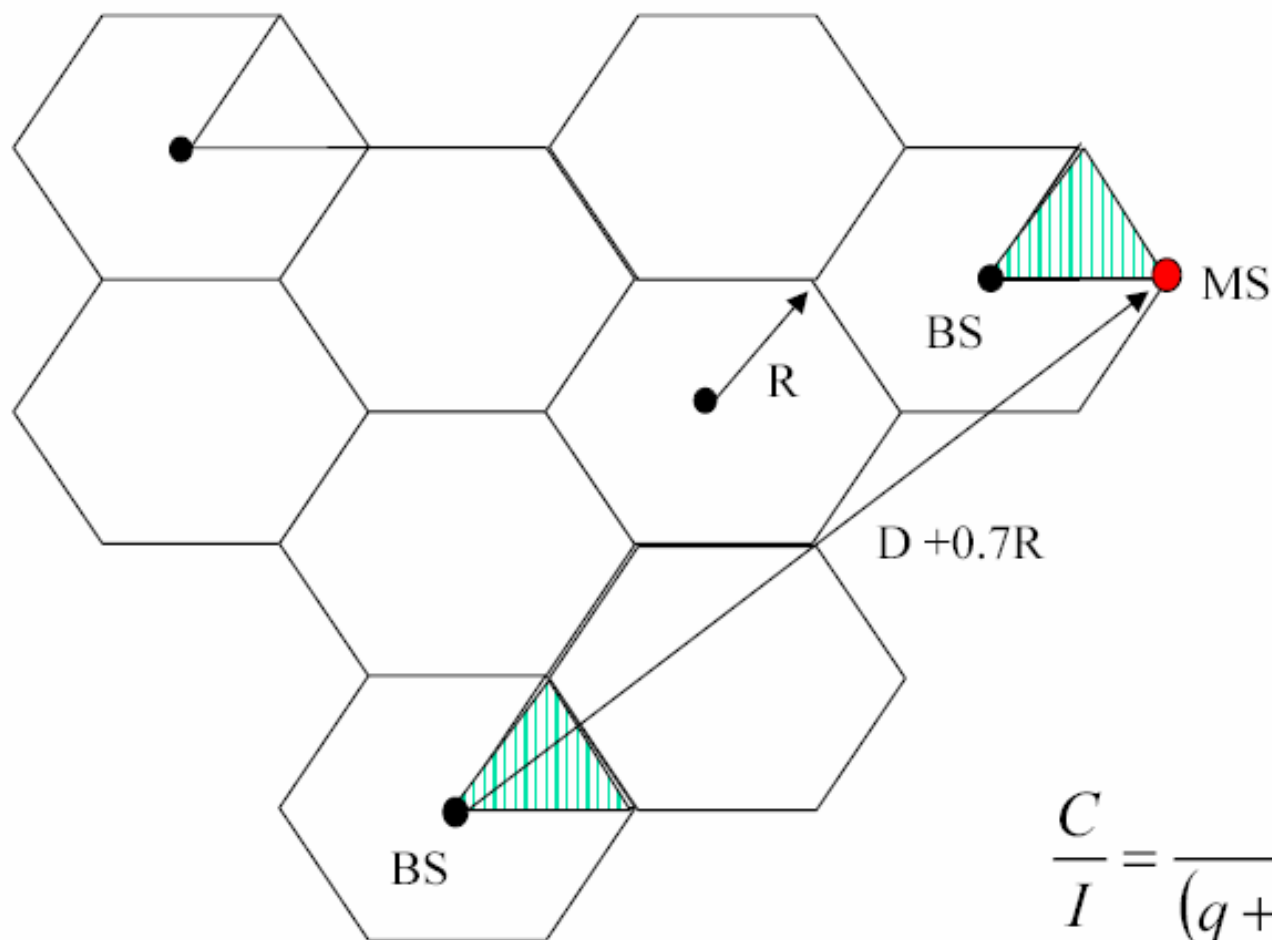


# Worst Case for Forward Channel Interference in Three-sectors



$$\frac{C}{I} = \frac{C}{q^{-\gamma} + (q + 0.7)^{-\gamma}}$$

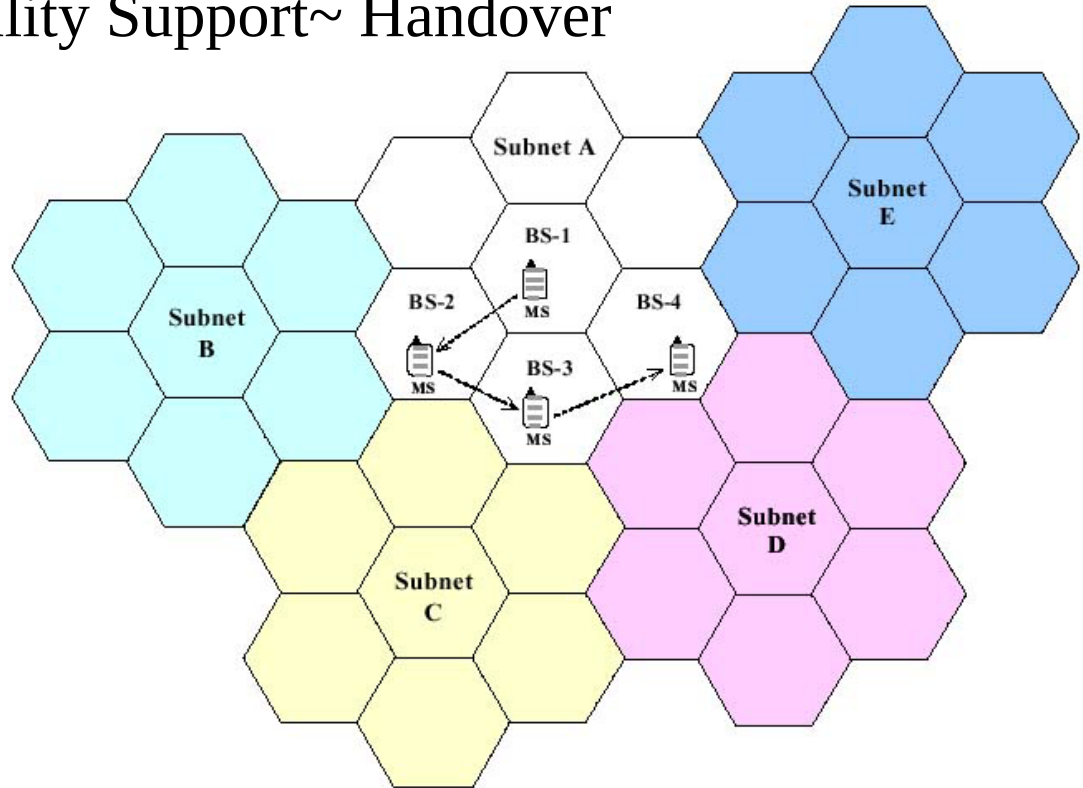
# Worst Case for Forward Channel Interference in Six-sectors



