Introduction to Wireless Communications

Wireless Communications

Wireless Communications

Course Informations

Principles of Wireless Communications —— 无线通信原理

- 面向电子信息类专业学生开设的一门专业课程；
- 了解和掌握无线通信的基本原理、概念、方法及关键技术；
- 初步掌握无线通信系统的性能评价和设计方法；
- 熟悉无线通信专业知识在英语背景中的表达和运用。

“Red Gene” of NJUPT

Course Informations

➢COURSE TEXTBOOK

[1] Theodore S. Rappaport著，孟庆民、邹玉龙、时艳玲、宛汀编. Wireless Communications Principles and Practice (2nd Edition). 电子工业出版社，2018年版

[2] Theodore S. Rappaport著， 周文安等译. 无线通信原理与应用. 电子工业出版社，2006年版

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- 2. The Cellular Concept: System Design Fundamentals

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- 3. Mobile radio propagation : Large-scale path loss

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- 4. Small-scale fading, multipath, and introduction of MIMO Technologies

  第四章 小尺度衰落、多径和MIMO技术简介

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Introduction to Wireless Communications

- Definition and Development of Wireless Communications
- Current Wireless Communication Systems
- Mobile communication networks
- Basics of communication and capacity

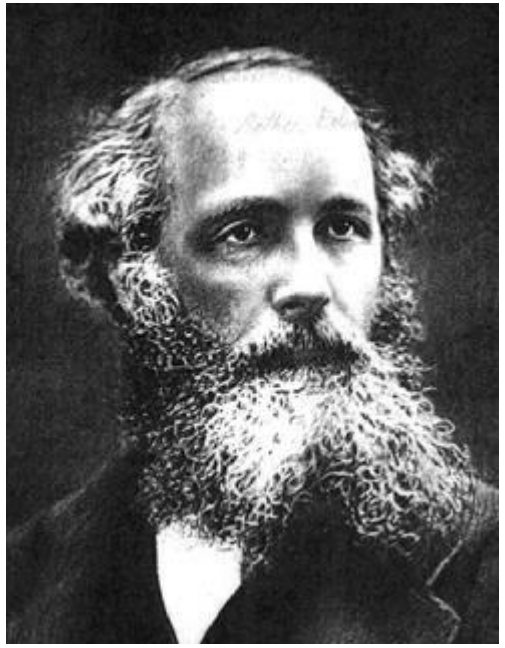
Introduction to Wireless Communications

1. Definition and Development of Wireless Communication

Definition of Wireless Communications

- **Wireless communication : The transfer of information over a distance without the use of electrical conductors or "wires".**
- **Electromagnetic waves (usually radio waves) are used in wireless communication to carry the signals.**

Devlopment of Wireless Communications



James Clerk Maxwell，
1831.06.13 - 1879.11.05

Heinrich Rudolf Hertz ,
1857.02.22 - 1894.01.01

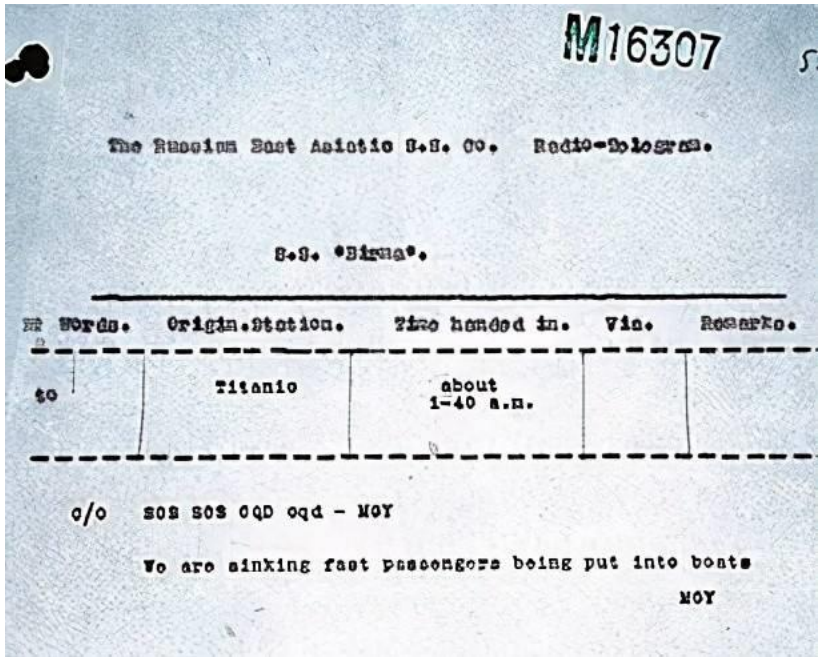
Devlopment of Wireless Communications

Guglielmo Marconi，1874.04.25 - 1937.07.20.

- 1894-96 First Transmitter – First Patent
- 1897 World's First Wireless Telegraph & Signal Company
- 1901 Telegraph across the atlantic ocean
- 1909 Nobel prize
- 1920 Discovery of short wave

学习科学家们勇于探索、不断超越自我的精神！

Titanic



M16307

The Russian East Asiatic S.S. Co. Radio-Telegram.

S.S. "Birma".

Words.	Origin. Station.	Time handed in.	Via.	Remarks.
to	Titanic	about 1-40 a.m.		

c/o SOS SOS CQD cqd - MGY

We are sinking fast passengers being put into boats

MGY

Distress telegraph

"Those who had been saved, had been saved through one man, Mr. Marconi... and his marvellous invention."

History of Wireless Communication

1920’s: Radio broadcasting became popular

1920’s: Mobile receivers installed in police cars in Detroit

1928: Many TV broadcast trials

1930’s: TV broadcasting development

1950’s: Communications satellites launched

1960’s: Bell Labs developed cellular concept

1970’s:Technology advances enable affordable cellular telephone

1974-1978: First field trial for cellular system

Band Division of Electromagnetic Waves

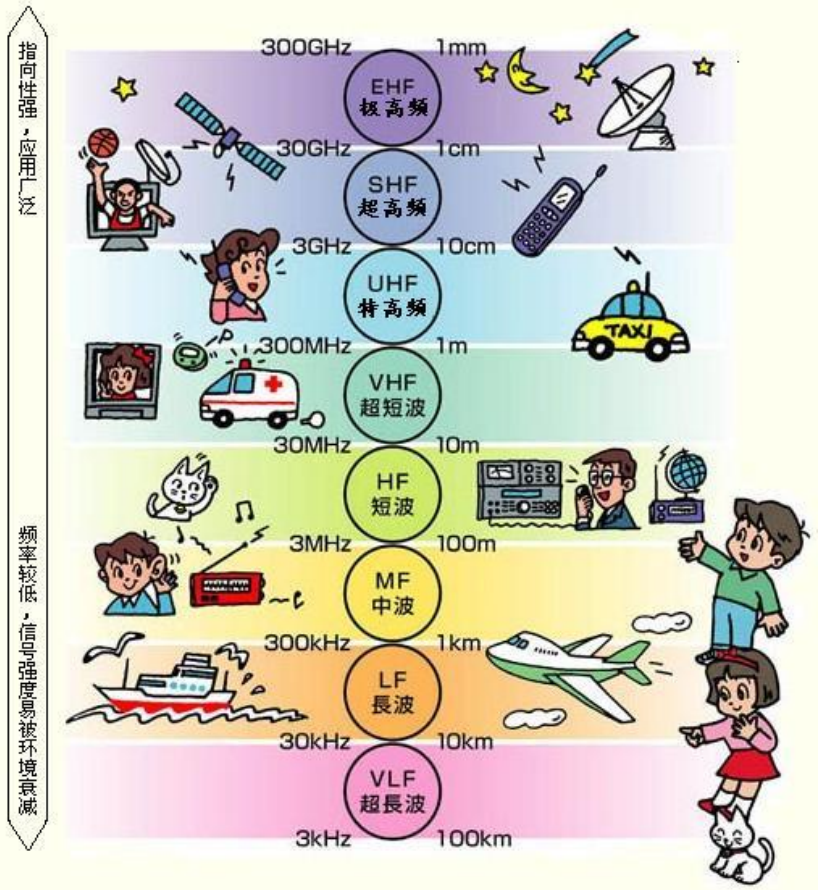
“ frequency ”

$$f = \frac{C}{\lambda}$$

“velocity of light ”

“ wavelength ”

