Unit 3

Cellular wireless Networks

Principles of cellular networks – cellular network organization, operation of cellular systems, Handoff. Generation of cellular networks – 1G, 2G, 2.5G, 3G and 4G.

Principles of cellular networks – cellular network organization, operation of cellular systems, Handoff:

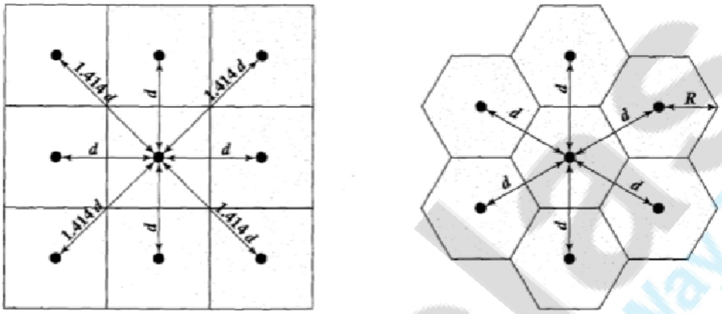
- Cellular radio is a technique that was developed to increase the capacity available for mobile radio telephone service. Prior to the introduction of cellular radio, mobile radio telephone service was only provided by a high-power transmitter/receiver.
- A typical system would support about 25 channels with an effective radius of about 80 km. The way to increase the capacity of the system is to use lower-power systems with shorter radius and to use numerous transmitters/receivers.
- We begin this section with a look at the organization of cellular systems and then examine some of the details of their implementation.

Cellular Network Organization:

- The essence of a cellular network is the use of multiple low-power transmitters, on the order of 100 W or less. Because the range of such a transmitter is small, an area can be divided into cells, each one served by its own antenna.
- Each cell is allocated a band of frequencies and is served by a base station, consisting of transmitter, receiver, and control unit. Adjacent cells are assigned different frequencies to avoid interference or crosstalk. However, cells sufficiently distant from each other can use the same frequency band.
- The first design decision to make is the shape of cells to cover an area. A matrix of square cells would be the simplest layout to define (Figure 1O.la).
- However, this geometry is not ideal. If the width of a square cell is d, then a cell has four neighbours at a distance d and four neighbours at a distance V2d.
- As a mobile user within a cell moves toward the cell's boundaries, it is best if all of the adjacent antennas are equidistant. This simplifies the task of determining when to switch the user to an adjacent antenna and which antenna to choose.
- A hexagonal pattern provides for equidistant antennas (Figure 1O.lb). The radius of a hexagon is defined to be the radius of the circle that

circumscribes it (equivalently, the distance from the center to each vertex; also equal to the length of a side of a hexagon).

- For a cell radius R, the distance between the cell center and each adjacent cell center is d = V3R. In practice, a precise hexagonal pattern is not used. Variations from the ideal are due to topographical limitations, local signal propagation conditions, and practical limitation on siting antennas.



(a) Square pattern (b) Hexagonal pattern

Figure 10.1 Cellular Geometries

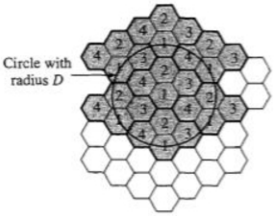
Frequency Reuse:

In a cellular system, each cell has a base transceiver. The transmission power is carefully controlled (to the extent that it is possible in the highly variable mobile communication environment) to allow communication within the cell using a given frequency band while limiting the power at that frequency that escapes the cell into adjacent cells. Nevertheless, it is not practical to attempt to use the same frequency band in two adjacent cells.

