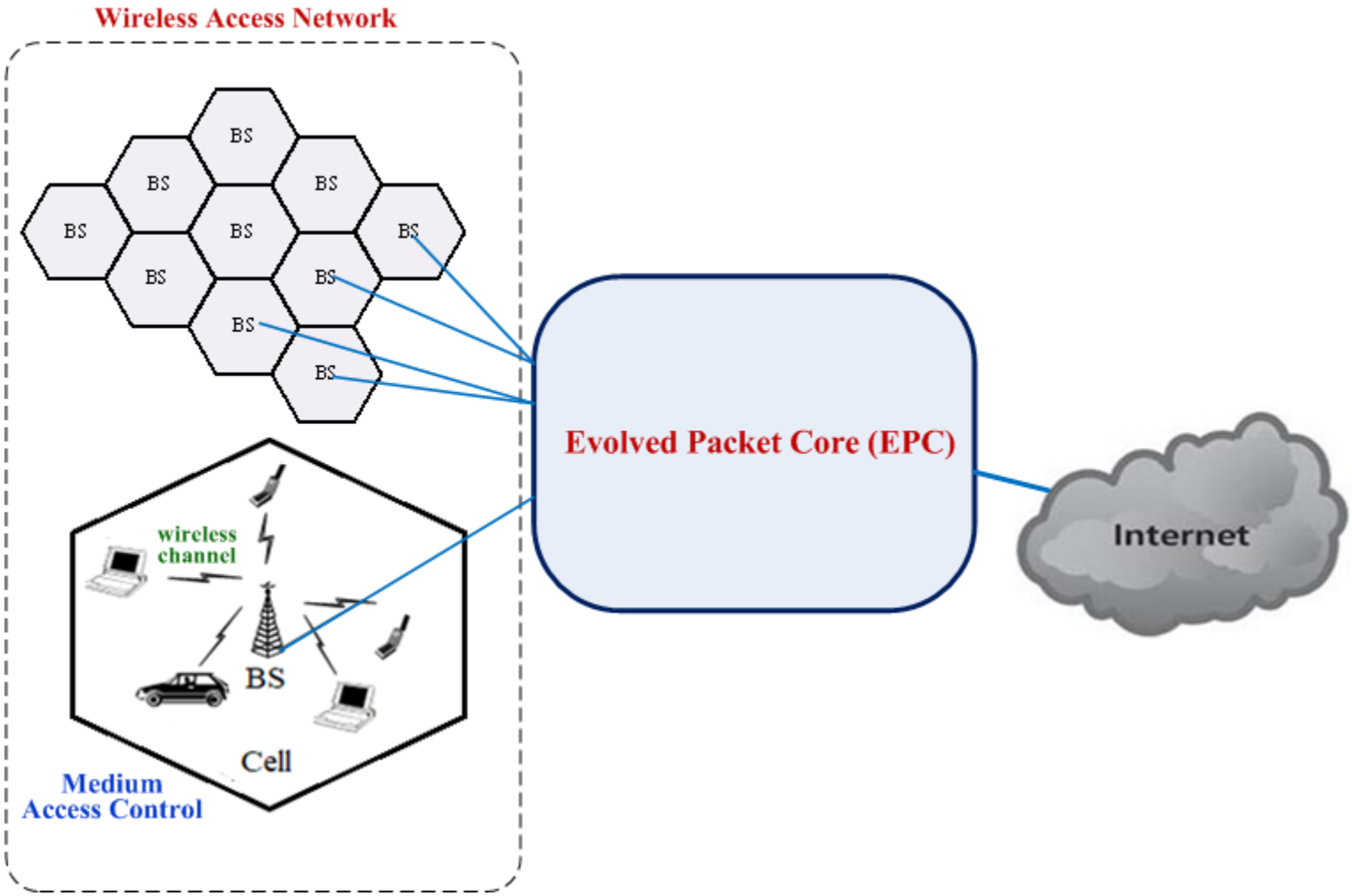
Cellular Networks

Fall 2021

전화숙

Cellular Networks



Introduction (1)

- Wireless Network
  - Flexible user interface
- Mobile Network
  - User mobility support with portable devices
- Wireless Channel
  - Medium: radio/infrared
  - Radio propagation
    - shadowing, multipath, pathloss
  - Time-varying channel

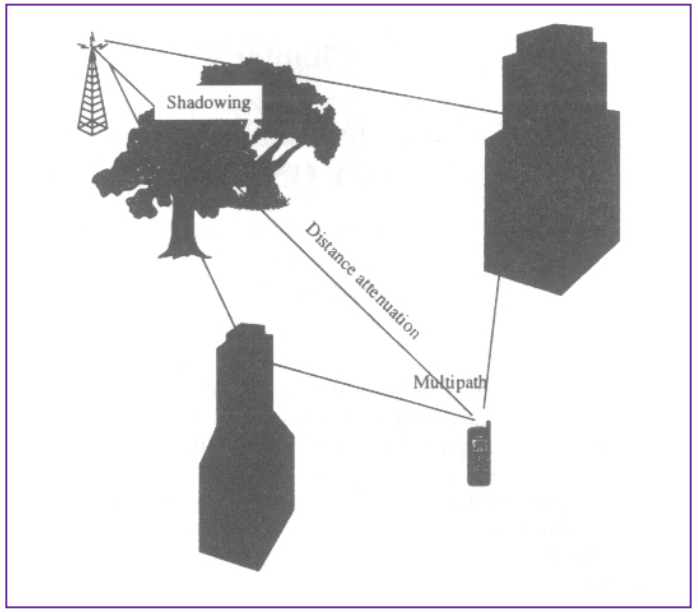
  $\Rightarrow$ Hostile transmission environment

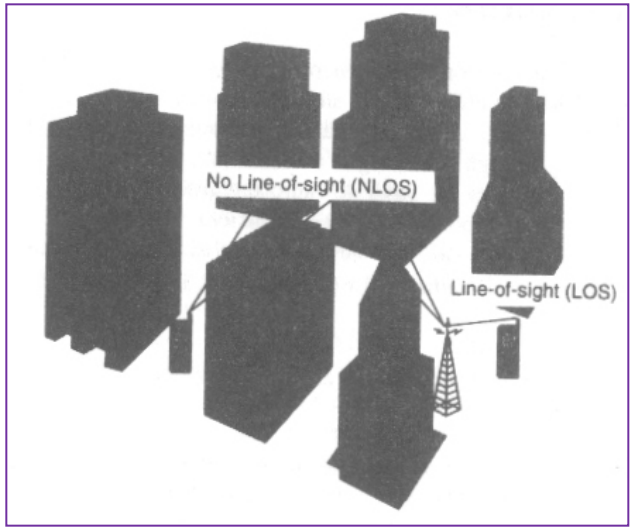
Introduction (2)

- Radio frequency
  - Scare resource
  - Time-varying channel → dynamic channel capacity
  - should utilize very efficiently
    → cellular system, multiple access, radio resource management
- Cellular system
  - Spectrum reuse
  - Sectored cell, relay-assisted cell
  - Heterogeneous system: macrocell, femtocell
- Multiple access scheme
  - Efficient resource sharing among users in a cell
  - FDMA, TDMA, CDMA, OFDMA

Radio channel

- Signal Fading
  - large-scale path loss component
  - medium-scale slow varying component (shadowing)
    - log-normal distribution
  - small-scale fast varying component (multipath fading)
    - Impulse response (delay profile)
    - LOS (lone-of-sight):
    - NLOS (non-LOS)





Path Loss & Shadowing

❖ Path loss

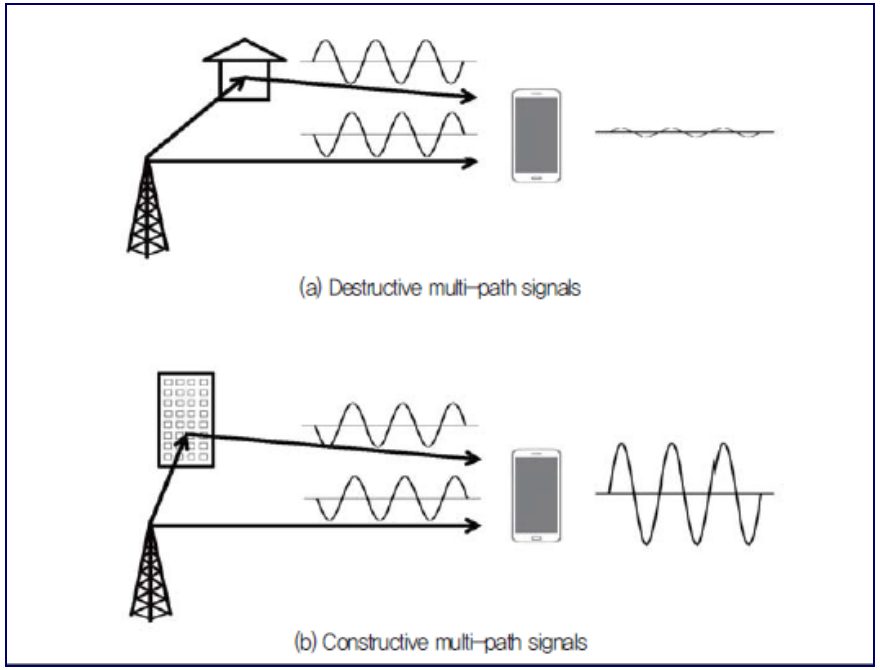
- Caused by dissipation of the power radiated by the transmitter
- Depends on the distance between transmitter and receiver
- $P_r = P_t K d^{-r}$ $(2 \le r \le 5)$
  - P_t : transmit power, P_r : received power
  - d: distance between transmitter and receiver
  - r: path loss exponent, K: constant

