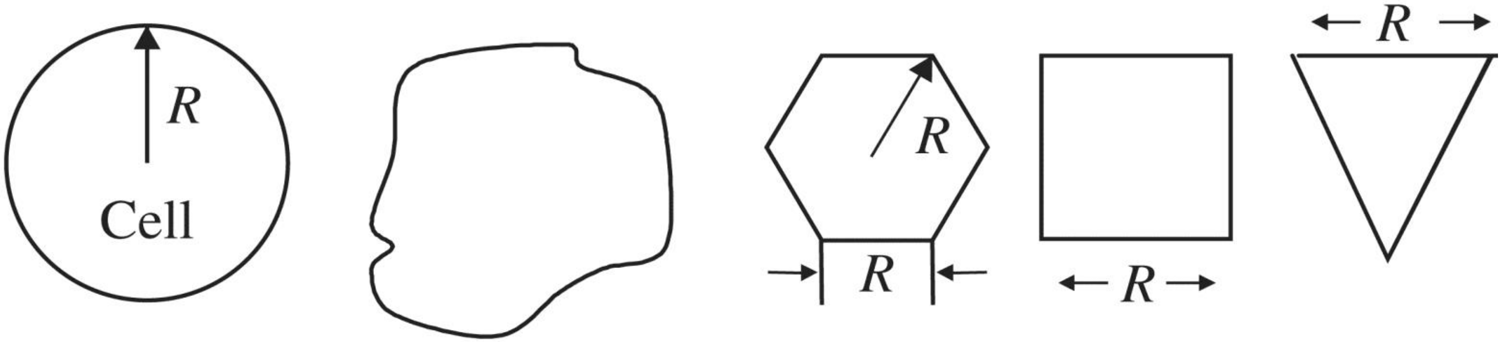
Cellular Concept

Cell Area (1/2)

- Cell: radio area covered by a transmitting station or a BS.
- Size & shape



(a) Ideal cell (b) Actual cell (c) Different cell models

Figure 5.1 Shape of the cell coverage area.

Cell Area (2/2)

Table 5.1: ▶ Impact of Cell Shape and Radius on Service Characteristics

Shape of the Cell	Area	Boundary	Boundary Length/ Unit Area	Channels/Unit Area with N Channels/Cells	Channels/Unit Area when Number of Channels Increased by a Factor K	Channels/Unit Area when Size of Cell Reduced by a Factor M
Square cell (side = R)	R^2	$4R$	$\frac{4}{R}$	$\frac{N}{R^2}$	$\frac{KN}{R^2}$	$\frac{M^2N}{R^2}$
Hexagonal cell (side = R)	$\frac{3\sqrt{3}}{2}R^2$	$6R$	$\frac{4}{\sqrt{3}R}$	$\frac{N}{1.5\sqrt{3}R^2}$	$\frac{KN}{1.5\sqrt{3}R^2}$	$\frac{M^2N}{1.5\sqrt{3}R^2}$
Circular cell (radius = R)	πR^2	$2\pi R$	$\frac{2}{R}$	$\frac{N}{\pi R^2}$	$\frac{KN}{\pi R^2}$	$\frac{M^2N}{\pi R^2}$
Triangular cell (side = R)	$\frac{\sqrt{3}}{4}\mathrm{R}^2$	$3R$	$\frac{4\sqrt{3}}{R}$	$\frac{4\sqrt{3}N}{3R^2}$	$\frac{4\sqrt{3}KN}{3R^2}$	$\frac{4\sqrt{3}M^2N}{3R^2}$

Signal Strength and Cell Parameters (1/5)

- Ideal & actual signal strength

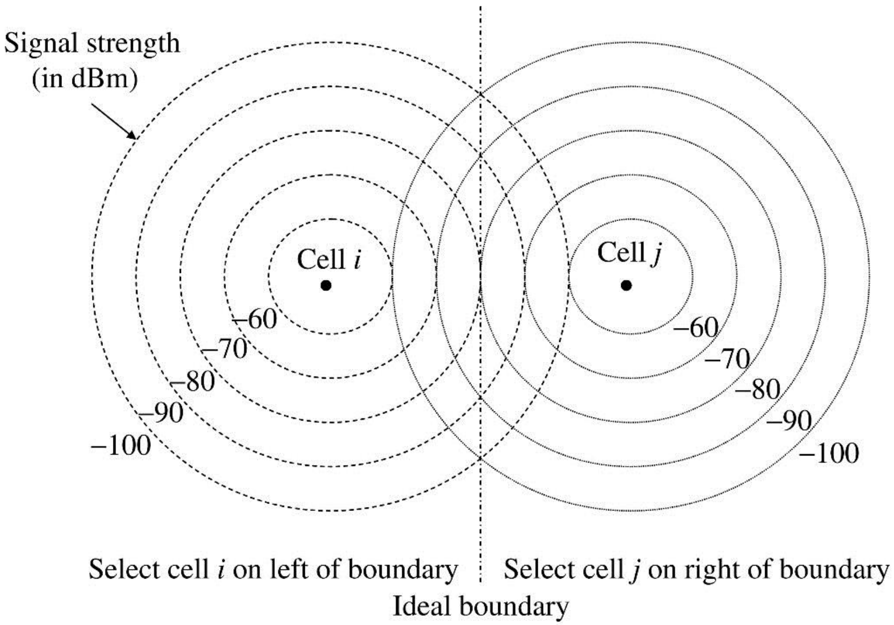


Figure 5.2 Signal strength contours around two adjacent cells *i* and *j*.

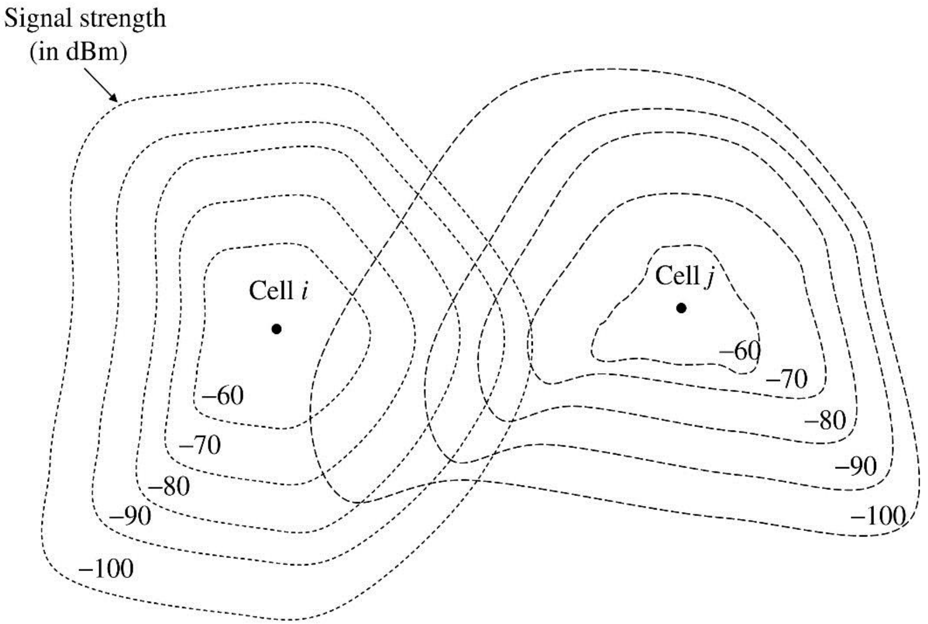


Figure 5.3 Received signal strength indicating actual cell tiling.