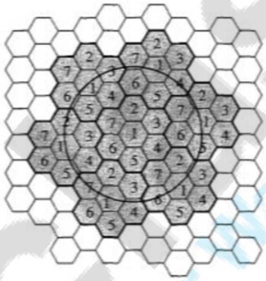
- Instead the objective is to use the same frequency band in multiple cells at some distance from one another. This allows the same frequency band to be used for multiple simultaneous conversations in different cells. Within a given cell, multiple frequency bands are assigned, the number of bands depending on the traffic expected.
- A key design issue is to determine the minimum separation between two cells using the same frequency band, so that the two cells do not interfere with each other. Various patterns of frequency reuse are possible. Figure 10.2 shows some examples.
- If the pattern consists of N cells and each cell is assigned the same number of frequencies, each cell can have KIN frequencies, where K is the total number of frequencies allotted to the system.
- For AMPS, K = 395, and N = 7 is the smallest pattern that can provide sufficient isolation between two uses of the same frequency. This

implies that there can be at most 57 frequencies per cell on average. In characterizing frequency reuse, the following parameters are commonly used:

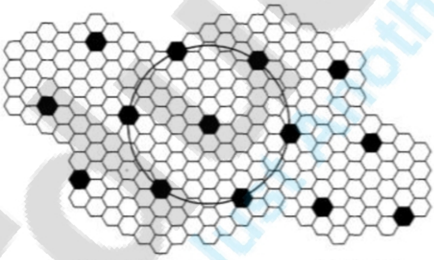
- D = minimum distance between centers of cells that use the same frequency band (called cochannels)
- R = radius of a cell d = distance between centers of adjacent cells (d = V3R)
- N = number of cells in a repetitious pattern (each cell in the pattern uses a unique set of frequency bands), termed the reuse factor



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



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



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

Figure 10.2 Frequency Reuse Patterns

- In a hexagonal cell pattern, only the following values of N are possible:

$$N = I^2 + J^2 + (I \times J), \quad I, J = 0, 1, 2, 3, \ldots$$

Hence, possible values of N are 1,3,4,7,9,12,13,16,19,21, and so on. The following relationship holds:

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

This can also be expressed as $D/d = \sqrt{N}$.

Increasing Capacity In time, as more customers use the system, traffic may' build up so that there are not enough frequency bands assigned to a cell to handle its calls. A number of approaches have been used to cope with this situation, including the following:

- **Adding new channels:** Typically, when a system is set up in a region, not all of the channels are used, and growth and expansion can be managed in an orderly fashion by adding new channels.
- **Frequency borrowing:** In the simplest case, frequencies are taken from adjacent cells by congested cells. The frequencies can also be assigned to cells dynamically.
- **Cell splitting:** In practice, the distribution of traffic and topographic features is not uniform, and this presents opportunities of capacity increase. Cells in areas of high usage can be split into smaller cells. Generally, the original cells are about 6.5 to 13 km in size.
  The smaller cells can themselves be split; however, lo5-km cells are close to the practical minimum size as a general solution (but see the subsequent discussion of microcells).
  To use a smaller cell, the power level used must be reduced to keep the signal within the cell. Also, as the mobile units move, they pass from cell to cell, which requires transferring of the call from one base transceiver to another. This process is called a handoff as the cells get smaller, these handoffs become much more frequent. Figure 10.3 indicates schematically how cells can be divided to provide more capacity. A radius reduction by a factor of P reduces the coverage area and increases the required number of base stations by a factor of p2.
- **Cell sectoring:** With cell sectoring, a cell is divided into a number of wedge shaped sectors, each with its own set of channels, typically 3 or 6 sectors per cell.
  Each sector is assigned a separate subset of the cell's channels, and directional antennas at the base station are used to focus on each sector.
- **Microcells:** As cells become smaller, antennas move from the tops of tall buildings or hills, to the tops of small buildings or the sides of large buildings, and finally to lamp posts, where they form microcells.
  Each decrease in cell size is accompanied by a reduction in the radiated power levels from the base stations and the mobile units.
  Microcells are useful in city streets in congested areas, along highways, and inside large public buildings.

Table 10.1 suggests typical parameters for traditional cells, called microcells, and microcells with current technology. The average delay spread refers to multipath delay spread; that is, the same signal follows different paths and there is a time delay between the earliest and latest arrival of the signal at the receiver. As indicated, the use of smaller cells enables the use of lower power and provides superior propagation conditions.