频带名称	频率范围	波段名称	波长范围
至低频（TLF）	0.03-0.3Hz	至长波或千兆米波	10000-1000 兆米（Mm）
至低频（TLF）	0.3-3Hz	至长波或百兆米波	100-100 兆米（Mm）
极低频(ELF)	3-30Hz	极长波	100-10 兆米（Mm）
超低频(SLF)	30-300Hz	超长波	10-1 兆米（Mm）
特低频(ULF)	300-3000Hz	特长波	1000-100 千米(Km)
甚低频(VLF)	3-30KHz	甚长波	100-10 千米(Km)
低频(LF)	30-300KHz	长波	10-1 千米(Km)
中频(MF)	300-3000KHz	中波	1000-100 米(m)
高频(HF)	3-30MHz	短波	100-10 米(m)
甚高频(VHF)	30-300MHz	米波	10-1 米(m)
特高频(UHF)	300-3000MHz	分米波	10-1 分米(dm)
超高频(SHF)	3-30GHz	厘米波	10-1 厘米(cm)
极高频(EHF)(	30-300GHz	毫米波	10-1 毫米(mm)
至高频(THF)	300-3000GHz	丝米波或亚毫米波	10-1 丝米(dmm)

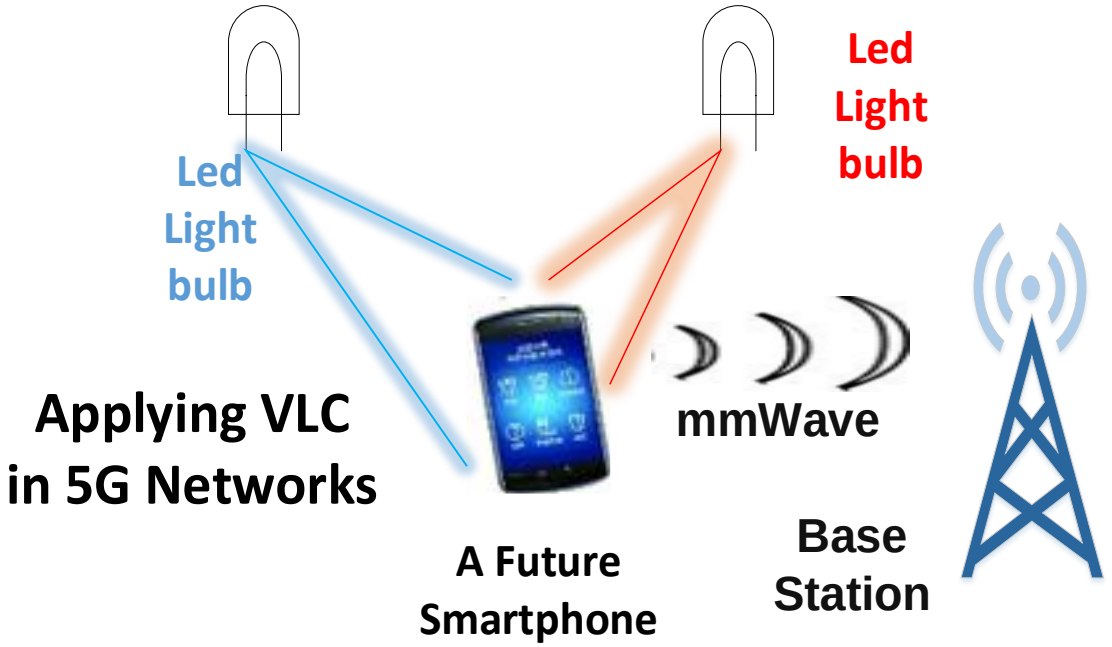


How do cell phones work ?

“ Radio Frequency (RF) ”

- **Radio wave, one type of electromagnetic waves, is used for such form of wireless communication.**
- **Most cell phones operate in the frequency range of 800 to 2,200 Megahertz.**

What frequency do cell phones operate on?



The mmWave and visible light communications (VLC) are two promising technologies for future 5G indoor communications.

What frequency do cell phones operate on?

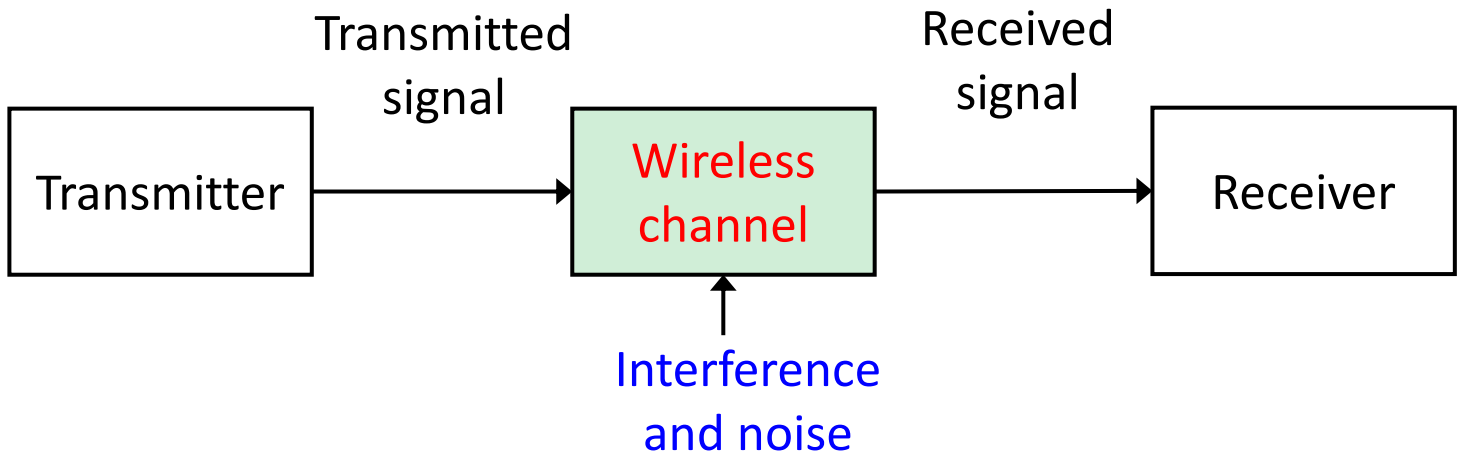
- **FR1 : Sub-6 GHz (4.5 GHz – 6 GHz)**
- **FR2 : mmWave (24.2 GHz – 52.6 GHz)**

For example, if a carrier frequency f = 30 GHz is adopted for the 5G New Radio, the wavelength λ of the carrier wave is

$$\lambda = \frac{C}{f} = \frac{3\times10^{8}}{30\times10^{9}} = 10\ (\text{mm})$$

- **The higher the frequency, the higher the potential speed of the signal.**
- **The higher the frequency, the larger the propagation loss.**

Wireless Vs. Wire Communications



- **The channel is a medium through which the transmitter output is sent.**
- **Based on the channel type, communication systems can be divided into wire communication systems and wireless communication systems.**

Wireless Vs. Wire Communications

Challenges in Wireless Communication Systems

- **Information is transmitted by radio waves**

  Radio channel is not a good transmission channel:

  - **Large path loss**
  - **Multipath**
  - **Time-varing**

- **In complex interference environment**

  Interferences from

  - **Space (cosmic, atmosphere phenomenon)**
  - **Industry equipment**
  - **Other electronic and communication systems**
  - **Themselves such as multiuser interference (MUI).**

Although wireless is much less reliable than wire, it is inevitable !

