5. CELLULAR WIRELESS NETWORK

CS-1699 Wireless Networks
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CELLULAR NETWORKS

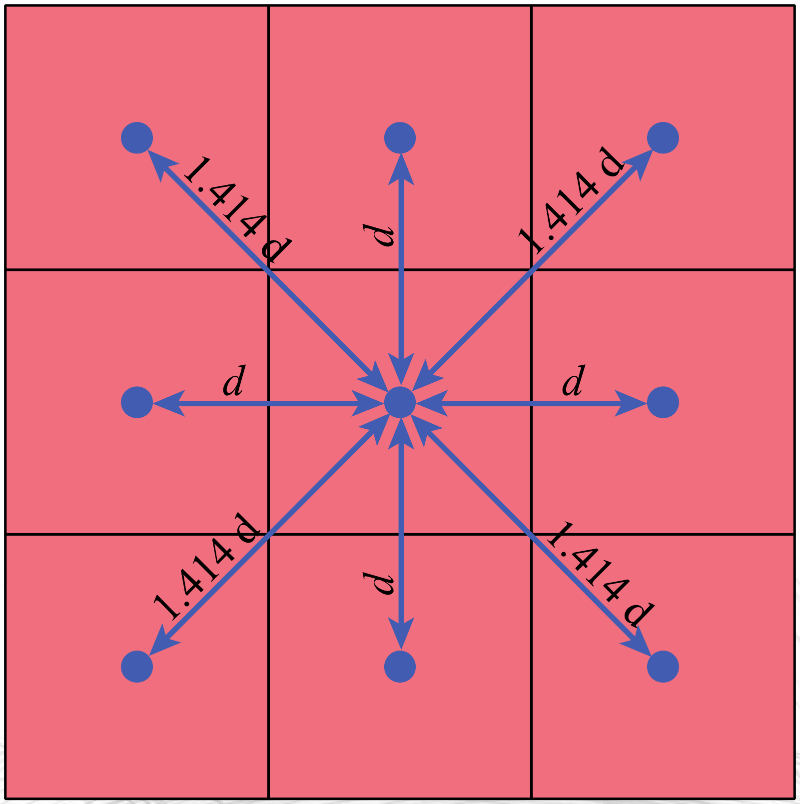
- Revolutionary development in data communications and telecommunications
- Foundation of mobile wireless
  - Telephones, smartphones, tablets, wireless Internet, wireless applications
- Supports locations not easily served by wireless networks or WLANs
- Four generations of standards
  - 1G: Analog
  - 2G: Still used to carry voice
  - 3G: First with sufficient speeds for data networking, packets only
  - 4G: Truly broadband mobile data up to 1 Gbps

CELLULAR NETWORK ORGANIZATION

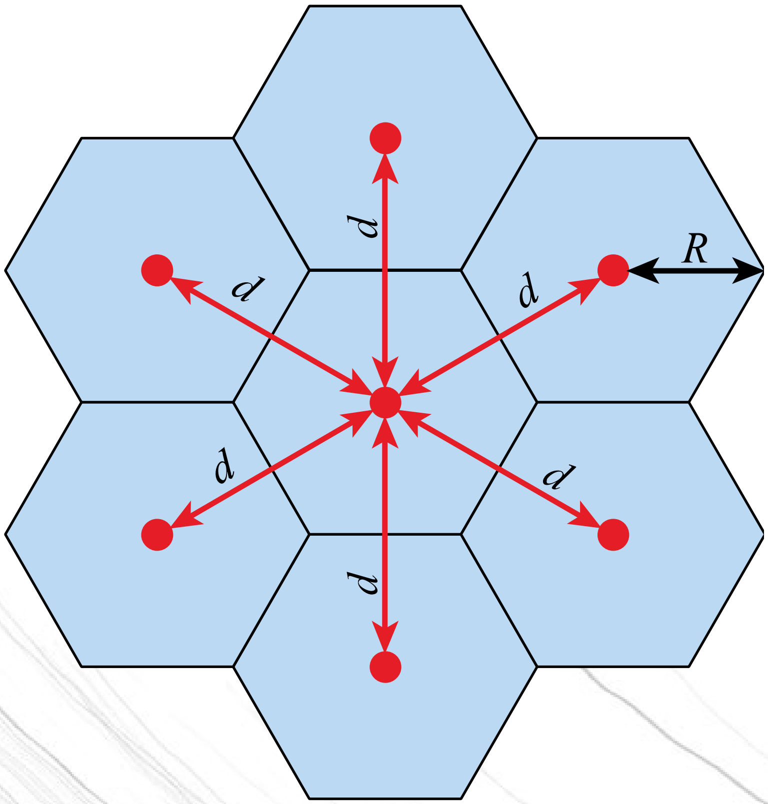
- Use multiple low-power transmitters (100 W or less)
- Areas divided into cells
  - Each served by its own antenna
  - Served by base station consisting of transmitter, receiver, and control unit
  - Band of frequencies allocated
  - Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)
    - Idealized pattern, in order to approximate coverage