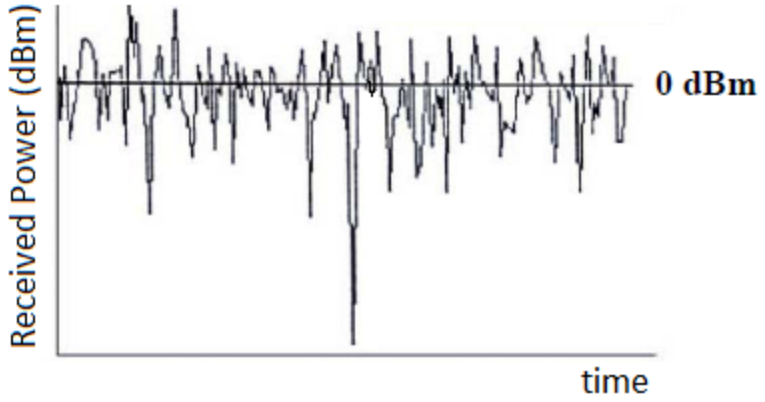
❖ Shadowing

- Caused by obstacles between transmitter and receiver that absorb power

Multipath fading (1)

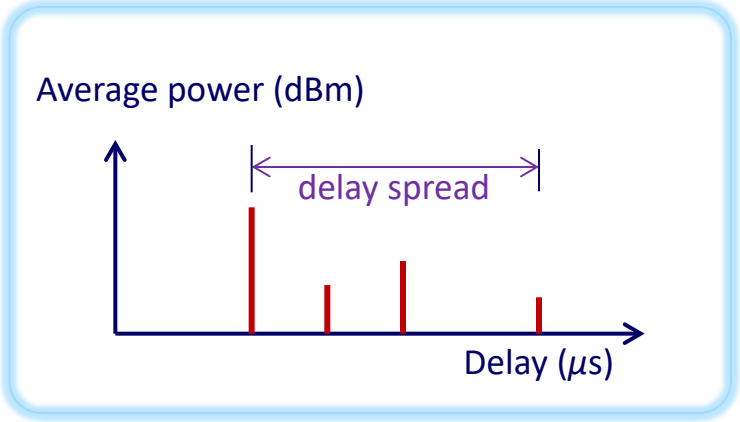
- Short-term fluctuation of the received signal caused by multipath propagation
- when mobile is moving
- fading becomes fast as a mobile moves faster

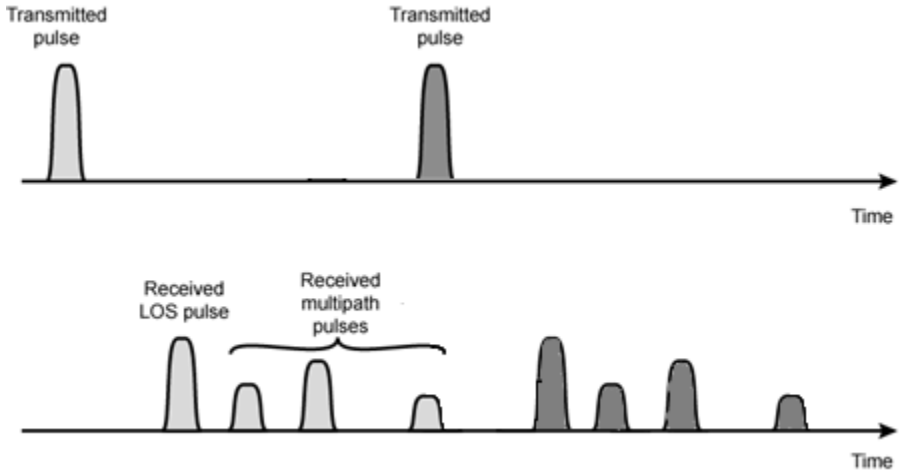




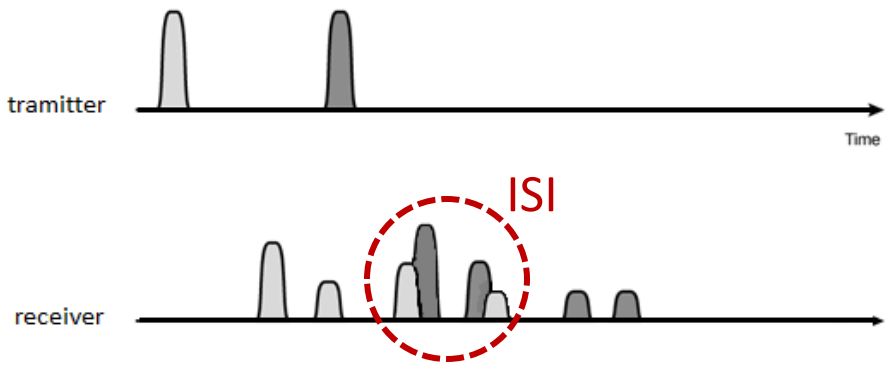
Multipath fading (2)

- Delay-power profile (delay spread)



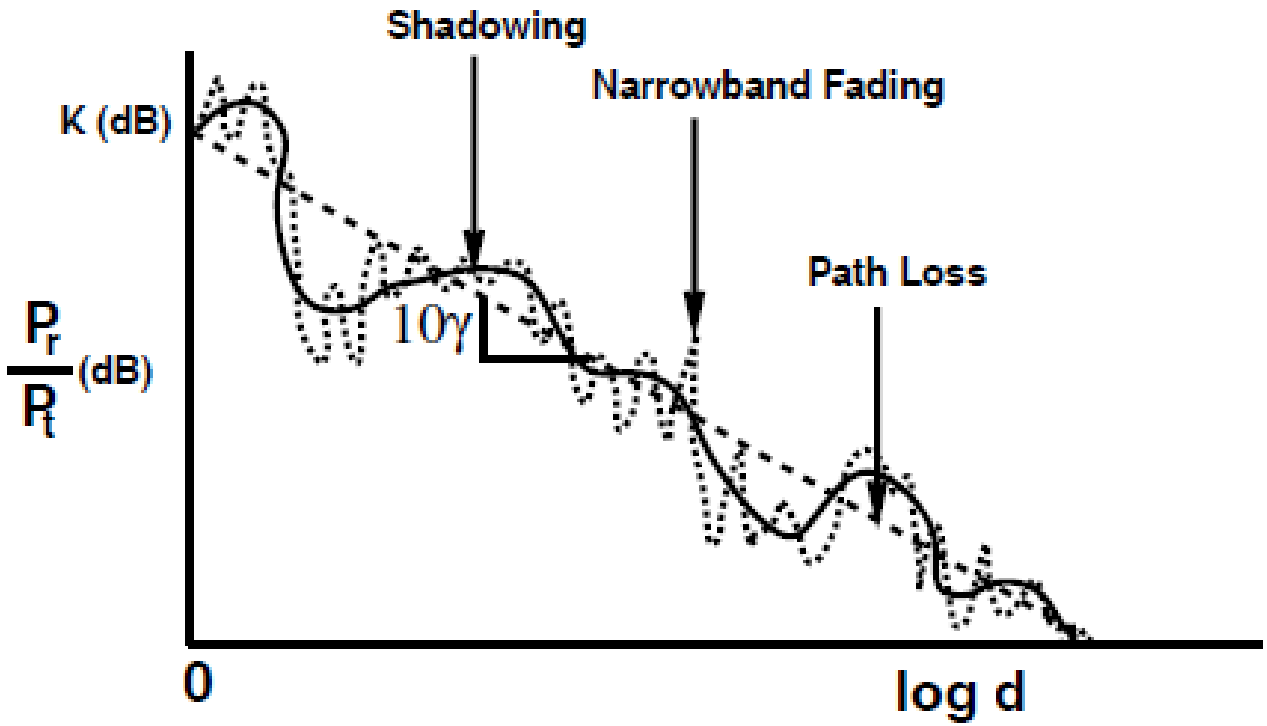


- Inter Symbol Interference (ISI)



