4th Edition

Introduction to Wireless & Mobile Systems

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Qing-An Zeng

International Edition

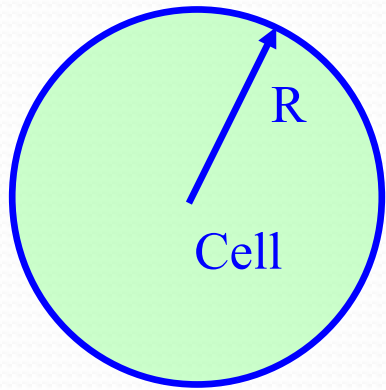NOT FOR SALE IN USA, CANADA, OR AUSTRALIA

Chapter 5

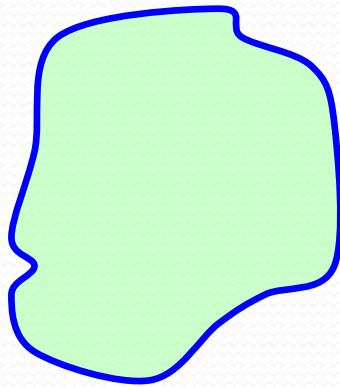# The Cellular Concept

CENGAGE Learning®

Outline

- Cell Area
  - ➢ Actual cell/Ideal cell
- Signal Strength
- Handoff Region
- Capacity of a Cell
  - ➢ Traffic theory
  - ➢ Erlang B and Erlang C
- Frequency Reuse
- How to form a Cluster
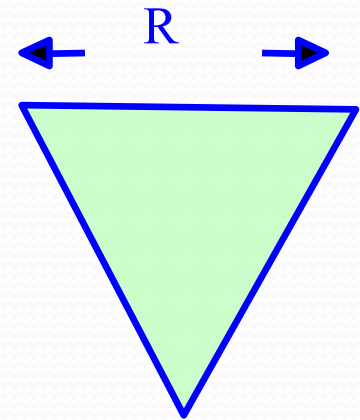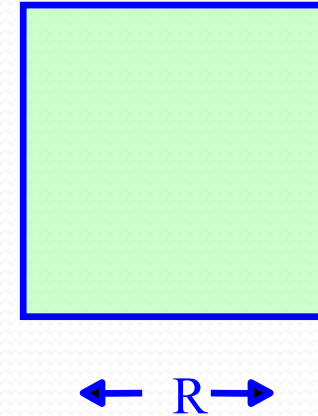- Co-channel Interference
- Cell Splitting
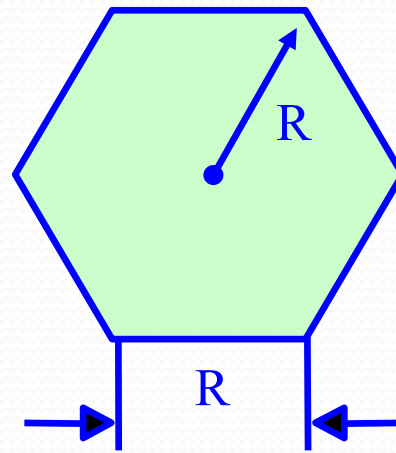- Cell Sectoring
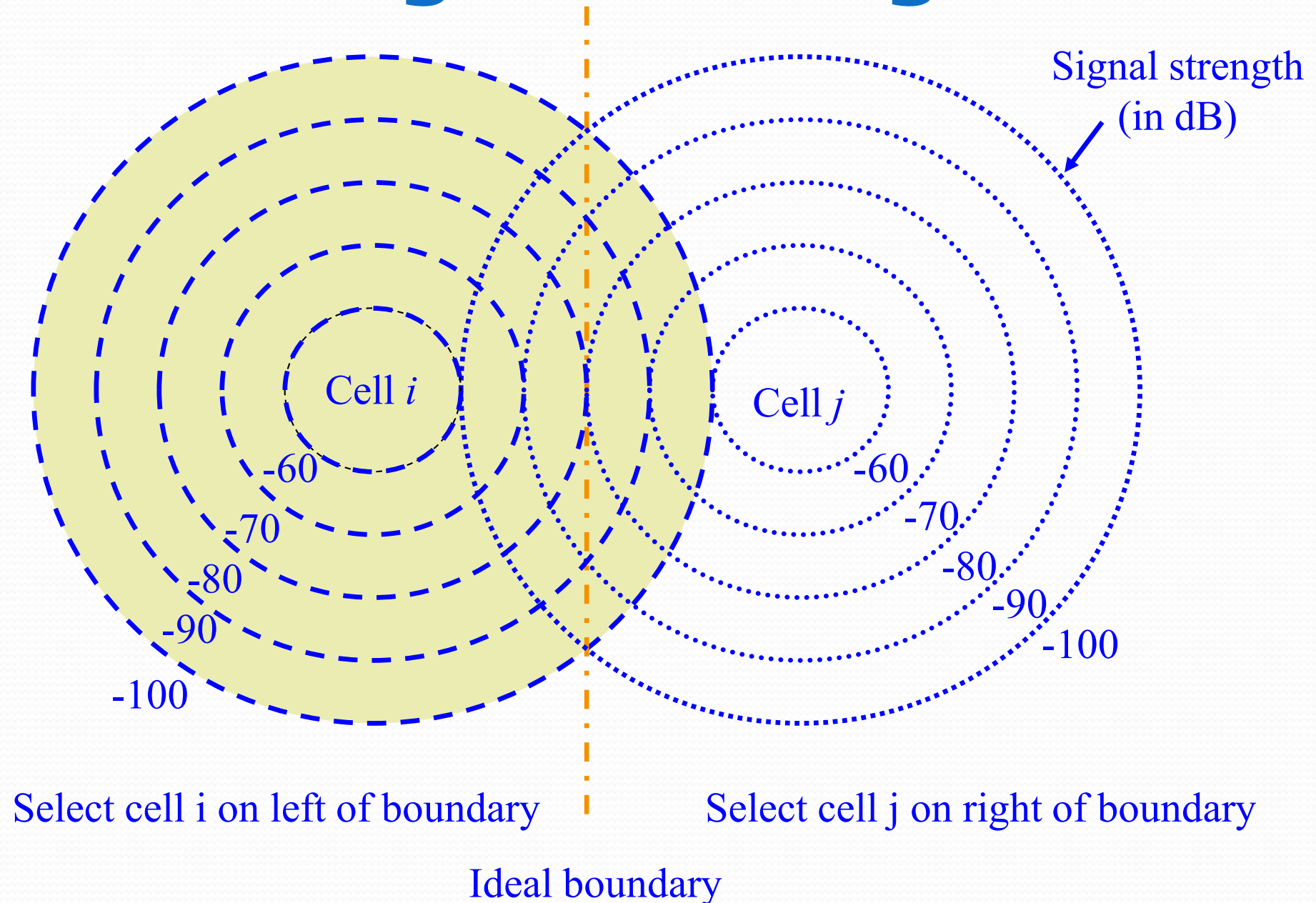
Cell Shape
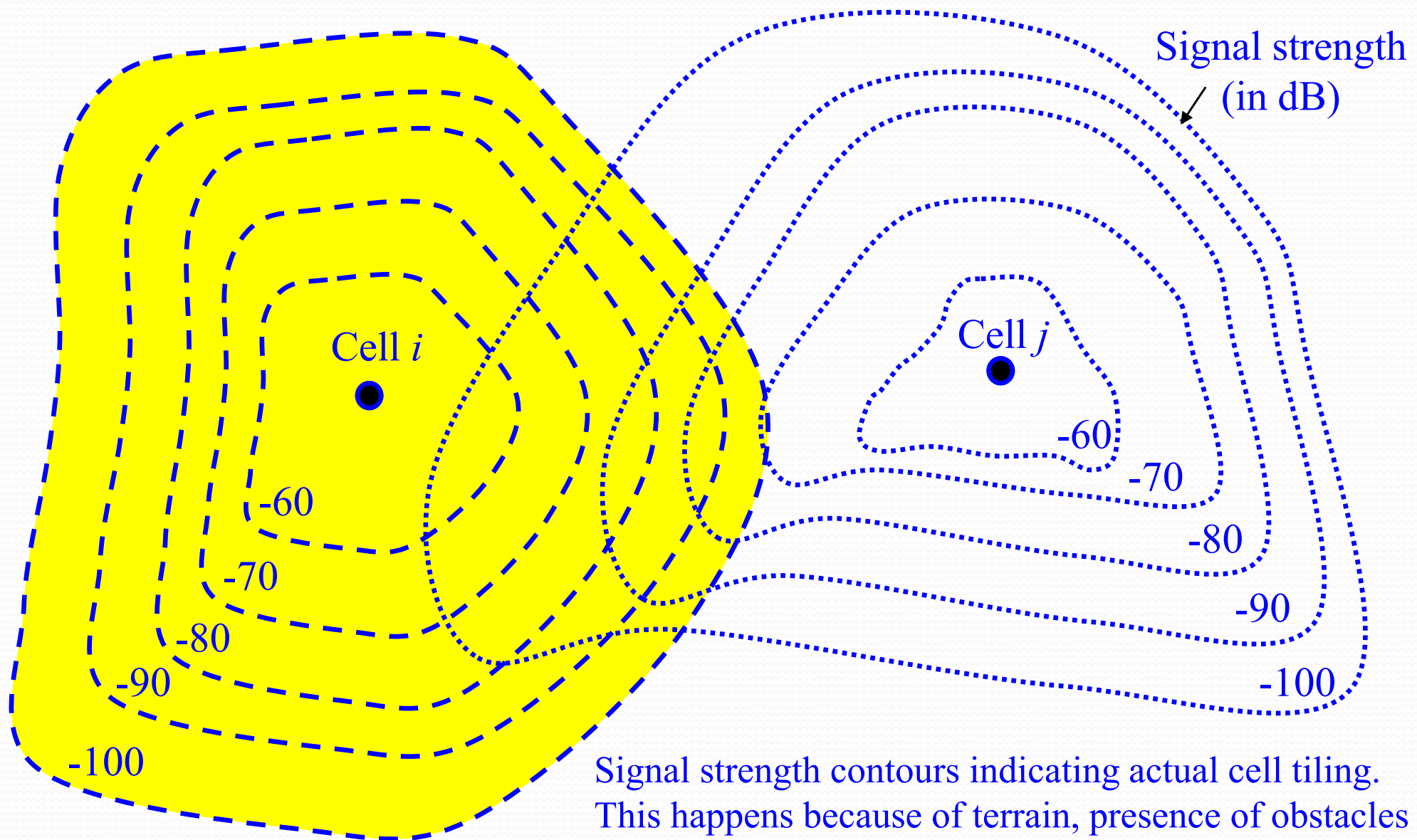
(a) Ideal cell

(b) Actual cell

(c) Different cell models

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/ Cell	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	$4R$	$\dfrac{4}{R}$	$\dfrac{N}{R^2}$	$\dfrac{KN}{R^2}$	$\dfrac{M^2N}{R^2}$
Hexagonal cell (side=R)	$\dfrac{3\sqrt{3}}{2}R^2$	$6R$	$\dfrac{4}{\sqrt{3}R}$	$\dfrac{N}{1.5\sqrt{3}R^2}$	$\dfrac{KN}{1.5\sqrt{3}R^2}$	$\dfrac{M^2N}{1.5\sqrt{3}R^2}$
Circular cell (radius=R)	πR^2	$2\pi R$	$\dfrac{2}{R}$	$\dfrac{N}{\pi R^2}$	$\dfrac{KN}{\pi R^2}$	$\dfrac{M^2N}{\pi R^2}$
Triangular cell (side=R)	$\dfrac{\sqrt{3}}{4}R^2$	$3R$	$\dfrac{4\sqrt{3}}{R}$	$\dfrac{4\sqrt{3}N}{3R^2}$	$\dfrac{4\sqrt{3}KN}{3R^2}$	$\dfrac{4\sqrt{3}M^2N}{3R^2}$