CELLULAR NETWORK ORGANIZATION

- Why not a large service area
  - Number of simultaneous user to serve would be limited
  - Mobile handset needs to have larger power requirement
- Smaller cells
  - Allows frequency reuse, hence increased capacity for the same area of coverage
  - Lower power handset
  - Cons : Cost of cells, hands off between cells must be supported, need to track user to route incoming call or message.



(a) Square pattern

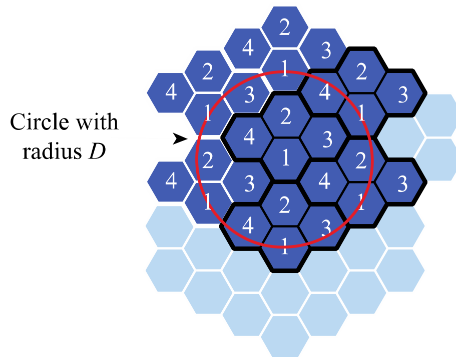


(b) Hexagonal pattern

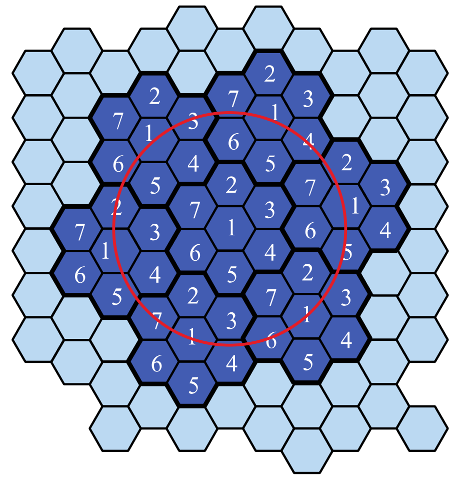
13.1 CELLULAR GEOMETRIES

FREQUENCY REUSE

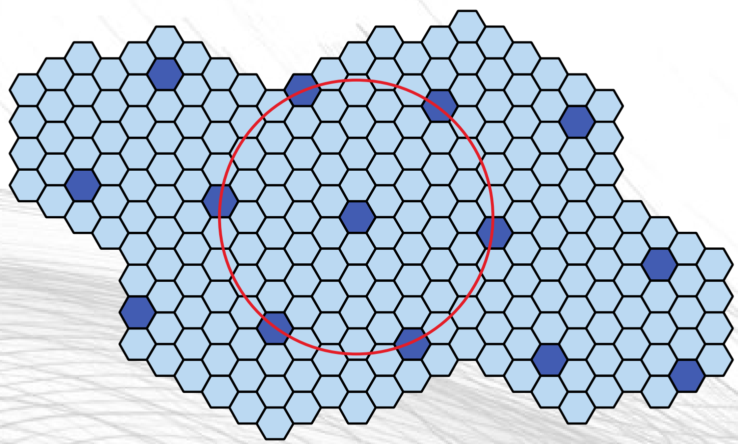
- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Objective is to reuse frequency in nearby cells
  - 10 to 50 frequencies assigned to each cell
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells
  - The issue is to determine how many cells must intervene between two cells using the same frequency