Signal Strength and Cell Parameters (2/5)

- Received power vs. distance

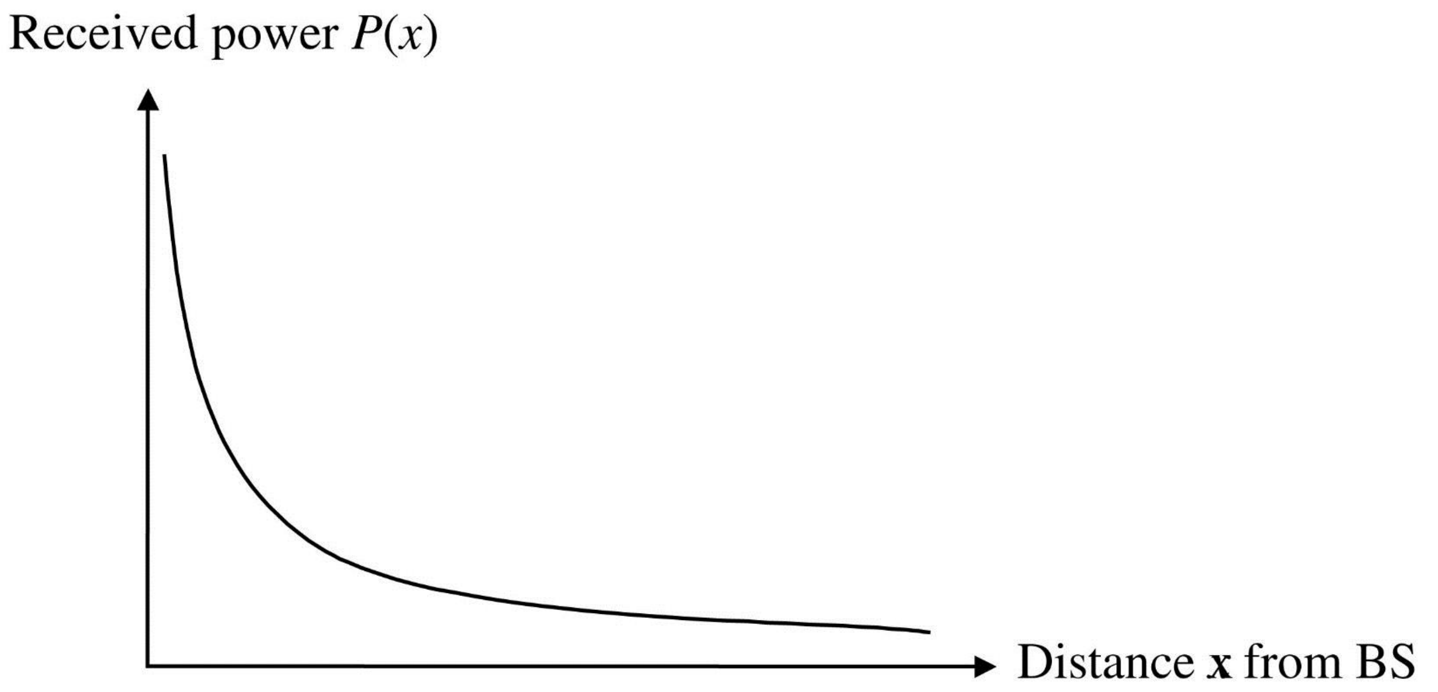


Figure 5.4 Variation of received power from a base station.

Signal Strength and Cell Parameters (3/5)

- Handoff (handover)
  - Handoff area: (X3-X4)
  - Ping-pong effect (Xth)

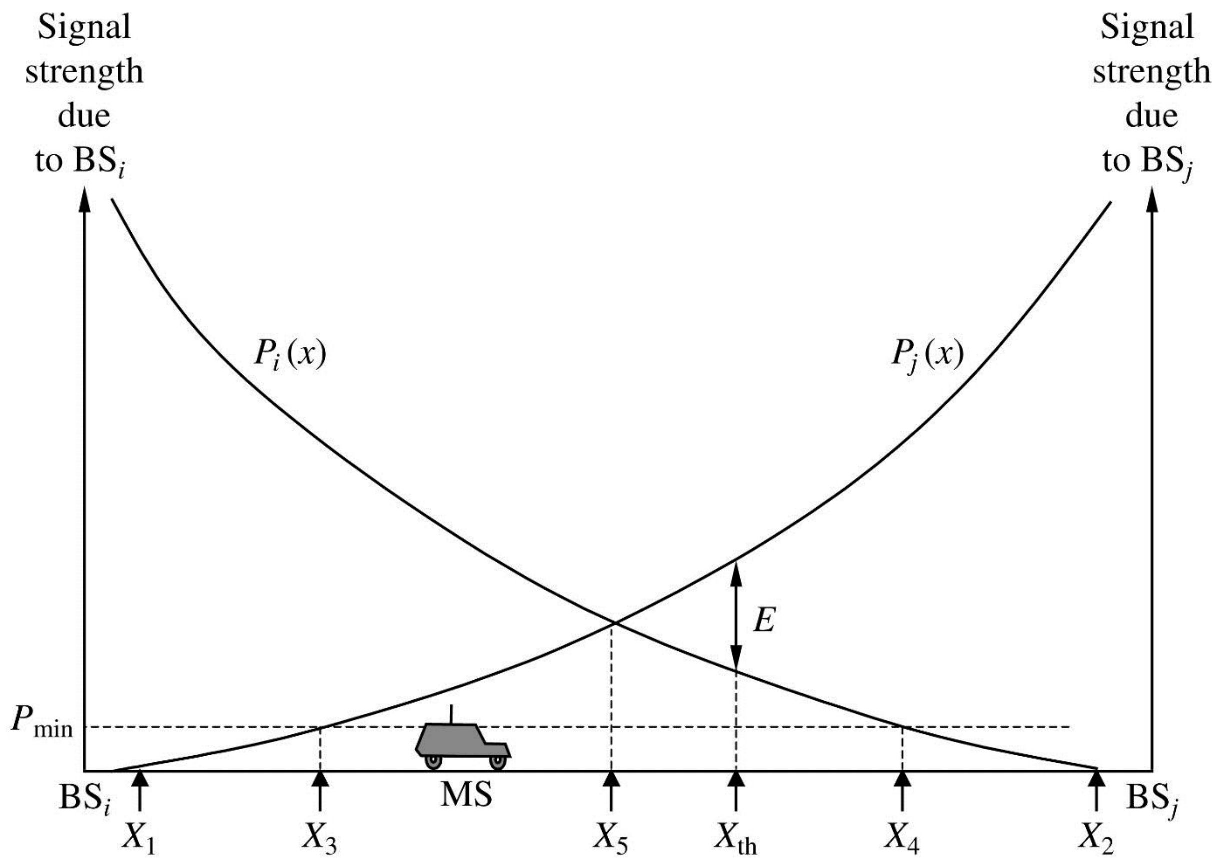


Figure 5.5 Handoff region.

Signal Strength and Cell Parameters (4/5)

- Minimization of handoff rate for a given θ

N_1: the number of MSs having handoff per unit length in horizontal direction

N_2: the number of MSs having handoff per unit length in vertical direction

λ_H: total handoff rate

Assume fixed area (i.e., A)

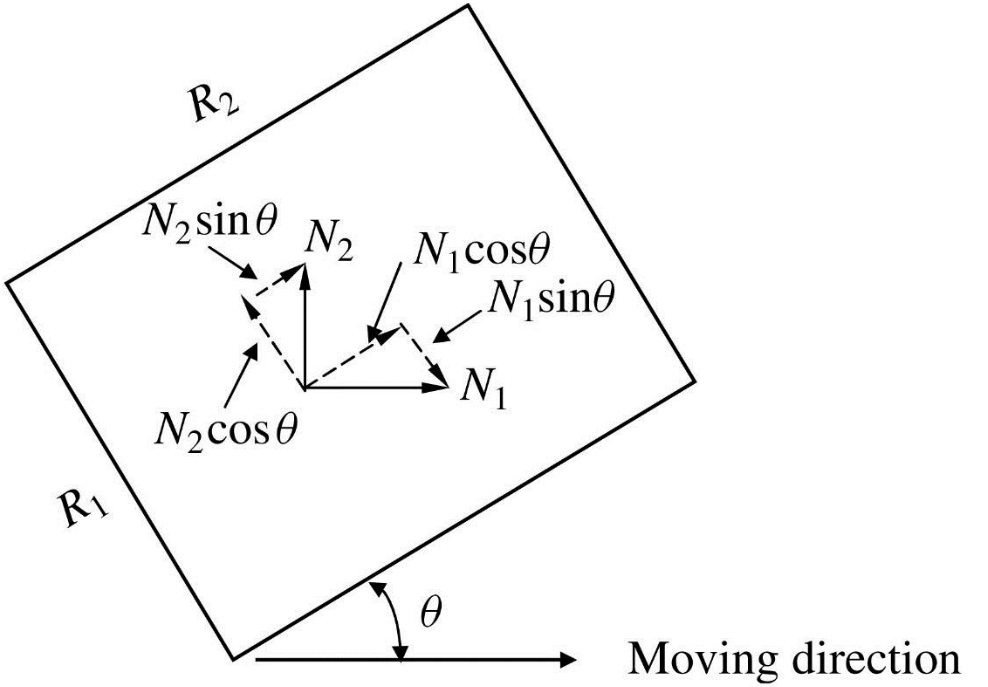


Figure 5.6 Handoff rate in a rectangular cell.

