Chapter 1

Introduction

The History of Mobile Radio Communication (1/5)

- **1860: Maxwell's equation relating electric and magnetic fields**
- **1880: Hertz – Initial demonstration of practical radio communications**
- **1897: Marconi – Radio transmission to a tugboat over an 18-mile path**
- **1921: Detroit Police Department: -- Police car radio dispatch (2 MHz frequency band)**
- **1946: Bell Telephone Laboratories – 152 MHz (Simplex)**
- **1964: FCC (Federal Communications Commission) – 152 MHz (Full Duplex)**
- **1981: FCC – Release of cellular land mobile phone service in the 40 MHz bandwidth in the 800 to 900 MHz range for commercial operation**

The History of Mobile Radio Communication (2/5)

- **1984: AMPS (Advanced Mobile Phone System) used in the North America and Australia refers to the first-generation of wireless telephone technology which is the analog telecommunications. The download speeds is 28 kbit/s ~ 56 kbit/s.**
- **1988: TDMA (Time Division Multiple Access) voted as a digital cellular standard in North America.**
- **1992: GSM (Global System for Mobile Communications) operable in Germany D2 system. The download speeds is about 100k bits/s for 2.5G.**
- **1993: CDMA (Code Division Multiple Access) voted as another digital cellular standard in North America.**

The History of Mobile Radio Communication (3/5)

- **1999: ITU (International Telecommunication Union) decides the 3rd generation mobile communication systems (e.g., W-CDMA, CDMA 2000, etc)**
- **2001: the UMTS (Universal Mobile Telecommunication Systems) used primarily in Europe, Japan, China.**
- **2002: the CDMA2000 system used in North America and South Korea, sharing infrastructure with the IS-95 2G standard.**
- **2006: The pre-4G systems Mobile WiMAX in South-Korea. Peak down load 128 Mbit/s and peak upload 56 Mbit/s.**
- **2009: The TD-SCDMA (Time Division Synchronous Code Division Multiple Access) radio interface was commercialized in China.**

The History of Mobile Radio Communication (4/5)

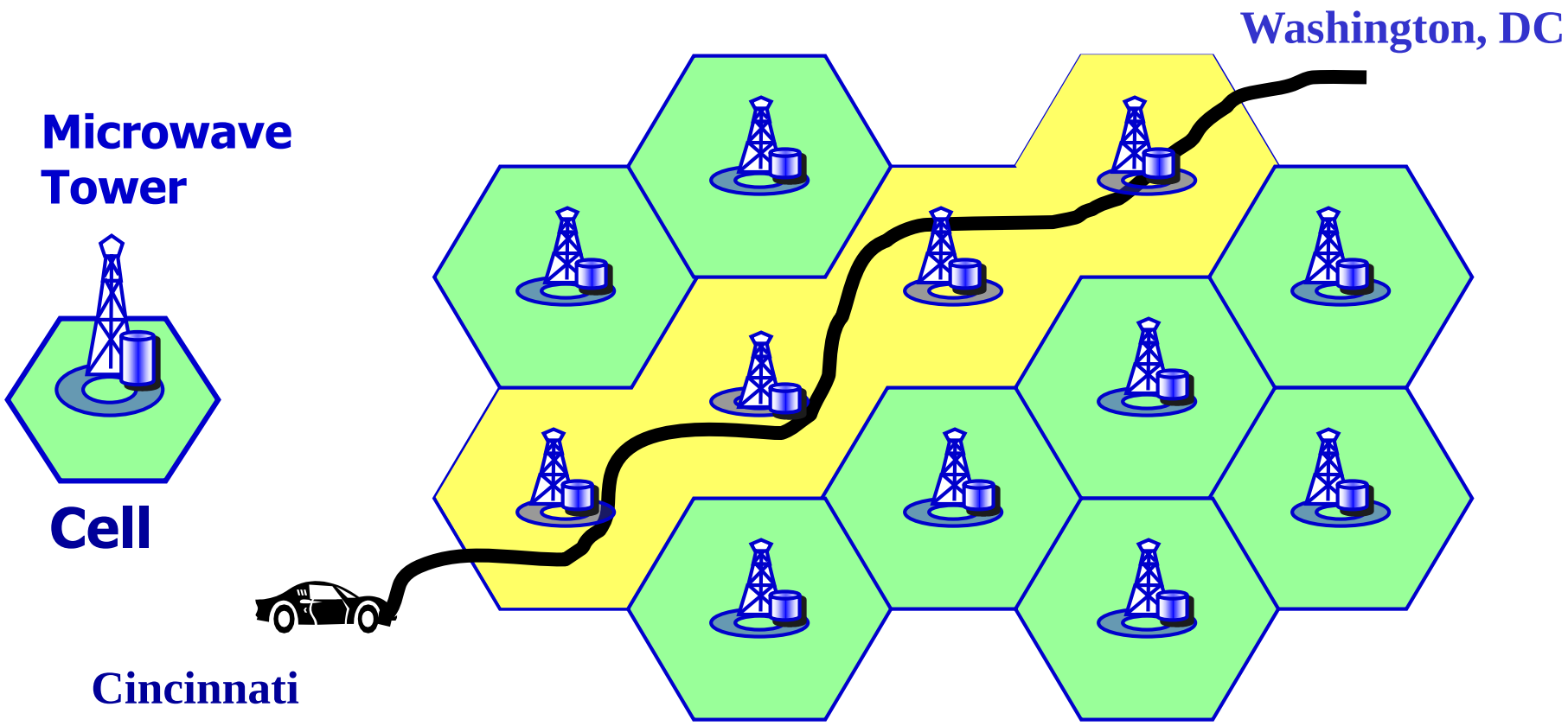
- **2009: The world's first publicly available LTE (Long Term Evolution) service was opened in, Stockholm (Ericsson and Nokia Siemens Networks systems) and Oslo (a Huawei system) on 14 December 2009, and branded 4G. Peak down load 100 M bits/s and peak upload 50 M bits/s.**
- **2013: LTE Advanced (Long Term Evolution Advanced) is a candidate for IMT-Advanced standard, formally submitted by the 3GPP (3rd Generation Partnership Project) organization to ITU-T in the fall 2009. Peak down load 1G bits/s and peak upload 500M bits/s.**
- **2020: 5G is also referred to as beyond 2020 mobile communications technologies.**
- **2030: 6G?**

The History of Mobile Radio Communication (5/5)

- **2020: 5G is also referred to as beyond 2020 mobile communications technologies. 5G is a unified platform that is more capable than 4G(support all spectrum types (licensed, shared, unlicensed) and bands (low, mid, high),), 5G uses spectrum better than 4G (<1 G Hz , 1G Hz ~ 6G Hz, > 24G Hz) , 5G is faster than 4G (20 Gigabits-per-second peak data rates and 100+ Megabits-per-second average data rates.), 5G has more capacity than 4G (x 100 traffic capacity), 5G has lower latency than 4G (1 ~ 4 ms)**
- **What are the 5 G Applications?**

- **2030: 6G?**

Universal Cell Phone Coverage



Maintaining the telephone number across geographical areas in a wireless and mobile system

Table 1.2. Frequency bands and their common uses

Band Name	Frequency	Wavelength	Applications
Extremely low frequency (ELF)	30 to 300 Hz	10000 to 1000 Km	Powerline frequencies
Voice Frequency (VF)	300 to 3000 Hz	1000 to 100 Km	Telephone communications
Very low frequency (VLF)	3 to 30 KHz	100 to 10 Km	Marine communications
Low frequency (LF)	30 to 300 KHz	10 to 1 Km	Marine communications
Medium frequency (MF)	300 to 3000 KHz	100 to 100 m	AM broadcasting
High frequency (HF)	3 to 30 MHz	100 to 10 m	Long-distance aircraft / ship communications
Very high frequency (VHF)	30 to 300 MHz	10 to 1 m	FM broadcasting
Ultra high frequency (UHF)	300 to 3000 MHz	100 to 10 cm	Cellular telephone
Super high frequency (SHF)	3 to 30 GHz	10 to 1 cm	Satellite communications, microwave links
Extremely high frequency (EHF)	30 to 300 GHZ	10 to 1 mm	Wireless local loop, 5 G
Infrared	300 GHz to 400 THz	1 mm to 400 nm	Consumer electronics
Visible light	400 THz to 900 THz	770 nm to 330 um	Optical communications

First Generation Cellular Systems and Services

1970s	Developments of radio and computer technologies for 800/900 MHz mobile communications
1976	WARC (World Administrative Radio Conference) allocates spectrum for cellular radio
1979	NTT (Nippon Telephone & Telegraph) introduces the first cellular system in Japan
1981	NMT (Nordic Mobile Telephone) 900 system introduced by Ericsson Radio System AB and deployed in Scandinavia
1984	AMPS (Advanced Mobile Phone Service) introduced by AT&T in North America

Second Generation Cellular Systems and Services

1982	CEPT (Conference Europeenne des Post et Telecommunications) established GSM to define future Pan-European cellular Radio Standards
1990	Interim Standard IS-54 (USDC) adopted by TIA (Telecommunications Industry Association)
1990	Interim Standard IS-19B (NAMPS) adopted by TIA
1991	Japanese PDC (Personal Digital Cellular) system standardized by the MPT (Ministry of Posts and Telecommunications)
1992	Phase I GSM system is operational
1993	Interim Standard IS-95 (CDMA) adopted by TIA
1994	Interim Standard IS-136 adopted by TIA
1995	PCS Licenses issued in North America
1996	Phase II GSM operational
1997	North American PCS deploys GSM, IS-54, IS-95
1999	IS-54: North America IS-95: North America, Hong Kong, Israel, Japan, China, etc GSM: 110 countries

Third Generation Cellular Systems and Services

IMT-2000	Fulfill One's Dream of Anywhere, Anytime Communications
Key Features	- High degree of commonality of design worldwide - Compatibility of services within IMT-2000 and with the fixed networks - High quality - Small terminal for worldwide use - Worldwide roaming capability - Capability for multimedia applications and a wide range of services and terminals
Important Component	- 2 Mbps for fixed environment - 384 kbps for indoor/outdoor and pedestrian environment - 144 kbps for vehicular environment
Standardization Work	- In progress (see Table 1.6)
Scheduled Service	- Started in October 2001 in (W-CDMA) - Started in December 2001 in Europe - Started in January 2002 in South Korea - Started in October 2003 in USA - Started in April 2009 in China

Fourth Generation Cellular Systems and Services

IMT-Advanced	Major Features and Services
Key Feature	- High speed of communication - High quality - Wide spectrum - Full integration of a variety of business - Great compatibility - Channel-dependent Scheduling - Link Adaptation - Mobile-IP utilized for mobility - IP-based Femtocells
Access Technique	- FDD-LTE: Frequency Division Duplex Long Term Evolution - TD-LTE： Time Division Long Term Evolution
Important Component	- FDD-LTE: Uplink rate is 150Mbps; Downlink rate is 40Mbps - TD-LTE: Uplink rate is 100Mbps; Downlink rate is 50Mbps
Scheduled Service	- FDD-LTE started in December 2009 in Sweden - FDD-LTE started at the end of 2010 in USA - FDD-LTE started in July 2011 in South Korea - TD-LTE started in December 2013 in China