(a) Frequency reuse pattern for $N = 4$



(b) Frequency reuse pattern for $N = 7$



(c) Black cells indicate a frequency reuse for $N = 19$

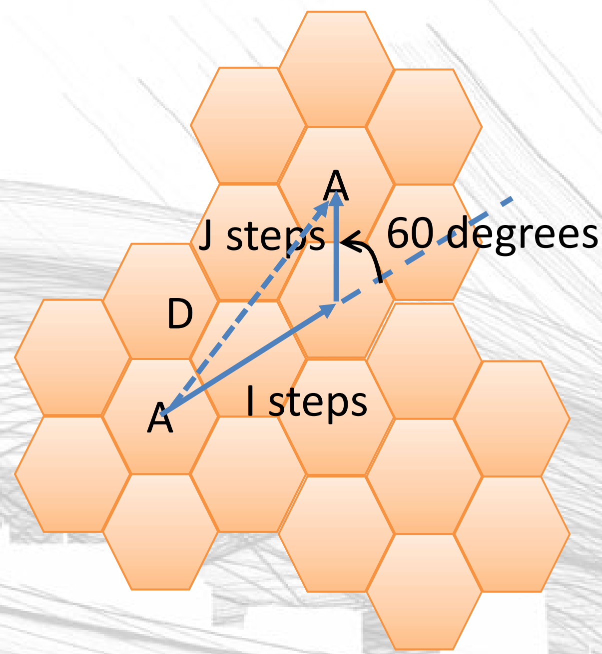
13.2 FREQUENCY REUSE PATTERNS

FREQUENCY REUSE

- D= Minimum distance between center of cells that use the same frequency band (called co-channels)
- R=Radius of a cell
- d=Distance between centers of adjacent cells
  - Relation : $d = R\sqrt{3}$
- N=Number of cells in a repetitious pattern (each cell in the pattern uses a unique hexagonal geometry)
  - Possible N : $N = I^2 + J^2 + (I.J)$, where I,J=0,1,2,3…
  - Following relation holds :$\frac{D}{R} = \sqrt{3N}$ and $\frac{D}{d} = \sqrt{N}$

