Module 3
Cellular Wireless Networks

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- Principles of cellular network
- Cellular network organization
- Operation of cellular systems
- Handoff
- Generation of cellular networks- 1G, 2G, 2.5G, 3G, 4G.

1. Principles of Cellular Networks

- Underlying technology for mobile phones, personal communication systems, wireless networking etc.
- Developed for mobile radio telephone
  - —Replace high power transmitter/receiver systems
    - Typical support for 25 channels over 80km
  - —Use lower power, shorter range, more transmitters

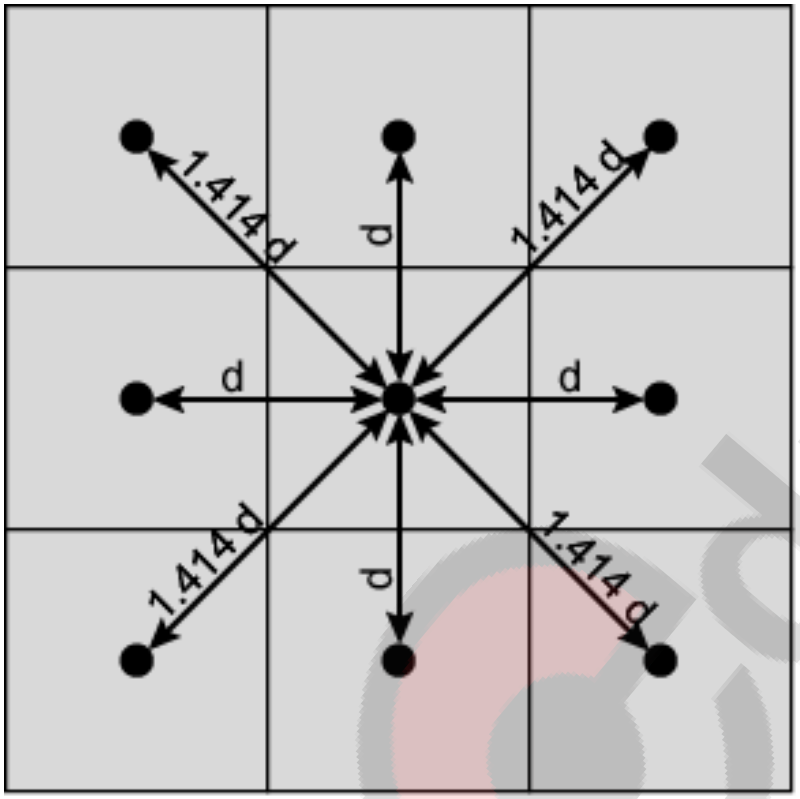
2. Cellular Network Organization

- Multiple low power transmitters
  - —100w or less
- Area divided into cells
  - —Cell- radio coverage area by a single base station.
  - —Each with own antenna
  - —Each with own range of frequencies
  - —Served by base station
    - Transmitter, receiver, control unit
  - —Adjacent cells on different frequencies to avoid crosstalk
  - —To increase system capacity- Frequency reuse, use of smaller cells, use of antenna within a sector.

