# Wireless Communications

EENG 5820

Lecture 3

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# Today

- Interference and System Capacity
- Trunking and Grade of Service
- Improving Coverage and Capacity in Cellular Systems

# Co-Channel Interference

- Co-channels are nearby channels with the same frequency
- Co-channel interference causes
  - Voice channel: loss of quality
  - Control channel: dropped calls
- Increasing SNR does NOT solve co-channel interference (in fact, it can make it worse)
- Reduce co-channel interference by increasing distance between co-channels
  - R (Radius of each cell), D (Distance between center of cells)
  - Q = co-channel reuse ratio = D/R = $\sqrt{3N}$
    - Small Q increases system capacity
    - Small Q increases co-channel interference

# Co-Channel Interference

## Signal-to-interference ratio

- S = signal strength (power)
- I = co-channel interference strength (power)
- $I_i$ = power of co-channel interference from $i^{th}$ cell

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

**Typical S/I must be 15 – 18 dB for good reception**

# Co-Channel Interference

## In the case of Hexagonal cells

- $S = P_0$ = worst-case signal is measured at the outer edge of the cell
- $d_0$ = distance to where S is measured = R
- $I_i = P_r$ = power of interference from the $i^{th}$ cell
- d = distance to the $i^{th}$ cell $D_i$

