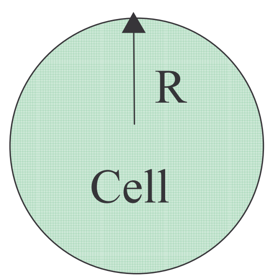
4ICT9

Cells and Cell Design Issues

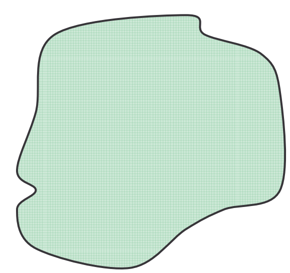
Outline

- Cell Shape
  - Actual cell/Ideal cell
- Signal Strength
- Handoff Region
- Cell Capacity
  - Traffic theory
  - Erlang B and Erlang C
- Cell Structure
- Frequency Reuse
- Reuse Distance
- Cochannel Interference
- Cell Splitting
- Cell Sectoring

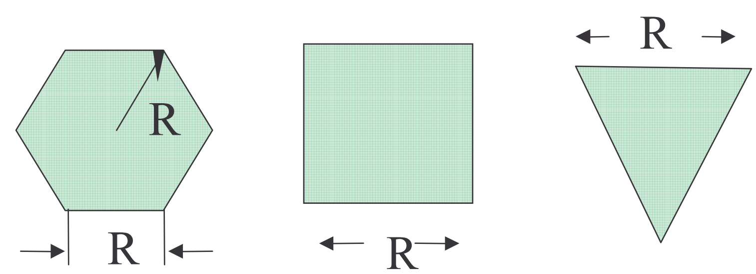
Cell Shape



(a) Ideal cell



(b) Actual cell