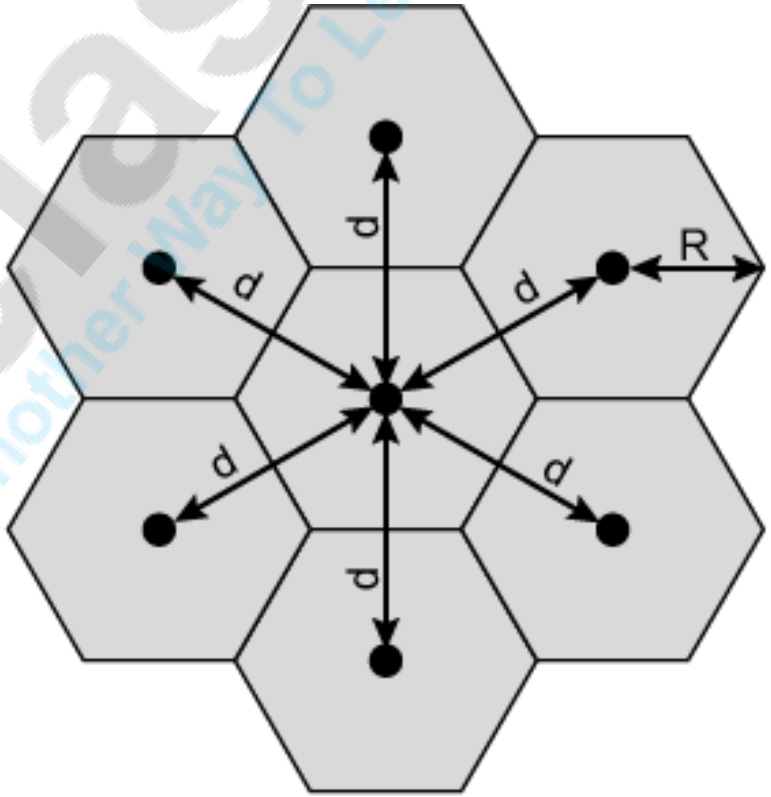
Shape of Cells

- **Square**
  - Width d cell has four neighbors at distance d and four at distance $\sqrt{2}\,d$
  - Better if all adjacent antennas equidistant
    - Simplifies choosing and switching to new antenna
- **Hexagon**
  - Provides equidistant antennas
  - Radius defined as radius of circum-circle
    - Distance from center to vertex equals length of side
  - Distance between centers of cells radius R is $\sqrt{3}\,R$
  - Not always precise hexagons
    - Topographical limitations
    - Local signal propagation conditions
    - Location of antennas

Cellular Geometries



(a) Square pattern



(b) Hexagonal pattern

Cell types

- **Omni-directional cell**
  - Base station antenna- omnidirectional.
  - Center- base station is situated.
- **Sector cell**
  - Base station in each cell with directional antenna.
  - Cells divided into sectors with fixed angular distribution.

Cell Cluster

- Cluster- a group of cells with different frequency.
- Different standards for cell structuring:
  - —4 cell standrard with all omni directional cells.
  - —7 cell standrard with all omni directional cells.
  - —12 cell standrard with all omni directional cells.
  - —21 cell standrard with 7 base stations, each associated with 3 sector cells.
  - —24 cell standrard with 4 base stations, each associated with 3 sector cells.

Frequency Reuse

- Simultaneous use of same frequency in different distinct set of cells.
- Power of base transceiver controlled
  - Allow communications within cell on given frequency
  - Limit escaping power to adjacent cells
  - Allow re-use of frequencies in nearby cells
  - Use same frequency for multiple conversations
  - 10 – 50 frequencies per cell
- *E.g.*
  - *N* cells all using same number of frequencies
  - *K* total number of frequencies used in systems
  - Each cell has *K/N* frequencies
  - Advanced Mobile Phone Service (AMPS) *K*=395, *N*=7 giving 57 frequencies per cell on average

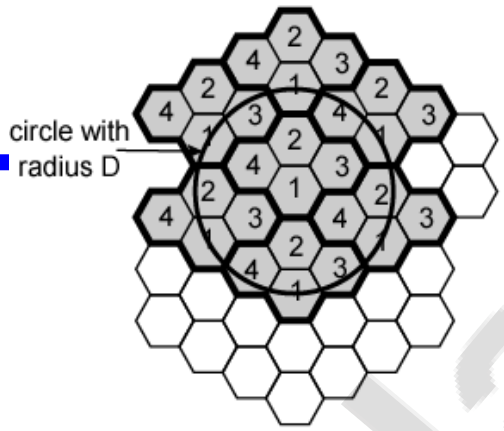
Characterizing Frequency Reuse

- D = minimum distance between centers of cells that use the same band of frequencies (called cochannels)
- R = radius of a cell
- d = distance between centers of adjacent cells (d = R)
- N = number of cells in repetitious pattern-**frequency reuse factor**
  - Reuse factor
  - Each cell in pattern uses unique band of frequencies
- Hexagonal cell pattern, following values of N possible
  - $N = I^2 + J^2 + (I \times J)$, $I, J = 0, 1, 2, 3, \ldots$
- Possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, …
- $D/R = \sqrt{3N}$
- $D/d = \sqrt{N}$

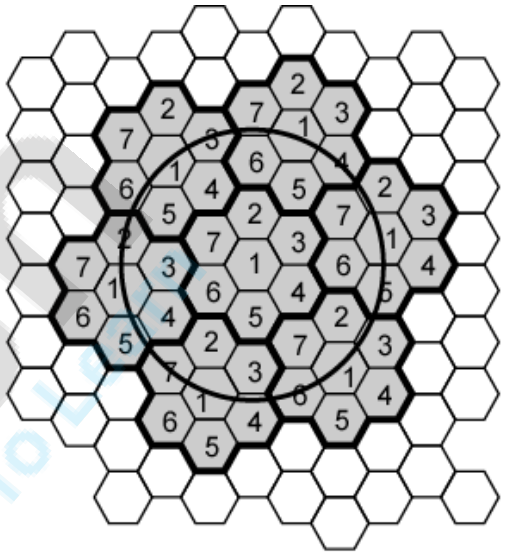
Co-channel and Adjacent channel interference

- **Intra-cell interference**- interference from other mobiles residing at the same cell.
- **Inter cell interference**- interference between different cells.
- Frequency reuse introduces co-channel interference.
- **Co-channel interference**- interference from co-channel cells.
- **Adjacent channel interference**- results from signals, which are adjacent in frequency to the desired signal.