lower symbol rate for avoiding ISI

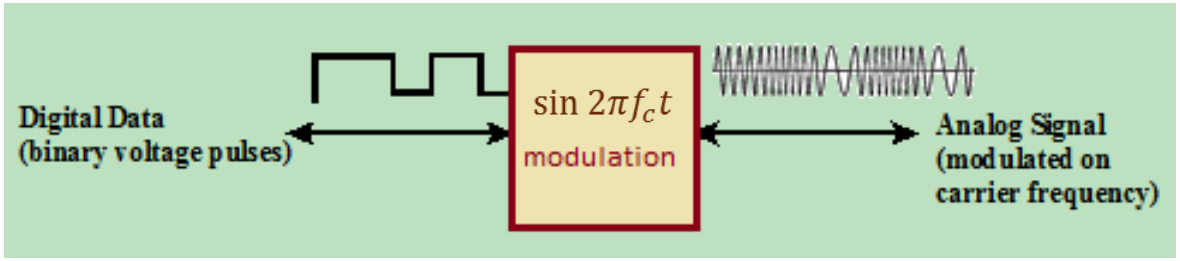
Combined Channel Model



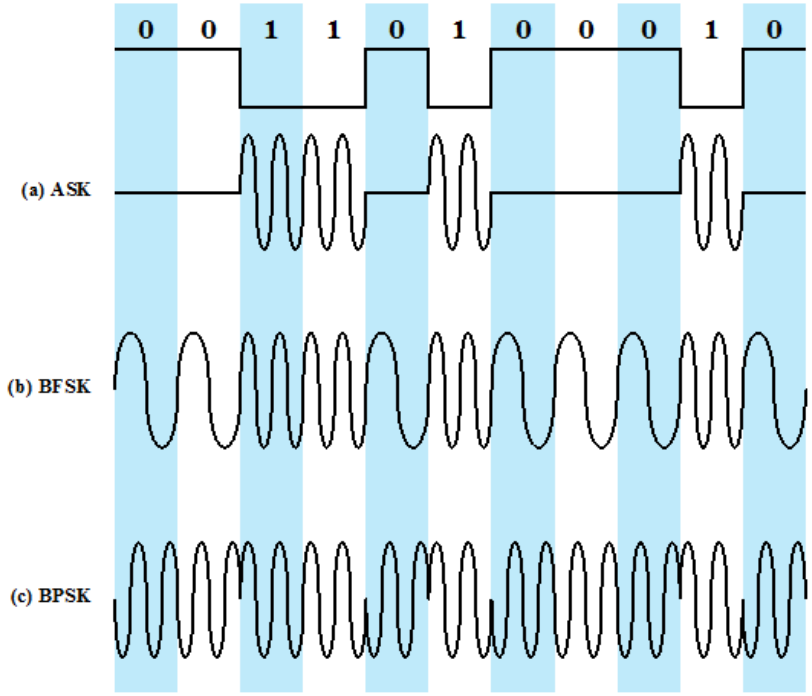
$$P_r = P_t K\, d^{-r} \quad \Rightarrow \quad 10\log\frac{P_r}{P_t} = 10\log K - 10r\log d$$

Data Transmission on Wireless Channel

❖Modulation

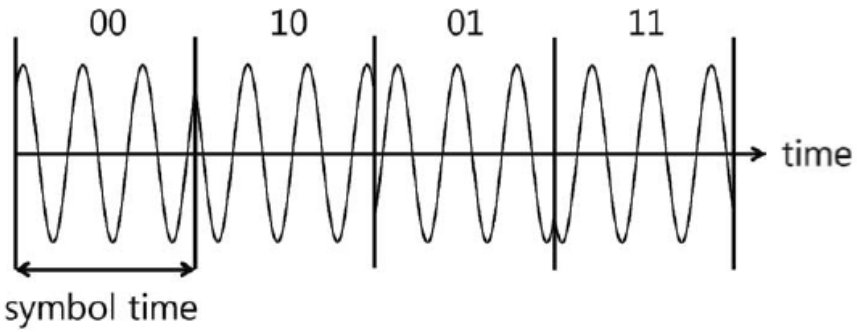


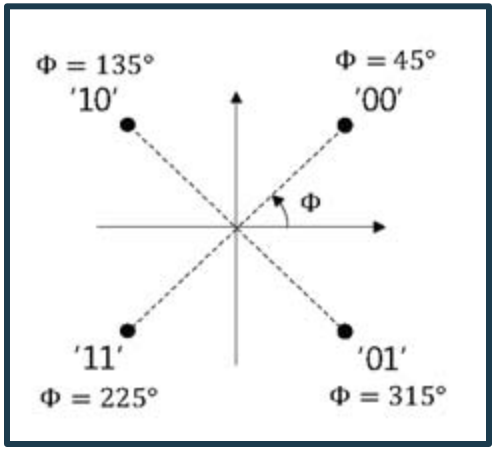
	Binary 0	Binary 1
Amplitude Shift Keying	0	$\sin 2\pi f_c t$
Frequency Shift Keying	$\sin 2\pi f_1 t$	$\sin 2\pi f_2 t$
Phase Shift Keying	$\sin(2\pi f_c t + \pi)$	$\sin 2\pi f_c t$



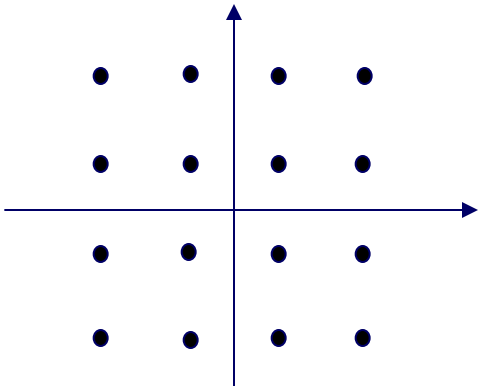
Modulation (1)

- QPSK

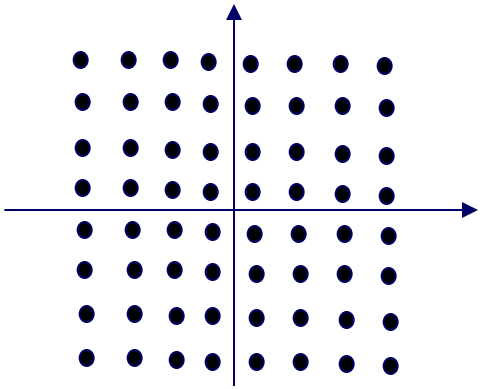




- High Order Modulation



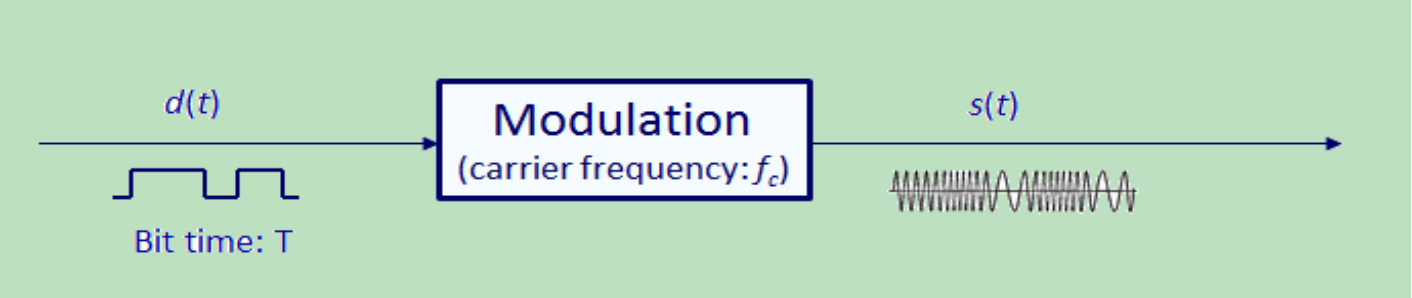
16QAM



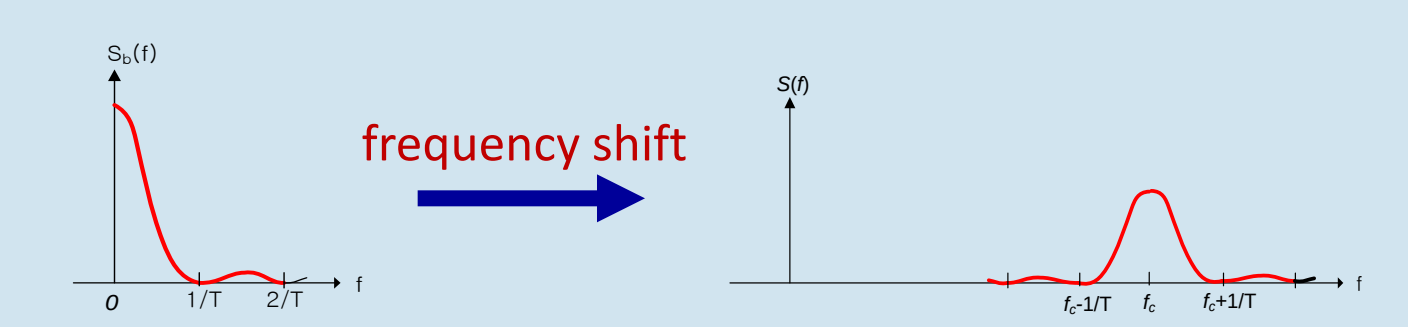
64QAM

Modulation (2)

