INTRODUCTION TO WIRELESS COMMUNICATION SYSTEMS

First Mobile Radio Telephone 1924

Evolution of Mobile Radio Communications

- Major Mobile Radio Systems
  - 1934 - Police Radio uses conventional AM mobile communication system.
  - 1935 - Edwin Armstrong demonstrate FM
  - 1946 - First public mobile telephone service - push-to-talk
  - 1960 - Improved Mobile Telephone Service, IMTS - full duplex
  - 1960 - Bell Lab introduce the concept of Cellular mobile system
  - 1968 - AT&T propose the concept of Cellular mobile system to FCC.
  - 1976 - Bell Mobile Phone service, poor service due to call blocking
  - 1983 - Advanced Mobile Phone System (AMPS), FDMA, FM
  - 1991 - Global System for Mobile (GSM), TDMA, GMSK
  - 1991 - U.S. Digital Cellular (USDC) IS-54, TDMA, DQPSK
  - 1993 - IS-95, CDMA, QPSK, BPSK

Evolution of Mobile Radio Communications

- Major Mobile Radio Systems
  - 1997 — Release of IEEE 802.11 WLAN protocol
  - 1999 — Bluetooth specification introduced
  - 1999 — First of the "third generation" cellular systems are standardized: Universal Mobile Telecommunication System (UMTS) and cdma2000
  - 2005 — First mobile WiMAX system (IEEE 802.16e)
  - 2009 — Release of IEEE 802.11n WLAN protocol, supporting up to 150 Mbit/s data rates in both the 2.4 GHz and 5 GHz ISM bands.
  - 2010 — LTE (4G) mobile and then LTE-A in 2013
  - 2019— 5G and beyond

Example of Mobile Radio Systems

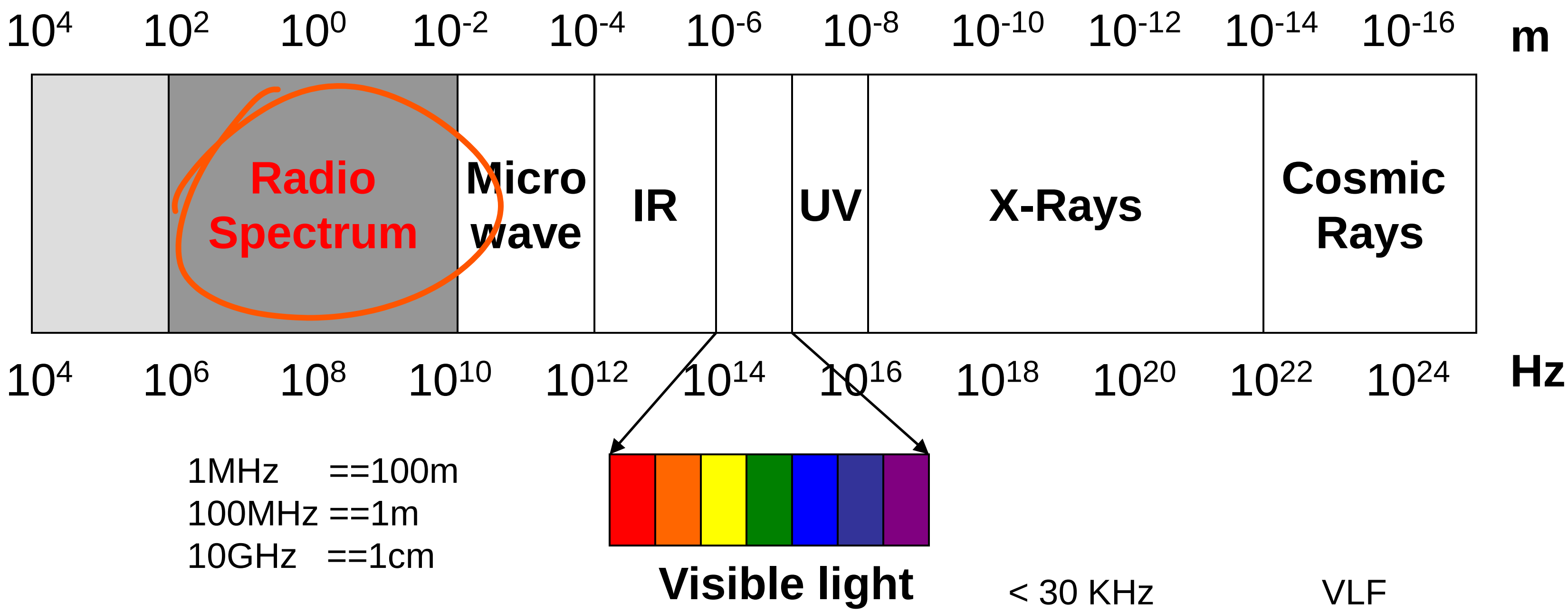
- Examples
  - Cordless phone
  - Remote controller
  - Hand-held walkie-talkies
  - Pagers
  - Cellular telephone
  - Wireless LAN
- Mobile - any radio terminal that could be moved during operation
- Portable - hand-held and used at walking speed
- Subscriber - mobile or portable user

Wireless Communication

基本定义

- Transmitting voice and data using electromagnetic waves in open space
- Electromagnetic waves
  - Travel at speed of light ($c = 3 \times 10^8$ m/s) → 速度 v
  - Has a frequency (f) and wavelength (λ) $\Rightarrow \lambda = \frac{v}{f}$
    - $\boxed{c = f \times \lambda}$ 或 $v = f\lambda$
  - Higher frequency means higher energy photons
  - The higher the energy photon the more penetrating is the radiation

Electromagnetic Spectrum



1MHz ==100m
100MHz ==1m
10GHz ==1cm

长波

< 30 KHz	VLF
30-300KHz	LF
300KHz – 3MHz	MF
3 MHz – 30MHz	HF
30MHz – 300MHz	VHF
300 MHz – 3GHz	UHF
3-30GHz	SHF
> 30 GHz	EHF

Wavelength of Some Technologies

global system for mobile Commu.