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}}$$

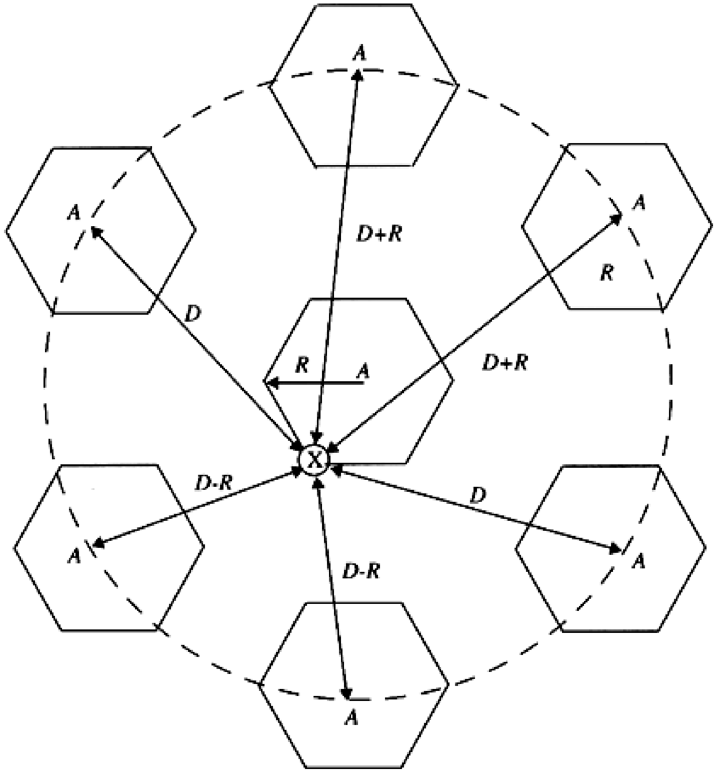
First layer →

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0}$$

# Co-Channel Interference

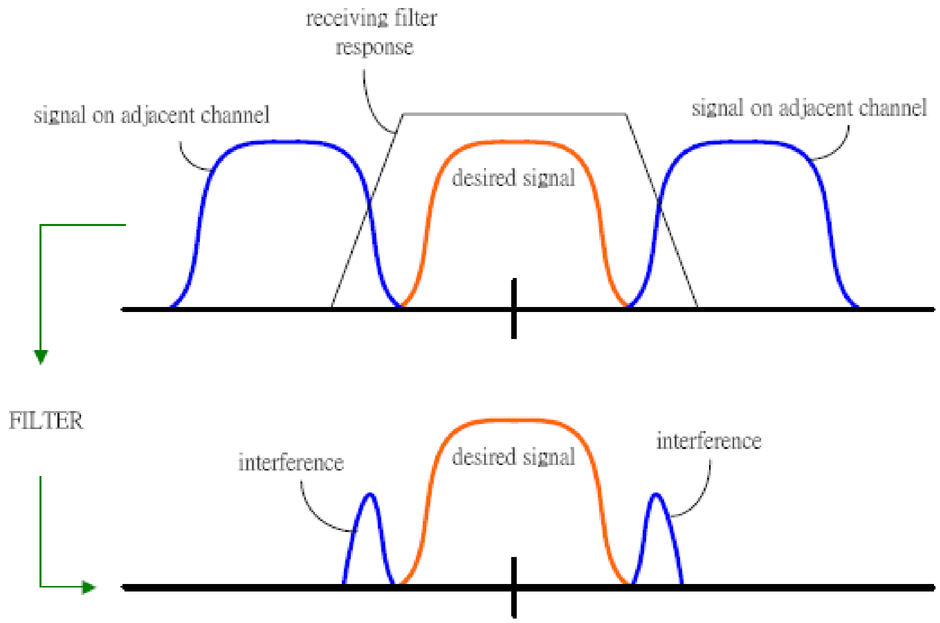
- For hexagonal geometry with 7-cell cluster, with the mobile unit being at the cell boundary, the SIR for the worst case can be approximated as

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D+R)^{-4} + 2D^{-4}}$$



# Adjacent Channel Interference

- **Adjacent channel interference: from adjacent in frequency to the desired signal**
  - Imperfect receiver filters allow nearby frequencies to leak into the passband
  - FCC regulate the “out of band” noise that TX can have
  - Engineers design “tight” input filters so that their systems do not pick up out of band noise



# Adjacent Channel Interference

- **Adjacent channel interference: from adjacent in frequency to the desired signal**
  - Performance degrade seriously due to near-far effect
  - If a nearby transmitter has just a little bit of out-of-band noise, it might swamp out the desired signal transmitted by a transmitter far away. This near-far problem is reduced by controlling the power level that is transmitted by the mobiles to keep everyone on as close to the same power level as possible at the receiver base station. This means that antennas far away must transmit larger power than those nearby. This saves on battery life, as well as reducing adjacent channel interference.
  - When you are using your cell phone inside your car, it is partially blocked by the metal car structure. It must send much higher power levels in order to get the power to the base station.

# Power Control for Reducing Interference

- **Ensure each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel**
  - Long battery life
  - Increase SIR
  - Solve the near-far problem

# Trunking

- Sharing a pool of lines or channels between a larger number of users. Statistically, they are not all likely to be on the phone at the same time. But as the number of lines is reduced, an individual user may sometimes be unable to access a free line.
- Queue: May be used to hold users waiting for a line and increase the quality of service for the user. The user just waits for (hopefully a short period of time) for a dial tone.

# Grade of Service (GoS)

- **Quality of Service (QoS)**
- **Erlang = total use of one channel (1 call per hour that lasts an hour)**
- **Set-up time: the time required to allocate a trunk radio channel to a requesting user.**
- **Blocked call: call that cannot be completed due to congestion = lost call**
- **Holding time: average duration of call. Denoted by *H* (in seconds)**

# Grade of Service

- **Traffic Intensity: average channel usage (in Erlang, dimensionless), denoted by *A*.**
- **Load: traffic intensity across the entire trunked radio system, measured in Erlangs**
- **Request Rate: the average number of call request per unit time, Denoted by $\lambda$ requests/second**
- **GoS**
  - Erlang B: typical likelihood that a call will be blocked
  - Erlang C: typical likelihood that a user will have to wait beyond a certain time
- **Number of users: *U***
- **Number of available channels: *C***

# Grade of Service

- **Traffic intensity of a single user**
  - $A_u = \lambda H$
- **Total traffic intensity of the system**
  - $A = UA_u$
- **Traffic intensity per channel**
  - $A_c = A/C = UAu/C$
  - This is the traffic that is requested by the system, but may not be carried by the system if the capacity is not large enough
  - Maximum capacity = C (Erlangs)
- **Examples**
  - AMPS: Allow GoS = 2% (which means that 2 out of 100 calls will be blocked during busiest hour)