Introduction to Wireless Communications

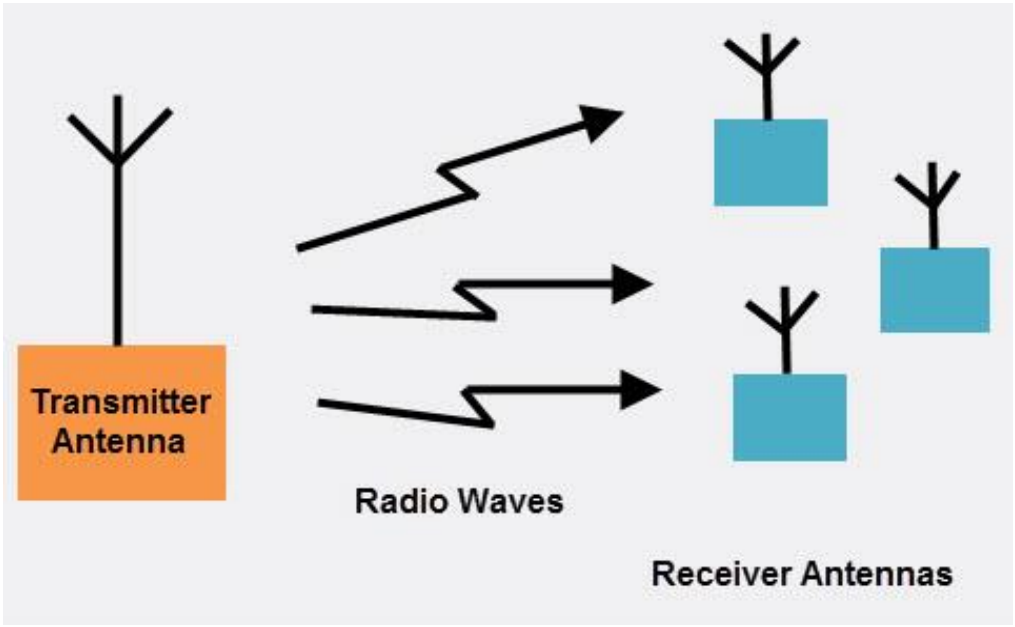
2. Current Wireless Systems

- **Applications of wireless communications**
- **Types of wireless communications**

Applications of Wireless Communications

- Broadcast radio and television
- Mobile communication-cellular phone
- Satellite telephone
- Data Transmission—WiFi, Bluetooth, zigbee, WIMAX
- Emergency service—Radio emergency location beacon
- Identification—RFID (Radio Frequency Identification) Card
- Radar, navigation

Broadcast Radio



Although radio broadcasting is not more popular than television in modern life, the basic idea of wireless communication remains hugely important.

Microwave Wireless Communication

Microwave wireless communication is an effective type of communication, mainly this transmission uses radio waves, and the wavelengths of radio waves are measured in centimeters.

Mobile communication - cellular phone and satellite telephone are two application of Microwave wireless communication.

Data Transmission

- ZigBee
- WiFi
- Bluetooth
- BLE
- WiMax

Data Transmission

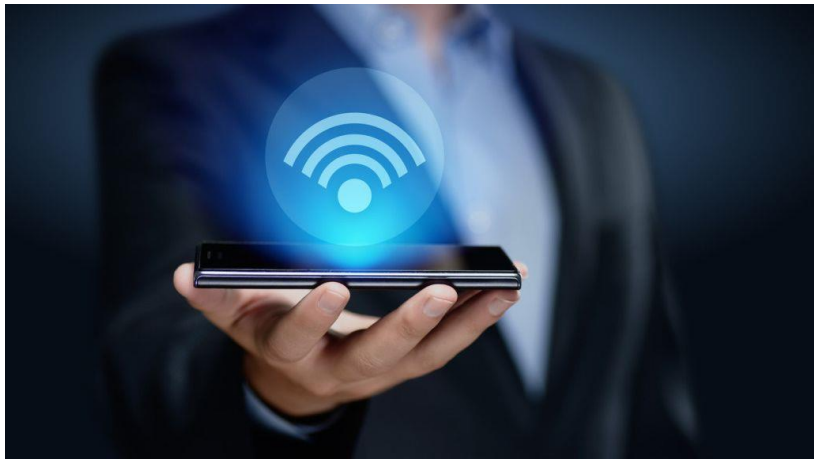
“ ZigBee ”

ZigBee (IEEE 802.15.4 Protocol) is an open global standard and is designed specifically to be used in M2M networks.

Zigbee技术具有低速、低耗电、低成本、低复杂度等特点，适用于传输范围短、传输速率低的通信场景，在智能家居、物流仓储等领域都有广泛的应用。

Data Transmission

“ WIFI ”

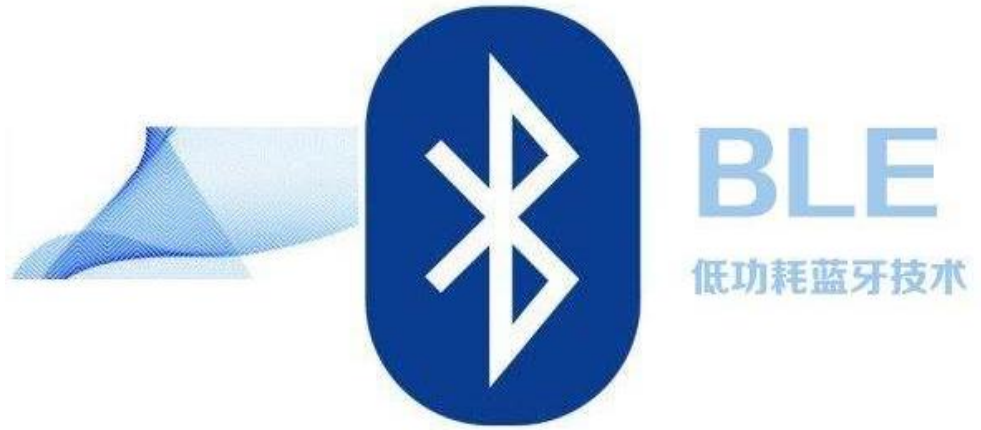


- WiFi uses radio waves (RF) to allow two devices to communicate with one another.
- WiFi is a wireless local network (WLAN) that runs of the IEEE 802.11 standards set.

智能手机、平板电脑和笔记本电脑都支持 WiFi 上网。

Data Transmission

“ Bluetooth ”

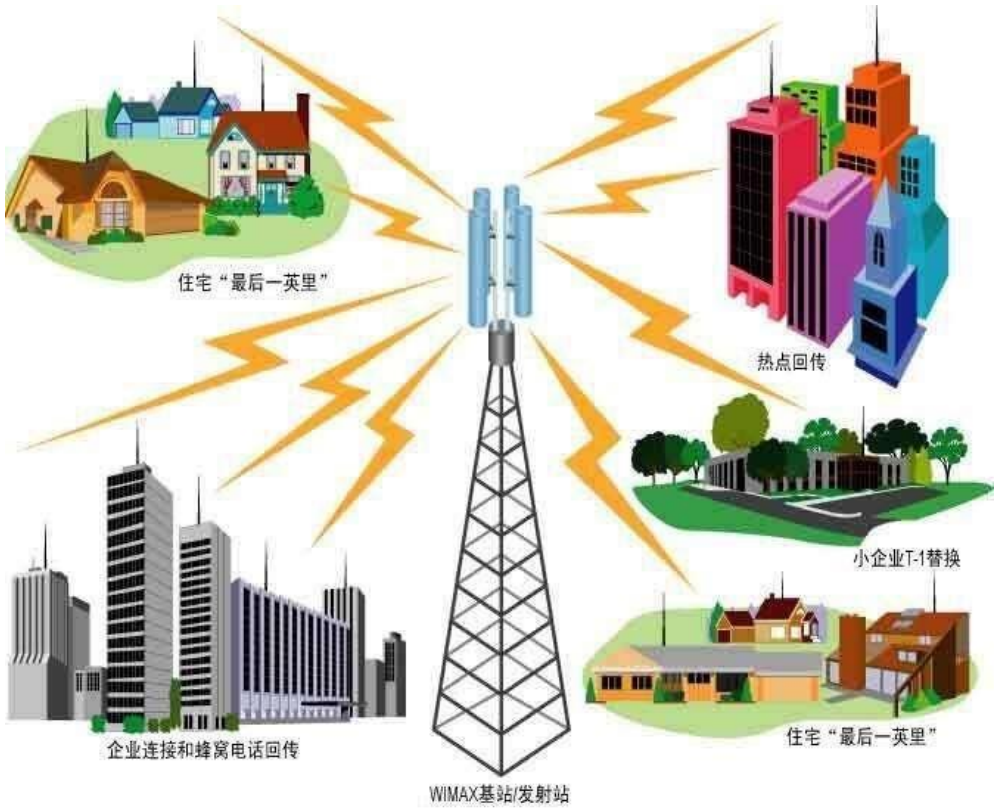


- **Bluetooth** (IEEE 802.15.1 Protocol) is a wireless technology used to transfer data over short distances.
- **Bluetooth Low Energy (BLE):** 低功耗蓝牙，在保持同等通信范围的情况下，能够显著降低功耗和成本。

Data Transmission

“ WiMax ”