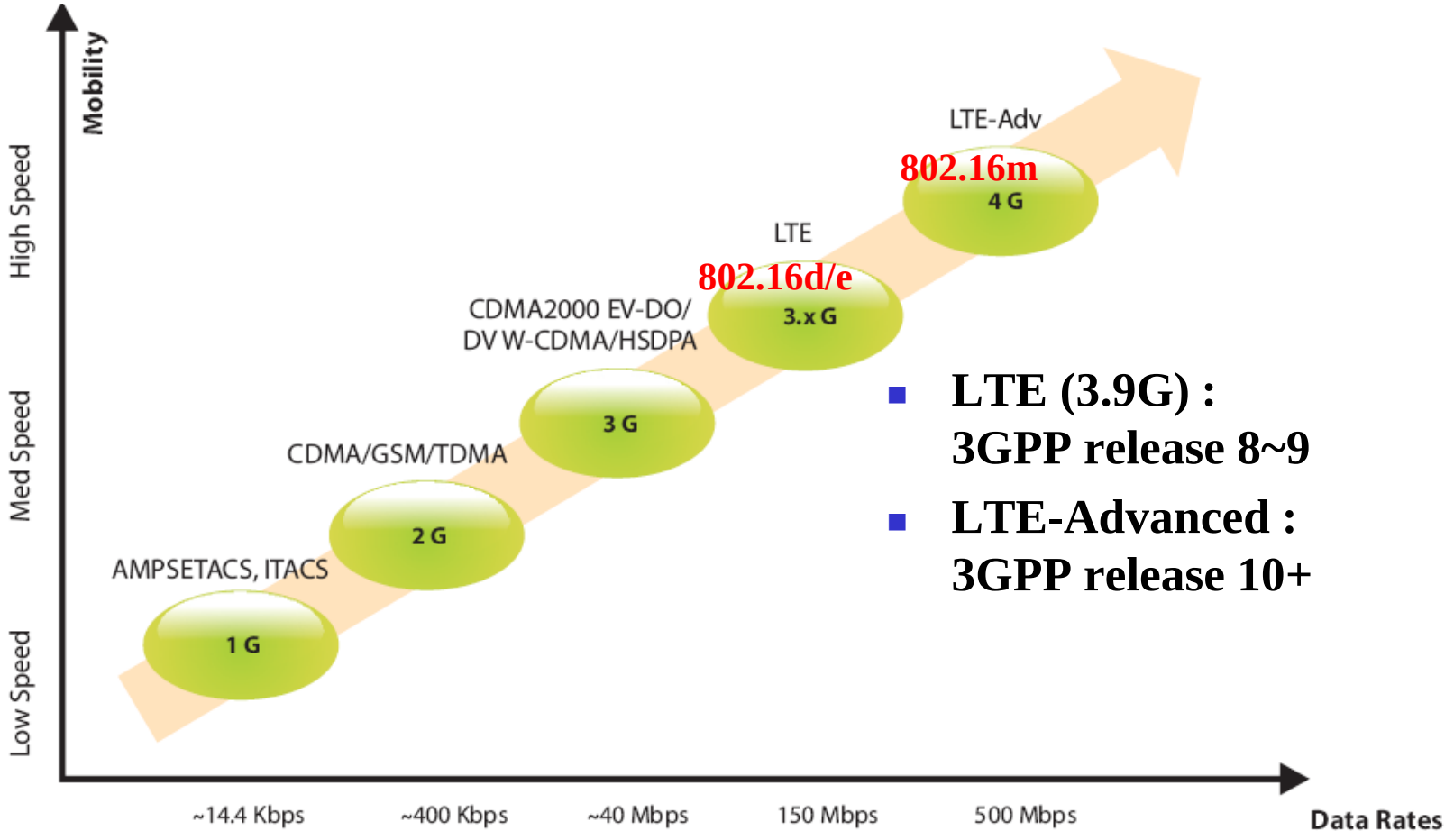
3GPP Release Dates and Contents (1/2)

3GPP Release	Release Date	Summary
Release 99	1999	First release of the UMTS standard
Release 4	2001	This release was originally referred to as Release 2000 and added features including an all-IP core network.
Release 5	2002	This release introduced the IP multimedia subsystem, IMS (IP multimedia subsystem), and high-speed packet downlink access, HSDPA (high-speed downlink packet access).
Release 6	2004	This release integrated the operation of UMTS with wireless LAN networks and added enhancements to IMS (including Push to talk over cellular), and GAN (generic access network). It also added high speed packet uplink access, HSUPA (high-speed uplink packet access).
Release 7	2007	This release detailed improvements to QoS (Quality of Service) for applications such VoIP (Voice over IP). It also detailed upgrades for high-speed packet access evolution, HSPA+ (high-speed packet access), as well as changes for EDGE (enhanced data rates for GSM evolution) evolution and also provided interfaces to enable operation with NFC (near field communication) technology.

3GPP Release Dates and Contents (2/2)

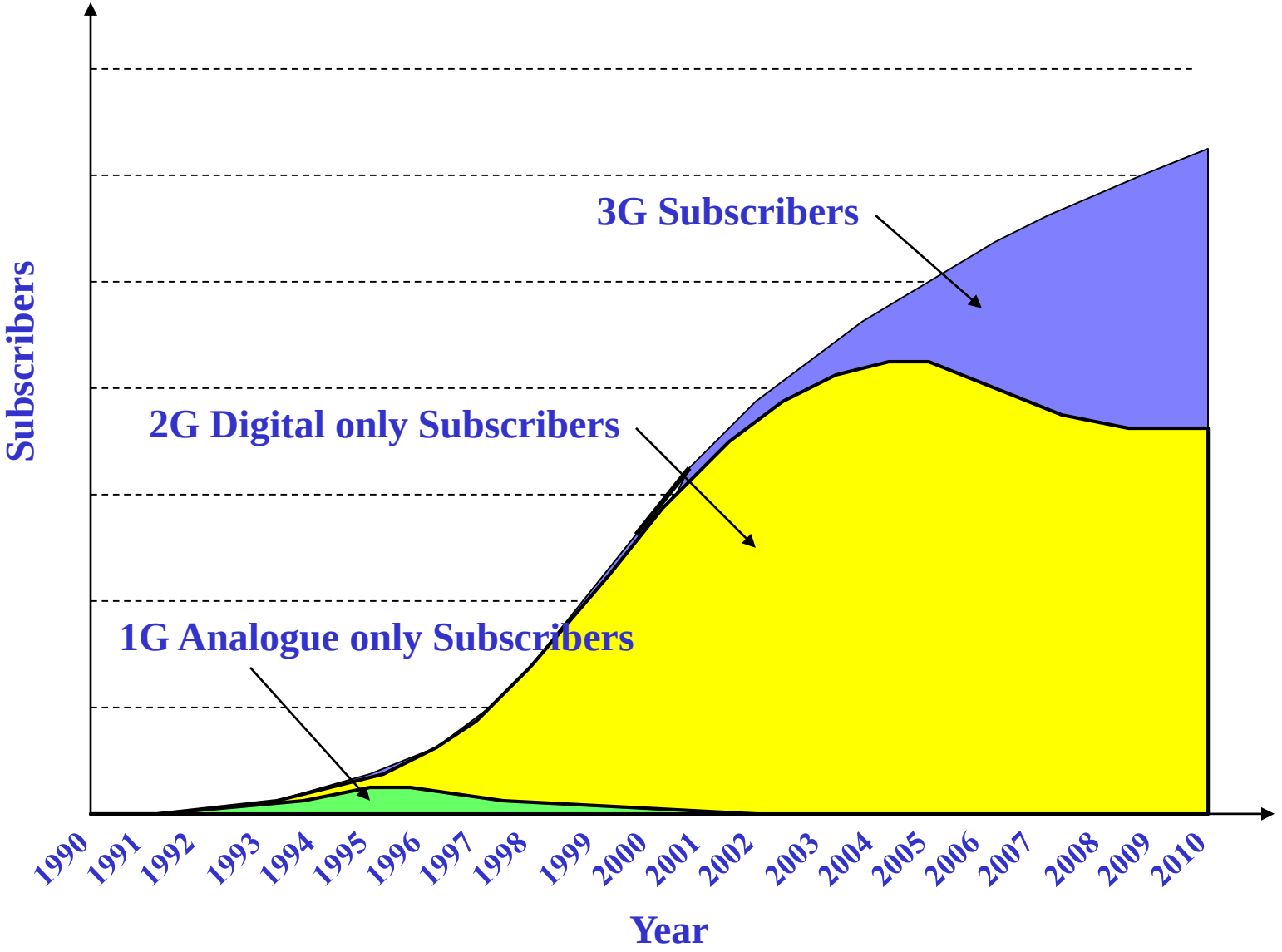
3GPP Release	Release Date	Summary
Release 8	2008	This release provided the details of the LTE (long-term evolution) system architecture evolution (SAE), and an all-IP network architecture providing the capacity and low latency required for LTE and future evolutions.
Release 9	2009	This release added further enhancements to the SAE as well as allowing for WiMAX (worldwide interoperability for microwave access) and LTE/UMTS interoperability.
Release 10	2011	LTE Advanced fulfilling IMT Advanced 4G requirements. Backwards compatible with Release 8 (LTE). Multi-cell HSDPA (4 carriers).
Release 11	2012	Advanced IP interconnection of services. Service layer interconnection between national operators/carriers as well as third party application providers. Heterogeneous networks (HetNet) improvements, coordinated multi-point operation (CoMP). In-device co-existence (IDC).
Release 12	Planned to 2014	Content still open