Signal Strength and Cell Parameters (5/5)

$$\lambda_H = R_1(N_1\cos\theta + N_2\sin\theta) + R_2(N_1\sin\theta + N_2\cos\theta)$$

$$A = R_1 R_2$$

$$\frac{\mathrm{d}\lambda_H}{\mathrm{d}R_1} = \frac{\mathrm{d}}{\mathrm{d}R_1}\left[R_1(N_1\cos\theta + N_2\sin\theta) + \frac{A}{R_1}(N_1\sin\theta + N_2\cos\theta)\right]$$

$$= N_1\cos\theta + N_2\sin\theta - \frac{A}{R_1^2}(N_1\sin\theta + N_2\cos\theta) = 0$$

$$R_1^2 = A\frac{N_1\sin\theta + N_2\cos\theta}{N_1\cos\theta + N_2\sin\theta}$$

$$R_2^2 = A\frac{N_1\cos\theta + N_2\sin\theta}{N_1\sin\theta + N_2\cos\theta}$$

$$\boxed{\begin{cases} \min\ \lambda_H = 2\sqrt{AN_1N_2} \\ \frac{R_2}{R_1} = \frac{N_1}{N_2} \end{cases}}$$

$$\lambda_H = 2\sqrt{A\left[N_1N_2 + (N_1^2 + N_2^2)\cos\theta\sin\theta\right]}$$

Cell Capacity (1/4)

- Traffic load representation (*a*)
  - Average number of MSs requesting the service (average call arrival rate λ)
  - Average time length MSs requiring the service (average holding time *T*)
  - $a = \lambda\, T$
- A serving channel kept busy for an hour is quantitatively defined as one Erlang.
- Queueing model: M/M/S/S
- Blocking probability: *P*(*S*)
- Efficiency=traffic nonblocked/capacity

$$P(i) = \frac{a^i}{i!}P(0) \quad P(S) = \frac{\frac{a^S}{S!}}{\sum_{i=0}^{S} \frac{a^i}{i!}}$$

$$a = \lambda/\mu$$

$$P(0) = [\sum_{i=0}^{S} \frac{a^i}{i!}]^{-1}$$

Cell Capacity (2/4)

- An example
  - 100 MSs
  - 30 request are generated during an hour
  - Average holding time T=360 secs
  - λ =30/3600secs
  - a=30/3600*360=3 Erlangs
  - S=2
  - Blocking probability B(2, 3)=0.529
  - Fraction of 0.529 calls are blocked, and need to be reinitiated
  - Efficiency=3*(1-0.529)/2=0.7065

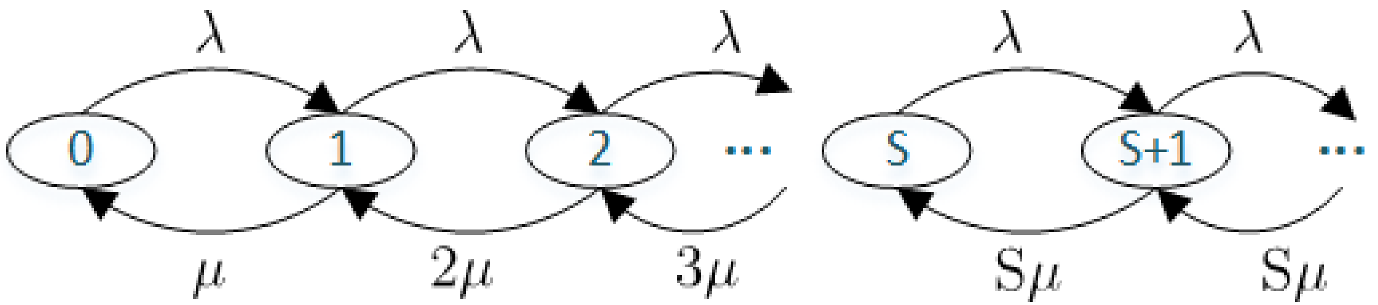
Cell Capacity (3/4)

- Queueing model: M/M/S
- Erlang C: the probability of an arriving call being delayed

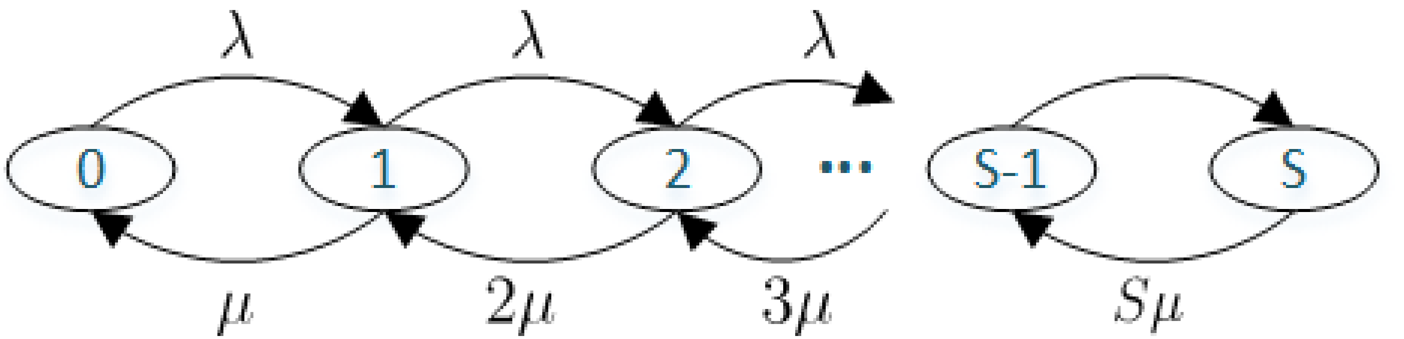
$$C(S,a) = \frac{SB(S,a)}{S-a[1-B(S,a)]}, a < S$$

Cell Capacity (4/4)

