EEE4121F Module A

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Wireless Communications

What is *wireless*?

- Communications without cables or cords, primarily using radio frequency or infrared waves
- 1893 - Tesla made first demo of radio communications

How is it better than *wired*?

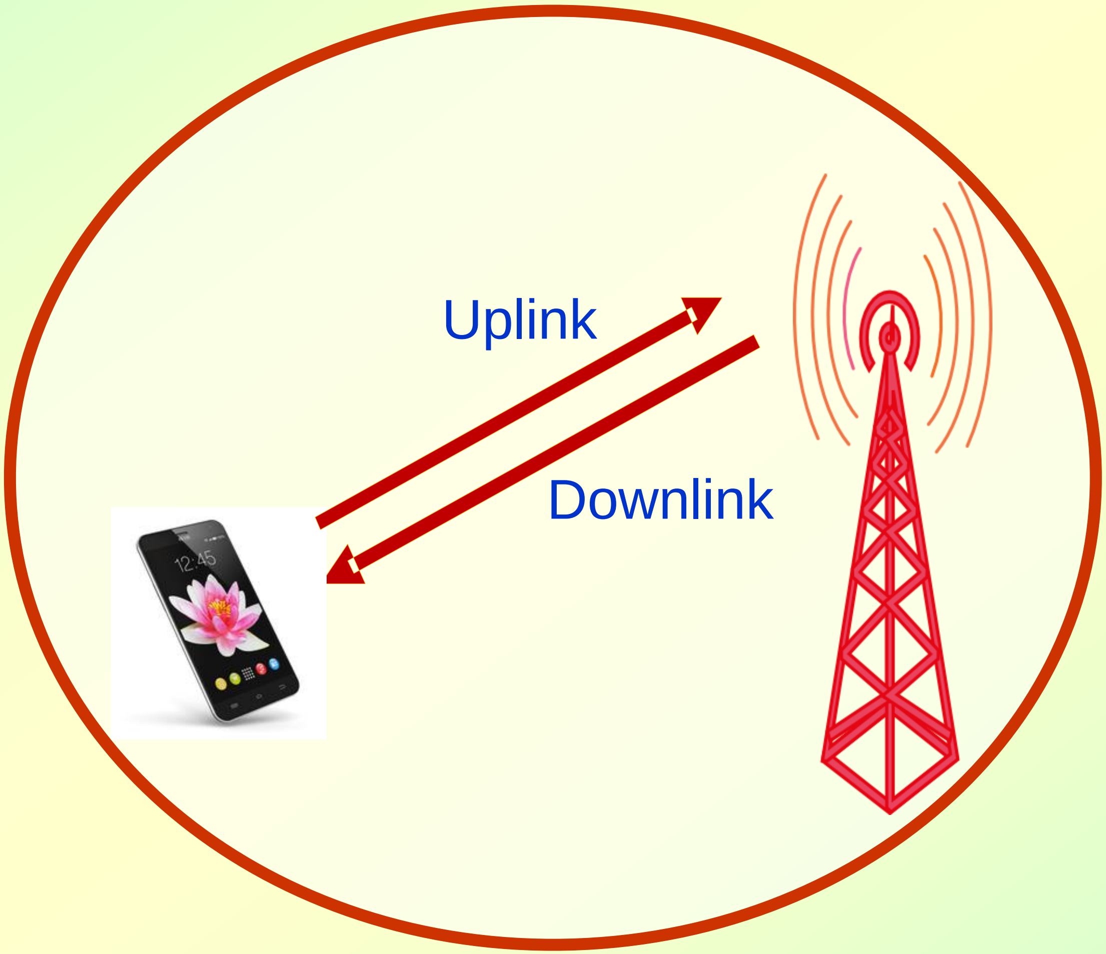
- Less expensive deployment covering a wider geographic area
- Smaller and user-friendly devices
- Less prone to theft
- Anytime, anywhere access – supports mobility

Wireless Networks

Transmitter

Medium

Receiver

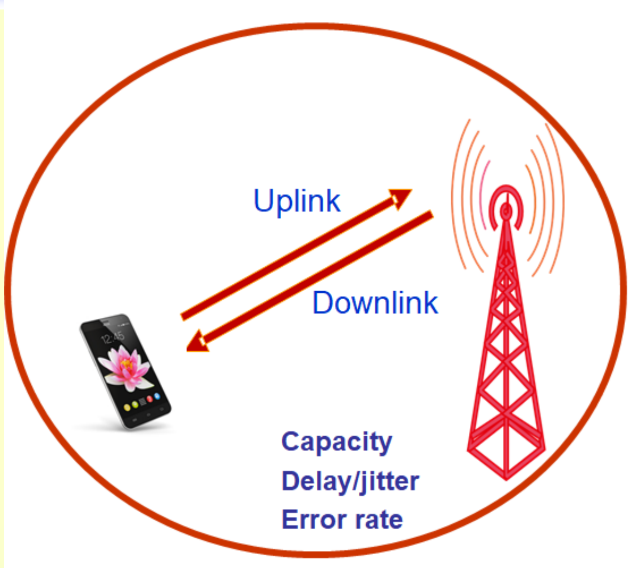


Capacity

Delay/jitter

Error rate

Wireless Networks



Basic Communications System

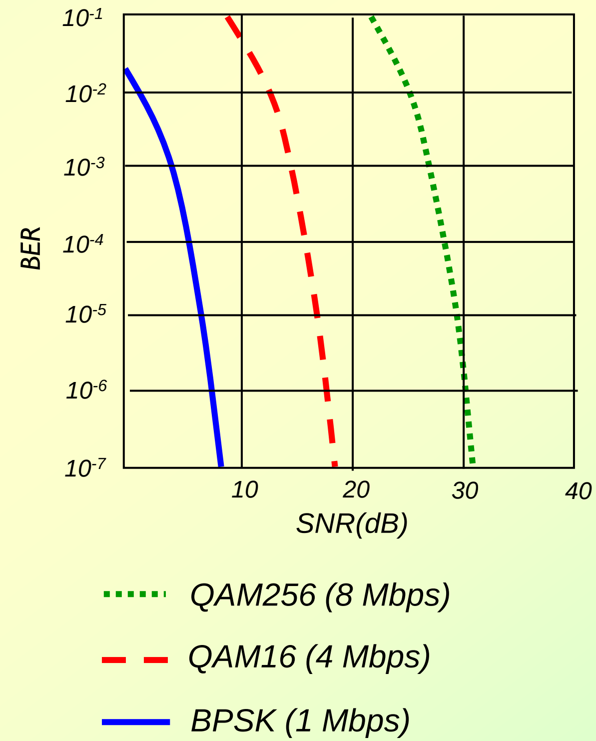
- ♦ Transmitter
- ♦ Receiver
- ♦ Medium: wireless

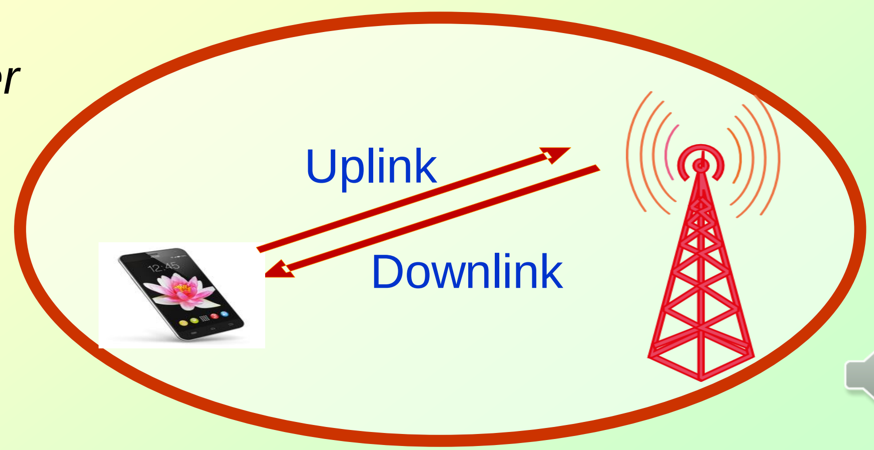
Purpose of a Communication System

- ♦ Deliver as much information as possible from the source to the destination (capacity).
- ♦ Capacity may be measured in bits per second (bps)
- ♦ Information may be of different natures, such as voice, video, or data
- ♦ Deliver information in shortest time (delay). Delays are measured in milliseconds or in round trip delay
- ♦ Reduce errors in delivery of information (error detection/correction)
- ♦ Errors can be measured as Bit Error Rate (BER) or Frame Error Rate (FER).