Signal Strength

Signal strength (in dB)

Cell i

Cell j

-60

-70

-80

-90

-100

-60

-70

-80

-90

-100

Select cell i on left of boundary   Select cell j on right of boundary

Ideal boundary

Actual Signal Strength

Signal strength (in dB)

Cell i

Cell j

-60

-70

-80

-60

-70

-80

-90

-90

-100

-100
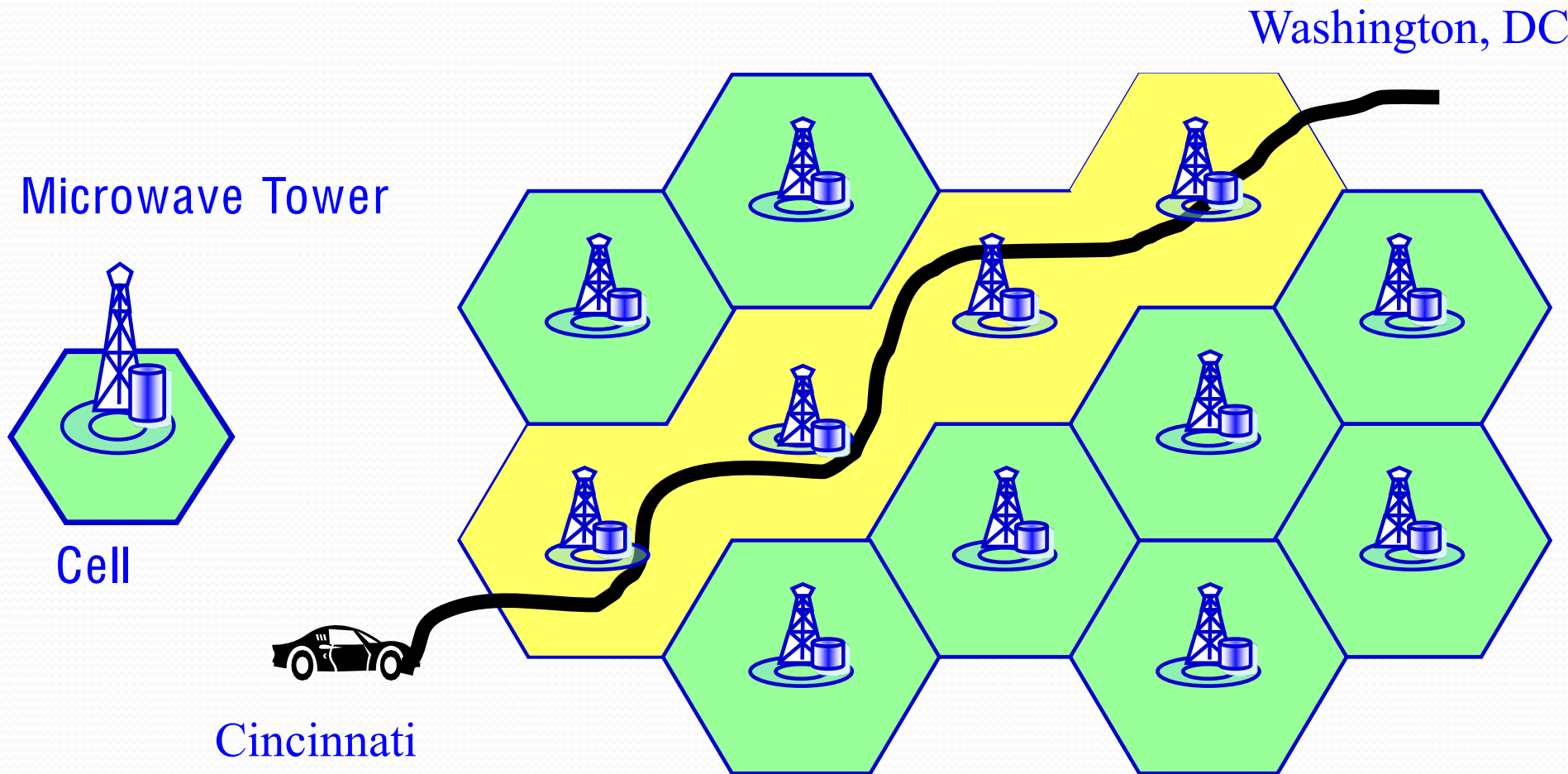
Signal strength contours indicating actual cell tiling. This happens because of terrain, presence of obstacles and signal attenuation in the atmosphere.
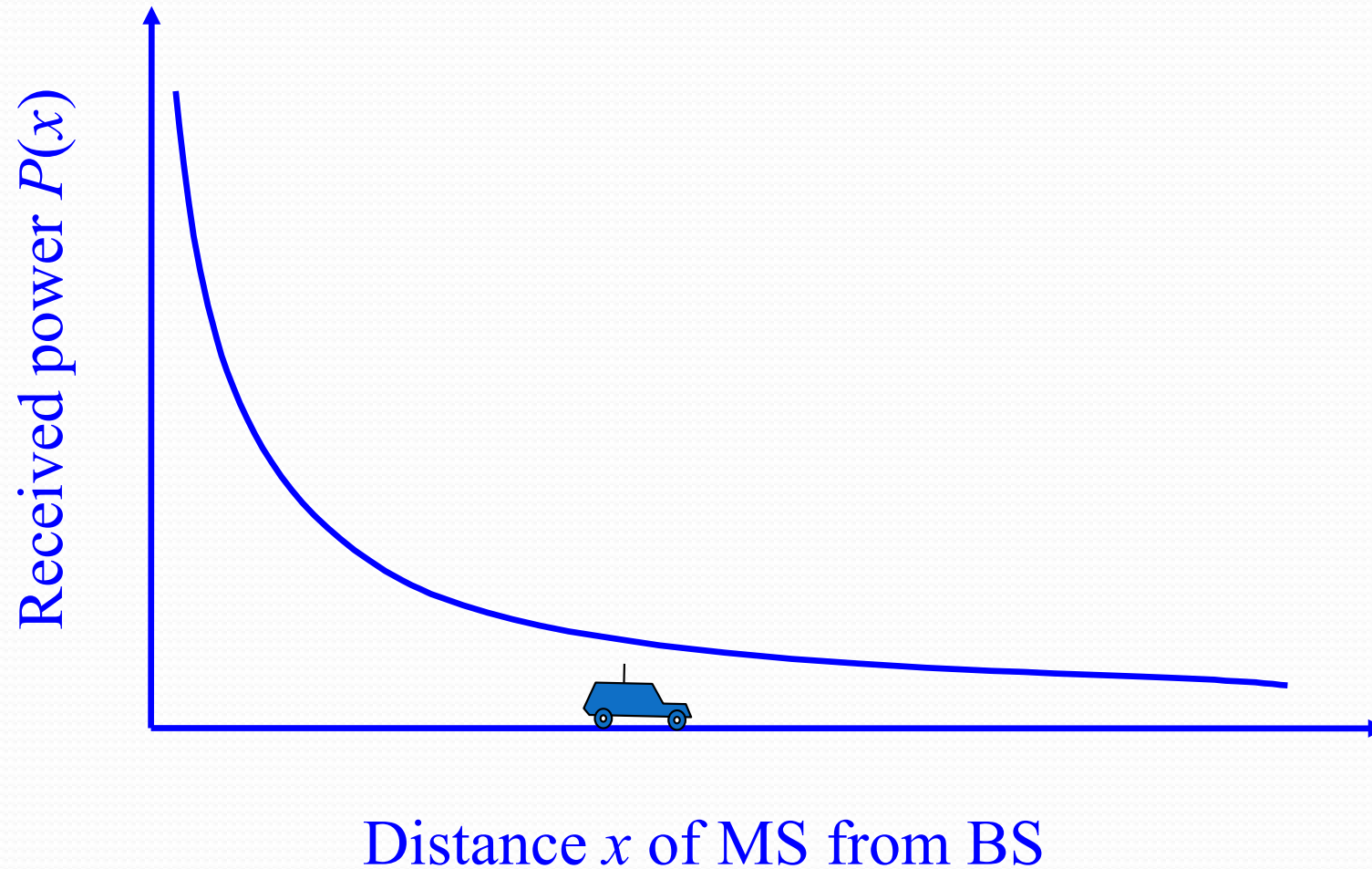
Universal Cell Phone Coverage

Washington, DC

Microwave Tower

Cell

Cincinnati

Maintaining the telephone number across geographical areas in a wireless and mobile system

Variation of Received Power

Received power $P(x)$

Distance x of MS from BS

8

Handoff Region

交接

Signal strength
due to BS$_i$

Signal strength
due to BS$_j$

交接：(I) P$_{min}$ (II) Max-signal first (III) threshold 臨界值

(IV) (V) ⇒ project

P$_i$(X)

P$_j$(X)