- M/M/S state transition diagram



- M/M/S/S state transition diagram



Frequency Reuse

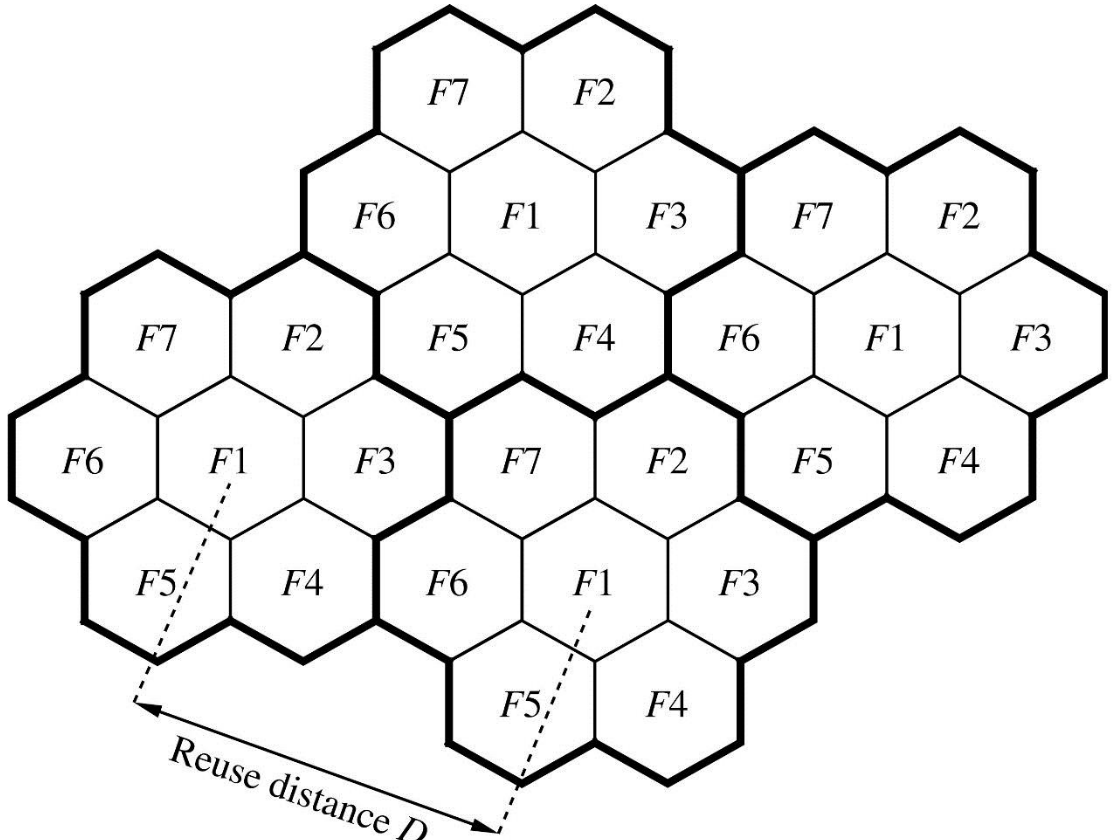
- Reuse distance

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

- Reuse factor

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

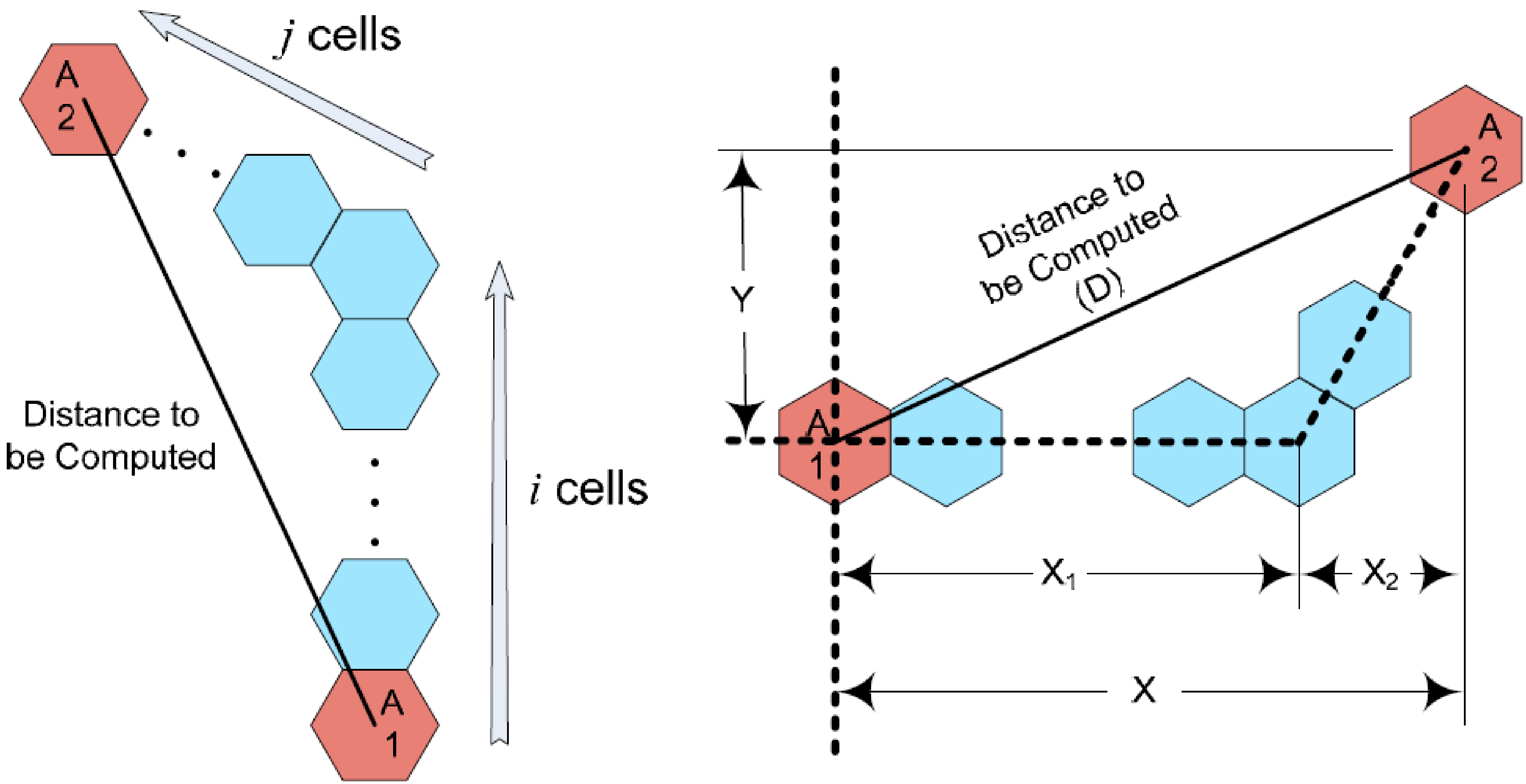
- Cells per cluster
  - 1, 3, **4**, **7**, 9, 12, 13..



Fx: A set of frequency bands

Figure 5.7 Illustration of frequency reuse.

Formula Derivation (1/2)



Formula Derivation (2/2)

[redacted]

$$X = X_1 + X_2 = R\sqrt{3}\left(i + \frac{j}{2}\right)$$

$$Y = 2j\left(\frac{\sqrt{3}R}{2}\right)\sin(60^o) = \frac{3jR}{2}$$

$$D = \sqrt{3R^2\left(i + \frac{j}{2}\right)^2 + \frac{9j^2R^2}{4}} = R\sqrt{3(i^2 + ij + j^2)}$$

$$\text{Let } N = i^2 + ij + j^2$$

[redacted]

Cluster Formation (1/5)

- $N = i^2 + ij + j^2$
  - i and j are integers
  - $i \geq j$
  - $j = 1$
- Coordinate plane: u-axis and v-axis
  - Intersection angle: 60^o
- $L = [(i+1)u + v] \mod N$

Cluster Formation (2/5)