Wireless Networks: Wireless Link Characteristics

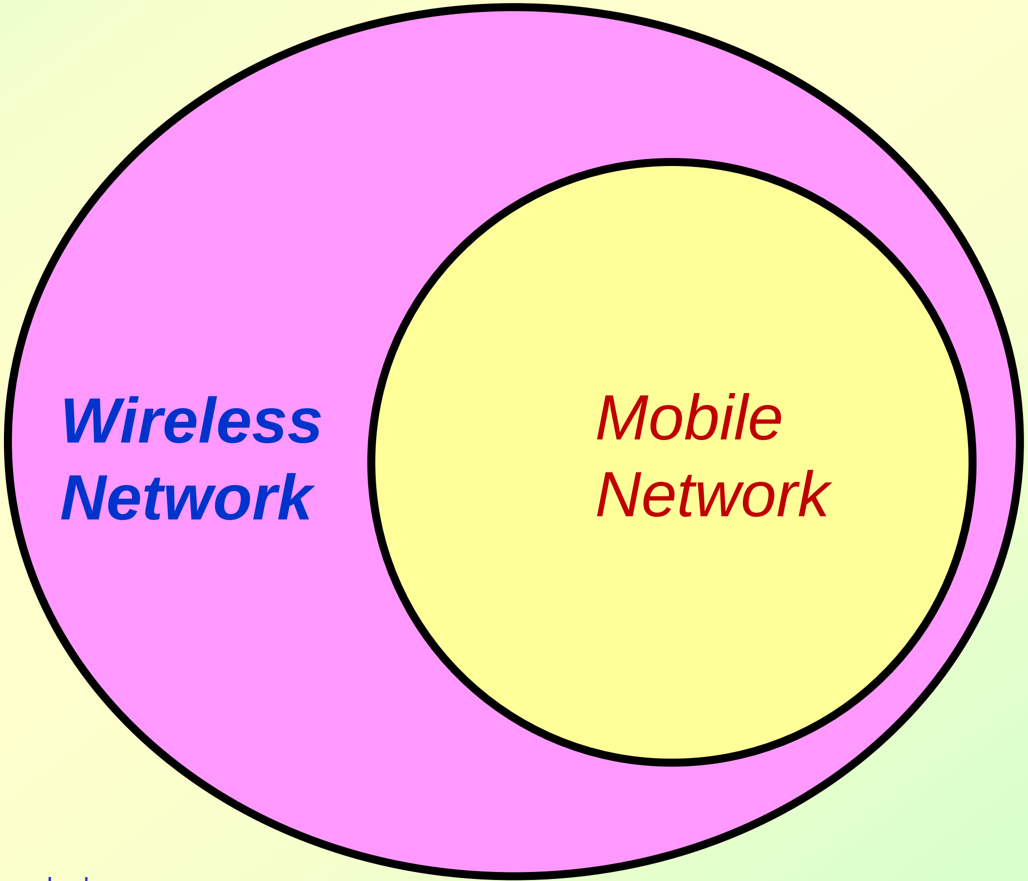
- *SNR: signal-to-noise ratio*
  - *larger SNR – easier to extract signal from noise (a "good thing")*
- *SNR versus BER tradeoffs*
  - *given physical layer: increase power -> increase SNR->decrease BER*
  - *given SNR: choose physical layer that meets BER requirement, giving highest throughput*
    - *SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)*





Question 1

What is the difference between a wireless network and a mobile network?



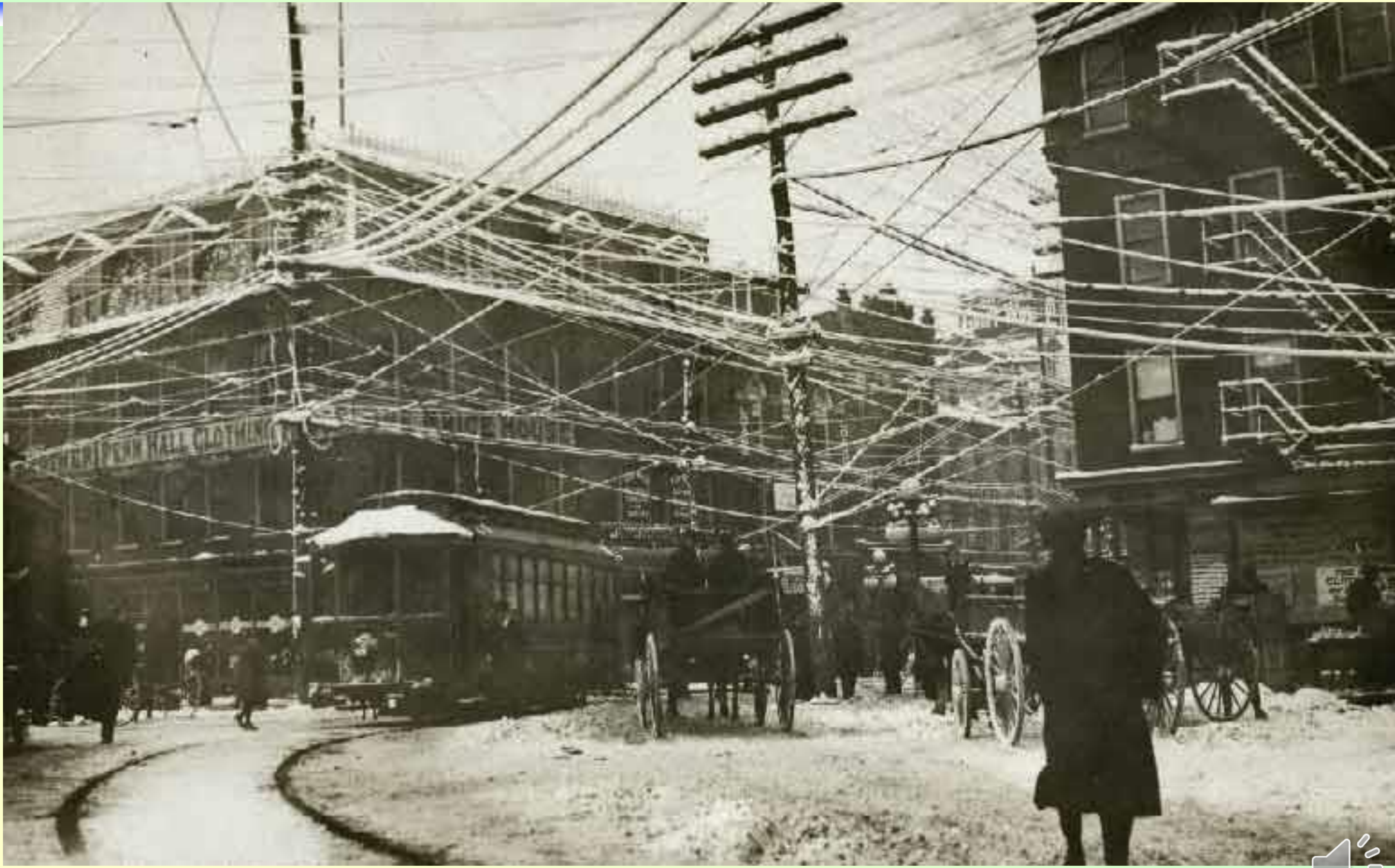
Communication History Highlight

- Telephone is a combination of two Greek words: tele (meaning far off) and phone (meaning voice or sound), hence the term for far-speaking
- 1800s – Sir Charles Wheatstone, co-inventor of the telegraph, applied the term telephonic to describe his invention, an enchanted lyre, which transmitted music from one room to another
- 1860 – Philip Reis developed a telephone.
- 1874 – Alexander Graham Bell discovered the principle of the telephone