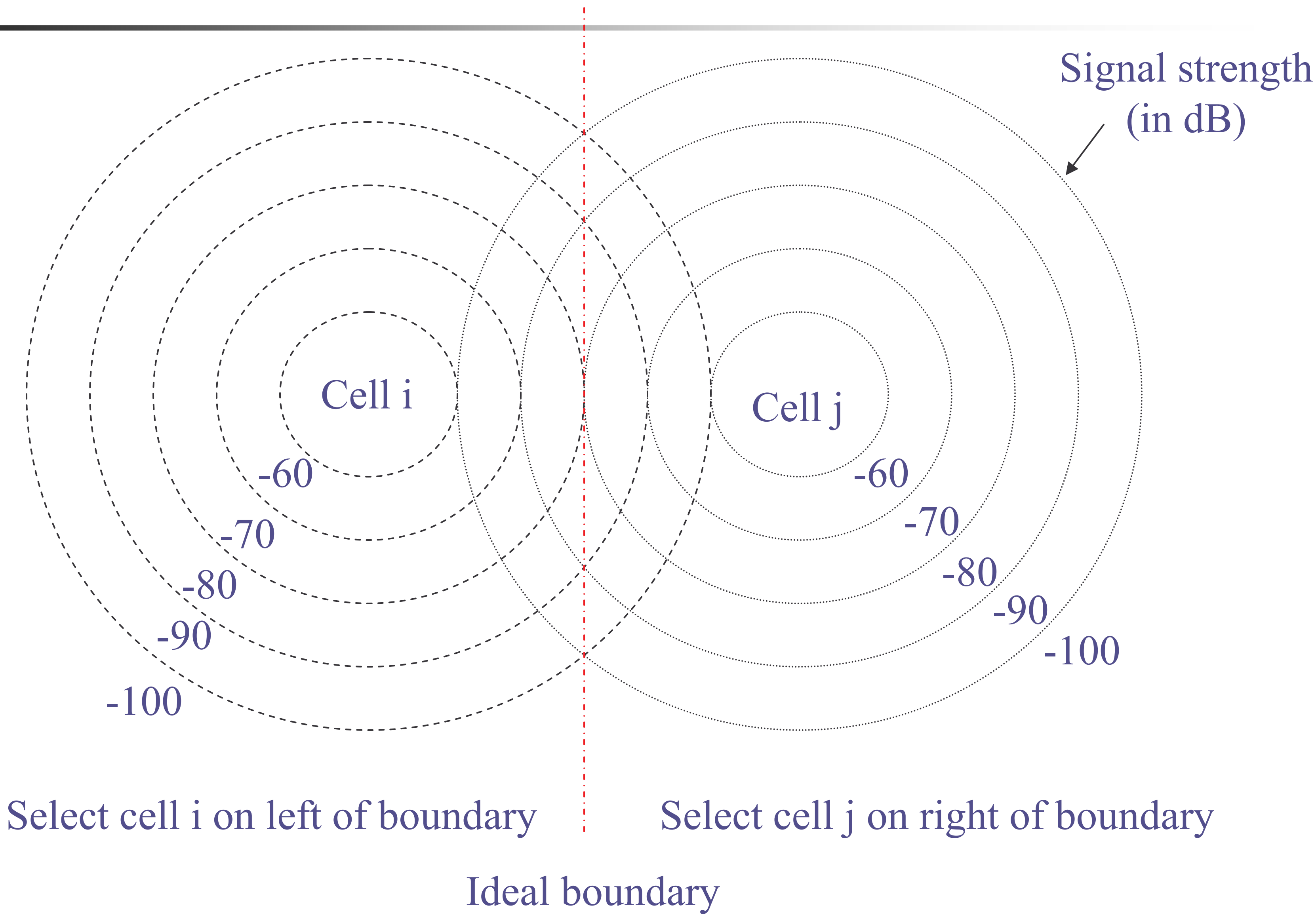


(c) Different cell models

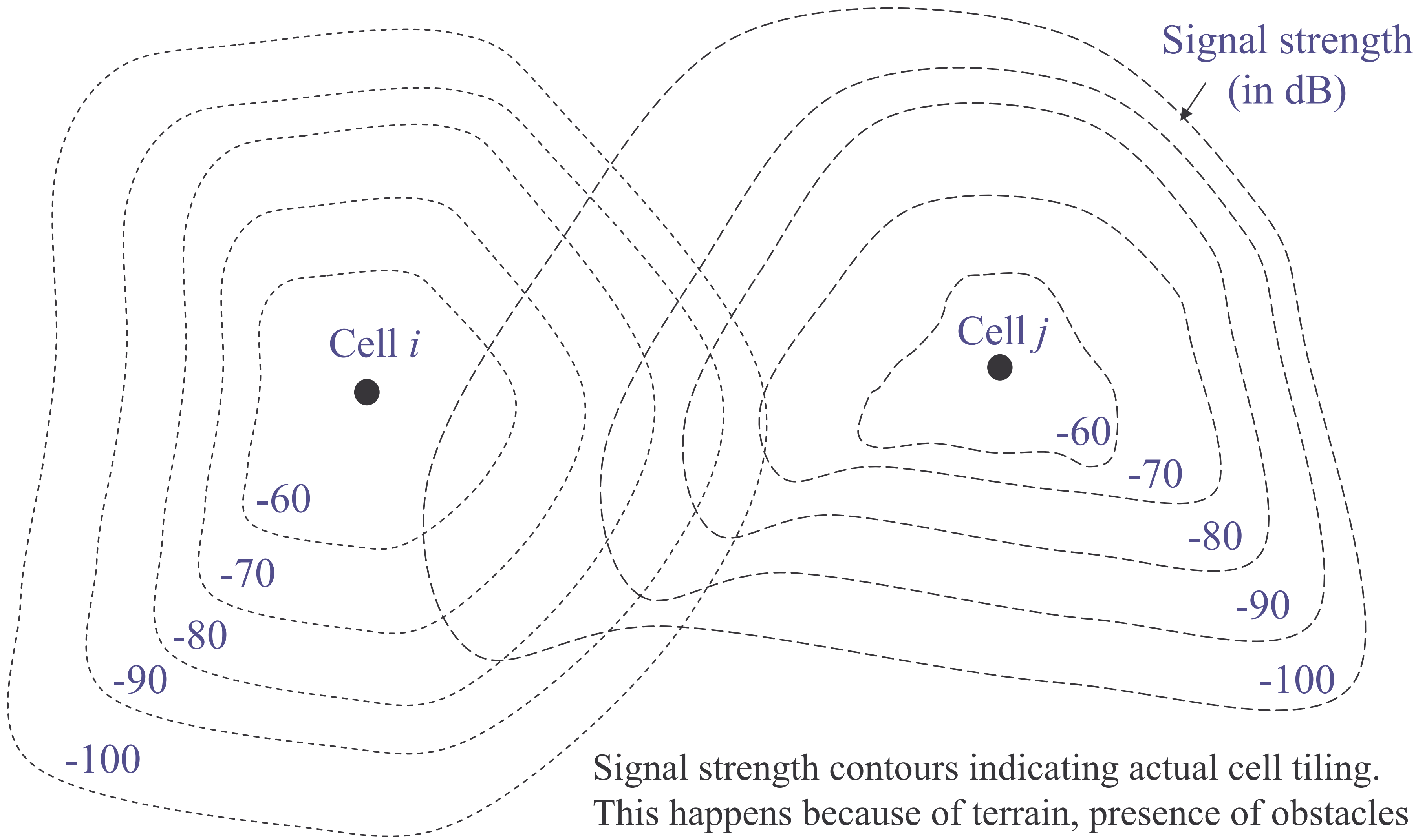
Impact of Cell Shape and Radius on Service Characteristics

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

Signal Strength

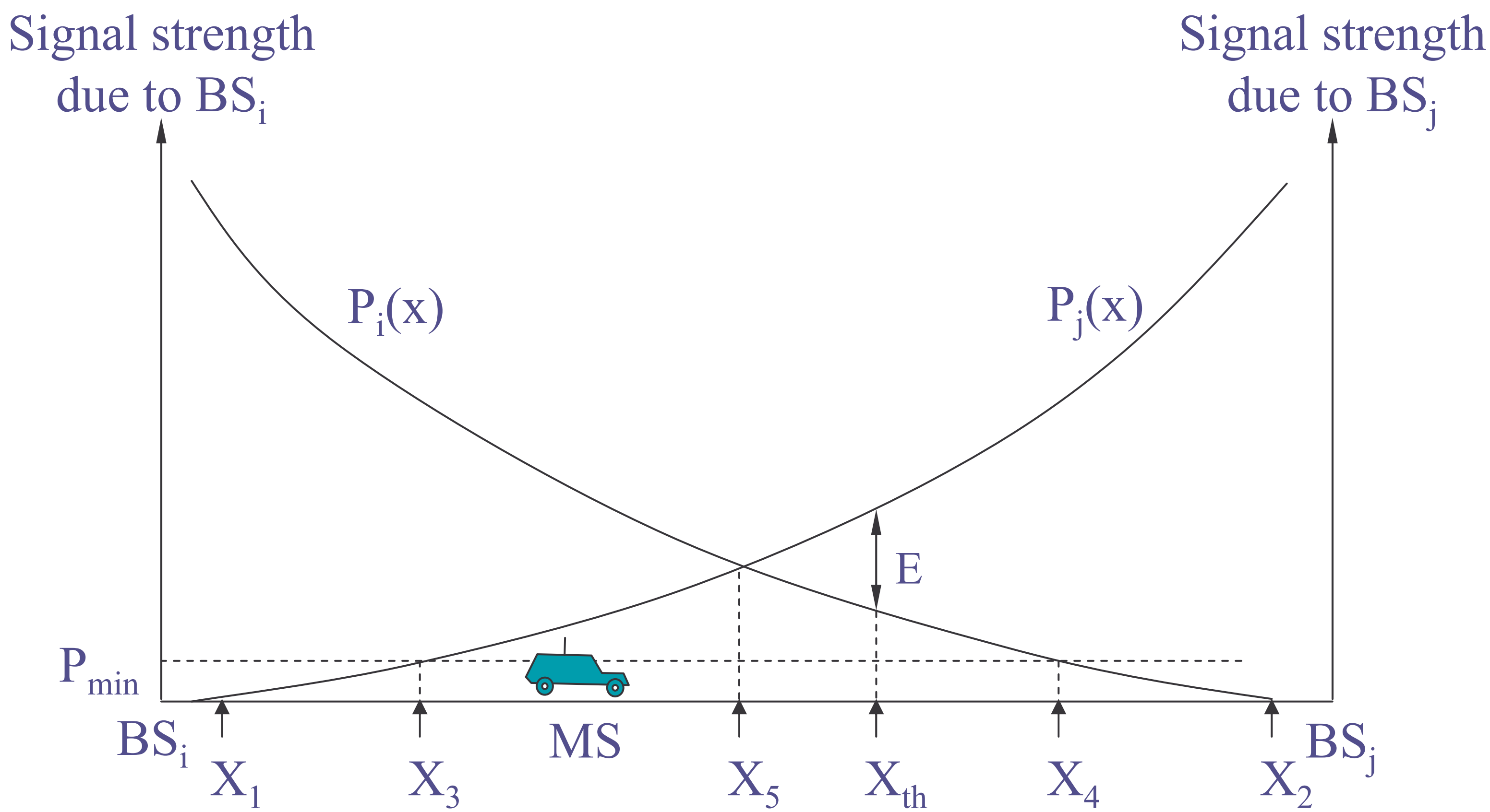


Signal Strength



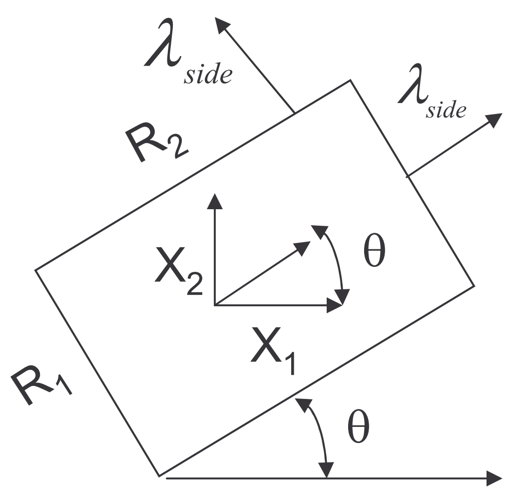
Signal strength contours indicating actual cell tiling. This happens because of terrain, presence of obstacles and signal attenuation in the atmosphere.