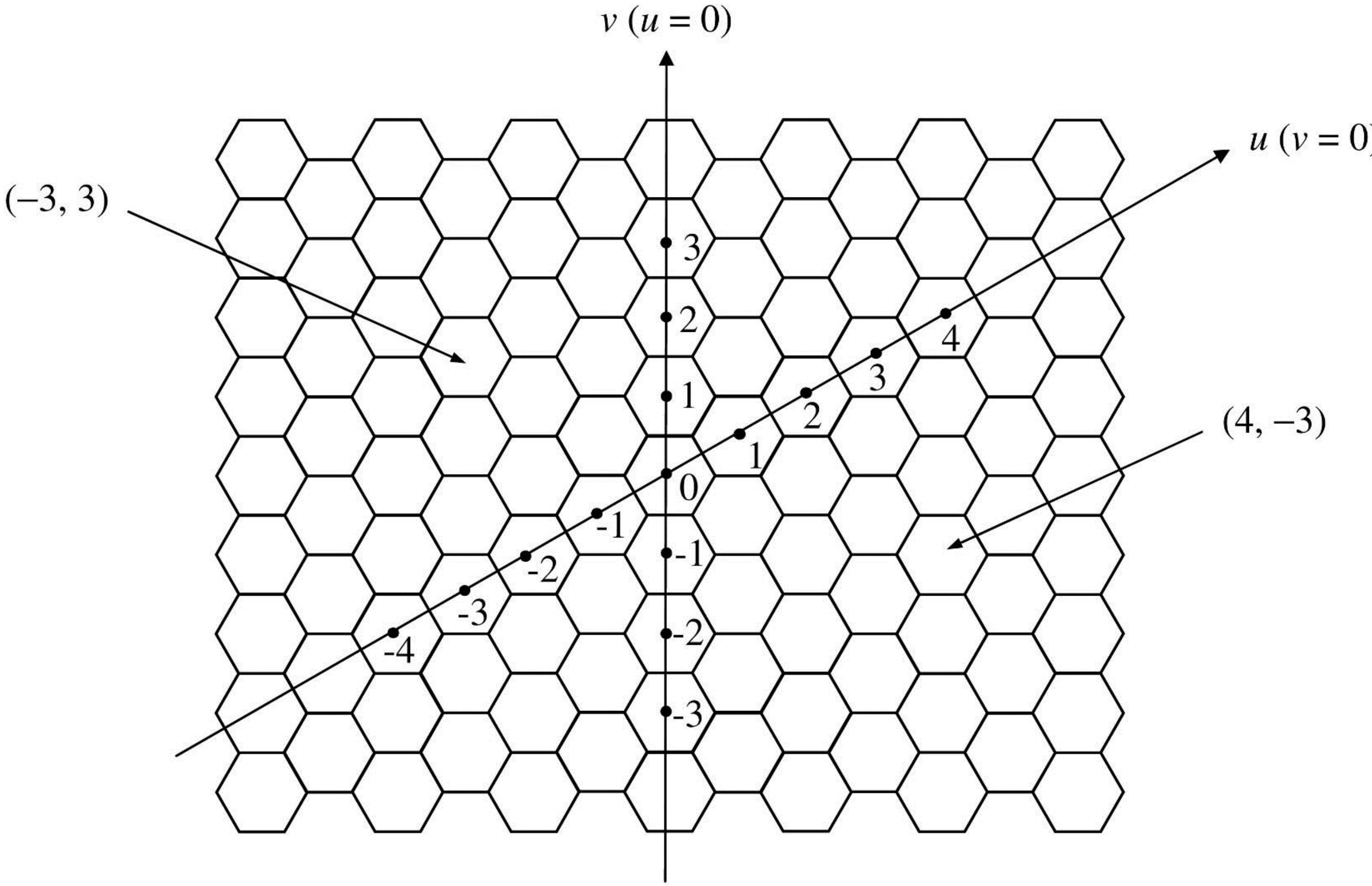


Figure 5.9 *u* and *v* coordinate plane.

Cluster Formation (3/5)

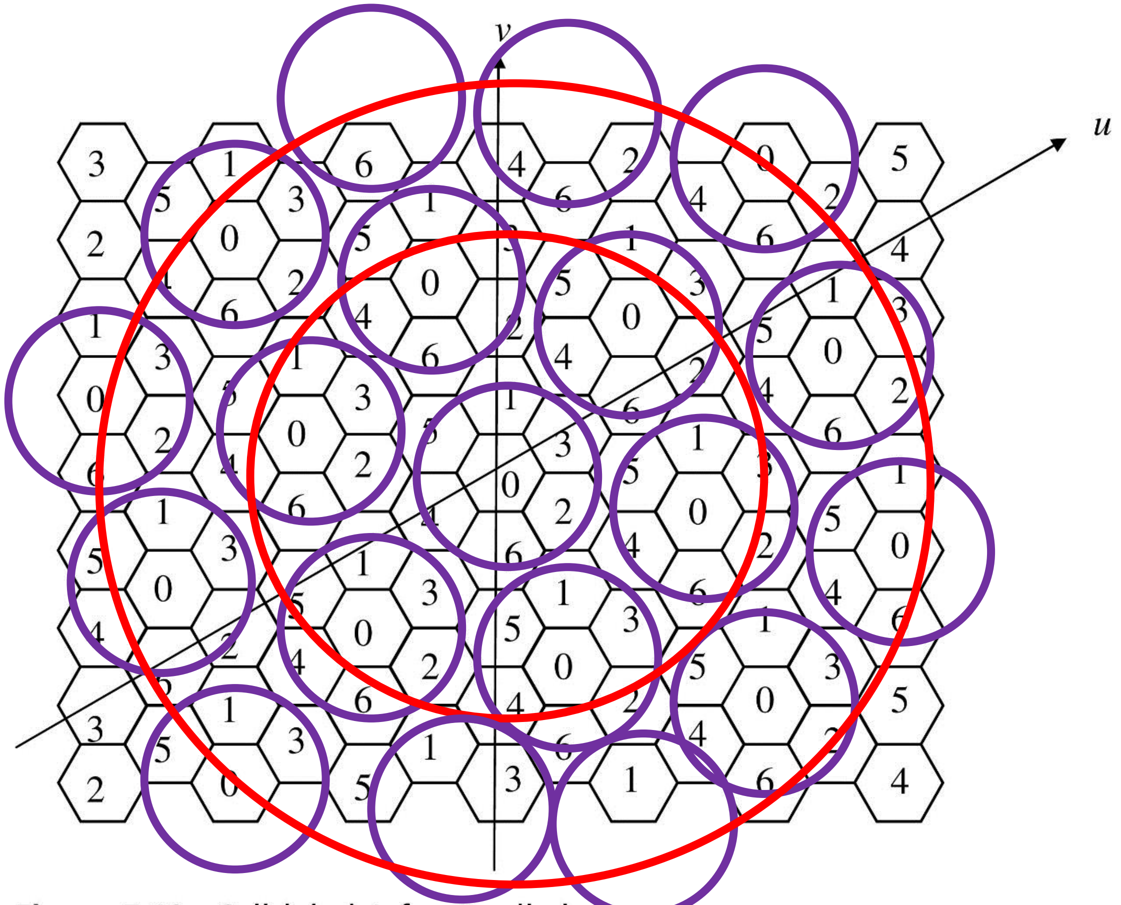


Figure 5.10 Cell label L for 7-cell cluster.

Cluster Formation (4/5)

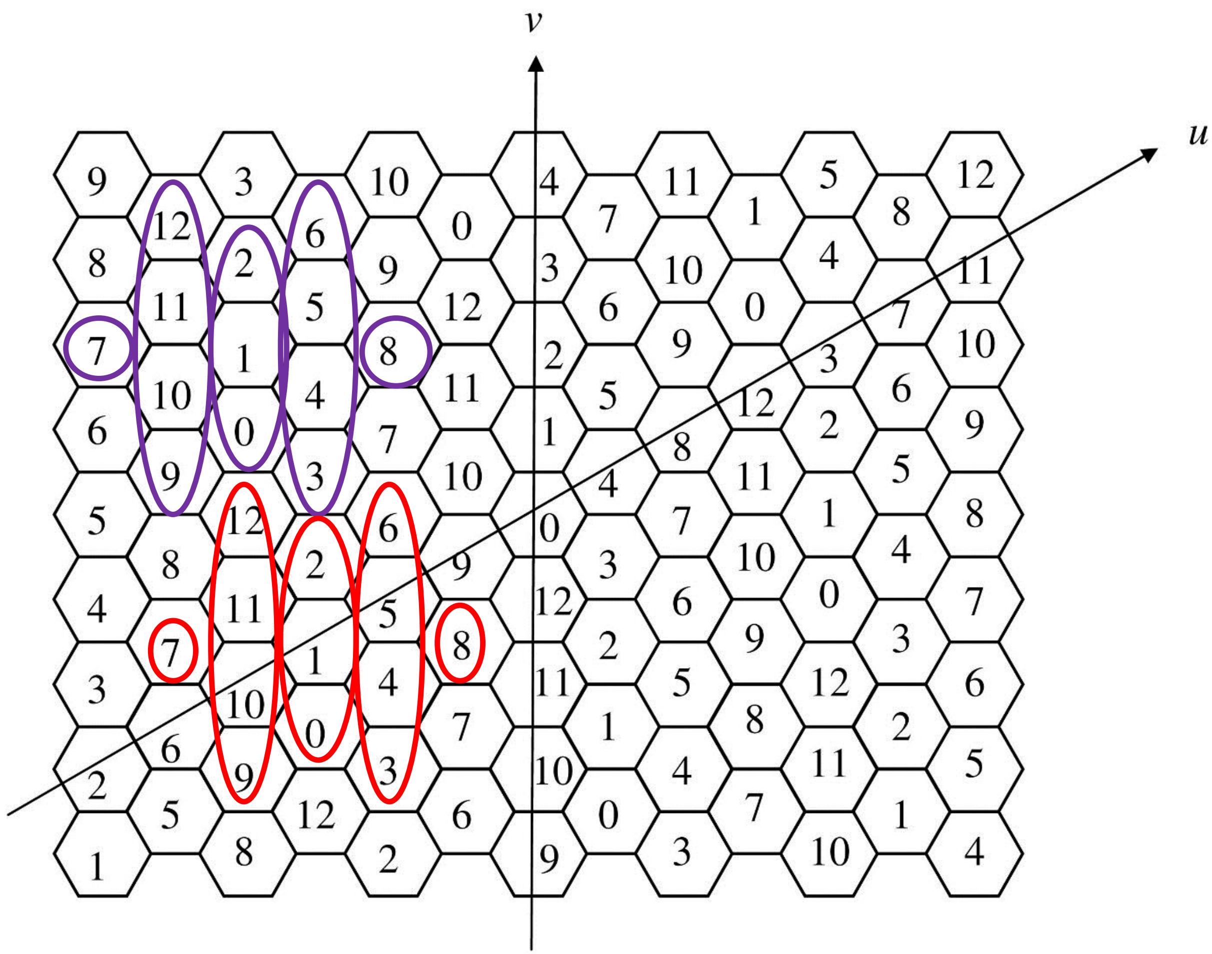


Figure 5.11 Cell label *L* for 13-cell cluster.

