Channel Allocation

Introduction

- What is channel allocation?
  - A given radio spectrum is to be divided into a set of disjointed channels that can be used simultaneously while minimizing interference in adjacent channel by allocating channels appropriately

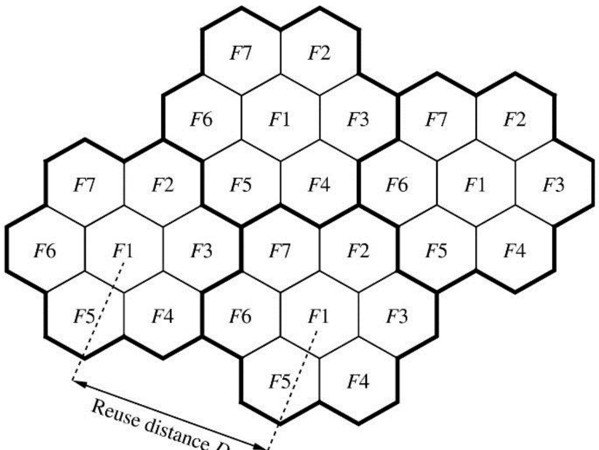


Figure 5.7 Illustration of frequency reuse.

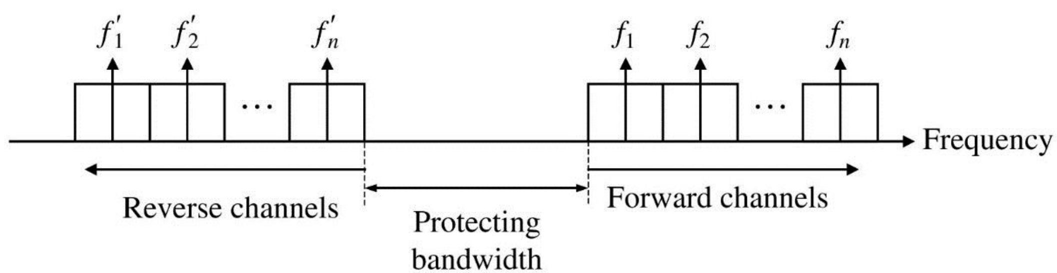


Figure 7.3 Structure of forward and reverse channels in FDMA.

Static vs. Dynamic Channel Allocation

- Static: a fixed number (equal or non-uniform) of channels is allocated to each cell
- Dynamic: channel allocation to different cells is done dynamically, as needed
- Classification of channel allocation schemes
  - Fixed Channel Allocation schemes (FCA schemes)
  - Dynamic Channel Allocation schemes (DCA schemes)
  - Hybrid Channel Allocation schemes (HCA schemes: combining both FCA and DCA techniques)

FCA (1/8)

- A set of channels is permanently allocated to each cell
- Due to short term fluctuations in the traffic, FCA schemes are often not able to maintain high quality of service and capacity attainable with static traffic demands
  - Solutions are non-uniform channel allocation and static borrowing

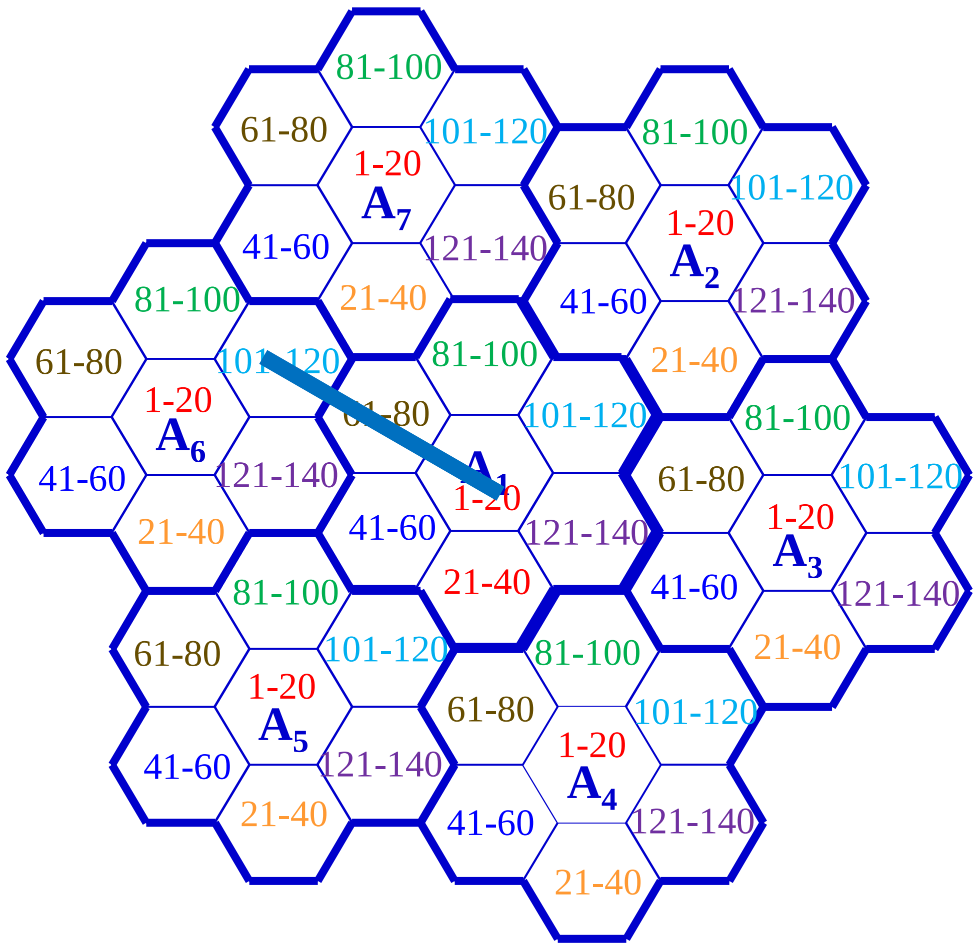
FCA (2/8)

- Number of available channels S is divided into sets, the minimum number of channel sets N required is related to the frequency reuse distance D as follows:

$$N = \frac{D^2}{3R^2} \text{ or } \sqrt{N} = \frac{D}{\sqrt{3}R}$$

- If a cell of cluster A_1 borrows channel, there should not be interference with cells A_2, A_3, A_4, A_5, A_6, and A_7 (refer to the figure on pp. 6) [note A_i means cluster]
  - $A_{1,1}$: Channels 1-20, $A_{1,2}$: Channels 21-40
  - $A_{1,3}$: Channels 41-60, $A_{1,4}$: Channels 61-80
  - $A_{1,5}$: Channels 81-100, $A_{1,6}$: Channels 101-120
  - $A_{1,7}$: Channels 121-140

FCA (3/8)


81-100
61-80
101-120
1-20
A7
41-60
121-140
21-40
81-100
61-80
101-120
1-20
A2
41-60
121-140
21-40
81-100
61-80
101-120
1-20
A6
41-60
121-140
21-40
81-100
61-80
101-120
A1
1-20
41-60
121-140
21-40
81-100
61-80
101-120
1-20
A3
41-60
121-140
21-40
81-100
61-80
101-120
1-20
A5
41-60
121-140
21-40
81-100
61-80
101-120
1-20
A4
41-60
121-140
21-40

FCA (4/8)

- Non-uniform channel allocation
  - Preliminary: known expected traffic profile per cell
  - Non-uniform compact pattern allocation (the approach proposed in 1991, and we will introduce in next week)
    - Objective: minimizing the average system blocking probability
    - <u>Allocation pattern</u>: formed by [allocated channel + co-channel cells]
    - <u>Compact allocation pattern of a channel</u>: the pattern with minimum average distance between cells
    - <u>Non-uniform compact pattern allocation</u>: the compact pattern allocation with the minimum system blocking probability

FCA (5/8)