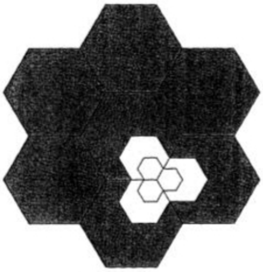


Figure 10.3 Cell Splitting

Table 10.1 Typical Parameters for Macrocells and Microcells [ANDE95]

	Macrocell	Microcell
Cell radius	1 to 20 km	0.1 to 1 km
Transmission power	1 to 10 W	0.1 to 1 W
Average delay spread	0.1 to 10 μs	10 to 100 ns
Maximum bit rate	0.3 Mbps	1 Mbps

Example 10.1 [HAAS00]. Assume a system of 32 cells with a cell radius of 1.6 km, a total of 32 cells, a total frequency bandwidth that supports 336 traffic channels, and a reuse factor of $N = 7$. If there are 32 total cells, what geographic area is covered, how many channels are there per cell, and what is the total number of concurrent calls that can be handled? Repeat for a cell radius of 0.8 km and 128 cells.

Figure 10.4a shows an approximately square pattern. The area of a hexagon of radius R is $1.5R^2\sqrt{3}$. A hexagon of radius 1.6 km has an area of 6.65 km^2, and the total area covered is $6.65 \times 32 = 213$ km^2. For $N = 7$, the number of channels per cell is $336/7 = 48$, for a total channel capacity of $48 \times 32 = 1536$ channels. For the layout of Figure 10.4b, the area covered is $1.66 \times 128 = 213$ km^2. The number of channels per cell is $336/7 = 48$, for a total channel capacity of $48 \times 128 = 6144$ channels.

Operation of Cellular Systems:

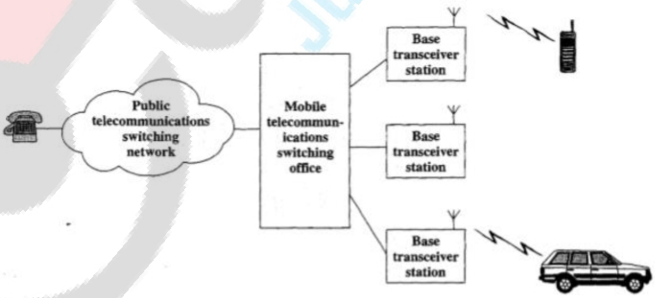


Figure 10.5 Overview of Cellular System

- Figure 10.5 shows the principal elements of a cellular system. In the approximate center of each cell is a base station (BS).

- The BS includes an antenna, a controller, and a number of transceivers, for communicating on the channels assigned to that cell. The controller is used to handle the call process between the mobile unit and the rest of the network.
- At any time, a number of mobile units may be active and moving about within a cell, communicating with the BS. Each BS is connected to a mobile telecommunications switching office (MTSO), with one MTSO serving multiple BSs.

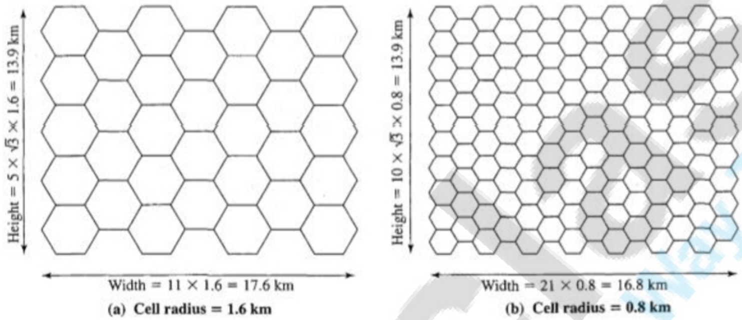


Figure 10.4 Frequency Reuse Example

- Typically, the link between an MTSO and a BS is by a wire line, although a wireless link is also possible. The MTSO connects calls between mobile units.
- The MTSO is also connected to the public telephone or telecommunications network and can make a connection between a fixed subscriber to the public network and a mobile subscriber to the cellular network. The MTSO assigns the voice channel to each call, performs handoffs (discussed subsequently), and monitors the call for billing information.
- The use of a cellular system is fully automated and requires no action on the part of the user other than placing or answering a call. Two types of channels are available between the mobile unit and the base station (BS): control channels and traffic channels.
- Control channels are used to exchange information having to do with setting up and maintaining calls and with establishing a relationship between a mobile unit and the nearest BS.
- Traffic channels carry a voice or data connection between users. Figure 10.6 illustrates the steps in a typical call between two mobile users within an area controlled by a single MTSO:
    - **Mobile unit initialization:** When the mobile unit is turned on, it scans and selects the strongest setup control channel used for this