- GSM Phones:
  - frequency ~= 900 MHz
  - wavelength ~= 33cm
- PCS Phones
  - frequency ~= 1.8 GHz
  - wavelength ~= 17.5 cm
- Bluetooth:
  - frequency ~= 2.4GHz
  - wavelength ~= 12.5cm

Personal commu. sys.

Frequency Carriers/Channels

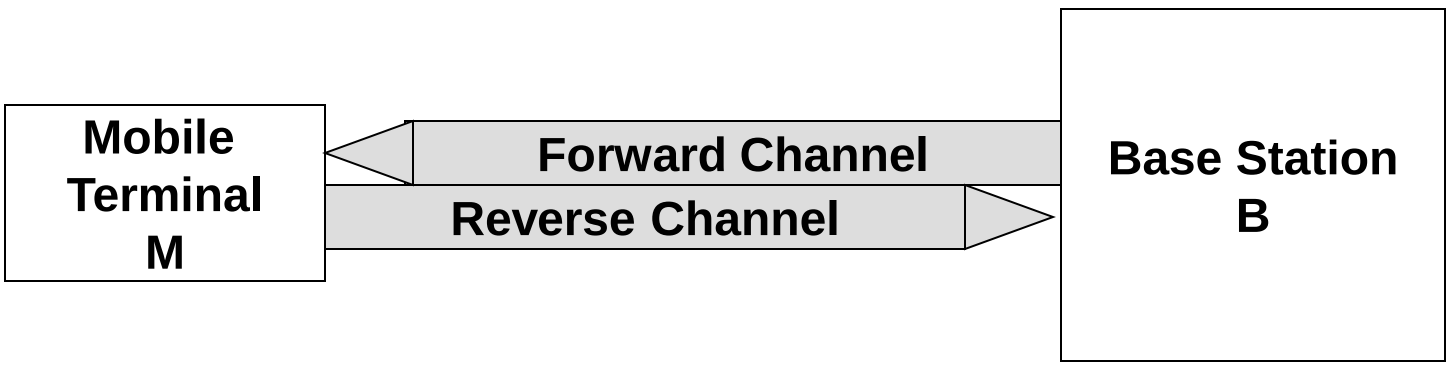
- The information from sender to receiver is carried over a well-defined frequency band.
  - This is called a channel
- Each channel has a fixed frequency bandwidth (in kHz) and Capacity (bit-rate)
- Different frequency bands (channels) can be used to transmit information in parallel and independently.

Simplex/Duplex Communication

- Normally, on a channel, a station can transmit only in one way.
  - This is called simplex transmission
- To enable two-way communication (called half/full-duplex communication)
  - We can use Frequency Division Multiplexing
  - We can use Time Division Multiplexing