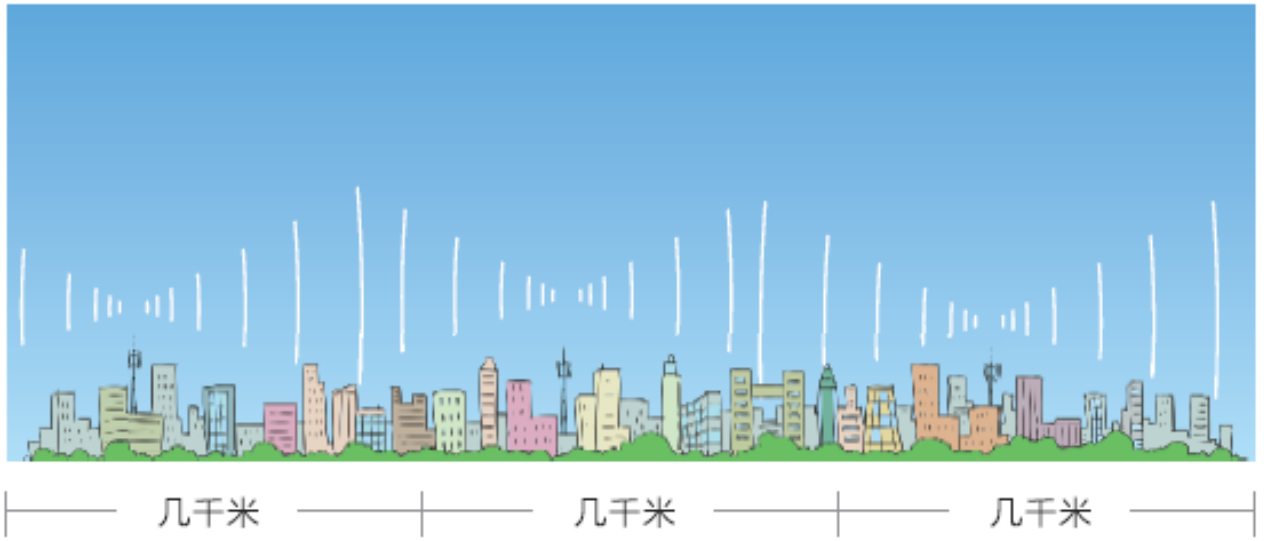
- WiMax stands for Worldwide Interoperability for Microwave Access. This wireless technology allows data to be transferred at a rate of 30–40 Mbps.
- It refers specifically to interoperable implementations of the IEEE 802.16 wireless family.



Types of Wireless Communications

- Cellular Systems (WWANs)
- Satellite Systems
- Wireless Metropolitan Area Networks (WMANs)
- Wireless Local Area Networks (WLANs)
- Wireless Personal Area Networks (WPANs)

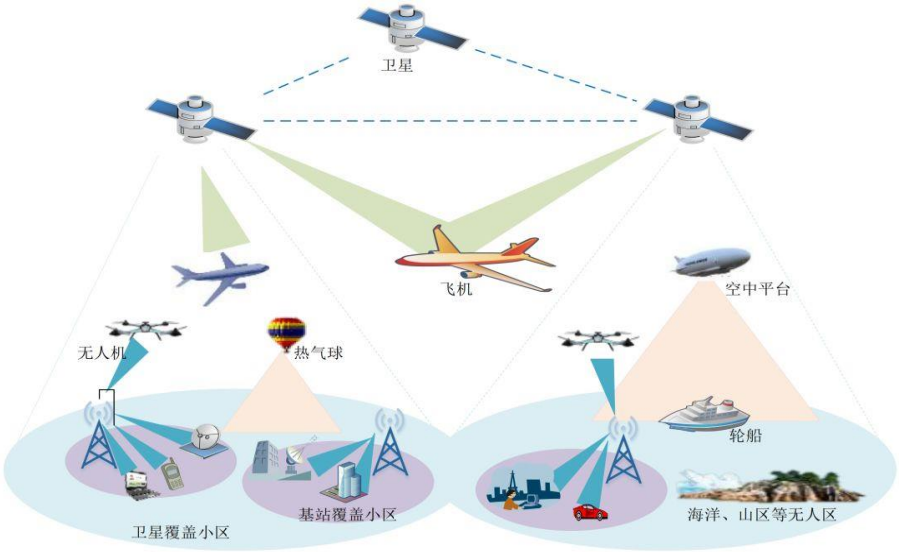
Cellular Systems



Wireless Wide Area Networks (WWAN): WWANs are created through the use of mobile phone signals typically provided and maintained by specific mobile cellular service providers.

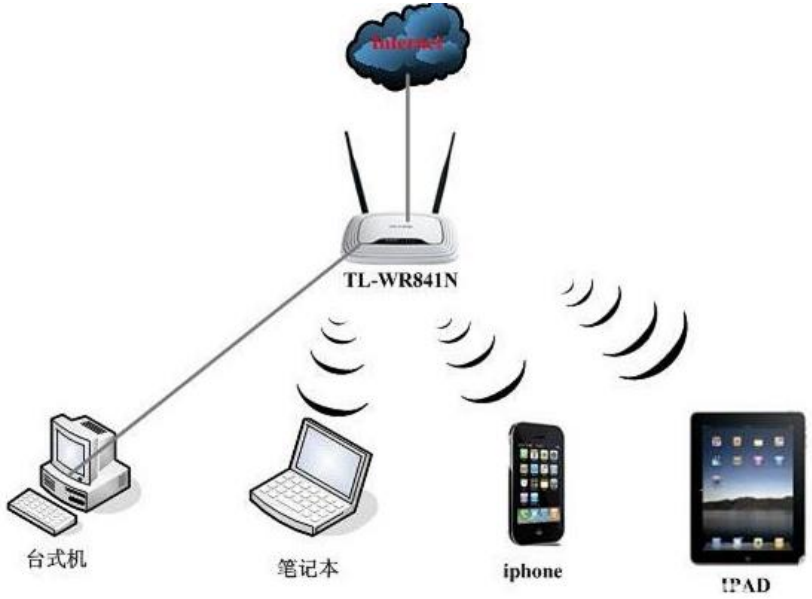
无线广域网接入技术，可以使笔记本或者其他的移动设备（例如智能手机、平板电脑等），在数百乃至上千公里的覆盖范围内连接到互联网。

Satellite Systems



- **Satellite communication** is one type of self-contained wireless communication technology, it is widely spread all over the world to allow users to stay **connected almost anywhere on the earth**.
- The **future 6G** mobile communication networks may integrate the ability of satellite communication networks.

Wireless local area networks



- **Wireless Local Area Network (WLAN)** is a local area network built with radio frequency radio wave communication technology.
- Wireless data communication can be used as a **supplement and extension** to wired data communication.

