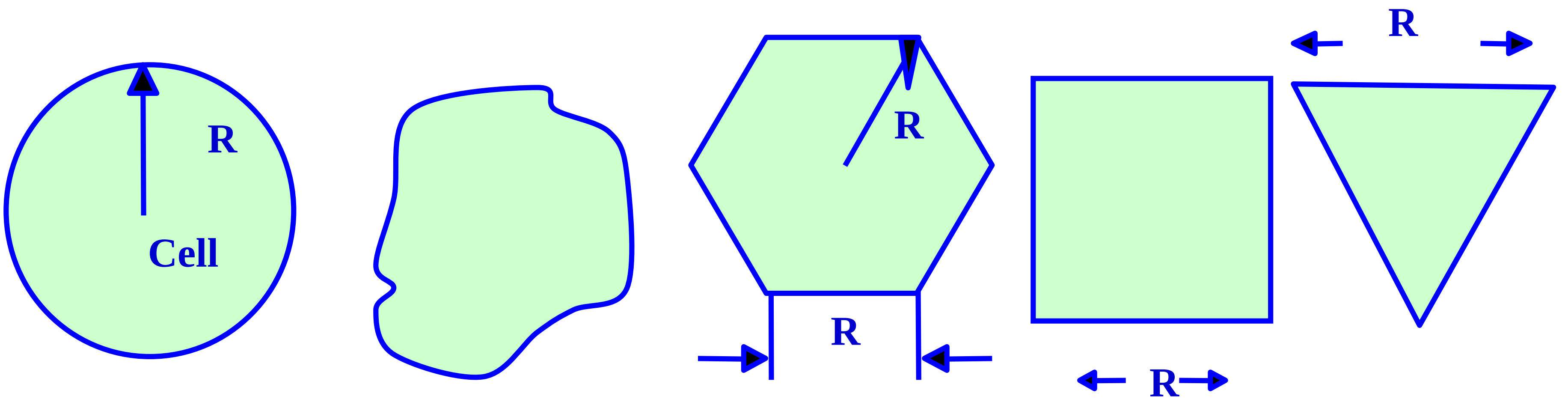
Chapter 5

The Cellular Concept

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
- Cochannel Interference
- Cell Splitting
- Cell Sectoring

Cell Shape

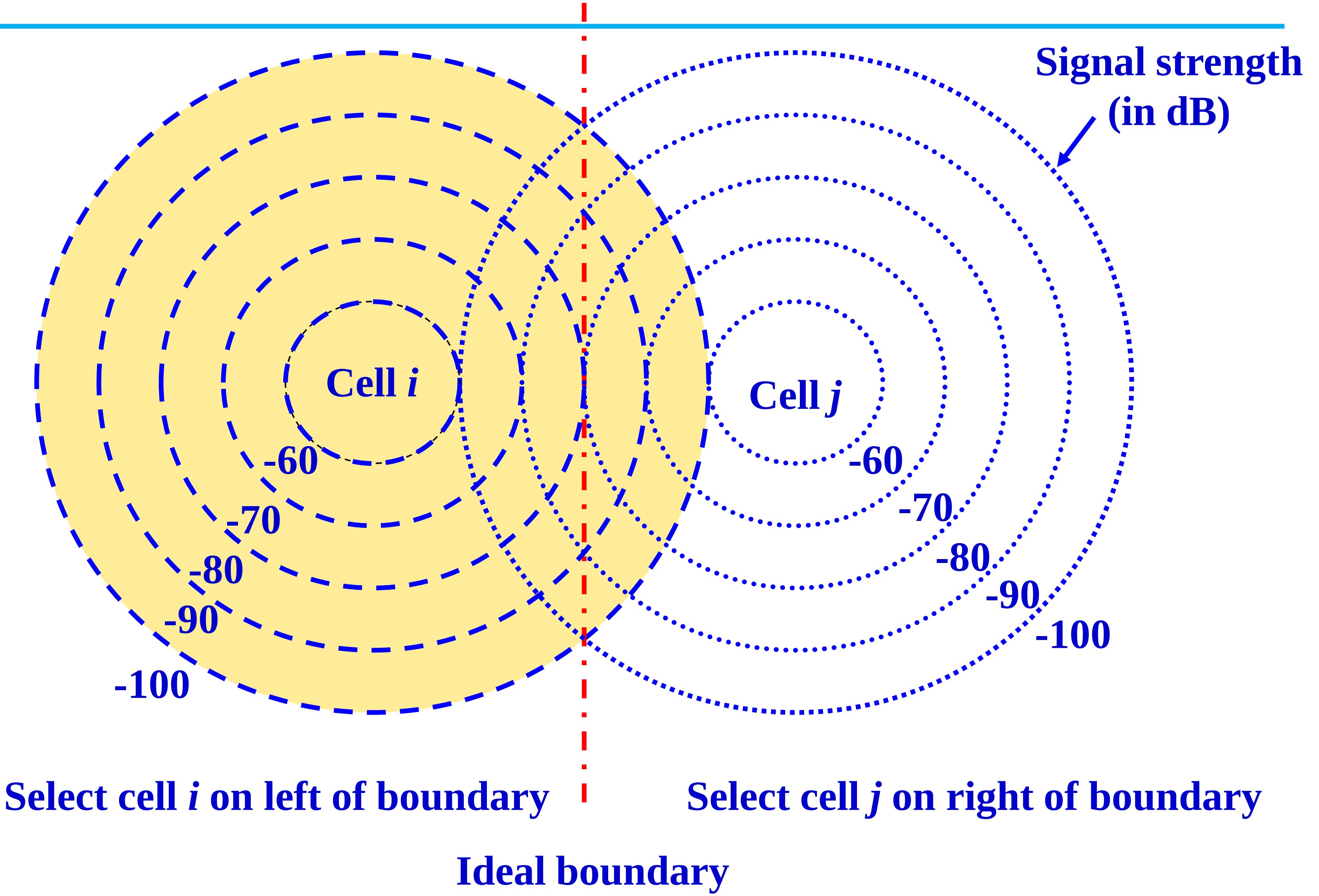


(a) Ideal cell (b) Actual cell (c) Different cell models

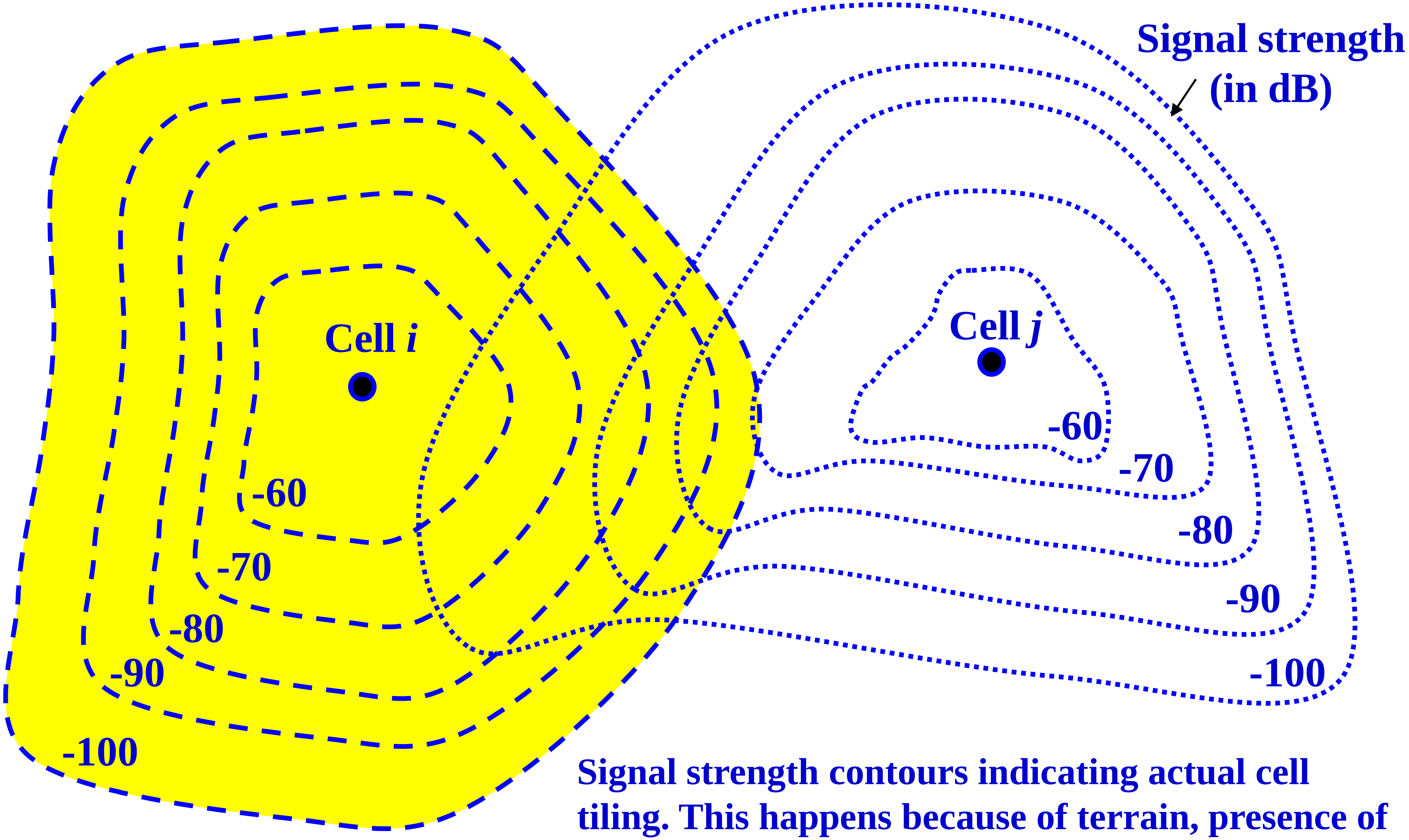
Impact of Cell Shape and Radius on Service Characteristics