Duplex Communication - FDD

- FDD: Frequency Division Duplex

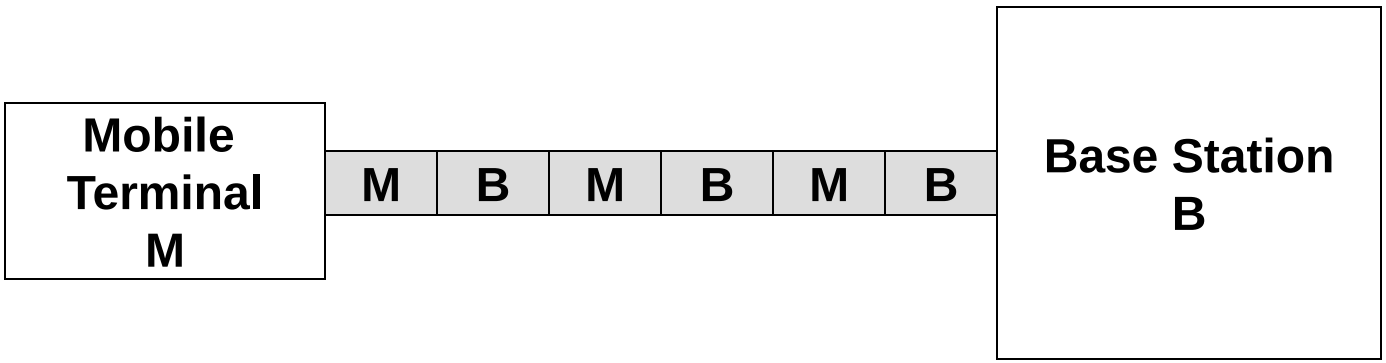


Forward Channel and Reverse Channel use different frequency bands

simultaneously

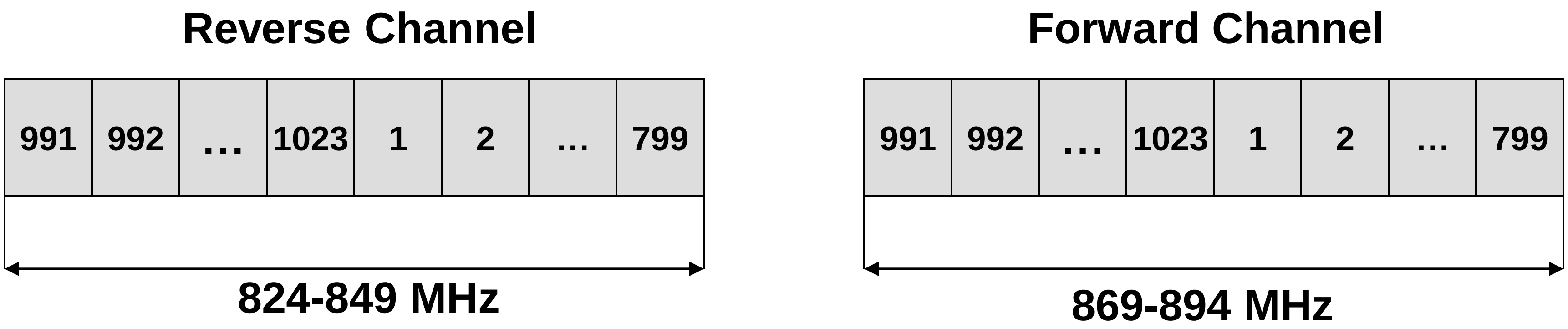
Duplex Communication - TDD

- TDD: Time Division Duplex



A singe frequency channel is used. The channel is divided into time slots. Mobile station and base station transmits on the time slots alternately.

Example - Frequency Spectrum Allocation in U.S. Cellular Radio Service



	Channel Number	Center Frequency (MHz)
Reverse Channel	1 <=N <= 799	0.030N + 825.0
	991 <= N <= 1023	0.030(N-1023) + 825.0
Forward Channel	1 <=N <= 799	0.030N + 870.0
	991 <= N <= 1023	0.030(N-1023) + 870.0

(Channels 800-990 are unused)

What is Mobility 移动

- Initially Internet and Telephone Networks is designed assuming the user terminals are static
  - No change of location during a call/connection
  - A user terminals accesses the network always from a fixed location
- Mobility and portability
  - Portability means changing point of attachment to the network offline
  - Mobility means changing point of attachment to the network online

Degrees of Mobility

- Walking Users
  - Low speed
  - Small roaming area
- Vehicles
  - High speeds
  - Large roaming area
  - Uses sophisticated terminal equipment (cell phones)