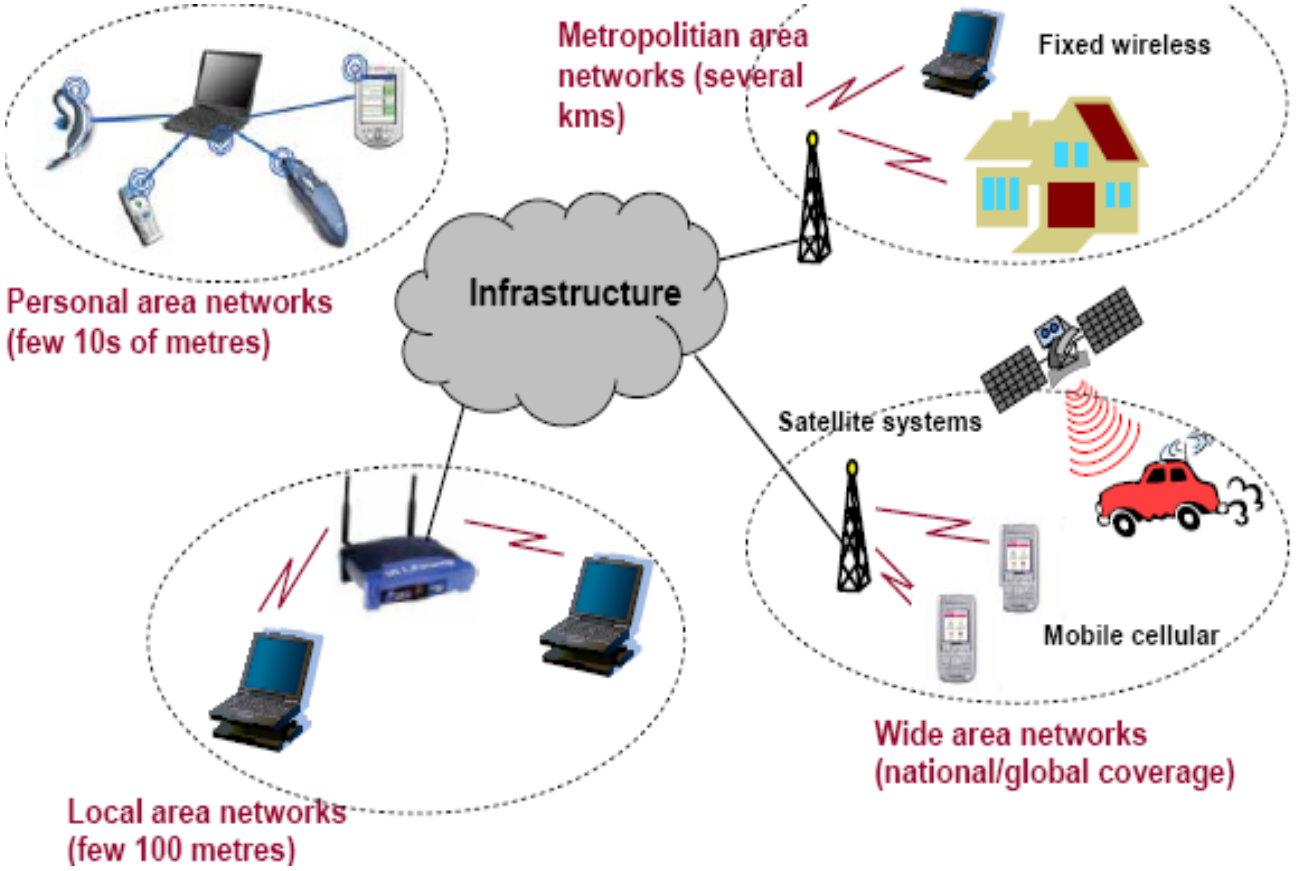
Wireless Metropolitan Area Networks

- Based on the IEEE 802.16 standard, a wireless metropolitan area networks (WMAN) is a form of wireless networking that has an intended coverage area of approximately the size of a city.
- A WMAN spans a larger area than a wireless local area network (WLAN) but smaller than a wireless wide area network (WWAN).

Wireless Personal Area Networks

A wireless personal area network (WPAN) is a type of personal network that uses wireless communication technologies to communicate and transfer data between the user's connected devices.

Classification of wireless networks



(*Referred to Kaustubh Phases, UPPSALA Uni.)*

Networking standards with different requirement of data rate and distance

Introduction to Wireless Communications

3. Mobile Communication Networks

Contents

- Basic cellular systems
- 1G, 2G, 3G, 4G, 5G

2G cellular systems

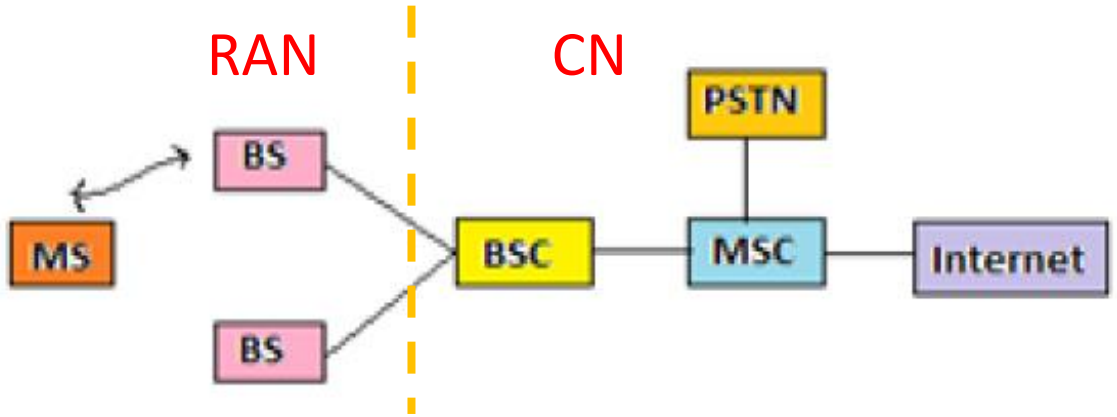


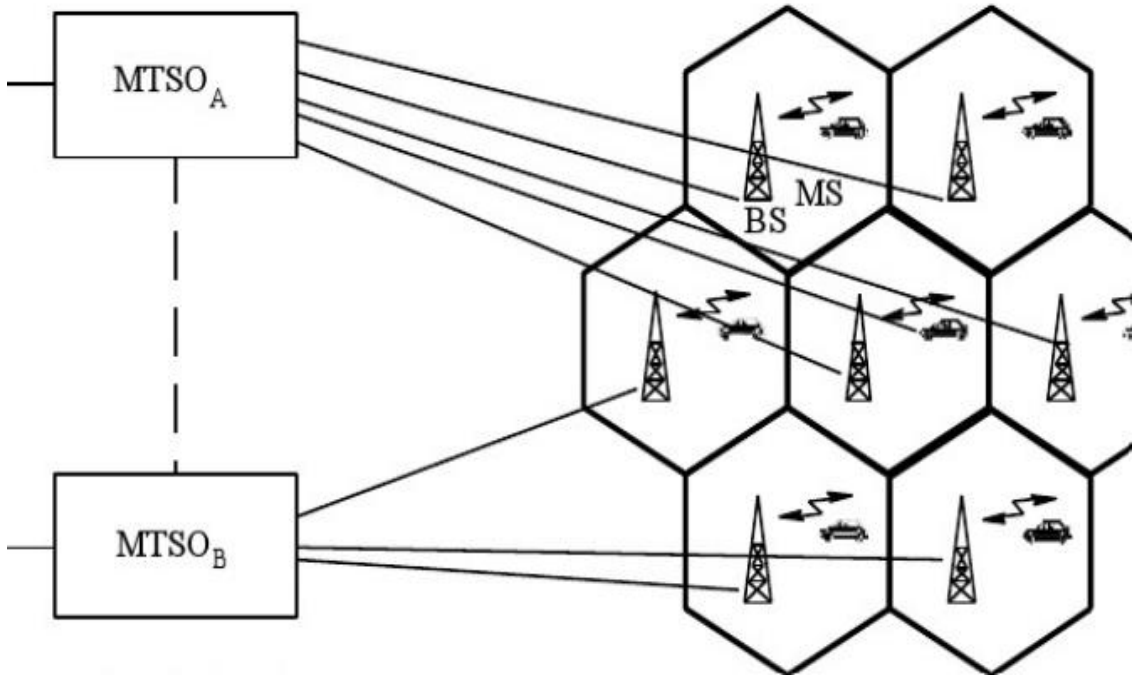
Figure. The Architecture of 2G Mobile Phone Systems

(Reference: Ms. Anju Uttam Gawas, An Overview on Evolution of Mobile Wireless Communication Networks: 1G-6G, JRITCC, Volume 3 Issue 5, May 2015.)

- **The whole architecture contains the radio access network (RAN) and the core network (CN).**
- **MS and BS are GSM RAN elements, while BSC, MSC are GSM core network elements.**

Technique Terms

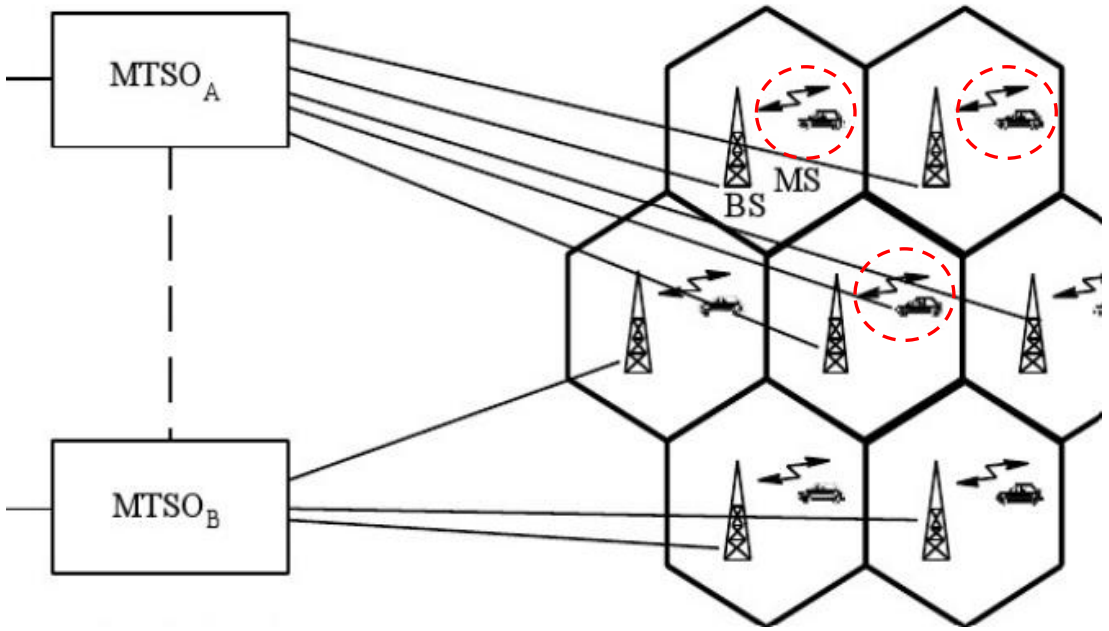
- Mobile Station (MS)
- Base Station (BS)
- Mobile Switching Center (MSC)
- Control Channel
- Forward Channel
- Reverse Channel
- Full Duplex
- Half Duplex
- Handoff