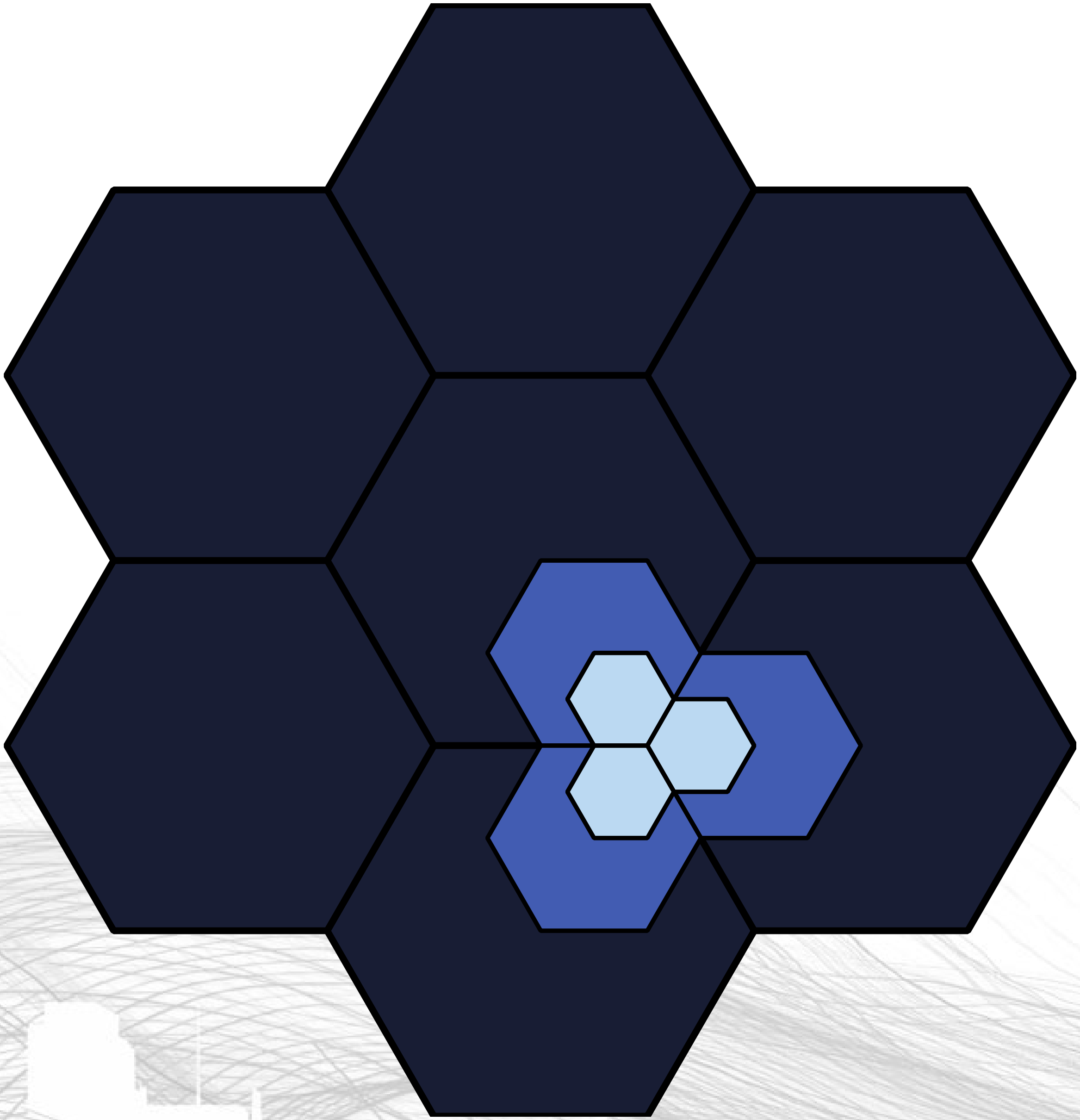
CELLULAR CONCEPT

- (N=7, where I=2, and J=1). Move I cells along any chain of hexagons, and turn 60 degrees ccw and move J steps



APPROACHES TO COPE WITH INCREASING CAPACITY

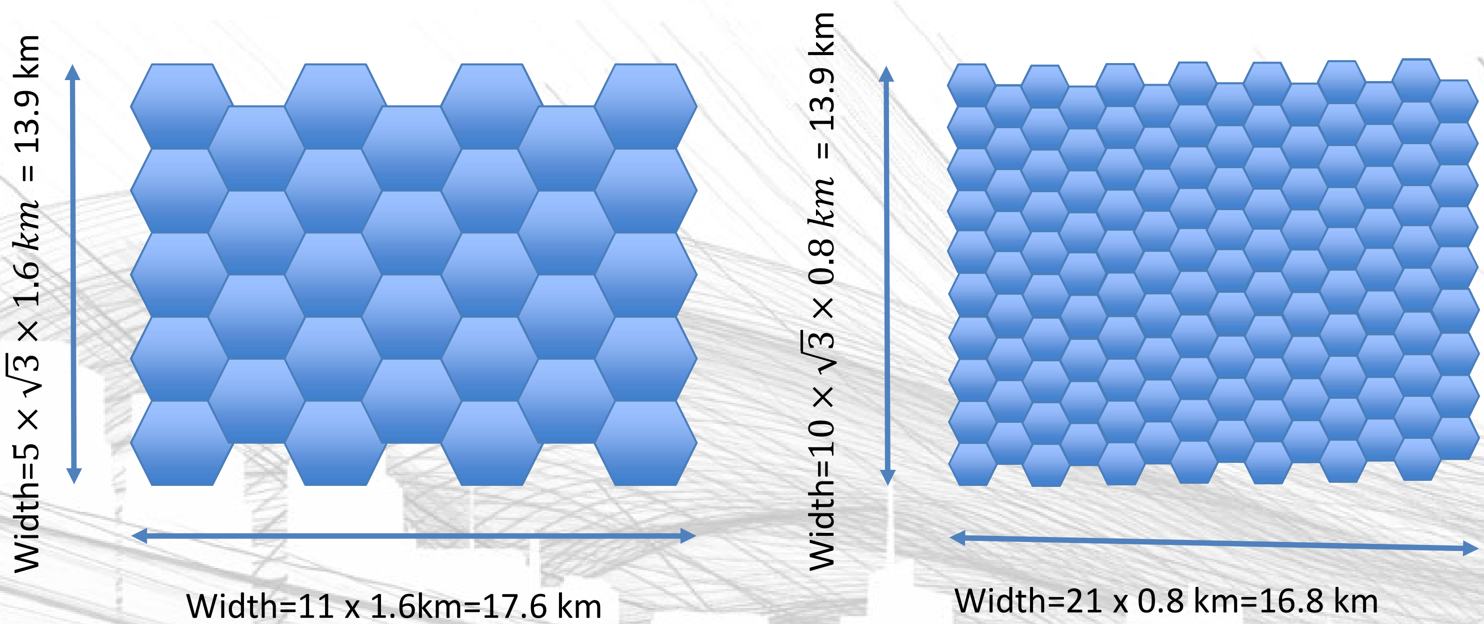
- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels
- Network densification – more cells and frequency reuse
  - Microcells – antennas move to buildings, hills, and lamp posts
  - Femtocells – antennas to create small cells in buildings
- Interference coordination – tighter control of interference so frequencies can be reused closer to other base stations
  - Inter-cell interference coordination (ICIC)
  - Coordinated multipoint transmission (CoMP)