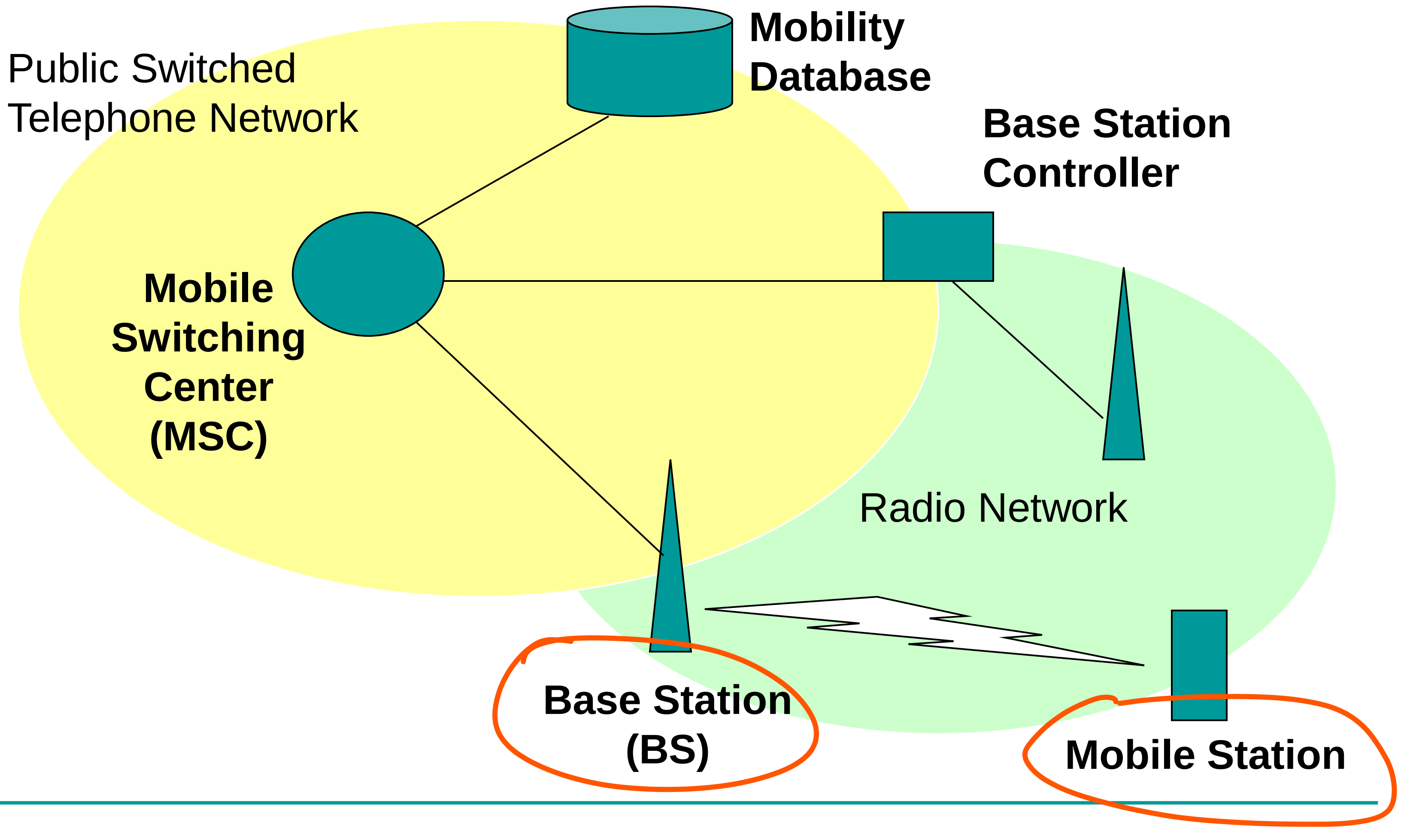
The Need for Wireless/Mobile Networking

无处不在的

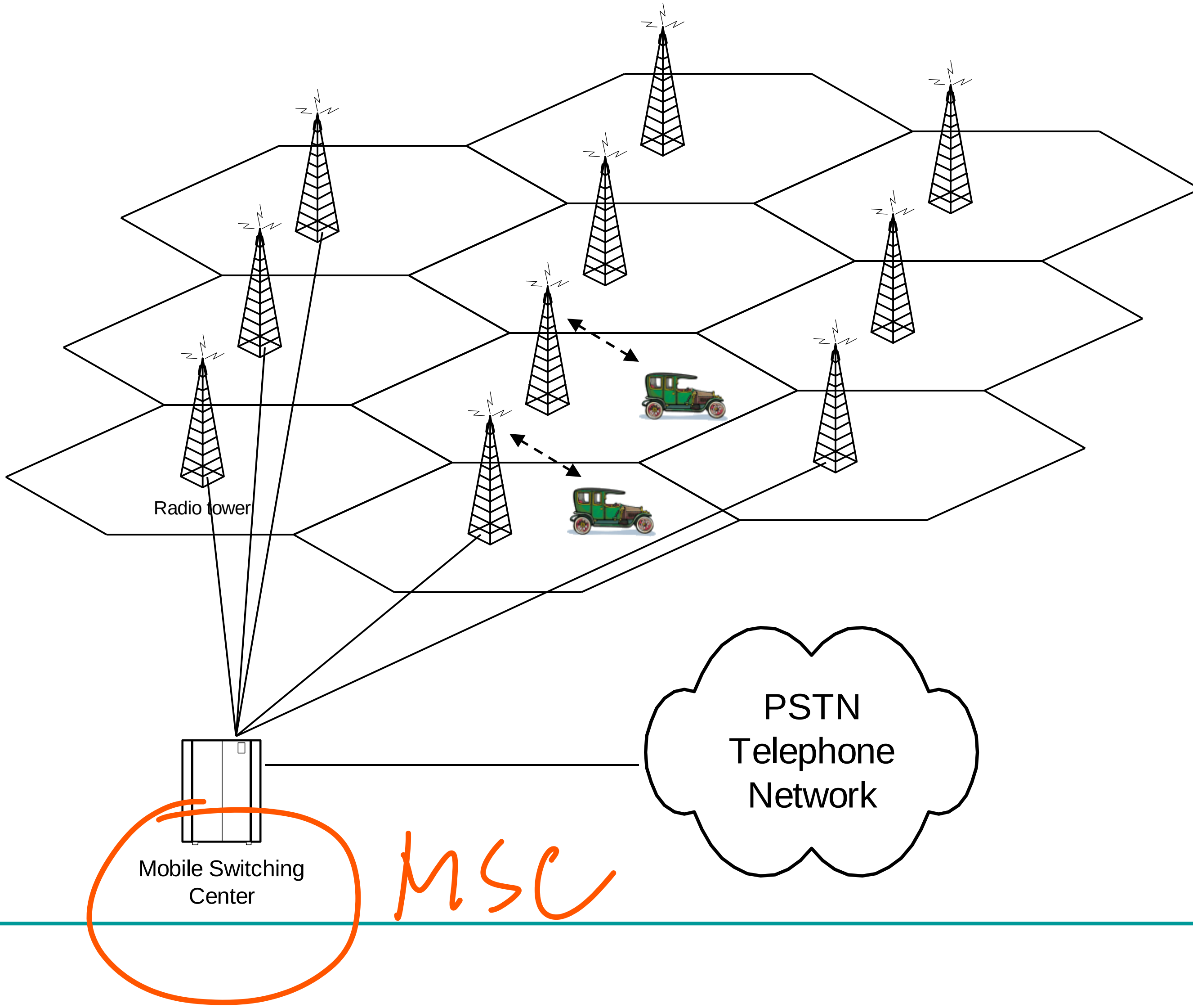
- Demand for Ubiquitous Computing
  - Anywhere, anytime computing and communication
    - You don't have to go to the lab to check your email
  - Pushing the computers more into background
    - Focus on the task and life, not on the computer
    - Use devices seamlessly to help you and to make your life easier.

      不停顿的，无缝的
  - Devices should be location aware
    - Adapt to the current location, discover services