- Static borrowing
  - Unused channels from lightly loaded cells are re-assigned to heavily loaded ones at distances ≥ the minimum reuse distance
  - The number of channels assigned in each cell may be reassigned periodically according to spatial inequities in the load in a scheduled or predictive manner
  - Static borrowing deals with long-term allocation of borrowed channels to cells

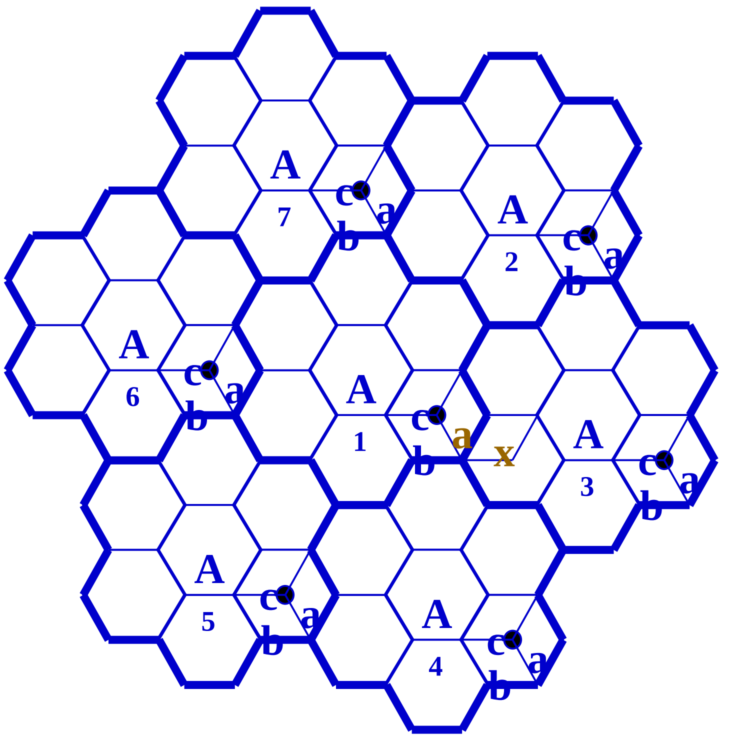
FCA (6/8)

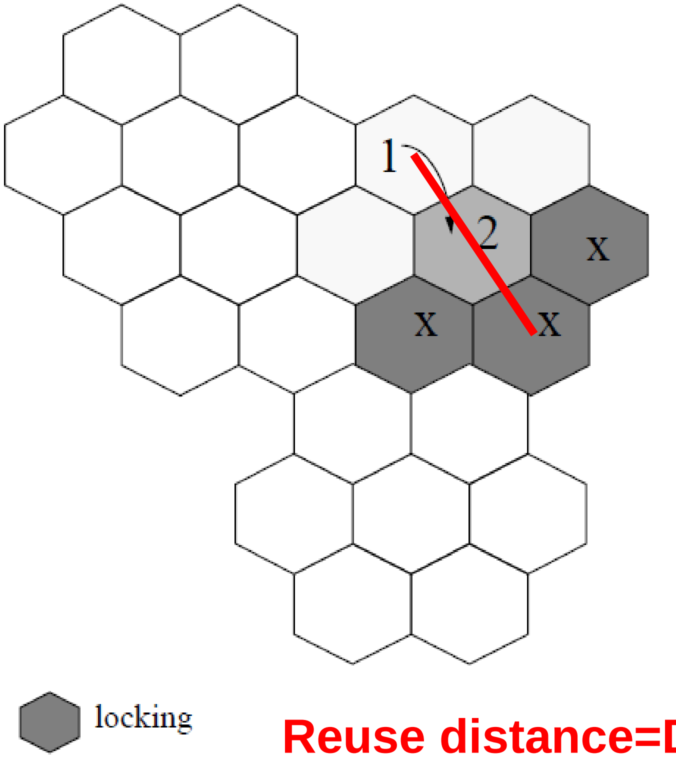
- Simple borrowing schemes
  - Acceptor cell vs. donor cell
  - Challenge: which neighboring cell?
  - **Borrowing from the richest**: from an adjacent cell which has the largest number of free channels (locked channels excluded)
  - **Borrow-first-available**: select the first free channel found based on a predefined sequence
  - **Basic algorithm with reassignment**: return borrowed channel when a nominal channel becomes available
  - (+) reduce call blocking
  - (-) channel locking: considering interference
  - (-) future channel usage in co-channel sets

FCA (7/8)

- Complex borrowing schemes
  - Simple hybrid channel borrowing strategy
    - Two channel groups--permanent and reserved
    - Permanent for local calls (不外借); reserved can be lent to neighboring cells (可外借)
  - Borrowing with channel ordering
    - Prioritize channels of each cell
    - Local calls: from high-priority channel to low-priority channel
    - Channel borrowing: from low-priority channel to high-priority channel
  - Borrowing with directional channel locking
    - Locking affected sectors only

FCA (8/8)





Reuse distance=D

Figure 3: Channel Locking

DCA (1/5)

- Utilizing a central channel pool
- The selected cost function of channel selection might depend on:
  - Future blocking probability in neighboring cells
  - Reuse distance
  - Usage frequency of the candidate channel
  - Average blocking probability of the overall system
  - Instantaneous channel occupancy distribution
- Classifications: centralized (基地台之間不用交換資訊) and distributed (要交換資訊)

DCA (2/5)

- Centralized DCA schemes
  - First available (FA): the first available channel satisfying reuse distance requirement is assigned to the call
  - Locally optimized dynamic assignment (LODA): cost function is based on the future blocking probability in the neighboring cells
  - Selection with maximum usage on the reuse ring (RING): a candidate channel is selected which is in use in the most cells in the co-channel set
  - Channel rearrangement is required to improve the performance of DCA

DCA (3/5)

- Distributed DCA schemes
  - Cell-based: a channel is allocated to a cell by the BS at which the call is initiated (BSs have to keep info about current available channels in its vicinity)
    - Local packing dynamic distributed channel assignment (LP-DDCA)
      - Augmented channel occupancy (ACO) matrix
      - BSs update channel assignment information
    - Adjacent channel interference constraint (ACI): LP-DDCA+ACI
      - Required channel separation is N_{adj}
      - The $(N_{\mathrm{adj}} - 1)$ columns to the left and right of that assigned channel should have empty entries

DCA (4/5)

Base Station Number	*Channel Number*								*Number of Assignable Channels*
	1	2	3	4	5	6	... ...	M	
i		x					...		0
i_1	x			x			...		0
i_2			x				...		2
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
i_{k_i}			x		x				4

Table 8: ACO Matrix at Base Station i

DCA (5/5)

- Signal strength measurement-based: mobiles and BSs estimate carrier-to-interference ratio (CIR) and allocate a channel to a call when predicted CIRs are above a threshold
  - Sequential channel search (SCS)
    - All mobile/BS pairs examine channels in the same order and choose the first available with acceptable CIR
    - Service interrupt: the CIR of established calls is deteriorated → premature service termination (deadlock)
    - Instability: the interrupted call finds an acceptable channel, setting up a link using the new channel can cause interruption of another established link
    - Block: no channel is available for the initial call request

HCA (1/2)

- Hybrid channel allocation scheme
  - Fixed +DCA
  - Channels are divided into fixed and dynamic sets
  - Each cell is given a fixed number of exclusive channels
  - Dynamic channel requests are performed on exhausted channels
  - Dynamic channel set employs any of DCA schemes
  - Design issue: ratio between fixed and dynamic channels

HCA(2/2)

- Flexible channel allocation scheme
  - Fixed and flexible channel sets
  - A fixed channel set per cell to handle lighter loads
  - Channel assignment of flexible channel set
    - Scheduled
      - Measuring traffic variation
      - Predetermining peaks of traffic change
    - Predictive
      - Monitoring traffic intensity and blocking probability