$$\frac{C}{I} = \frac{C}{(q + 0.7)^{-\gamma}}$$

# Handoff Parameters

Mobility Support~ Handover

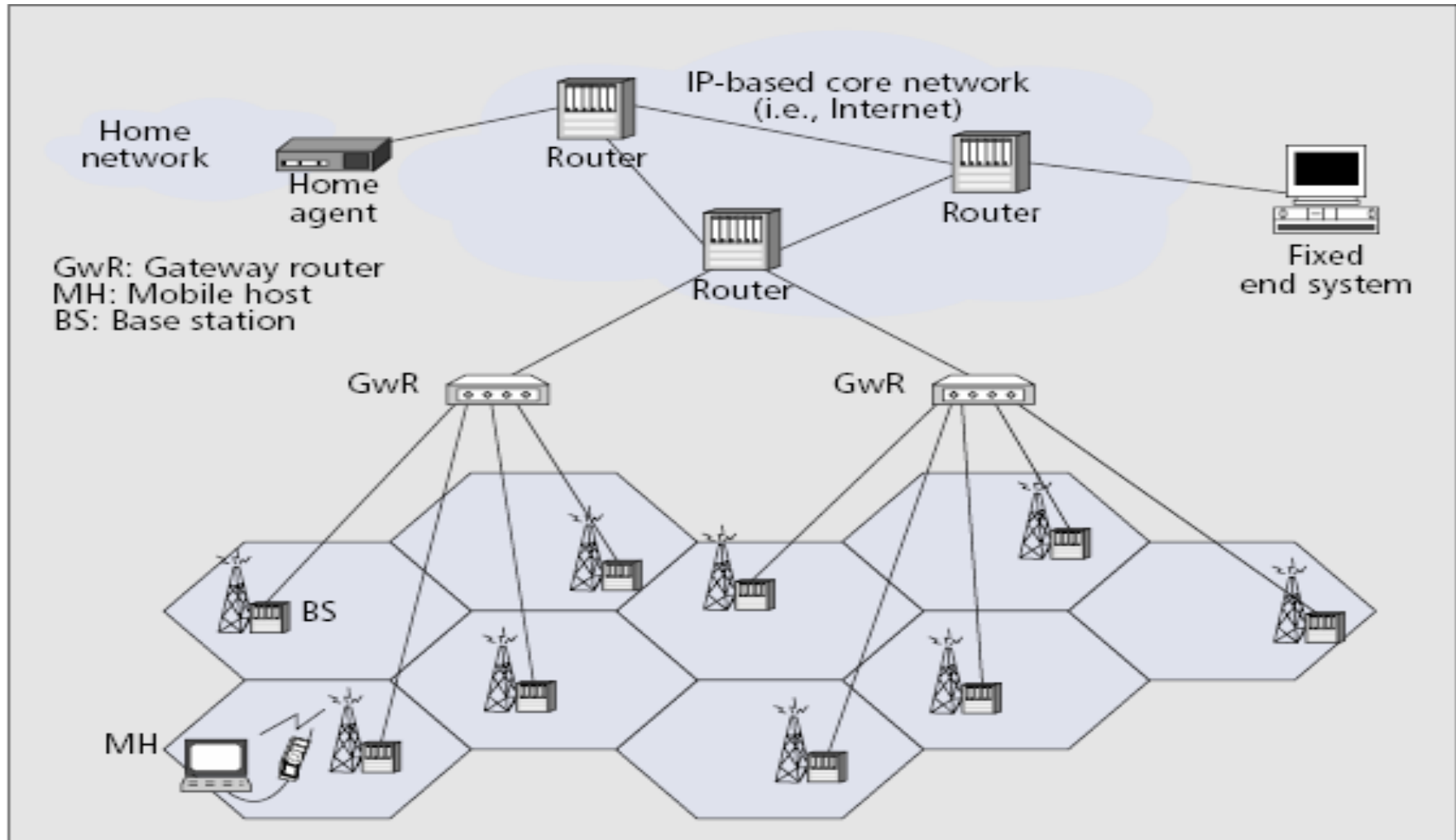


Channel Allocations: Reuse

# Performance Index

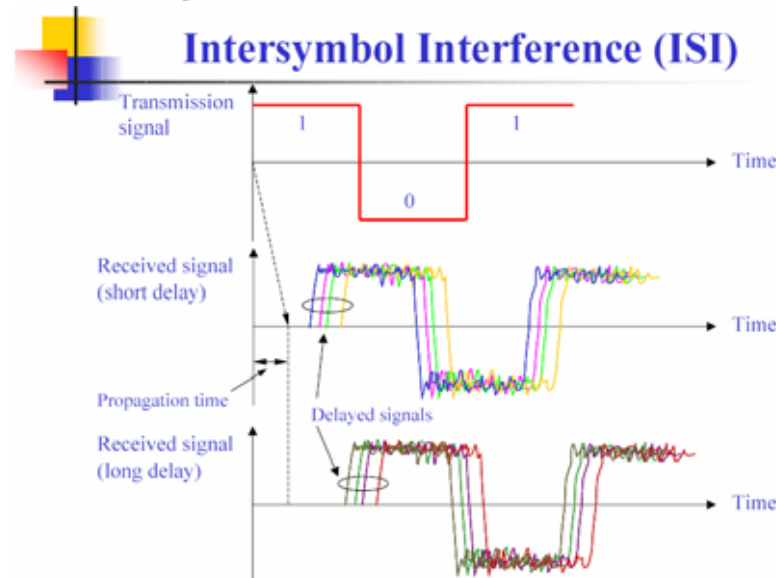
- ◆ Traffic Request: (QoS)
  - New Call Probability
  - Handoff Call Probability
  - Traffic Requirements (Bandwidth, delay)
  - Call Holding Time