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

Signal Strength

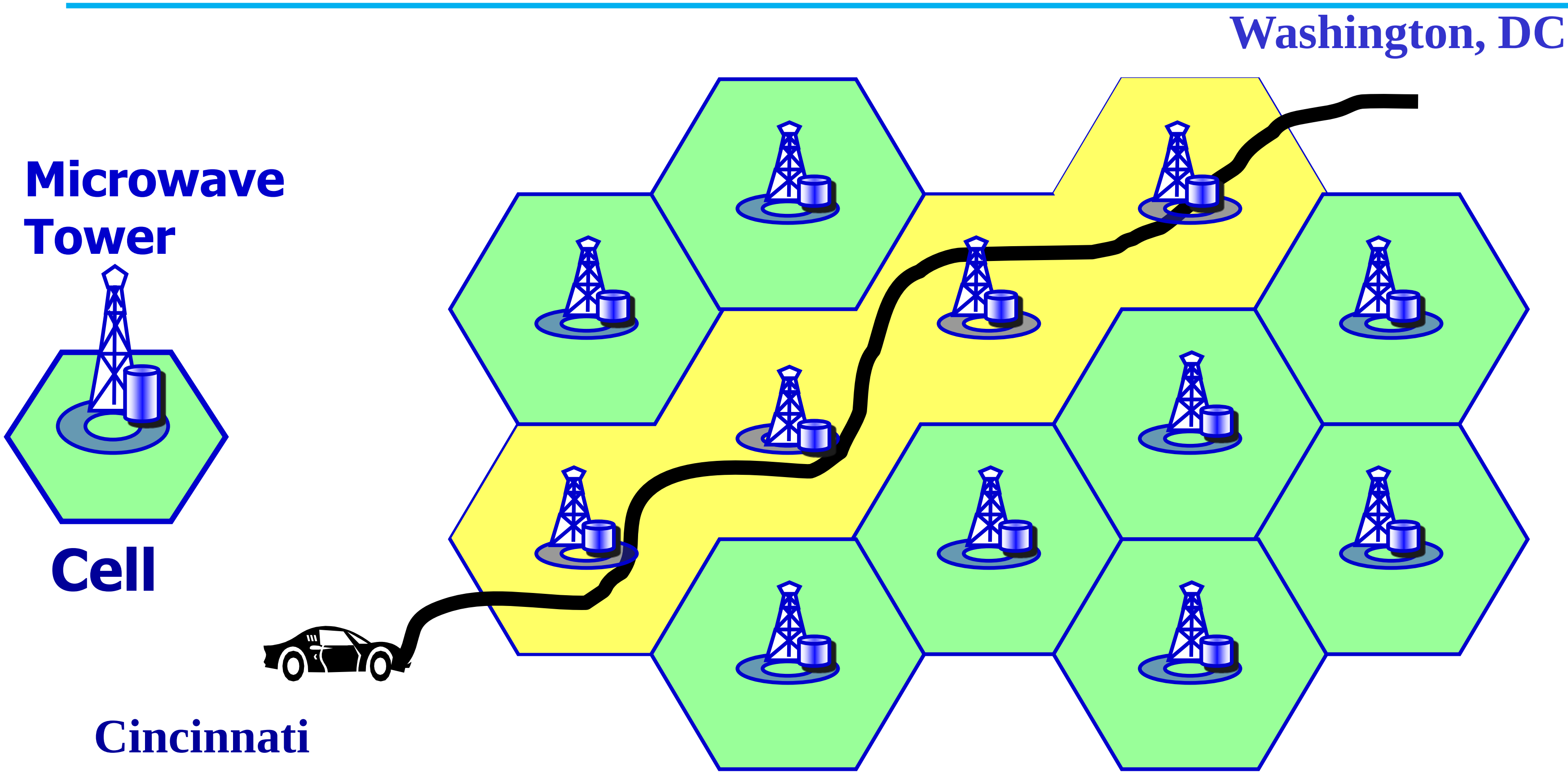


Actual Signal Strength



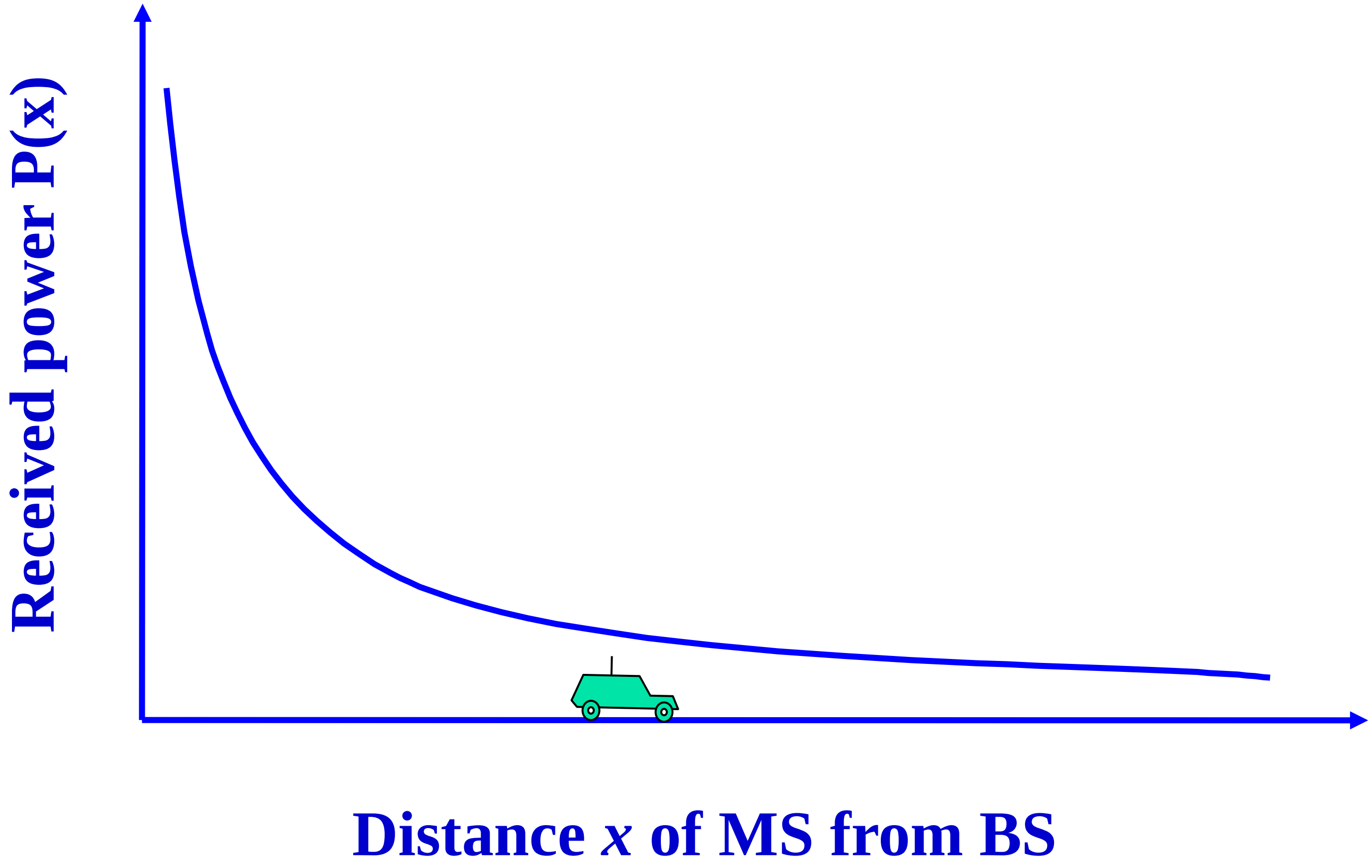
Signal strength contours indicating actual cell tiling. This happens because of terrain, presence of obstacles and signal attenuation in the atmosphere.