13.3 CELL SPLITTING

INCREASING CAPACITY EXAMPLE

- If a cellular system supports K channels, and reuse factor is N (or the number of cells in every unique pattern), then
  - Number channel per-cell is defined as $\frac{K}{N}$
- Example



INCREASING CAPACITY EXAMPLE

- Given : Number of total channel K : 336 channels, reuse factor N=7.
  - (Left figure) R=1.6 km, number of cell : 32 cells

    Each cell has area of $\approx 2.6 \times R^2 = 6.656km^2$

    Total coverage area = $32 \times 6.656km^2 = 213km^2$

    Number of channel per cell, $\frac{K}{N} = \frac{336}{7} = 48\ channels$

    Total channel capacity $32 \times 48 = 1536\ channels$

  - (Right figure). R=0.8 km

    Each cell has area of $\approx 2.6 \times R^2 = 1.664\ km^2$

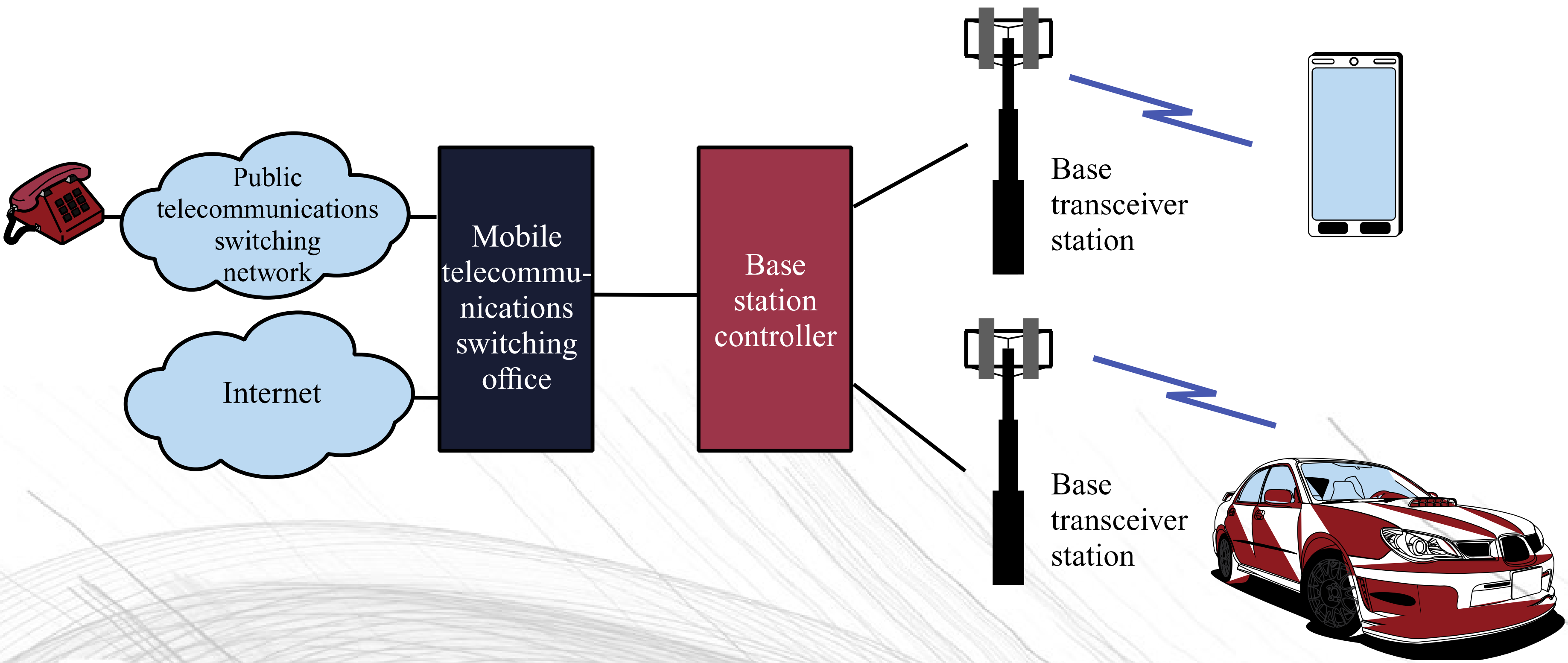
    To cover 213 km, number of cells would be $\frac{213}{1.664}$ =128 cells