Cluster Formation (5/5)

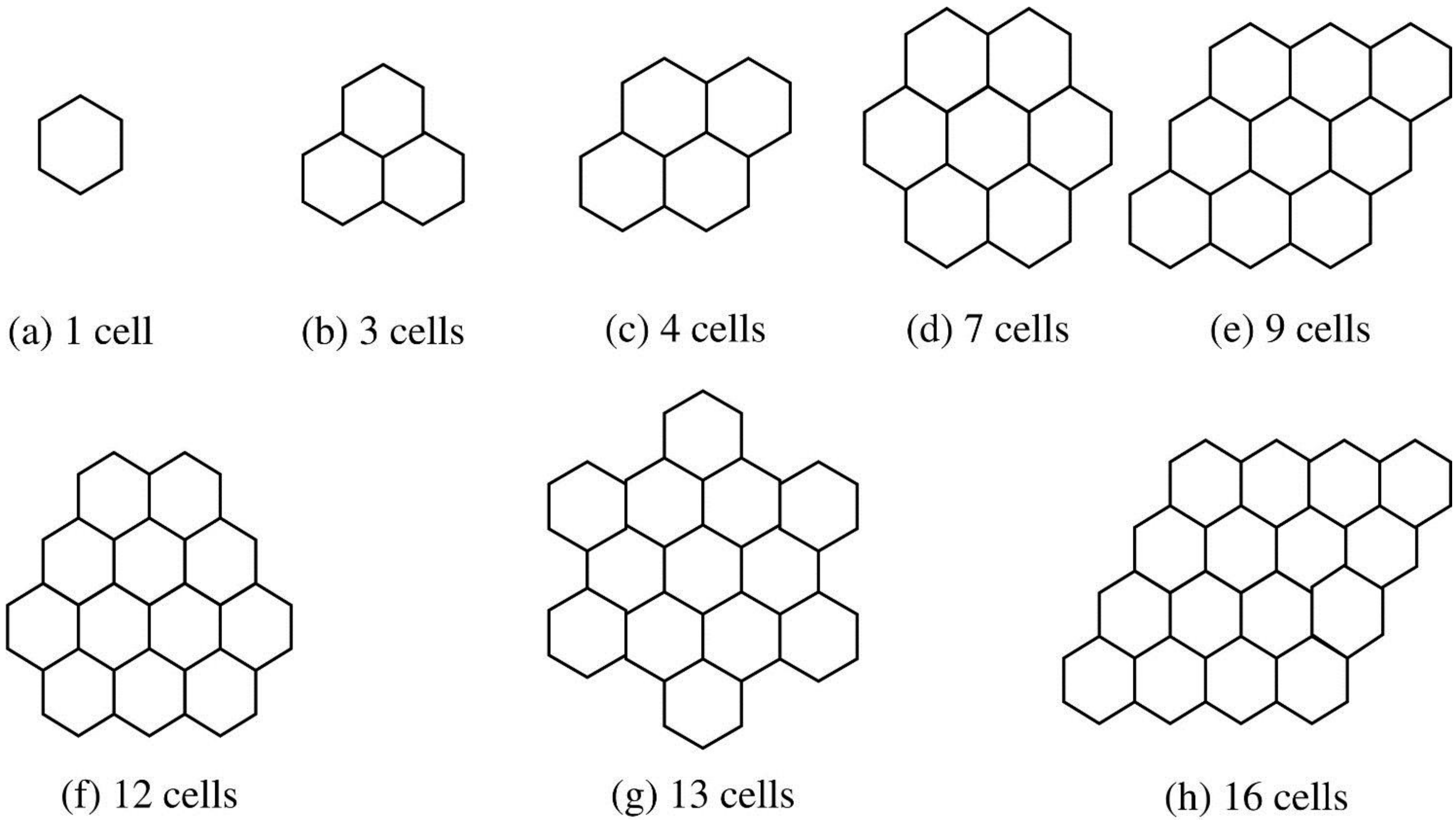


Figure 5.12 Common reuse pattern of hex cell clusters.

Co-Channel Interference (1/4)

- Using N=7 as an illustrative example, there are tier-1 co-channel interference, tier-2 co-channel interference, tier-3 co-channel interference, and so on
- Count tier-1 co-channel interference only

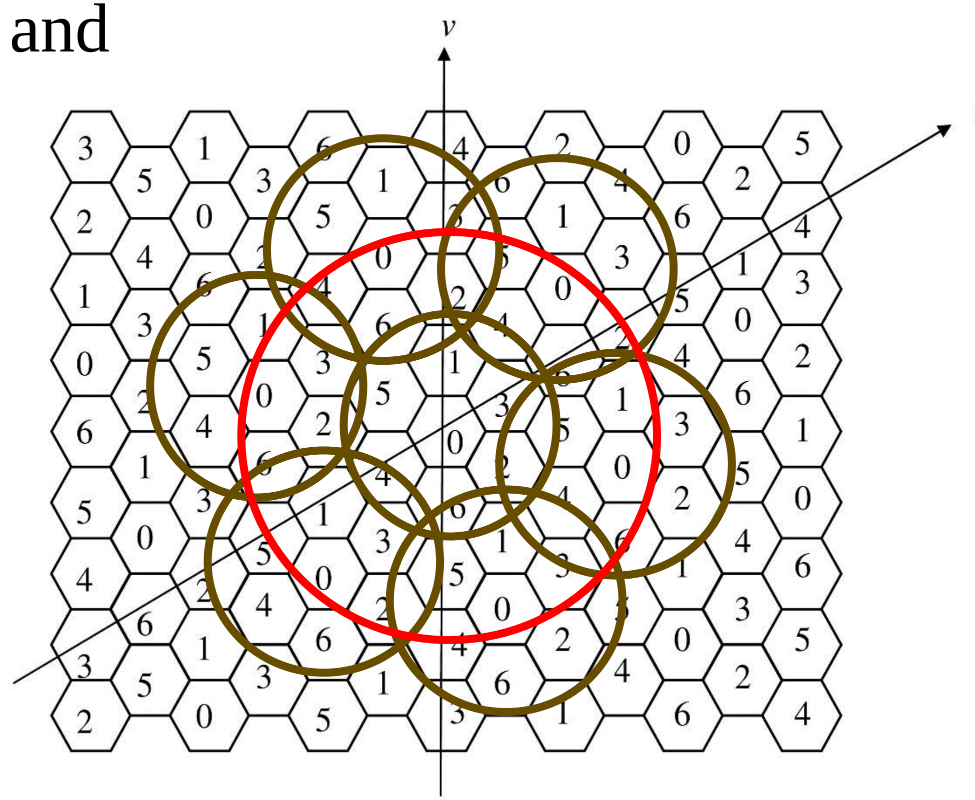


Figure 5.10 Cell label *L* for 7-cell cluster.