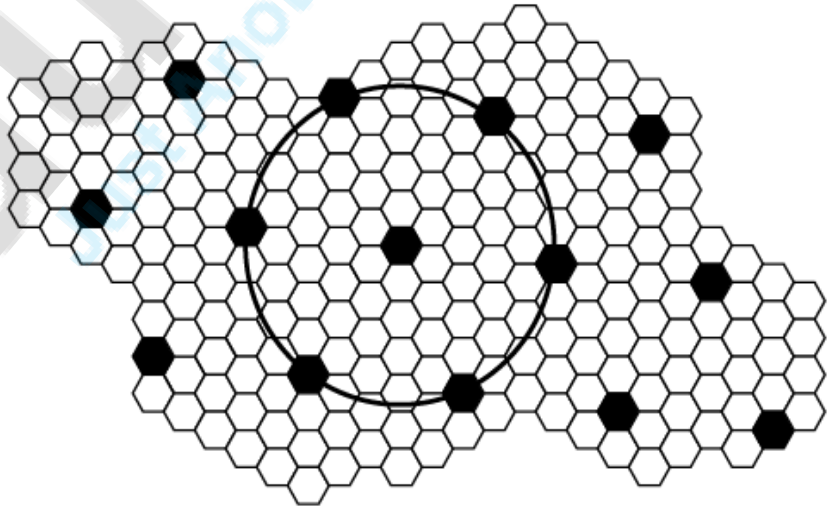
Frequency Reuse Patterns



(a) Frequency reuse pattern for N = 4



(b) Frequency reuse pattern for N = 7

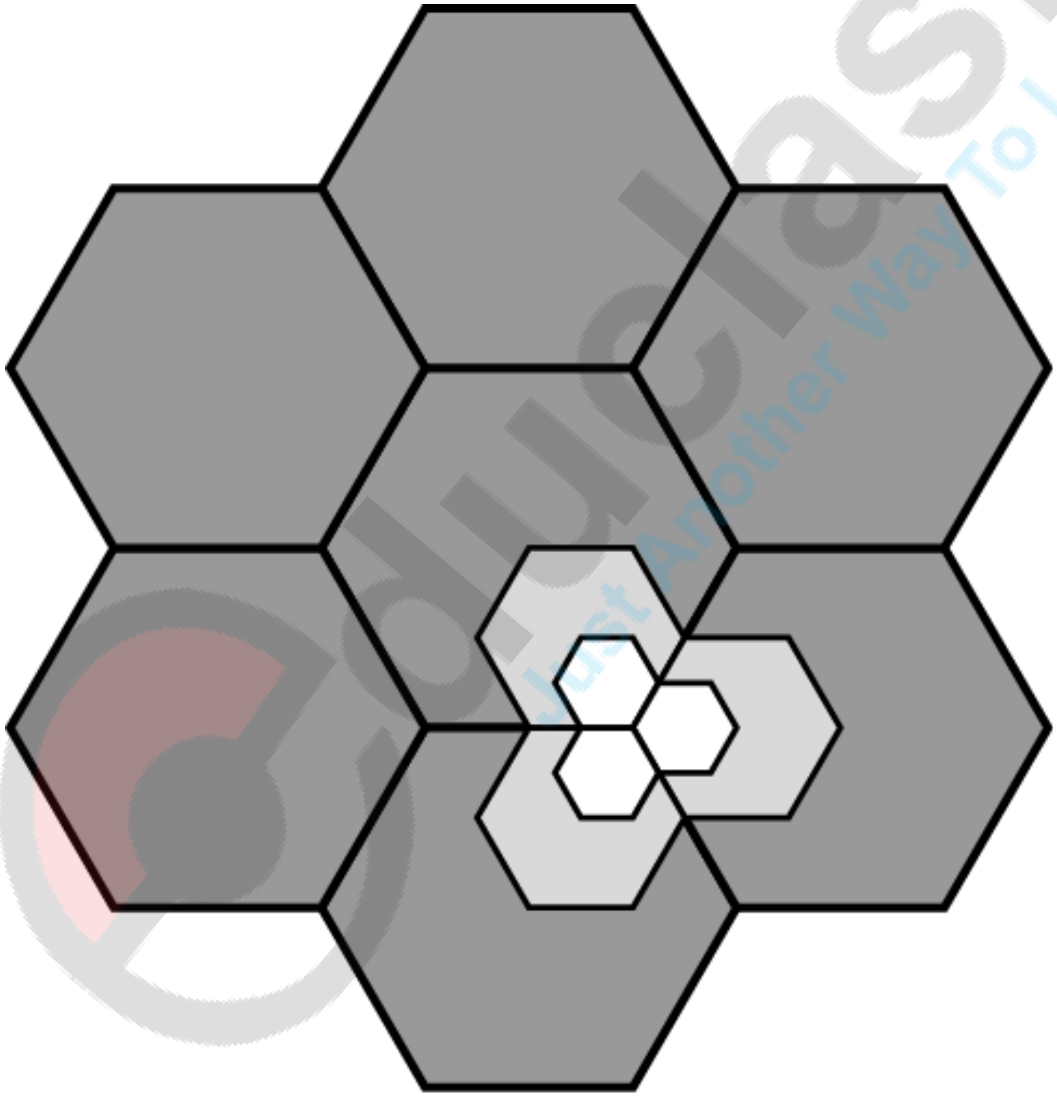


(c) Black cells indicate a frequency reuse for N = 19

Increasing Capacity (1)

- **Add new channels**
  - —Not all channels used to start with
- **Frequency borrowing**
  - —Taken from adjacent cells by congested cells