The architecture of the 2G cellular mobile phone systems

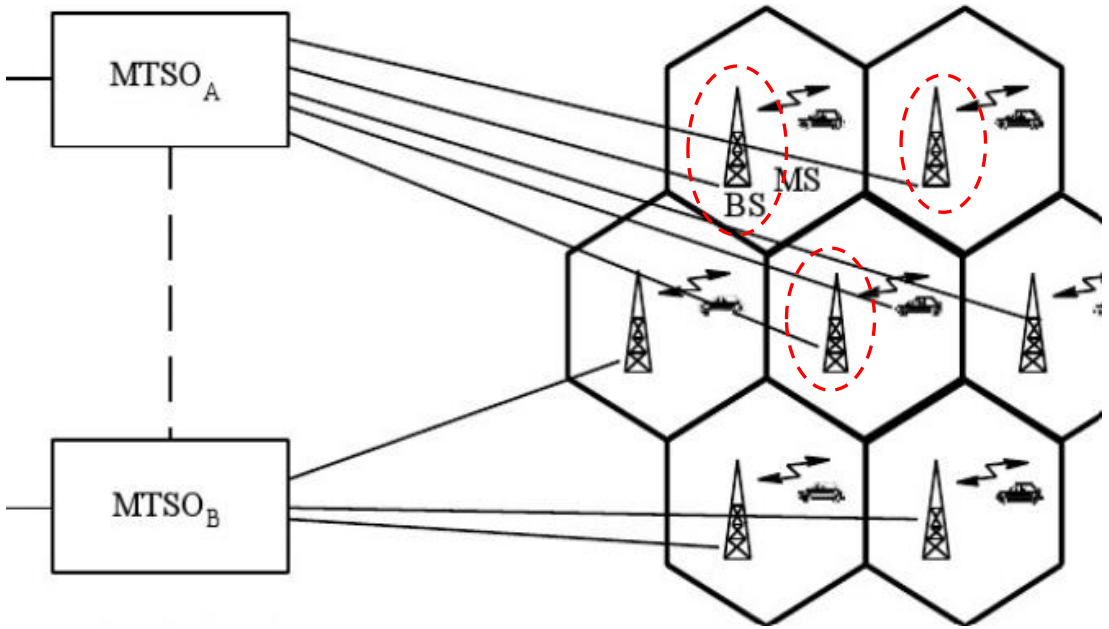
Mobile Station 移动台

- **Mobile Station (MS) : A station in the cellular radio service intended for use while in motion at unspecified locations.**
- **MSs may be hand-held personal units or installed in vehicles (mobiles).**



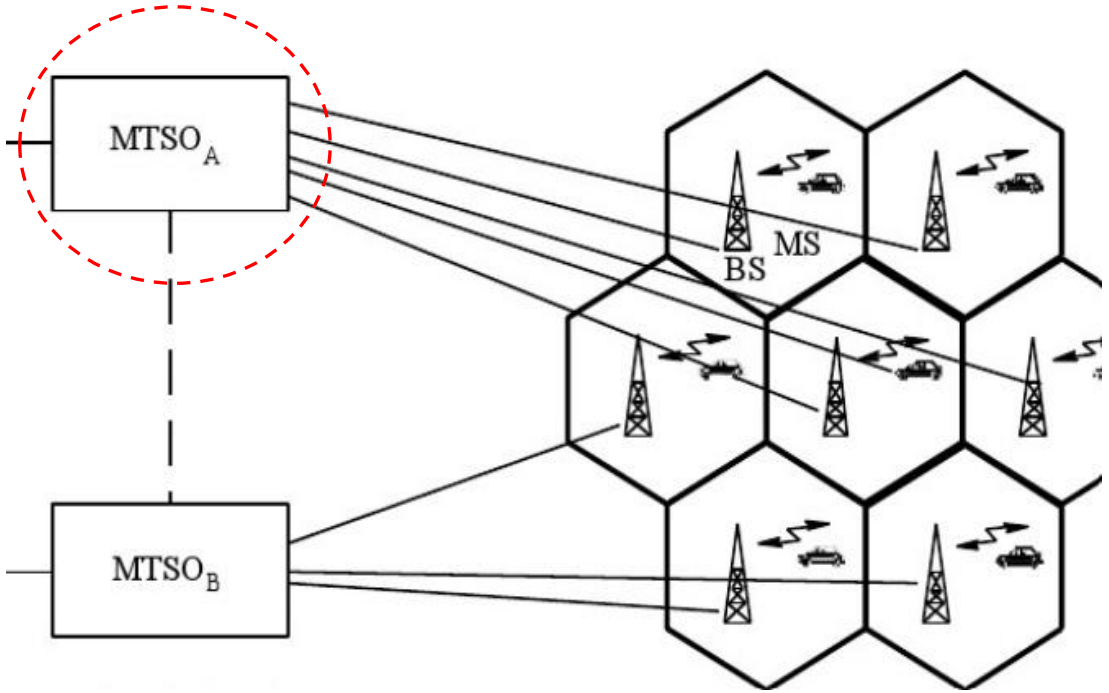
Base Station 基站

- **Base Station (BS) : A fixed station in a mobile radio system used for radio communication with mobile stations.**
- **BSs are located at the center or on the edge of a coverage region, and consist of radio channels and transmitter and receiver antennas mounted on a tower.**



Mobile Switching Center 移动交换中心

- **Mobile Switching Center (MSC) : coordinating the routing of calls in a large service area.**
- **In a cellular system, the MSC connects the cellular base stations and the mobiles to the PSTN. An MSC is also called a mobile telephone switching office (MTSO).**



- **Control channel** : for initiating, re-questing, or paging a call 控制信道
- **Forward channel** : from BS to the mobile station (also Subscriber) 前向信道
- **Reverse channel** : from the mobile to BS 反向信道
- **Handoff** : The process of transferring a mobile station from one channel or base station to another 切换

Operating Modes 工作模式

- **Simplex system :**

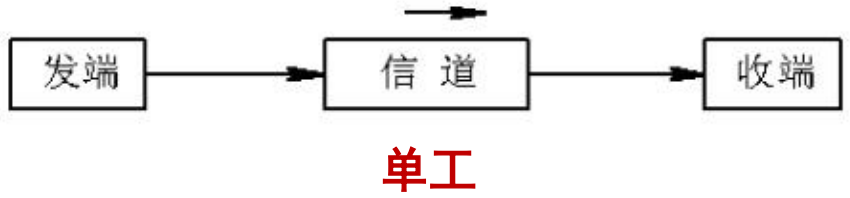
  One-way communication

- **Half-duplex systems :**

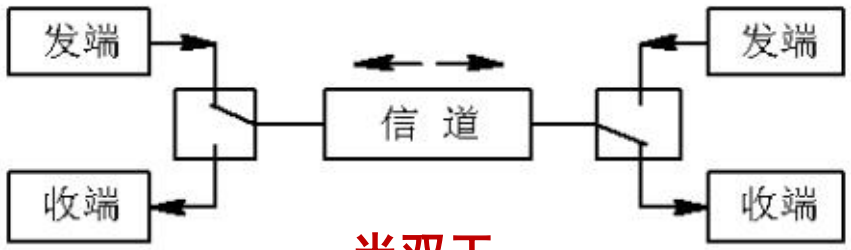
  Allowing two-way but non-simultaneous communication

- **Full-duplex systems :**

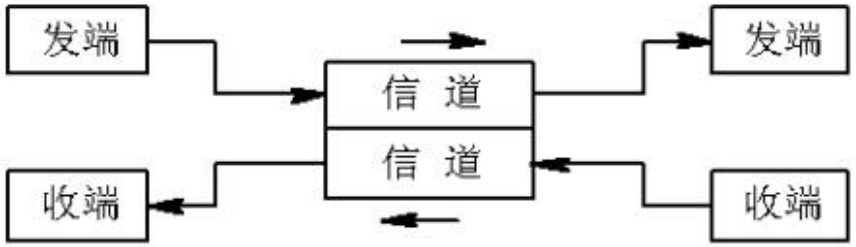
  Allowing simultaneous two-way communication



单工



半双工



全双工

Full duplexing 全双工

- **FDD (Frequency division duplexing) :**

  FDD system means that the system uses different frequencies (channels) for transmitting and receiving data, and there is a duplex interval between the uplink and downlink frequencies.