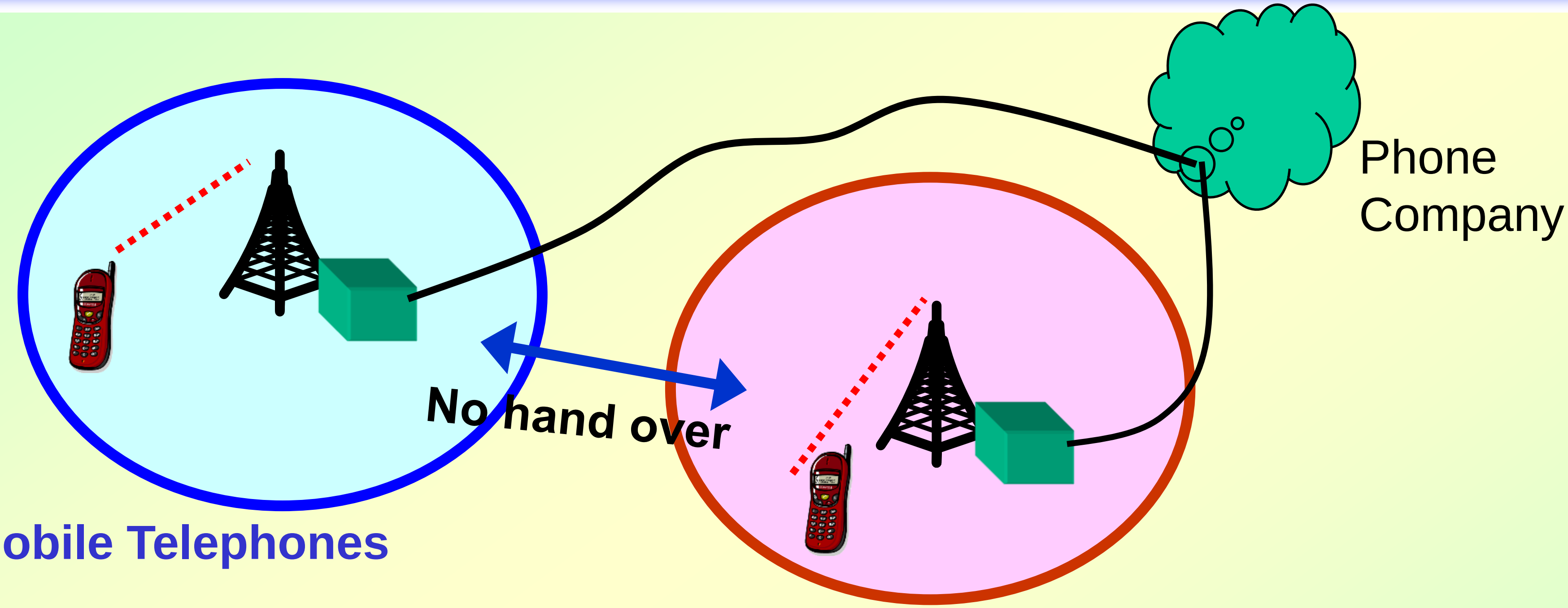
Communication History Highlight

- **1876** U.S. Patent No. 174,465, was issued for improvements in telegraphy to Alexander Graham Bell
- **1877** Commercial telephone service began in the United States.
- **1879** Telephone subscribers began to be designated by numbers rather than names
- **1891** First automatic dial system was patented by a Kansas City undertaker
- **1927** Bell System developed the French phone, with the transmitter and receiver in a single handset
- **1927** Transatlantic wireless service from New York to London became operational
- **1946** First commercial mobile telephone service
- 1955 – Laying of transatlantic telephone cables began

Early Days of Telecommunication



Mobile Phones - History



Mobile Telephones

- ♦ Unlike the traditional telephone, which requires wire connections between telephones, the mobile telephone broadcasts its signals through the air
- ♦ The first wireless telephone system used a single transmission that covered a large area
- ♦ Very powerful transmitters and very high antenna towers were required to provide coverage

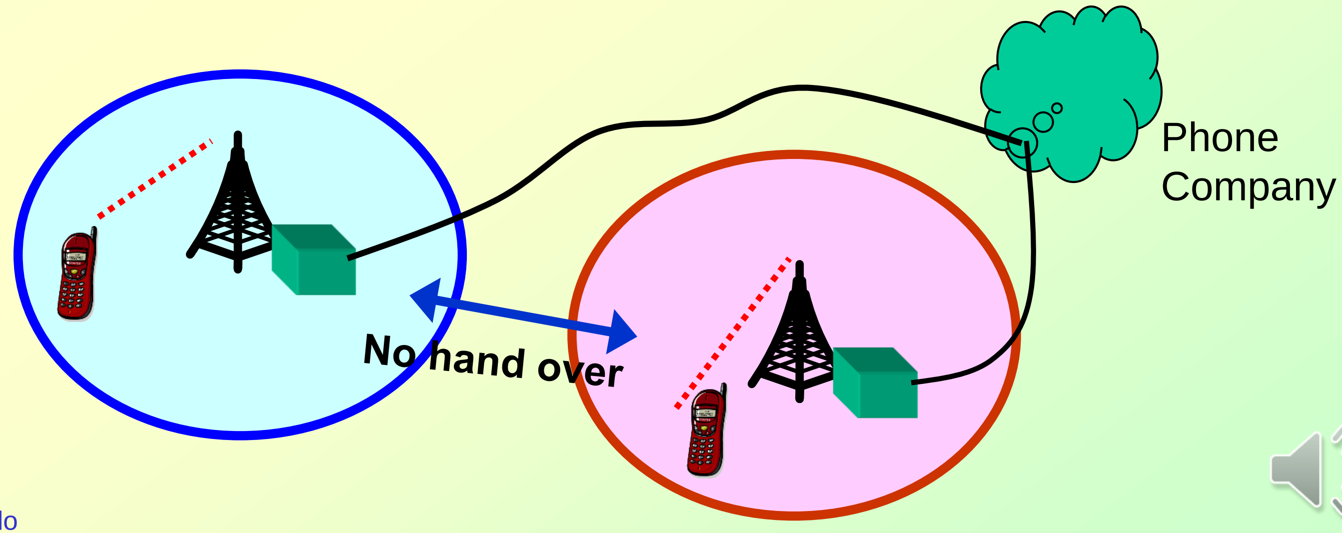
Mobile Phones - History

Advantages of the mobile telephone

- Limited mobility

Disadvantages of the mobile telephone

- Cost for phones and airtime was expensive.
- Phones were big and bulky.
- Coverage was limited to a single cell. Upon reaching the edge of the cell either the user stopped, or the call would drop.
- No privacy
- Low capacity

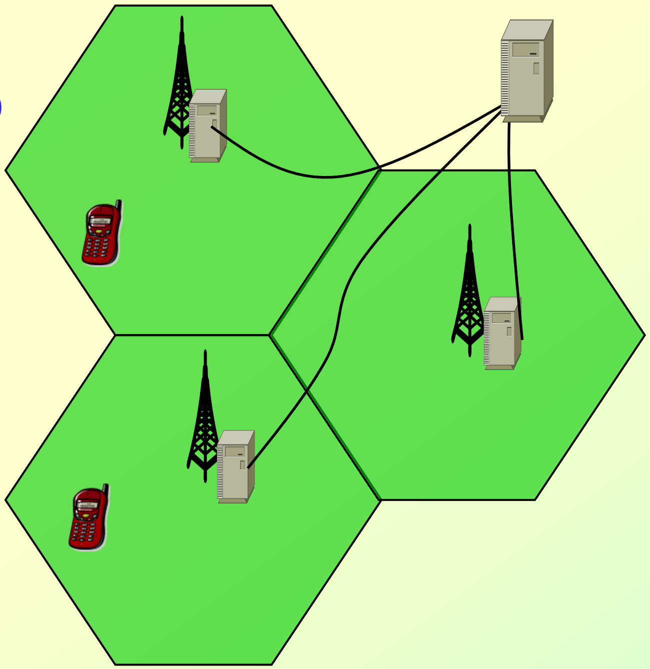


Cellular Telephony and Network

New Wireless Service

♦Tests for cellular networks were conducted in Chicago in the early 1980s. Commercial services started shortly after the testing.

♦New methods of control were developed which allowed for better services, more service providers, and greater mobility.



Network Components

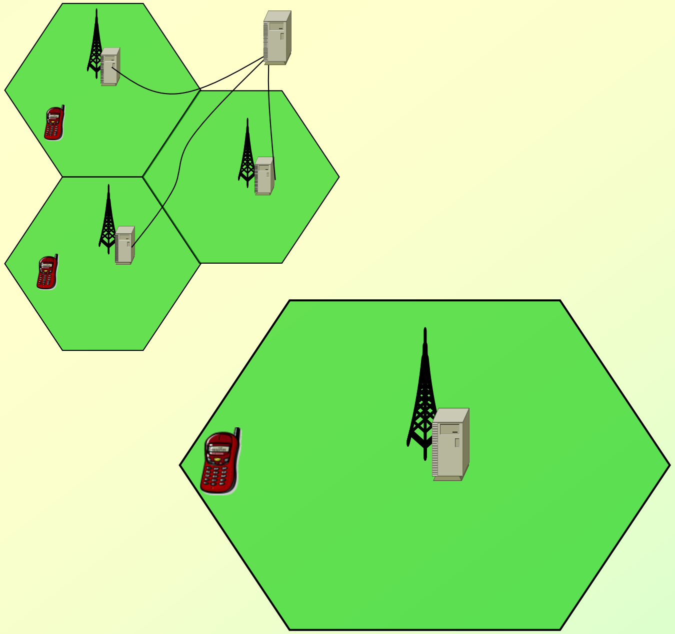
♦Cell site – transmitter and receiver (transceiver) for phone connection