  - Dwell Time (Channel Occupation) for a handoff call or new call
  - Delay/Distance/Un-necessary handoff
- ◆ Mobility:
  - Resident time in a cell
  - Hand off rate
- ◆ Channel Resource:
  - Channel assignment
  - Blocking Rate (New Call blocking rate, Handoff blocking rate)

# IP-based 3G Wireless Network



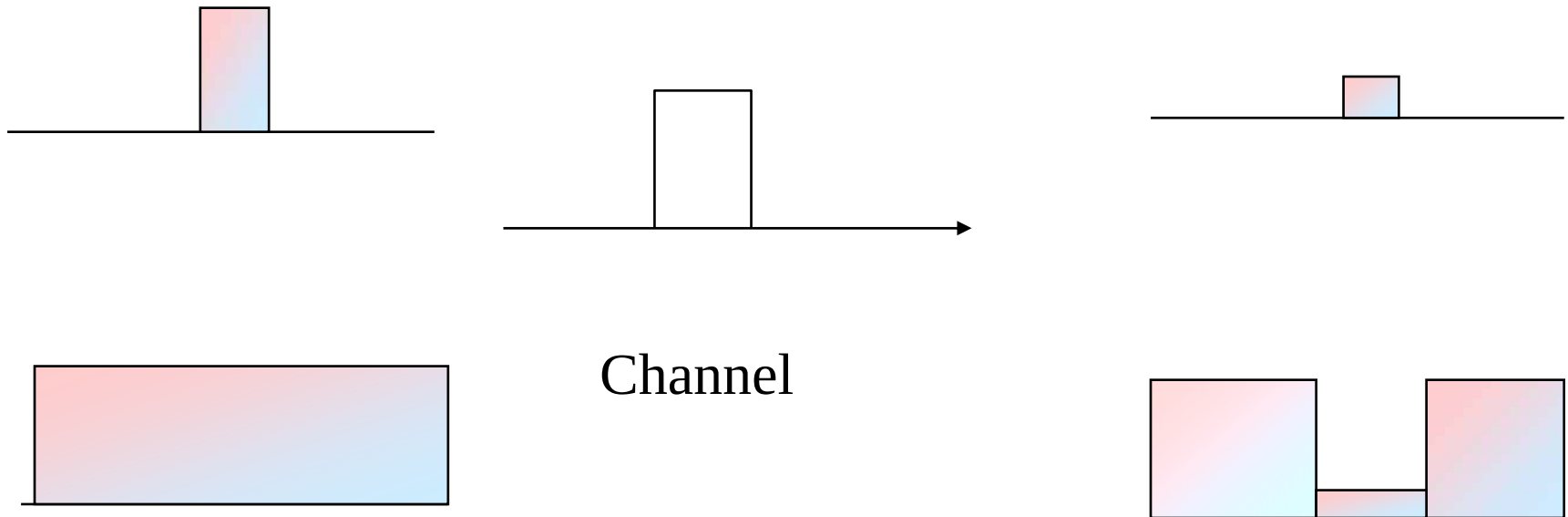
# Multi-path Effect (Time)