Channel Allocation in One-Dimensional Systems

- Special case: highway
- Considered criteria
  - Reuse distance

Allocate the new initiated call the same channel as MU e

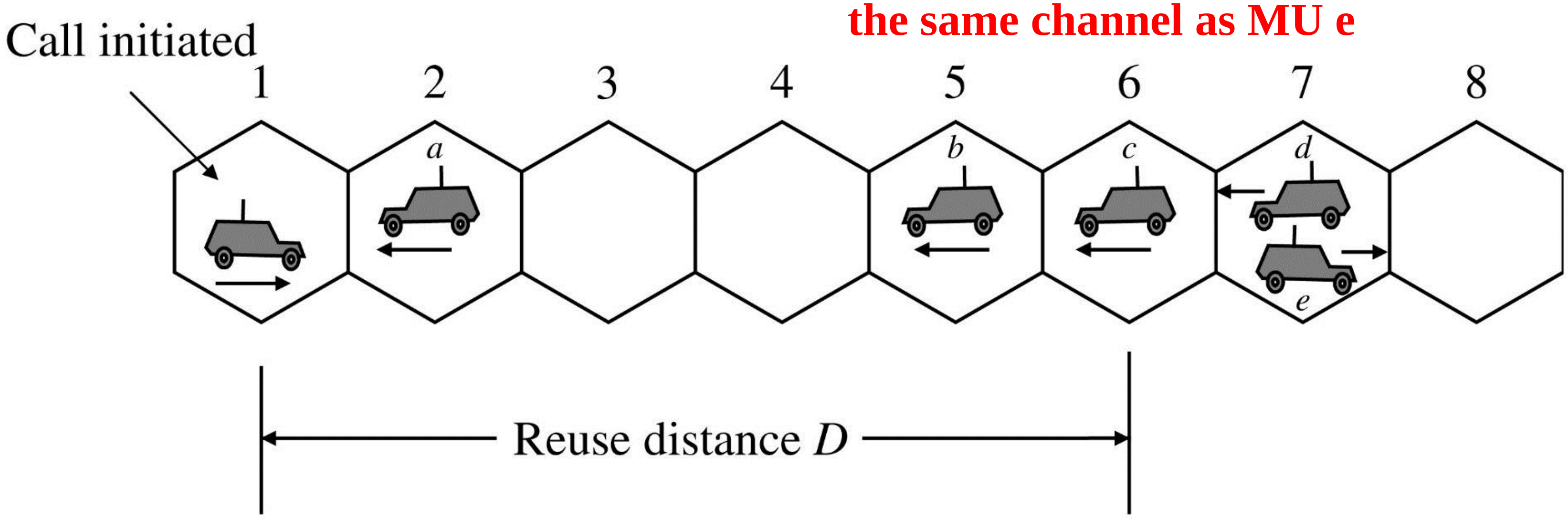


Figure 8.3 Allocation of channels in one-dimensional moving direction.

Reuse Partitioning-Based Channel Allocation

- Inner zone vs. outer zone
  - Lesser power and lower value of reuse distance
- Assignment
  - MS: sorting from best to worst
  - CH assignment: from the best (inner zone) to the worst (outer zone)
- Channel group adjustment
  - SIR changes
  - Periodical SIR measurement

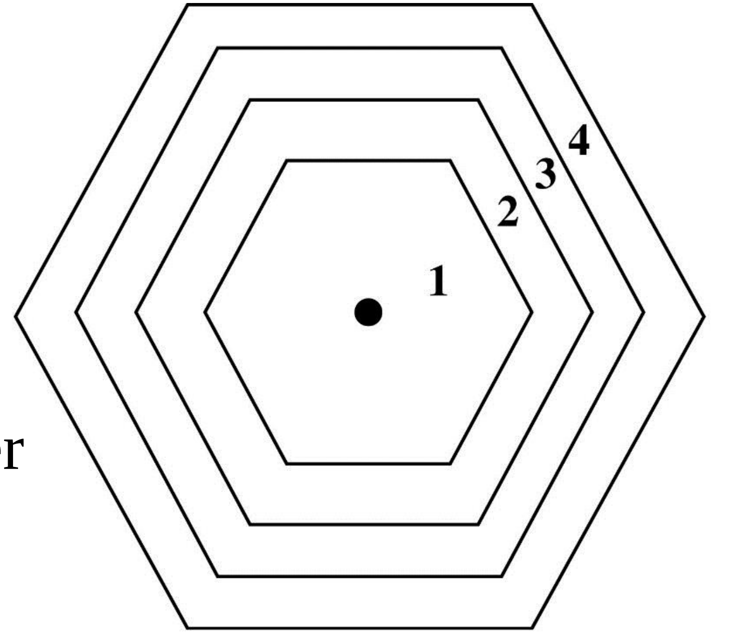


Figure 8.4 Concentric zone of a cell

Overlapped Cells-Based Channel Allocation (1/3)

- Cell vs. microcell
  - Layout 1
    - Alternative one
      - Slow mobility: channel is assigned by microcell BS
      - Fast mobility: channel is assigned by cell BS
      - Channels per tier (allocation criteria)
        - Total number of channels
        - Covered area
        - Average MS moving speed in each tier
        - Call arrival rate
        - Information duration per tier
        - Desirable blocking and dropping probabilities
        - Number of channels set aside for handoffs

Overlapped Cells-Based Channel Allocation (2/3)

- Alternative two
  - Low traffic: microcell is turned off
  - As traffic increases, the corresponding microcells are turned on if
    - an unacceptable level of co-channel interference, or
    - unavailability of resources leads to forced call blocking

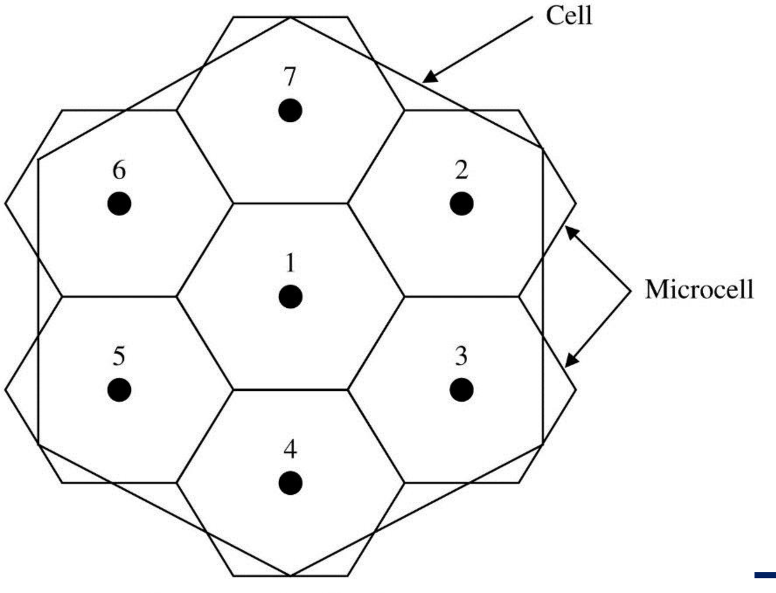


Figure 8.5 Illustration of cell splitting.