Evolution of Radio Access Technologies

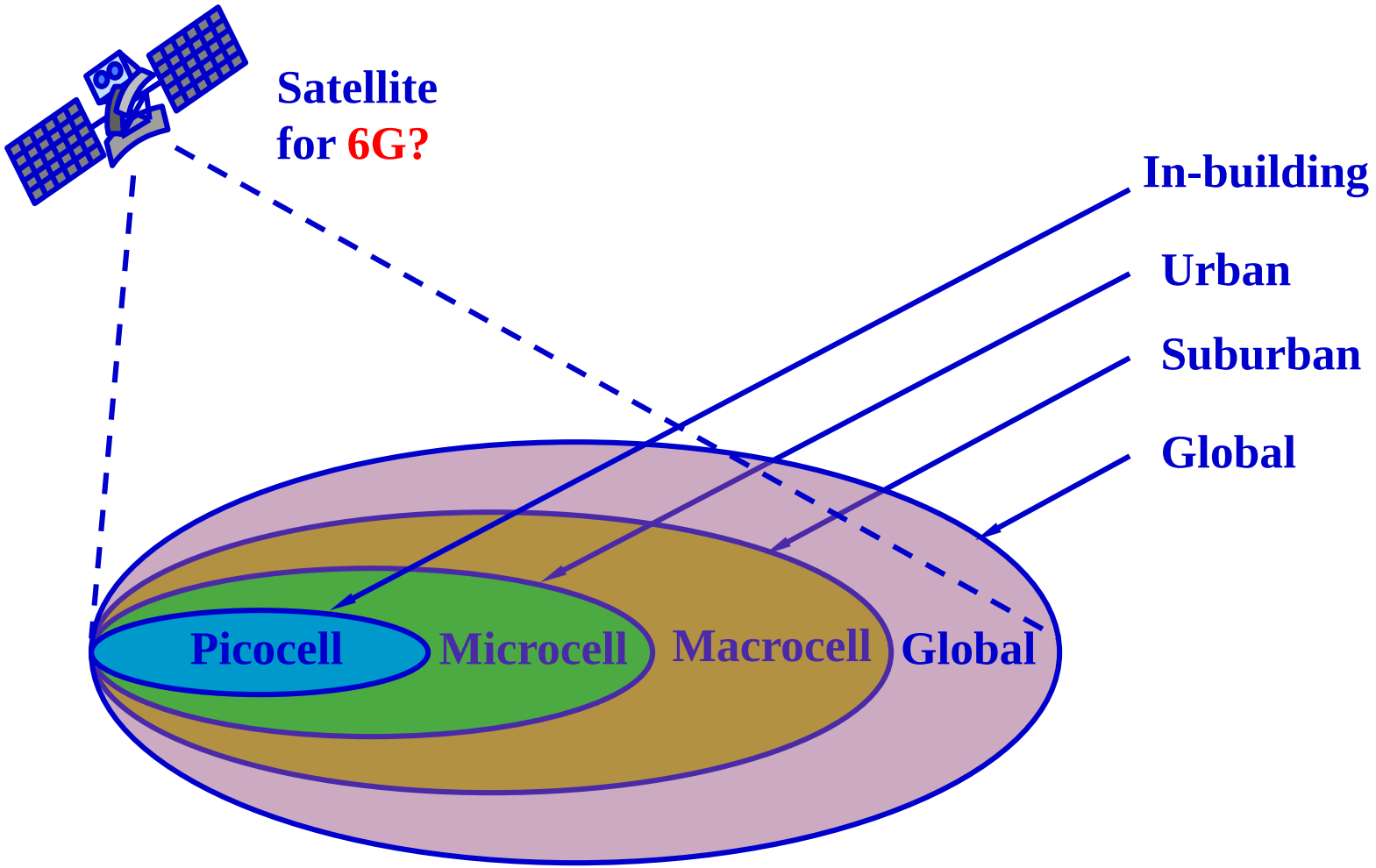


- **LTE (3.9G) : 3GPP release 8~9**
- **LTE-Advanced : 3GPP release 10+**

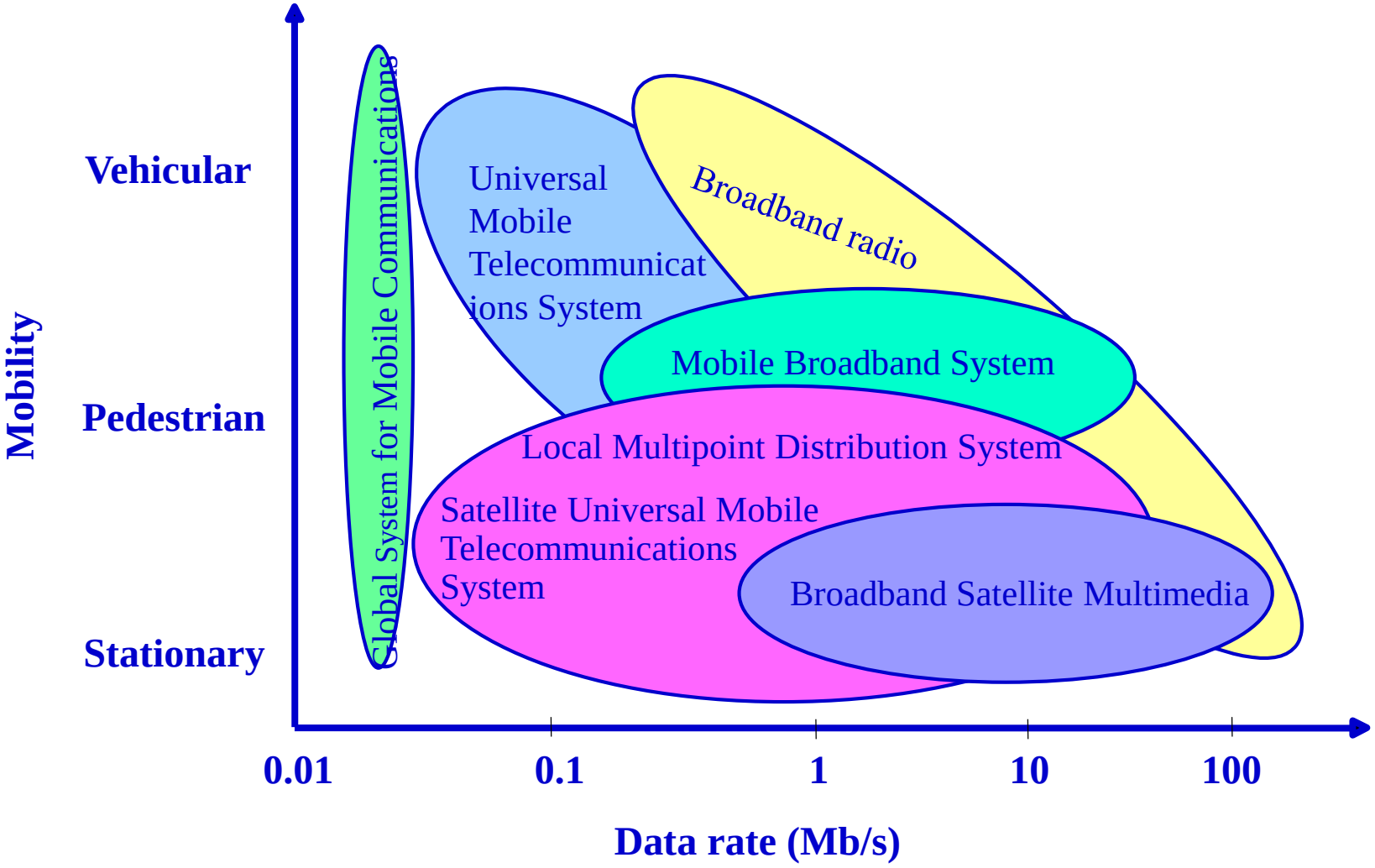
Subscriber Growth



Coverage Aspect of Next Generation Mobile Communication Systems



Transmission Capacity



Transmission capacity as a function of mobility in some radio access systems

Wireless Technology and Associated Characteristics

- Cellular
- Wireless LAN/PAN
- GPS
- Satellite Based PCS
- Home Networking
- Ad Hoc Networks
- Sensor Networks
- Bluetooth, Zigbee
- LoRA, Sigfox, NB-IoT (5G)

Applications: Medical and Healthcare

In Hospital
Physician

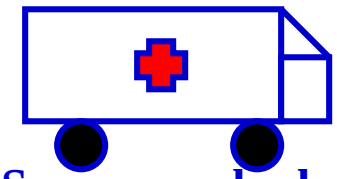
Base station

Switch

Backbone
Network

Remote
Databases

Switch



Sensors on body

Wireless Remote
consultation from
Ambulance

Possibility for Remote consulting
(including Audio Visual communication)

Fundamentals of Cellular Systems

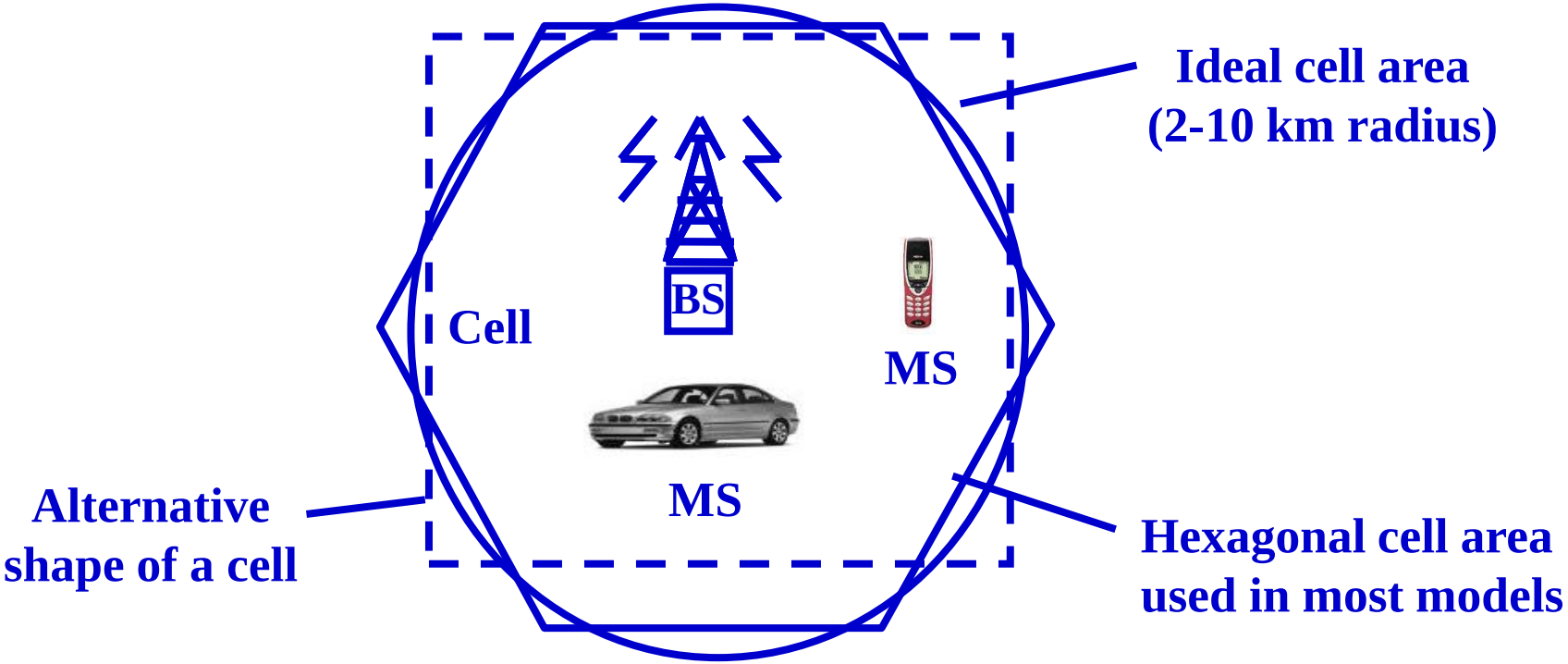
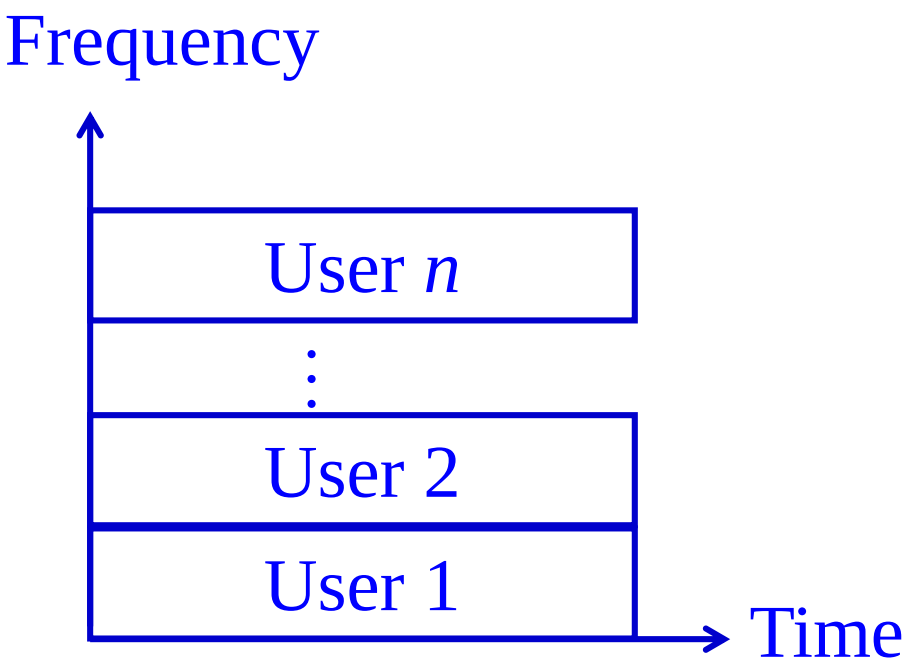
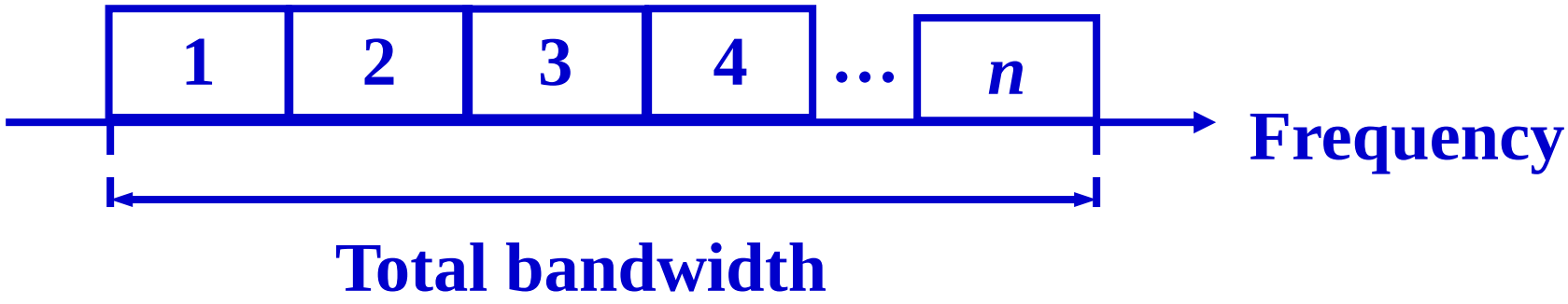


Illustration of a cell with a mobile station and a base station

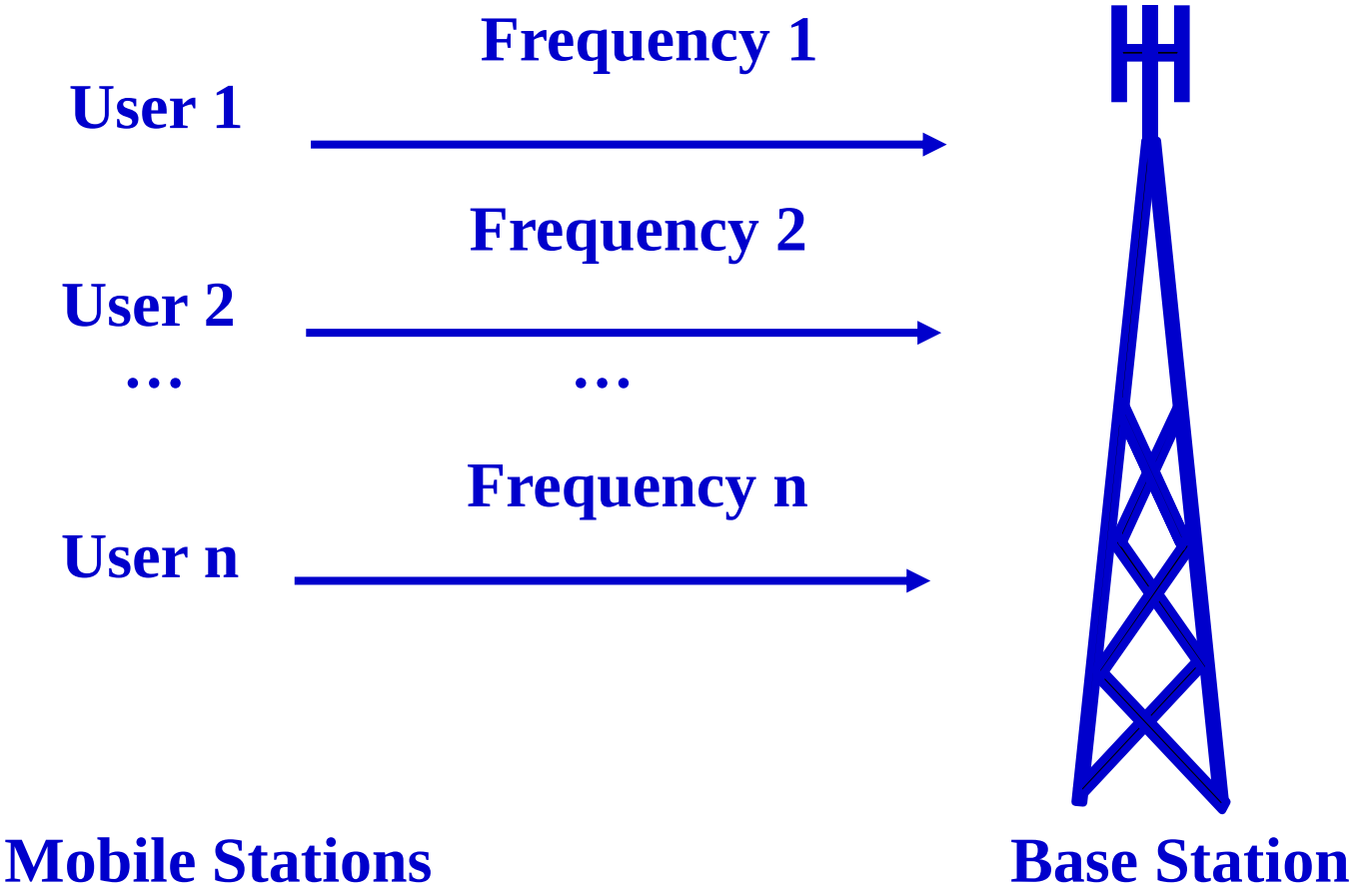
FDMA (Frequency Division Multiple Access)