- Time domain



- Frequency domain



Data rate: $^1/_T$

Data Rate and Bandwidth

- Shannon Capacity
  - a direct relationship between data rate and bandwidth

$$C = B \log_2 (1 + \text{SINR})$$

Maximum rate

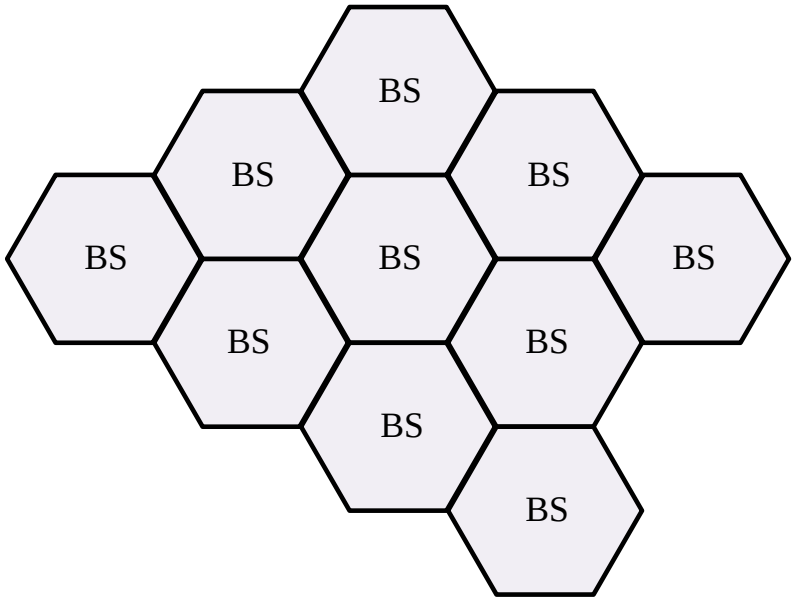
Bandwidth

Ratio of signal power to interference and noise power

Cellular Architecture

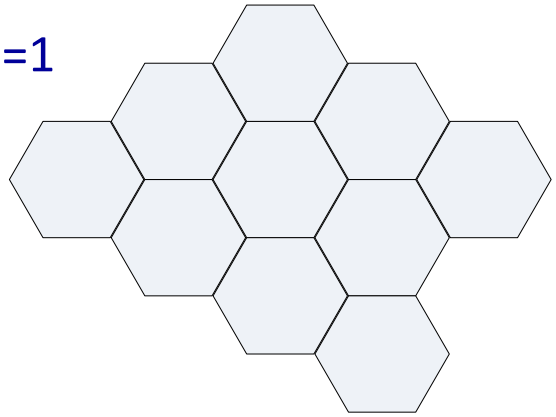
- The service area is divided into several small areas, called cells
- Each cell is served by a base station
- Wider coverage in service area
- Frequency reuse

  => the increased capacity
- Handoff
- Location management

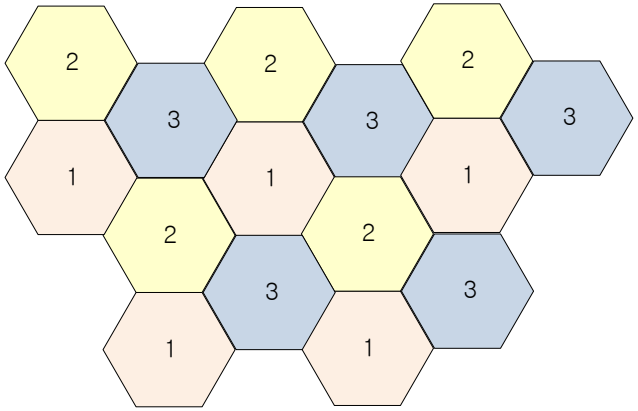


Frequency Reuse Factor

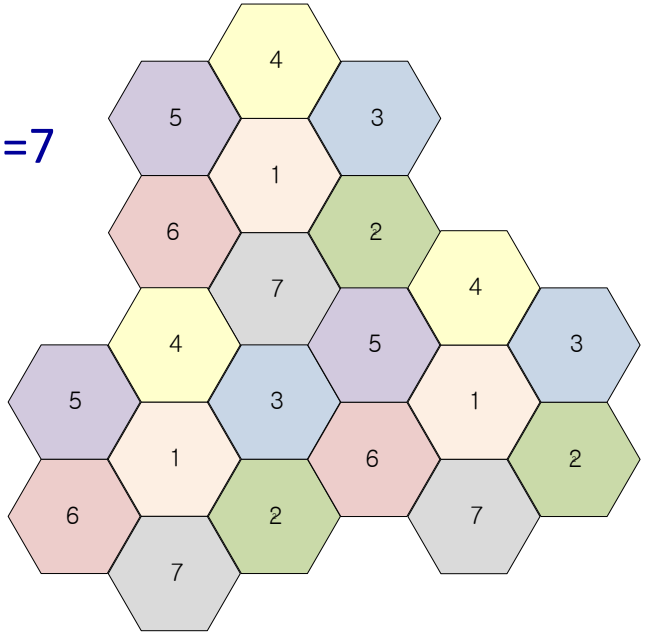
N=1

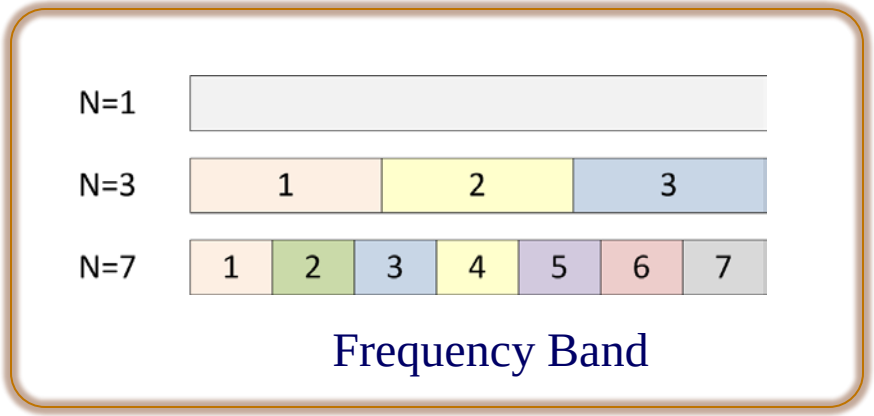


N=3



N=7



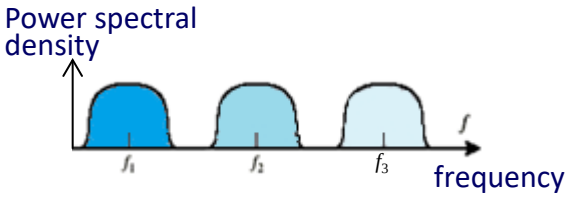


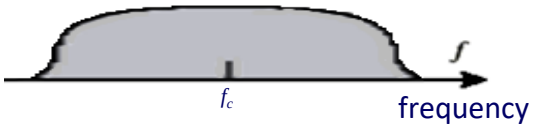
Cellular Networks Generation

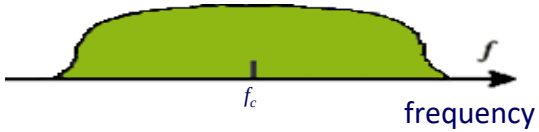
	1G	2G	3G	4G
System	AMPS	GSM, IS-95	WCDMA	LTE, LTE-A
Implementation	1984	1991	2002	2012
Main service	Voice (analog)	Voice (digital)	Packetized data	All IP based
Rate	1.9 kbps	14.4 kbps	2 Mbps	200 Mbps
Multiple Access	FDMA	TDMA, CDMA	CDMA	OFDMA

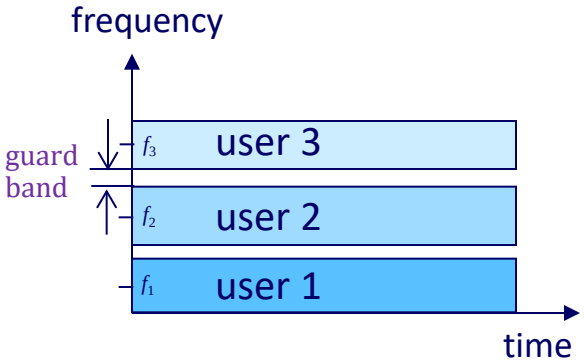
Multiple Access Scheme

- FDMA (frequency division multiple access)
- TDMA (time division multiple access)
- CDMA (code division multiple access)
- OFDMA (orthogonal FDMA)