♦Mobile Telephone Switching Office (MTSO) – control and operational purposes

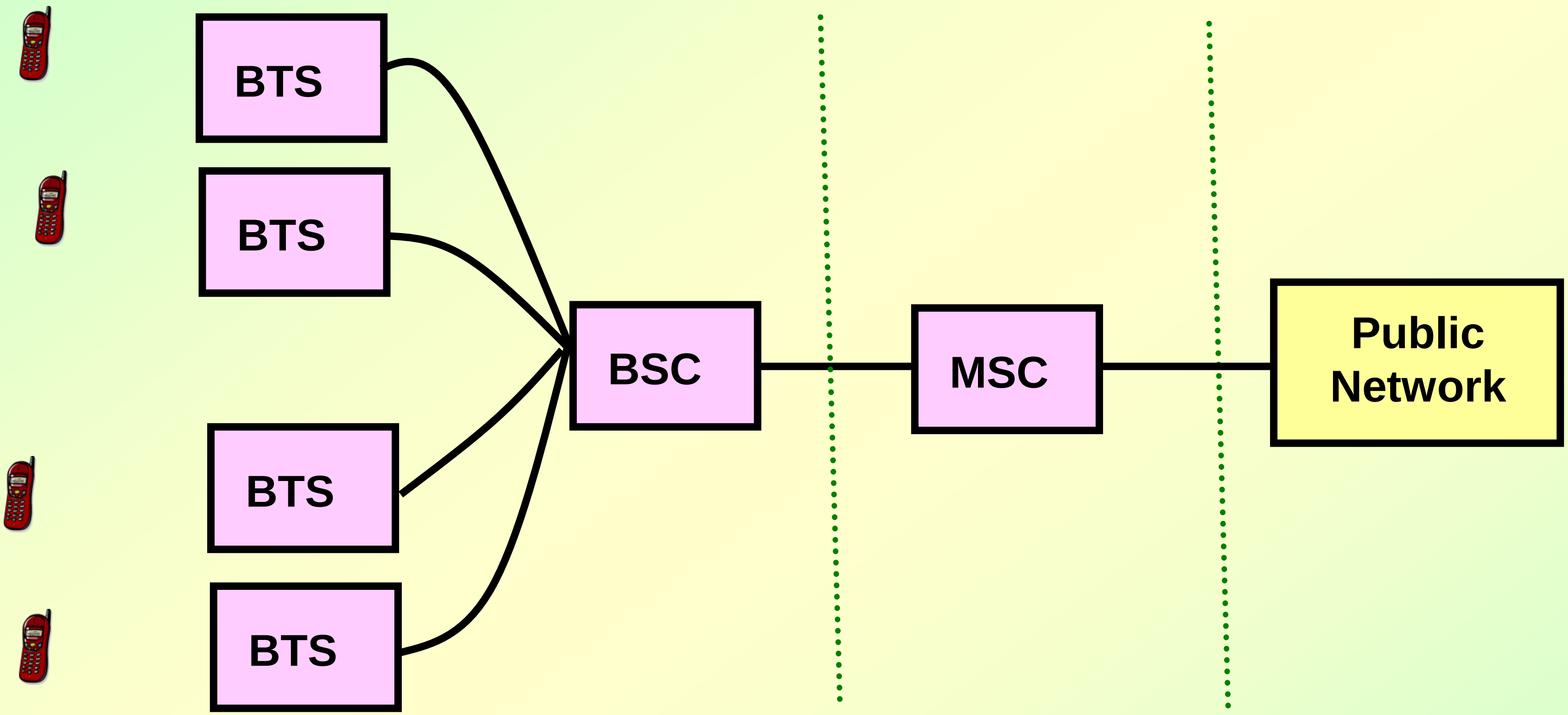
♦Public Switched Telephone Network (PSTN) – connection to phones located in individual homes

Advantages of Cellular Concept

- Truly mobile communications – calls could be handed over from one cell site to another
- Increased capacity
- Reduced power use
- Larger coverage area
- Reduced interference from other signals
- Reduced health hazard
- Cost for phones and airtime less



Cellular Systems



Basic components of cellular networks

Wireless Network Components

Mobile Phones

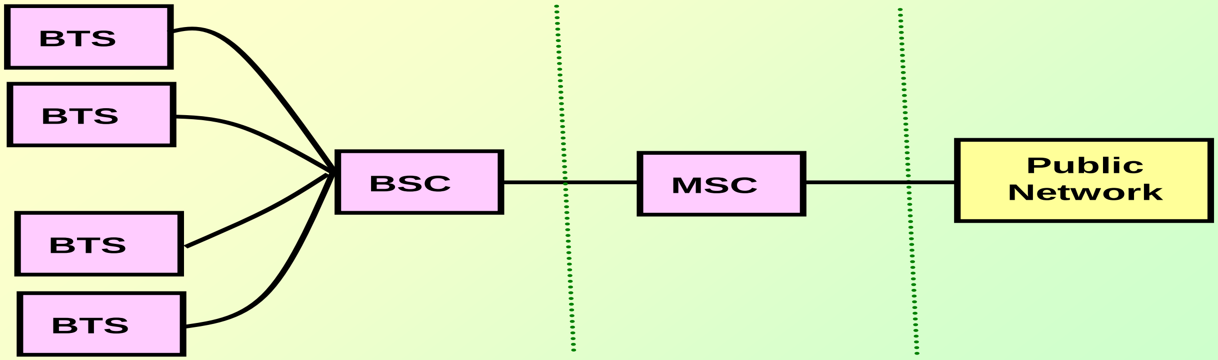
- Mobile phones, mobile station (MS), portable, subscriber, user terminal (UT), user equipment, smartphone

Base Transceiver Station (BTS)

- BTS is the cell site radio transmitter and receiver. Within the BTS are modems designed to modulate an information signal onto a radio signal.
- BTS may come as an omnidirectional or sectorized version. The size and number of racks will depend on manufacturer and configuration.

Base Station Controller (BSC)

- BSC typically handles technology specific functions, such as vocoding operation.
- Size and number of racks will depend on manufacturer and configuration.



Wireless Network Components

Mobile Switching Center

- The Mobile Switching Center (MSC) handles the call controls, switching, billing support, and roaming support
- The MSC may also be referred to as a Mobile Telephone Switching Office (MTSO). The term MTSO usually is in reference to the analog networks and provides interface between the PSTN and the BSC

Public Switched Telephone Network

- The PSTN is an entity commonly referred to as the "phone company" that includes global landline and wireless telecommunications networks, switching equipment, telephone lines, optic fiber networks, microwave links, and wireless infrastructure equipment from other service providers

Wireless Network Components

PSTN / LEC / LDC

- **PSTN** – Public Switched Telephone Network
- **LEC** – Local Exchange Carrier
- **LDC** – Long Distance Carrier

Why do we need a them?

- To expand our services to include domestic and international telephone networks, with access to land line phones and other wireless networks

Where do calls originate?

- Some from landline subscribers – Home, business, and pay phones
- Some from wireless subscribers – Cellular, PCS, and Wireless Local Loop (WLL) phones

How are calls initiated?

- Landline phones – pick up the handset to go “off-hook”
- Wireless phones – press the SEND button
- Non-voice applications are device specific

What happens next?

- A connection is requested to the facility
- The numbers are dialed through and the connection at the far end is made

Types of Cells

There are four main types of cells namely Macro cell, Microcell, Picocell, and Femtocells. They are different with respect to the following features: location (indoor or outdoor), coverage area, antenna height, and access restriction (public, private access, or hybrid).

(1) Macro Cells

- Conventional base stations that use dedicated backhaul and open to public access.
- Macro cells provide the largest coverage area within a mobile network.
- The antennae for macro cells are usually mounted on ground-based masts, rooftops or other existing structures and are positioned at a height that is not obstructed by terrain or buildings.
- Typically, macro-cell base stations have a power output in tens of watts. Macro cells are used to cover the widest range of cell sizes.
- They are found in rural areas or along highways

Types of Cells

(2) Microcells

- Micro cells are used over a smaller cell area such as in a densely populated urban area.
- These enable greater frequency reuse by allowing radio frequency propagation to be confined to a small local area.
- A micro cell is served by a low-power tower, covering a limited area such as a small colony, mall, hotel or transportation hub.

(3) Picocells

- Pico cells are used in areas smaller than micro cells, such as part of a building, a street corner or an airplane cabin.
- A cellular base station designed to serve a relatively small area, such as a single building or a city block, is the basic motive of picocells.
- Usually, picocells are used to extend coverage to indoor areas where outdoor signals do not reach well or to add network capacity in areas with very dense phone usage.
- They use low power base stations with dedicated backhaul connections, and are open to public access

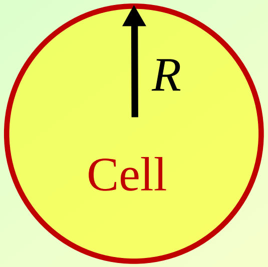
Types of Cells

(4) Femtocells

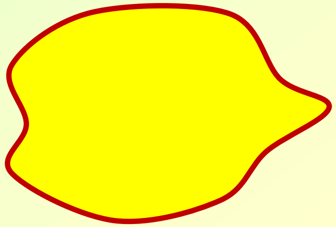
- Currently, the smallest area of coverage that is proposed to be implemented is with a femtocell.
- Femtocells are proposed to be used in homes or small offices.
- They are perhaps the most exciting products and challenging technology emerging in the communications market today.
- Femtocells are consumer-deployable base stations that utilize consumer's broadband connection as backhaul.
- Femto base stations may have restricted association.