Overlapped Cells-Based Channel Allocation (3/3)

- Layout 2
  - **Directed retry**: if a MS located in the shaded area cannot find any free channels from cell A, then it can use a free channel from cell B
  - **Directed handoff**: free up a channel by forcing some of the existing connections in the shaded area of cell A to do forced handoff to cell B, if a new call in cell A do not find a free channel

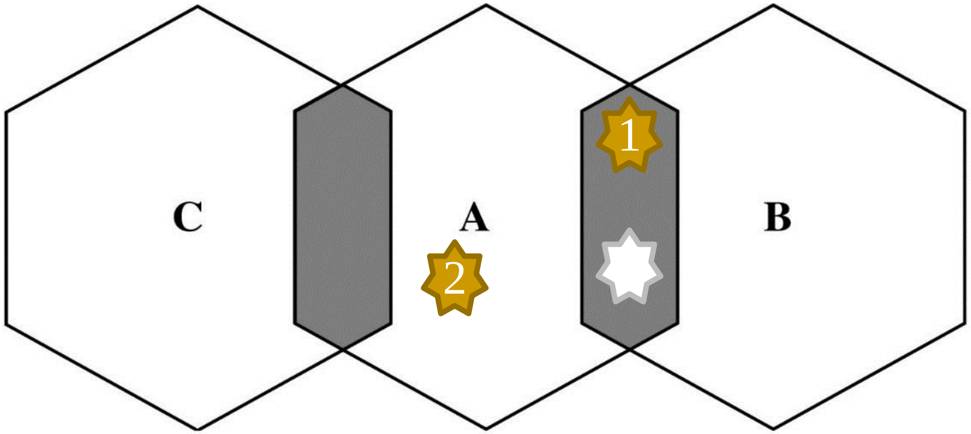


Figure 8.6 Use of overlapped cell areas.

System Modeling (1/8)

- Blocking probability (originating calls): B_O
- Drop probability (handoff calls): B_H
- Notations

λ_O : average arrival rate of originating calls

λ_H : average arrival rate of handoff calls

μ : average service rate for calls

$P(i)$: the probability of i channels to be busy

B_O : the blocking probability of originating calls

B_H : the blocking probability of handoff calls

S : the total number of channels allocated to a cell

System Modeling (2/8)

- Case 1: all channels are shared by originating and handoff calls

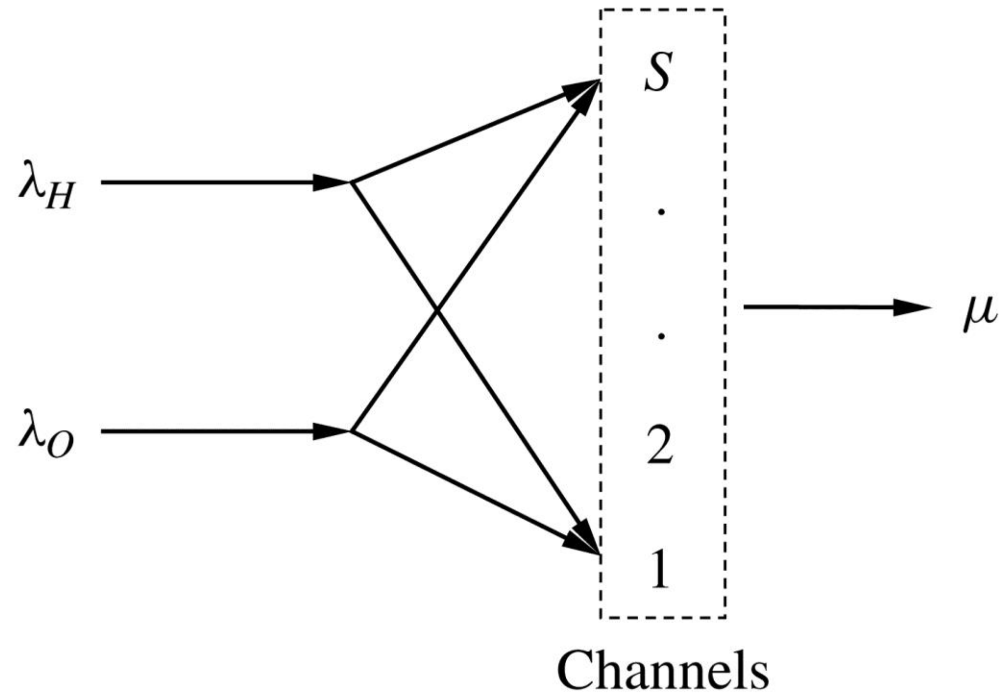
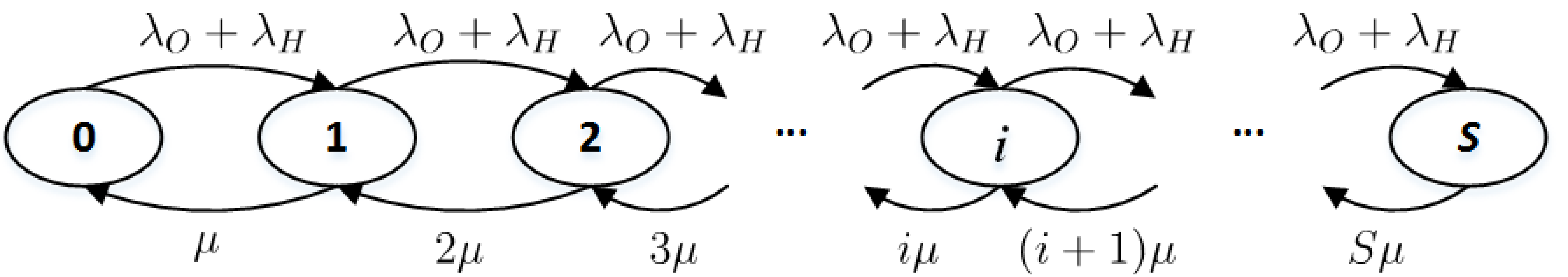


Figure 8.7 A generic system model for a cell.

System Modeling (3/8)

- State transition diagram of the queueing model M/M/S/S



System Modeling (4/8)

- Derivation
  - For state *i*

$$P(i) = \frac{(\lambda_O+\lambda_H)}{i\mu}P(i-1), \;\; 0 \le i \le S$$

$$\sum_{i=0}^{S} P(i) = 1$$

$$P(i) = \frac{(\lambda_O+\lambda_H)^i}{i!\mu^i}P(0)$$

$$P(0) = [\sum \frac{(\lambda_O+\lambda_H)}{i!\mu^i}]^{-1}$$

$$B_O = B_H = P(S) = \frac{\frac{(\lambda_O+\lambda_H)^S}{S!\mu^S}}{\sum_{i=0}^{S} \frac{(\lambda_O+\lambda_H)^i}{i!\mu^i}}$$

System Modeling (5/8)

- Case 2: channel reservation for handoff calls
  - Two more notations

S_R : channels exclusively to handoff calls

S_C : channels shared by both originating and handoff calls

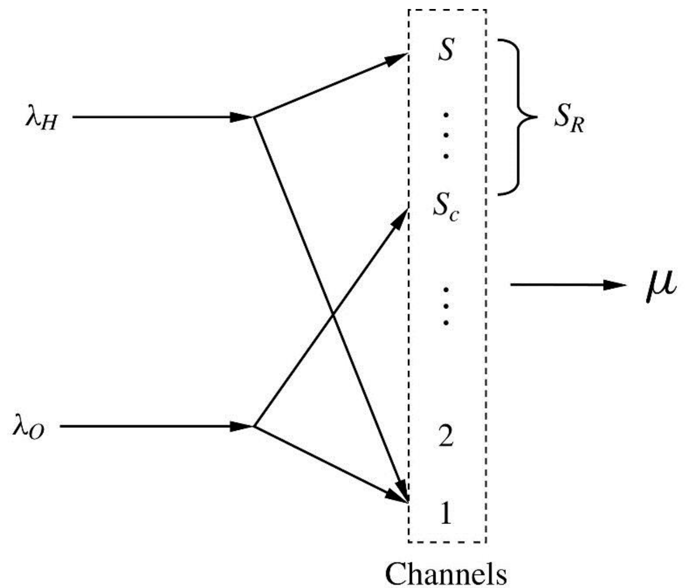
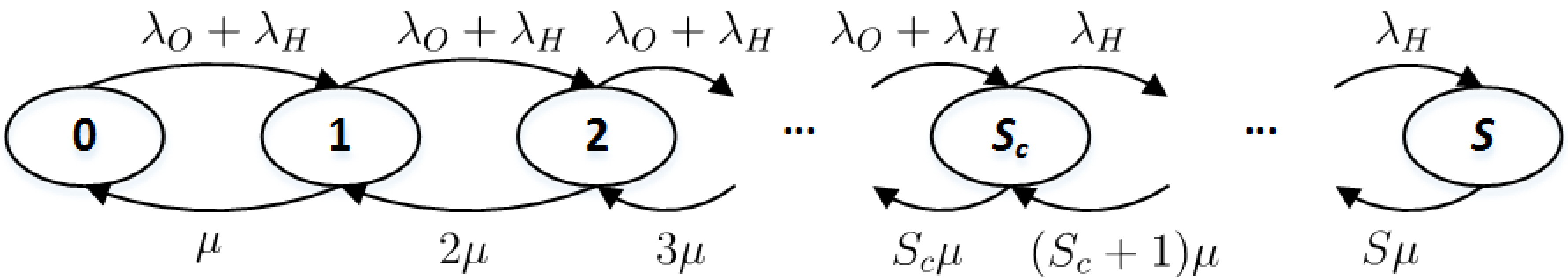


Figure 8.9 System model with reserved channels for handoff calls.