  频分双工系统是指移动通信系统在发送数据和接收数据时使用了不同的频率，并且在上行和下行频率之间有双工间隔。

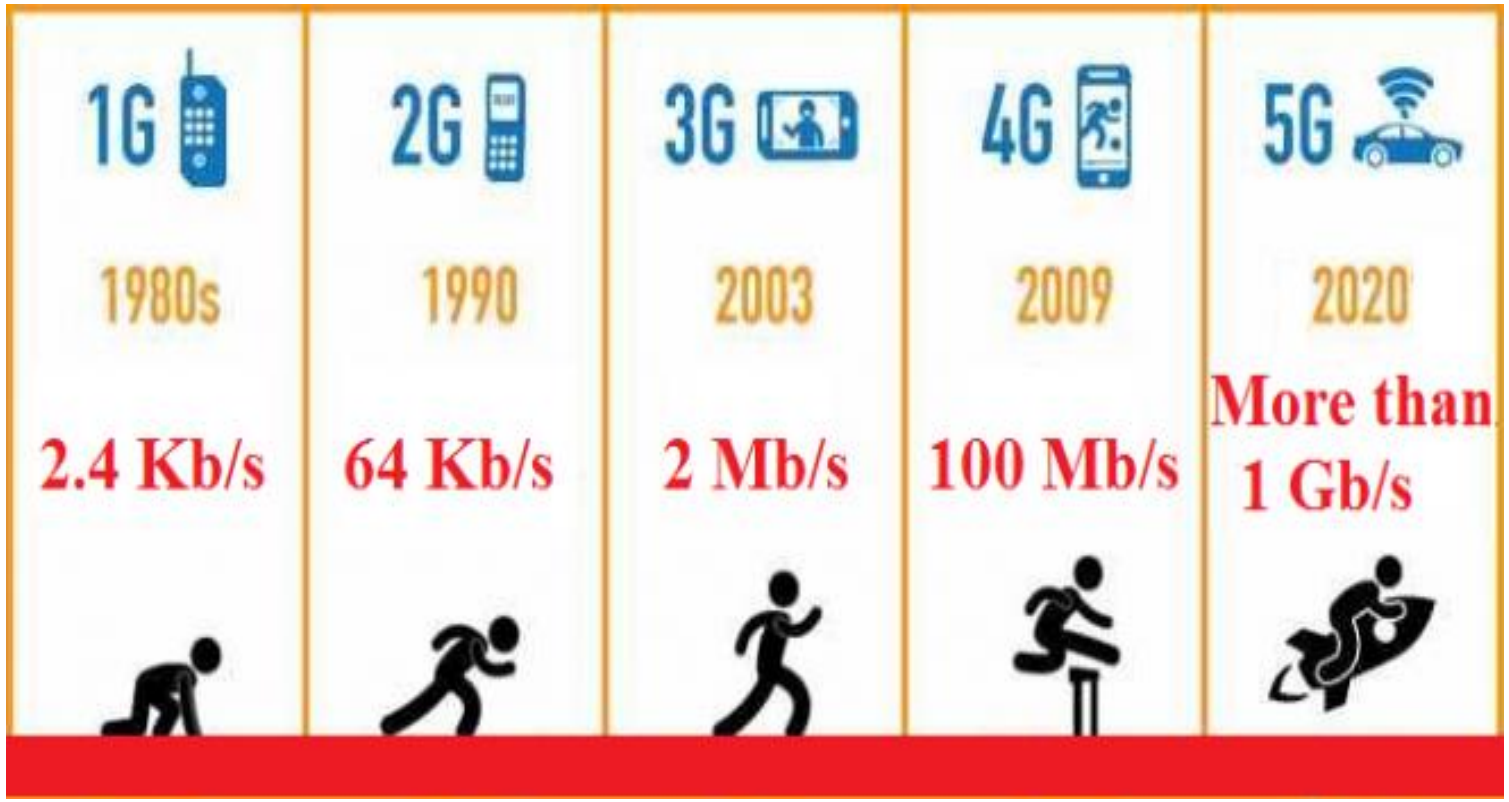
- **TDD (Time division duplexing) :**

  TDD uses the fact that it is possible to share a single radio channel in time, so that a portion of the time is used to transmit from the base station to the mobile, and the remaining time is used to transmit from the mobile to the base station.

  时分双工在时间上共享一条信道，将其一部分时间(例如时隙1)用于从基站向用户发送信号，而其余的时间(例如时隙2)用于从用户向基站发送信号。

1G, 2G, 3G, 4G, 5G

Evolution of wireless technologies



1G, 2G, 3G, 4G, 5G

Comparisons among 1G, 2G, 3G, 4G, 5G

	1G	2G	3G	4G	5G
Technology	Analog cellular	digital cellular	CDMA2000, UMTS, EDGE, TD-SCDMA	WiMax, LTE, Wi-Fi	5G NR
Multiple Access (Multiplexing)	FDMA	TDMA, narrow-band CDMA	CDMA	OFDMA / SC-FDMA	new OFDM-based
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet
Switching	Circuit	Circuit, Packet	Packet	All Packet	All Packet
Throughput (Peak)	14.4Kbps	14.4 Kbps -171.2 Kbps	3.1 Mbps -14.4 Mbps	100-300 Mbps	20 Gbps

1G

- Analog cellular systems
- Only carry voice traffic
- Include standards such as : AMPS 30KHz FM FDMA

2G

- Digital cellular systems
- Can support high bit rate voice, limited data communication
- Improve quality of service

GSM was the most applied technology of Cellular networks.

2G standards include :

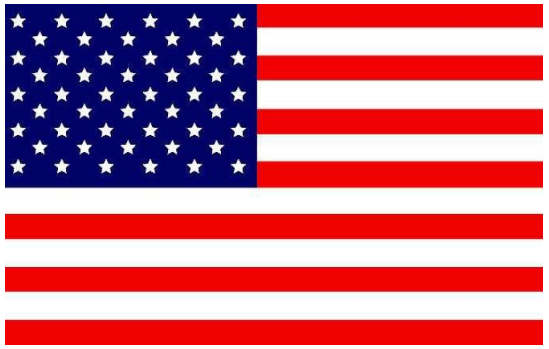
- GSM : 200 KHz TDMA (was the dominant one in china)
- IS-95 : 1.23 MHz, CDMA, signal bandwidth of a single channel is 1.23 MHz

3G

3G offers enhancements to current applications including greater data speeds, increased capacity for voice and data and a broader range of services.

In 2000, ITU approved the following three standards :

CDMA2000



WCDMA

TD-SCDMA

Highest data rate of 3G is as following :

- **144 Kb/s in a vehicular environment**
- **384 Kb/s in a pedestrian environment**
- **2048 Kb/s in an indoor office environment**

4G

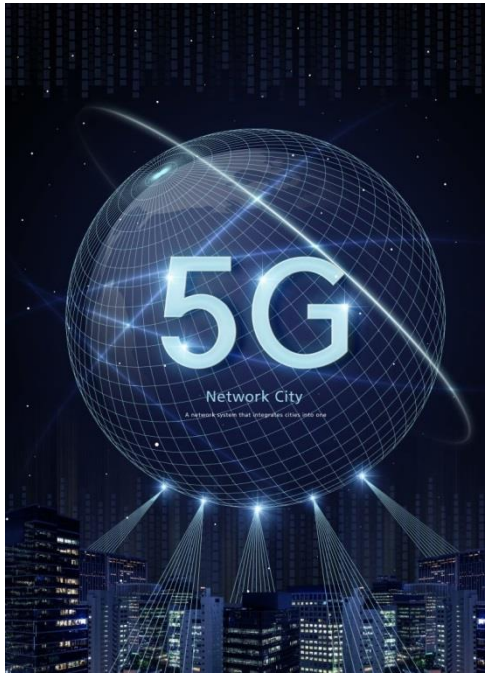
- LTE : Long Term Evolution
- LTE-A (4G) : LTE-advanced，Release 10, 11

4G adopts:

- OFDM : Orthogonal Frequency Division Multiplexing， 正交频分复用
- MIMO : Multi-Input and Multi-Output， 多输入多输出

5G

- Next major phase of mobile communication wireless system
- 10 times more capacity than 4G
- Expected speed up to 1 Gbps
- More faster reliable than 4G
- Lower cost than previous generations



The main features of 5G are the millimeter wavelength, ultra-wideband, ultra-high speed, ultra-low latency.