- (5) Megacells – Satellite communications

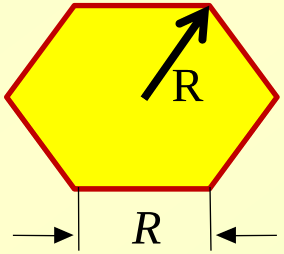
Cell Shape



(a) Ideal cell



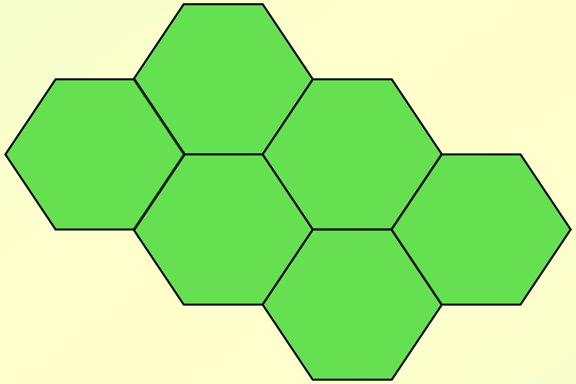
(b) Actual cell



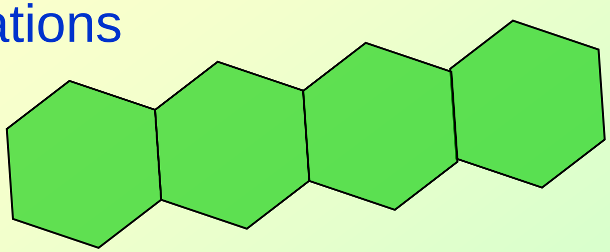
(c) Hexagonal Cell model

Cell Structure

- Cells are usually organized into clusters
- Linear structure is suitable for covering roads in remote locations



(a) Cell cluster



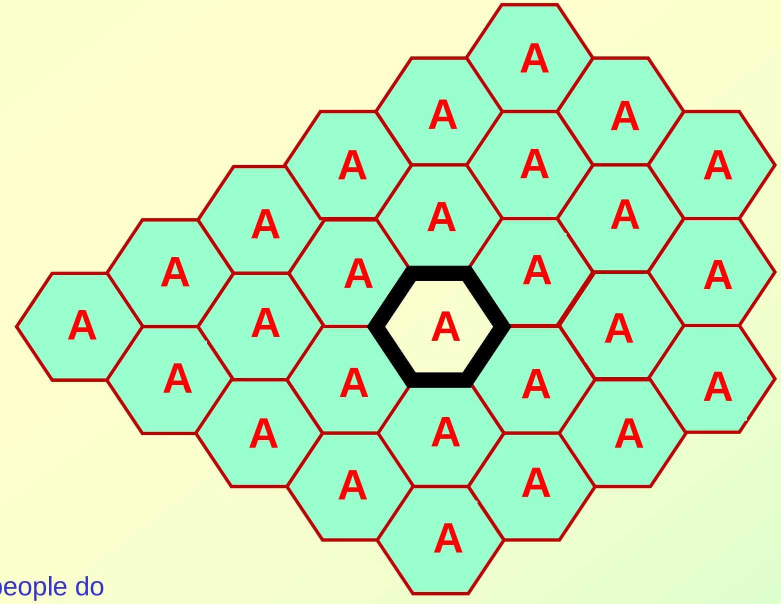
(b) Linear cell structure

Frequency Reuse Concepts

♦ The band of frequency allocated for cellular system use can be reused with different clusters.

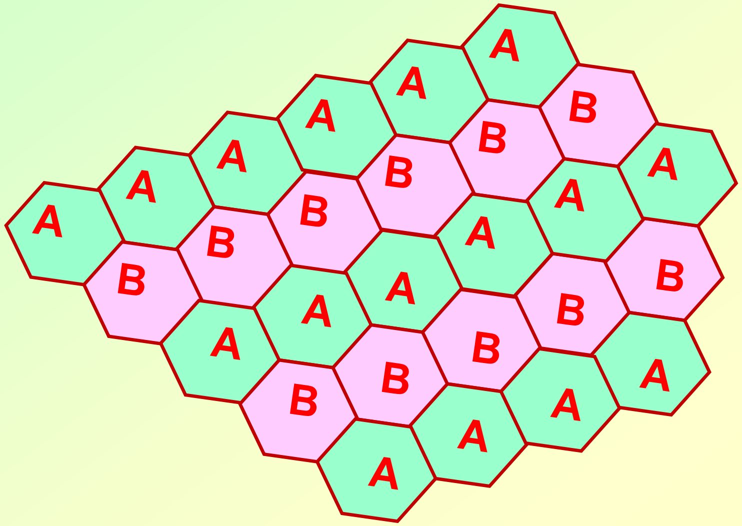
♦ Different cluster shapes with different frequency reuse factors are considered in the following diagrams:

(a) Universal frequency reuse: 1-Cell Frequency Reuse Cluster (Frequency Reuse Factor = 1): Example is the CDMA technology



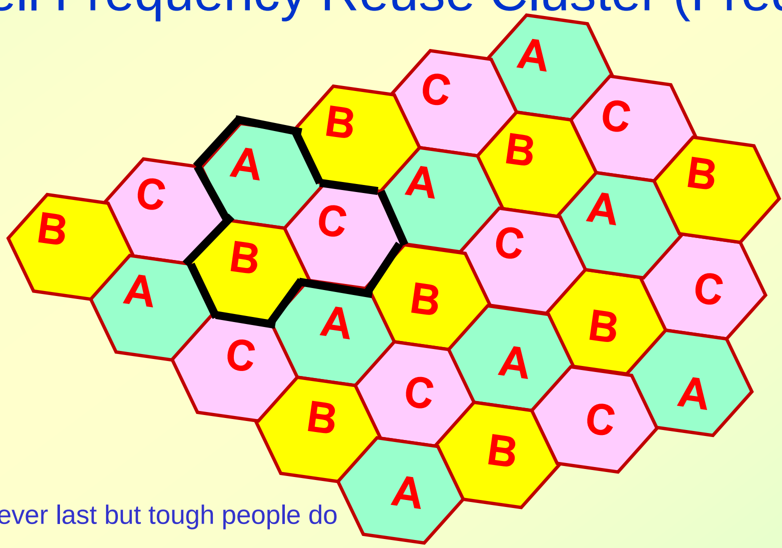
Frequency Reuse Concepts

(b) 2-Cell Frequency Reuse Cluster (Frequency Reuse Factor = 1/2): ~~not valid~~



- the allocated band is divided into 2 bands, which are reused in an alternating fashion somehow.
- two neighbouring cells have the same frequency, therefore the configuration is not valid

(c) 3-Cell Frequency Reuse Cluster (Frequency Reuse Factor = 1/3): valid



- the allocated frequency is divided into 3 bands
- the three sub-bands are reused in an alternating fashion
- no neighbouring cells have the same frequency in the configuration resulting in it being the cluster with the least number of cells that is provides practical frequency reuse

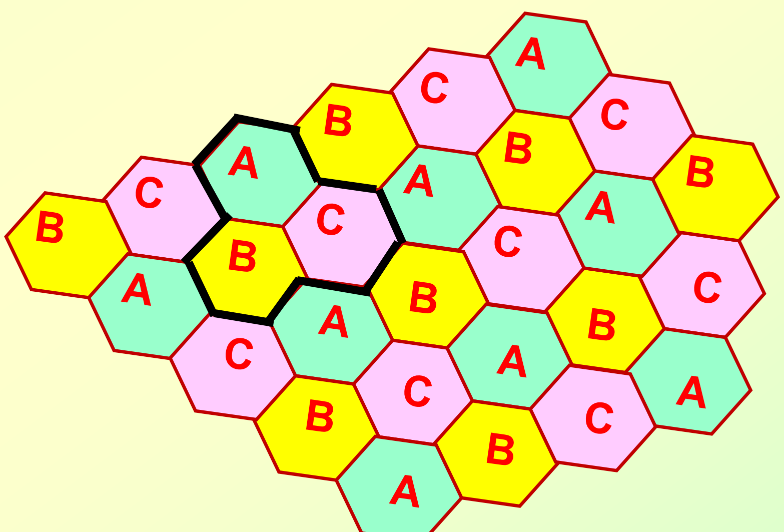
Frequency Reuse Concepts

- The increased capacity in a cellular network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area for a completely different transmission.
- If there is a single plain transmitter, only one transmission can be used on any given frequency.
- With frequency reuse, a set of Z different frequencies $\{f_1, ..., f_z\}$ are used for each cluster of Z adjacent cells. Cluster patterns and the corresponding frequencies are re-used in a regular pattern over the entire service area.
- To avoid interference in a standard FDMA system, there must be at least a one cell gap between cells which reuse the same frequency.
- The frequency reuse factor is the rate at which the same frequency can be used in the network.
- It is given as 1/K, where K is the number of cells which cannot use the same frequencies for transmission.

Frequency Reuse

The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area

- Cells are assigned a group of channels that is completely different from neighbouring cells
- The coverage area of cells is called the footprint and is limited by a boundary so that the same group of channels can be used in cells that are far enough apart
- Cells with the same value have the same set of frequencies

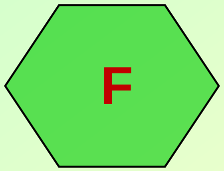


Frequency Reuse Concepts

- Common values for the frequency reuse factor are 1/3, 1/4, 1/7, 1/9 and 1/12.
- In case of N sector antennas on the same base station site, each with different direction, the base station site can serve N different sectors. N is typically 3.
- A **reuse pattern** of N/K denotes a further division in frequency among N sector antennas per site. Some current and historical reuse patterns are 3/7 (North American AMPS), 6/4 (Motorola NAMPS), and 3/4 (GSM).
- If the total available bandwidth is B, each cell can only utilize a number of frequency channels corresponding to a bandwidth of B/K, and each sector can use a bandwidth of B/NK.