System Modeling (6/8)

- State transition diagram with channel reservation



System Modeling (7/8)

- Derivation

$$\begin{cases} i\mu P(i) = (\lambda_O + \lambda_H) P(i-1), & 0 \le i \le S_c \\ i\mu P(i) = \lambda_H P(i-1), & S_c < i \le S. \end{cases}$$

$$\sum_{i=0}^{S} P(i) = 1$$

$$P(i) = \begin{cases} \frac{(\lambda_O+\lambda_H)^i}{i!\mu^i} P(0), & 0 \le i \le S_c \\ \frac{(\lambda_O+\lambda_H)^{S_c} \lambda_H^{i-S_c}}{i!\mu^i} P(0), & S_c < i \le S. \end{cases}$$

System Modeling (8/8)

$$P(0) = [\sum_{i=0}^{S_c} \frac{(\lambda_O+\lambda_H)^i}{i!\mu^i} + \sum_{i=S_c+1}^{S} \frac{(\lambda_O+\lambda_H)^{S_c}\lambda_H^{i-S_c}}{i!\mu^i}]^{-1}$$

$$B_O = \sum_{i=S_c}^{S} P(i)$$

$$B_H = P(S) = \frac{(\lambda_O+\lambda_H)^{S_c}\lambda_H^{S-S_c}}{S!\mu^S} P(0)$$

Fractional Frequency Reuse (FFR) (1/5)

- Kinds of interference management
  - FFR
  - Power control
  - Smart antenna (nulling)
- Motivation: aggressive spectrum reuse (reuse 1) to achieve high system capacity and simplify radio network planning
- Two categories
  - Hard FFR (strict FFR)
  - Soft FFR

Fractional Frequency Reuse (FFR) (2/5)

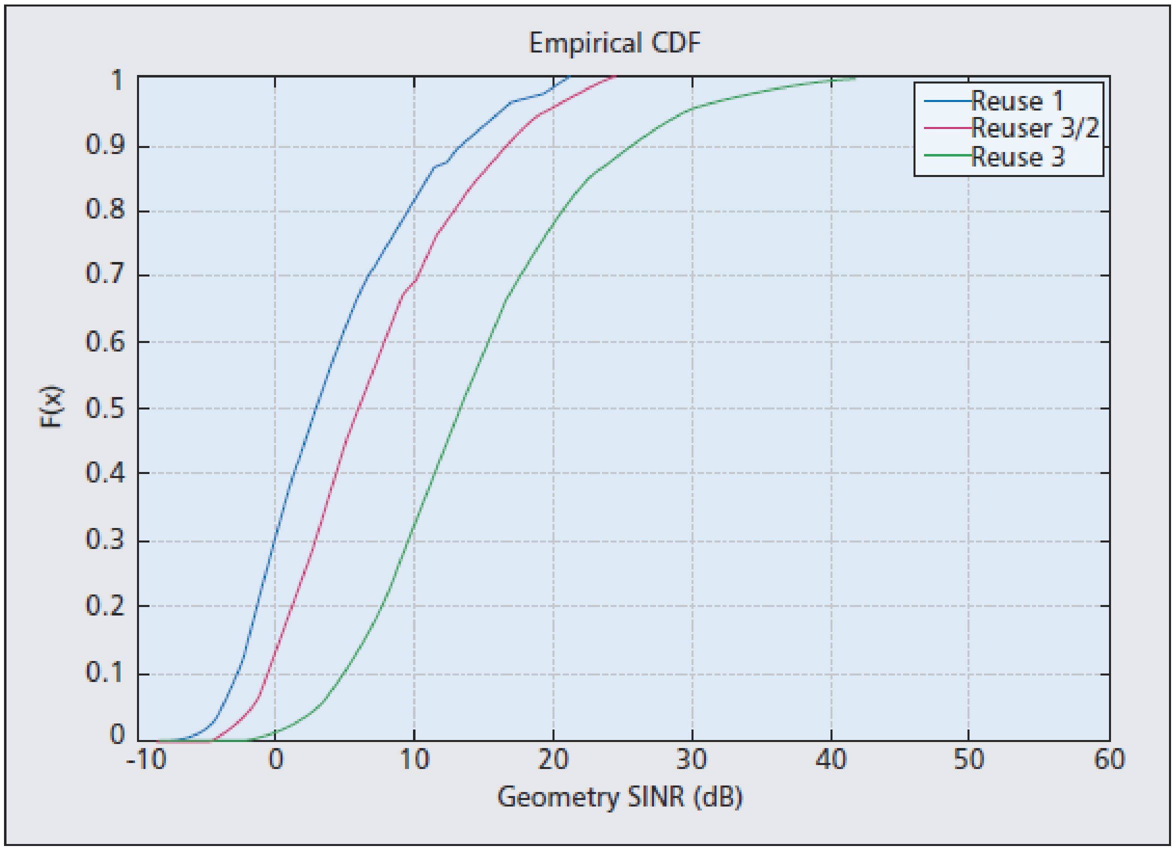
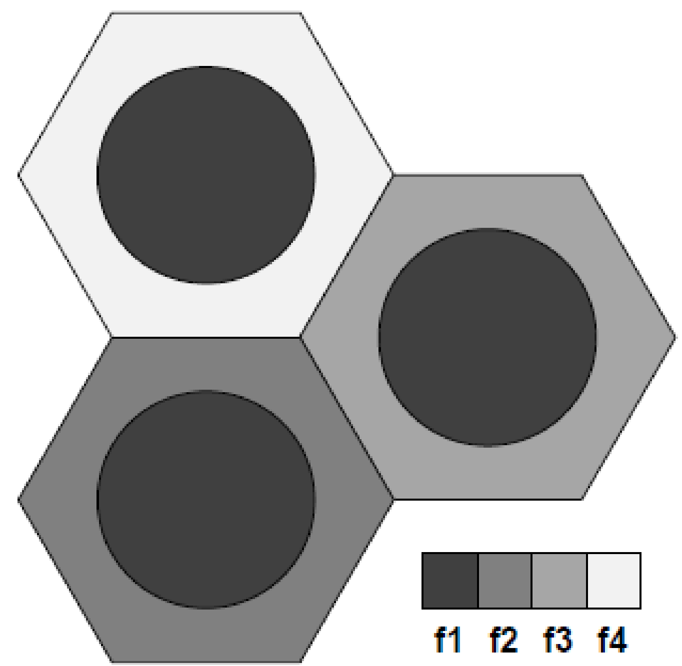


Figure 1. *Geometric SINR distribution for a network with multiple frequency reuse factors (500 m cell).*