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 Rate in a Rectangular



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

$$\lambda_H = R_1(X_1\cos\theta + X_2\sin\theta) + R_2(X_1\sin\theta + X_2\cos\theta)$$

where $A = R_1 R_2$ is the area and assuming it constant, differentiate with respect to R_1 (or R_2) gives

$$R_1^2 = A\frac{X_1\sin\theta + X_2\cos\theta}{X_1\cos\theta + X_2\sin\theta} \qquad R_2^2 = A\frac{X_1\cos\theta + X_2\sin\theta}{X_1\sin\theta + X_2\cos\theta}$$

Total handoff rate is

$$\lambda_H = 2\sqrt{A(X_1\cos\theta + X_2\sin\theta)(X_1\sin\theta + X_2\cos\theta)}$$

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

$$\lambda_H = 2\sqrt{AX_1X_2} \qquad and \qquad \frac{R_1}{R_2} = \frac{X_1}{X_2}$$

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 $\lambda=30/3600$ 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 during a short interval t is given by λt
- Assuming Poisson distribution of service requests, the probability $P(n, t)$ for n calls to arrive in an interval of length t is given by

$$P(n,t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}$$

- Assuming μ to be the service rate, probability of each call to terminate during interval t is given by μt.

  Thus, probability of a given call requires service for time t or less is given by

$$S(t) = 1 - e^{-\mu t}$$

Erlang B and Erlang C

- Probability of an arriving call being blocked is

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

where S is the number of channels in a group.

- Probability of an arriving call being delayed is

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

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

Efficiency (Utilization)

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

$$= \frac{Erlangs \times portions\ of\ nonrouted\ \ traffic}{Number\ of\ trunks\ (channels)}$$

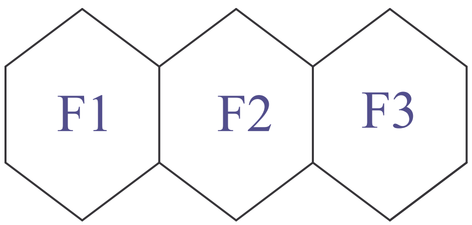
- Example: for previous example, if S=2, then

  B(S, a) = 0.6, ------ Blocking probability, i.e., 60% calls are blocked.

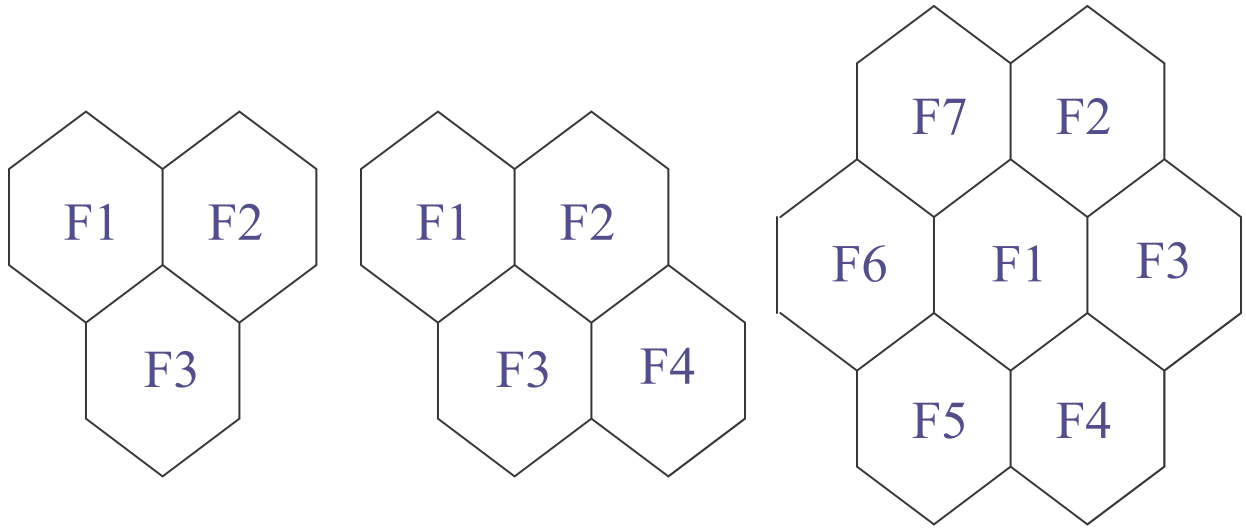
  Total number of rerouted calls = 30 x 0.6 = 18