system (Figure 10.6a). Cells with different frequency bands repetitively broadcast on different setup channels.
The receiver selects the strongest setup channel and monitors that channel. The effect of this procedure is that the mobile unit has automatically selected the BS antenna of the cell within which it will operate.2 Then a handshake takes place between the mobile unit and the MTSO controlling this cell, through the BS in this cell.
The handshake is used to identify the user and register its location. As long as the mobile unit is on, this scanning procedure is repeated periodically to account for the motion of the unit. If the unit enters a new cell, then a new BS is selected. In addition, the mobile unit is monitoring for pages, discussed subsequently.

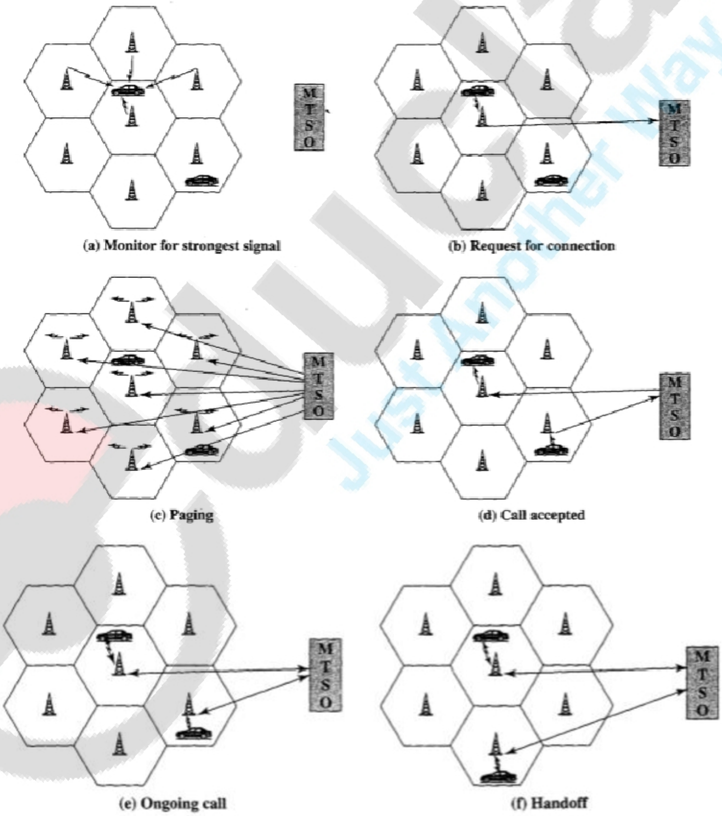


Figure 10.6 Example of Mobile Cellular Call

- **Mobile-originated call:** A mobile unit originates a call by sending the number of the called unit on the preselected setup channel (Figure lO.6b).
  The receiver at the mobile unit first checks that the setup channel is idle by examining information in the forward (from the BS) channel.
  When an idle is detected, the mobile unit may transmit on the corresponding reverse (to BS) channel. The BS sends the request to the MTSO.
- **Paging:** The MTSO then attempts to complete the connection to the called unit. The MTSO sends a paging message to certain BSs depending on the called mobile unit number (Figure 10.6c). Each BS transmits the paging signal on its own assigned setup channel.
- **Callaccepted:** The called mobile unit recognizes its number on the setup channel being monitored and responds to that BS, which sends the response to the MTSO. The MTSO sets up a circuit between the calling and called BSs. At the same time, the MTSO selects an available traffic channel within each BS's cell and notifies each BS, which in turn notifies its mobile unit (Figure 10.6d). The two mobile units tune to their respective assigned channels.
- **Ongoing call:** While the connection is maintained, the two mobile units exchange voice or data signals, going through their respective BSs and the MTSO (Figure 10.6e).
- **Handoff:** If a mobile unit moves out of range of one cell and into the range of another during a connection, the traffic channel has to change to one assigned to the BS in the new cell (Figure 10.6f). The system makes this change without either interrupting the call or alerting the user.