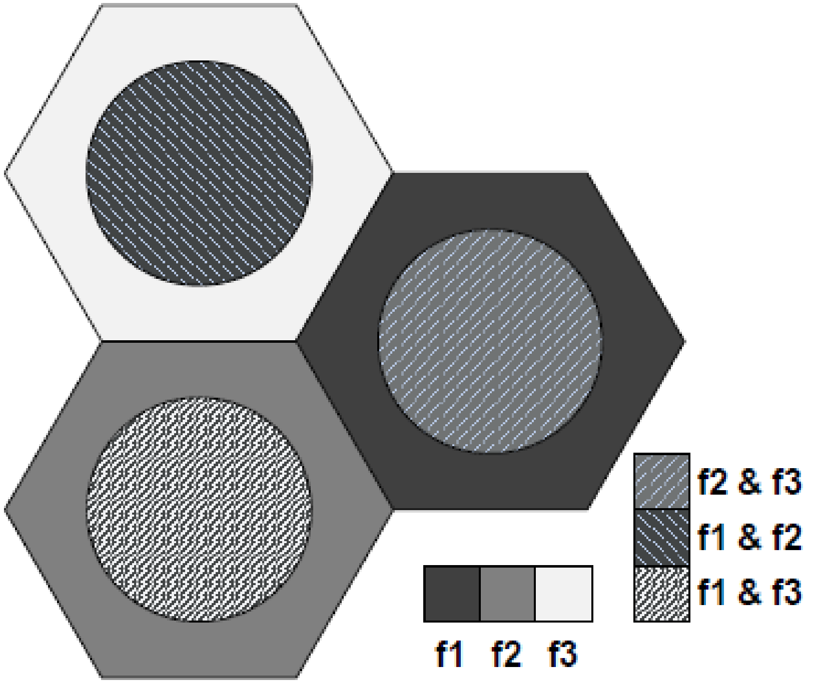
Fractional Frequency Reuse (FFR) (3/5)

- Hard FFR
  - Cell center reuse factor: 1
  - Cell edge reuse factor: Δ (e.g., 3)
  - Require channels in total: $\Delta + 1$
  - Interior users do not share any spectrum with edge users

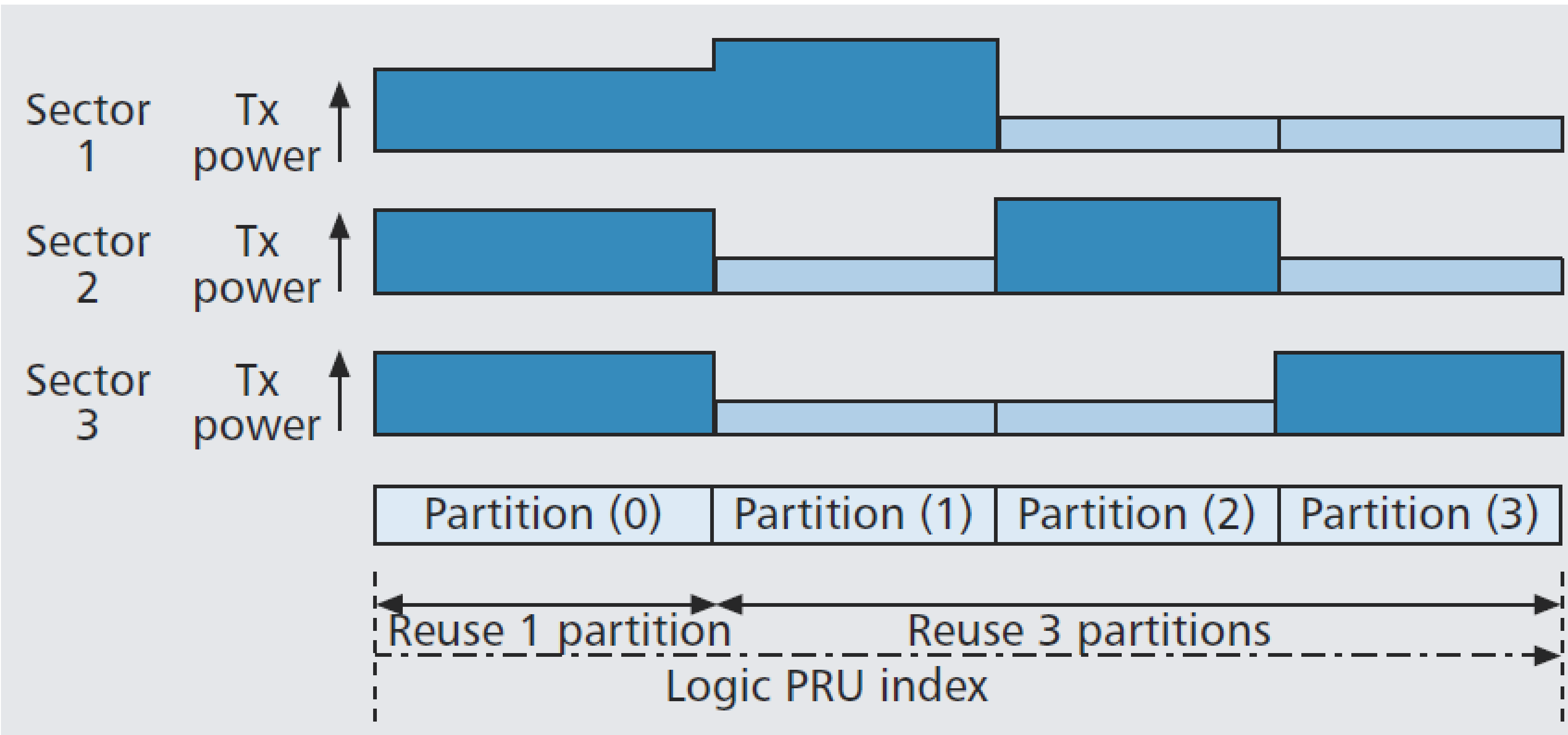


Fractional Frequency Reuse (FFR) (4/5)

- Soft FFR
  - Interior users are allowed to share sub-bands with edge users in other cells
  - Cell interior users typically transmit at low power levels than the cell edge users
  - How to classify cell center or cell edge users?
    - BS-to-UE SNR
    - UE location



Fractional Frequency Reuse (FFR) (5/5)



Non-uniform Compact Pattern Allocation (1/11)

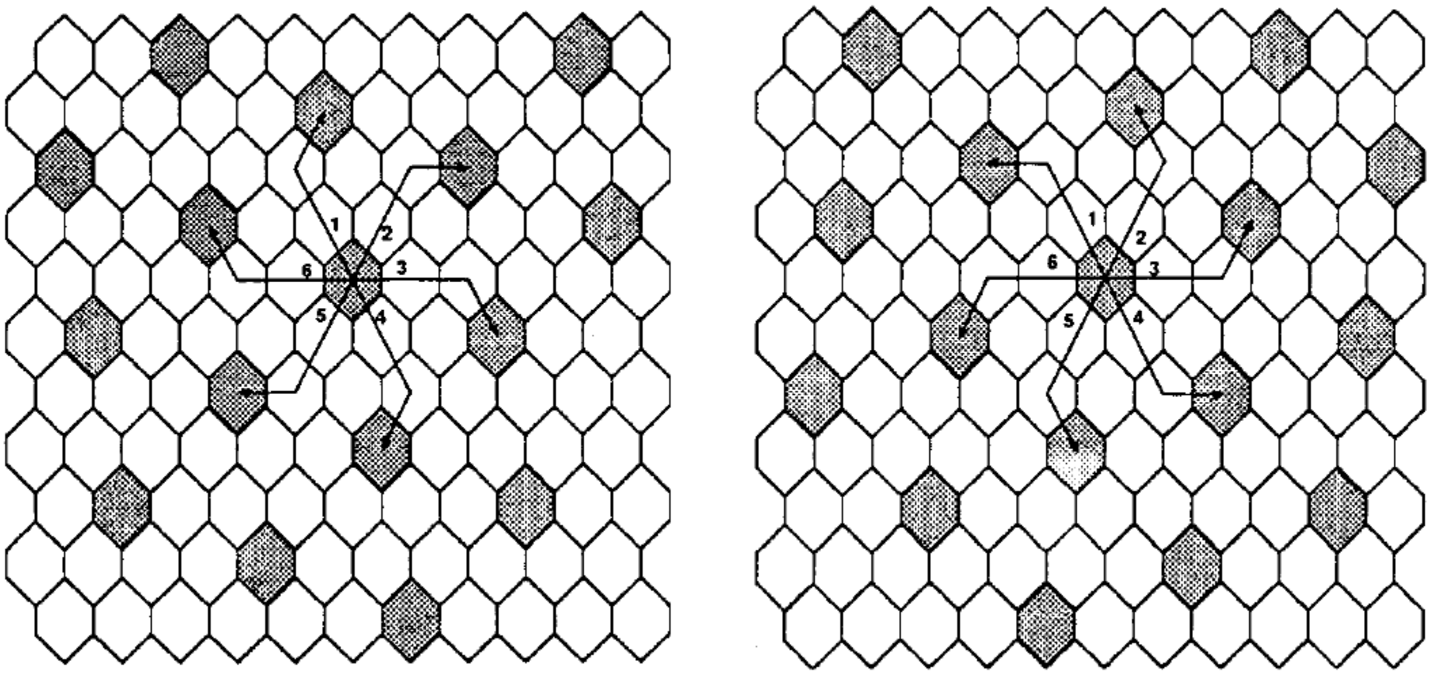
- Co-channel allocation pattern (for channel k, denoted as π_k): the set of cells that use channel k without co-channel interference
  - Definition of indicator function $I_i(k)$