Universal Cell Phone Coverage

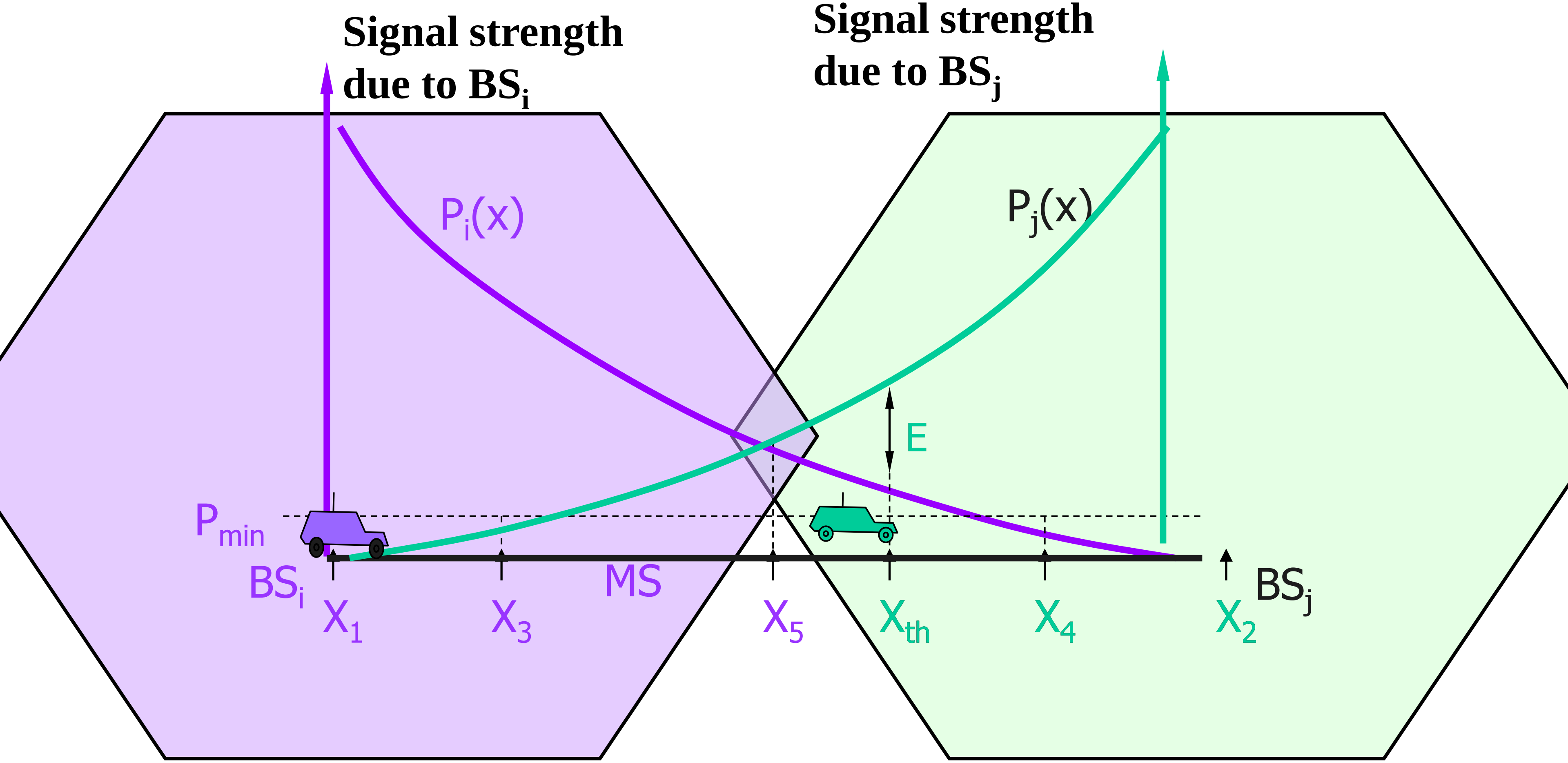


Maintaining the telephone number across geographical areas in a wireless and mobile system

Variation of Received Power



Handoff Region



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

Handoff Strategies Used to Determine Instant of Handoff (1/3)

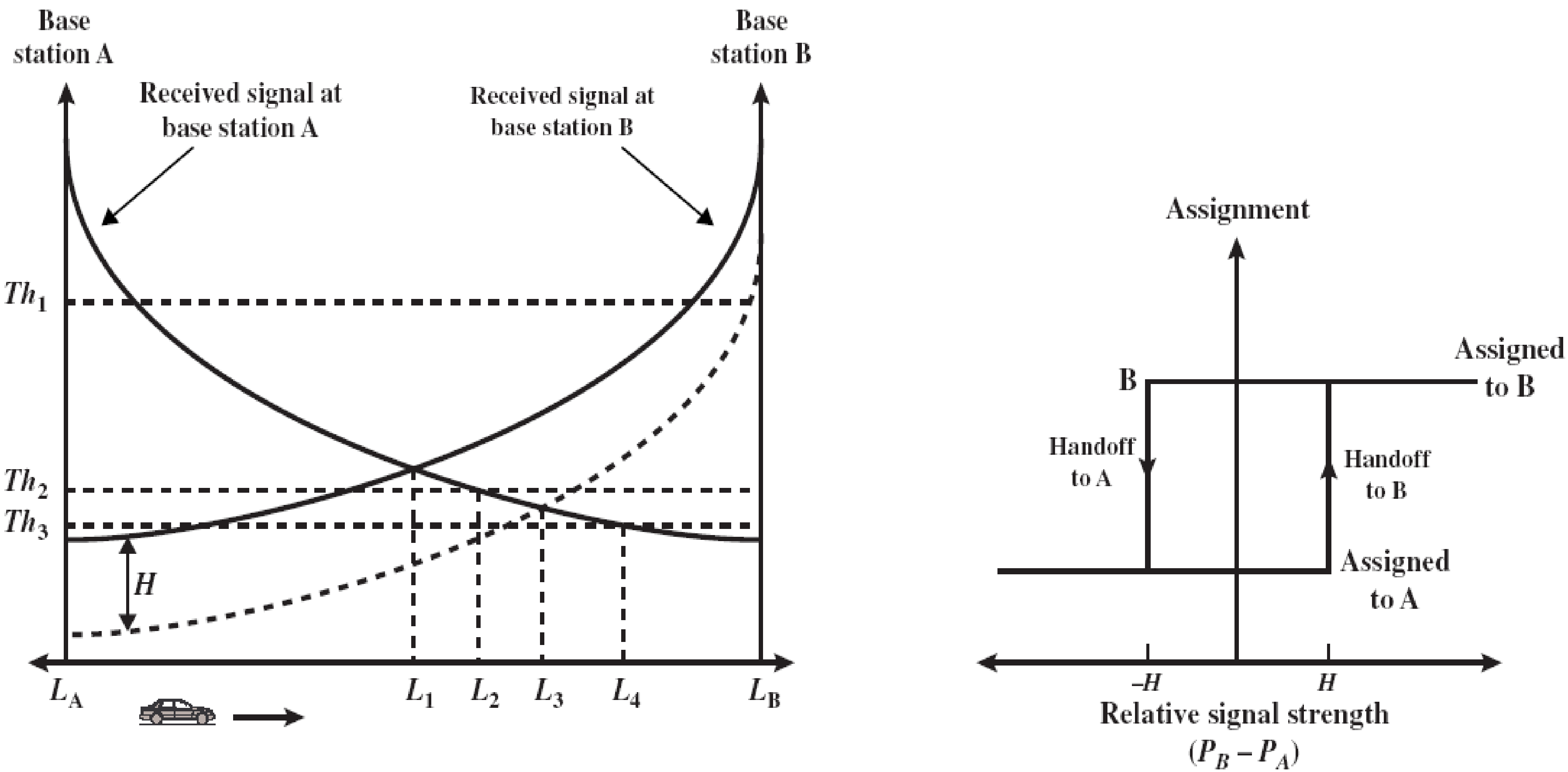
- Relative signal strength
- Relative signal strength with threshold
- Relative signal strength with hysteresis
- Relative signal strength with hysteresis and threshold
- Prediction techniques

Handoff Strategies Used to Determine Instant of Handoff (2/3)

- Relative signal strength
  - The MS is handed off from BS A to BS B when the signal strength at B first exceeded that at A
- Relative signal strength with threshold
  - Handoff only occurs if (1) the signal at current BS is sufficiently weak (less than a predefined threshold) and (2) the other signal is the stronger of the one.
  - For example, if a high threshold (Th_1) is used in Fig. 10.7, this scheme performs as the relative signal strength scheme.

Handoff Strategies Used to Determine Instant of Handoff (3/3)

- Relative signal strength with hysteresis
  - Handoff occurs only if the new BS is sufficiently stronger (by a margin *H* in Figure 10.7 a) than the current one.
  - This scheme prevents the ping-pong effect.
- Relative signal strength with hysteresis and threshold
  - Handoff occurs only if (1) the current signal level drops below a threshold, and (2) the target station is stronger than the current one by a hysteresis margin *H*.
- Prediction techniques
  - The handoff decision is based on the expected future value of the received signal strength.



(a) Handoff decision as a function of handoff scheme

(b) Hysteresis mechanism

Figure 10.7 Handoff Between Two Cells

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 = 30/3600 requests/sec**
  - **A channel kept busy for one hour is defined as one Erlang (a), i.e,**

$$a = \frac{30\ Calls}{3600\ Sec} \cdot \frac{360\ Sec}{call} = 3\ Erlangs$$

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 *S* is the number of channels
- The steady state probability $P(i)$ for this system in the form (for i =0, 1, …, *S*)

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

Where $a = \dfrac{\lambda}{\mu}$ and $P(0) = \left[\sum_{i=0}^{S} \dfrac{a^i}{i!} \right]^{-1}$

Capacity of a Cell

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

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

- **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**

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

- **So, the number of calls blocked 30 x 0.529 = 15.87**

Capacity of a Cell

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

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

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

The probability of a call being delayed:

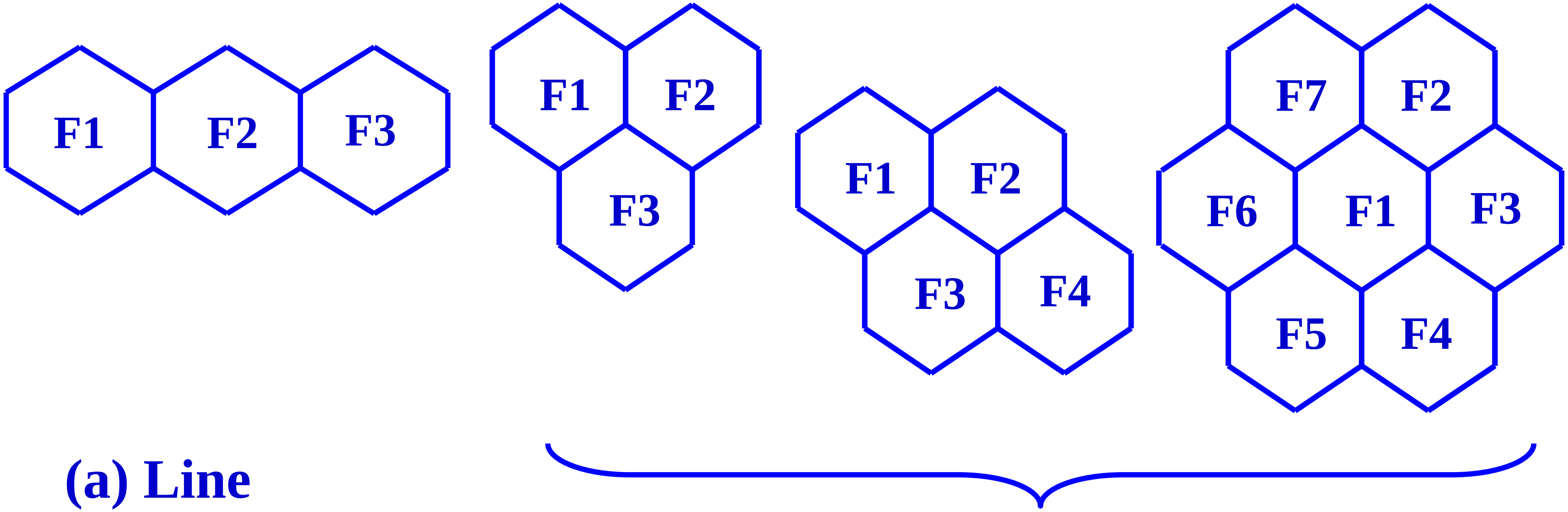
$$C(S,a) = \frac{\dfrac{a^S}{(S-1)!(S-a)}}{\dfrac{a^S}{(S-1)!(S-a)} + \displaystyle\sum_{i=0}^{S-1} \frac{a^i}{i!}}$$

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

This is Erlang *C* Formula

For *S* = 5, *a* = 3, *B*(5, 3) = 0.11
Gives *C*(5, 3)=0.2360

Cell Structure

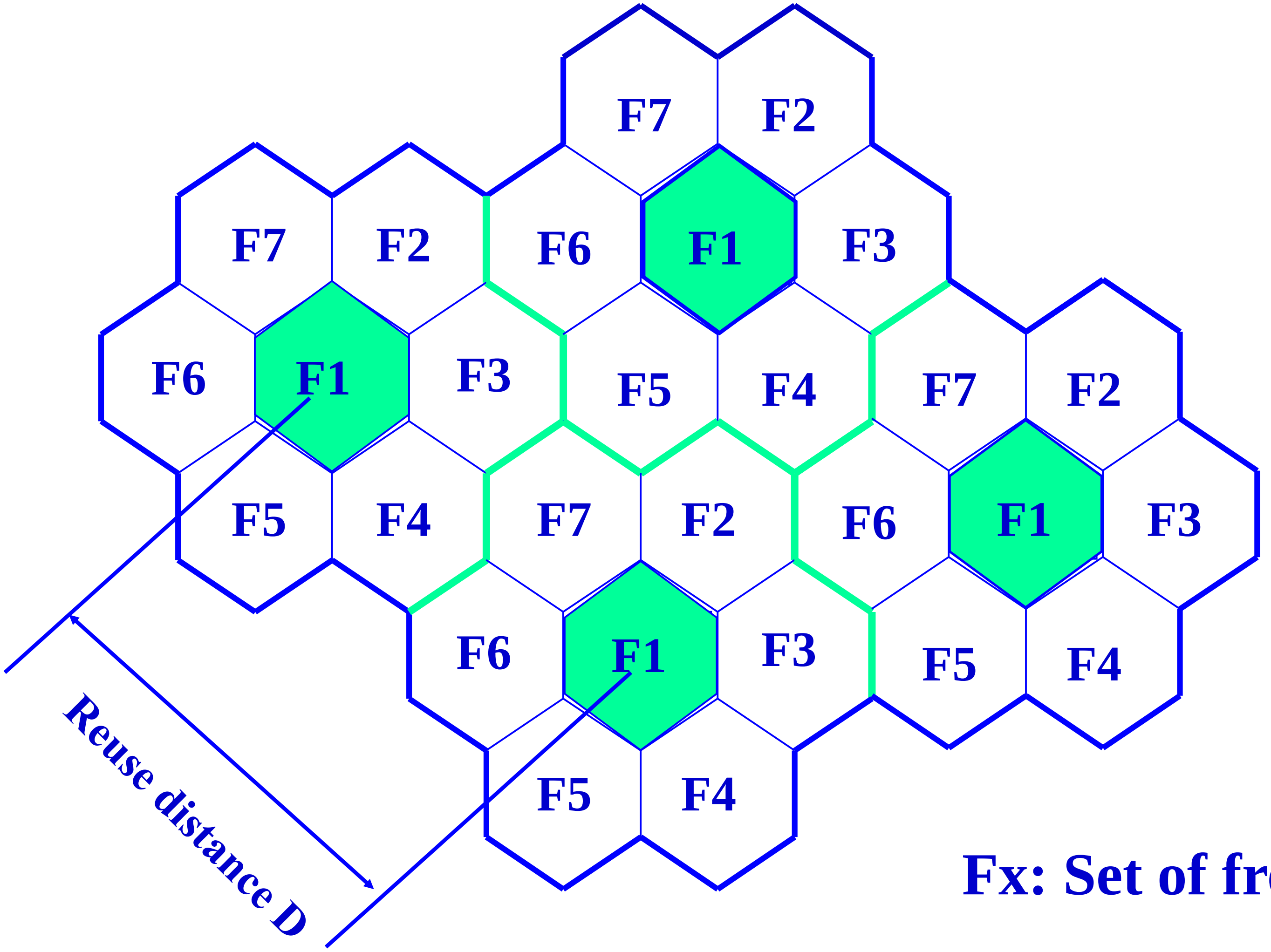


(a) Line Structure

(b) Plan Structure

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

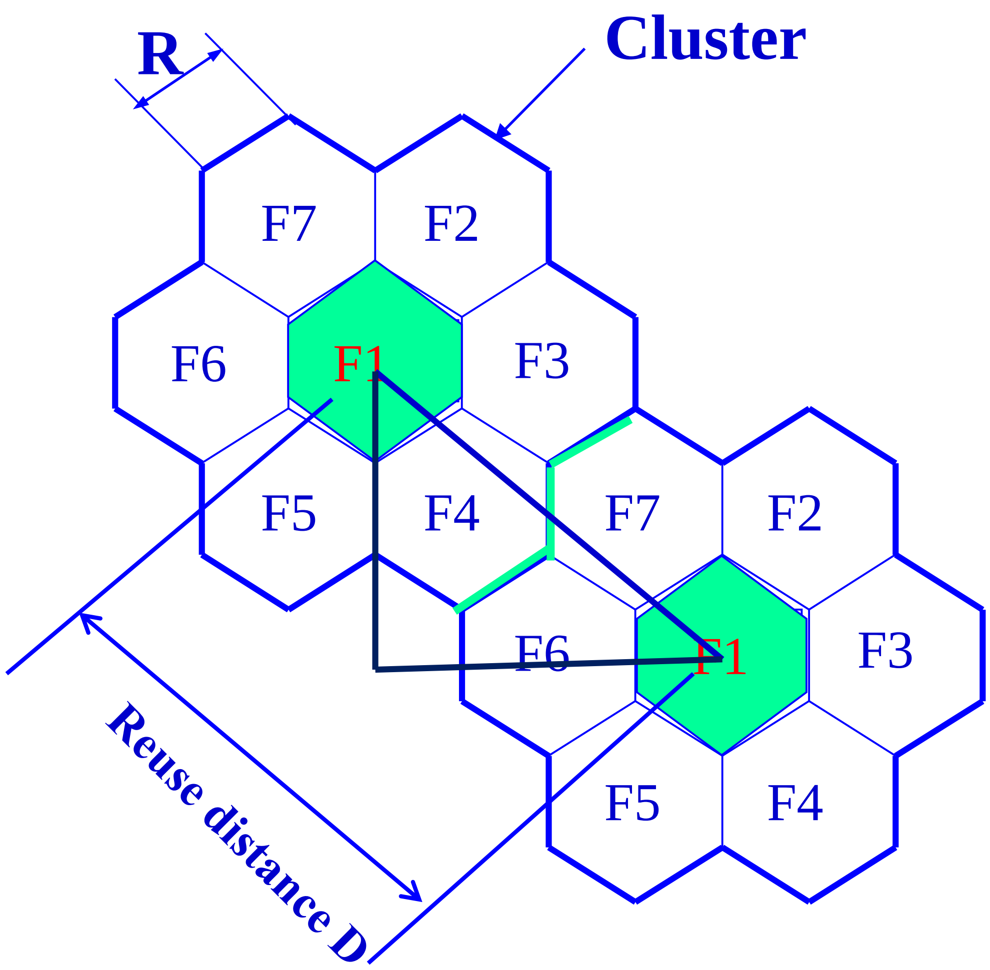
Frequency Reuse



Fx: Set of frequency

7 cell reuse cluster

Reuse Distance (1/3)