  Efficiency = 3(1-0.6)/2 = 0.6

Cell Structure



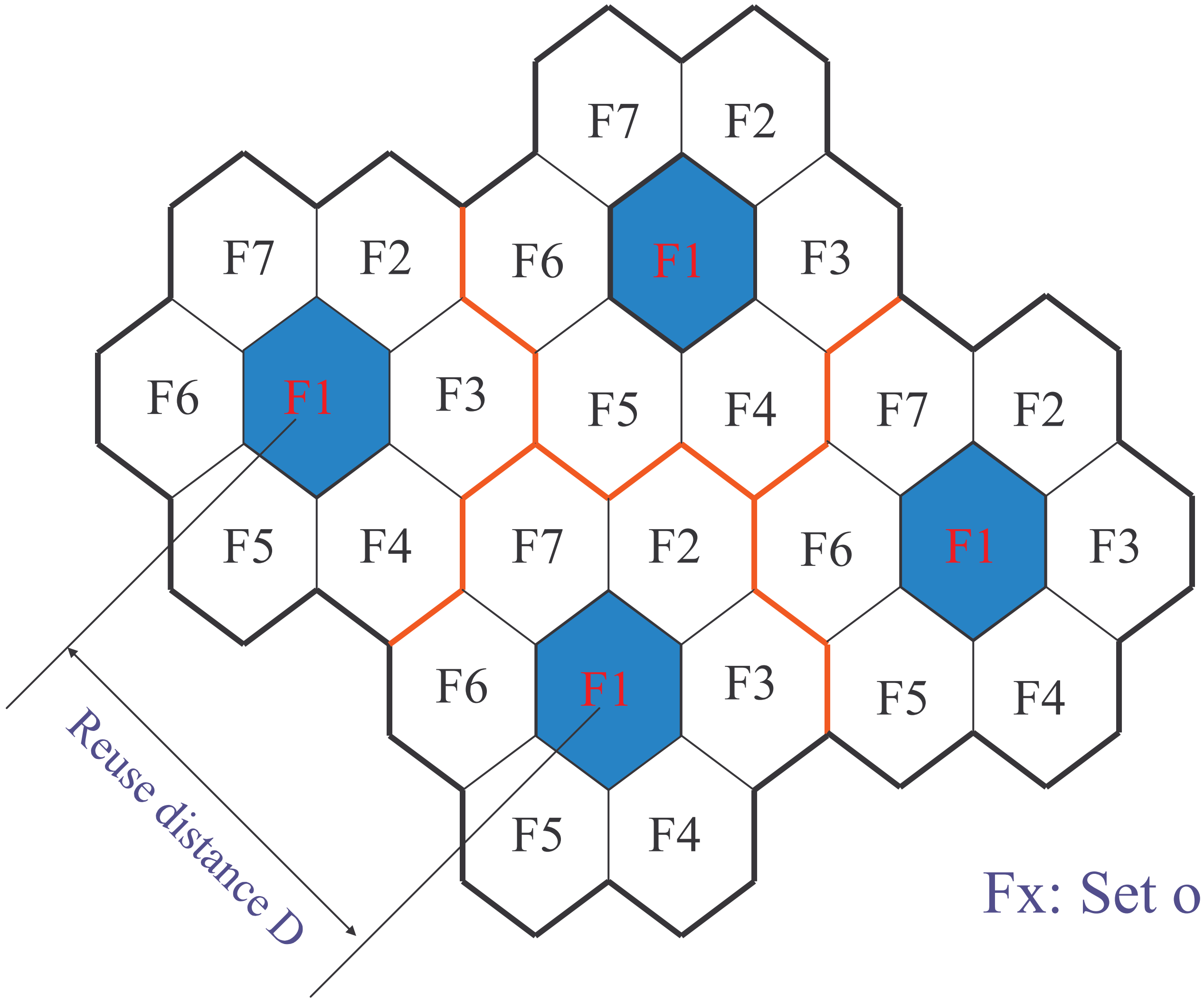
(a) Line Structure



(b) Plan Structure

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

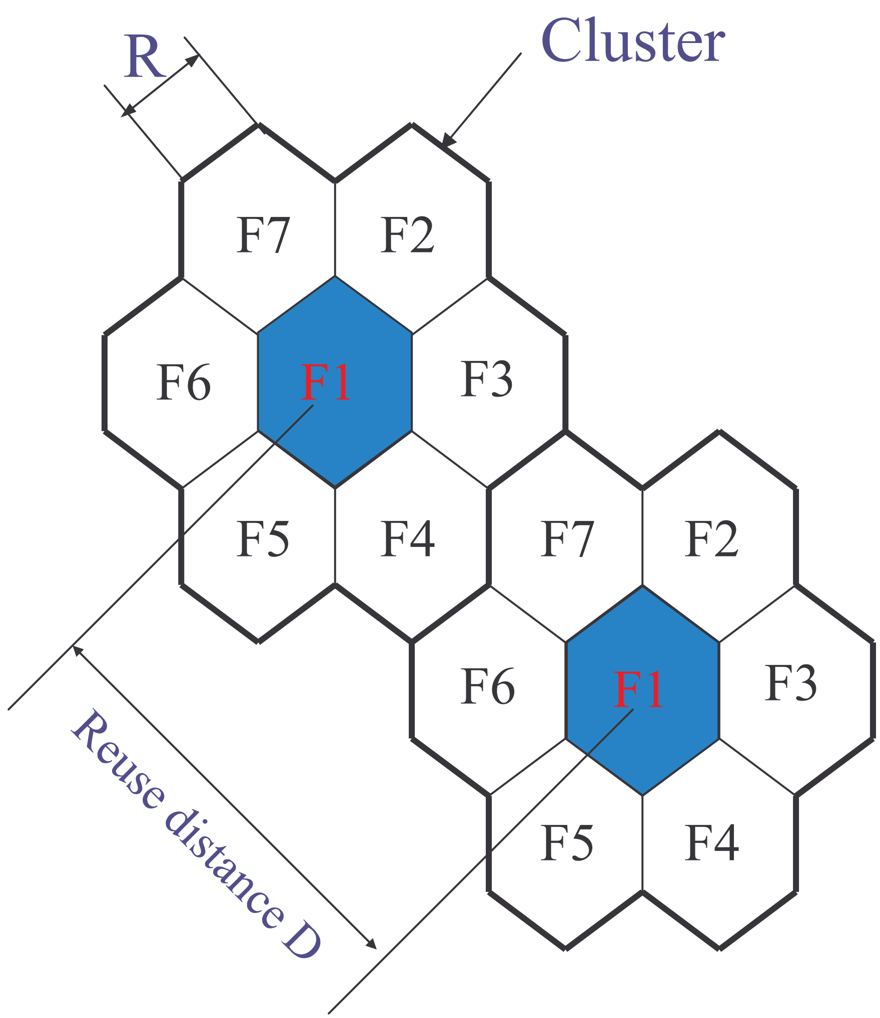
Frequency Reuse



7 cell reuse cluster

Fx: Set of frequency

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

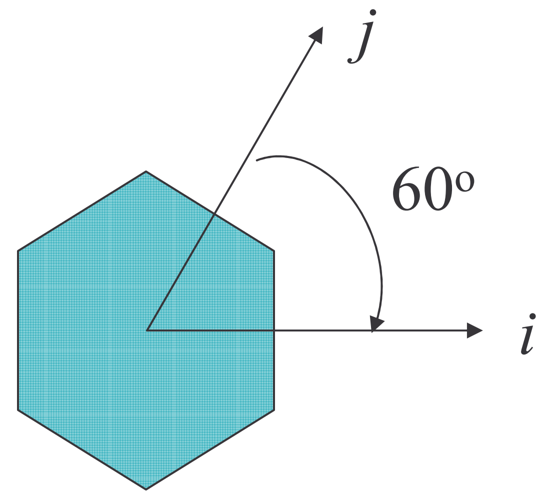
$$q = \frac{D}{R} = \sqrt{3N}$$

Reuse Distance (Cont'd)

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

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

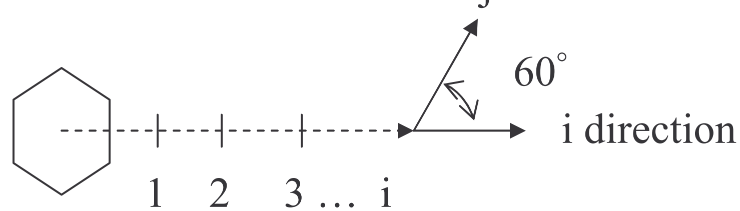
where i and j are integers.



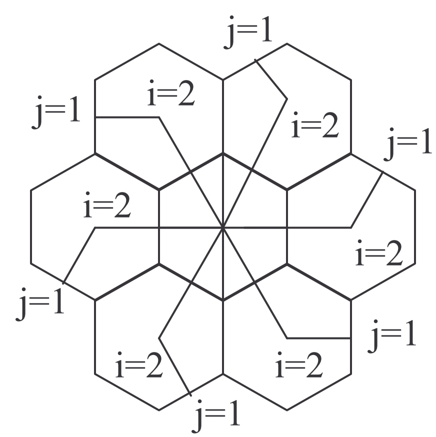
- N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 28, …, etc.