- ◆ RMS > Symbol Duration:
  - ISI (handled by Equalizer)
- ◆ RMS < Symbol Duration:
  - More than one paths signal arrive (might have different phases)

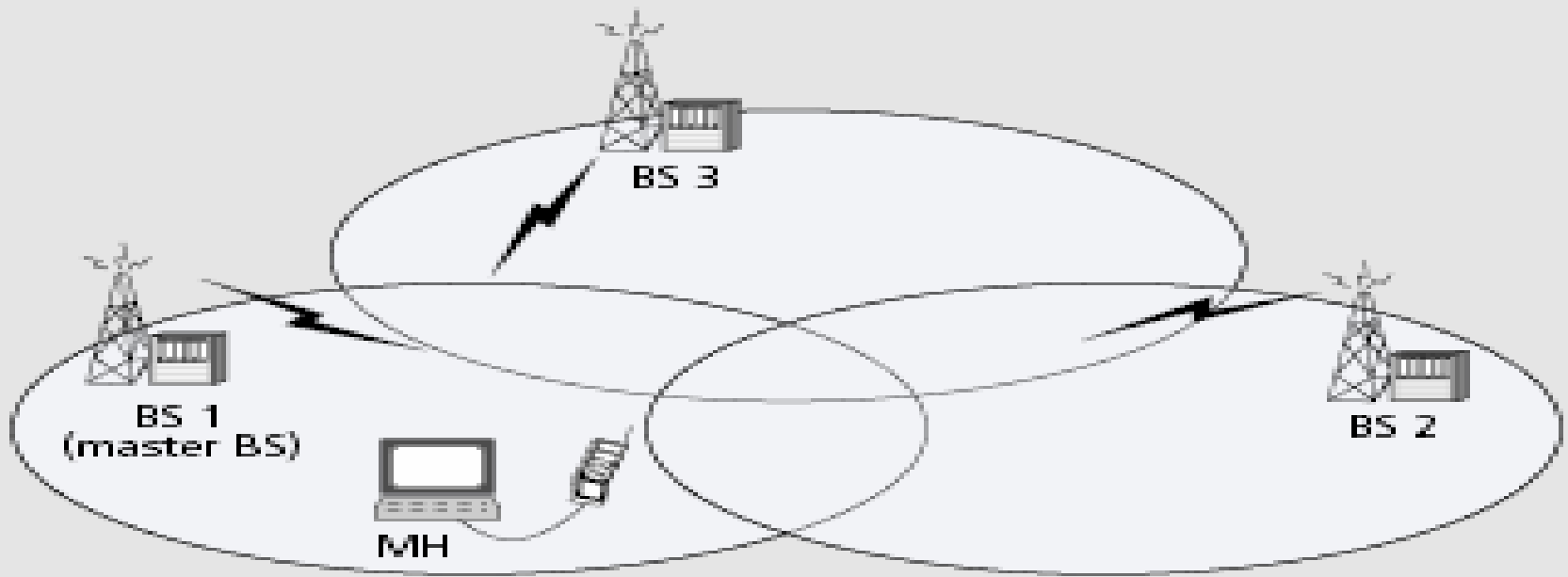


# Coherence Bandwidth (Bandwidth)

- ◆ Coherence Bandwidth  $<$  BW of signal:
  - Frequency Selective Fading
- ◆ Coherence Bandwidth  $>$  BW of signal:
  - Flat Fading



# BS and BS list in MS



<BS list architecture in mobile host>

| IP address     | Beacon signal strength |
|----------------|------------------------|
| 163.152.200.36 | -60 dBm                |
| 163.152.19.34  | -90 dBm                |
| 163.152.19.32  | -80 dBm                |