- **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**

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

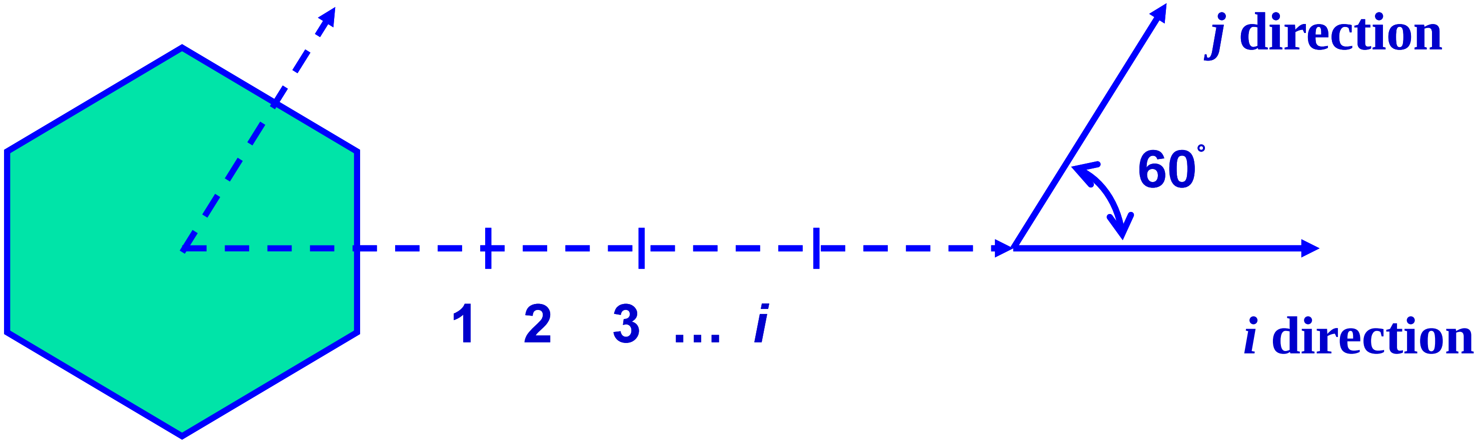
Reuse Distance (2/3)

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

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

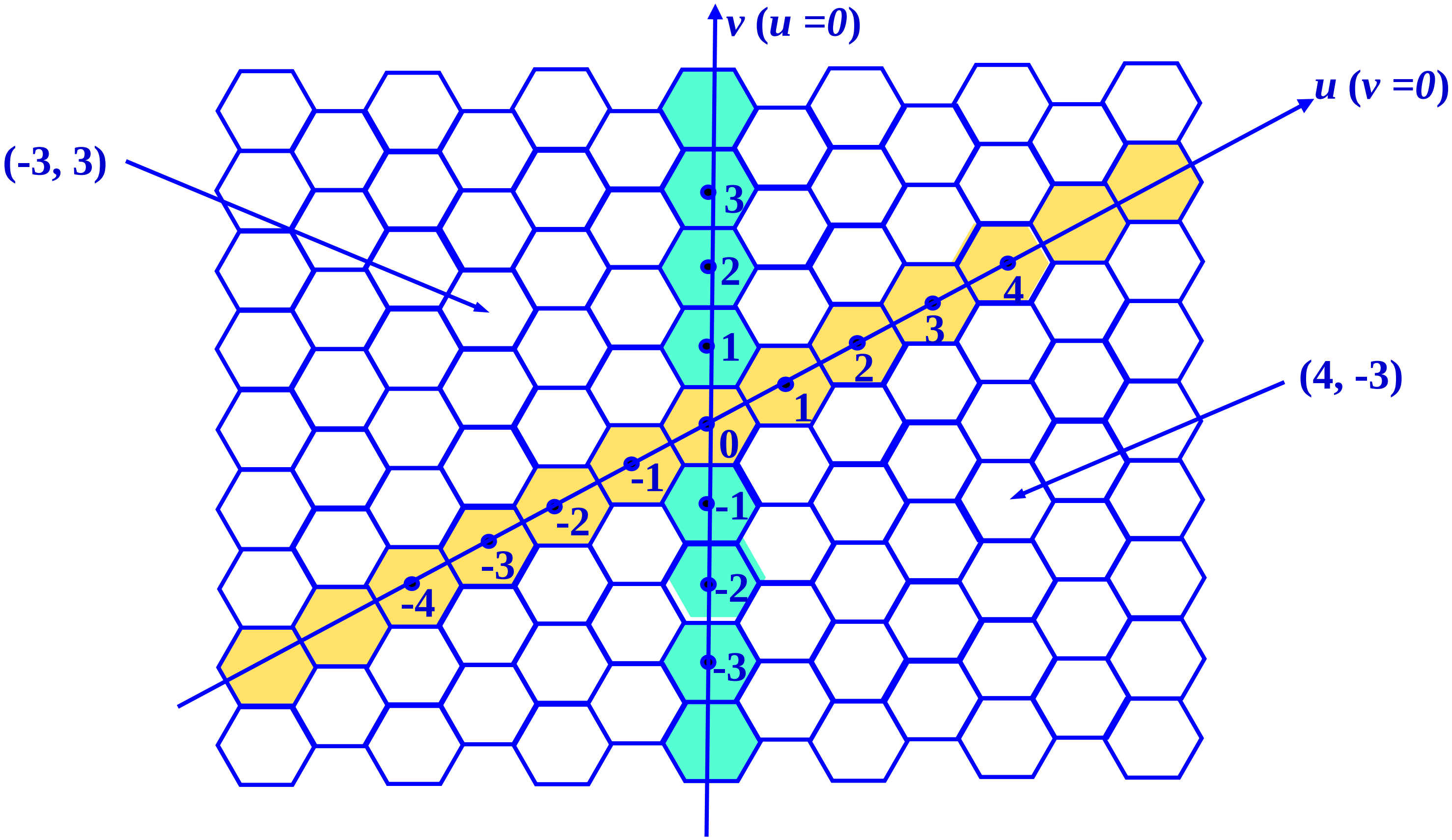
where i and j are integers

- N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, …, etc.
  The popular value of N being 4 and 7



Reuse Distance (3/3)

$$N = i^2 + ij + j^2$$ **with *i* and *j* as integers**



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

Reuse Distance and Channel Set to Use (1/2)

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

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

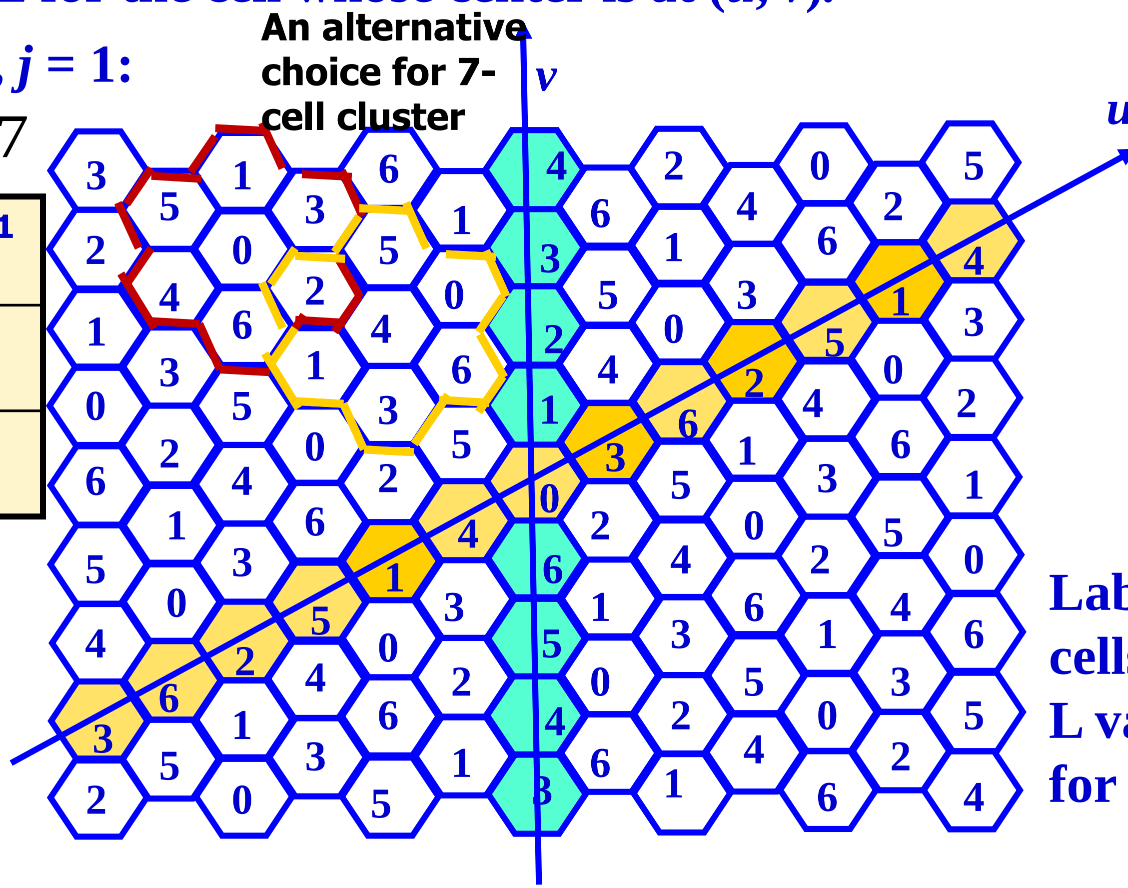
We can obtain label L for the cell whose center is at (u, v).