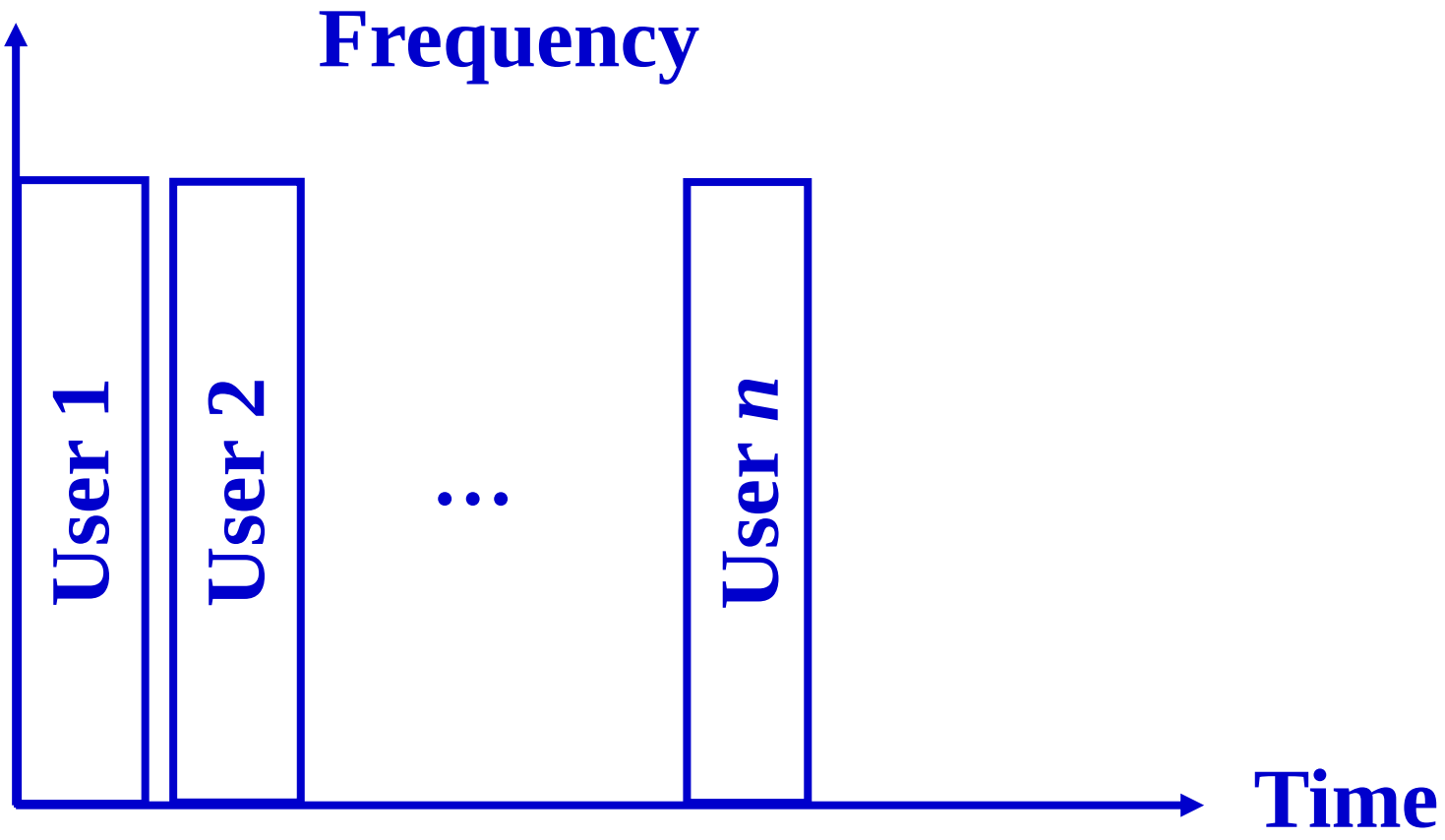
FDMA Bandwidth Structure



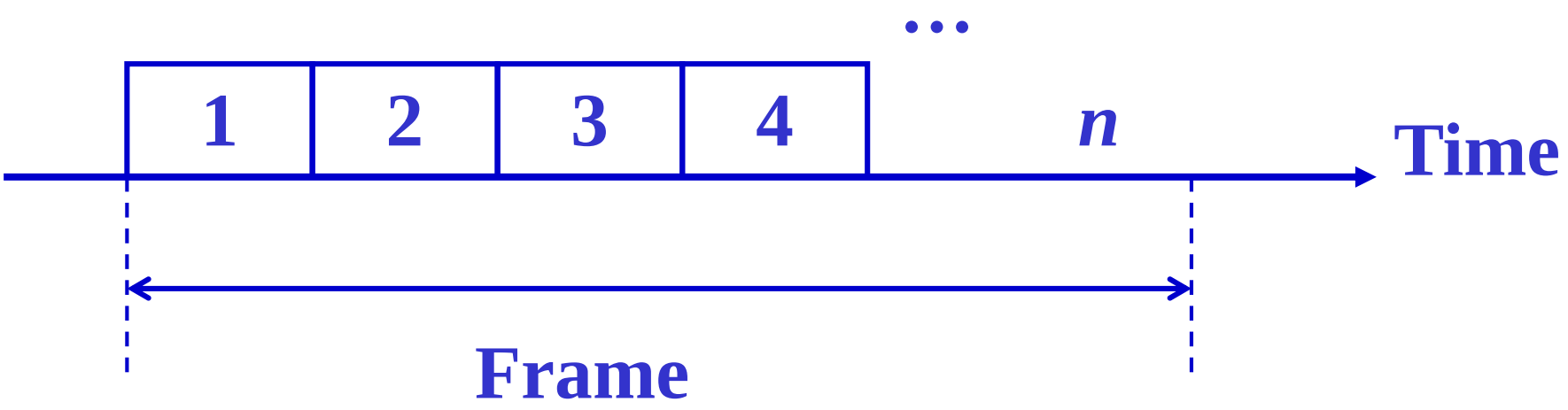
FDMA Channel Allocation



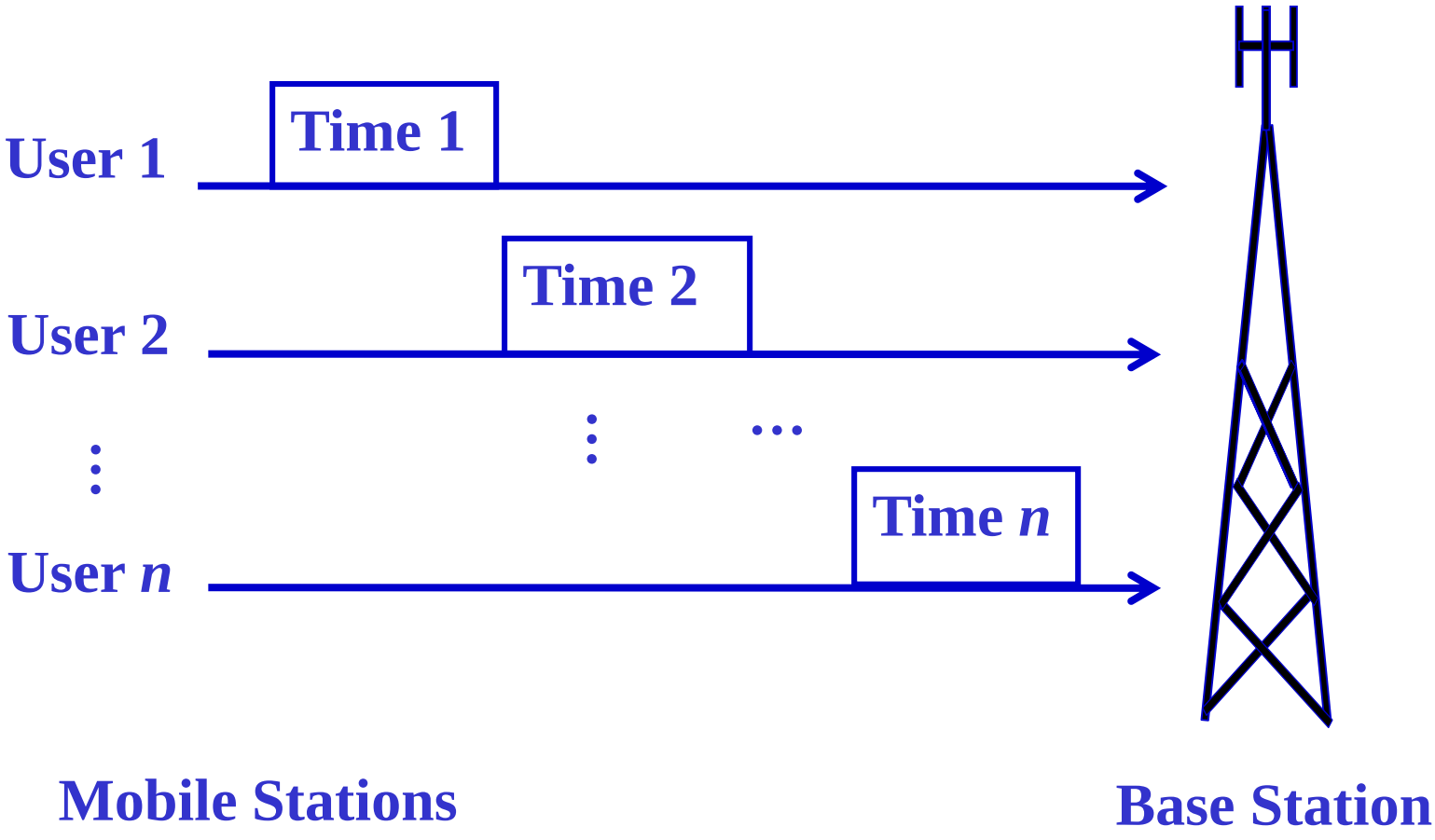
TDMA (Time Division Multiple Access)