# Types of Trunked Systems

- **Erlang B: Blocked Calls Cleared (no queue)**
- **Erlang C: Blocked Calls Delayed**
- **Assumption of Erlang B**
  - Calls arrive according to a Poisson distribution (in time)
  - Infinite # of users
  - All users, including those that are blocked, may request a channel at any time
  - Probability of a user occupying a channel is exponentially distributed (longer calls happen exponentially less often)
  - Finite # of channels *C*

**Probability of a blocked call**

$$\Pr[blocking] = GoS(Erlang\ \mathrm{B}) = \frac{\dfrac{\mathrm{A}^C}{\mathrm{C}!}}{\sum_{\mathrm{k}=0}^{\mathrm{C}} \dfrac{\mathrm{A}^k}{\mathrm{k}!}}$$

# Capacity of an Erlang B System

**Table 3.4**

| # of CHs, C | Capacity (Erlangs) for GoS | | | |
|---|---|---|---|---|
| | 0.01 | 0.005 | 0.002 | 0.001 |
| 2 | 0.153 | 0.105 | 0.065 | 0.046 |
| 4 | 0.869 | 0.701 | 0.535 | 0.762 |
| 5 | 1.36 | 1.13 | 0.900 | 0.762 |
| 10 | 4.46 | 3.96 | 3.43 | 3.09 |
| 20 | 12.0 | 11.1 | 10.1 | 9.41 |
| 24 | 15.3 | 14.2 | 13.0 | 12.2 |
| 40 | 29.0 | 27.3 | 25.7 | 24.5 |
| 70 | 56.1 | 53.7 | 51.0 | 49.2 |
| 100 | 84.1 | 80.9 | 77.4 | 75.2 |

- **10 channels with GoS = 0.01 can support?**
- **2 groups of 5 channels can support?**

# Blocked Calls Delayed

## Assume blocked calls are held in a queue and delayed

### Probability of a blocked call (delay > 0)

$$\Pr[delay > 0] = \frac{A^C}{A^C + C!\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C-1} A^k}$$

> Erlang B

### Probability of a user will wait more than t seconds

$$\Pr[delay > t] = \Pr[delay > 0]\Pr[delay > t \mid delay > 0]$$
$$= \Pr[delay > 0]\exp\left(\frac{-(C-A)t}{H}\right)$$