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

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

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

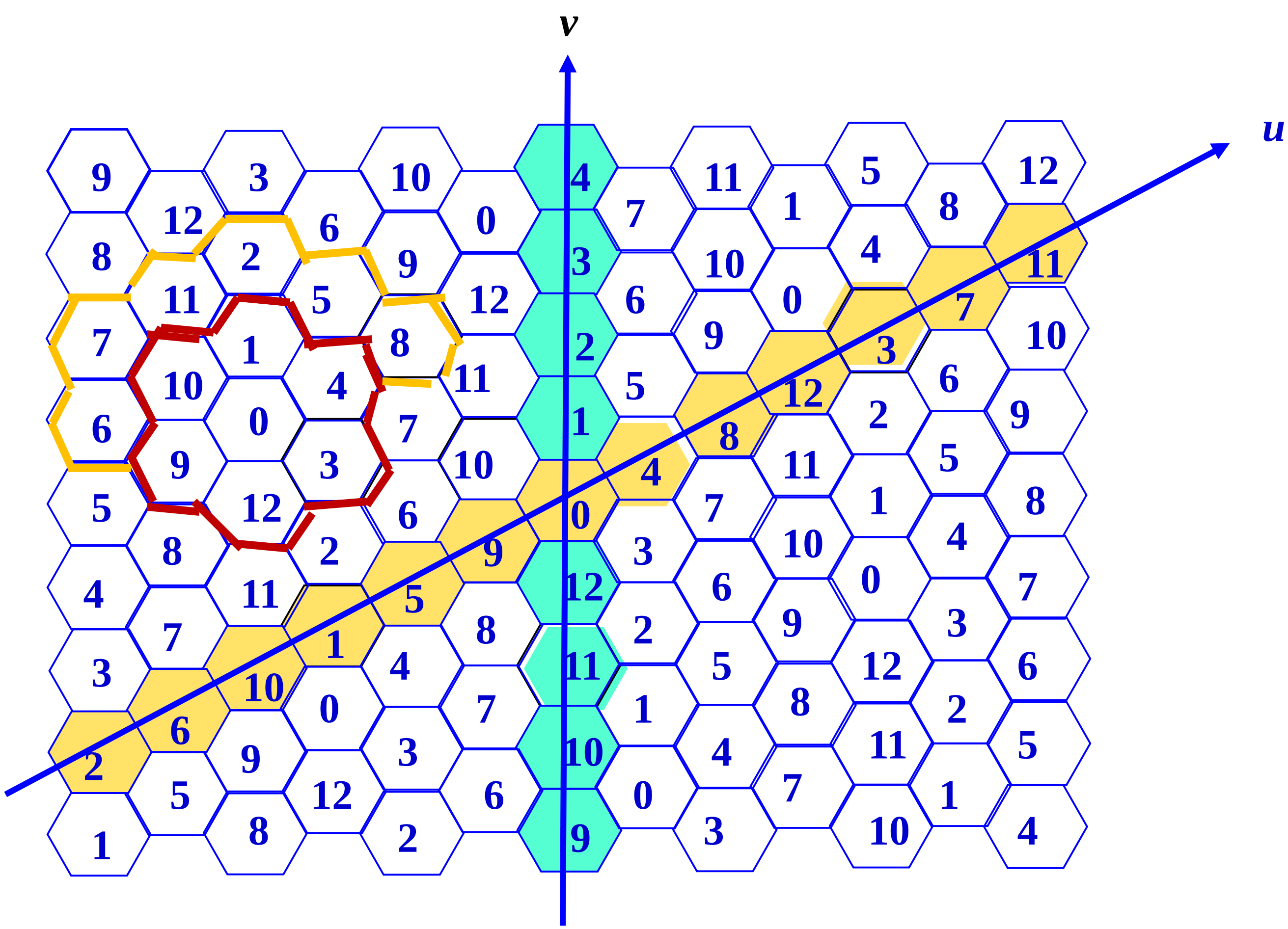


Labeling cells with L values for N=7

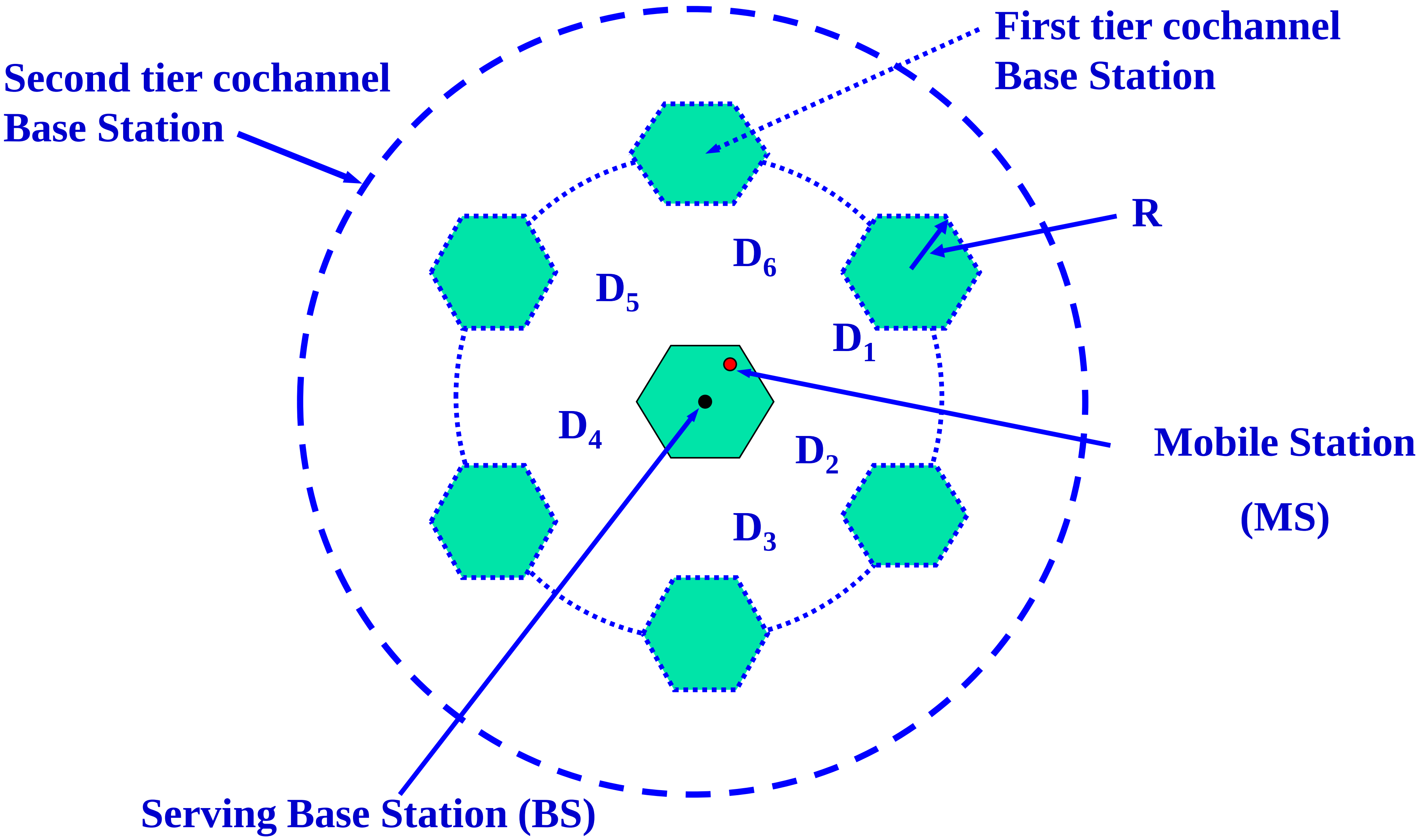
Reuse Distance and Channel set to use (2/2)