E

P$_{min}$

BS$_i$
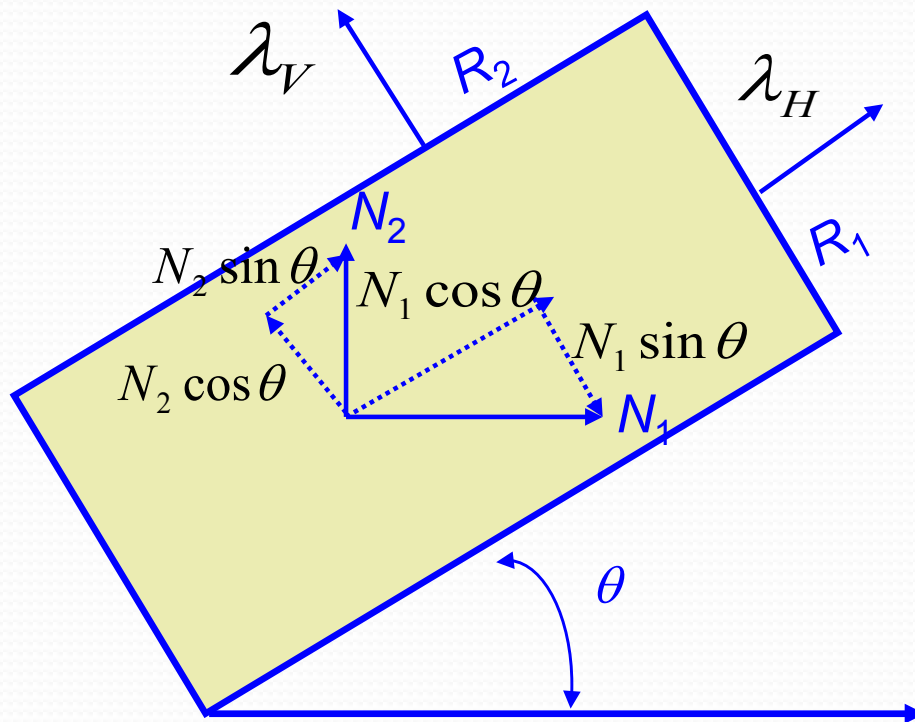
MS

BS$_j$

X$_1$ X$_3$ X$_5$ X$_{th}$ X$_4$ X$_2$
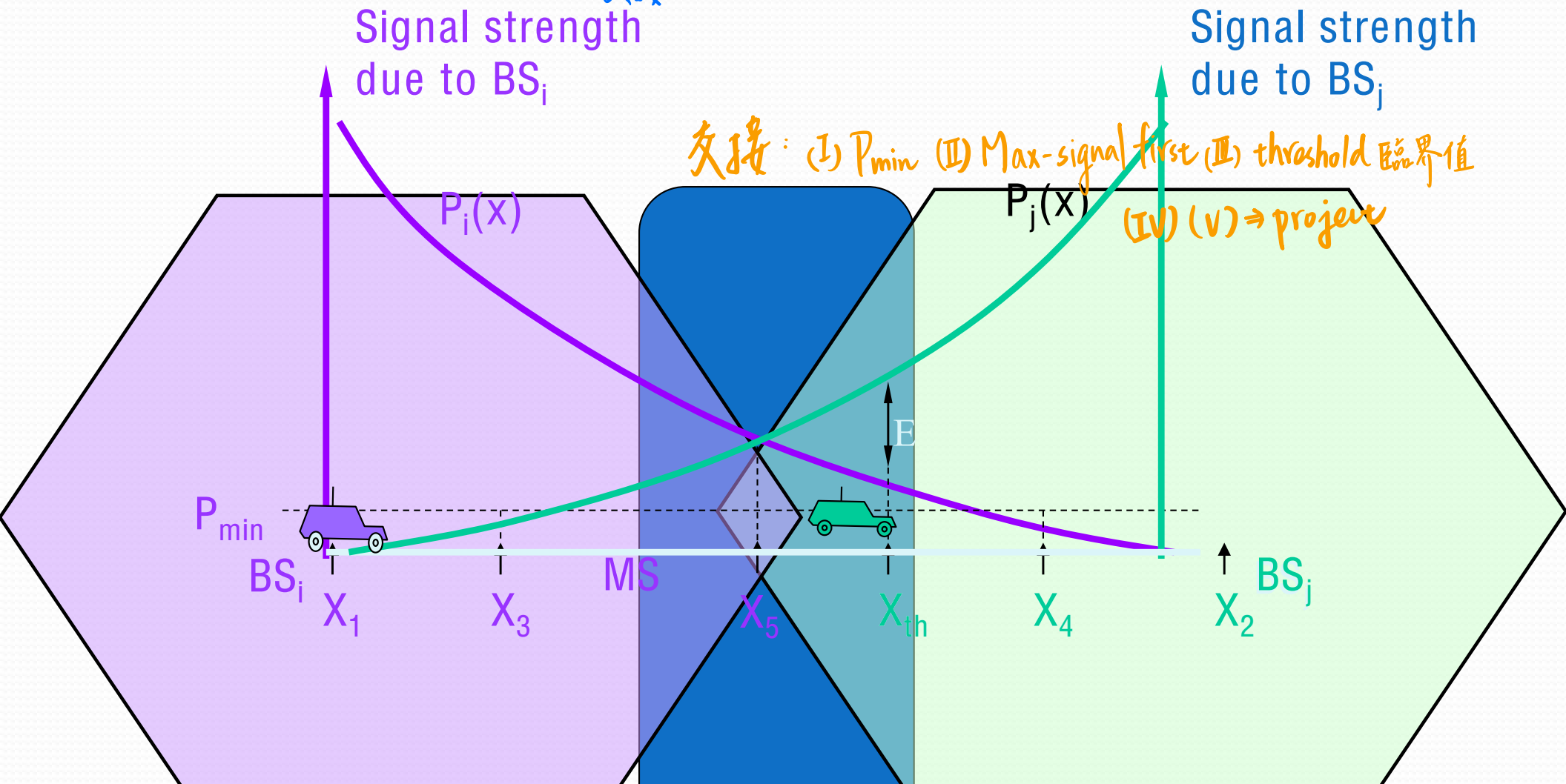
By looking at the variation of signal strength from either base station it is
possible to decide on the optimum area where handoff can take place

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Handoff Rate in a Rectangular Area

N_1 is the number of MSs per unit length in horizontal direction

N_2 is the number of MSs per unit length in vertical direction

Since handoff can occur at sides R_1 and R_2 of a cell

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

Assuming area $A=R_1 R_2$ is fixed, substitute $R_2 = A/R_1$, differentiating λ_H with respect to R_1 and equating to 0 gives

$$N_1 cosq + N_2 sinq - A/R_1^2 (N_1 sinq + N_2 cosq) = 0$$

Handoff Rate in a Rectangular Area

Thus, we have:

$$R_1{}^2 = A\frac{N_1 \sin\theta + N_2 \cos\theta}{N_1 \cos\theta + N_2 \sin\theta} \qquad R_2{}^2 = A\frac{N_1 \cos\theta + N_2 \sin\theta}{N_1 \sin\theta + N_2 \cos\theta}$$

Simplifying through few steps gives:

$$\lambda_H = 2\sqrt{A(N_1 \cos\theta + N_2 \sin\theta)(N_1 \sin\theta + N_2 \cos\theta)}$$

λ_H is minimized when $\theta = 0$, giving

$$\lambda_H = 2\sqrt{AN_1N_2} \qquad and \qquad \frac{R_1}{R_2} = \frac{N_1}{N_2}$$

Cell Capacity

- Average number of MSs requesting service (Average arrival rate): λ

- Average length of time MS requires service (Average holding time): T

- Offered load: $a = \lambda T$

e.g., in a cell with 100 MSs, on an average 30 requests are generated during an hour, with average holding time *T=360 seconds*

Then, arrival rate *λ=30 requests/3600* seconds
$$=1/120 \text{ requests/sec}$$

A channel kept busy for one hour is defined as one Erlang (*a*), i.e.,

$$a = \# calls * duration = \frac{30\ Calls}{3600\ Sec} \cdot \frac{360\ Sec}{call} = 3\ Erlangs$$
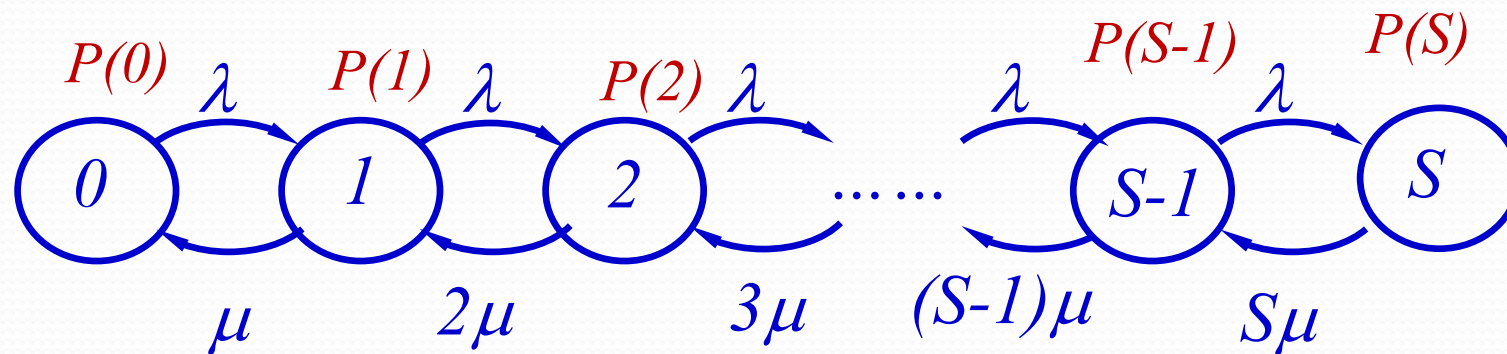
Cell Capacity

- Average arrival rate λ during a short interval t is given by λt
- Average service (departure) rate is μ
- The system can be analyzed by a *M/M/S/S* queuing model, where *M* is interarrival time of users, *M* is distribution of service time, *S* is the number of channels, and *S* is the maximum number of users in the system
- The steady state probability *P(i)* for this system in the form (for *i* =0, 1,……, S)
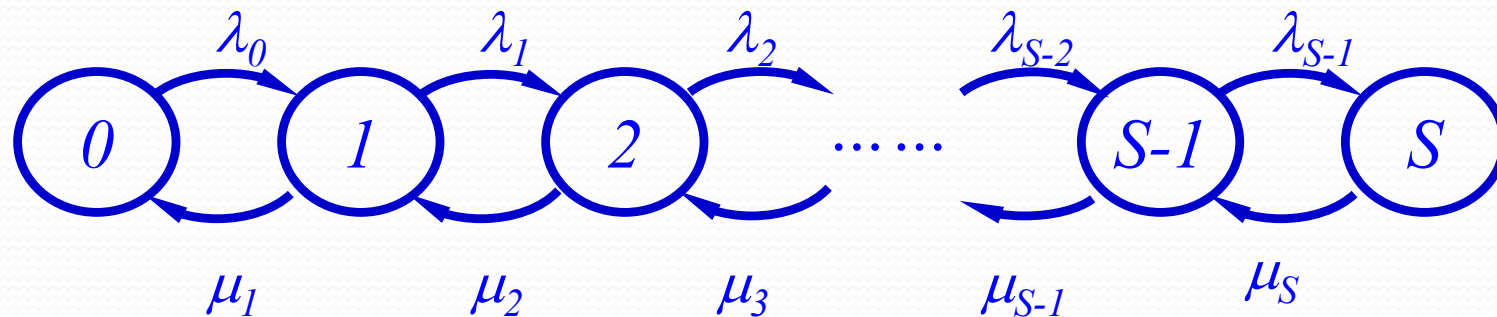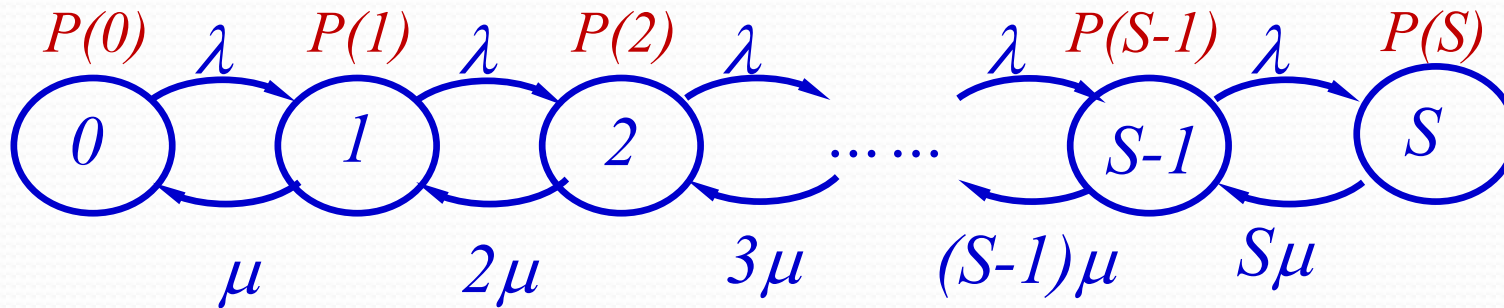
Cell Capacity
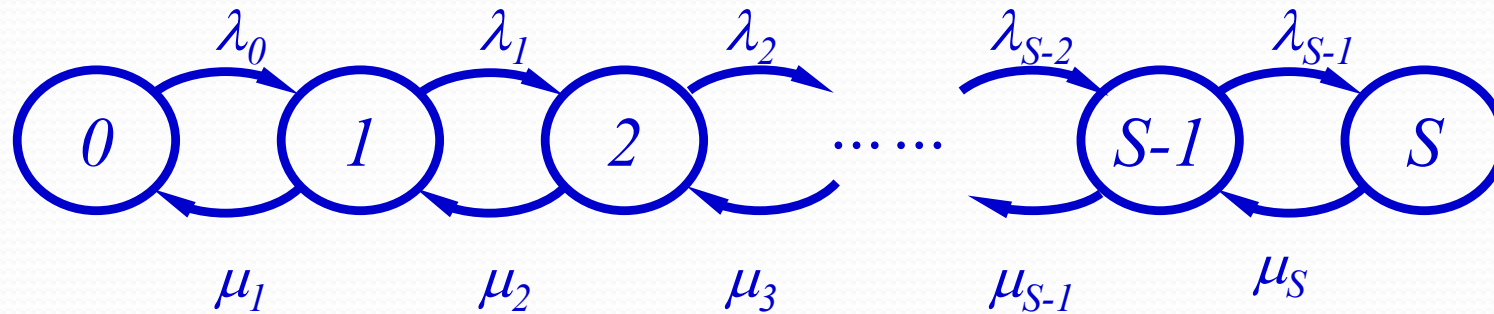
Assuming equal probability of an event

$$\lambda P(0) = \mu P(1)$$

$$(\lambda + \mu)P(1) = \lambda P(0) + 2\mu P(2)$$

$$(\lambda + i\mu)P(i) = \lambda P(i-1) + (i+1)\mu P(i+1), \ S > i \geq 1$$

Cell Capacity

$$P(i) = \left(\tfrac{\lambda}{i\mu}\right)^i P(0), = \frac{a^i}{i!} P(0) \quad i \geq 1 \; where \; a = \tfrac{\mu}{\lambda}$$