  - —Or assign frequencies dynamically
- **Cell splitting**
  - —Non-uniform distribution of topography and traffic
  - —Smaller cells in high use areas
    - Original cells 6.5 – 13 km
    - 1.5 km limit in general
    - More frequent handoff
    - More base stations

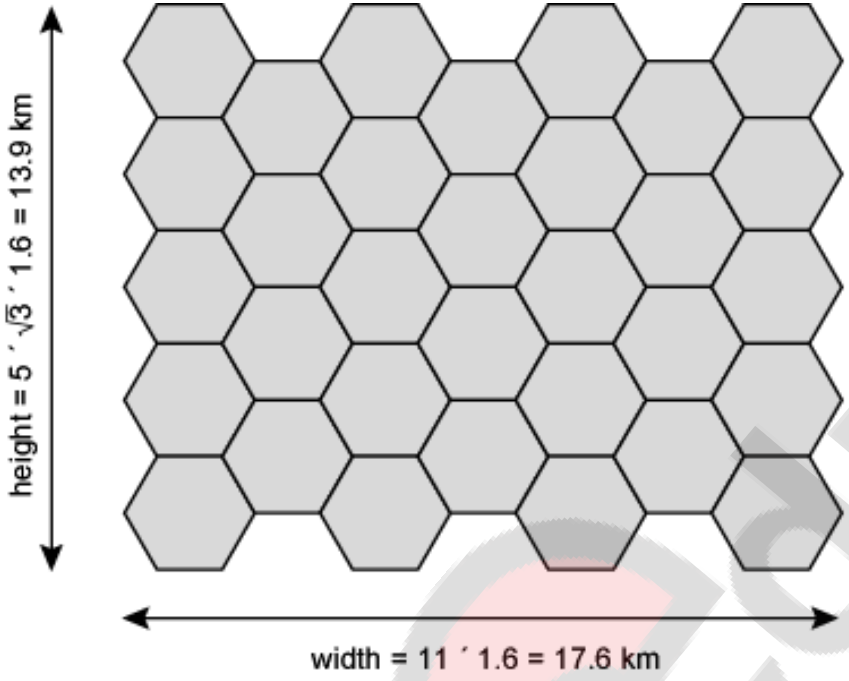
Cell Splitting



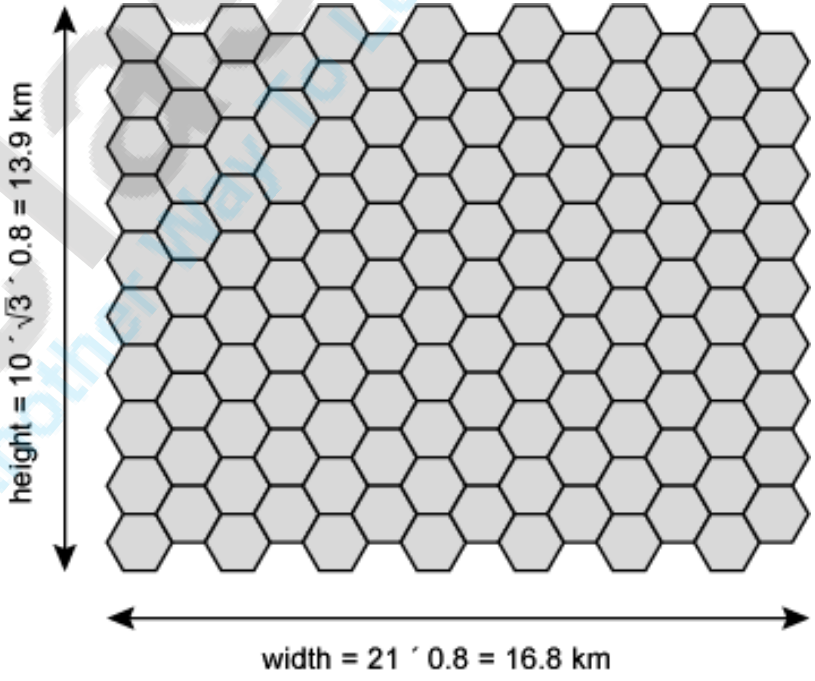
Increasing Capacity (2)