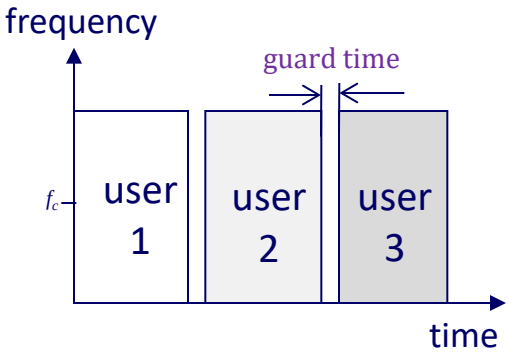




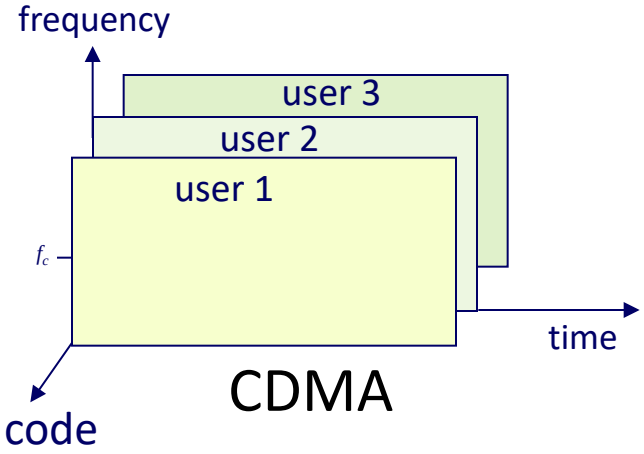




FDMA



TDMA

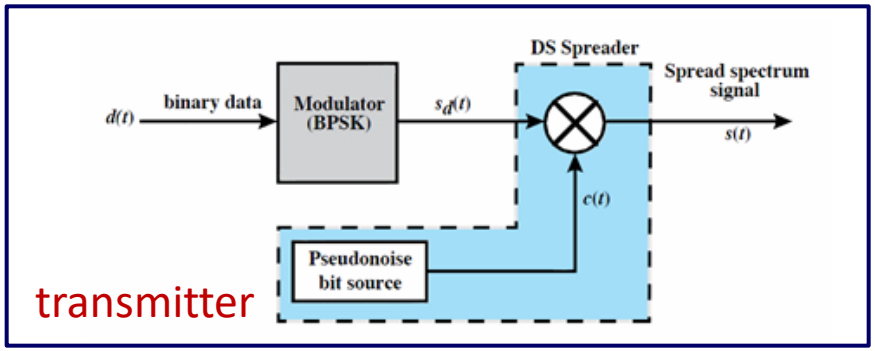


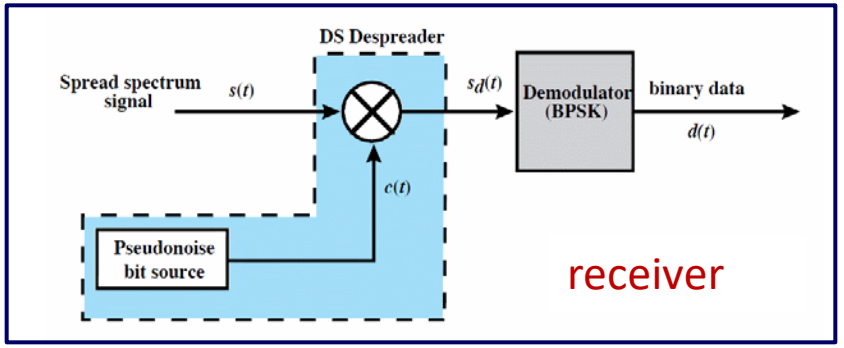
CDMA

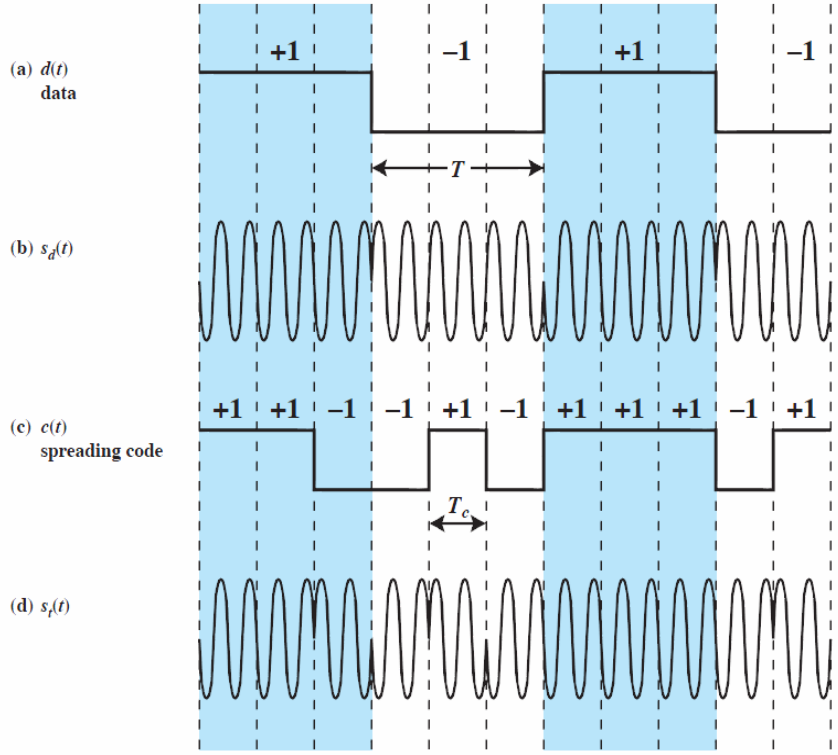
Spread Spectrum

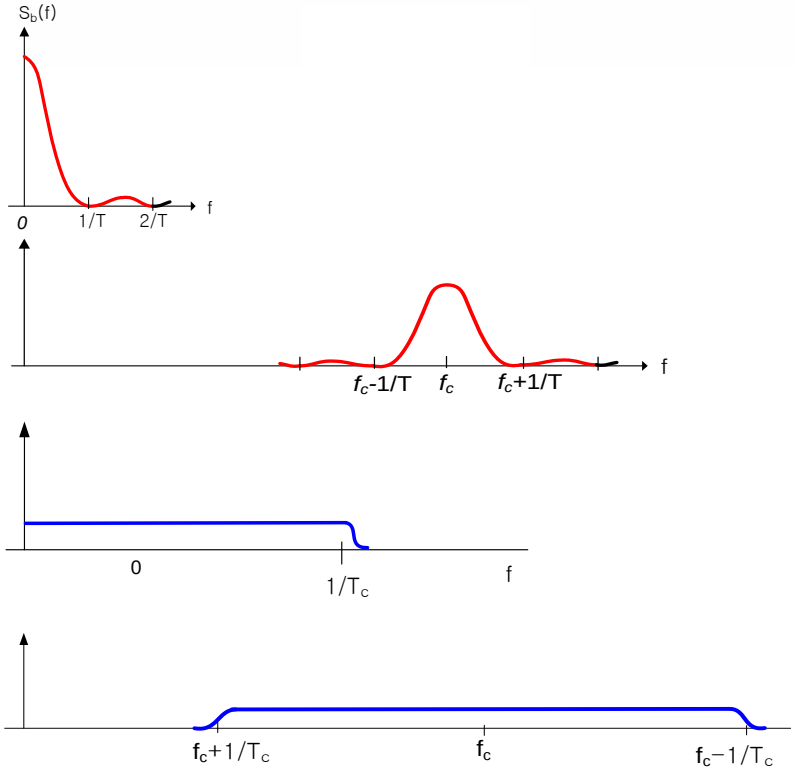
- Developed initially for military application
- Spread the information signal over a wider bandwidth
- Types
  - Frequency hopping (FHSS)
  - Direct sequence (DSSS)

Direct Sequence Spread Spectrum (1)