    Number of channel per cell, $\frac{K}{N} = \frac{336}{7} = 48\ channels$

    Total channel capacity $128 \times 48 = 6144\ channels$

CELLULAR SYSTEMS TERMS

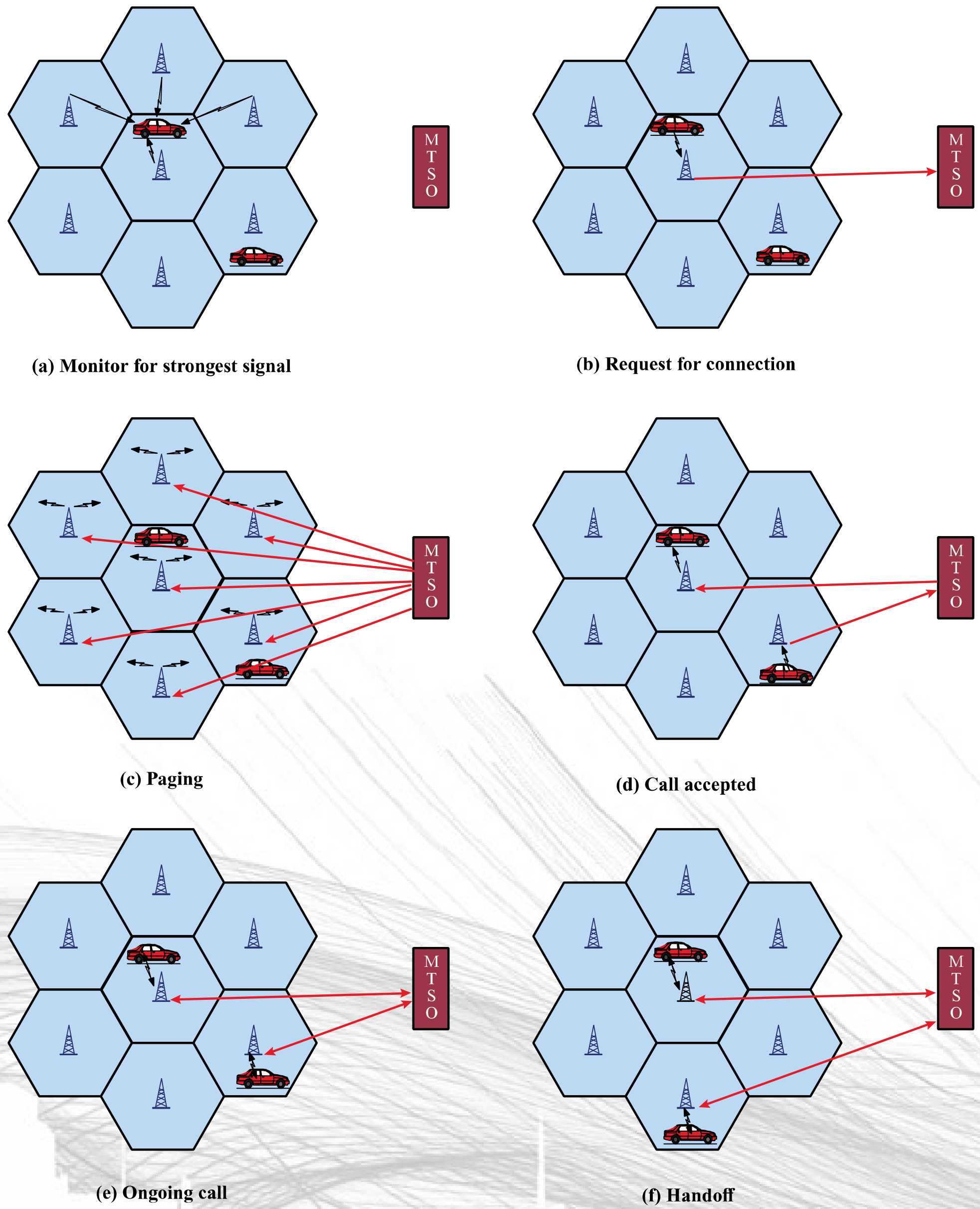
- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - Control channels – used to exchange information having to do with setting up and maintaining calls
  - Traffic channels – carry voice or data connection between users