### Average delay for all calls in a queued system

$$D = \Pr[delay > 0]\frac{H}{C-A}$$

# Figure 3.6

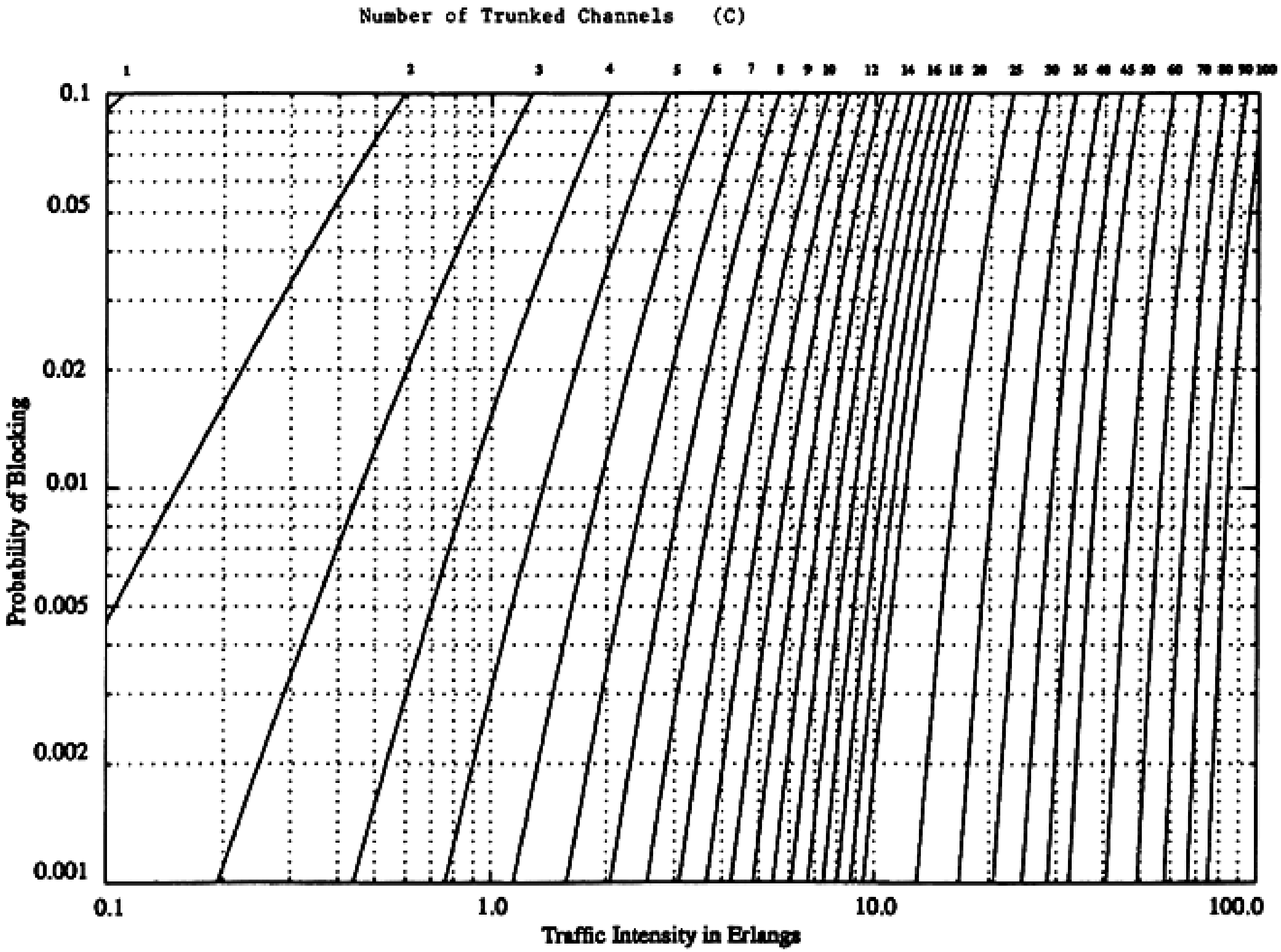



**Figure 3.6** The Erlang B chart showing the probability of blocking as functions of the number of channels and traffic intensity in Erlangs.