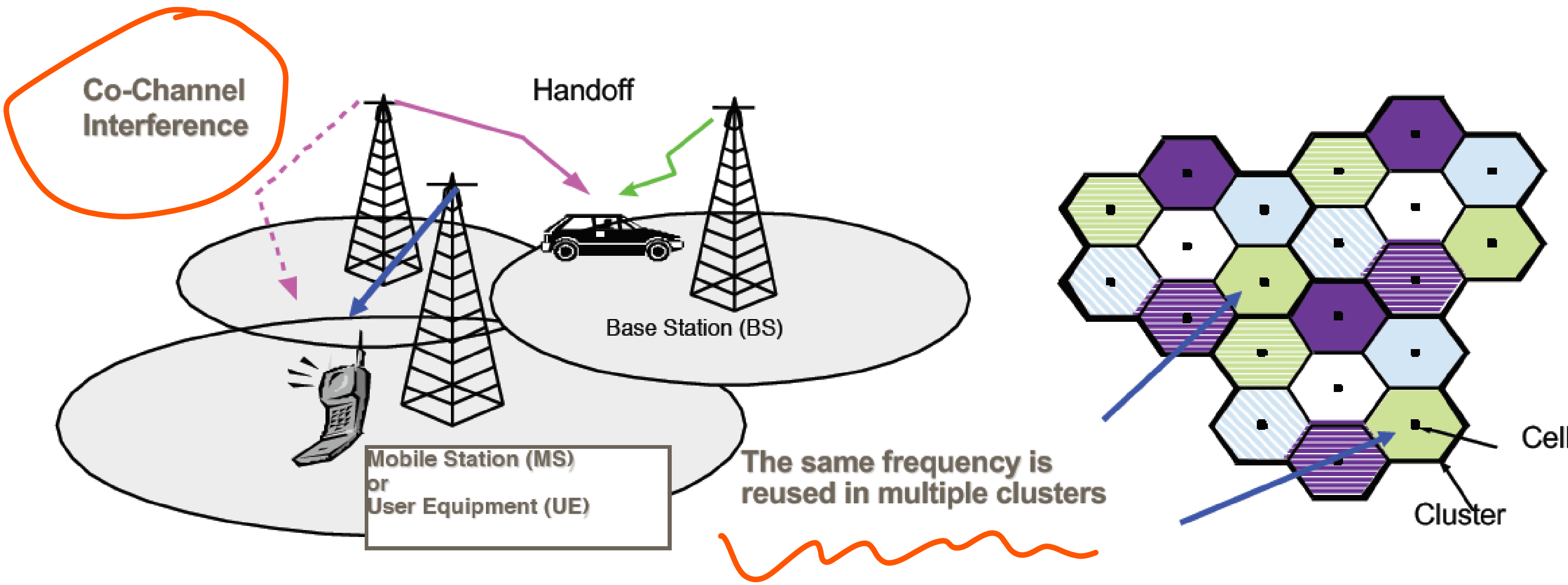
Very Basic Cellular Architecture



Cellular Telephony - Architecture



The Cellular Concept



- Base stations serve multiple subscribers
- Frequencies are geographically reused in cells
- Handoff provides seamless connection

Wireless System Definitions

无线系统的概念

- Mobile Station
  - A station in the cellular radio service intended for use while in motion at unspecified locations. They can be either hand-held personal units (portables) or installed on vehicles (mobiles)
- Base station
  - A fixed station in a mobile radio system used for radio communication with the mobile stations. Base stations are located at the center or edge of a coverage region. They consists of radio channels and transmitter and receiver antennas mounted on top of a tower.

Wireless System Definitions

- Mobile Switching Center
  - Switching center which coordinates the routing of calls in a large service area. In a cellular radio system, the MSC connects the cellular base stations and the mobiles to the PSTN (telephone network). It is also called Mobile Telephone Switching Office (MTSO)
- Subscriber 用户
  - A user who pays subscription charges for using a mobile communication system
- Transceiver
  - A device capable of simultaneously transmitting and receiving radio signals

Wireless System Definitions

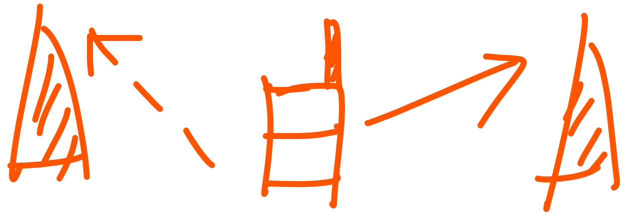
- Control Channel
  - Radio channel used for transmission of call setup, call request, call initiation and other beacon and control purposes.
- Forward Channel
  - Radio channel used for transmission of information from the base station to the mobile

forward

- Reverse Channel
  - Radio channel used for transmission of information from mobile to base station

reverse

Wireless System Definitions



- Handoff
  - The process of transferring a mobile station from one channel or base station to an other.

漫游

- Roamer

服务区

  - A mobile station which operates in a service area (market) other than that from which service has been subscribed.

寻呼

- Page
  - A brief message which is broadcast over the entire service area, usually in simulcast fashion by many base stations at the same time.

类似于广播

Cellular Telephony

- Characterized by
  - High mobility provision
  - Wide-range
  - Two-way voice communication
  - Handoff and roaming support
  - Integrated with sophisticated public switched telephone network (PSTN)

Evolution…

- 1G
- 2G
- 3G
- 4G
- 5G
- 6G ?

Evolution of cellular systems

1G

- First generation systems - known after the fact as 1G
  - Conceived in the 1960's
  - Deployed in the late 1970's / early 1980's
  - Built around analogue technology, FM modulation
  - Limited data, little security
  - Expensive due to analogue technology
  - Little roaming
  - Examples AMPS, NTT, NMT-450, etc.

Most of you in have never used 1G

Evolution of cellular systems

2G

- Second generation systems - known as 2G
  - Conceived in the 1980's
  - Deployed in the 1990's
  - Digital Voice
  - More subscribers per bandwidth, some data
  - Enabled roaming in Europe (GSM)
  - Examples GSM, IS-95, IS-136, PDC, EDGE (2.5G)

You may not have used 2G, but many phones are 2G compatible

Evolution of cellular systems

3G

- Third generation systems - known as 3G
  - Conceived in the 1990’s
  - Deployed in the 2000’s
  - Digital voice plus data
  - Video telephony
  - Higher capacity

码分多址

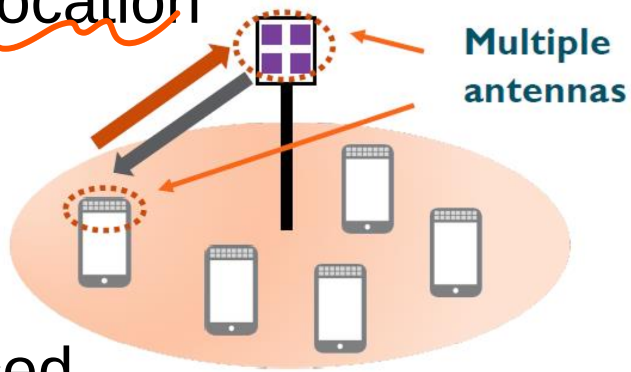
  - CDMA (code division multiple access)
  - Examples: 3GPP WCDMA, HSDPA, etc. 3GPP2 cdma2000, 1xEV, 1xEV-DO, 1xEV-DV, etc.