This is steady state probability $P(i)$

As $P(0)+P(1)+...P(S)=1$; substituting in terms of $P(0)$ gives

$$P(0) + \frac{a}{1!}P(0) + \frac{a^2}{2!}P(0) + \frac{a^3}{3!}P(0) + ... + \frac{a^S}{S!}P(0) = 1$$

Therefore $\quad P(0)\left[\sum_{i=0}^{S} \frac{a^i}{i!}\right] = 1, or \; P(0) = \left[\sum_{i=0}^{S} \frac{a^i}{i!}\right]^{-1}$

Capacity of a Cell

- The probability $P(S)$ of an arriving call being blocked is the probability that all S channels are busy

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

- This is Erlang B formula B(S, a)
- In the previous example, if S=2 and a=3, the blocking probability B(2, 3) is

$$B(2,3) = \frac{\dfrac{3^2}{2!}}{\displaystyle\sum_{k=0}^{2} \dfrac{3^k}{k!}} = \frac{\dfrac{9}{2}}{1+3+\dfrac{9}{2}} = \frac{9}{19} = 0.529$$

- So, the number of calls blocked 30x0.529=15.87

Capacity of a Cell

$$\text{Efficiency} = \frac{\text{Traffic nonblocked}}{\text{Capacity}}$$

$$= \frac{\text{Erlangs x portions of used channel}}{\text{Number of channels}}$$

$$= \frac{3(1-0.529)}{2} = \frac{1.413}{2} = 0.7065$$

The probability of a call being delayed:

$$C(S,a) = \frac{\frac{a^S}{(S-1)!(S-a)}}{\frac{a^S}{(S-1)!(S-a)} + \sum_{i=0}^{S-1}\frac{a^i}{i!}}$$

This is Erlang C Formula

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

$$as \ B(S,a) = \frac{\frac{a^S}{S!}}{\sum_{i=0}^{S}\frac{a^i}{i!}}$$

For S=5, a=3, B(5,3)=0.11, gives $C(5,3)$=0.2360

Erlang B and Erlang C

- Probability of an arriving call being blocked is

$$B(S,a) = \frac{a^S}{S!} \cdot \frac{1}{\displaystyle\sum_{k=0}^{S} \frac{a^k}{k!}}, \qquad \longleftarrow \quad \textit{Erlang B formula}$$

  where S is the number of channels in a group

- Probability of an arriving call being delayed is

$$C(S,a) = \frac{\dfrac{a^S}{(S-1)!(S-a)}}{\dfrac{a^S}{(S-1)!(S-a)} + \displaystyle\sum_{i=0}^{S-1} \frac{a^i}{i!}}, \qquad \longleftarrow \quad \textit{Erlang C formula}$$

  where $C(S, a)$ is the probability of an arriving call being delayed with a load and S channels

Cell Structure

囗可重複用的結構

(a) Line Structure

囗著色問題
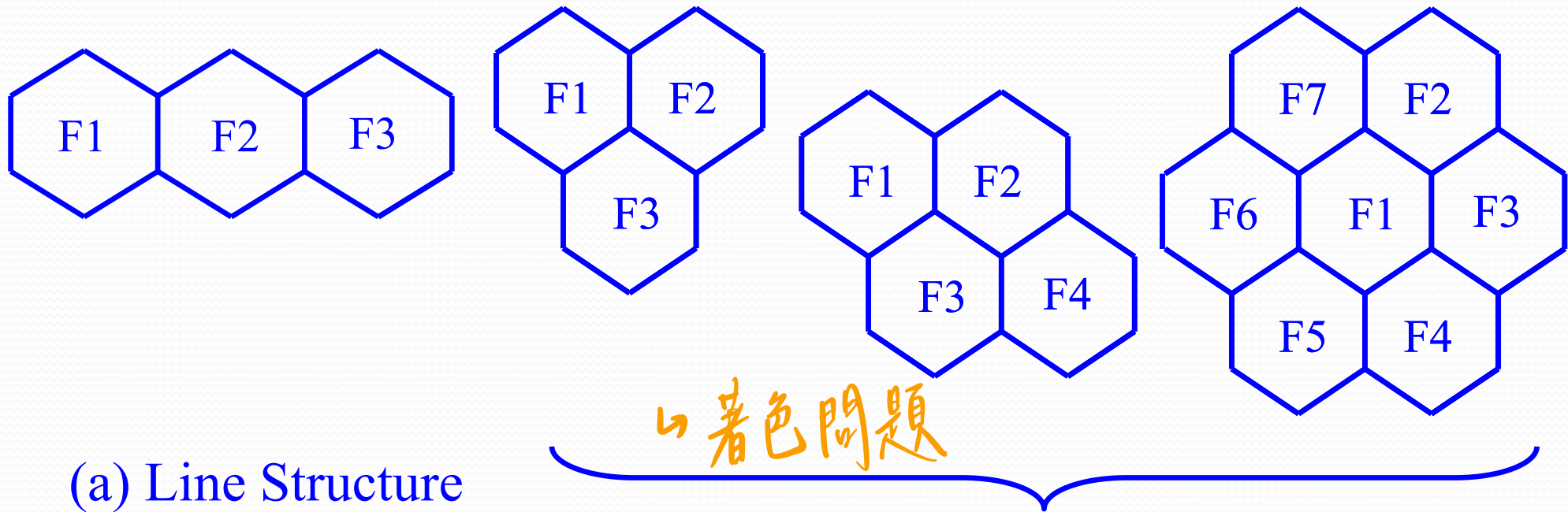
(b) Plan Structure

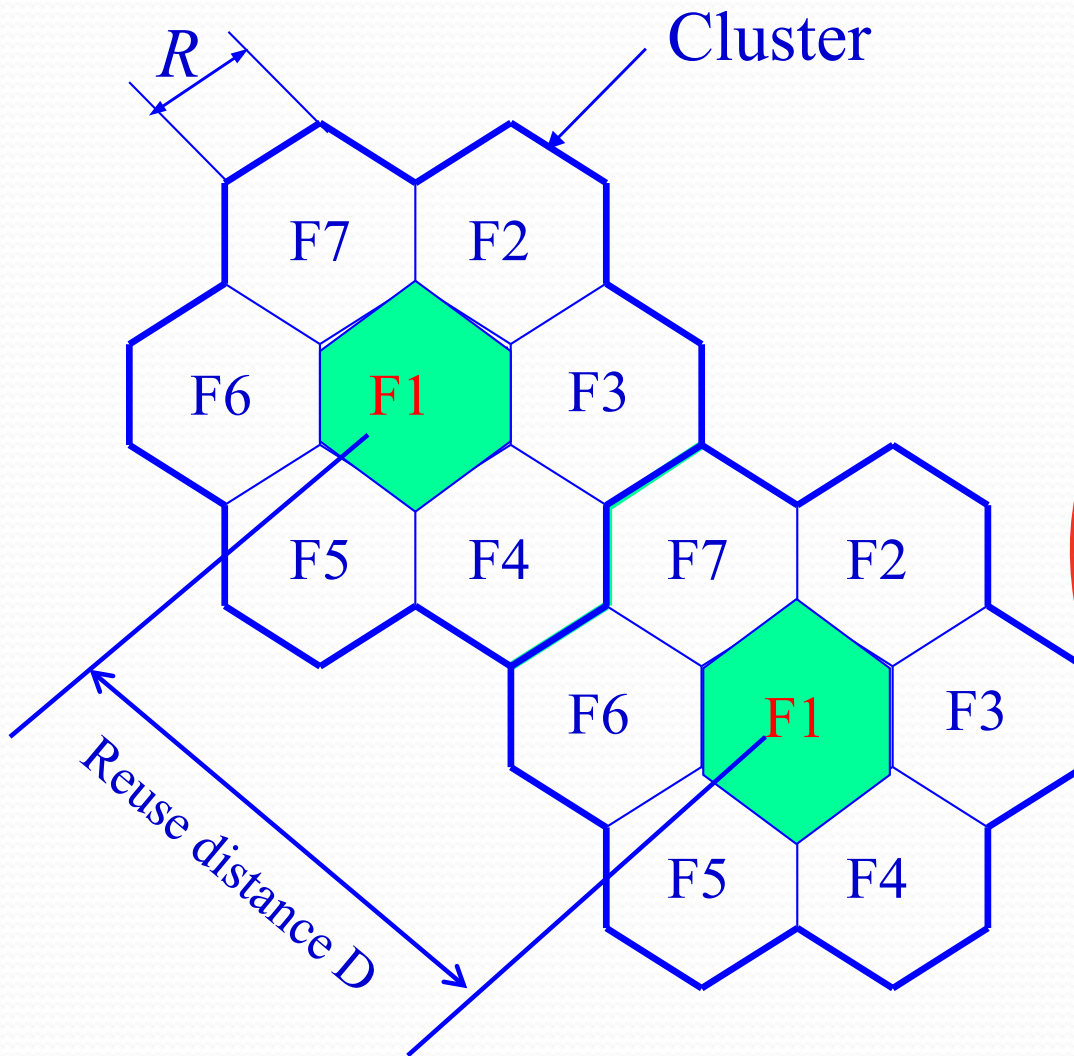Note: Fx is set of frequency, i.e., frequency group