The popular value of N being 4 and 7.

Reuse Distance (Cont'd)

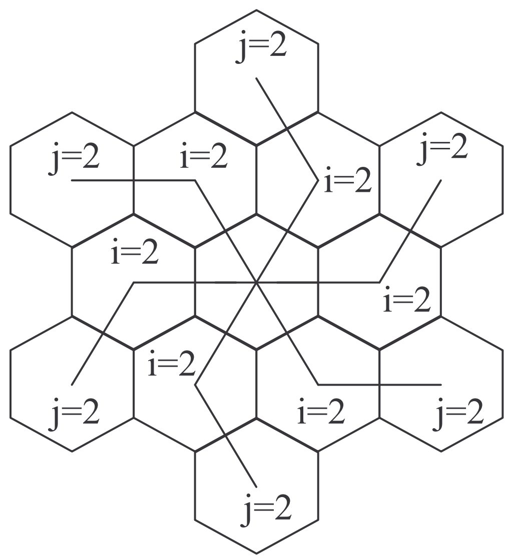


(a) Finding the center of an adjacent cluster using integers i and j (direction of i and j can be interchanged).

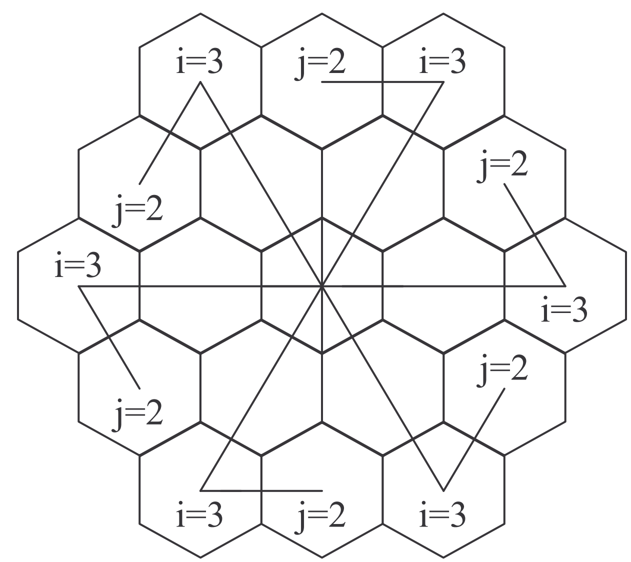


(b) Formation of a cluster for N = 7 with i=2 and j=1

Reuse Distance (Cont’d)