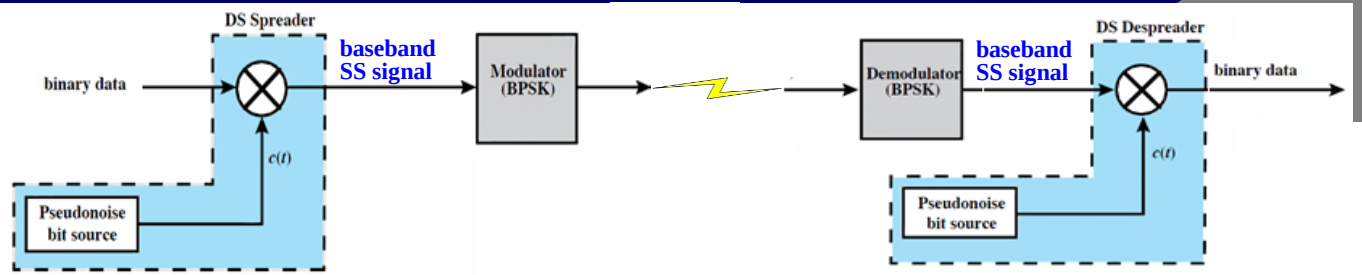




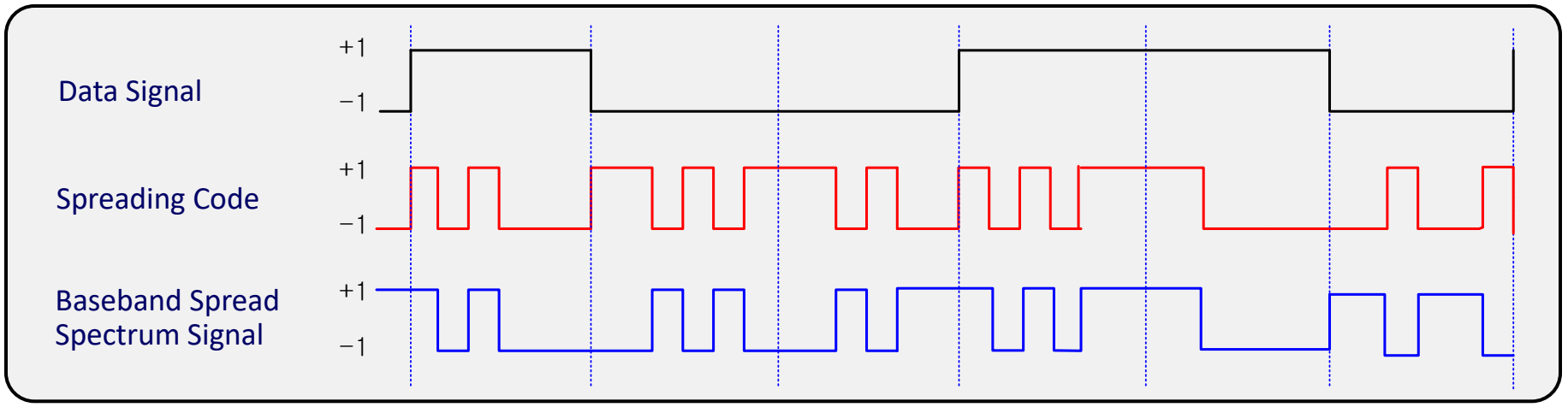




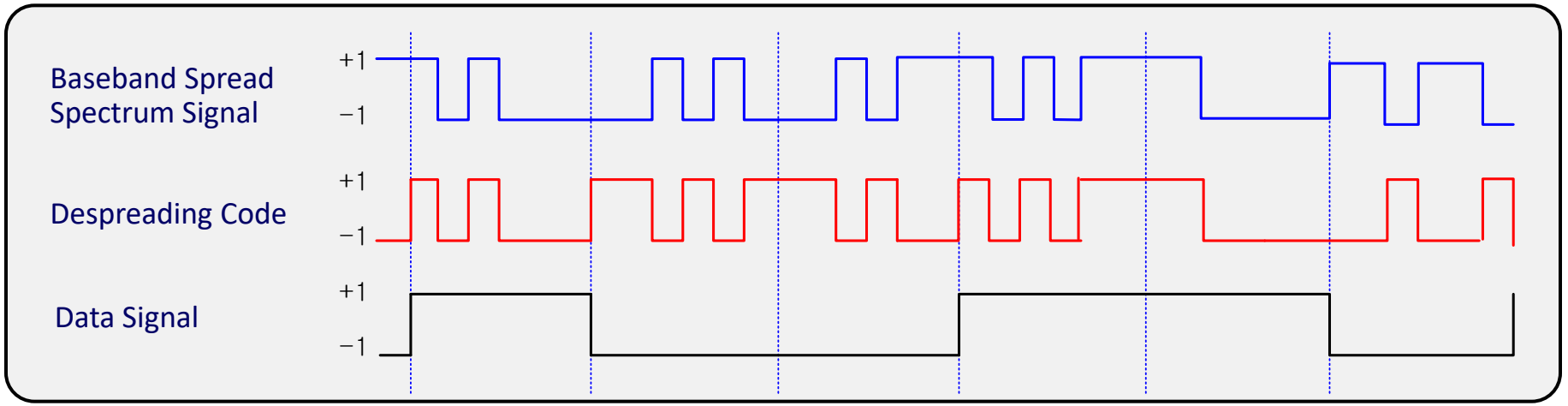
DSSS (2)



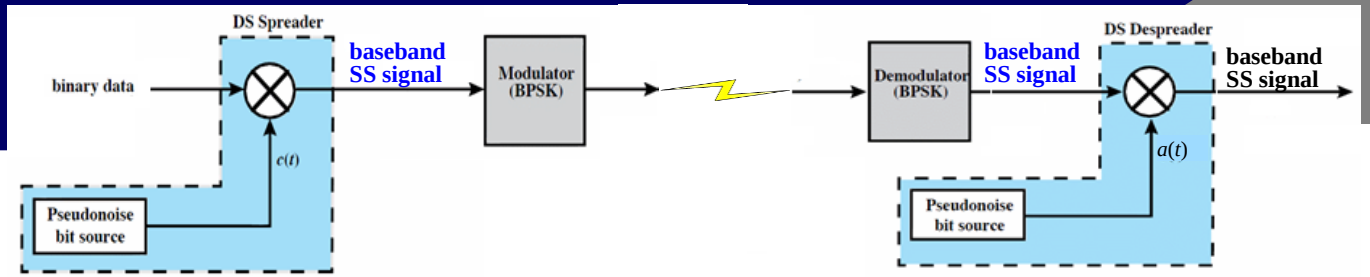
Transmitter 1



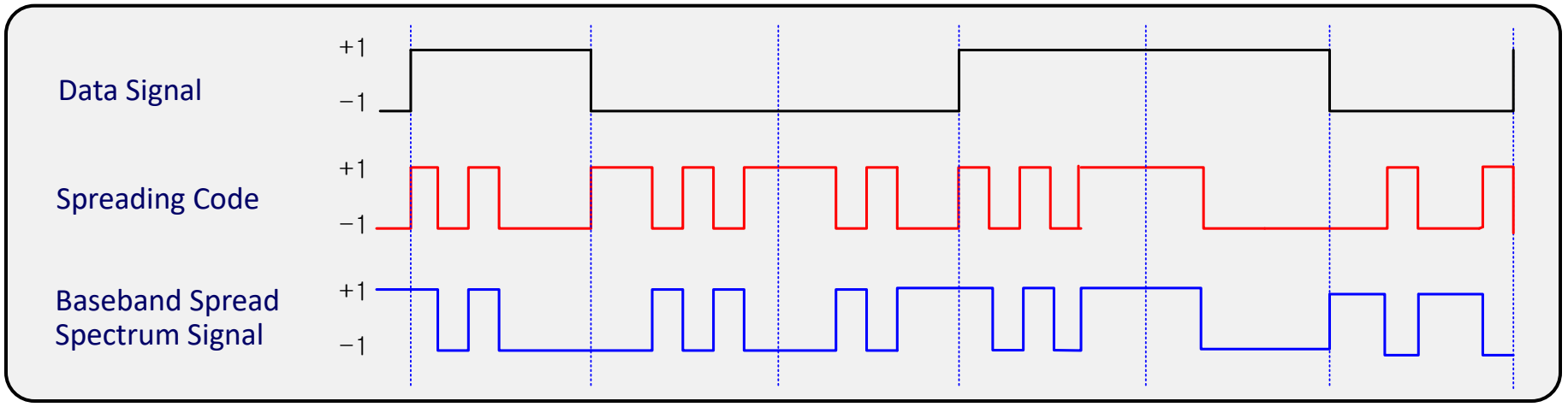
Receiver 1



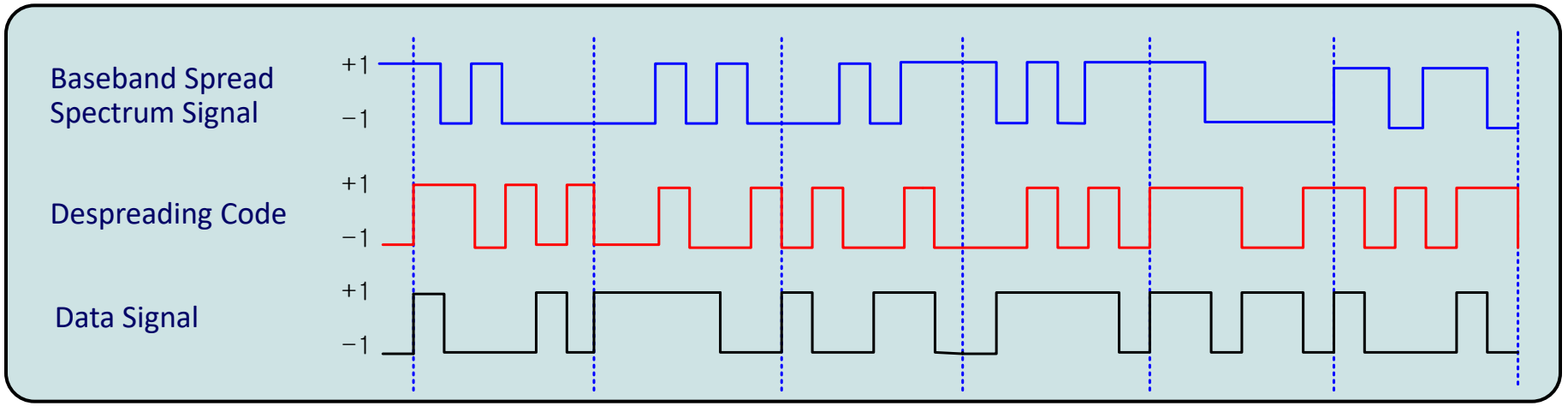
DSSS (3)