- **Cell Sectoring**
  - —Cell divided into sectors
  - —3 – 6 sectors per cell
  - —Each with own channel set
    - Subsets of cell's channels
  - —Directional antennas
- **Microcells**
  - —Move antennas from tops of hills and large buildings to tops of small buildings and sides of large buildings
    - Even lamp posts
  - —Form microcells
  - —Reduced power
  - —Good for city streets, along roads and inside large buildings

Frequency Reuse Example



(a) Cell radius = 1.6 km



(b) Cell radius = 0.8 km

Channel Assignment Schemes-I

- Assignment channels to base stations.
- Fixed channel assignment(FCA)
  - A fixed set of channels assigned to each cell.
  - Blocking of excess calls
  - Types:
    - Flexible Borrowing- 2 channels one for local use and other for borrowing.
    - Borrowing with Channel Ordering- borrowing based on priority
- Dynamic channel assignment(DCA)
  - Channels are allocated to users on demand from a central pool based on a cost function.
  - Types:
    - Random DCA- randomly
    - Channel Ordering- based on priority
    - Weighted carrier ordering- based on favourite channels based on past experiences.

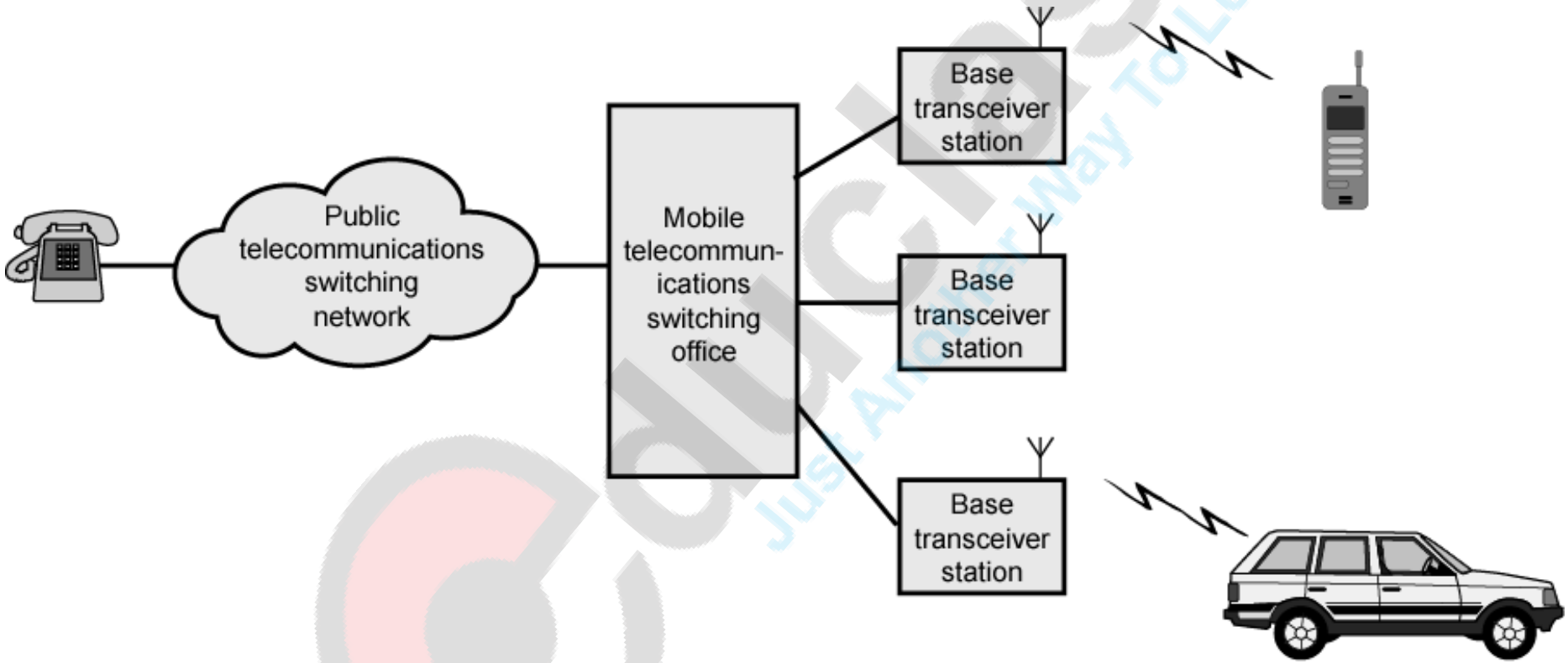
Channel Assignment Schemes-II

- Hybrid Assignment:
  - Fixed channels allotted to each cell.
  - Channel shortage- set of flexible channels according to DCA strategy.
  - Flexible channel assignment types:
    - Scheduled scheme- assumes future changes in traffic distribution.
    - Predictive schemes- continuously monitors the traffic in each cell for dynamic allocation.
  - Converges to Fixed channel assignment under heavy traffic.

3. Operation of Cellular Systems

- Base station (BS) at center of each cell
  - Antenna, controller, transceivers
- Controller handles call process
  - Number of mobile units may in use at a time
- BS connected to mobile telecommunications switching office (MTSO)