5G

The 5G era defines three application scenarios:

- **eMBB**

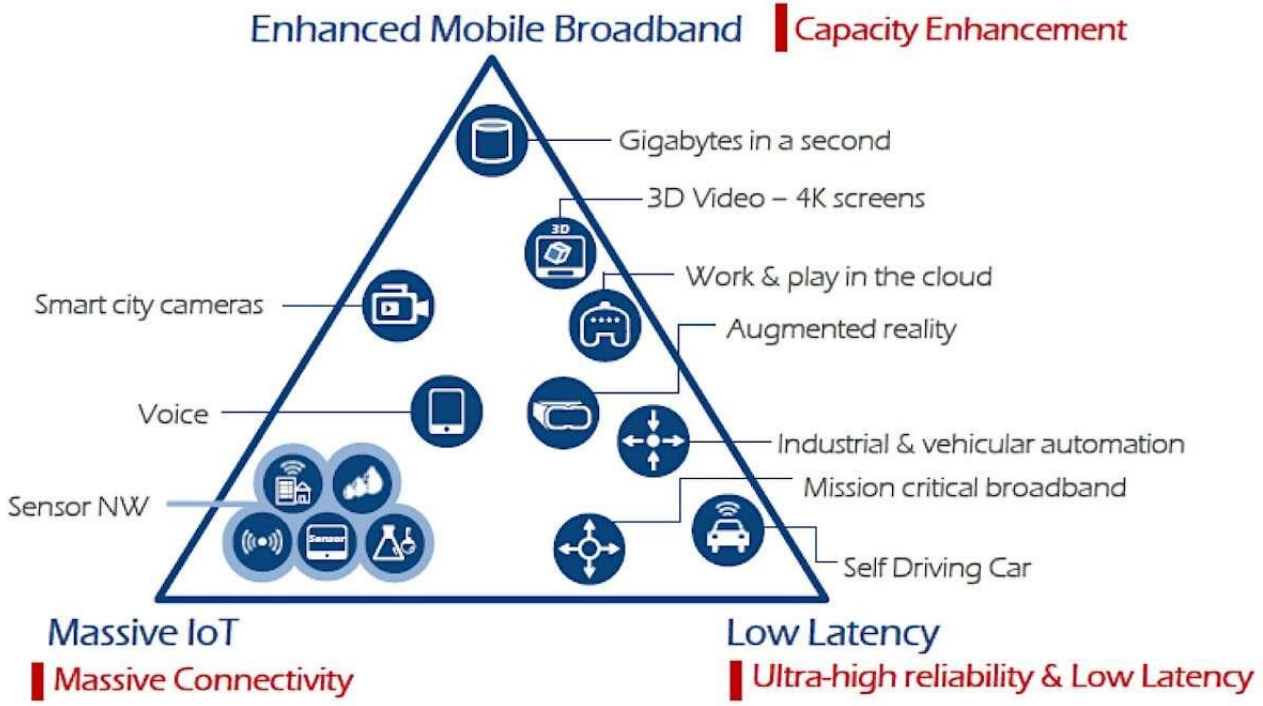
  Enhanced Mobile Broadband

- **URLLC**

  Ultra Reliable & Low Latency Communication

- **mMTC**

  Massive Machine Type Communication



Introduction to Wireless Communications

4. Basics of communication and capacity

Contents

- Antenna Gain and Wireless Channel Attenuation
- Noise, Interference, SNR
- Shannon capacity
- Concepts Related to Channel Capacity

Gain and Attenuation

Gain and attenuation **: the amplification or reduction of power**

We often describe the power, gain and attenuation in decibels :

- **Power : W or mW**
- **Power in decibels : dBW or dBm**

x **(W) = 10·lg**x **(dBW) =** y **(dBW)**

x **(mW) = 10·lg**x **(dBm) =** y **(dBm)**

Question**: 1 W = ? dBW = ? dBm**

Solution**: 1 (W) = 10·lg1 (dBW) = 0 (dBW)**

1 (W) = 1000 (mW) = 10·lg1000 (dBm) = 30 (dBm)

Gain and Attenuation

- **Power Ratio in decibels : dB**

  - **Gain or attenuation in dB : $10 \cdot \lg [P_{out}(W) / P_{in}(W)]$**
    $= P_{out}(dBm) - P_{in}(dBm)$

    - ☆ **Gain : $P_{out} > P_{in}$**
    - ☆ **Attenuation : $P_{out} < P_{in}$**

Question 1: X (dBm) + Y (dB) = ? dB or ? dBm

Answer 1: X (dBm) + Y (dB) = Z (dBm)

Question 2: X (dBm) – Y (dB) = ? dB or ? dBm

Answer 2: X (dBm) – Y (dB) = Z (dBm)

Question 3: X (dBm) – Y (dBm) = ? dB or ? dBm

Answer 3: X (dBm) – Y (dBm) = Z (dB)

dBm ± dB = dBm ; dBm – dBm = dB

Gain and Attenuation

Example **: Input power is 2 dBm, system gain is 5 dB, what's the output power ?**

Answer : ***2*** **(dBm)** ＋ ***5*** **(dB) =** ***7*** **(dBm)**

Antenna Gain and Wireless Channel Attenuation

(1) *Antenna gain*

- $G_{ant,tx}$ for Transmitter antenna
- $G_{ant,rx}$ for Receiver antenna

(2) *Wireless channel attenuation*

Signal-to-Noise Ratio

SNR

Signal power (Watt) / Noise power (Watt)

SNR is relate to the performance of communications systems such as

Bit-error probability

Shannon capacity

Signal-to-Interference Ratio

SIR

- **sometimes known as C/I (carrier-to-interference ratio)**
- **(signal power) / (interference power)**
- **Interference: signals from other simultaneous communications**

Shannon Capacity

Shannon Capacity Formula :

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

C: capacity (bits/s), B: bandwidth (Hz),

and S/N: Signal-to-Noise ratio

This theorem determines the theoretical limit on channel capacity for a given bandwidth (B) and signal-to-noise ratio (S/N) (in AWGN channel).

Shannon Capacity

How to evaluate the performance of a communication scheme?

– How close to Shannon bound?

– Spectral efficiency (bandwidth efficiency) in unit of bit/s/Hz

$$\eta_B = R/B$$

R: data rate (bps), and B: bandwidth.

(*Referred to Lecture 2 by Hung-Yu Wei, National Taiwan University*)

Shannon Capacity

***Example*: Given B = 22MHz, signal strength S = -90dBm, N = -100dBm, please find the theoretical maximum bit-rate.**

***Solution*:**

Effective bits/sec : $C = B \cdot \log_2(1 + S/N)$

SNR = 10lg (S/N) = -90-(-100) = 10 dB → S/N=10

→ $C = 22 \cdot \log_2(1 + 10) = 76$ Mbps

Concepts Related to Channel Capacity

- **Data rate**
  - rate at which data can be communicated (bps)
- **Bandwidth**
  - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- **Noise**
  - average level of noise over the communications path
- **Error rate**
  - rate at which errors occur

Summary

- **无线通信的定义和发展**：了解无线通信的定义、产生和发展，以及无线通信的传输媒介和特性参数；
- **现代无线通信系统**：了解现代无线通信的典型应用，以及无线通信网络的分类；
- **移动通信网络**：掌握蜂窝移动通信的基本网络架构和技术名词，了解移动通信从1G到5G的发展历程及特点；
- **通信和容量基础**：掌握功率、增益和衰减在对数域的表示和单位之间的转换关系，熟悉香农容量的相关概念和计算。

Thanks !