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

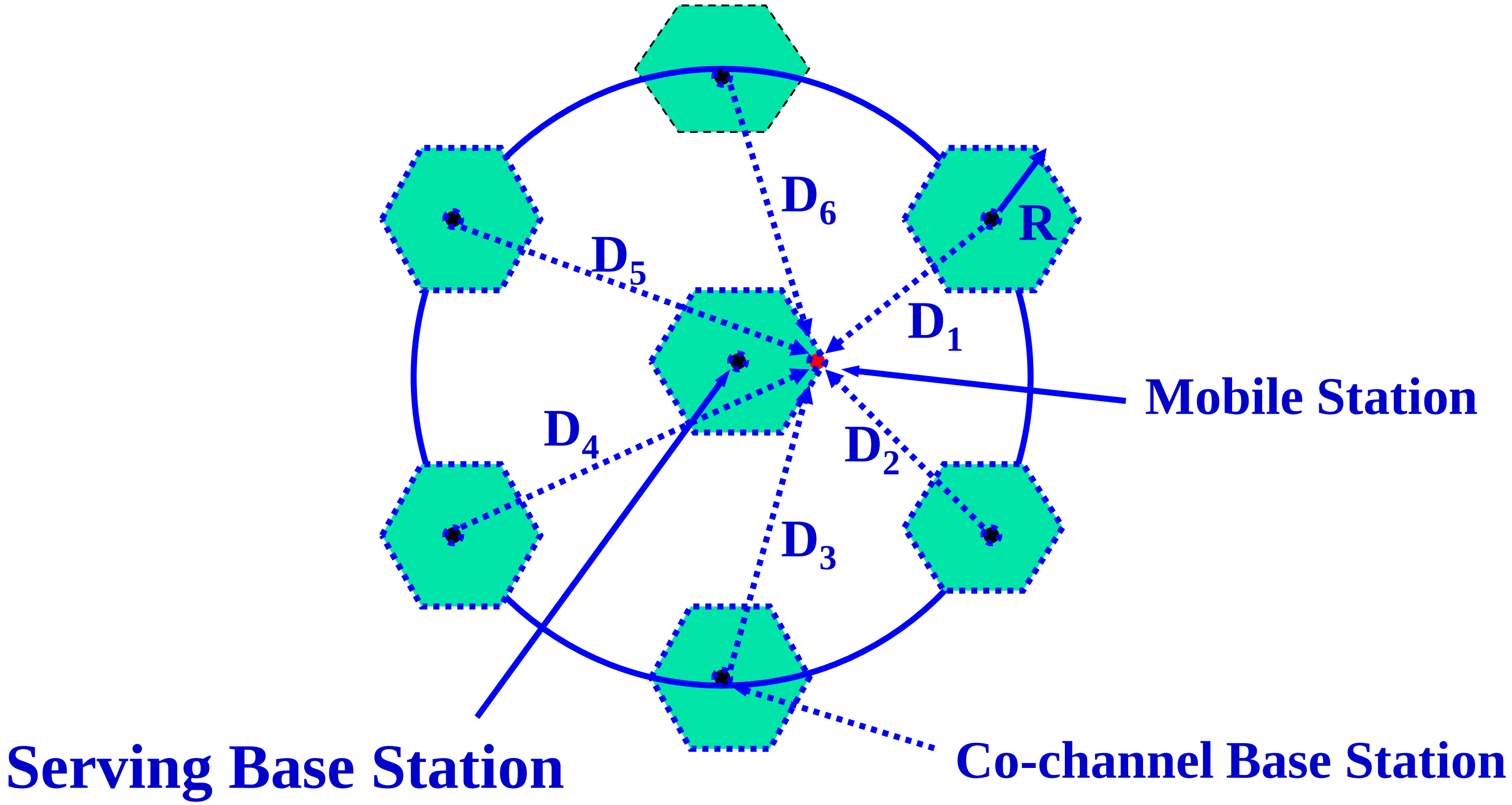
Cell labeled with L values for N = 13; 0 to 12



Co-channel Interference



Worst Case of Co-channel Interference



Co-channel Interference

- **Cochannel interference ratio is given by**

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

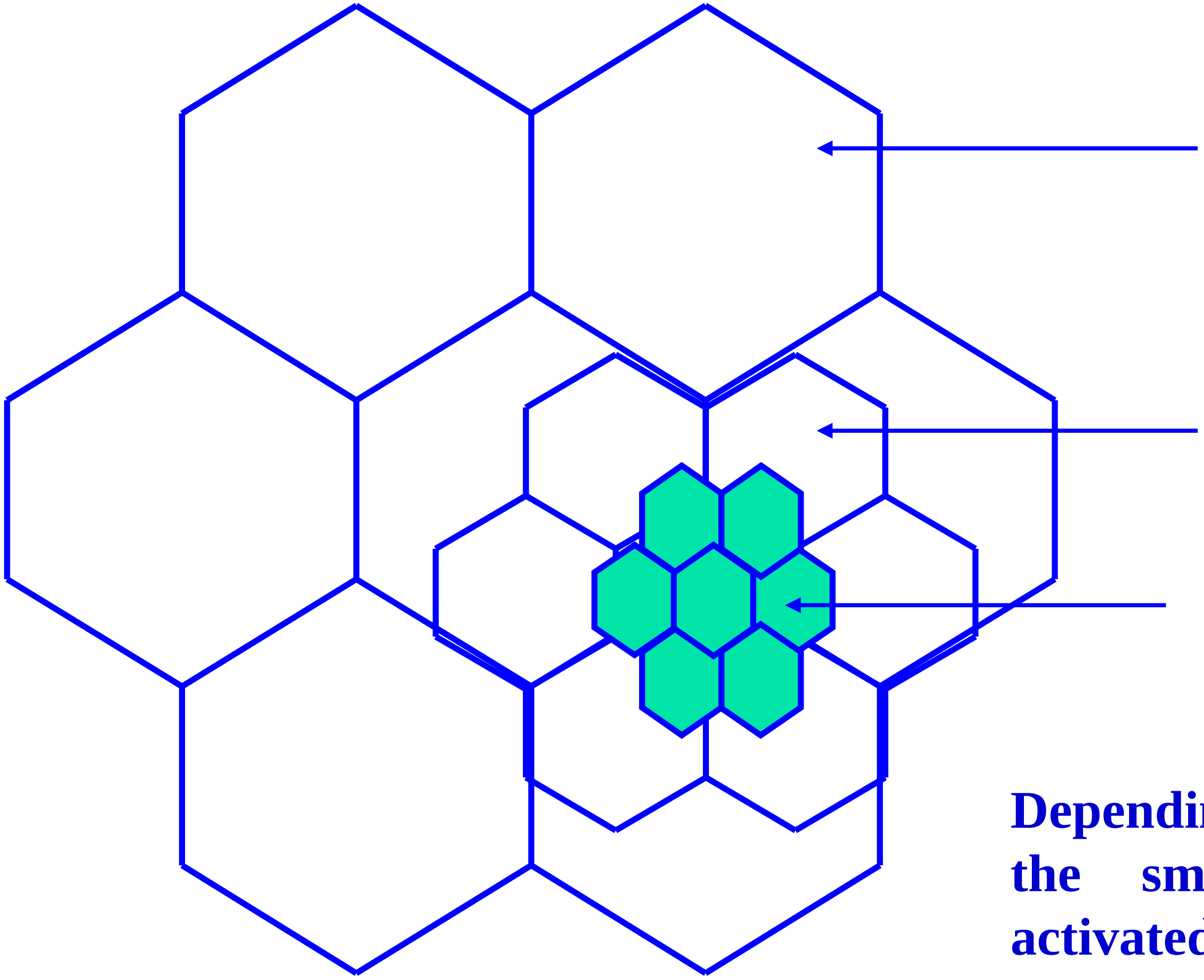
where *I* is co-channel interference and *M* is the maximum number of co-channel interfering cells

For *M* = 6, C/I is given by:

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

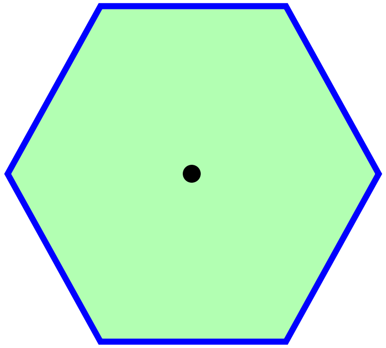
where γ is the propagation path loss slope and γ = 2 ~ 5

Cell Splitting

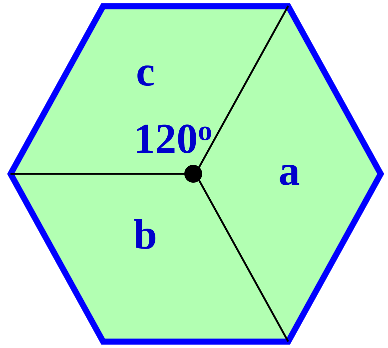


Depending on traffic patterns the smaller cells may be activated/deactivated in order to efficiently use cell resources.

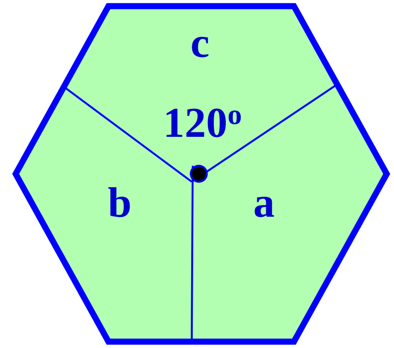
Cell Sectoring by Antenna Design (1/2)



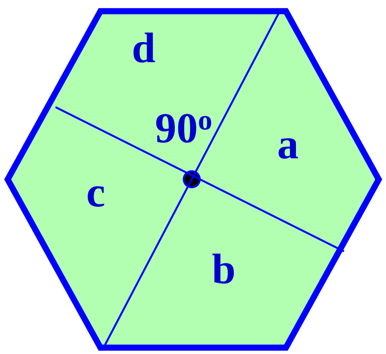
(a) Omni



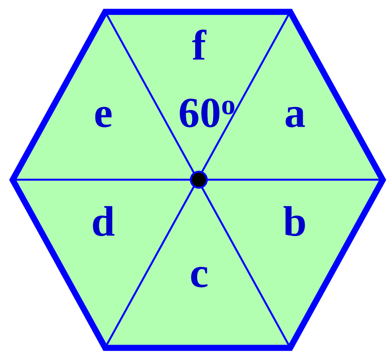
(b) 120^o sector



(c) 120^o sector (alternate)