Most phones are 3G compatible, and revert to 3G occasionally

Evolution of cellular systems

4G

- Fourth generation systems - known as 4G
  - IP based backbone, supports VoIP
  - OFDMA allows efficient resource allocation
  - MIMO (multiple antennas)
    - 8 @ base station, 4 at handset
  - Higher data rates
  - 3GPP Long Term Evolution Advanced

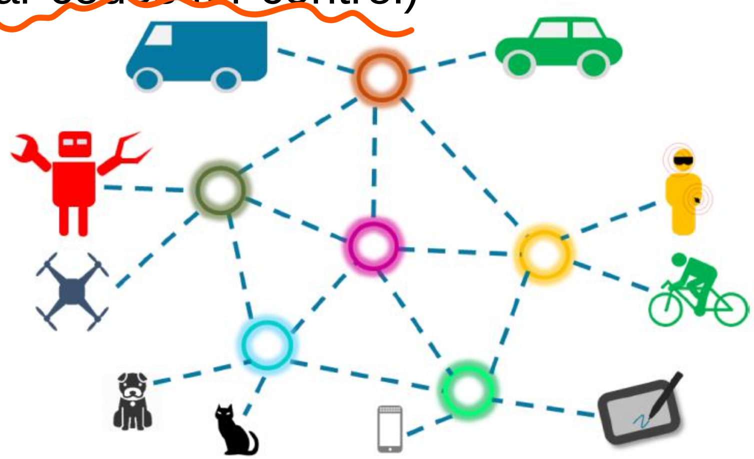


Most of you use 4G on a daily basis

Evolution of cellular systems

5G

- Fifth generation systems - known as 5G
- Key features include
  - Numerology, frame structure and initial access support for above-6 GHz – millimetre wave band
  - New channel coding (LDPC for data, Polar codes for control)
  - MIMO enhancements
    - beam management for above-6 GHz
- Other features
  - Vehicle to X (V2X)
  - Non-orthogonal multiple access (NOMA)
  - Industrial IoT
  - Location and positioning enhancements
  - URLLC enhancements



With 5G everything will be connected: you, your pet, your car, …

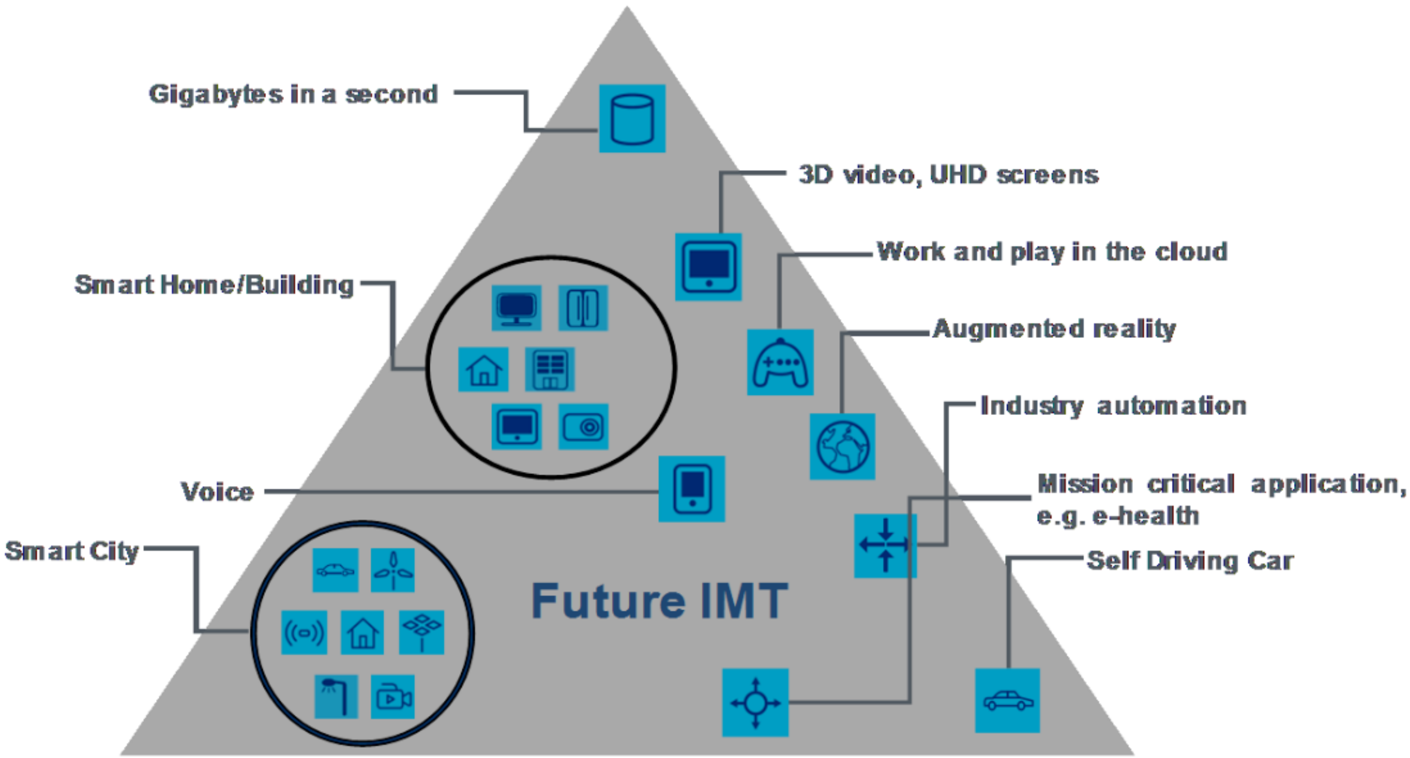
5G Usage Scenarios

Industry stakeholders identified several potential use cases for 5G networks, and the ITU-R has defined three important categories of these.