Frequency Reuse
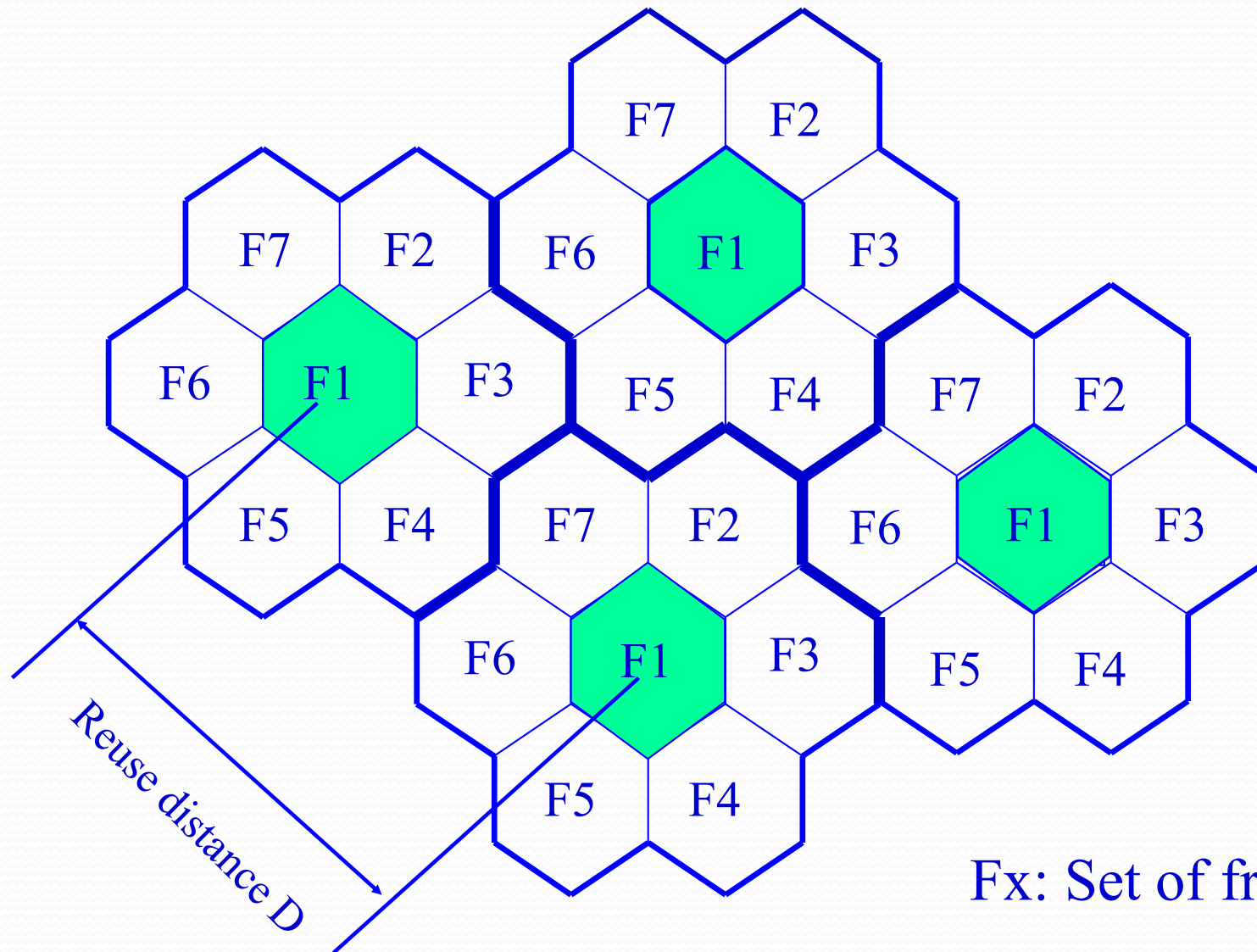
Fx: Set of frequency

Reuse distance D

7-cell reuse cluster

Reuse Distance

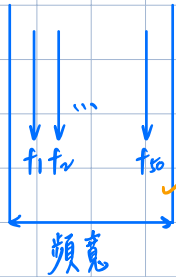

- For hexagonal cells, the reuse distance is given by

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

where R is cell radius and N is the reuse pattern (the cluster size or the number of cells per cluster).
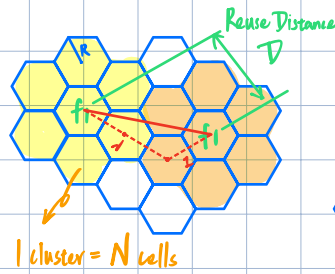
- Reuse factor is
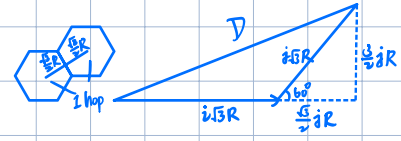
$$q \equiv \frac{D}{R} = \sqrt{3N}$$

- **Frequency Reuse**

$f_1 \, f_2 \quad \cdots \quad f_{50}$

FDMA：相鄰 f 可能會互相干擾

頻寬

R
Reuse Distance D

f_1 f_1

1 cluster = N cells

(i, j) pair：從圓心往一方向走了 i hops 再轉 60° 走 j hops

題目

1 hop

D

$i\sqrt{3}R$ $\frac{\sqrt{3}}{2}jR$

$j\sqrt{3}R$ $\frac{1}{2}jR$

60°

$\therefore D^2 = \left(\frac{1}{2}jR\right)^2 + \left(i\sqrt{3}R + \frac{\sqrt{3}}{2}jR\right)^2$

$= 3\left(i^2 + ij + j^2\right)R^2 = 3NR^2$

$\Rightarrow D = \sqrt{3N} \cdot R \quad \text{※}$

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 positive integers, i.e. $0 \geq i, j < \infty$
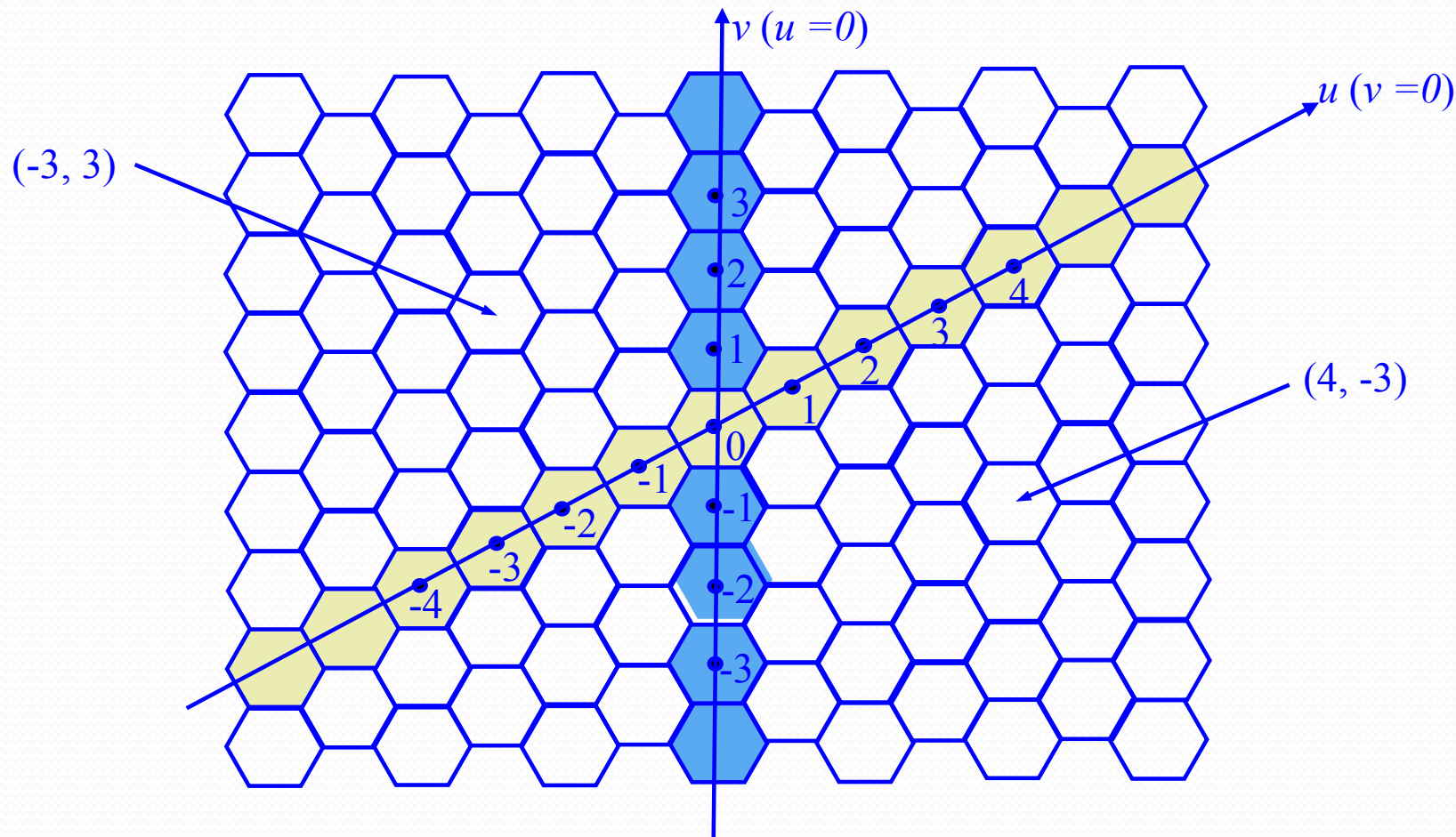
- N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, ….
  The popular value of N being 4 and 7

j direction cells

60°

1 2   3 … i cells

i direction
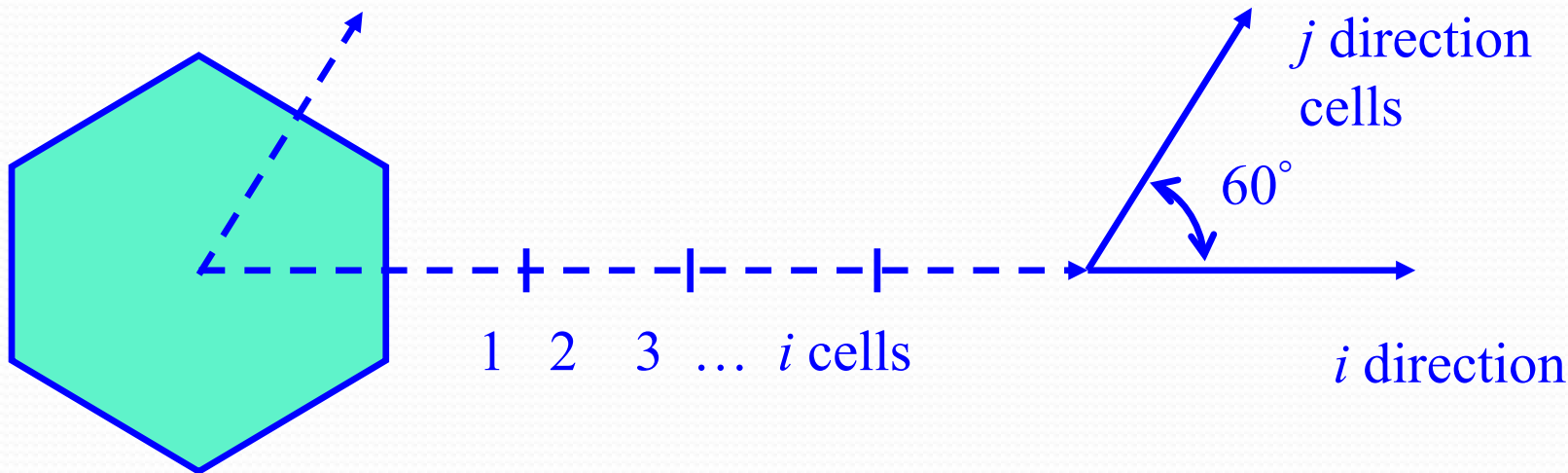
Reuse Distance (Cont'd)