  - One MTSO serves multiple BS
  - MTSO to BS link by wire or wireless
- MTSO:
  - Connects calls between mobile units and from mobile to fixed telecommunications network
  - Assigns voice channel
  - Performs handoffs
  - Monitors calls (billing)
- Fully automated

Overview of Cellular System



Channels

- Available between mobile unit and base station.
- Control channels
  - —Setting up and maintaining calls
  - —Establish relationship between mobile unit and nearest BS
- Traffic channels
  - —Carry voice and data

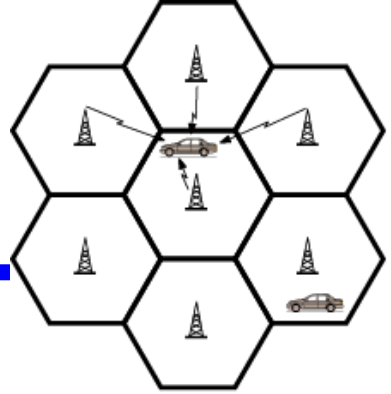
Typical Call in Single MTSO Area (1)

- Mobile unit initialization
  - Scan and select strongest set up control channel
  - Automatically selected BS antenna of cell
    - Usually but not always nearest (propagation anomalies)
  - Handshake to identify user and register location
  - Scan repeated to allow for movement
    - Change of cell
  - Mobile unit monitors for pages
- Mobile originated call
  - Check set up channel is free
    - Monitor forward channel (from BS) and wait for idle
  - Send number on pre-selected channel
- Paging
  - MTSO attempts to connect to mobile unit
  - Paging message sent to BSs depending on called mobile number
  - Paging signal transmitted on set up channel

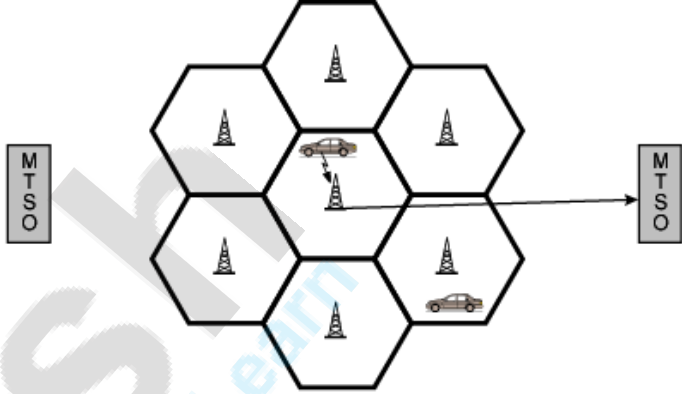
Typical Call in Single MTSO Area (2)

- Call accepted
  - Mobile unit recognizes number on set up channel
  - Responds to BS which sends response to MTSO
  - MTSO sets up circuit between calling and called BSs
  - MTSO selects available traffic channel within cells and notifies BSs
  - BSs notify mobile unit of channel
- Ongoing call
  - Voice/data exchanged through respective BSs and MTSO
- Handoff
  - Mobile unit moves out of range of cell into range of another cell
  - Traffic channel changes to one assigned to new BS
    - Without interruption of service to user