13.5 OVERVIEW OF CELLULAR SYSTEM

STEPS IN AN MTSO CONTROLLED CALL BETWEEN MOBILE USERS

- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff



13.6 EXAMPLE OF MOBILE CELLULAR CALL

ADDITIONAL FUNCTIONS IN AN MTSO CONTROLLED CALL

- Call blocking
- Call termination
- Call drop
- Calls to/from fixed and remote mobile subscriber

MOBILE RADIO PROPAGATION EFFECTS

- Signal strength
  - Must be strong enough between base station and mobile unit to maintain signal quality at the receiver
  - Must not be so strong as to create too much co-channel interference with channels in another cell using the same frequency band
- Fading
  - Signal propagation effects may disrupt the signal and cause errors

FREE SPACE LOSS

- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light (3×10^8 m/s)

  where d and λ are in the same units (e.g., meters)

FREE SPACE LOSS

- Free space loss equation can be recast:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\text{ dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\text{ dB}$$

PATH LOSS EXPONENT IN PRACTICAL SYSTEMS

- Practical systems – reflections, scattering, etc.
- Beyond a certain distance, received power decreases logarithmically with distance
  - Based on many measurement studies

$$\frac{P_t}{P_r} = \left(\frac{4\pi}{\lambda}\right)^2 d^n = \left(\frac{4\pi f}{c}\right)^2 d^n$$