$$N = i^2 + ij + j^2 \quad \text{with } i \text{ and } j \text{ as integers}$$

u and v coordinate representation of cells with $(0,0)$ center

Reuse Distance and Channel set to use

- For j=1, the cluster size is given by $N = i^2 + i + 1$

Then defining $L = [(i+1)u + v] \mod N$

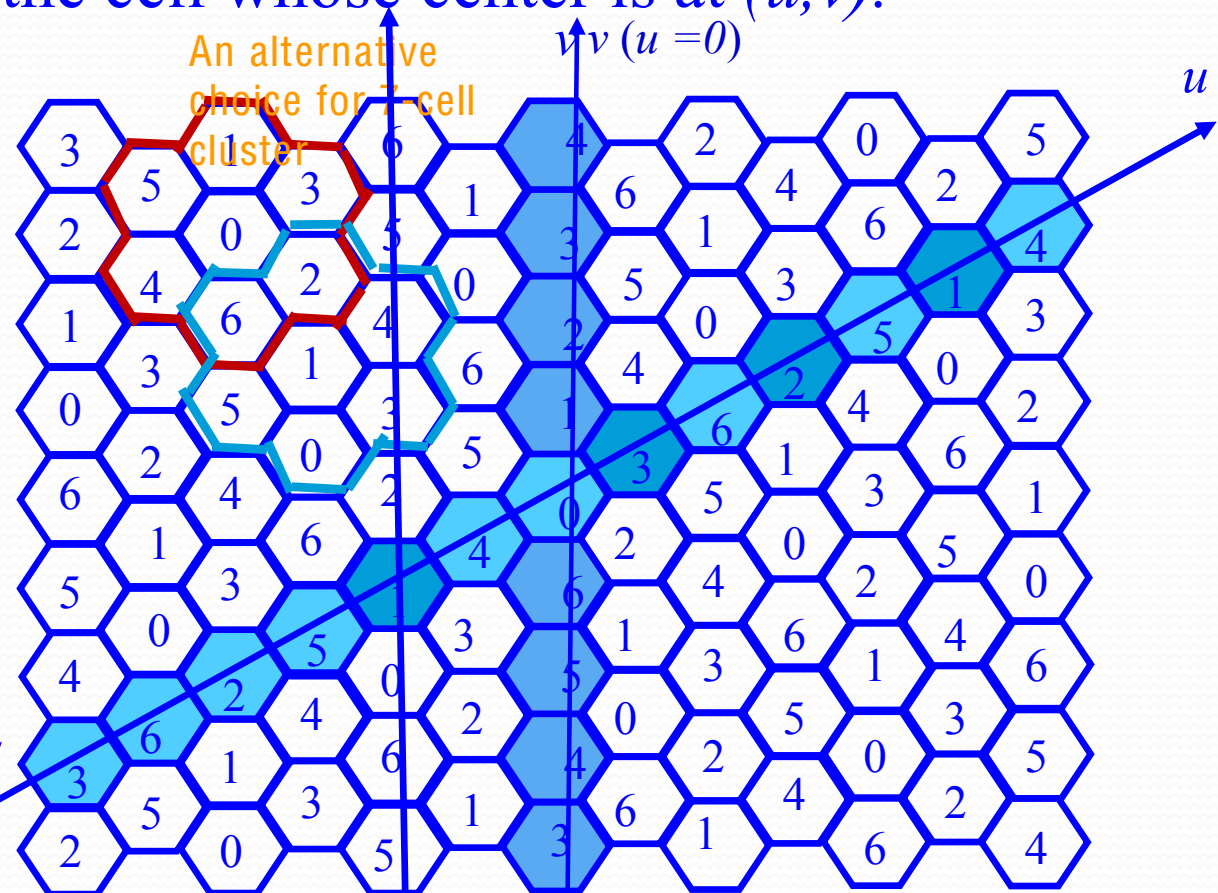We can obtain label L for the cell whose center is at (u,v).

For $N=7$, with $i=2, j=1$:

$$L = (3u + v) \mod 7$$

u	0	1	-1	0	0	1	-1
v	0	0	0	1	-1	-1	1
L	0	3	4	1	6	2	5

Gives assignment of channels to use in different cells

Labeling cells with L values for $N=7$

Reuse Distance and Channel set to use

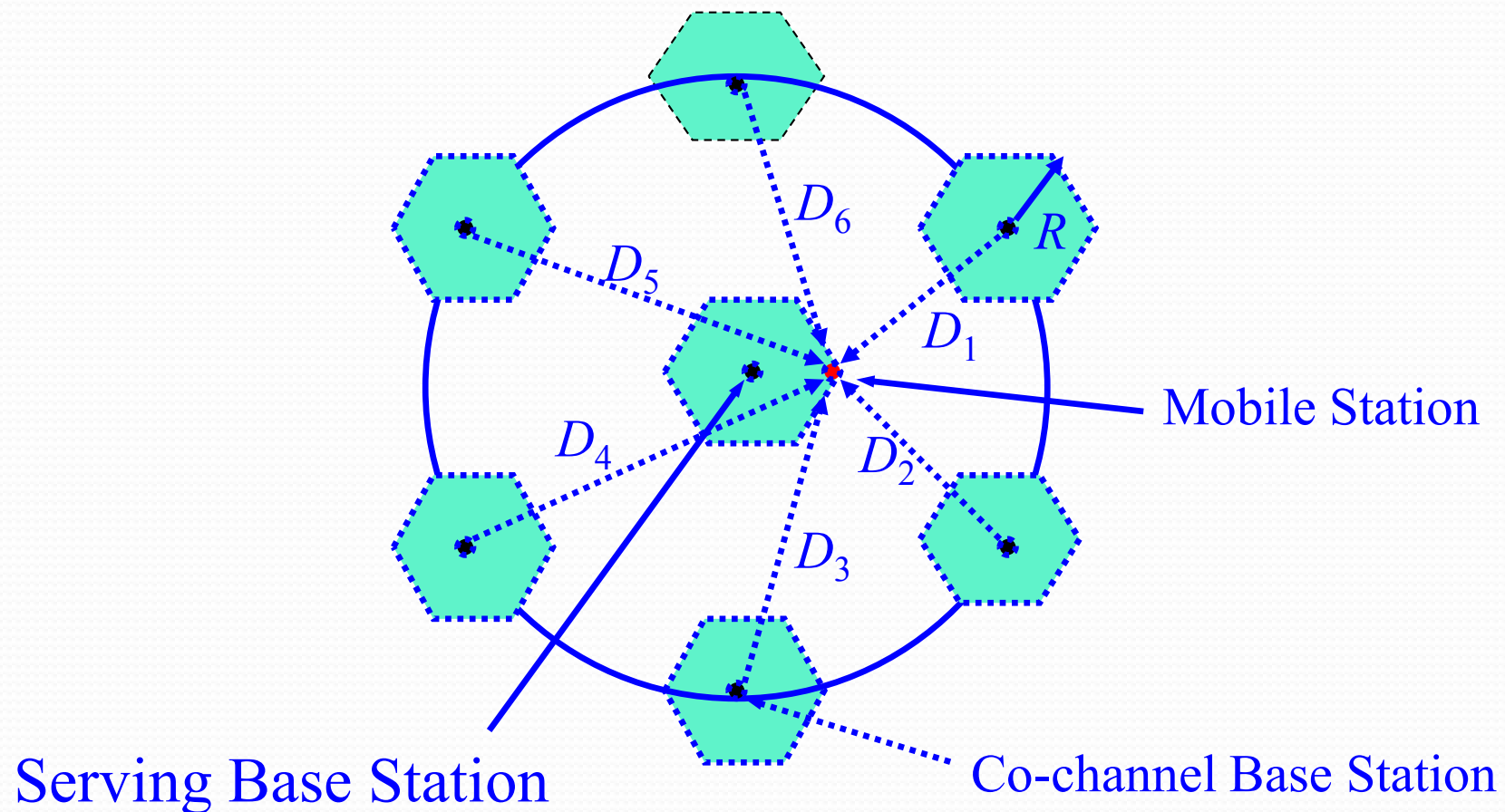For $N=13, i=3, j=1;$ $\qquad L = (4u + v) \bmod 13$

Cell labeled with L values for $N=13$; 0 to 12

Cochannel Interference

同频 干擾

Second tier co-channel Base Station ×1✓

First tier co-channel Base Station ×6.

D_6

D_5

R

D_1

D_4

Mobile Station

D_2

D_3

↳ D 越小越好
但不能產生干擾

Serving Base Station (BS)
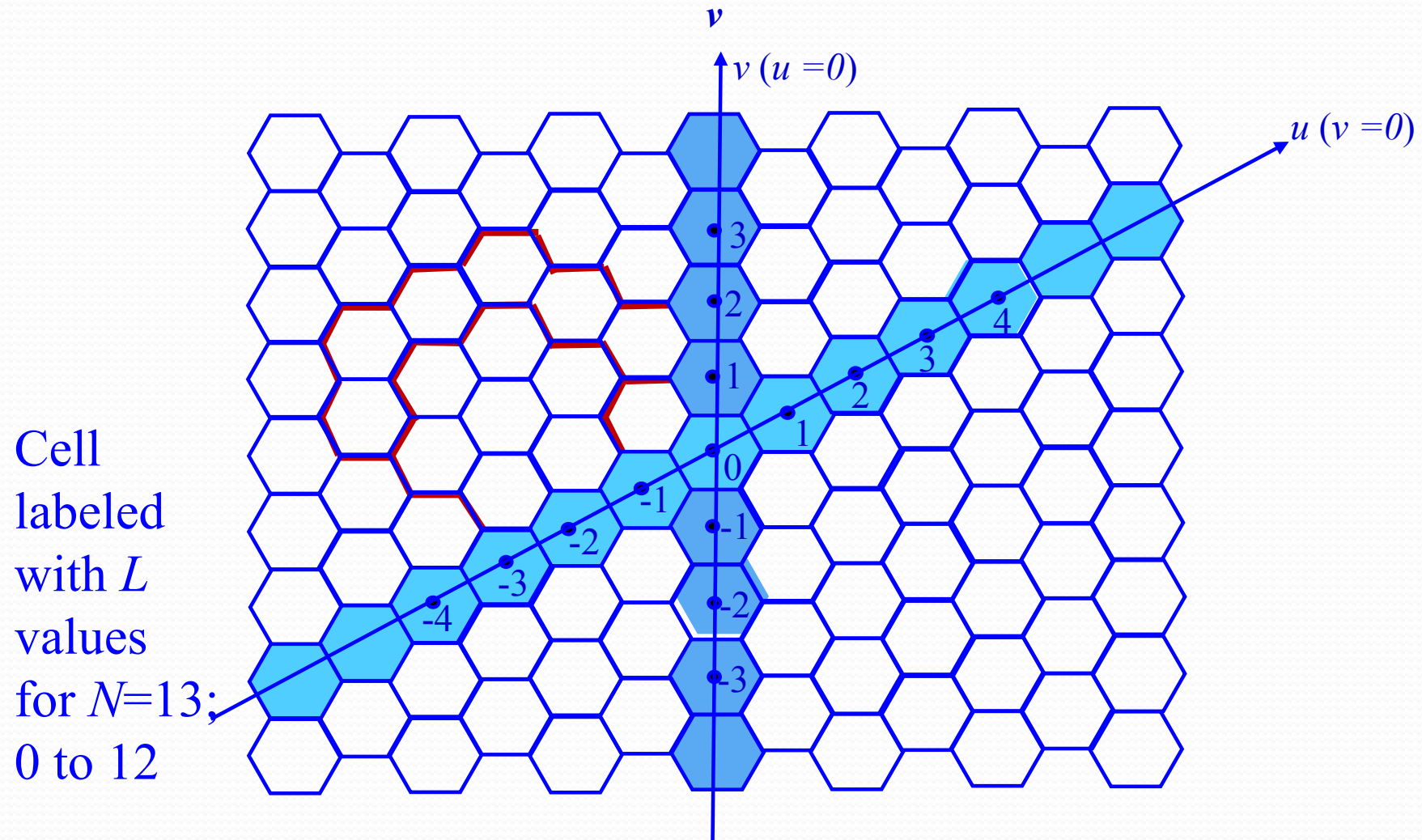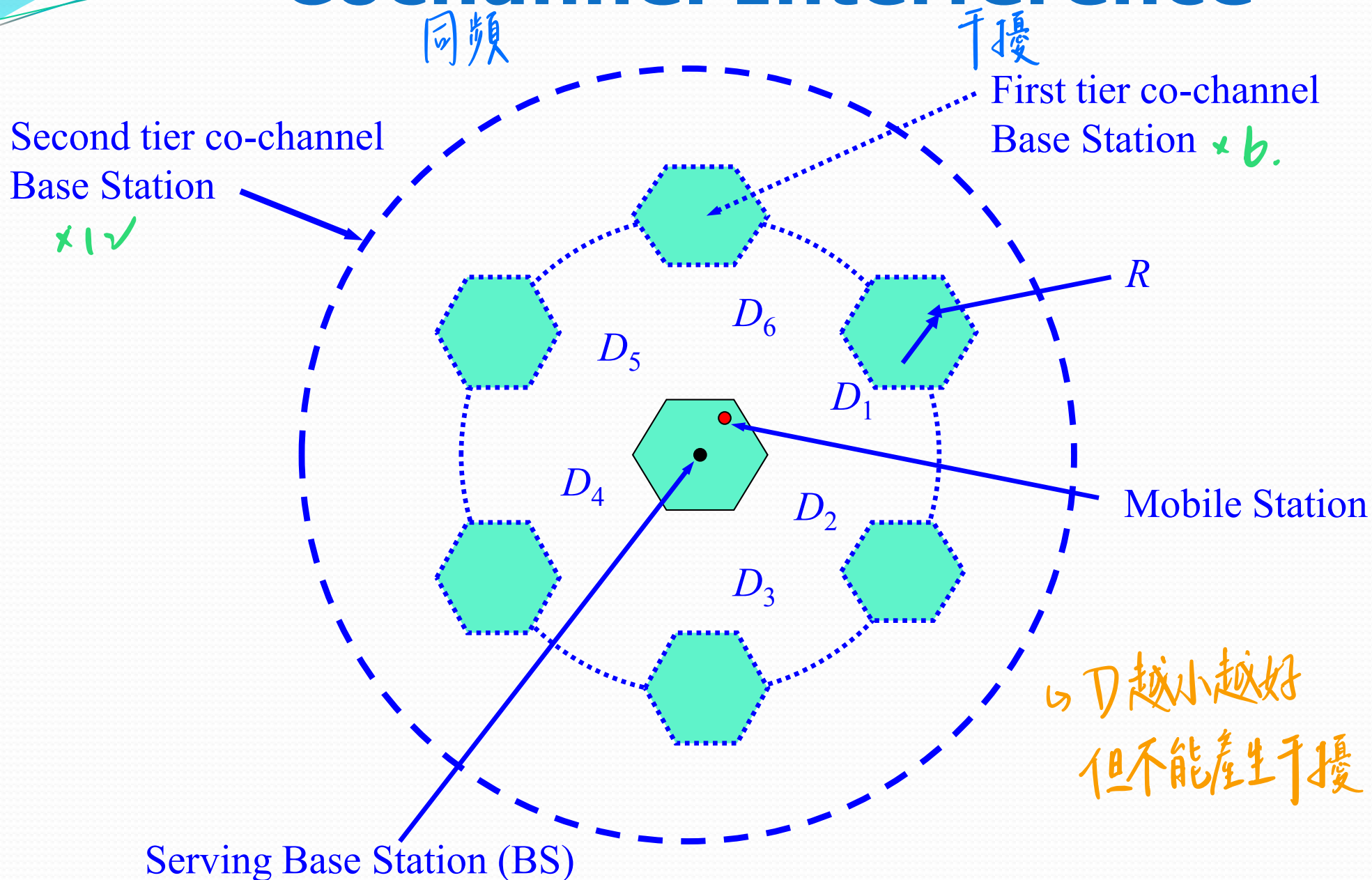
Worst Case of Cochannel Interference