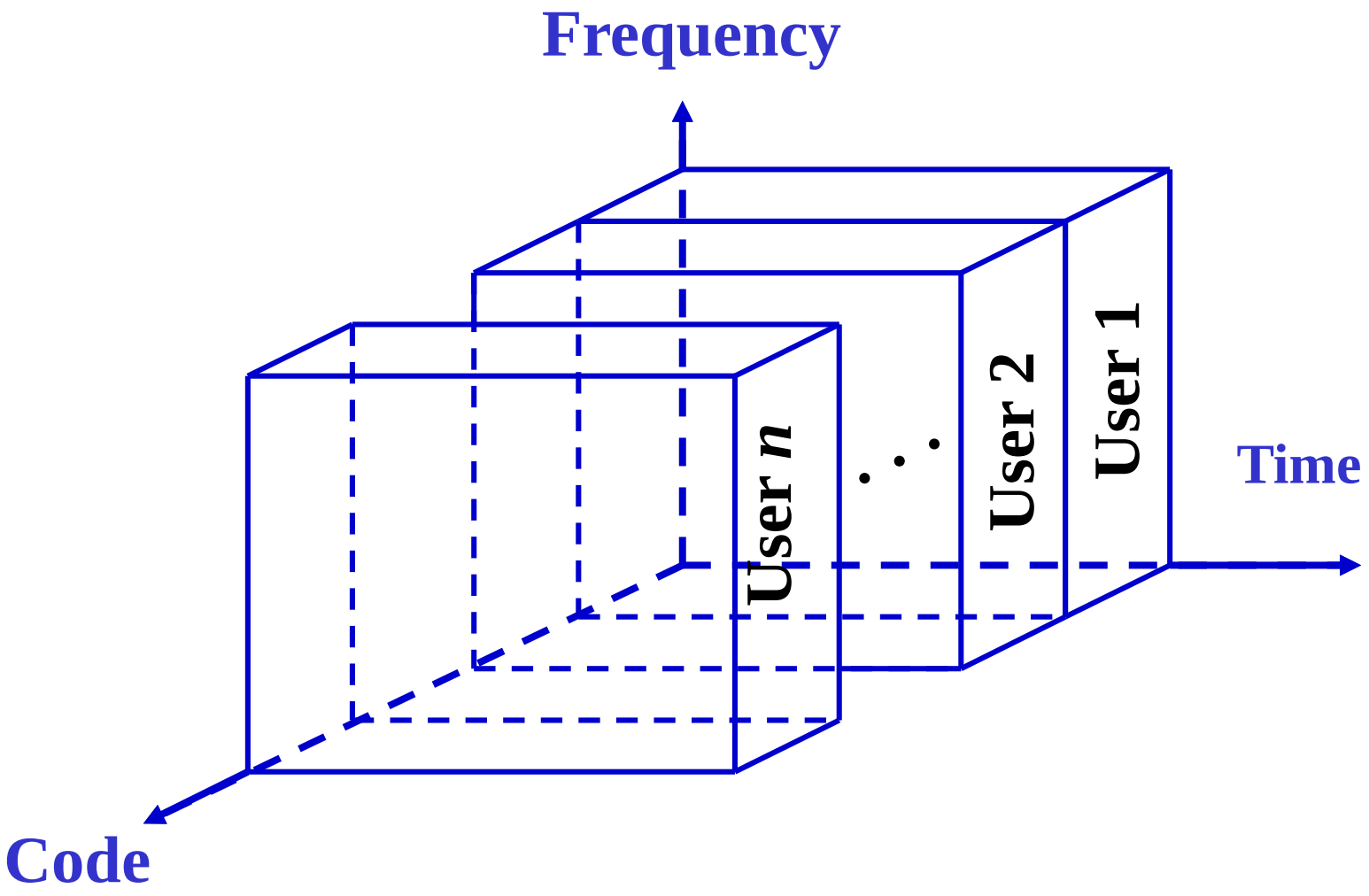
TDMA Frame Structure



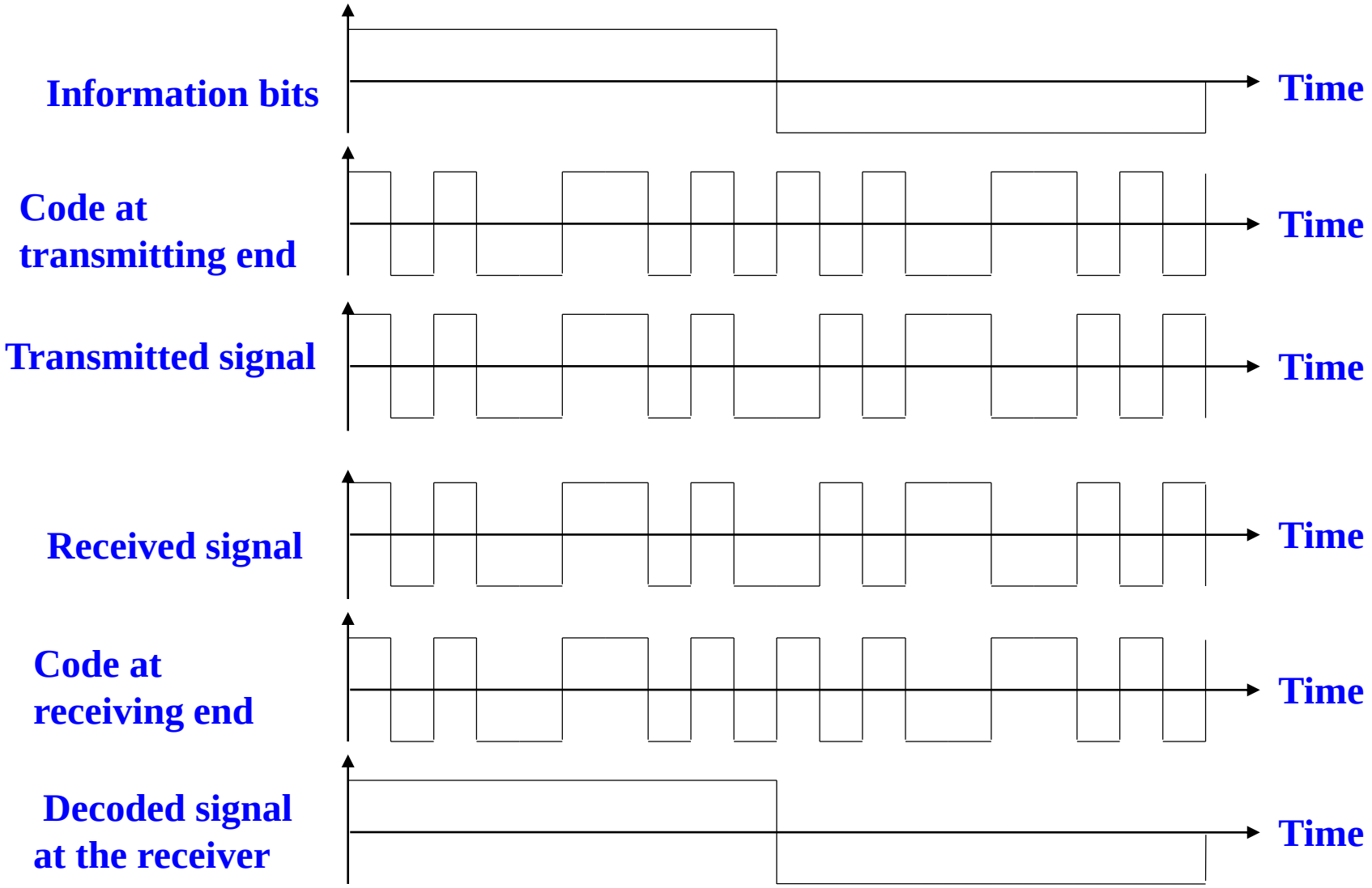
TDMA Frame Illustration for Multiple Users



CDMA (Code Division Multiple Access)



Transmitted and Received Signals in a CDMA System



CDMA Example (1/3)

- **If $k = 6$ and code is a sequence of 1s and -1s**
  - **For a '1' bit, A sends code as chip pattern**
  - **$\langle c1, c2, c3, c4, c5, c6\rangle$**
  - **For a '0' bit, A sends complement of code**
  - **$\langle -c1, -c2, -c3, -c4, -c5, -c6\rangle$**
- **Receiver knows sender's code and performs electronic decode function**

$$S_u(d) = d1\times c1 + d2\times c2 + d3\times c3 + d4\times c4 + d5\times c5 + d6\times c6$$

  - **$\langle d1, d2, d3, d4, d5, d6\rangle$ = received chip pattern**
  - **$\langle c1, c2, c3, c4, c5, c6\rangle$ = sender's code**

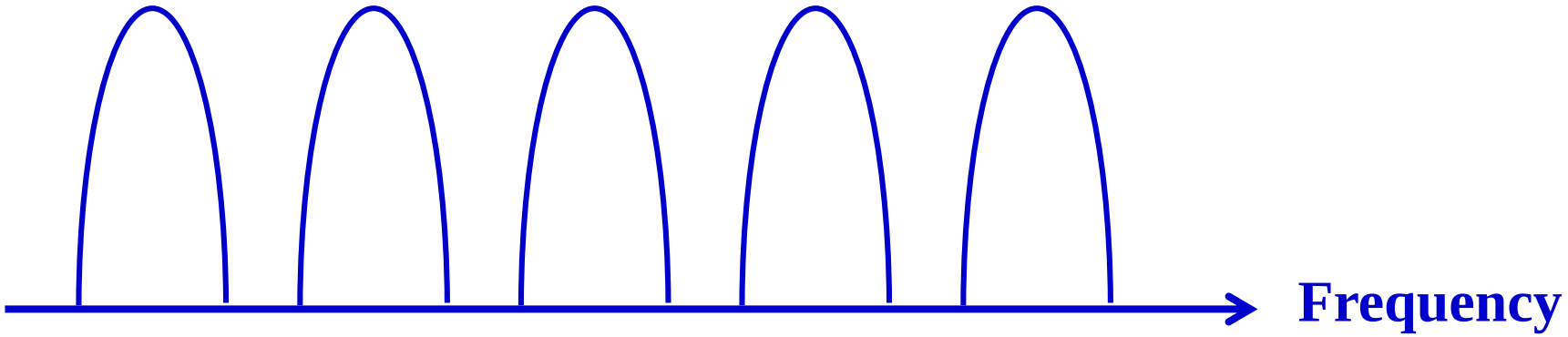
CDMA Example (2/3)

- **Each station has its own unique chip sequence (CS)**
- **All CSs are pairwise orthogonal**
- **For example :(codes *A*, *B*, *C* and *D* are pair-wise orthogonal)**
  - ***A*: 00011011 => (-1-1-1+1+1-1+1+1)**
  - ***B*: 00101110 => (-1-1+1-1+1+1+1-1)**
  - ***C*: 01011100 => (-1+1-1+1+1+1-1-1)**
  - ***D*: 01000010 => (-1+1-1 - 1-1-1+1-1)**

CDMA Example (3/3)

- $A \cdot B = (1+1-1-1+1-1+1-1) = 0$
- $B \cdot C = (1-1-1-1+1+1-1+1) = 0$
- Ex: If station C transmits 1 to station E, station B transmits 0 and station A transmits 1 simultaneously then the signal received by station E will become
  - $S_E = (-1+1-1+1+1+1-1-1) + (+1+1-1+1-1-1-1+1) + (-1-1-1+1+1-1+1+1) = (-1+1-3+3-1-1-1+1)$
  - E can convert the signal S_E to $S_E \cdot C = S_E(-1+1-1+1+1+1-1-1) = (1+1+3+3+1-1+1-1)/8 = 1$

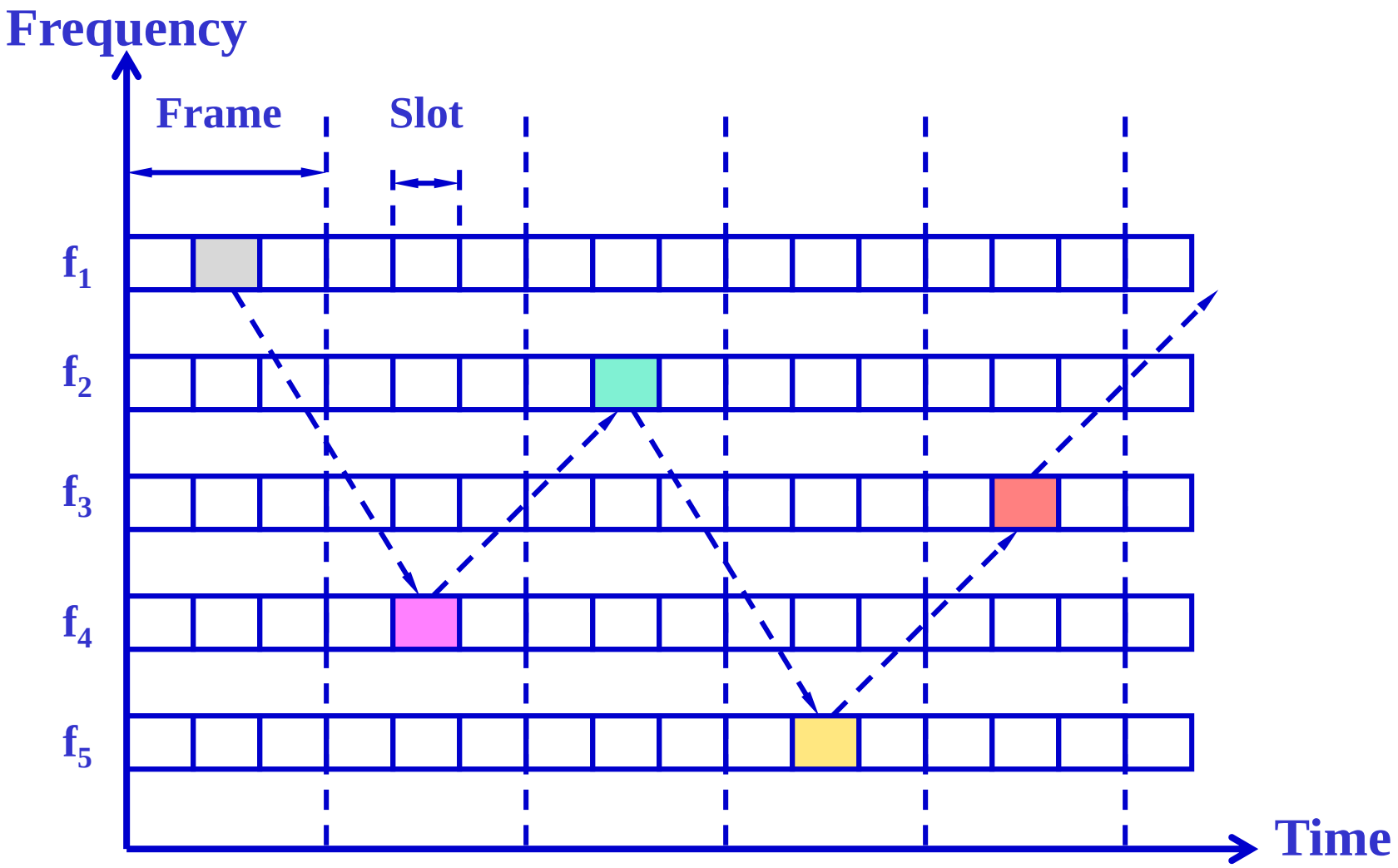
OFDM (Orthogonal Frequency Division Multiplexing)