# Figure 3.7

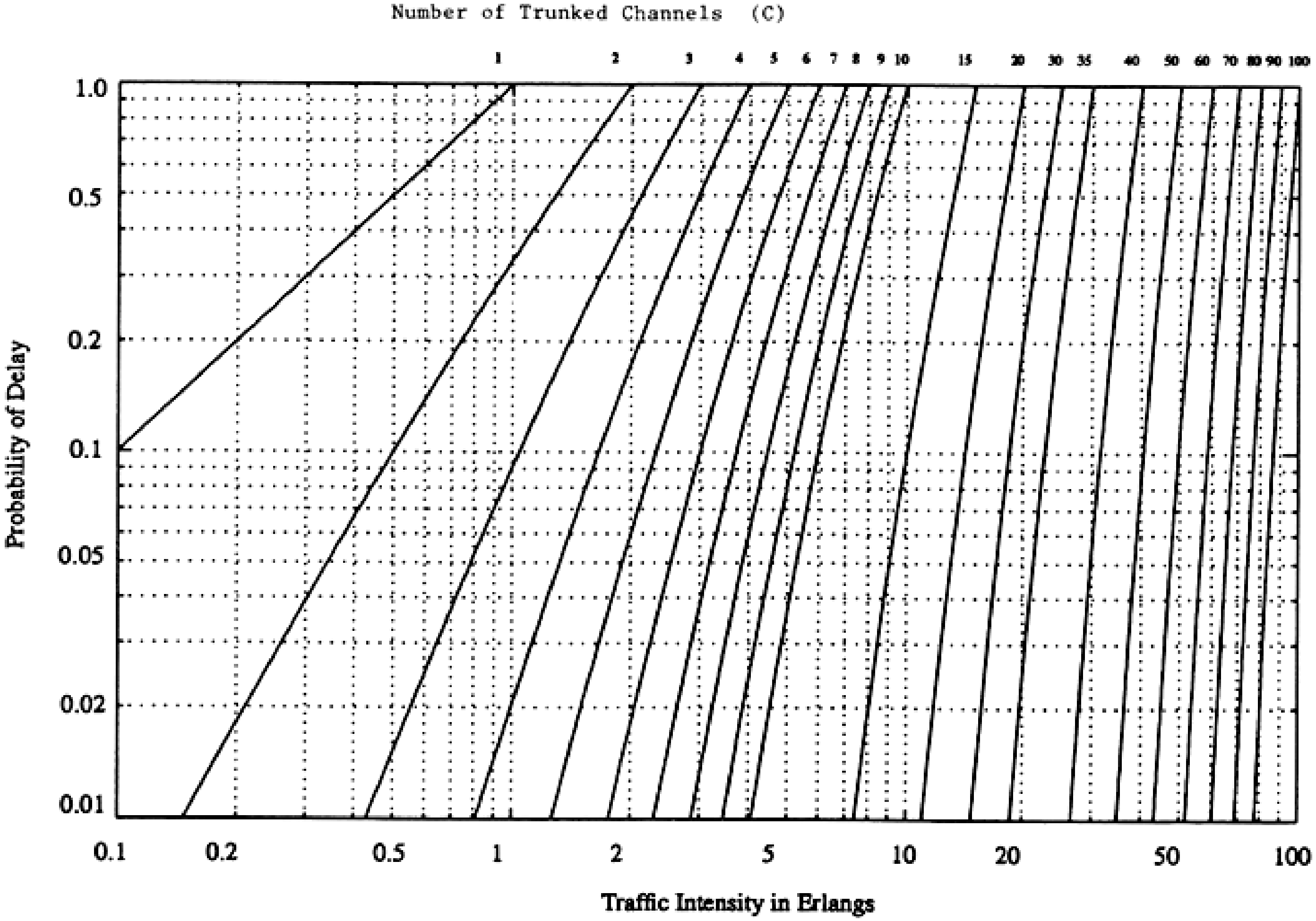



**Figure 3.7** The Erlang C chart showing the probability of a call being delayed as a function of the number of channels and traffic intensity in Erlangs.

# 3.7 Improving Capacity and Coverage

- **When a cells capacity is no longer able to provide an acceptable GoS, several methods are available to increase system capacity. Also, in areas where radio reception is poor, repeaters can be used to improve radio coverage.**

| Capacity Improving Methods | Coverage Improvement |
| --- | --- |
| Cell splitting (microcells) | Repeaters |
| Sectoring (directional antenna) | |
| Zone Microcell | |

# 3.7.1 Cell Splitting

## ■ How is it implemented

**The cell splitting method takes a large cell that can no longer provide acceptable service and divides it into smaller cells. These smaller cells are laid out to use the frequency reuses pattern already in the system.**

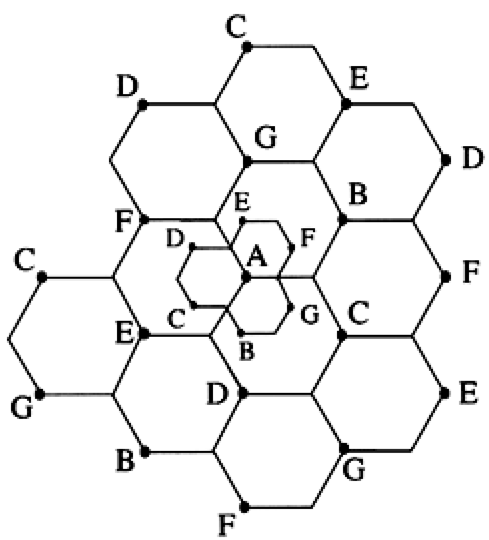



Illustration of cell splitting

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# 3.7.1 Cell Splitting

- **Advantages**
  - Because cells are smaller, system capacity increases. Also, less power is used by mobiles and base stations.
- **Drawbacks**
  - Handoffs become more common. To prevent handoffs and dropped calls, umbrella cells are needed for high speed traffic.
- **Cost of implementation**
  - Many new base stations are needed, increasing system complexity and load of MSC.