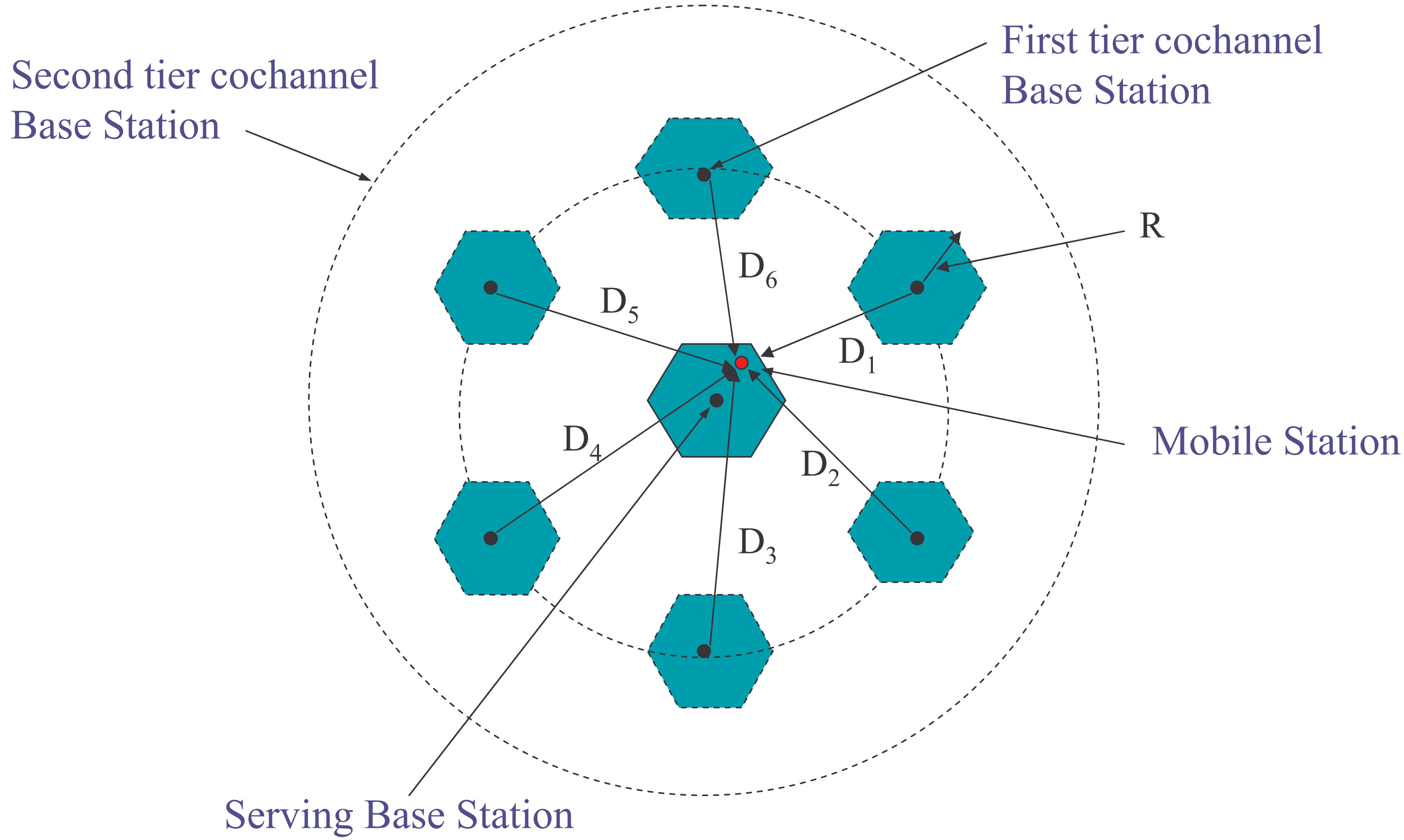


(c) A cluster with N =12 with i=2 and j=2

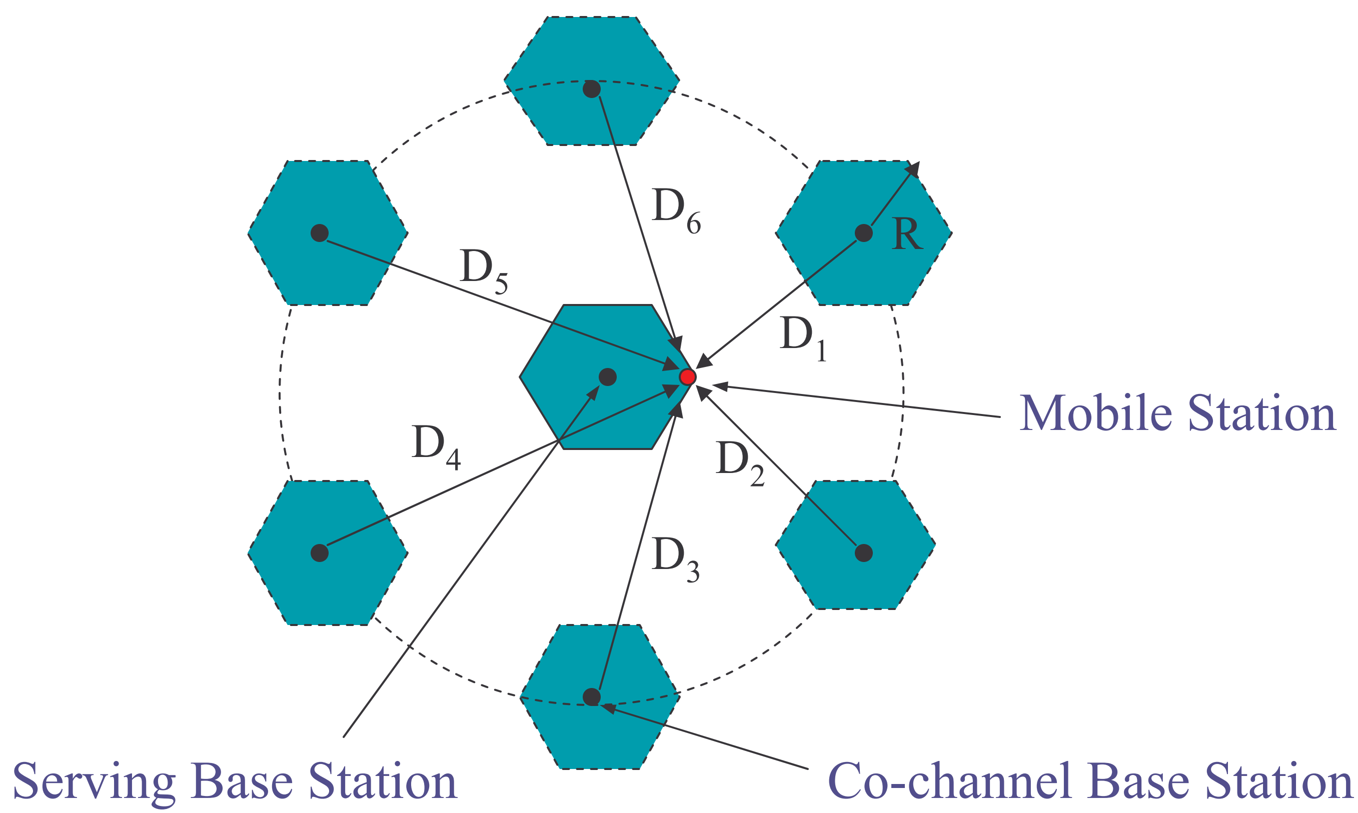


(d) A Cluster with N = 19 cells with i=3 and j=2

Cochannel Interference



Worst Case of Cochannel Interference



Cochannel Interference

- Cochannel interference ratio is given by

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

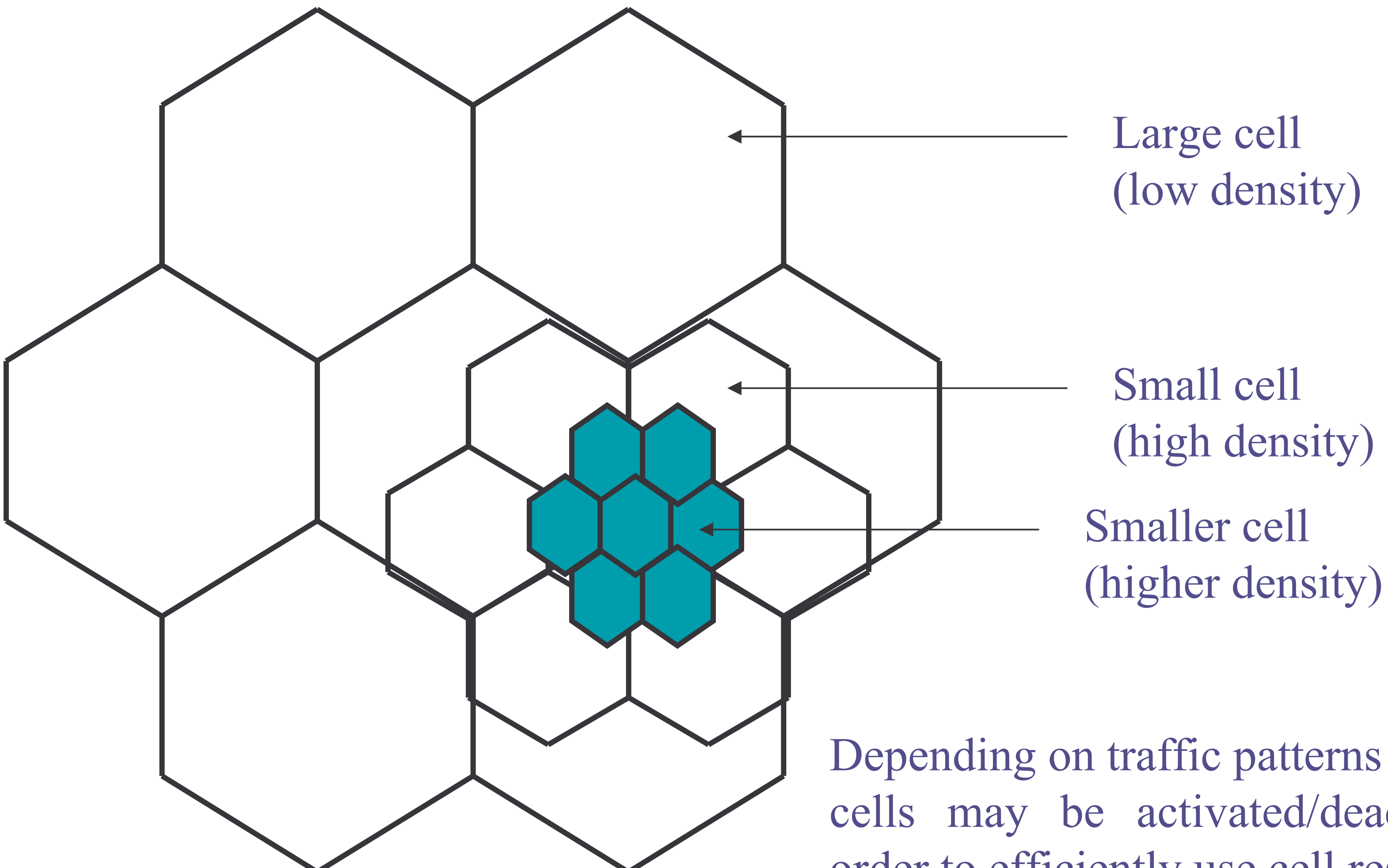
where I is co-channel interference and M is the maximum number of co-channel interfering cells.