Frequency Reuse Concepts

$F = F_a + F_b + F_c$



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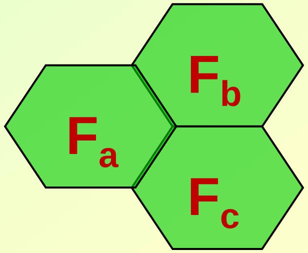

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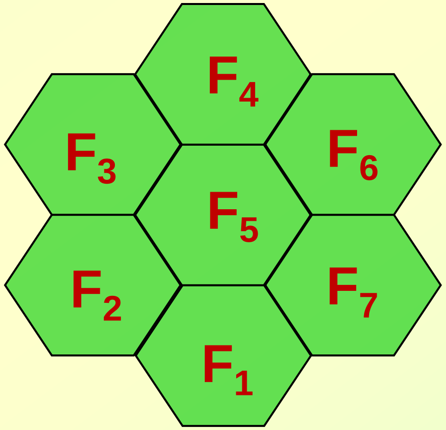


$F = F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7$

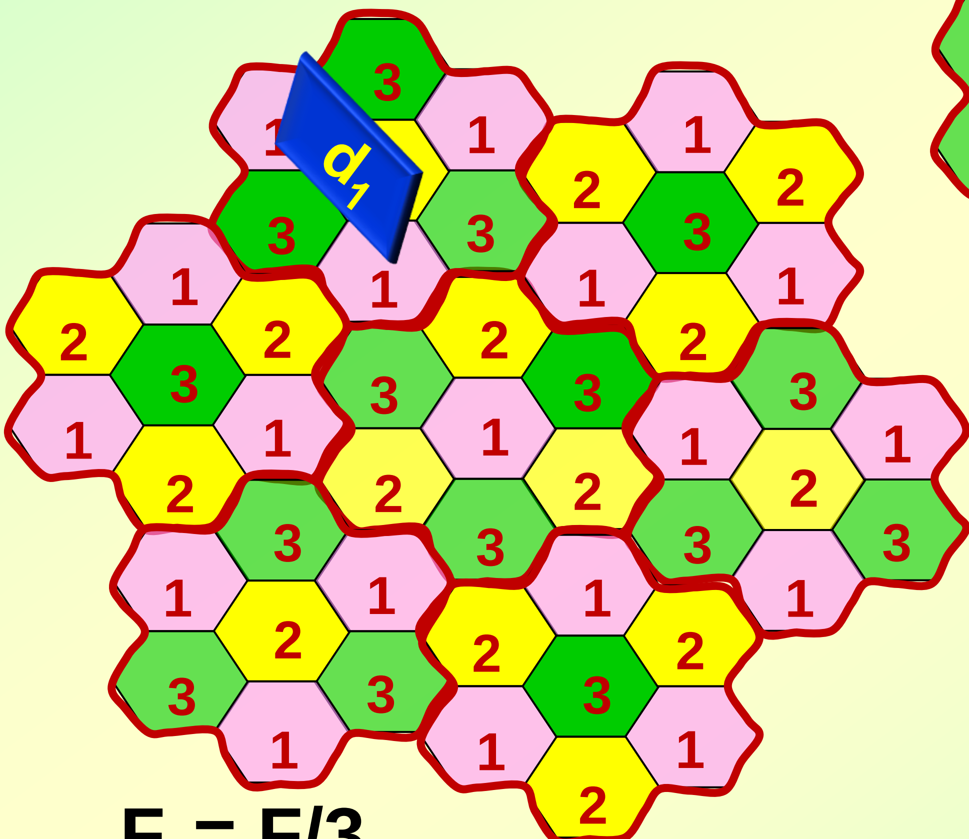
- ♦ Reusing frequencies by dividing the allocated band by a specific integer number of cells and assigning each cell one division and then repeating the assignment over and over produces a tradeoff between network capacity and reception quality as follows:

- ♦ The higher the number of divisions of the spectrum over cells (higher cell-reuse factor), the lower the capacity of the network but the further away cells with similar frequency allocations are located resulting in lower interference.

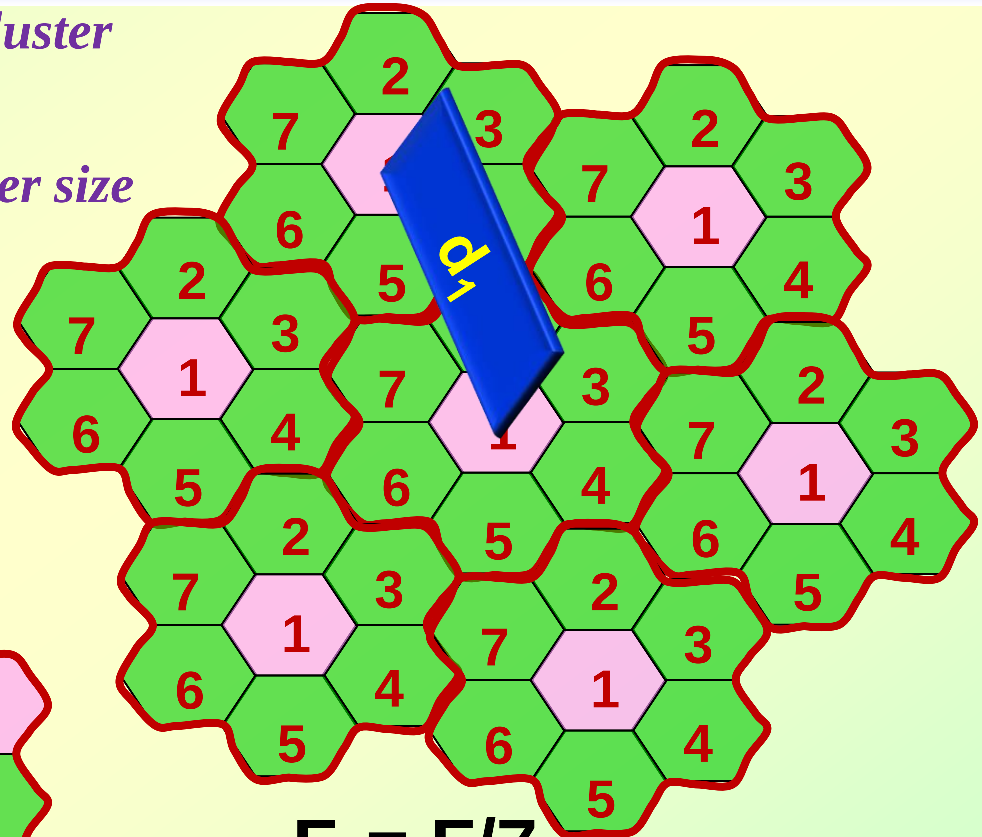
- ♦ The lower the number of divisions of the spectrum over cells (Lower cell-reuse factor), the higher the capacity of the network but the located resulting in higher interference.

Trade-offs of Frequency Reuse Factor

- *Interfering cells are closer by when cluster size is smaller.*
- *Capacity per cell is higher when cluster size is smaller.*



$F_1 = F/3$



$F_1 = F/7$

$$C = B \log_2 (1 + S/N)$$

Frequency Re-use

Each cell needs a set of unique channels or frequencies.

There are not enough channels in the world, so must re-use the channels in a pattern.

Geographical separation is needed to reduce interference.

Example: In each cell, only 1/7th of available channels can be used.

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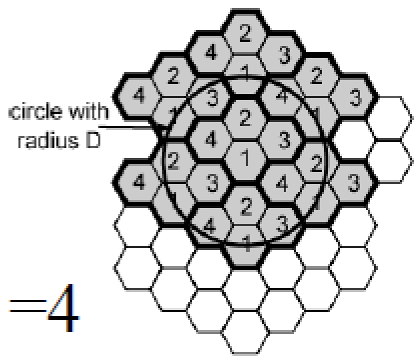
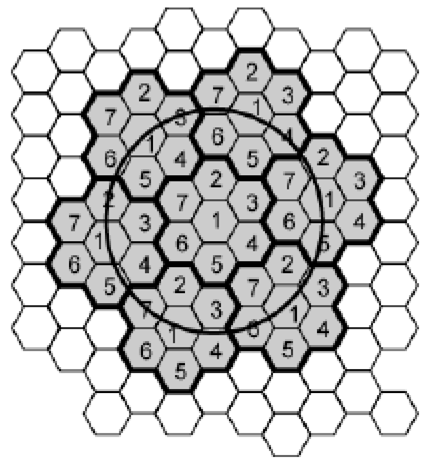
Cellular Frequency Reuse