$$I_i(k) = \begin{cases} 1, & \text{channel } k \text{ is allocated to cell } i \\ 0, & \text{otherwise} \end{cases}$$

  - Co-channel allocation pattern is described by $\{I_1(k), I_2(k), I_3(k),.., I_N(k)\}$
- Compact allocation pattern: the pattern with minimum average distance between co-channel cells

Non-uniform Compact Pattern Allocation (2/11)

- The example compact allocation patterns
- There are 7*2=14 compact allocation patterns, denoted as $G=\{g_1, g_2, \ldots, g_{14}\}$



Non-uniform Compact Pattern Allocation (3/11)

- Average call blocking
  - Let $n_i(m)$ be the total number of channels allocated to cell i given that m channels are allocated to the system. The

$$n_i(m) = \sum_{k=1}^{m} I_i(k),\ i = 1, 2, .., N$$

  - Let λ_i be the traffic in Erlangs to cell i and let the number of channels available in the cell be $n_i(m)$, then the call blocking probability in the cell is given by the Erlang B formula as

$$p(\lambda_i, n_i(m)) = \left[\sum_{k=1}^{n_i(m)} \frac{\lambda_i^k}{k!} \right]^{-1} \frac{\lambda_i^{n_i(m)}}{n_i(m)!}$$

Non-uniform Compact Pattern Allocation (4/11)

- The overall average blocking probability in the cellular system is

$$PB(m) = \sum_{i=1}^{N} w_i p(\lambda_i, n_i(m)), \text{ where } w_i = \frac{\lambda_i}{\sum_{k=1}^{N} \lambda_k}$$

- Channel allocation algorithm
  - Define π_i* be the allocation pattern of channel *i* that results in the largest drop of blocking probability
  - Considering the first channel allocation, the optimal allocation pattern for channel 1, π_1*, is the pattern that minimize $PB(1) = \sum_{i=1}^{N} w_i p(\lambda_i, n_i(1))$

Non-uniform Compact Pattern Allocation (5/11)

- Let the set of allocation patterns of the first *m* channels be

$$\Gamma_m = \{\pi_1^*, \pi_2^*, .., \pi_m^*\}$$

- With the addition of the $(m+1)^{th}$ channel, the number of allocated channel in cell *i* is

$$n_i(m+1) = n_i(m) + I_i(m+1), \; i = 1, 2, .., N$$

- The average blocking probability after the allocation of the $(m+1)^{th}$ channel is

$$PB(m+1) = \sum_{i=1}^{N} w_i p(\lambda_i, n_i(m) + I_i(m+1))$$

- To minimize PB(*m*+1) with respect to π, the allocation patterns from *G* is chosen and denote it as π_{m+1}^*, i.e.,

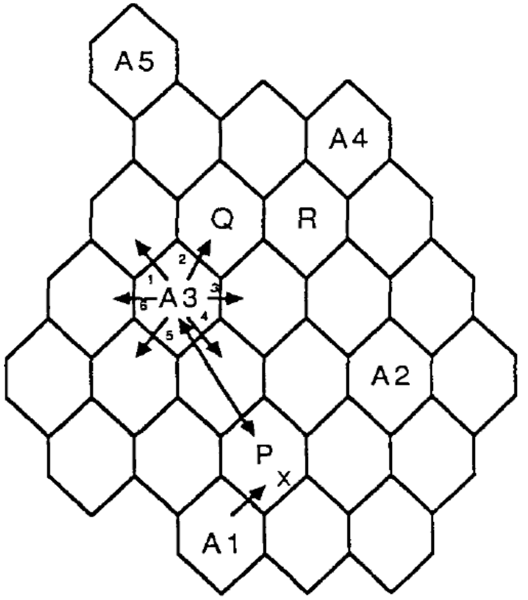
$$\Gamma_{m+1} = \Gamma_m \cup \{\pi_{m+1}^*\}$$

Non-uniform Compact Pattern Allocation (6/11)

- Channel assignment strategy
  - Fixed assignment (FA) strategy
    - The set of nominal channels is permanently allocated to each cell
    - An arriving call can only be served by the nominally allocated channels
    - If all nominal channels are assigned, new calls are blocked
  - Borrowing with channel ordering (BCO) strategy
    - All nominal channels are ordered such that the first channel has the highest priority to be assigned to the next local call and the last channel is given the highest priority to be borrowed by neighboring cells
    - After a channel is borrowed, lock the channel in the co-channel cells within the reuse distance of the borrowing cell

Non-uniform Compact Pattern Allocation (7/11)

- Borrowing with directional channel locking strategy
  - All channels are ordered
  - When a channel is borrowed, the locking of this channel in the co-channel cells is restricted only to the affected by this borrowing
    - Cell P borrows channel *x* from A1, then channel *x* in cell A3 needs to be blocked in directions 3, 4, and 5. Cells in directions 1, 2, and 6 are free to borrow channel *x*

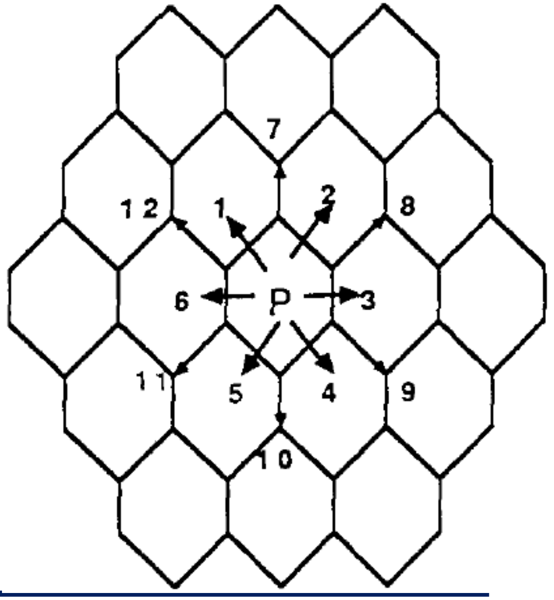


Non-uniform Compact Pattern Allocation (8/11)

- Locally optimized dynamic assignment (LODA)
  - No nominal channel is assigned to cells
  - Channels are shared by the entire mobile system
  - A particular cell having a call to serve evaluates the cost of using each candidate channel
  - The channel with the minimum cost is assigned
  - The cost here is a measure of the future call blocking probability

Non-uniform Compact Pattern Allocation (9/11)