Co-Channel Interference (2/4)

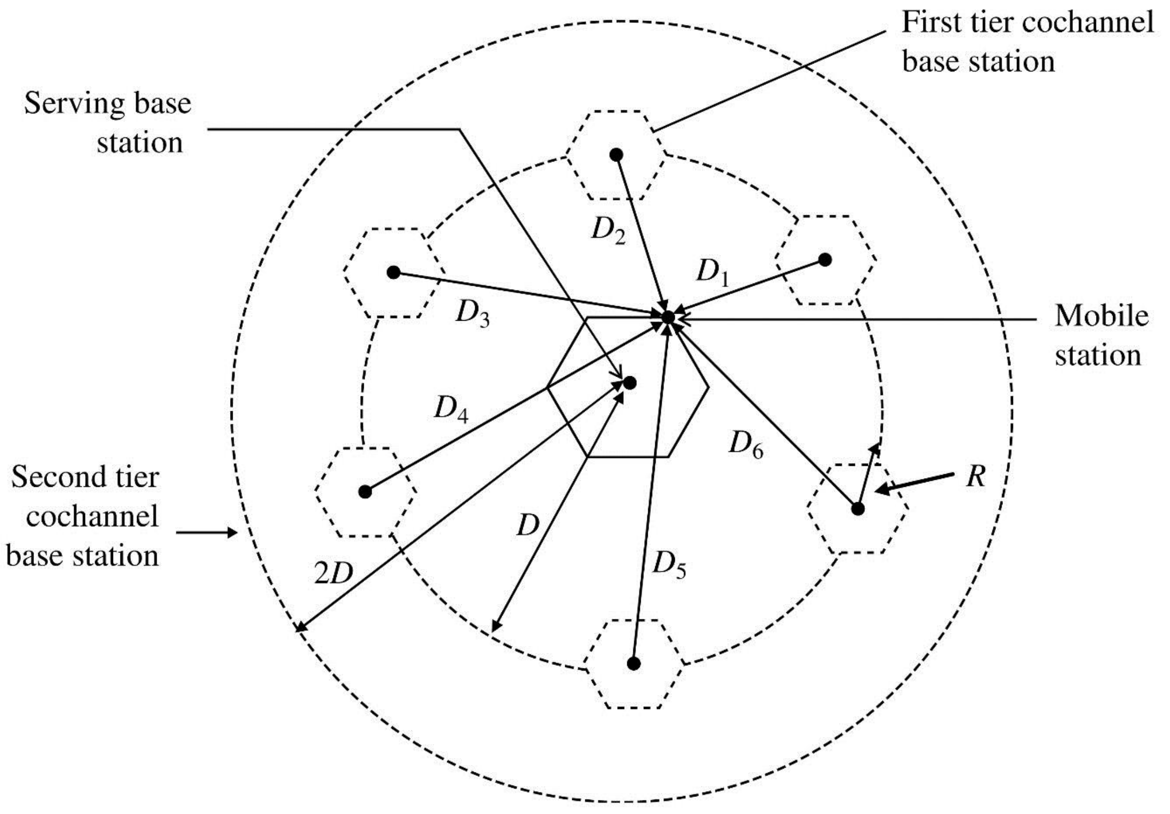


Figure 5.13 Cells with cochannels and their forward channel interference on transmitted signal.

Co-Channel Interference (3/4)

- Cochannel interference ratio (CCIR)
  - $\text{Carrirer/Interference} = \frac{C}{I} = \frac{C}{\sum_{k=1}^{M} I_k}$
    - I_k : cochannel interference from BS k
    - M : maximum number of cochannel interference cells
    - For $N = 7$,

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

γ is the propagation path loss slope and varies between 2 and 5

Co-Channel Interference (4/4)

- $D_1 = D_2 = D - R$
- $D_3 = D_6 = D$
- $D_4 = D_5 = D + R$

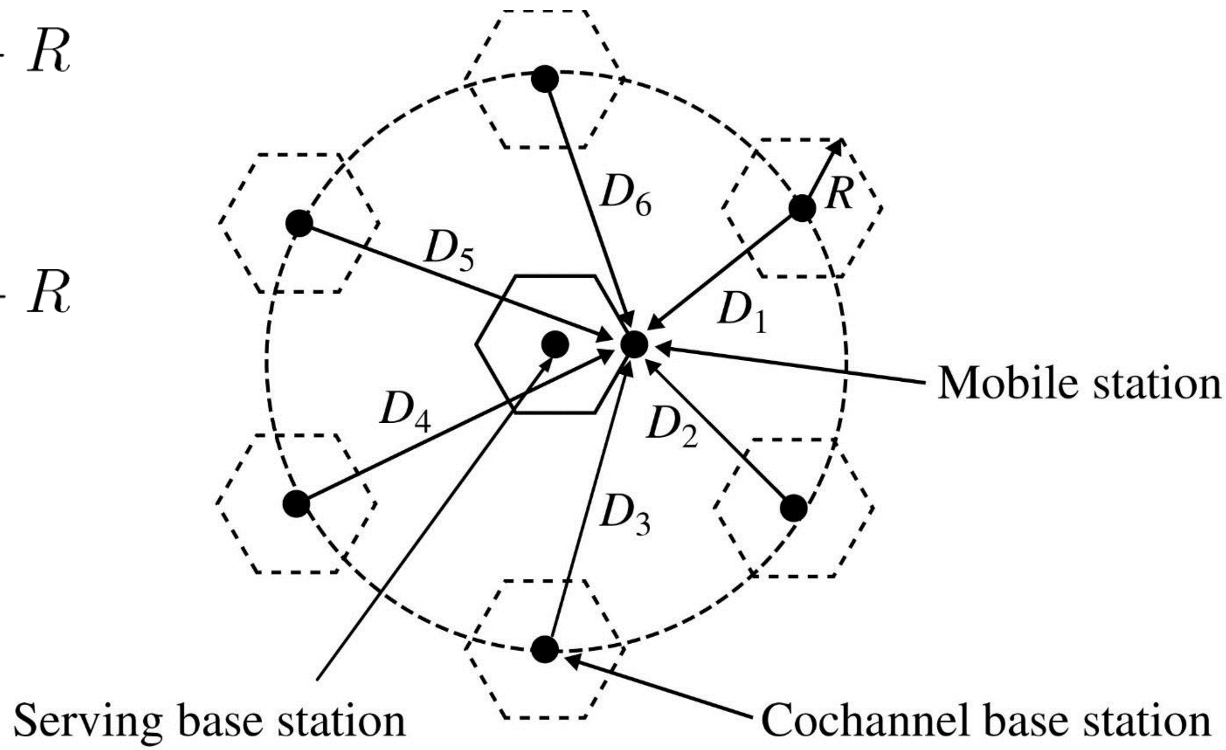


Figure 5.14 The worst case for forward channel interference (omnidirectional antenna).