- Enhanced mobile broadband (eMBB) – enhanced indoor and outdoor broadband, enterprise collaboration, augmented and virtual reality.
- Massive machine-type communications (mMTC) – IoT, asset tracking, smart agriculture, smart cities, energy monitoring, smart home, remote monitoring.
- Ultra-reliable and low-latency communications (URLLC) – autonomous vehicles, smart grids, remote patient monitoring and telehealth, industrial automation.

5G Use Cases & Requirement

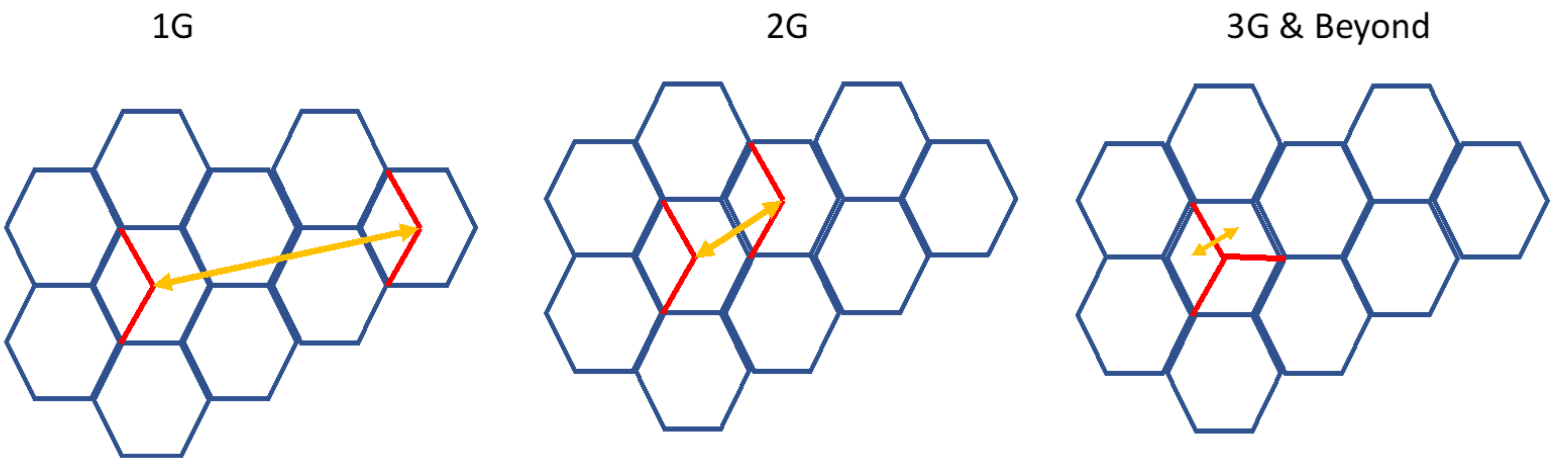
Enhanced Mobile Broadband (eMBB)
10 Gbps



Massive Machine Type Communication (mMTC)
1million/km^2

Ultra-Reliable and Low Latency Communications (URLLC)
99.999% reliability and availability with 1ms

Evolution of Frequency Reuse

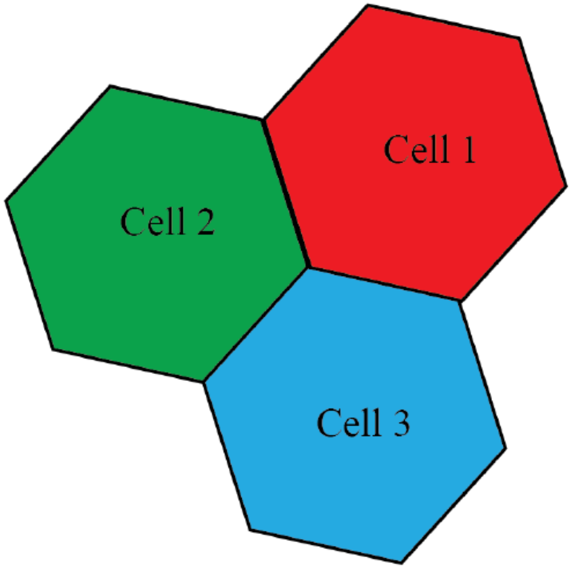


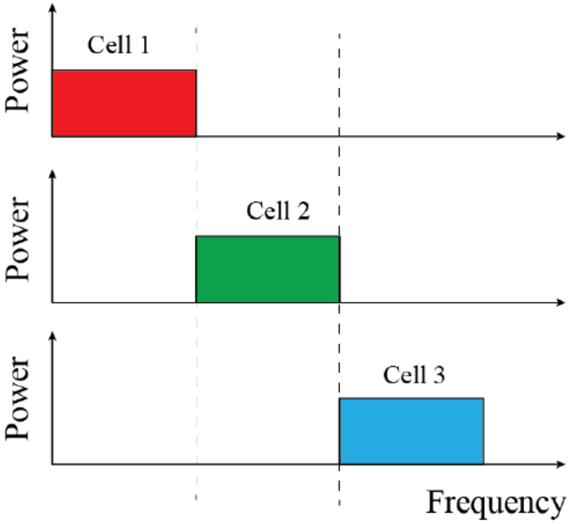
- Frequency reuse patterns have changed with each generation with wireless technology
- The sectors or cells are marked by the red “>” shape and the yellow arrow illustrate how far away the same frequency can be reused