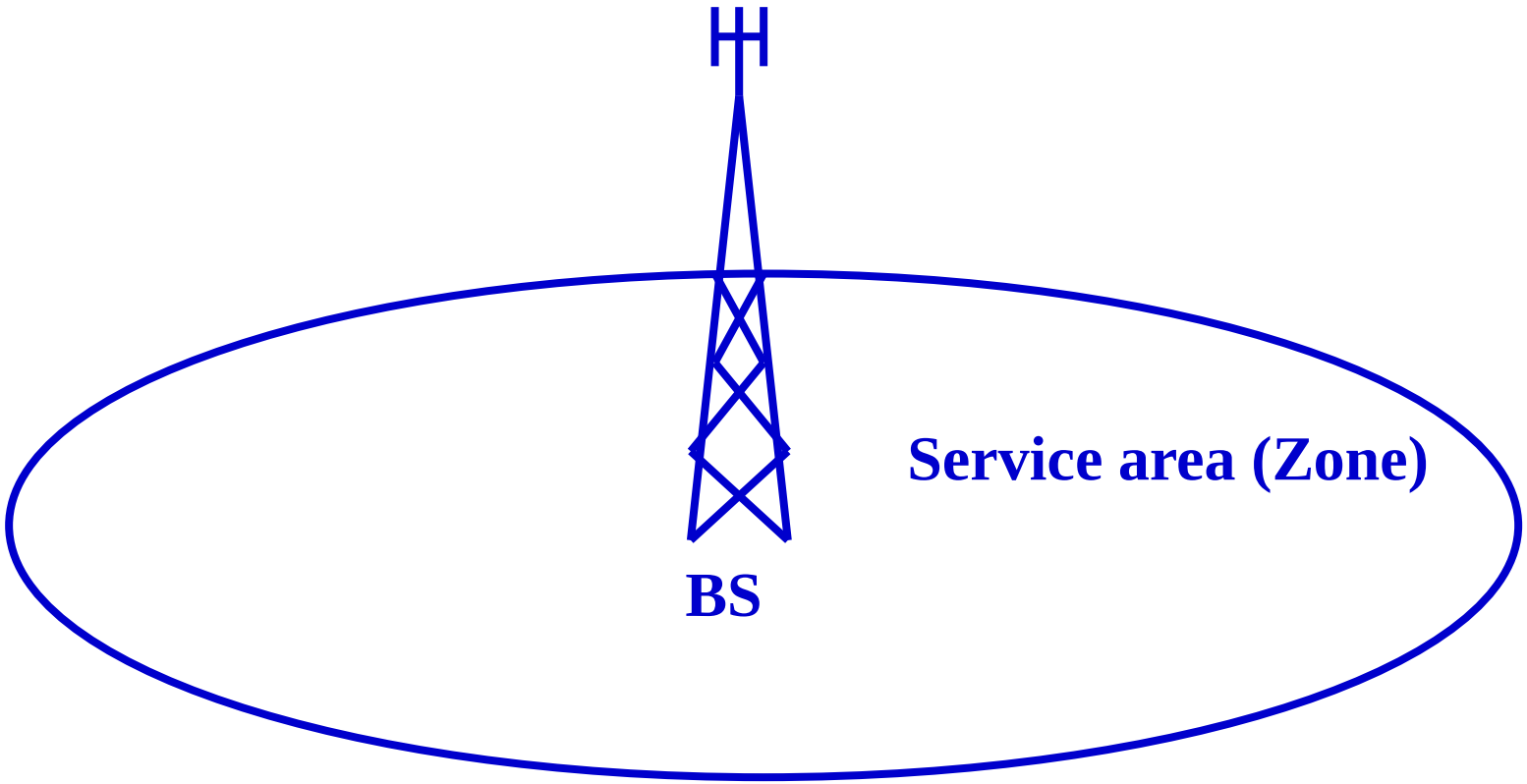
Conventional multicarrier modulation used in FDMA