For M = 6, C/I is given by

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

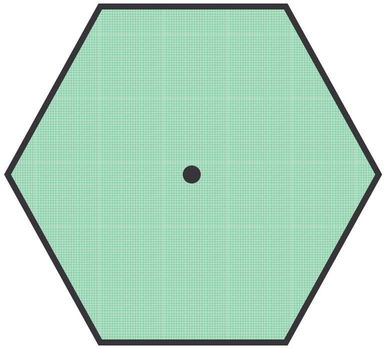
where γ is the propagation path loss slope and $\gamma = 2\sim5$.

Cell Splitting

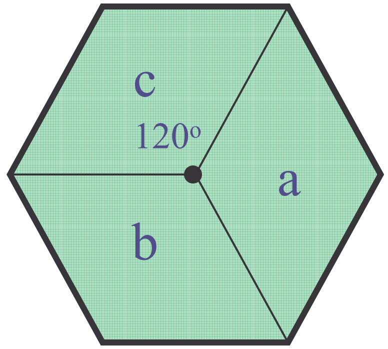


Depending on traffic patterns the smaller cells may be activated/deactivated in order to efficiently use cell resources.

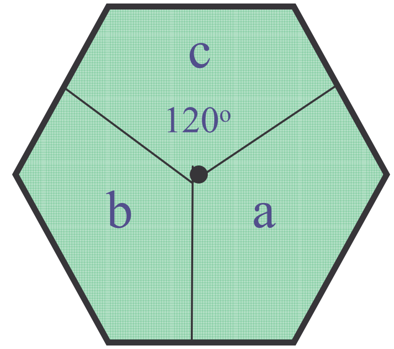
Cell Sectoring by Antenna Design



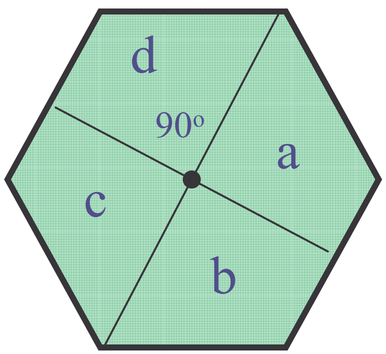
(a). Omni



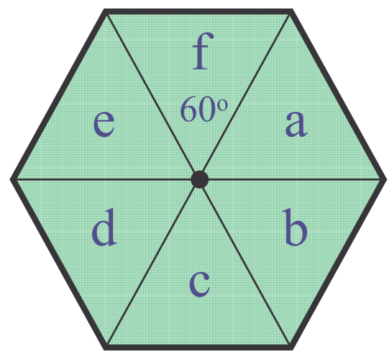
(b). 120° sector



(c). 120° sector (alternate)