Call Stages

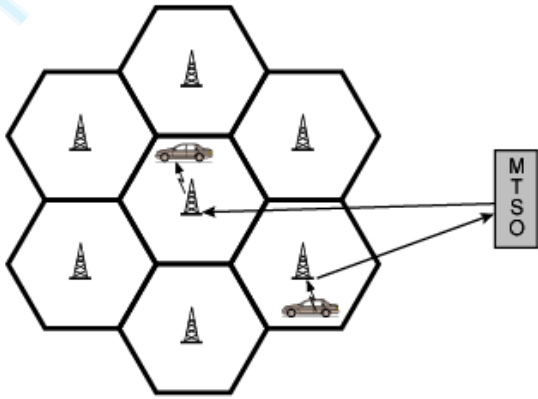


(a) Monitor for strongest signal

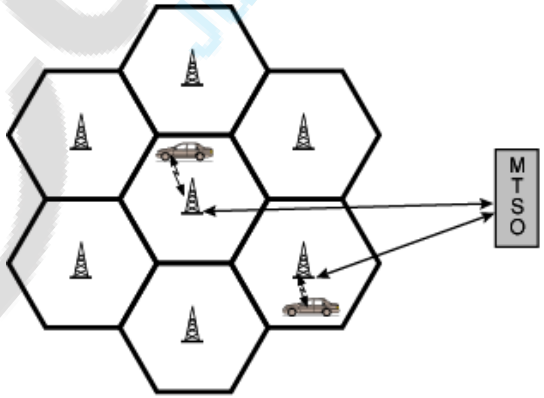


(b) Request for connection

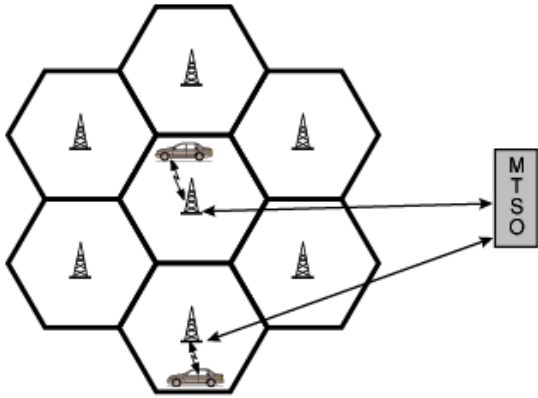
(c) Paging



(d) Call accepted



(e) Ongoing call



(f) Handoff

Other Functions

- Call blocking
  - During mobile-initiated call stage, if all traffic channels busy, mobile tries again
  - After number of fails, busy tone returned
- Call termination
  - User hangs up
  - MTSO informed
  - Traffic channels at two BSs released
- Call drop
  - BS cannot maintain required signal strength
  - Traffic channel dropped and MTSO informed
- Calls to/from fixed and remote mobile subscriber
  - MTSO connects to PSTN
  - MTSO can connect mobile user and fixed subscriber via PSTN
  - MTSO can connect to remote MTSO via PSTN or via dedicated lines
  - Can connect mobile user in its area and remote mobile user

Mobile Radio Propagation Effects

- Signal strength
  - Strength of signal between BS and mobile unit strong enough to maintain signal quality at the receiver
  - Not strong enough to create too much cochannel interference
  - Noise varies
    - Automobile ignition noise greater in city than in suburbs
    - Other signal sources vary
    - Signal strength varies as function of distance from BS
    - Signal strength varies dynamically as mobile unit moves
- Fading
  - Even if signal strength in effective range, signal propagation effects may disrupt the signal

4. Handoff(I)

- Procedure for changing the assignment of a mobile unit from one BS to another as the mobile unit moves from one cell to another.
- Types:
  - **Network initiated**: decision is made solely by the network measurements of received signals from the mobile unit.
  - **Mobile unit assisted**: enables mobile unit to participate in the handoff decision by providing feedback to the network concerning signals received at the mobile unit.

Handoff process (I)

- Involves identifying new cells.
- Re-association of voice and control channels.
- Two phases:
  - Initiation phase
  - Execution phase
- Initiated when average signal level from new BS exceeds that from the current BS by a specific threshold.
- Normal acceptable voice quality signal -90dBm to -100dBm.
- Slightly stronger signal level is used as a threshold.

Handoff process (II)

- Execution phase: allocation of new radio resource channels and exchange of control message.
- System designer must maintain an optimum signal level at which handoff should be initiated.
- Current BS monitors RSS quality from mobile station .
- If goes below threshold, mobile unit is ask to measure signal from neighboring base stations.
- Two cases:
  - Mobile unit sends collected information to BS.
  - Mobile unit itself selects the most suitable BS.