Orthogonal multicarrier modulation used in OFDM

Frequency Hopping

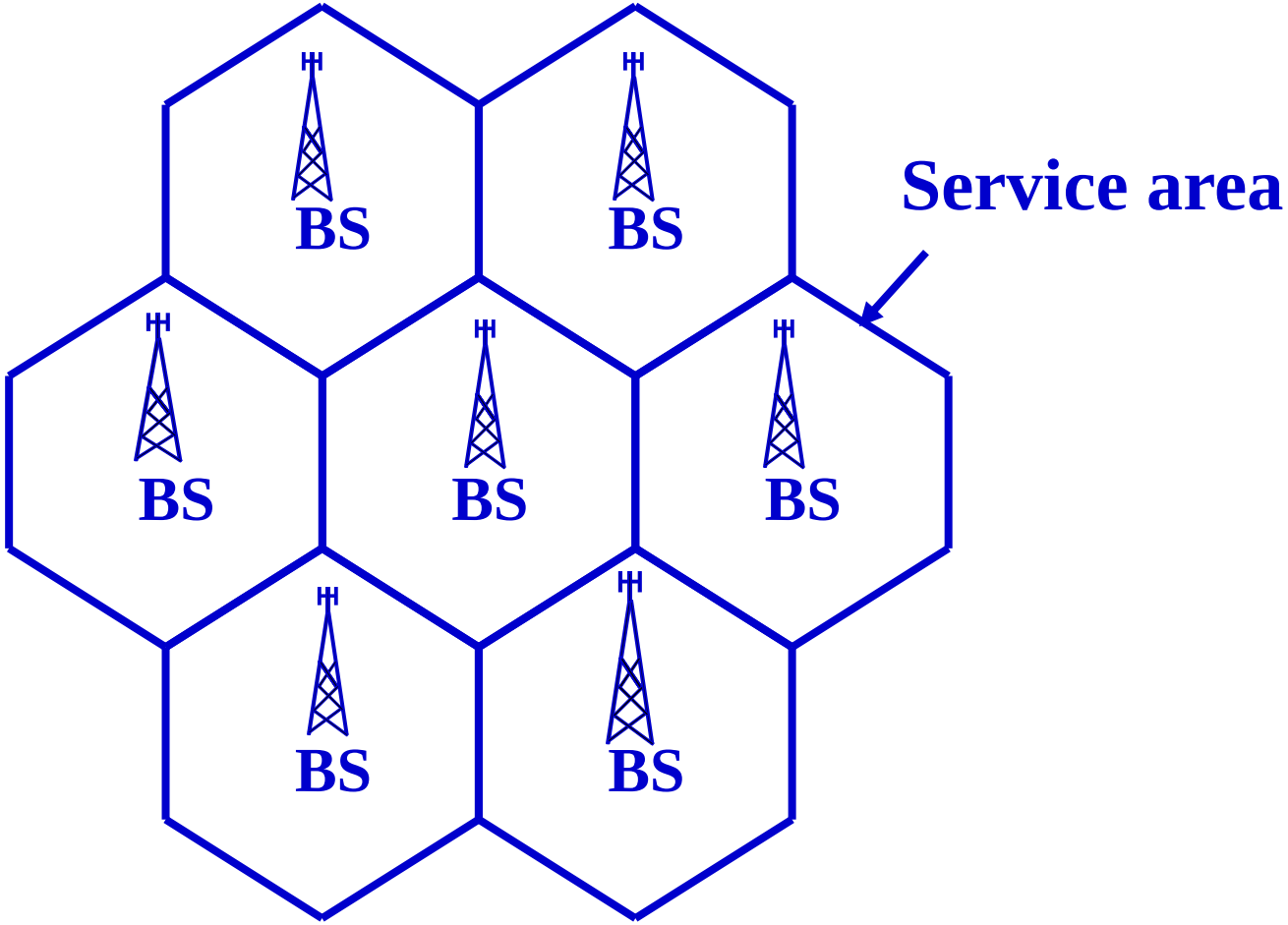


Cellular System Infrastructure

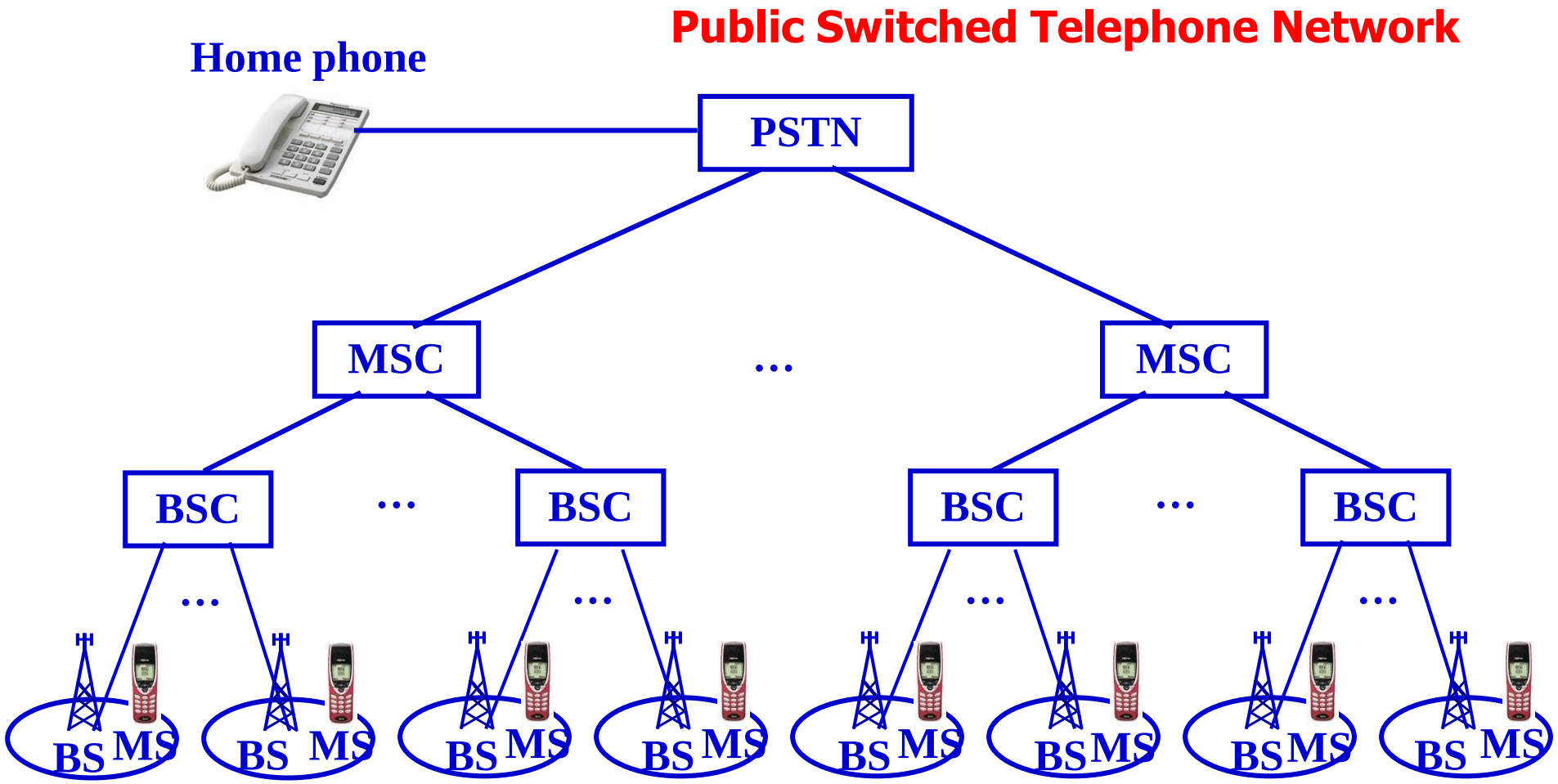


Early wireless system: *Large zone*

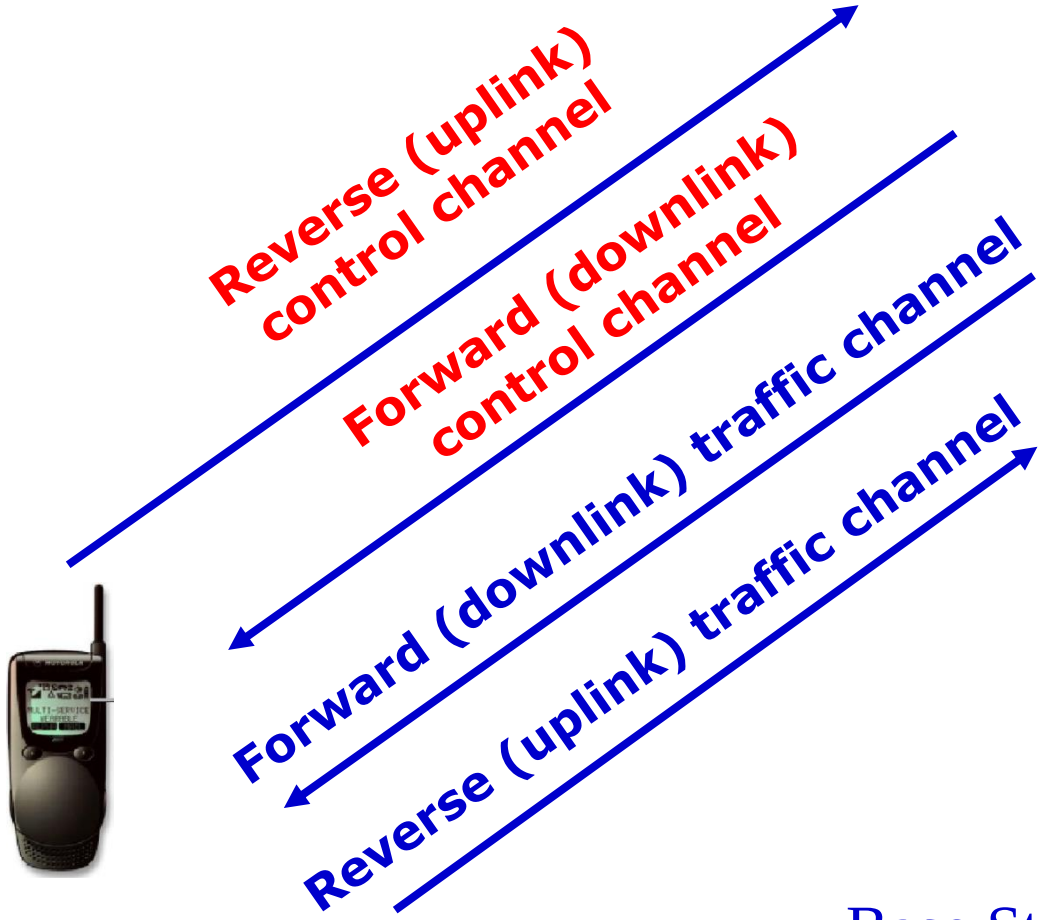
Cellular System: Small Zone



MS, BS, BSC, MSC, and PSTN



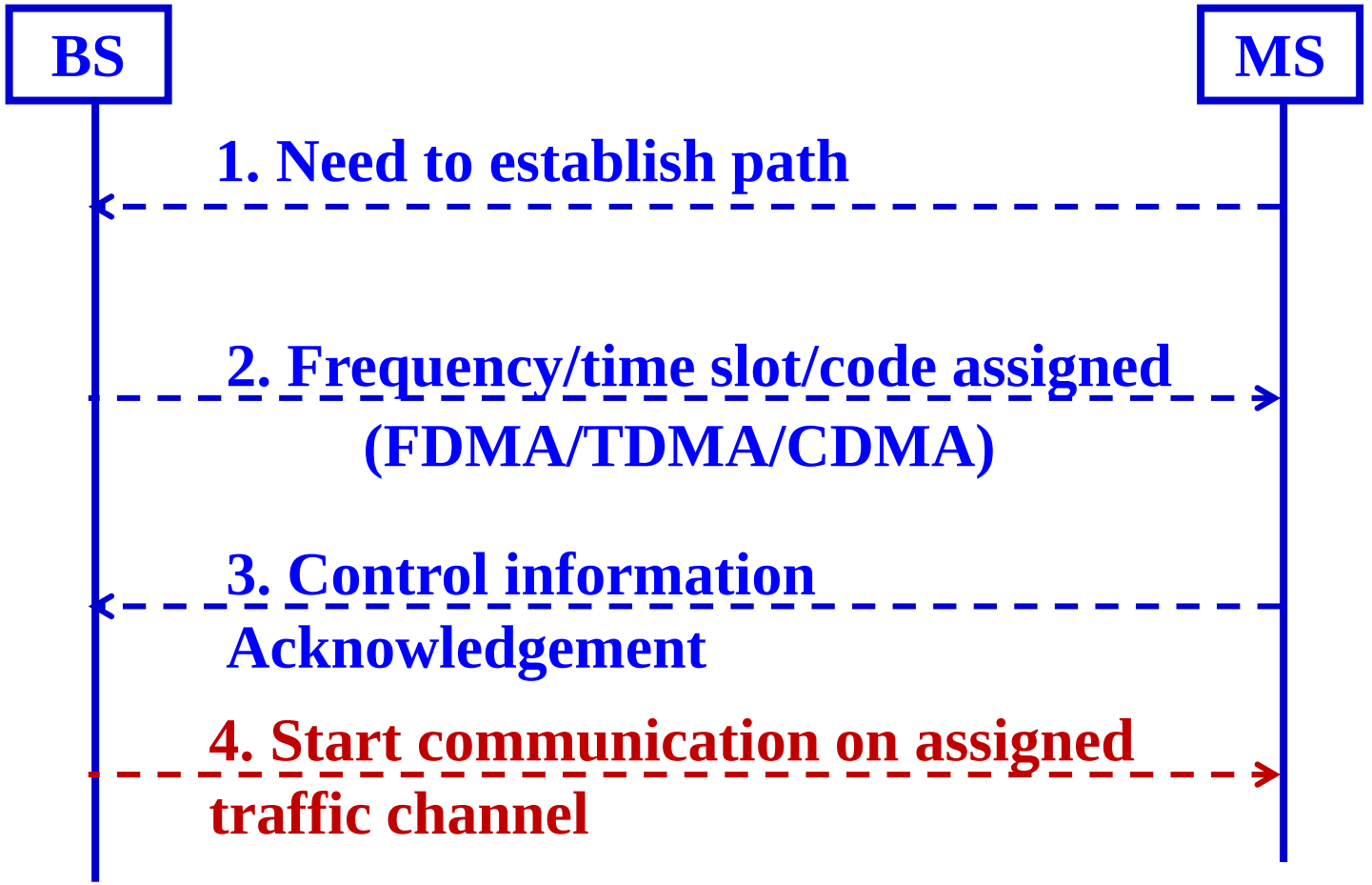
Control and Traffic Channels



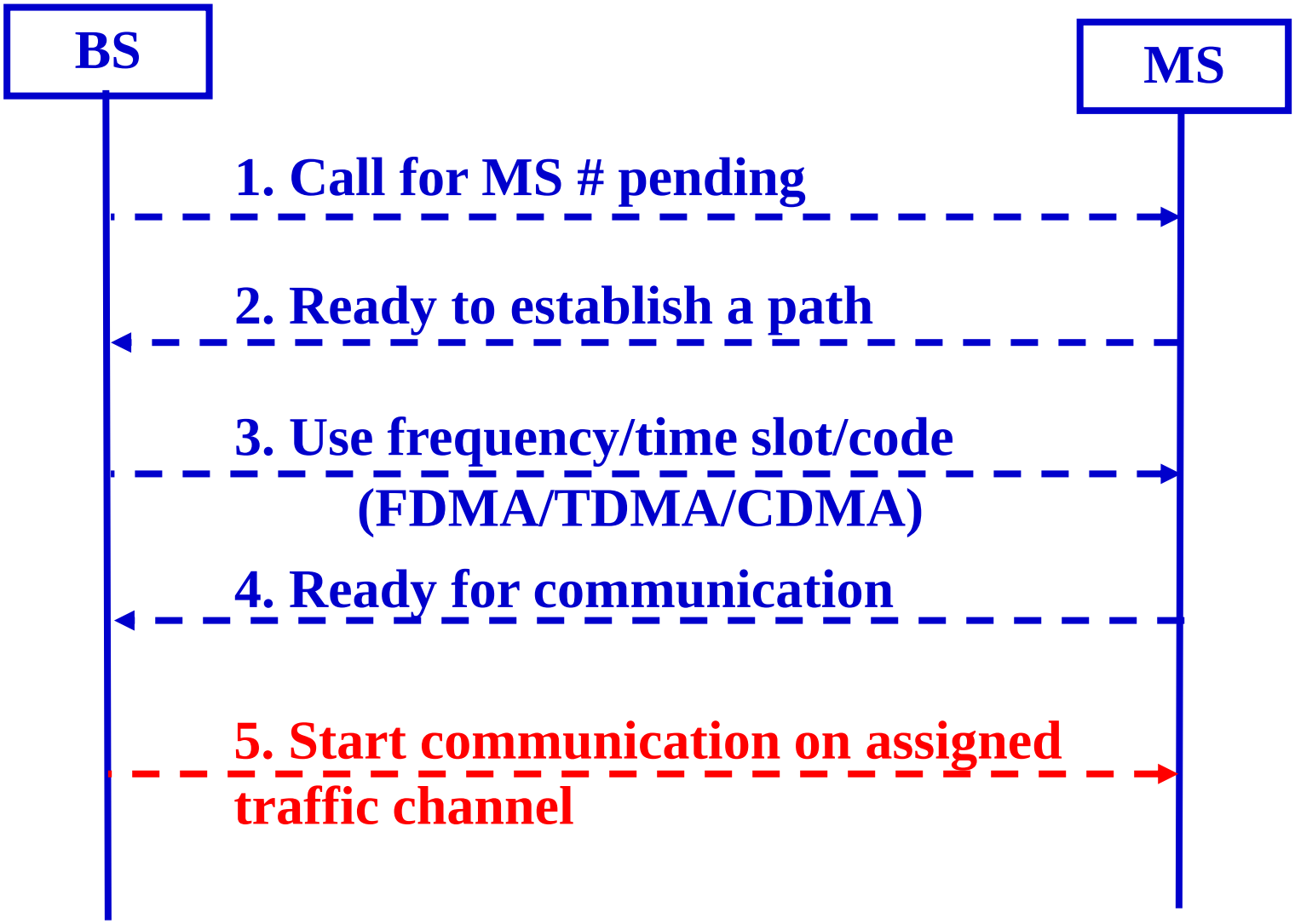
Mobile Station (MS)

Base Station (BS)

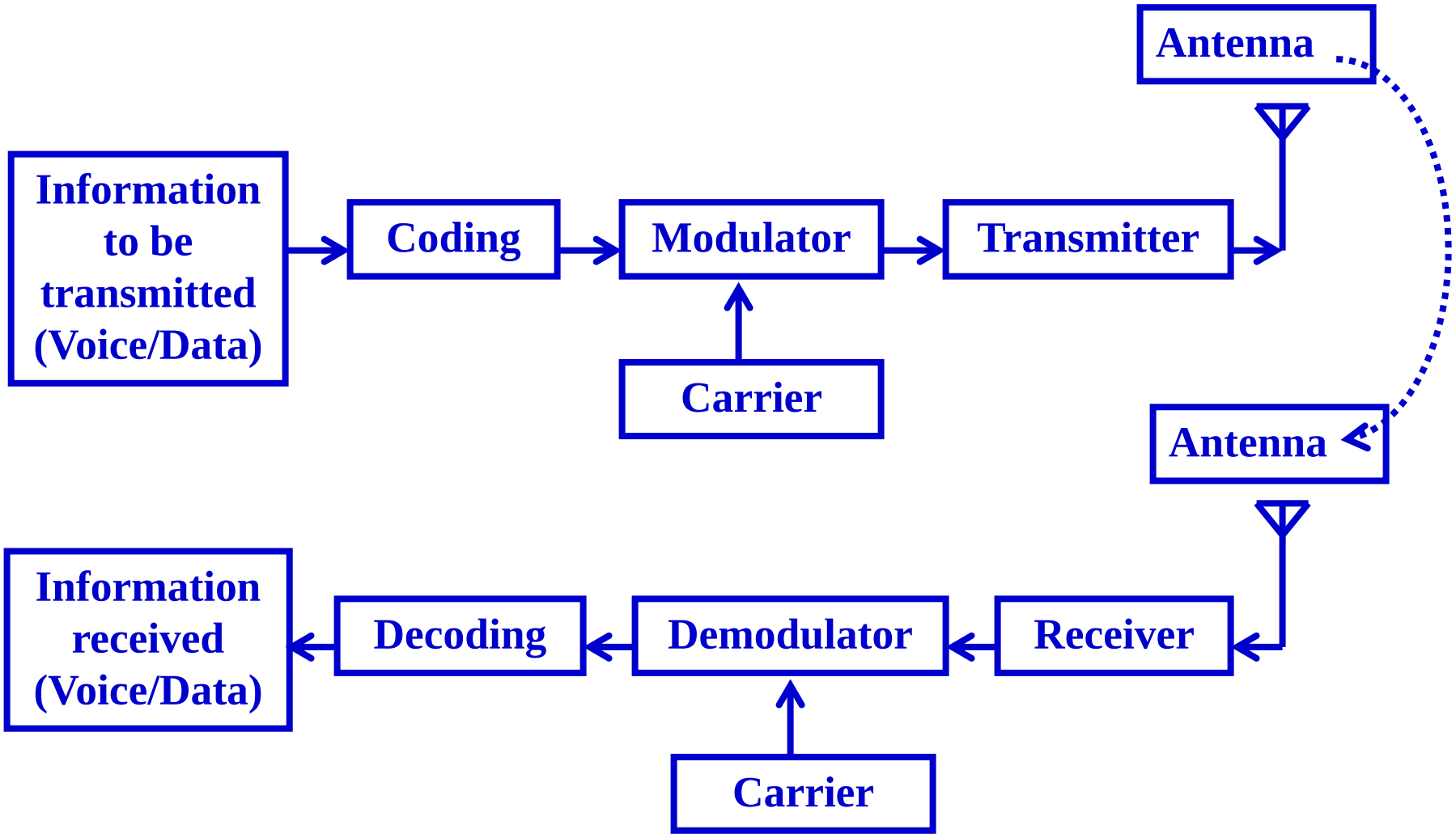
Call Setup from MS (Cell Phone) to BS?