ㄴ 離生訊號源最遠(角)

Mobile Station

Serving Base Station

Co-channel Base Station

Cochannel Interference

- Cochannel interference ratio is given by

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

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:

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

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

Cell Splitting

Large cell (low density)

Small cell (high density)

Smaller cell (higher density)
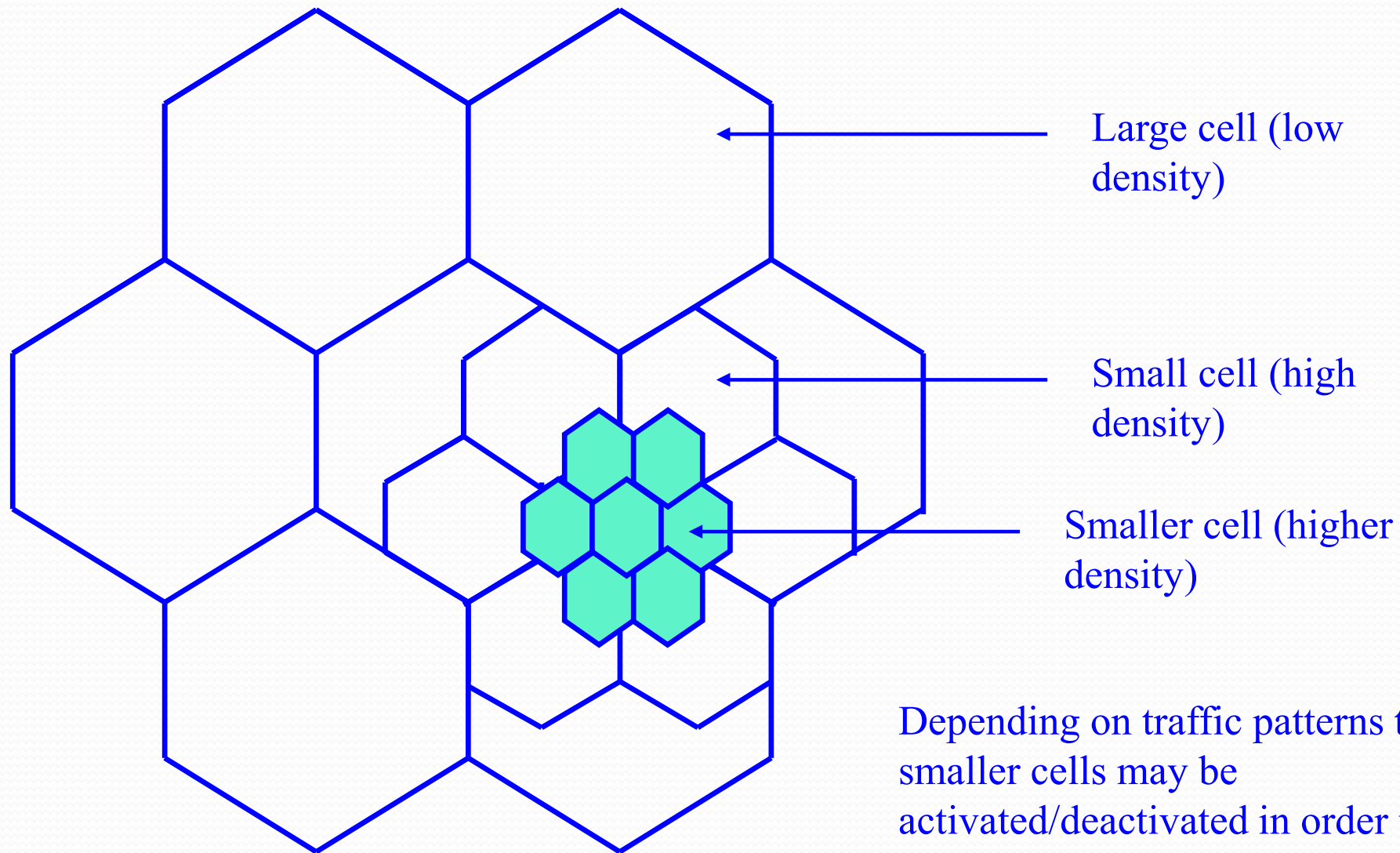
Depending on traffic patterns the smaller cells may be activated/deactivated in order to efficiently use cell resources.
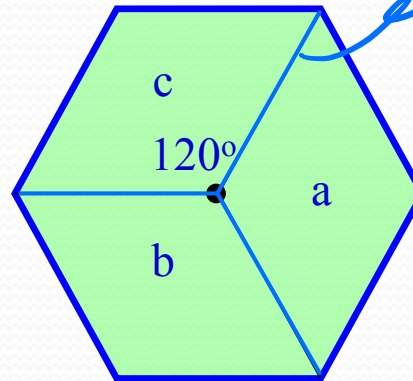
Cell Sectoring by Antenna Design
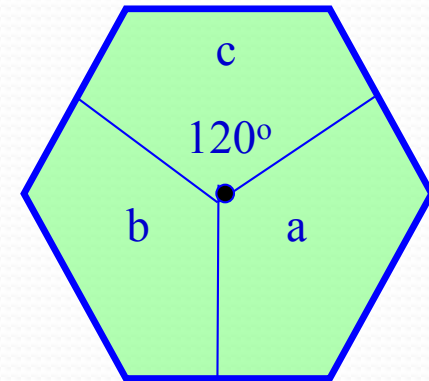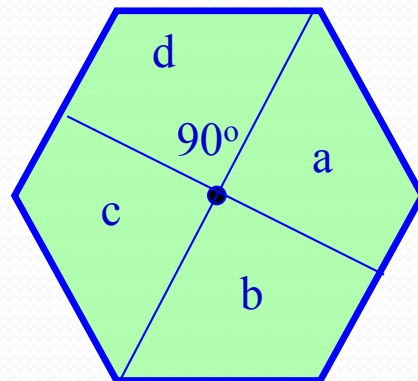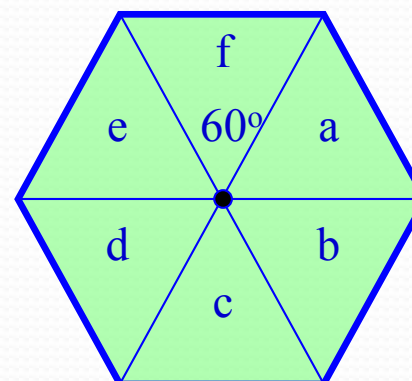
ㄥ切分 cell   定向天線
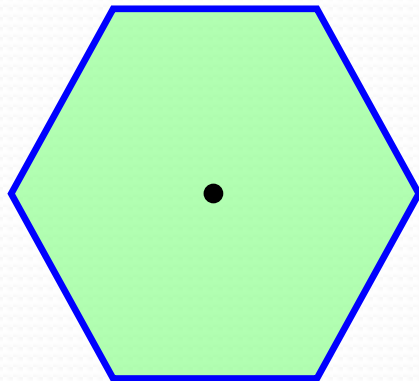
(a). Omni
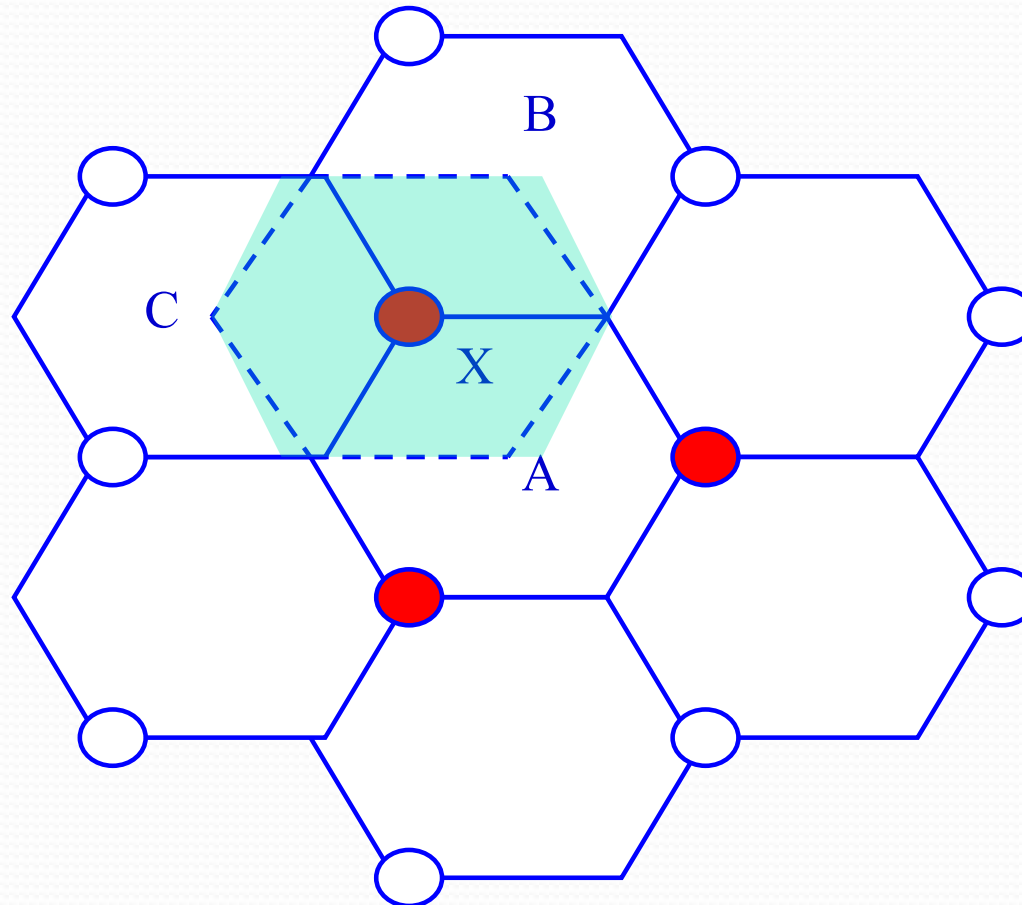
(b). 120° sector
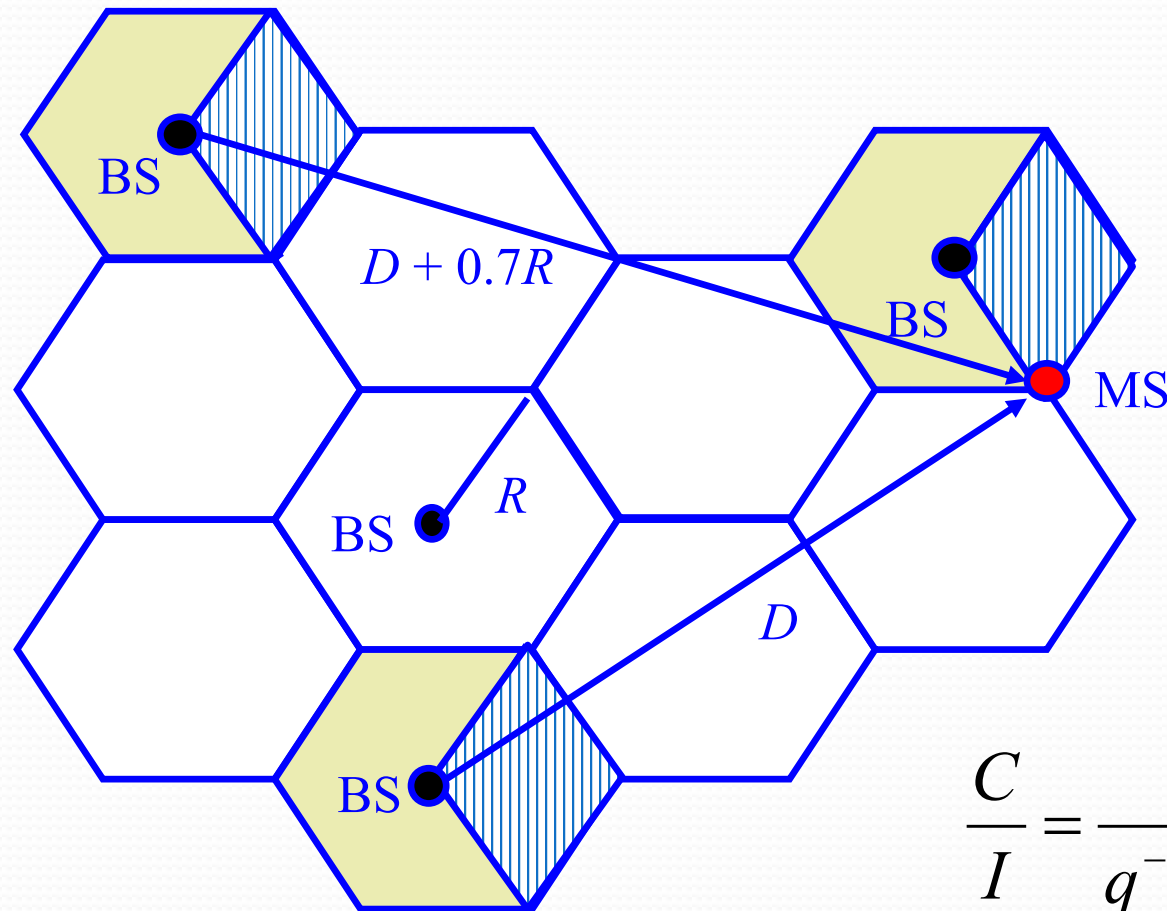
(c). 120° sector (alternate)