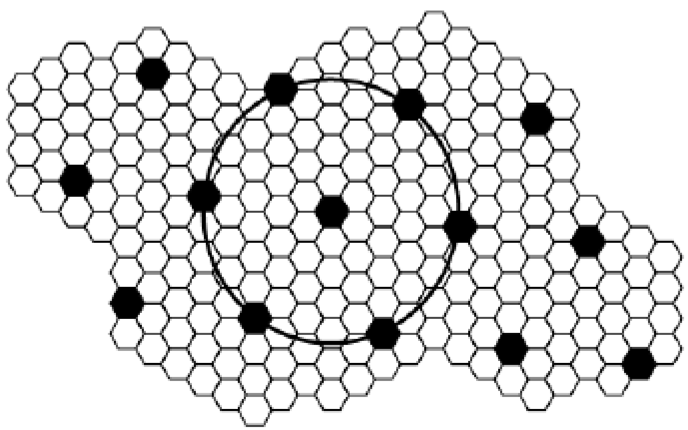


Cluster Size =4



Cluster Size =7

(a) Frequency reuse pattern for N = 4 (b) Frequency reuse pattern for N = 7

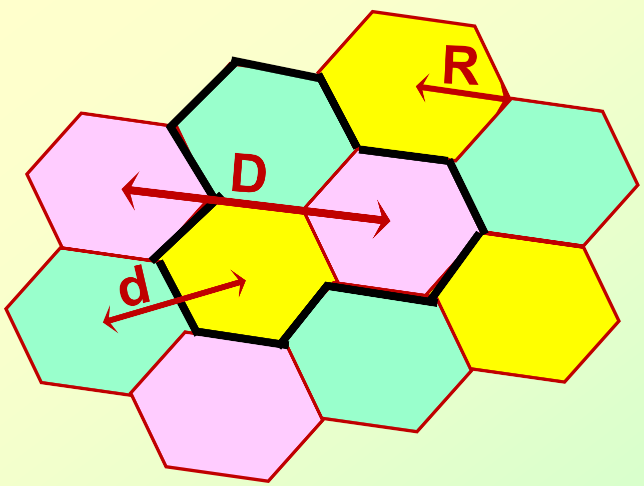


Cluster Size =19

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

Frequency Reuse Characterization

- ♦ In characterizing frequency reuse, the following parameter are commonly used:
- ♦ D = minimum distance between centres of cells that use the same band of frequency (called cochannels)
- ♦ R= radius of a cell
- ♦ d = distance between centres of adjacent cells ($d = \sqrt{3}.R$)
- ♦ N = number of cells in a repetitious adjacent cells, reuse factor
- ♦ In hexagonal cell pattern, only the following values of N are possible, $N = I^2 + J^2 + (I * J), \quad I, J = 0,1,2,3,4.........$
- ♦ Hence, N = 1, 3, 4, 7, 9, 12, 13, 16, 19, etc
- ♦ $D = R\sqrt{3N}, \quad D/d = \sqrt{N}$



Co-channel Interference and System Capacity

- The interference between signals from co-channel cells is called co-channel interference.
- Unlike thermal noise which can be overcome by increasing the signal-to-noise ratio (SNR), co-channel interference cannot be combated by simply increasing the carrier power of a transmitter.
- To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.
- When the size of each cell is approximately the same and the base stations transmit the same power, the co-channel interference ratio is independent of the transmitted power and becomes a function of the radius of the cell (R) and the distance between centres of the nearest co-channel cells (D).
- By increasing the ratio of D/R, the spatial separation between co-channel cells relative to the coverage distance of a cell is increased.
- Thus, interference is reduced from improved isolation of RF energy from the co-channel cell.

Co-channel Interference and System Capacity

$Q = D/R = \sqrt{3N}$

- A small value of Q provides larger capacity since the cluster size N is small.
- A large value of Q improves the transmission quality, due to a smaller level of co-channel interference.
- A trade-off must be made between these two objectives in actual cellular design.

Example 1

- What would be the minimum distance between the centres of two cells with the same band of frequencies if cell is 1 km and reuse factor is 12?

- Solution

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

D= 1 x $\sqrt{3 \, x \, 12}$

D = 6 km

Example 2

- If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice. Compute the number of channels available per cell in a system that uses (a) four-cell reuse, (b) seven-cell reuse, and (c) twelve-cell reuse.

Solution to Example 2

- Total bandwidth = 33 MHz
- Channel bandwidth = 25 kHz × 2 simplex channels

  = 50 kHz/duplex channel
- Total available channels = 33,000/50 = 660 channels

(a) For N = 4, total number of channels available per cell = 660/4 ≈ 165 channels.

(b) For N = 7, total number of channels available per cell = 660/7 ≈ 95 channels.

(c) For N = 12, total number of channels available per cell = 660/12 ≈ 55 channels

Increasing Cellular Network Capacity

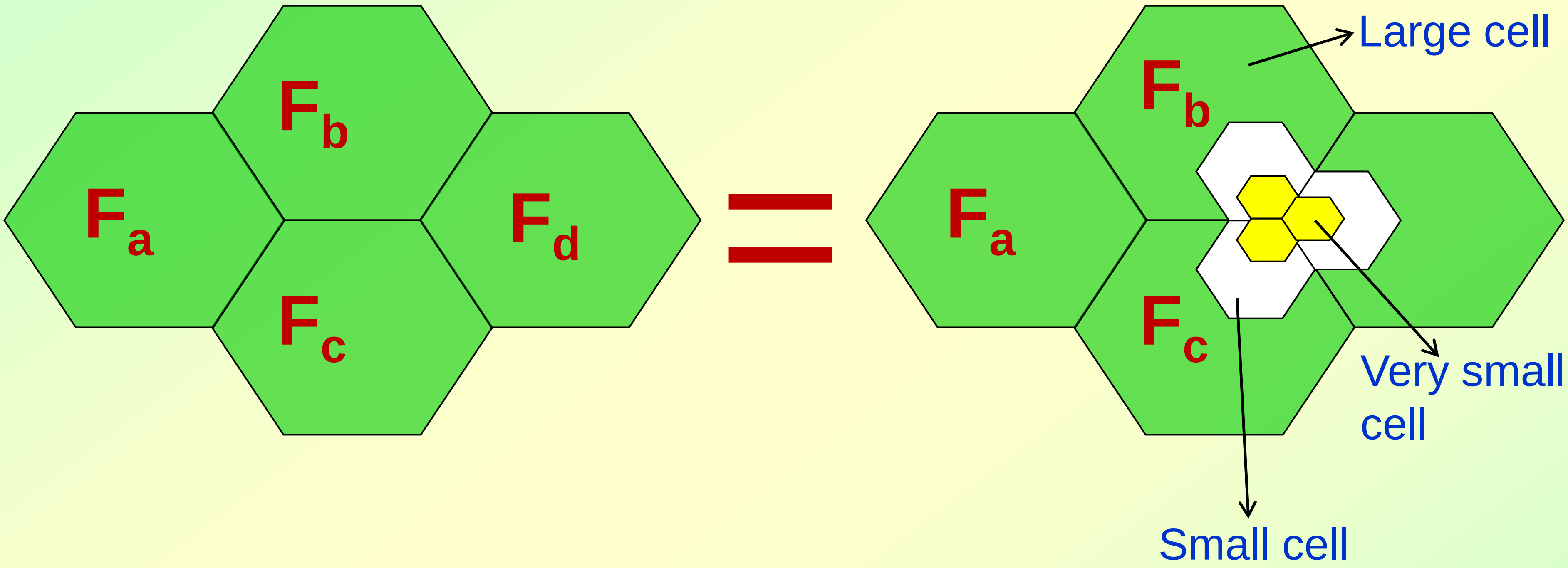
♦ As more customers use the system, traffic may build up so that there are not enough frequencies assigned to the cell to handle its calls.