Types of Handoffs

- **Hard Handoff**
  - Break before make.
  - GSM uses this technique.
  - Types-
    - Intra-cell handoff
    - Inter-cell handoff

- **Soft Handoff**
  - Make before break.
  - CDMA uses this technique.

Generation of Cellular Networks

- First generation cellular networks (1G)
  - Analog, voice only communications.
- Second generation cellular networks (2G)
  - Digital, Voice and data communications
- 2.5G
  - Digital, Voice and data communications
- Third generation cellular networks(3G)
  - Convergence of wireless and internet
- Fourth generation cellular networks(4G)

1G cellular networks

- Started in 1980s.
- Analog radio transmission and circuit switching.
- Circuit switched voice communication.
- Analog FM for speech transmission.
- Sharing of spectrum using FDMA.
- Different standards:
  - Nordic mobile Telephones (NMT)- Nordic countries
  - Total access communication systems(TACS)- UK and Ireland
  - Advanced Mobile Phone system(AMPS)- North America
  - Nippon Telephone and Telegraph(NTT)- Japan

1G- Architecture

- All 1G systems differ by features such as location of the spectrum band, channel capacity, spacing and also with data rate.
- Mobile station-----Base Station-----Mobile switching centre (MSC)-----PSTN.
- Radio access Network (RAN) consists of BS.
- MS connected to BS to access core network (CN).
- CN- wireline network to connect different RANs and other networks.
- MSC- main entity of RAN.
- **Drawbacks:**
  - Roaming between different operators.
  - Roaming between different countries not possible.
  - Inefficient use of frequency.

2G cellular networks

- Started in early 1990s.
- Use of TDMA and CDMA.
- GSM- popular 2G std. - uses TDMA.
- Supports roaming.
- Digital technology.
- Supports Voice, mobile data and internet services.
- **Standards:**
  - GSM in Europe.-uses TDMA
  - IS-136 in US.-uses TDMA
  - IS-95 in North America and South Korea.-uses CDMA
- **Architecture:**
  - Mobile terminal-----Base station----base station controller (BSC)-----Mobile switching centre(MSC)----PSTN

2.5G cellular networks

- 2G- circuit switched based data service with low rate(9.6 kbps)
- Support for packet switched data service.
- Standards;
  - **GPRS- General Packet Radio Service.**
    - Packet services over GSM radio systems.
    - Different paths for voice and data transmission.
  - **EDGE- Enhanced Data rates for Global GSM Evolution.**
    - Advanced modulation and channel encoding techniques for increased data rates – 384 kbps.
  - **CDMA based IS-95B.**
    - Circuit switching and packet switching over a common CDMA radio channel.

3G cellular networks

- Began in late 1990s.
- Purpose- to deliver high rate voice and data service.
- IP-based data.
- Voice and multimedia services with integration to internet.
- Improved interoperability to handle mobility across different radio technologies among different networks.
- IMT 2000-by ITU- to implement a global frequency in the range of 2000 MHz to support single ubiquitous wireless communication all over the world.
- ITU-IMT-2000 Standards:
  - UMTS Group – Universal Mobile Telecommunications System (3GPP- Third generation partnership project)
  - CDMA2000 group (3GPP2)

4G cellular networks

- Began in late 1990s.
- High speed data access and multimedia services.
- Integration of voice, video and data services.
- Use of IP.
- Traditional functionality of MSC is replaced by all-IP switching network.
- Wireless IP with self provisioning of different multimedia services like video, audio and games.
- Goal- single worldwide cellular network standard based on IPv6.
- Key technology- OFDM.
- Key features- mobile multimedia, anytime anywhere access, global mobility support, integrated wireless solution and customized personal service.

Reference books

[1] Wireless Communications & Networks, Second Edition, William Stallings, Pearson Education

[2] Wireless Communications and Networks, 3G and Beyond, Second Edition, ITI SahaMisra, McGraw Hill Education

Reference books (Topic-wise)

Sr. No.	Topic	Ref. book	Chapter No.
1	Principles of cellular network	Wireless Communications & Networks, Second Edition, William Stallings, Pearson Education	5
2	Cellular network organization	Wireless Communications & Networks, Second Edition, William Stallings, Pearson Education	5
3	Operation of cellular systems	Wireless Communications & Networks, Second Edition, William Stallings, Pearson Education	5
4	Handoff	Wireless Communications and Networks, 3G and Beyond, Second Edition, ITI SahaMisra, McGraw Hill Education	3
5	Generation of cellular networks- 1G, 2G, 2.5G, 3G, 4G.	Wireless Communications and Networks, 3G and Beyond, Second Edition, ITI SahaMisra, McGraw Hill Education	2

University Questions

1. Explain the generations of cellular networks- 8M- May 2016.