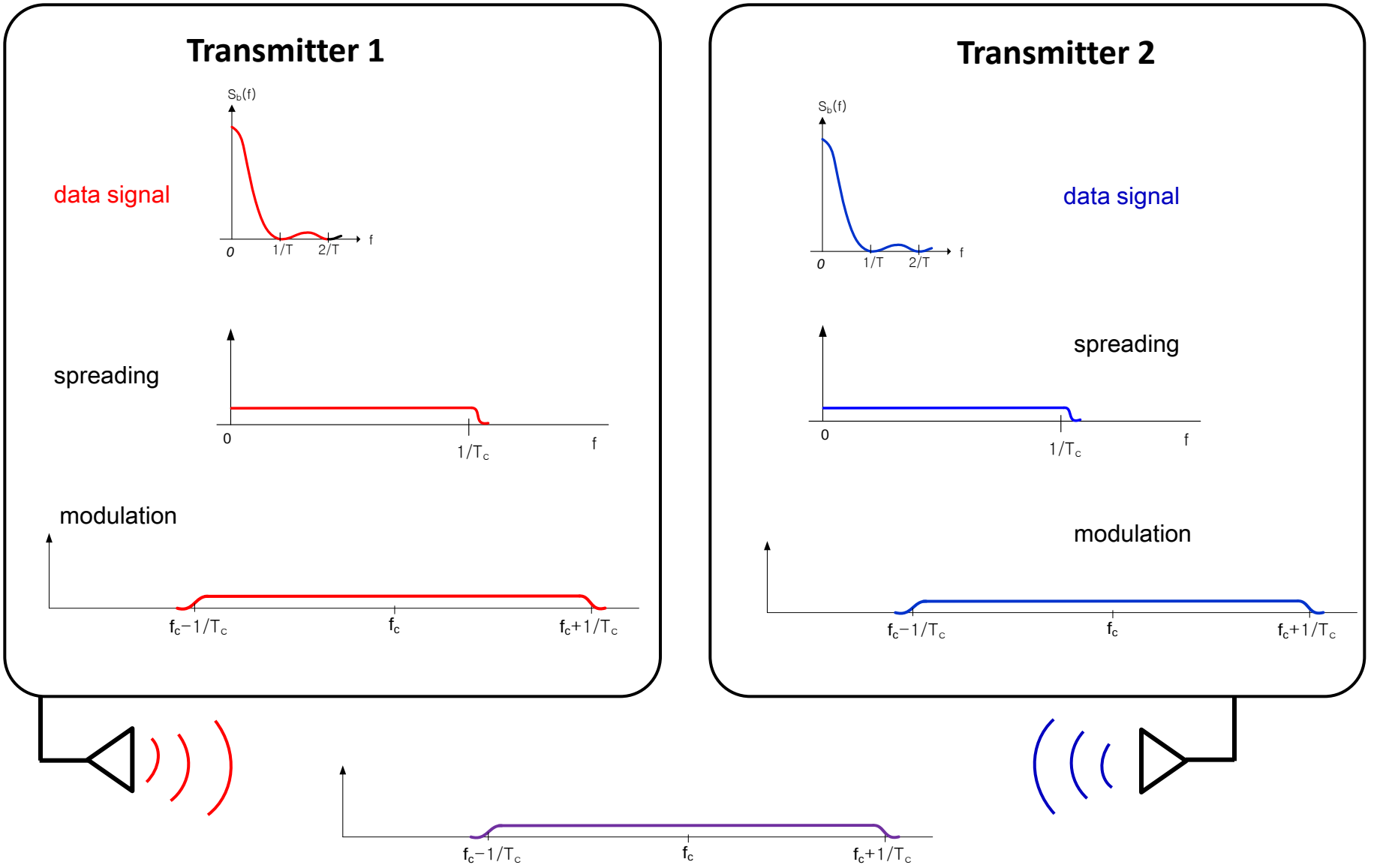
Transmitter 1



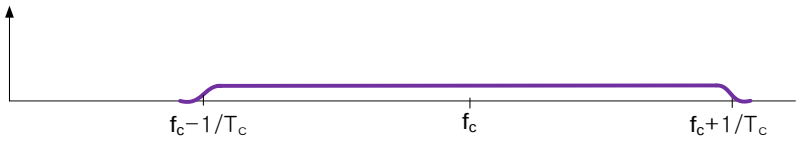
Receiver 2

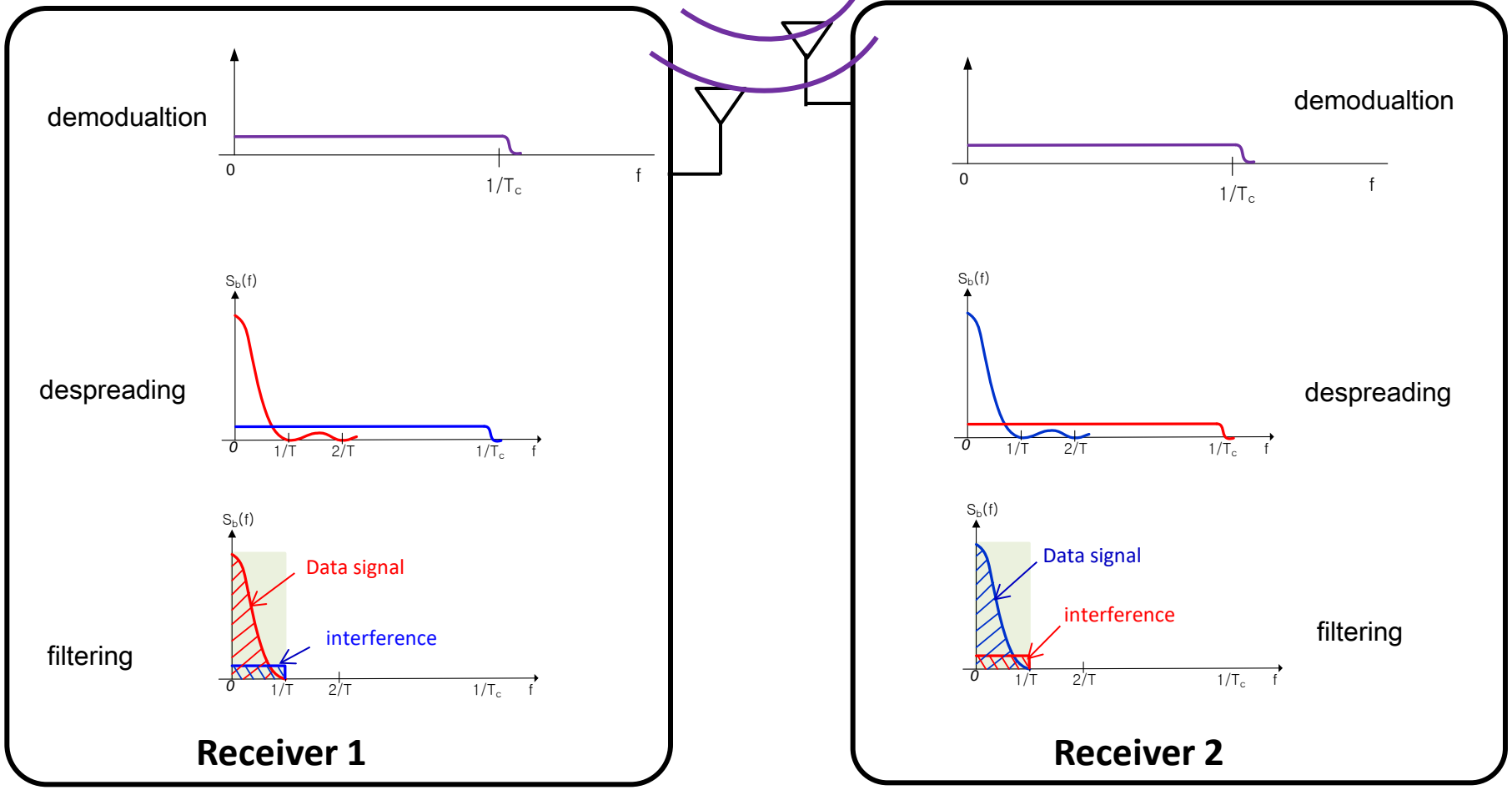


Interference in CDMA System (1)



Interference in CDMA System (2)