# 3.7.2 Sectoring

## ■ How is it implemented?

The cell is divided into sectors by using directional antennas. Common sectoring methods divide cells into 3 or 6 sectors.

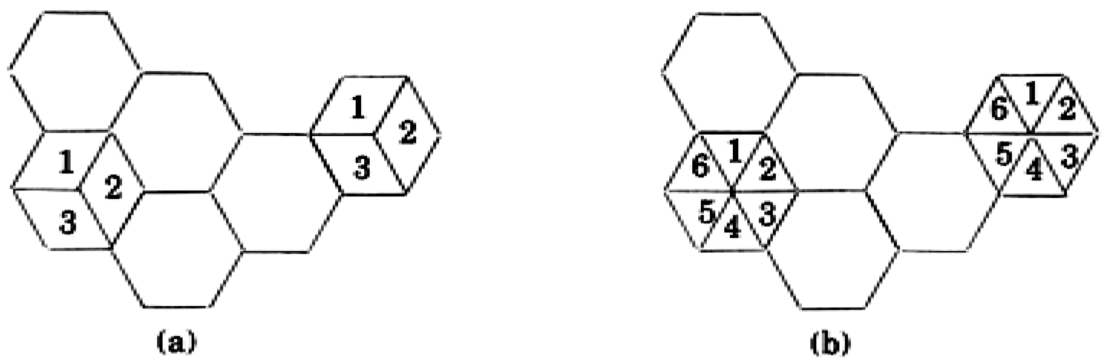


**Figure 3.10** (a) 120° sectoring; (b) 60° sectoring.


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# 3.7.2 Sectoring

- **Advantages**
  - The S/I ratio increases because interference is received from only 1 direction rather than all direction. This makes it possible for cluster size to be reduced, allowing more channels to be allocated to each cell.
- **Drawbacks**
  - Decreased trunking efficiency due to fewer channels per sector. Doesn't work well in high density urban areas due to reflection.
- **Cost of Implementations**
  - Increased complexity at base station due to additional antennas.