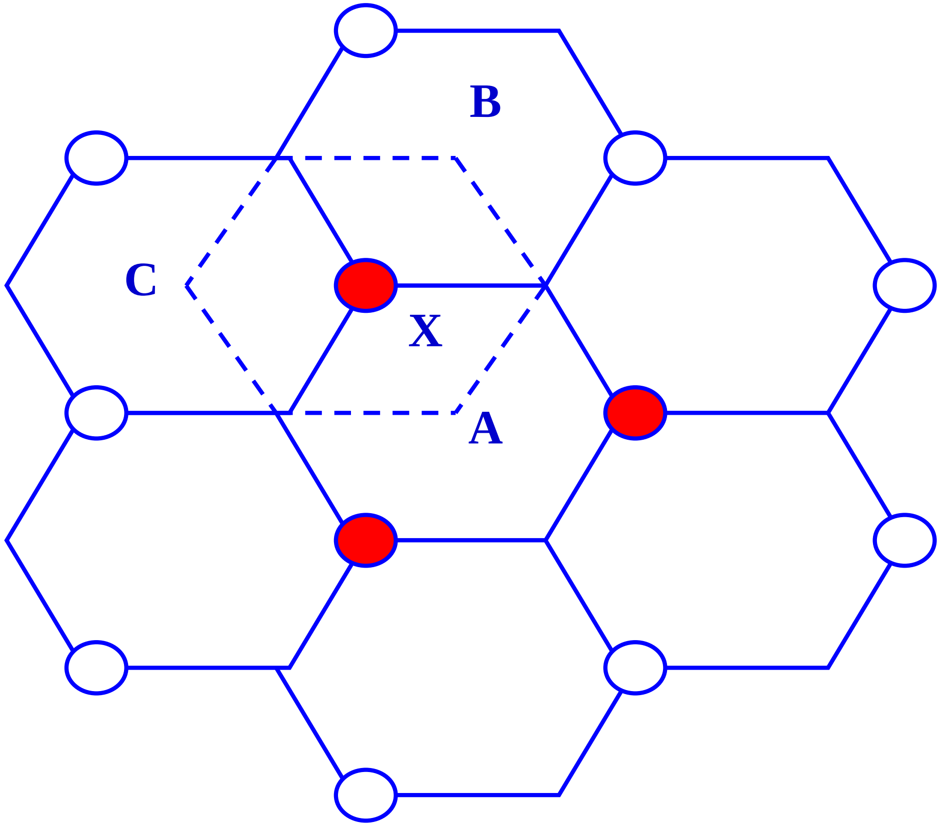
(d) 90^o sector



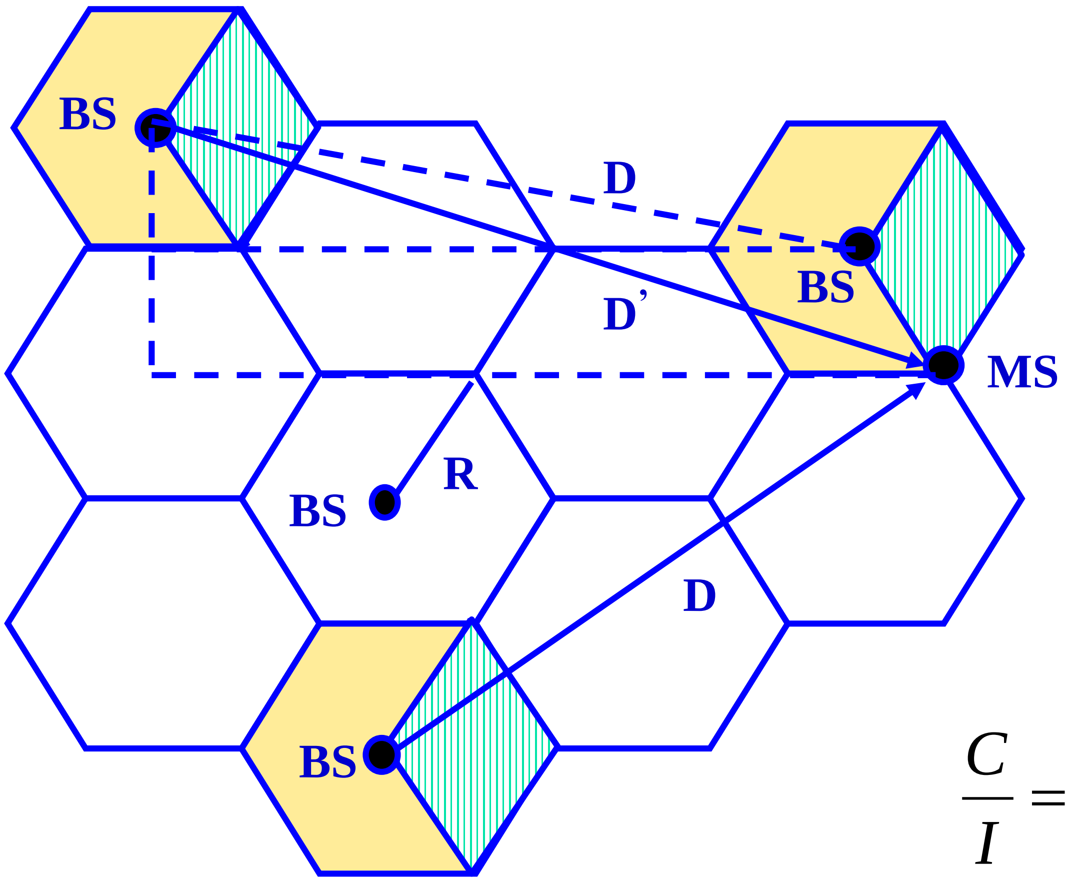
(e) 60^o sector

Cell Sectoring by Antenna Design (2/2)

- ✓ An alternative Placing directional transmitters
- ✓ at corners where three adjacent cells meet



Worst Case for Forward Channel Interference in Three-sectors

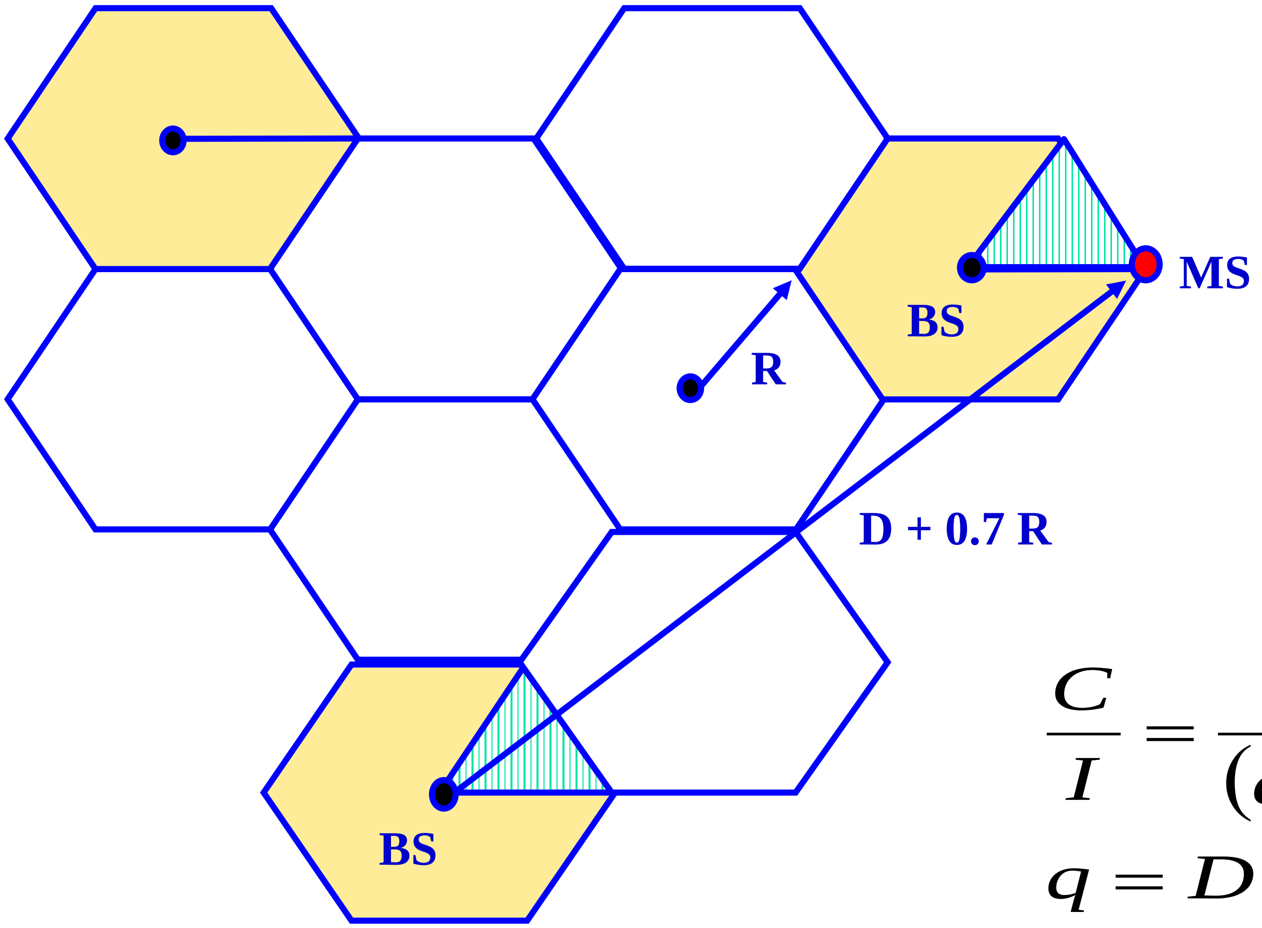


$$\frac{C}{I} = \frac{1}{q^{-\gamma} + (q + 0.7)^{-\gamma}}$$

$q = D/R = 4.58$ $D' = D + 0.7R$

where γ is the propagation path loss slope and γ = 2 ~ 5

Worst Case for Forward Channel Interference in Six-sectors



$$\frac{C}{I} = \frac{1}{\left(q + 0.7\right)^{-\gamma}}$$

$$q = D / R$$

where γ is the propagation path loss slope and γ = 2 ~ 5

Homework

- **Problem: 5.2, 5.6, 5.12, 5.15, 5.18**
- **Due: Oct. 14**