♦ Consequently, customers experience high call blocking probability

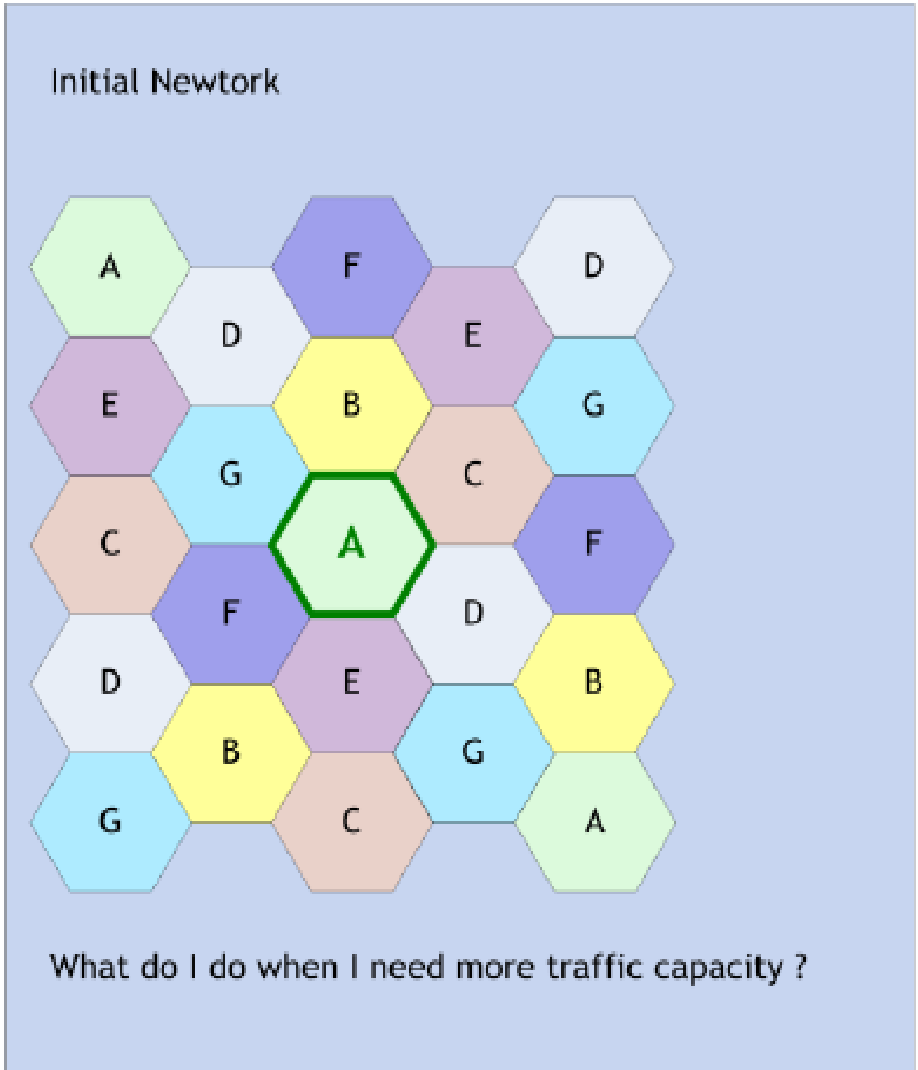
♦ The following approached can be used to increase network capacity in homogeneous cellular networks:

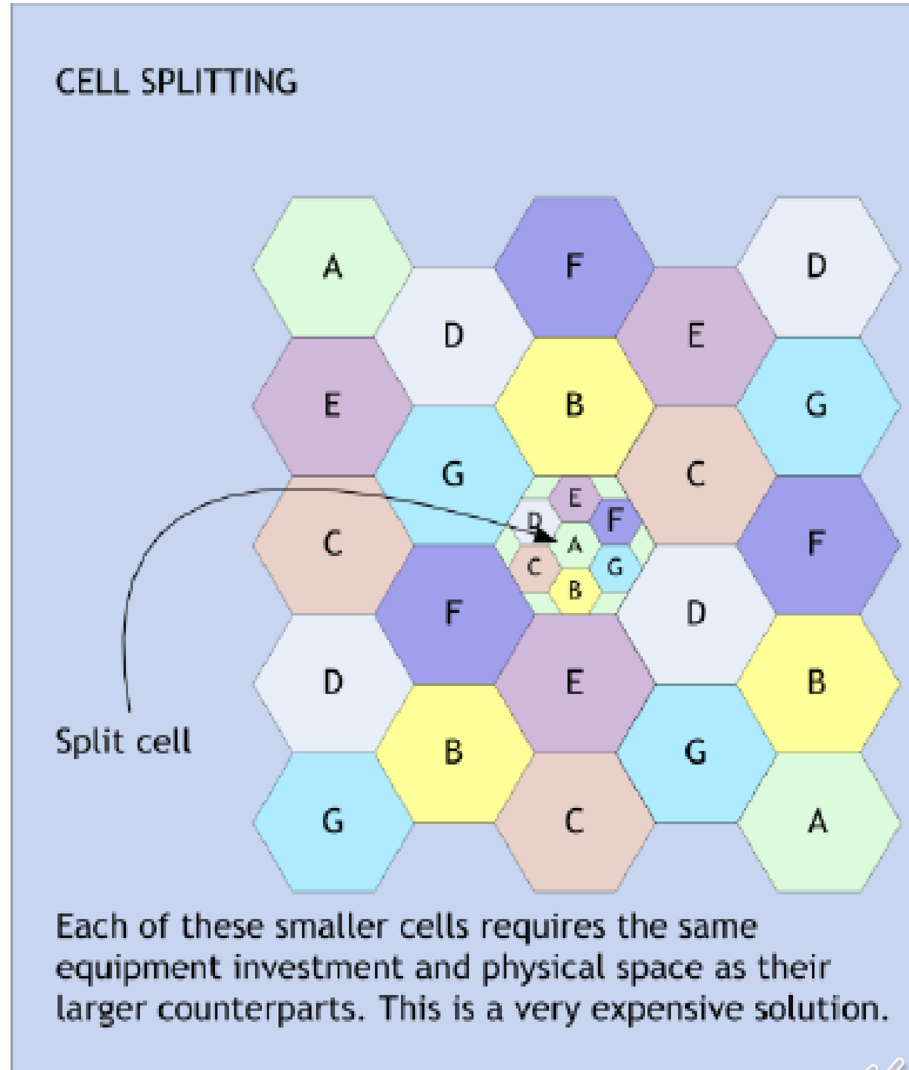
(1) Adding new channels
(2) Frequency borrowing: in the simplest case, frequencies are taking from adjacent cells by congested cell
(3) Cell splitting: cells in areas of high usage can be split into smaller cells
(4) Cell sectoring

Cell Splitting

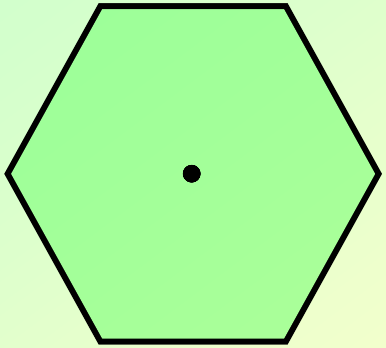


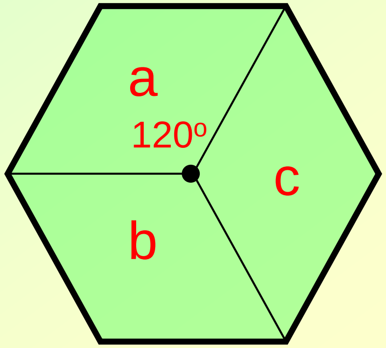
Cell Splitting



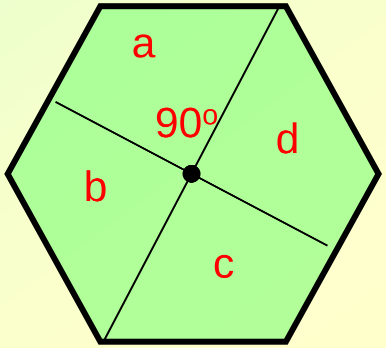


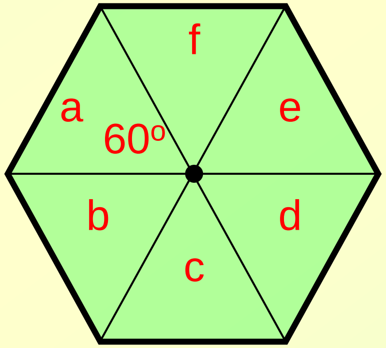
Cell Sectoring



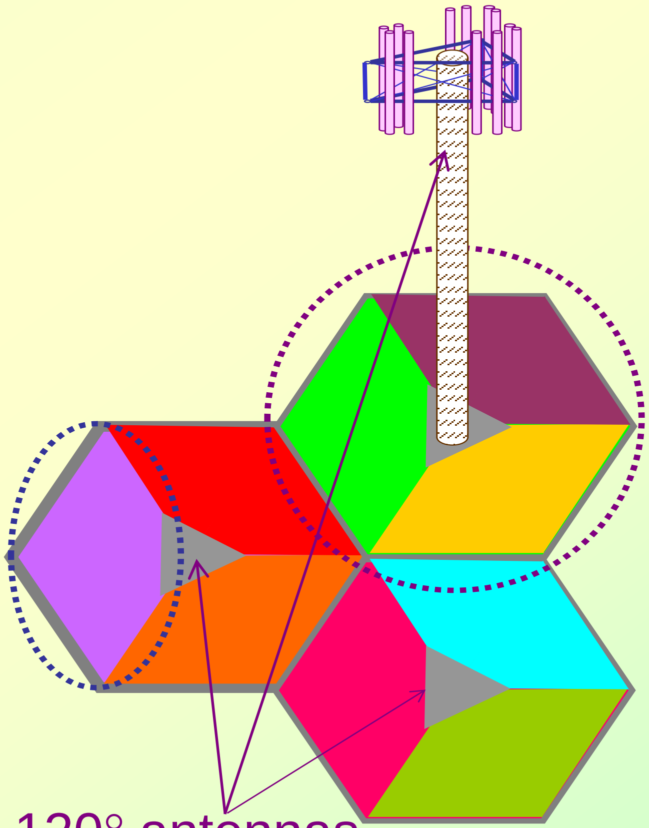


(a). Omni directional (b). 120º sector





(d). 90º sector (e). 60º sector



120° antennas facing the 3 sectors

EEE4121F Module A

He that sleeps for 8 hours everyday has spent 7 years sleeping at the age of 21.
You have to stay awake to make your dreams come true!

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