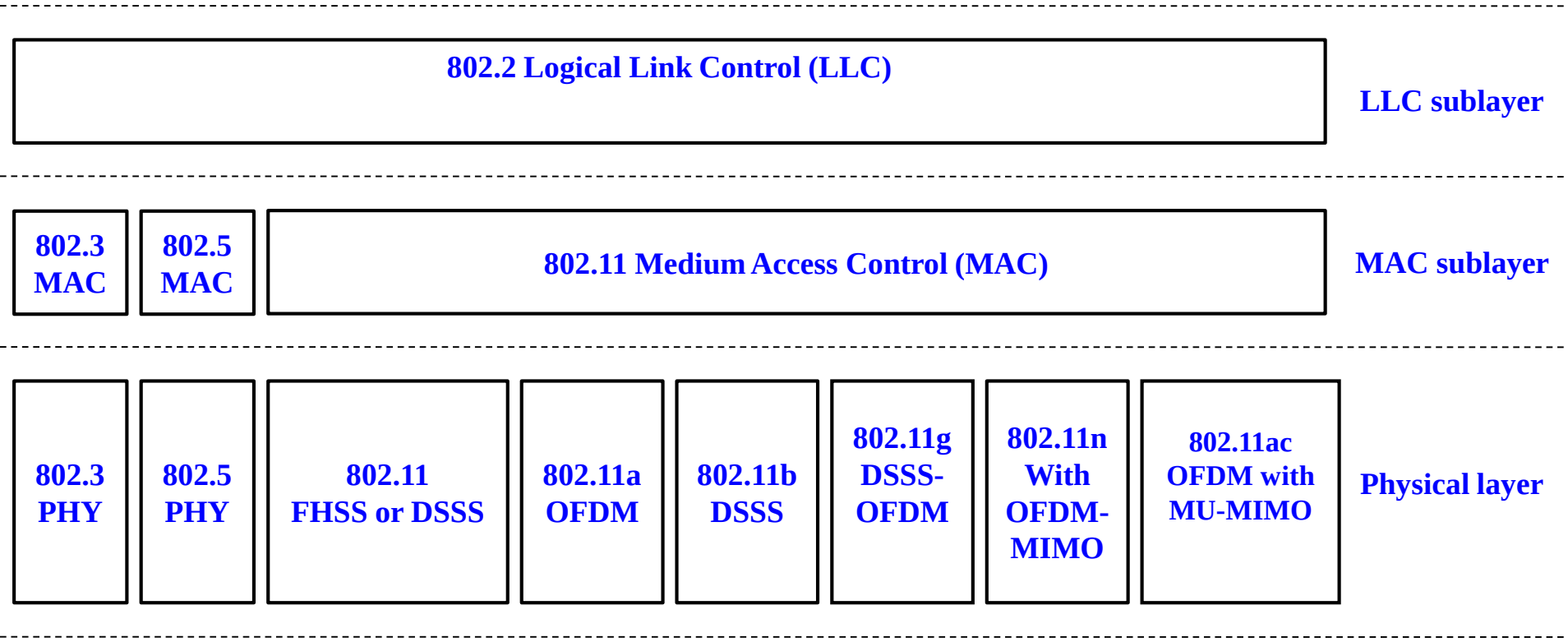
Steps for A Call Setup from BS to MS



A Simplified Wireless Communications System Representation



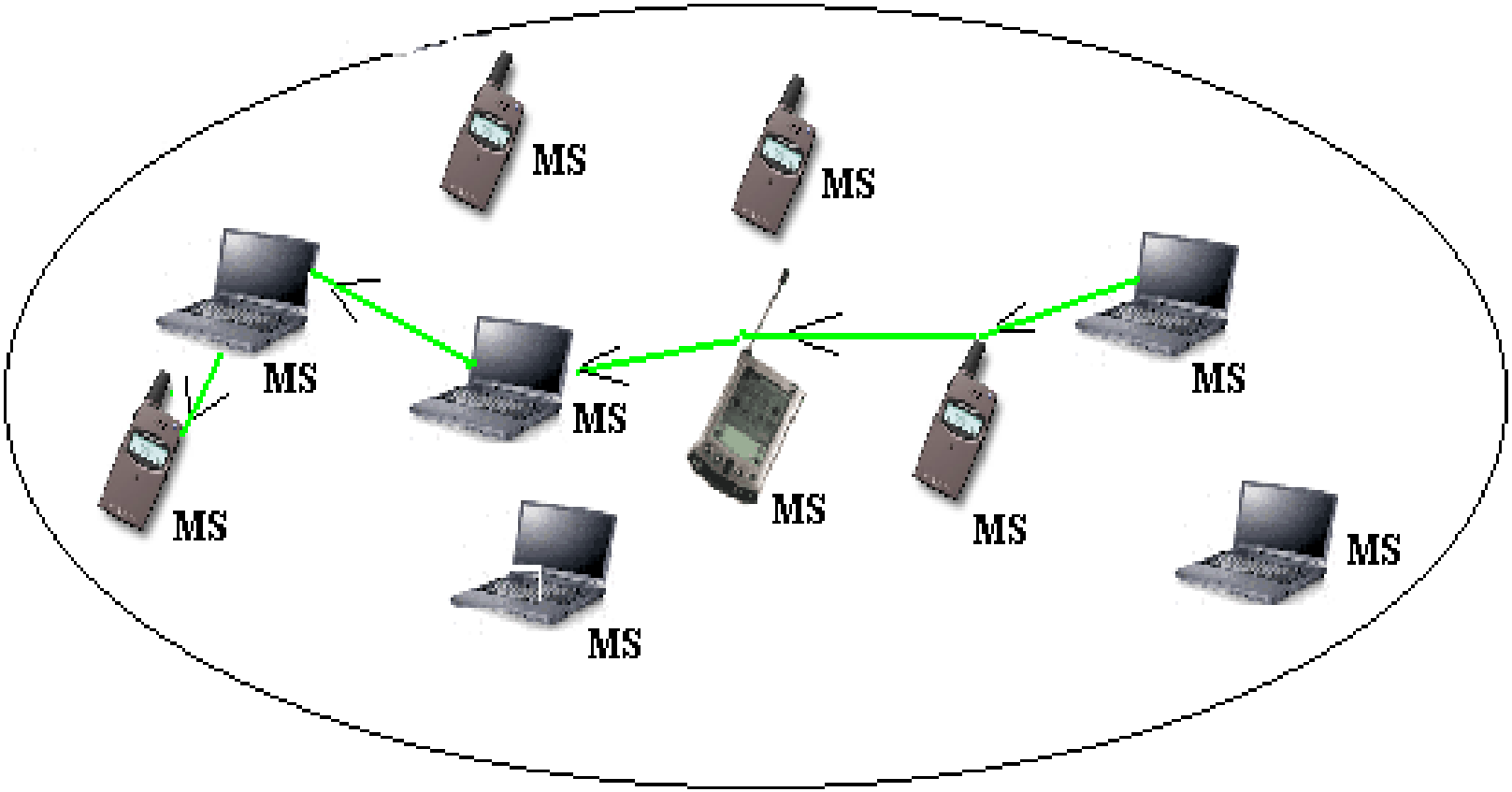
IEEE 802 Series Protocol Stack



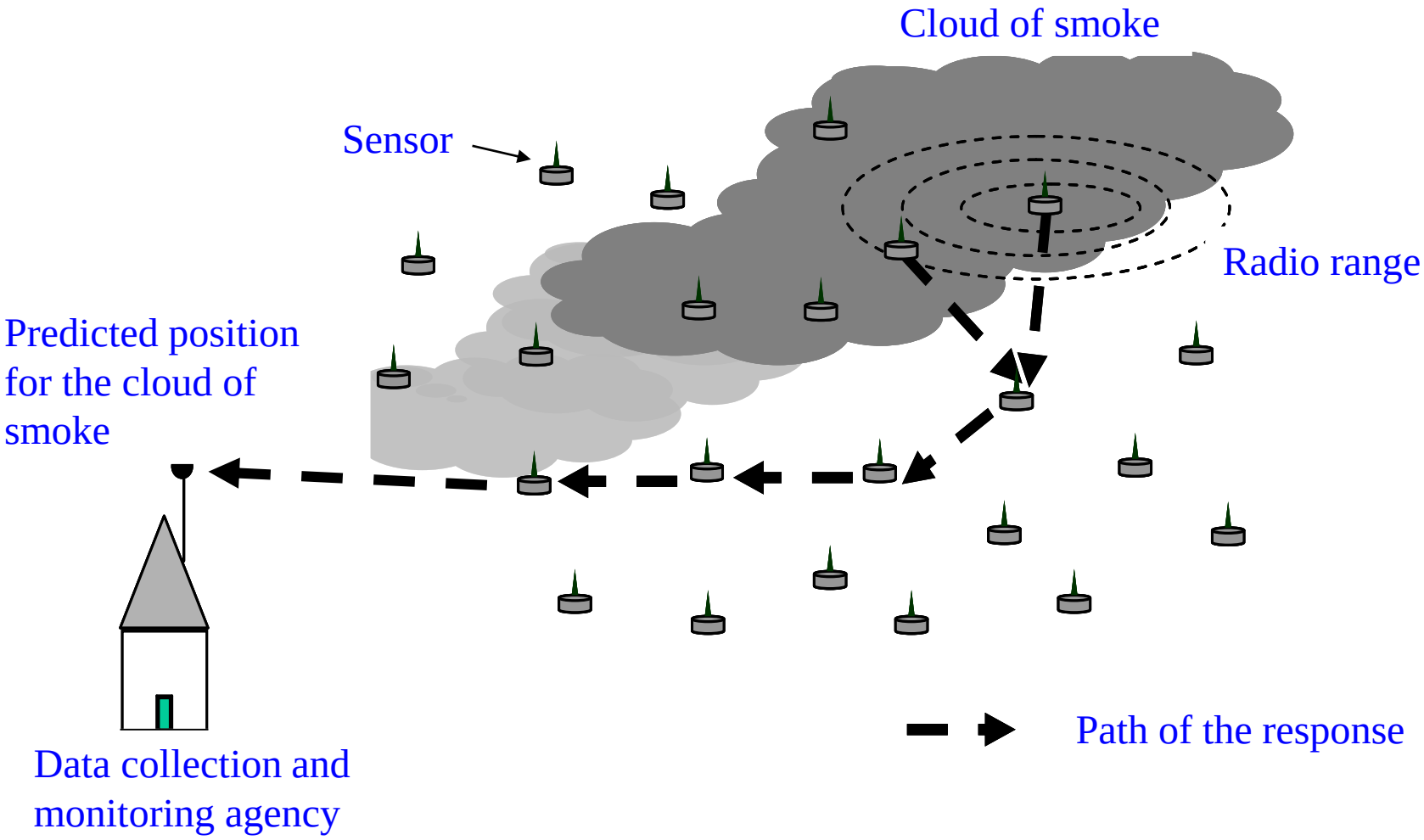
Network Architectures and Protocols

- **Protocol: Systematic Signaling Steps for Information Exchange**
- **Open Systems Interconnections (OSI)**
- **Transmission Control Protocol (TCP)**
- **Internet Protocol (IP)**
  - **Internet Protocol Version 4 (IPv4)**
  - **Internet Protocol Version 6 (IPv6) – Work in progress**
  - **Mobile IP**

Ad Hoc Networks



Wireless Sensor Networks



Wireless LAN, PAN, BAN, and MAN

- Wireless Local Area Network (LAN)
  - Using the IEEE 802.11 a/b/g/n/ac etc.
- Wireless Personal Area Network (PAN)
  - Bluetooth
- Wireless Body Area Network (BAN)
- Wireless Metropolitan Area Network (WMAN)
  - Using WiMAX
  - Using mesh network
  - Using 3G and 4G
  - LoRa, SigFox, NB-IOT

Exercises

- P1.3, P1. 10, P1.15, P. 16, P1.17 (Practice at home)
- Report: What are the differences between 4 G and 5G.