(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
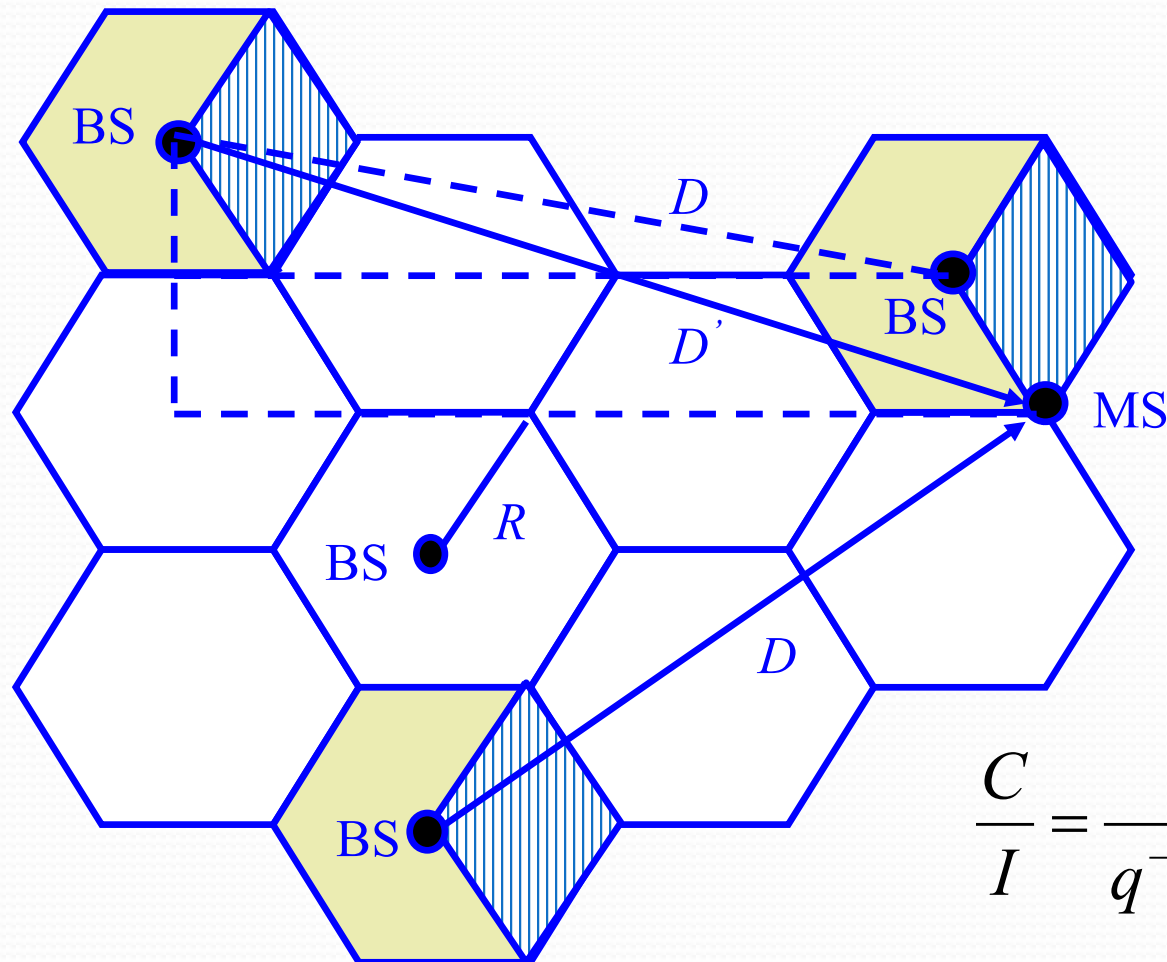

$D + 0.7R$
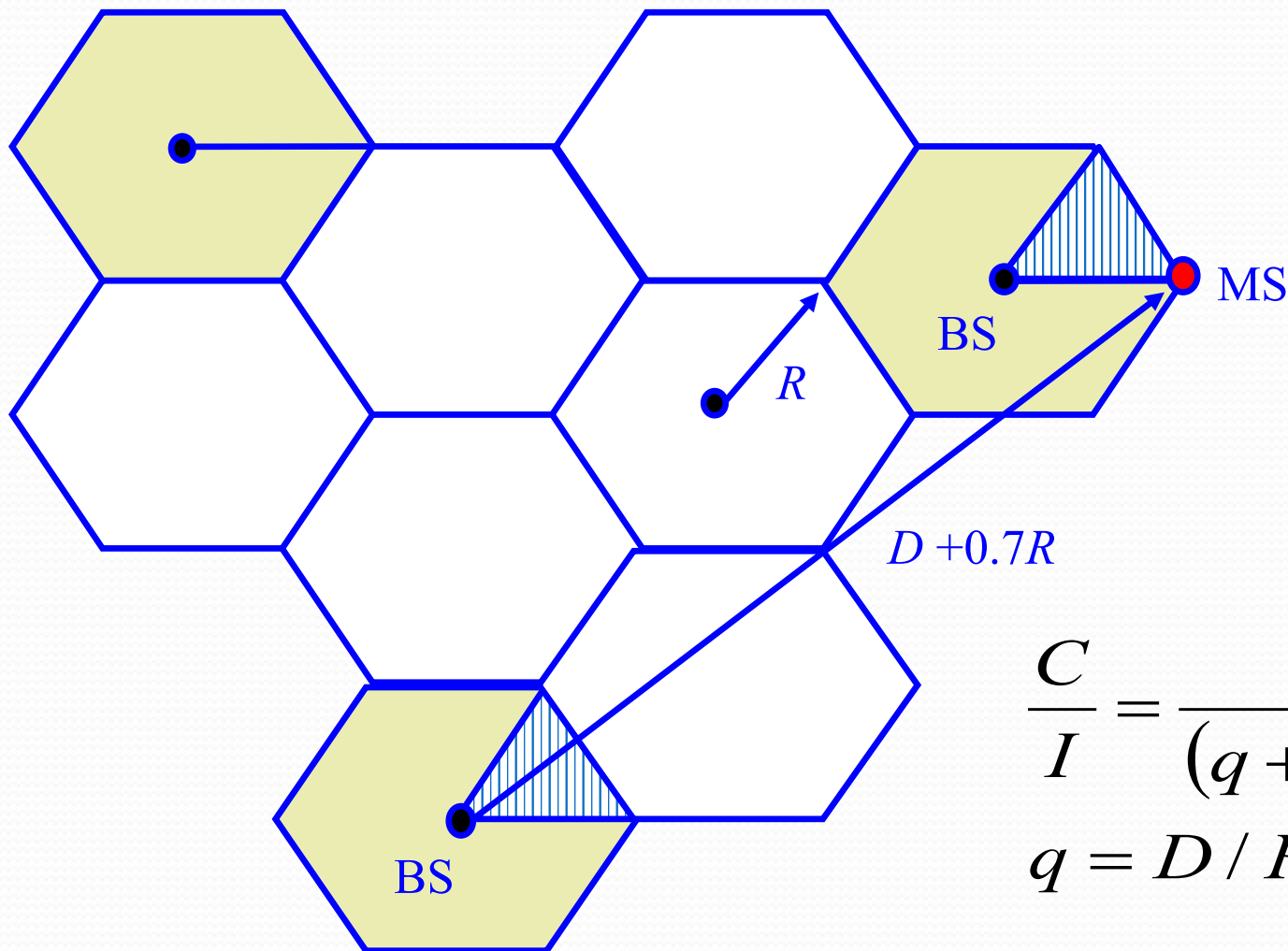
BS

BS

MS

R

BS

D

BS

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

$$q = D / R$$

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

Worst Case for Forward Channel Interference in Three-sectors

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

$$q = D / R$$

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

Worst Case for Forward Channel Interference in Six-sectors

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

$$q = D / R$$

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