$$L_{dB} = 20\log\left(f\right) + 10n\log\left(d\right) - 147.56 \text{ dB}$$

PATH LOSS EXPONENT IN PRACTICAL SYSTEMS

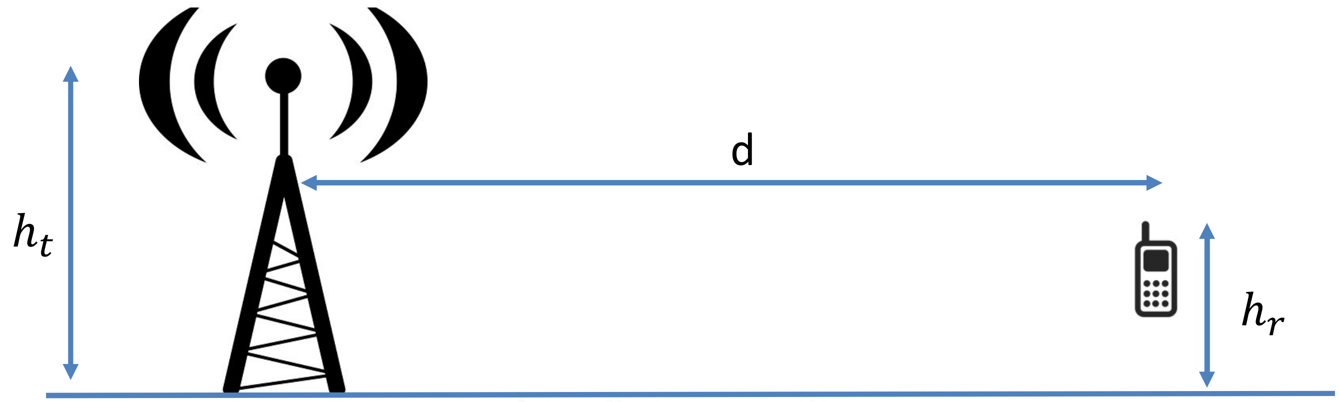
Table 6.5 Path Loss Exponents for Different Environments [RAPP02]

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

MODELS DERIVED FROM EMPIRICAL MEASUREMENTS

- Need to design systems based on empirical data applied to a particular environment
  - To determine power levels, tower heights, height of mobile antennas
- Okumura developed a model, later refined by Hata
  - Detailed measurement and analysis of the Tokyo area
  - Among the best accuracy in a wide variety of situations
- Predicts path loss for typical environments
  - Urban
  - Small, medium sized city
  - Large city
  - Suburban
  - Rural

OKUMURA-HATA MODEL



Path loss in urban environment, predicted path loss based on Okumura Hata is :

$$L_{dB} = 69.55 + 26.16 \times \log_{10} f_c - 13.82 \times \log_{10}(h_t)$$
$$-A(h_r) + (44.9 - 6.55 \times \log_{10} h_t) \log_{10} d$$

- f_c= carrier frequency in MHz, from 150 to 1500 MHz
- h_t= height of base station antenna, in m, from 30 to 300 meter
- h_r=height of receiving antenna(mobile unit), in m, from 1 to 10 m
- d= propagation distance between antenna in km, from 1 to 20 km
- $A(h_r)$= correction factor for mobile unit antenna height

OKUMURA-HATA MODEL

- Correction factor $A(h_r)$
  - Small of medium-sized city

$$A(h_r) = (1.1 \times \log_{10}(f_c) - 0.7)h_r - (1.56 \times \log_{10}(f_c) - 0.8) \quad \text{dB}$$

  - For large city

$$A(h_r) = 8.29 \times [\log_{10}(1.54h_r)]^2 - 1.1 \text{ dB} \quad \text{for } f_c \leq 300\ MHz$$
$$A(h_r) = 3.2 \times [\log_{10}(11.75h_r)]^2 - 4.97 \text{ dB} \quad \text{for } f_c \geq 300\ MHz$$

OKUMURA HATA MODEL

- Path loss for sub urban area : $L_{dB}(suburban)$

$$= L_{dB}(urban\ small/medium\ city\ ) - 2 \times \left[\log_{10}\left(\frac{f_c}{28}\right)\right]^2 - 5.4 \quad \text{dB}$$

- Path loss in open or rural area: $L_{dB}(rural)$

$$= L_{dB}(urban\ small/medium\ city\ ) - 4.78 \times [\log_{10}(f_c)]^2$$
$$-18.733 \times \log_{10}(f_c) - 40.98$$

OKUMURA HATA

- Example
  - Let f_c=900 MHz, h_t=40m, h_r=5 m, and d=10 km. Estimate the path loss for medium sized city, urban area

$A(h_r) = (1.1\log_{10}(900) - 0.7)5 - (1.56\log_{10}(900) - 0.8)$=12.75-3.8 =8.95 dB

L_{dB}=69.55+26.16 $\log_{10}(900) - 13.82 \times \log_{10}(40)$ -8.95
+(44.9-6.55 $\log_{10}(40)$) $\log_{10}(10)$=150.14 dB