# 3.7.2 Sectoring

## Sectoring improves S/I

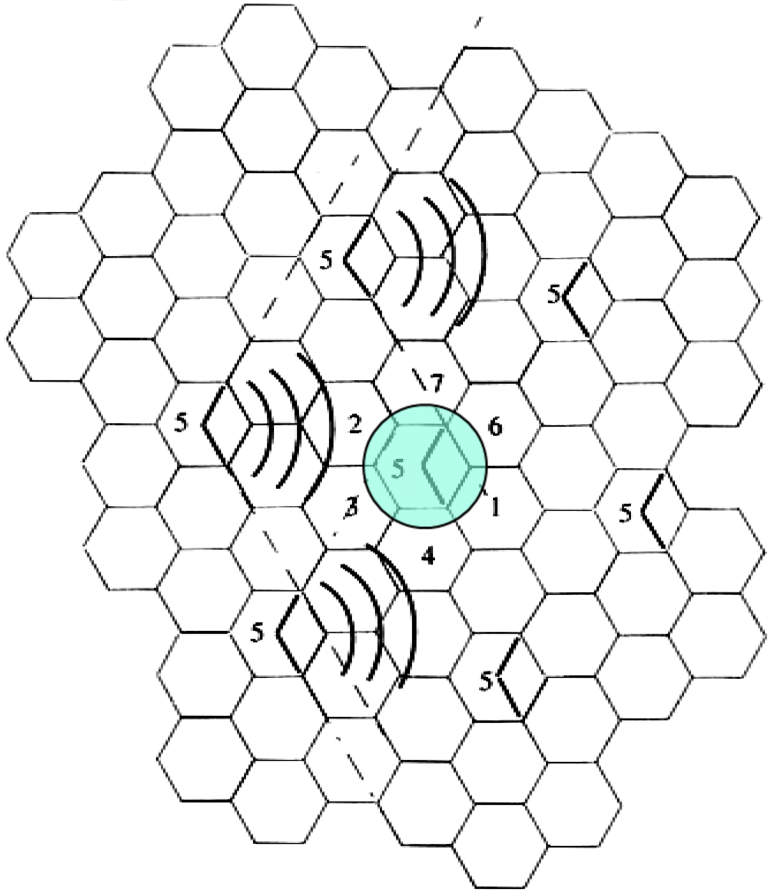


**Figure 3.11** Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.



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# 3.7.4 Zone Microcell

- **How is it implemented**

**Consists of a single base station with a distributed antenna system.**

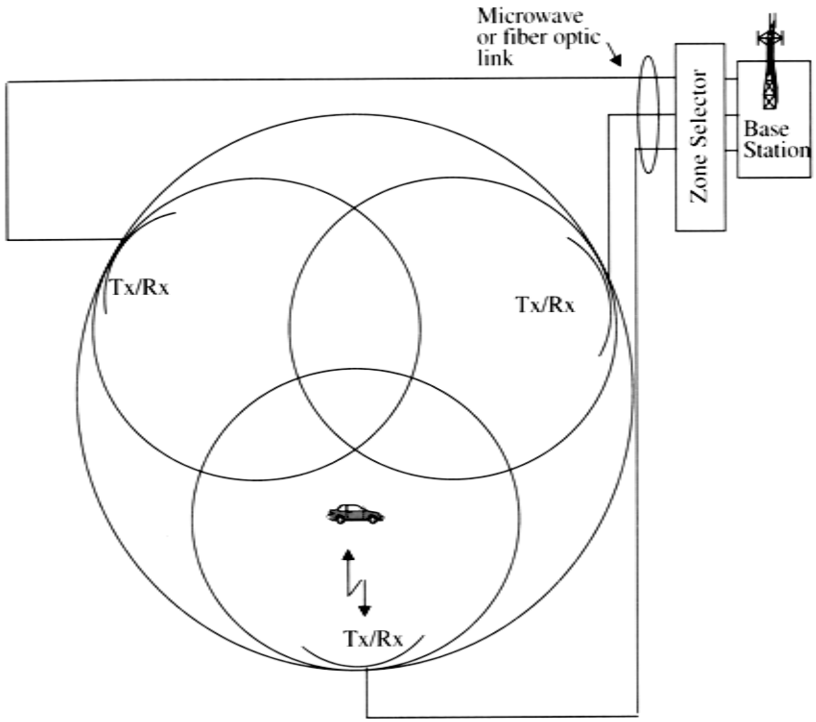


**Figure 3.13** The microcell concept [adapted from [Lee91b] © IEEE].

# 3.7.3 Zone Microcell

- **Advantages**
  - Only one base station needed. Because the system is distributed, less power is needed per antenna, and cells can be closer together without increasing SIR. The cluster size can be reduced, making it possible to allocate more channels to each cell. Handoff between microcells within the cell is handled by the base station, reducing the load on the MSC.
- **Drawbacks**
  - Base station are more complex as they must coordinate multiple antennas
- **Cost of implementation**
  - Antennas are connected to the base station via coaxial cable, fiber optics, or microwave link. Many antenna sights are needed.

# 3.7.3 Repeaters

- **How is it implemented**
  - A repeater is placed in a location that amplifies weak radio signals. The repeater can be placed at the entrance to a tunnel for tunnel coverage, or at a mountaintop, to service a valley on the other side.
- **Advantages**
  - Allows cell phone use in otherwise inaccessible areas without the additional cost of a new base station.
- **Drawbacks**
  - Doesn't increase system capacity
- **Cost of implementation**
  - A repeater has to be placed at the desired location

## Antenna boost

# Homework 2

## Turn in:

**3.1, 3.4, 3.7(v = 22.22m/s), 3.10, 3.15, 3.26**

## Review:

**3.5, 3.8, 3.9, 3.11, 3.13, 3.14, 3.16, 3.29**