Frequency Reuse Types

- Hard Frequency Reuse
- Strict Frequency Reuse
- Soft Frequency Reuse

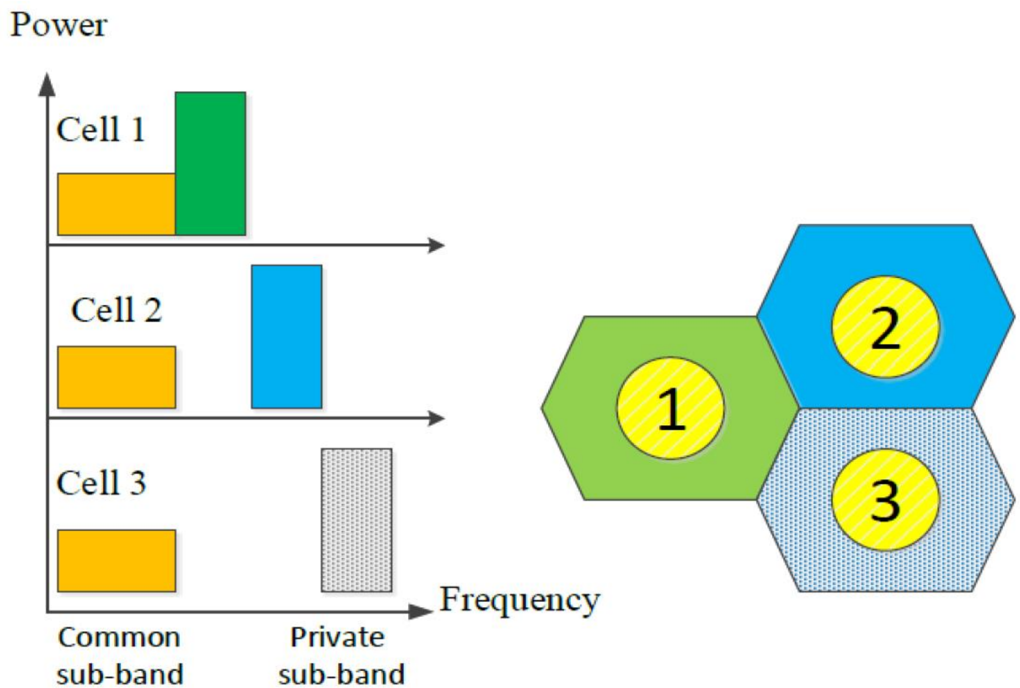
Hard Frequency Reuse





Strict Frequency Reuse

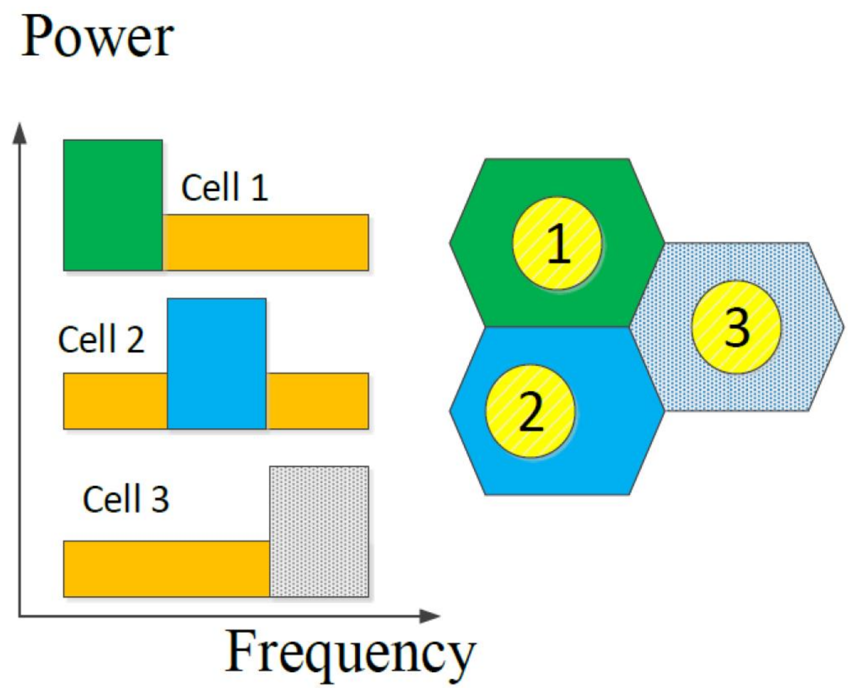
- Strict FR with reuse factor $\Delta = 3$
- Whole bandwidth divided into one common sub-band and Δ private sub-band group
- The common sub-bands are allocated to cell-centre area with low power level in every cell.
- Each private sub-band group is allocated to the cell-edge area at high power level.



- Cell-centre (cell-edge) user is only affected by interfering that is cause by base station transmitting on the same cell-centre (cell-edge) sub-band.

Soft Frequency Reuse

- In Soft FR scheme the whole bandwidth is divided into two sub-bands, called the cell-edge and cell-centre sub-bands.
- The main difference between Strict and Soft FR is that the cell-centre users share the allocated sub-bands with cell-edge users in adjacent cells in an effort to improve spectrum efficiency and system performance
- Because of sharing resource between cell-edge and cell-centre users, cell-edge users can use the whole cell-edge sub-bands



- The lack of spectrum at the cell edge may result in much reduced Shannon Capacity for that region. This is overcome by allocating high power carriers to the users in this region thus improving the SINR and the Shannon Capacity