Other functions performed by the system but not illustrated in Figure 10.6 include the following:

- **Call blocking:** During the mobile-initiated call stage, if all the traffic channels assigned to the nearest BS are busy, then the mobile unit makes a preconfigured number of repeated attempts. After a certain number of failed tries, a busy tone is returned to the user Can termination: When one of the two users hangs up, the MTSO is informed and the traffic channels at the two BSs are released.
- **Call drop:** During a connection, because of interference or weak signal spots in certain areas, if the BS cannot maintain the minimum required signal strength for a certain period of time,

the traffic channel to the user is dropped and the MTSO is informed.

- **Calls to/from fixed and remote mobile subscriber:** The MTSO connects to the public switched telephone network. Thus, the MTSO can set up a connection between a mobile user in its area and a fixed subscriber via the telephone network. Further, the MTSO can connect to a remote MTSO via the telephone network or via dedicated lines and set up a connection between a mobile user in its area and a remote mobile user.

Handoff:

- Handoff is the procedure for changing the assignment ofa mobile unit from one BS to another as the mobile unit moves from one cell to another.
- Handoff is handled in different ways in different systems and involves a number of factors. Here we give a brief overview. Handoff may be network initiated, in which the decision is made solely by the network measurements of received signals from the mobile unit.
- Alternatively, mobile unit assisted handoff schemes enable the mobile unit to participate in the handoff decision by providing feedback to the network concerning signals received at the mobile unit.
- In either case, a number of different performance metrics may be used to make the decision. [HAASOO] lists the following:
    - **Cell blocking probability:** The probability of a new call being blocked, due to heavy load on the BS traffic capacity. In this case, the mobile unit is handed off to a neighboring cell based not on signal quality but on traffic capacity.
    - **Call dropping probability:** The probability that, due to a handoff, a call is terminated Call completion probability: The probability that an admitted call is not dropped before it terminates.
    - **Probability of unsuccessful handoff:** The probability that a handoff is executed while the reception conditions are inadequate.
    - **Handoff blocking probability:** The probability that a handoff cannot be successfully completed.

- ○ **Handoff probability:** The probability that a handoff occurs before call termination.
- ○ **Rate of handoff:** The number of handoffs per unit time.

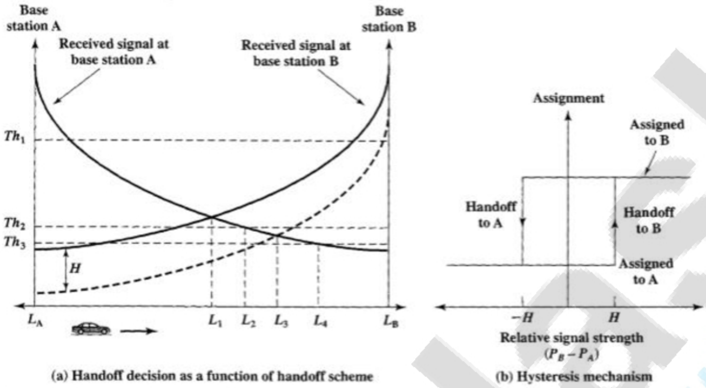


Figure 10.7 Handoff between Two Cells

- **Interruption duration:** The duration of time during a handoff in which a mobile unit is not connected to either base station.
- **Handoff delay:** The distance the mobile unit moves from the point at which the handoff should occur to the point at which it does occur.