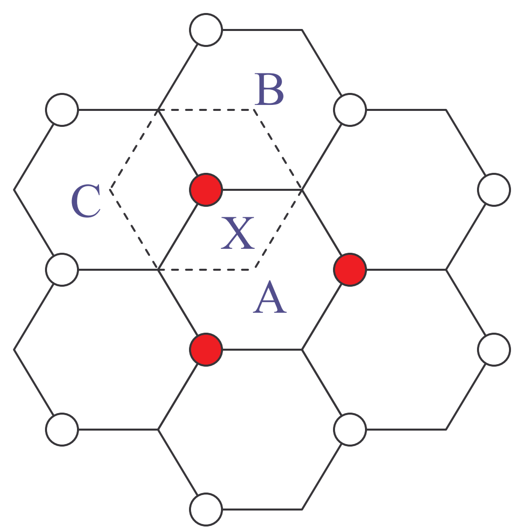
(d). 90° sector



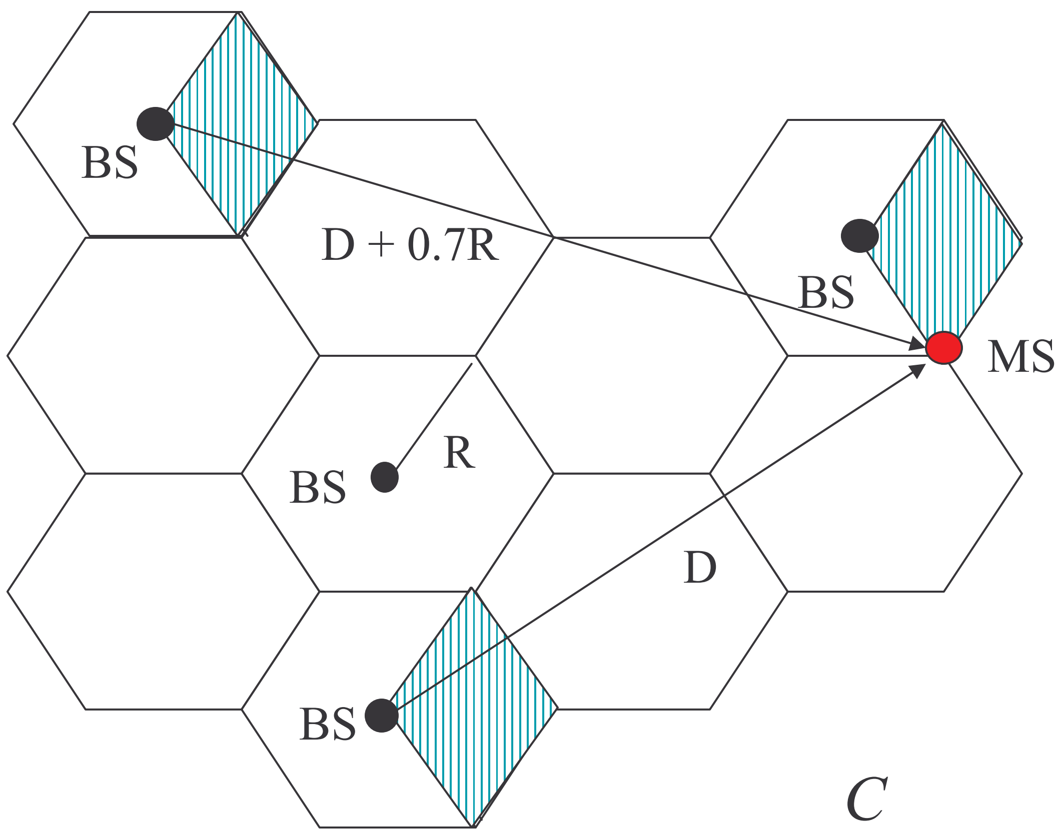
(e). 60° sector

Cell Sectoring by Antenna Design

- Placing directional transmitters at corners where three adjacent cells meet



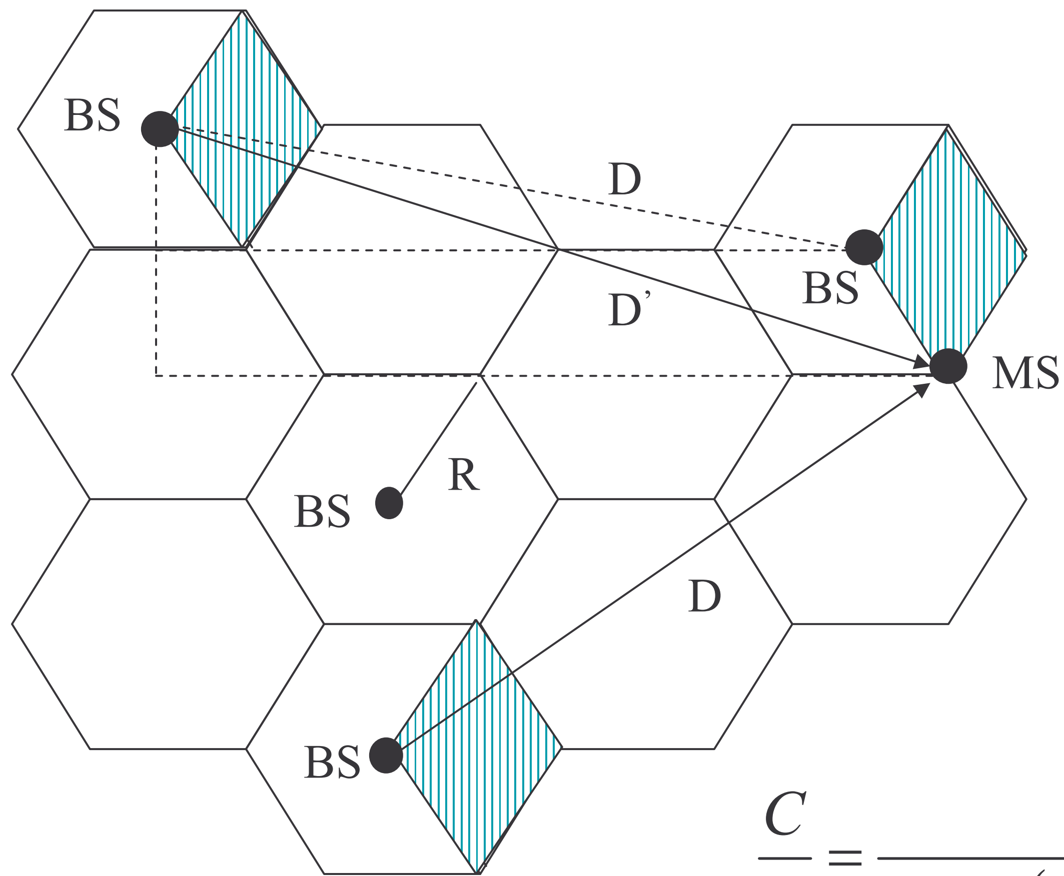
Worst Case for Forward Channel Interference in Three-sectors



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

$$q = D / R$$

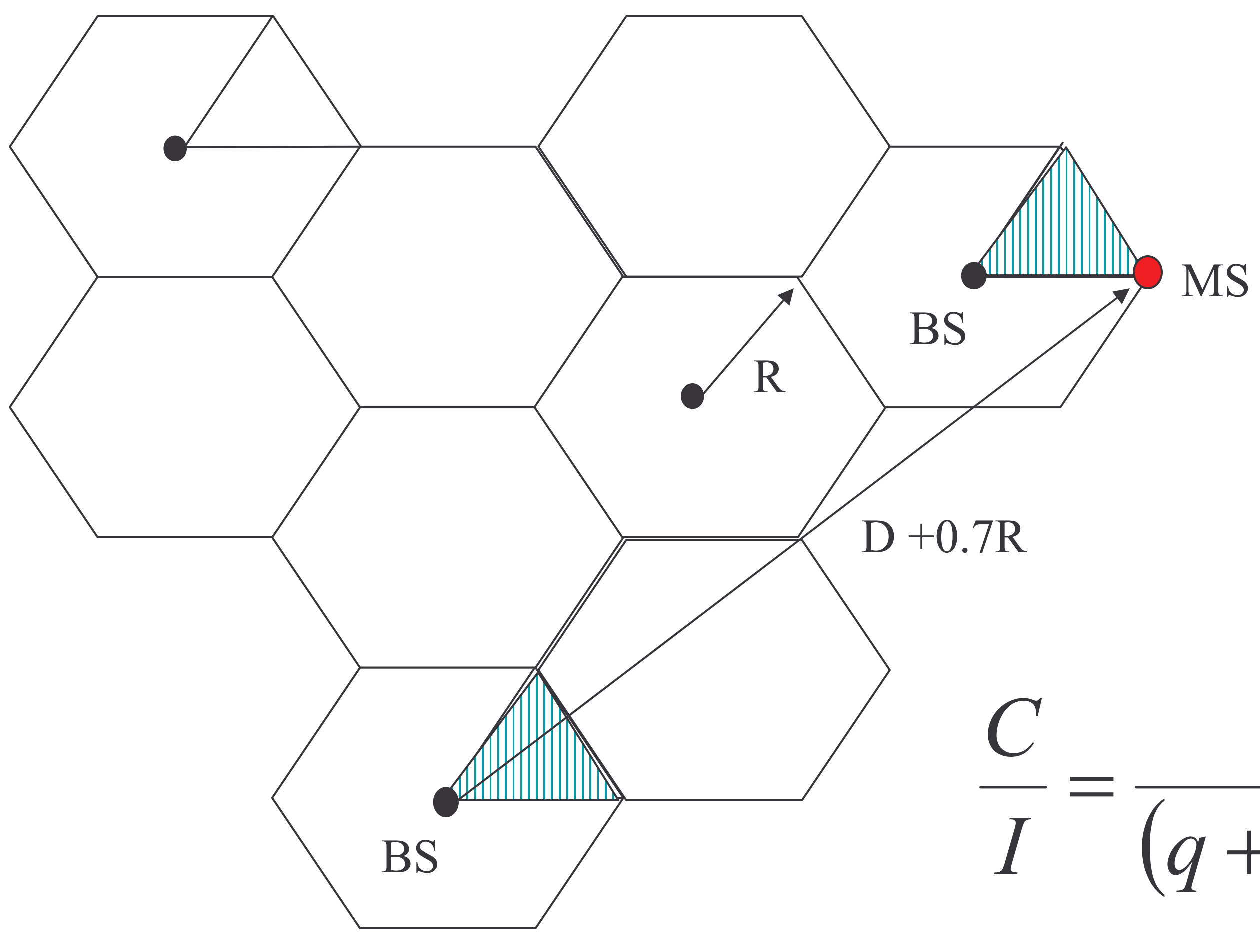
Worst Case for Forward Channel Interference in Three-sectors (Cont'd)



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

$$q = D / R$$

Worst Case for Forward Channel Interference in Six-sectors



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

$$q = D/R$$