Cell Splitting

- One technique to reduce interference
- Varying power levels

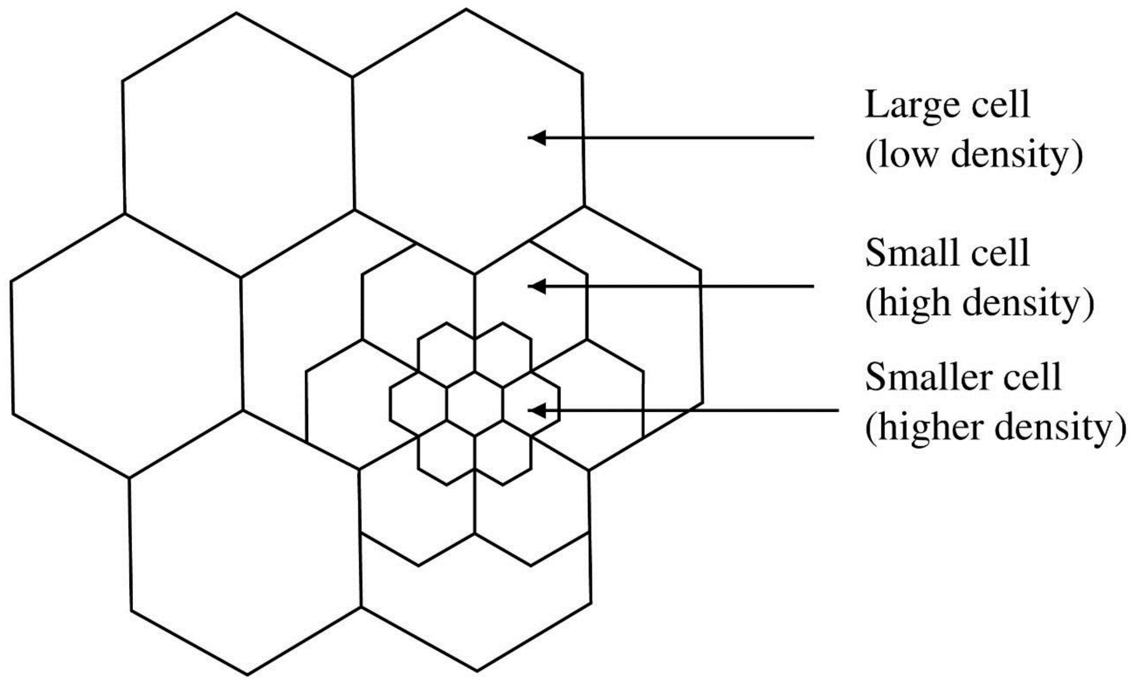
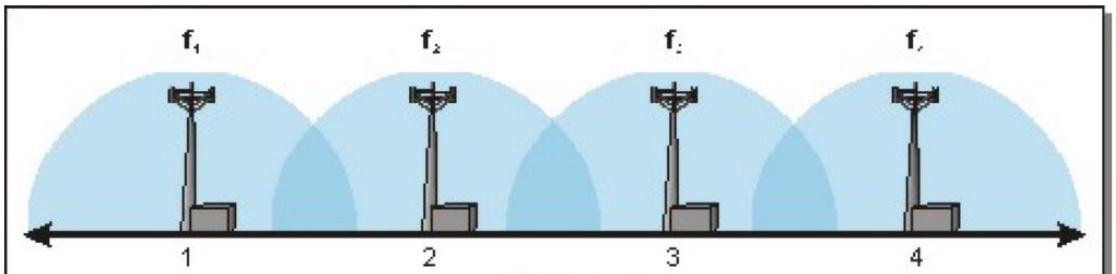


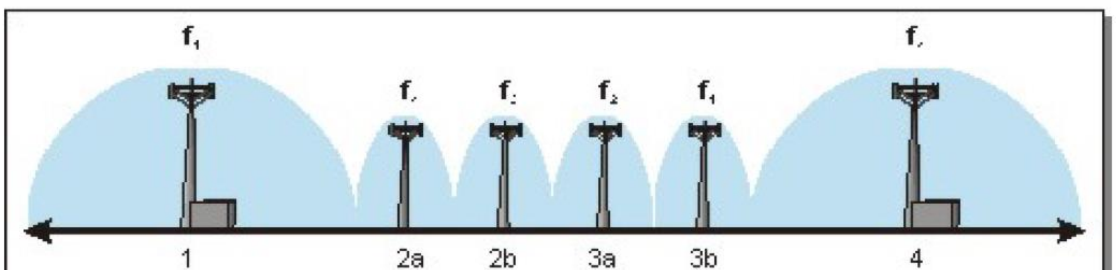
Figure 5.15 Illustration of cell splitting.

Cell Splitting Operation

- The radio coverage area of large cells sites are split by adjusting the power level and/or using reduced antenna height to cover a reduced area



A) Original



B) New

Cell Sectoring (1/3)

- Another technique to reduce interference
- Omnidirectional antenna vs. directional antenna
- Sectored cell

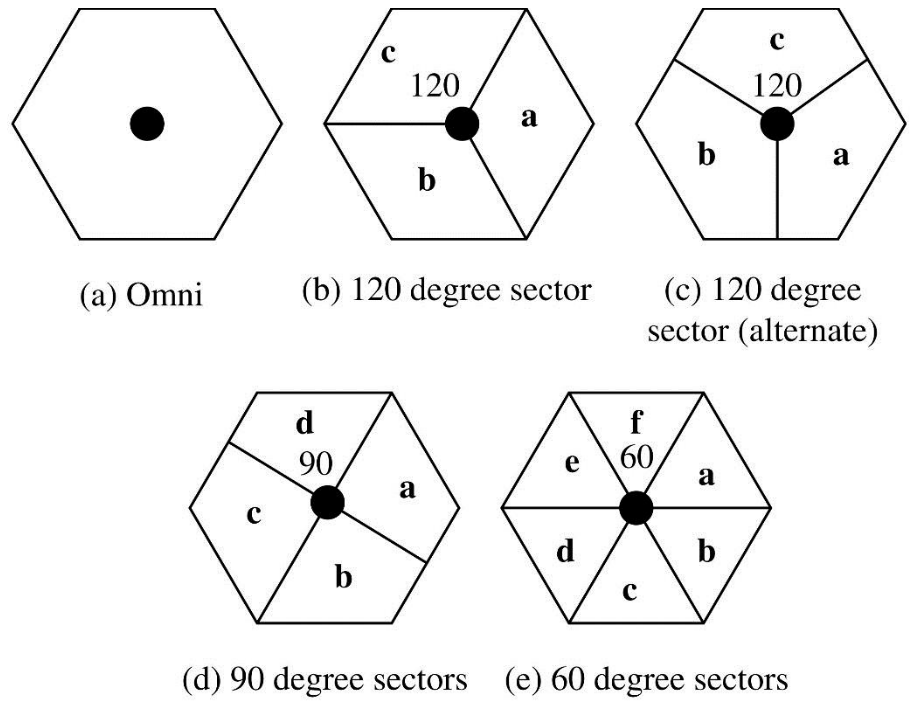


Figure 5.16 Sectoring of cells with directional antennas.

Cell Sectoring (2/3)

- Cochannel interference of cell sectoring

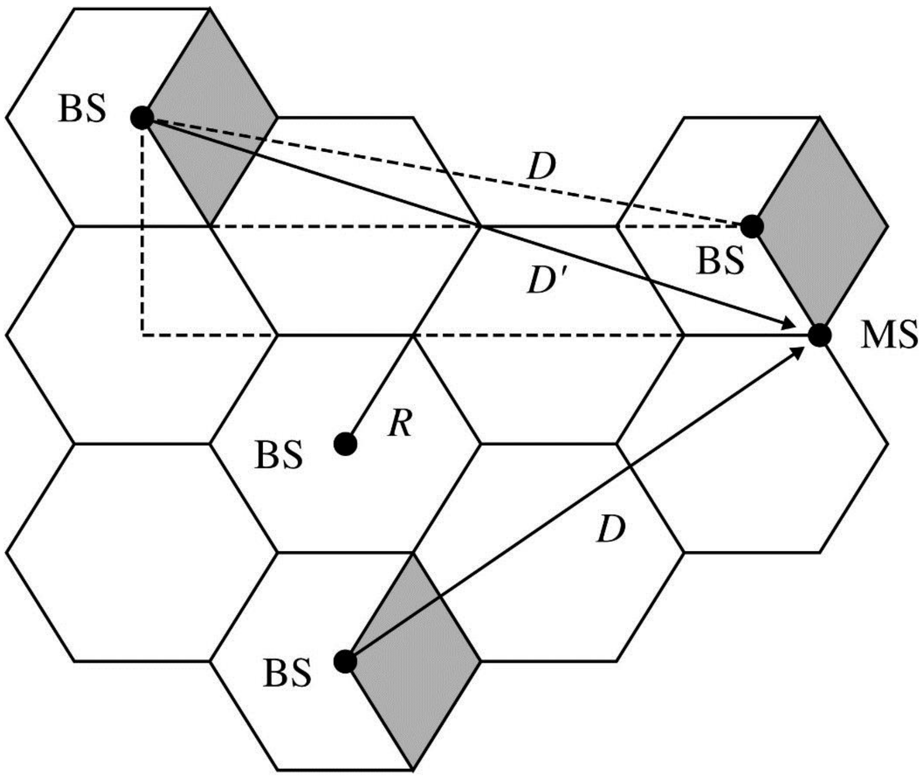


Figure 5.17 The worst case for forward channel interference in three sectors (directional antenna).

Cell Sectoring (3/3)

$$D = \sqrt{(\frac{9R}{2})^2 + (\frac{\sqrt{3}R}{2})^2} = \sqrt{21}R = 4.58R$$

$$D' = \sqrt{(5R)^2 + (\sqrt{3}R)^2} = \sqrt{28}R = 5.29R$$

$$\frac{C}{I} = \frac{1}{(4.58)^{\gamma} + (5.29)^{\gamma}}$$