The principal parameter used to make the handoff decision is measured signal strength from the mobile unit at the BS. Typically, the BS averages the signal over a moving window of time to remove the rapid fluctuations due to multipath effects. Figure 10.7a, based on one in [POLL96], shows the average received power level at two adjacent base stations as a mobile unit moves from BS A, at LA, to BS B, at LB' This figure is useful in explaining various handoff strategies that have been used to determine the instant of handoff:

- **Relative signal strength:** The mobile unit is handed off from BS A to BS B when the signal strength at B first exceeds that at A. If the signal strength at B subsequently falls below that of A, the mobile unit is handed back to A. In Figure 10.7a, handoff occurs at point L
  At this point, signal strength to BS A is still adequate but is declining. Because signal strength fluctuates due to multipath effects, even with power averaging, this approach can lead to a ping-pong effect in which the unit is repeatedly passed back and forth between two BSs.
- **Relative signal strength with threshold:** Handoff only occurs if (1) the signal at the current BS is sufficiently weak (less than a predefined threshold) and (2) the other signal is the stronger of the two. The intention is that so long as the signal at the current BS is adequate, handoff is unnecessary. If a high threshold is used, such as Th1, this

scheme performs the same as the relative signal strength scheme. With a threshold of Th2, handoff occurs at L2.

If the threshold is set quite low compared to the crossover signal strength (signal strength at L1), such as Th3, the mobile unit may move far into the new cell (L4) before handoff.

This reduces the quality of the communication link and may result in a dropped call. A threshold should not be used alone because its effectiveness depends on prior knowledge of the crossover signal strength between the current and candidate base stations.

- **Relative signal strength with hysteresis:** Handoff occurs only if the new base station is sufficiently stronger (by a margin H in Figure 10.7a) than the current one. In this case, handoff occurs at L3. This scheme prevents the ping-pong effect, because once handoff occurs, the effect of the margin H is reversed.
  The term hysteresis refers to a phenomenon known as relay hysteresis and can be appreciated with the aid of Figure 10.7b. We can think of the handoff mechanism as having two states. While the mobile unit is assigned to BS A, the mechanism will generate a handoff when the relative signal strength reaches or exceeds the H.
  Once the mobile unit is assigned to B, it remains so until the relative signal strength falls below - H, at which point it is handed back to A. The only disadvantage of this scheme is that the first handoff may still be unnecessary if BS A still has sufficient signal strength.
- Relative signal strength with hysteresis and threshold: Handoff occurs only if (1) the current signal level drops below a threshold, and (2) the target base station is stronger than the current one by a hysteresis margin H. In our example, handoff occurs at L3 if the threshold is either Th1 or Th2 and at L 4 if the threshold is at Th3.
- Prediction techniques: The handoff decision is based on the expected future value of the received signal strength.

The handoff decision is complicated by the use of power control techniques, which enable the BS to dynamically adjust the power transmitted by the mobile unit.

Generation of cellular networks – 1G, 2G, 2.5G, 3G and 4G:

1G:

- The original cellular telephone networks provided analog traffic channels; these are now referred to as first generation systems.
- Since the early 1980s the most common first-generation system in North America has been the Advanced Mobile Phone Service (AMPS) developed by AT&T.
- This approach is also common in South America, Australia, and China.

- Although it has been replaced, for the most part, by second-generation systems, AMPS is still in use.
- Advanced Mobile Phone Service (AMPS) invented at Bell Labs and first installed in 1982
- Used in England (called TACS) and Japan (called MCS-L1)
- Key ideas:
    - Exclusively analog.
    - Geographical area divided into cells (typically 10-25km)
    - Cells are small: Frequency reuse exploited in nearby (not adjacent) cells
    - As compared to IMTS, could use 5 to 10 times more users in same area by using frequency re-use (divide area into cells) o Smaller cells also required less powerful, cheaper, smaller devices.
- Cell design (around 10mile radius)
    - Served by base station consisting of transmitter, receiver, and control unit
    - Base station (BS) antenna is placed in high places (churches, high rise buildings).
    - Operators pay around $500 per month for BS
    - 10 to 50 frequencies assigned to each cell o Cells set up such that antennas of all neighbours are equidistant (hexagonal pattern)
- In North America, two 25-MHz bands allocated to AMPS
    - One for transmission from base to mobile unit
    - One for transmission from mobile unit to base
- Approaches to Increase Capacity:
    - Adding/reassigning channels - some channels are not used
    - 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
    - Microcells – antennas move to buildings, hills, and lamp posts
- Security Issues with 1G:
    - Analog cellular phones are insecure.
    - Anyone with an all band radio receiver can listen in (many scandals)
    - Theft of airtime:
        - all band radio receiver connected to a computer.
        - can record 32-bit serial number and phone number of subscribers when calling.
        - can collect a large database by driving around