- Shadow blocking factor
  - 12 directions regarding the shadow blocking factor (SBF) are indicated
  - If a channel can be reused in a neighboring cell, SBF=1
  - If a channel can be reused in a cell 2 cell units apart from P, SBF=2
  - If there is no shadow blocking, SBF=3
  - In previous example, for cell P, the value of SBF in all directions except direction 1 is 3; SBF(1)=2



Non-uniform Compact Pattern Allocation (10/11)

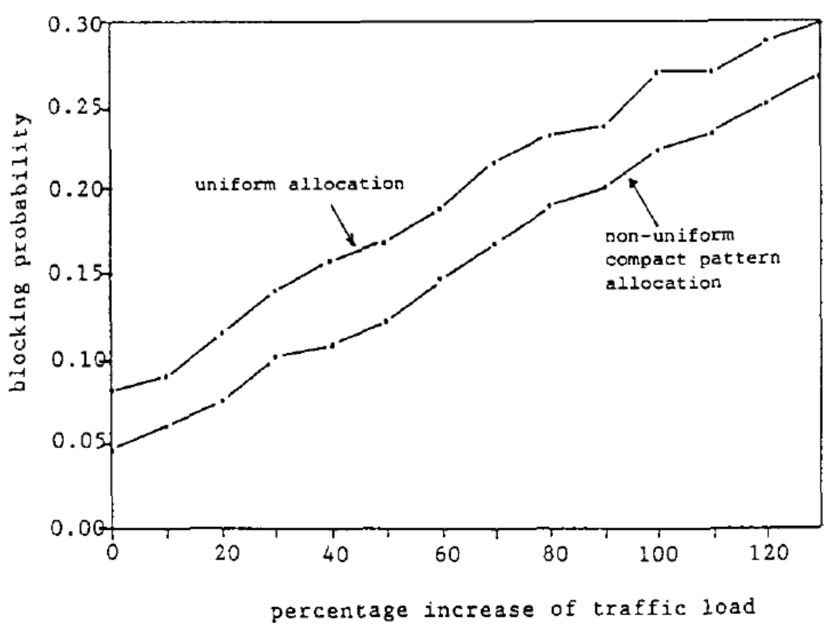


Fig. 6. FA assignment with nonuniform compact pattern allocation and uniform channel allocation.

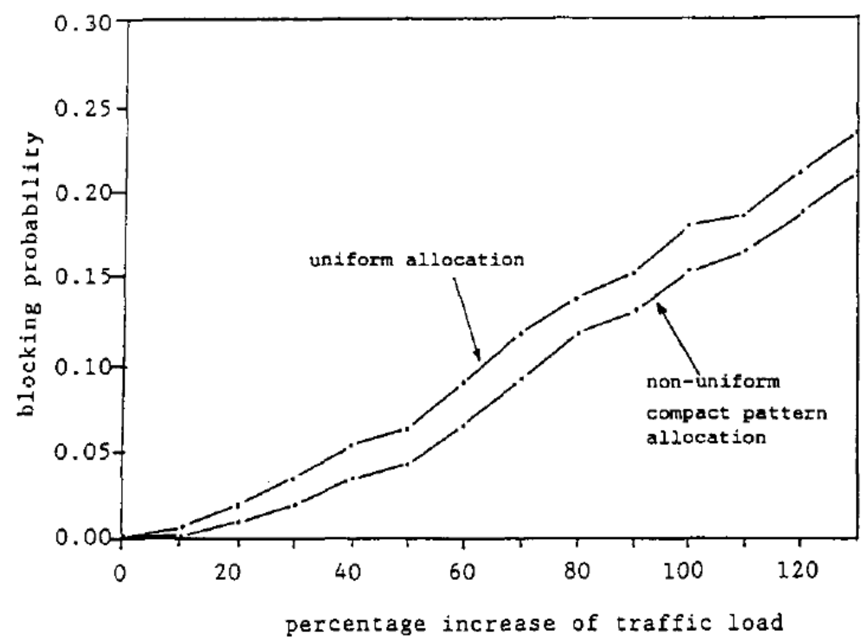
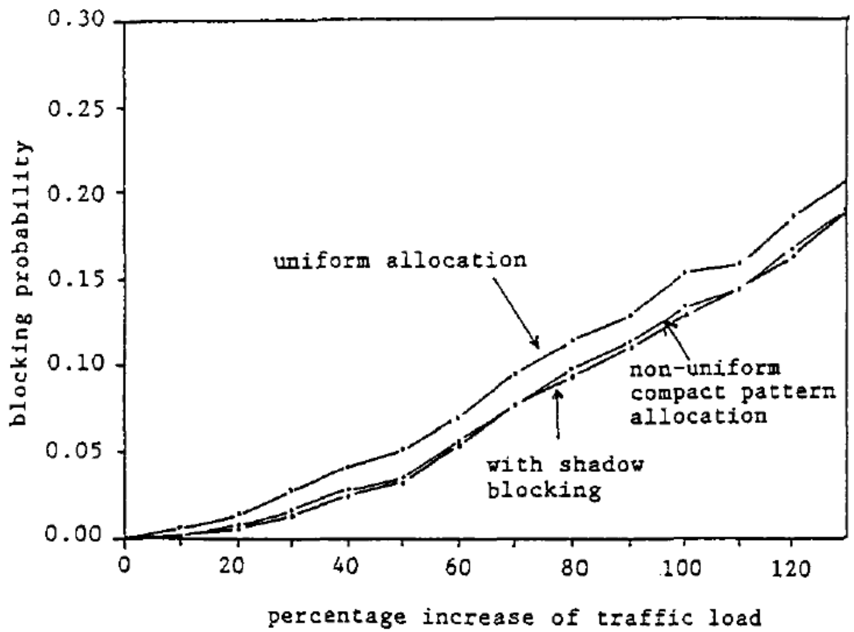


Fig. 7. BCO assignment with nonuniform compact pattern allocation and uniform channel allocation.

Non-uniform Compact Pattern Allocation (11/11)



'ig. 8. BDCL assignment with nonuniform compact pattern allocation and uniform channel allocation.

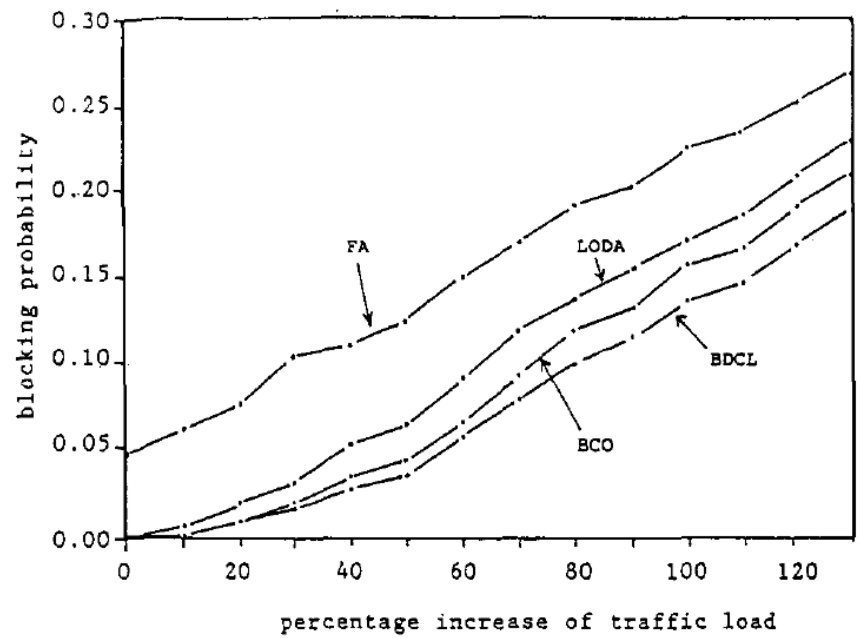


Fig. 9. Different channel assignment strategies with nonuniform compact pattern allocation.