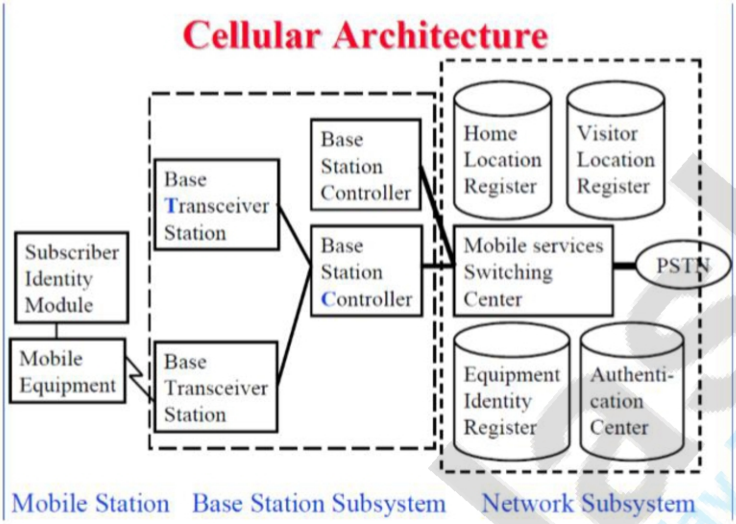
        - Thieves go into business - reprogram stolen phones and resell them.

2G:

- It us based on digital transmission
- Different approaches in US and Europe
- US: divergence:
    - Only one player (AMPS) in 1G
    - Became several players in 2G due to competition
    - Survivors:
        - IS-54 and IS-135: backward compatible with AMPS frequency allocation (dual mode - analog and digital)
        - IS-95: uses spread spectrum
- Europe: Convergence
    - 5 incompatible 1G systems (no clear winner)
    - European PTT development of GSM (uses new frequency and completely digital communication)

Cellular Architecture:

- Base station controller(BSC) and Base transceiver station (BTS)
- One BTS per cell.
- On BSC can control multiple BTS.
    - Allocates radio channels among BTSs.
    - Manages call handoff between BTSs.
    - Controls handset power levels
- Mobile switching Center (MSC) connects to PSTN and switches call between BSCs.
- Provides mobile registration, location, and authentication.
- Contains Equipment Identity Register.



- Advantages of Digital Communications for Wireless
  - Voice, data and fax can be integrated into a single system.
  - Better compression can lead to better channel utilization.
  - Error correction codes can be used for better quality
  - Sophisticated encryption can be used
- Differences Between First and Second Generation Systems:
  - Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
  - Encryption – all second generation systems provide encryption to prevent eavesdropping
  - Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
  - Channel access – second-generation systems allow channels to be dynamically shared by a number of users

2.5G:

- The mobile technology using general packet radio service (GPRS) standard has been termed as 2.5G.
- It adds packet-switched capabilities to existing GSM and TDMA networks.
- TCP provides a virtual end-to-end connection for reliability.
- The GPRS (2.5G) core network and service characteristics.
- Although GPRS is an extension to the radio access network, it requires whole new packet based IP data links, servers, and gateways in the core network.

- Thus GPRS adds several new components besides changing the existing GSM or TDMA network.

3G:

- The 3G technology adds multimedia facilities to 2G phones by allowing video, audio, and graphics applications.
- 3G cellular services, known as Universal Mobile Telecommunications System(UMTS) or IMT-2000, will sustain higher data rates and open the door to many Internet style applications.
- A single family of compatible standards that can be used worldwide for all mobile applications.
- Support for both packet-switched and circuit-switched data transmission.
- Data rates up to 2 Mbps (depending on mobility).
- Provides High spectrum efficiency.
- 3G technology puts a strong emphasis on Internet and multimedia services, such as web browsing, video conferencing and downloading music. High bandwidth-allows you quick and easy access to all online multimedia and Internet tools.
- While the maximum bandwidth for a stationary 3G device—is 2.05Mbps, when you are moving slowly (walking), this drops to 384Kbps.
- When you and your device are moving at high speeds (car), the maximum bandwidth drops to 128 Kbps. can utilize packet-based Internet protocol connectivity.
- This means your mobile device will always be online and ready for Internet access.
- In addition to being more expensive, 3G handsets also require more power than most 2G models.
    - Fast speeds. High bandwidth allows 3G networks to reach data transmission speeds of up to 2 megabytes. Such speed has allowed 3G phones to include Internet access and video calls in addition to voice calls.
    - Constant internet access. On a 3G network, the user is always online. There is no need to search for a wi-fi connection in order to access the Internet.
- There can also be drawbacks to 3G networks, however.
    - Connectivity problems. Users have had connection problems in certain areas. 3G networks tend to be area-specific, and people outside of a covered region will not be able to take full advantage of 3G.

- Software and hardware issues. Users of some mobile device including

4G:

- Seamless mobility (roaming)
  - Roam freely from one standard to another
  - Integrate different modes of wireless communications – indoor networks (e.g., wireless LANs and Bluetooth); cellular signals; radio and TV; satellite communications
- 100 Mb/se full mobility (wide area); 1 Gbit/s low mobility (local area)
- IP-based communications systems for integrated voice, data, and video
  - IP RAN(Radio Access Networks)
- Open unified standards
- Stream Control Transmission Protocol (SCTP)
  - replacement for TCP o Maintain several data streams within a single connection
  - Service Location Protocol (SLP)
  - Automatic resource discovery o Make all networked resources dynamically configurable through IP-based service and directory agents
  - Instead of hybrid technology used in 3G with the combination of CDMA and IS-95 a new technology OFDMA is introduced 4G. In OFDMA, the concept is again of division multiple accesses but this is neither time like TDMA nor code divided CDMA rather frequency domain equalization process symbolizes as OFDMA.
- Some Key Challenges:
- Coverage:
  - Transmit power limitations and higher frequencies limit the achievable cell size
- Capacity:
  - Current air interfaces have limited peak data rate, capacity, and packet data capability
- Spectrum:
  - Location and availability are key issues
  - Lower carrier frequencies (< 5 GHz) are best for wide-area coverage and mobility
- 4G Concept System:
- A demonstration of broadband mobile systems in Schaumburg, Illinois
  - A one-directional broadband downlink carrier on DVB-T (WA9XHI)

- A narrowband uplink via a cellular data connection (Sprint CDMA data)
- Proving ground for asymmetric mobile broadband
- Develop application understanding to apply to broadband air interface designs
- Platform to demonstrate custom applications
- Increasing levels of integration
    - Phase 1 – Vehicular mobility with a larger off-the-air receiver – May 2000
    - Phase 2 – Personal mobility with an integrated laptop receiver – Progressing
- 4G Air Interface Characteristics
- Higher bit rates than 3G (20 Mbps < peak < 200 Mbps)
- Higher spectral efficiency and lower cost per bit than 3G
- Air interface and MAC optimized for IP traffic (IPv6, QoS)
    - Adaptive modulation/coding with power control, hybrid ARQ
- 4G still in a formative stage (commercial 2010)
- Frequency bands less than 5 GHz preferred for wide-area, mobile services
- 4G system bandwidth between 20 and 100 MHz (paired or unpaired)
- ITU Working Group 8F beginning to consider the requirements and spectrum needs
- International 4G spectrum harmonization

University Questions:
Explain the generations of cellular networks- 8M- May 2016.