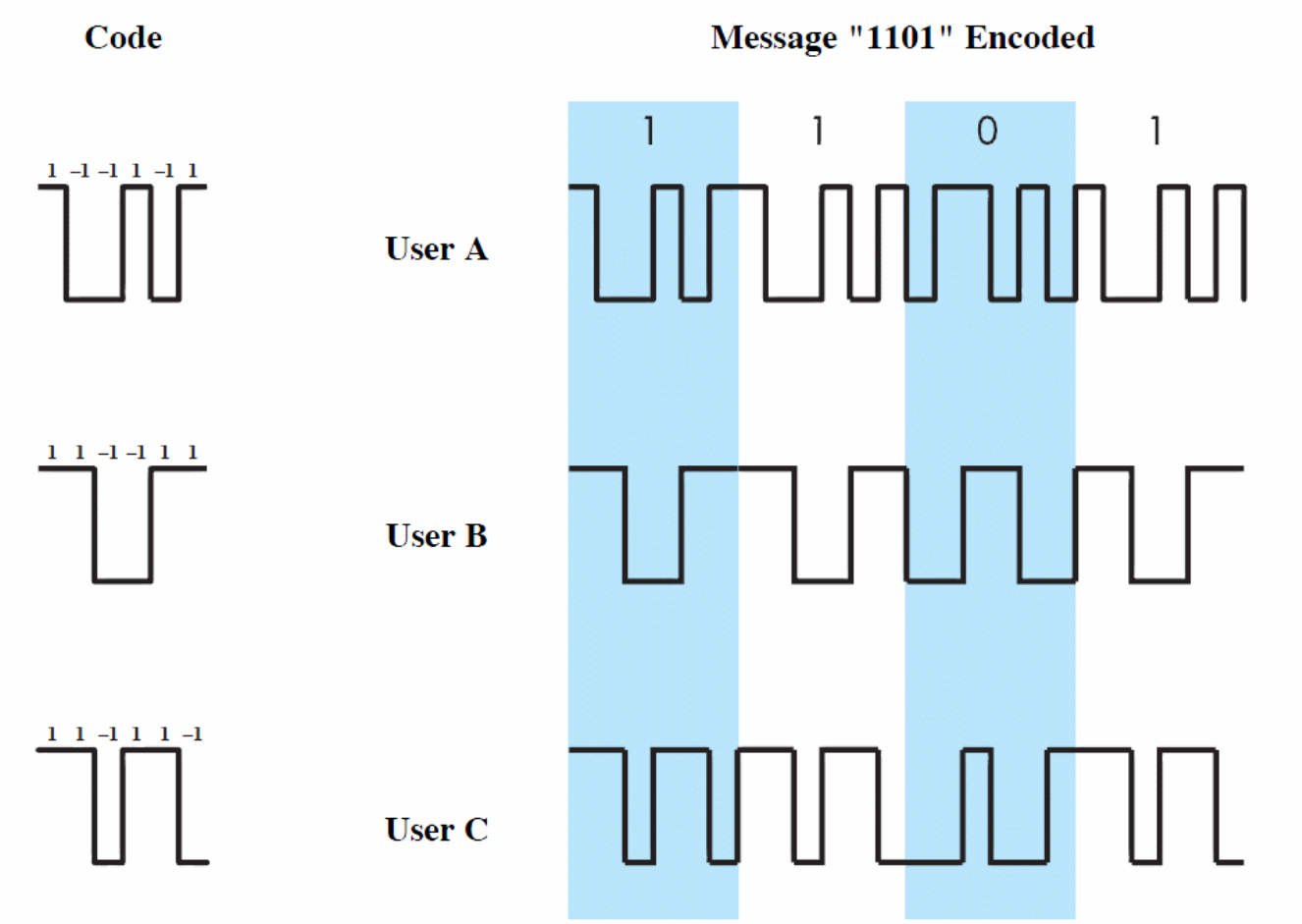


Motivation for Spread Spectrum

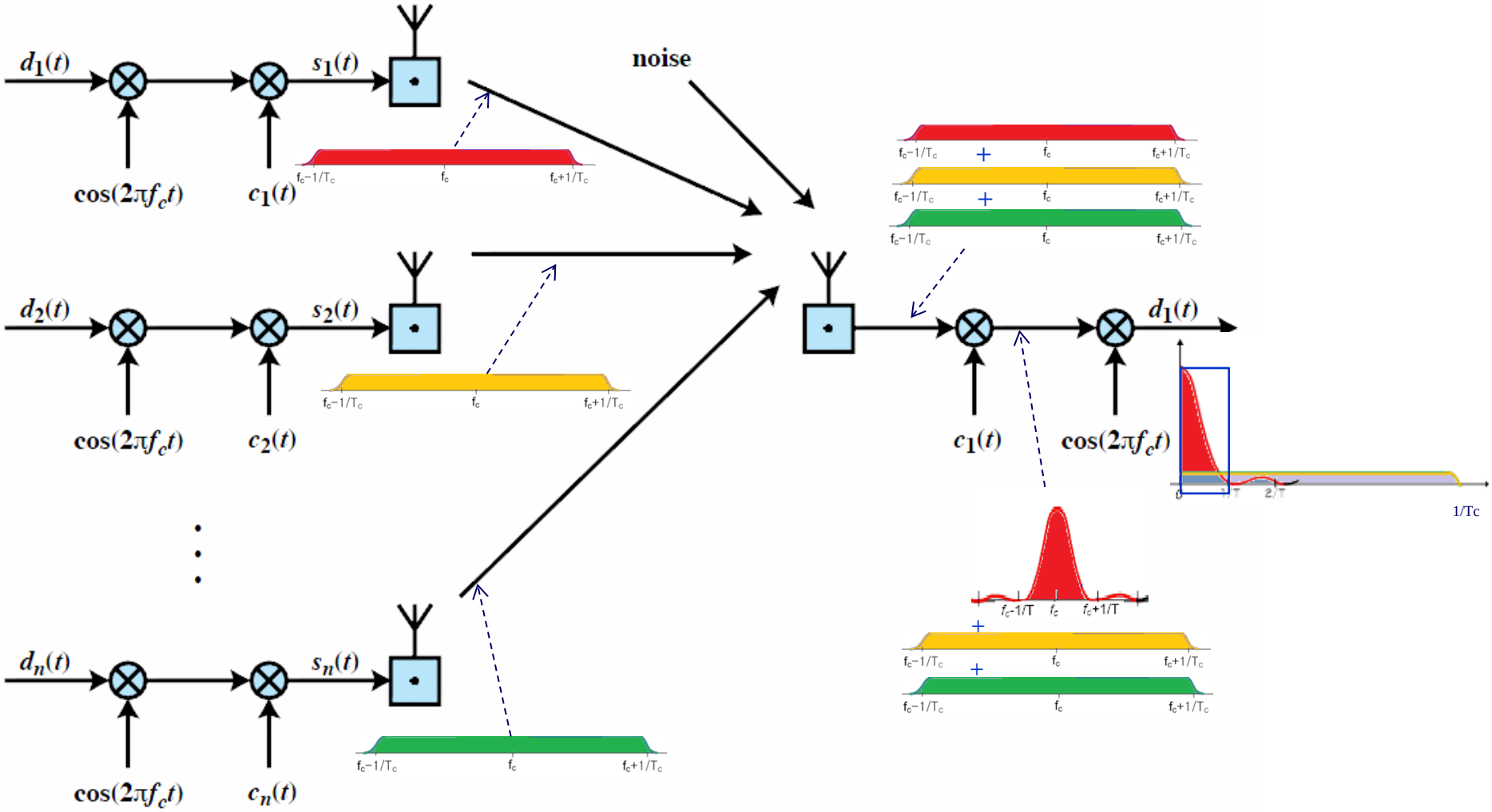
- Anti-jamming
- Low probability of Intercept
- Secure communication (Privacy)
- Protection against fading : WiFi-PHY
- Multiple access (MAC): CDMA

Code Division Multiple Access (1)

- Different code to each user

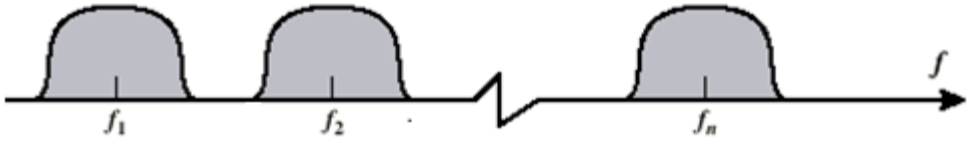


CDMA (2)

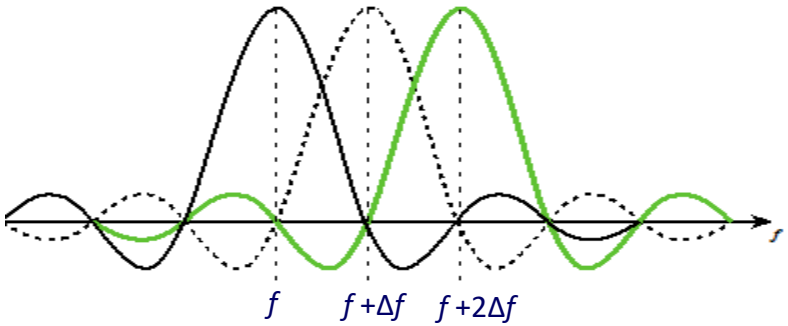

$d_1(t)$
$s_1(t)$
$\cos(2\pi f_c t)$
$c_1(t)$
noise
$d_2(t)$
$s_2(t)$
$\cos(2\pi f_c t)$
$c_2(t)$
$d_n(t)$
$s_n(t)$
$\cos(2\pi f_c t)$
$c_n(t)$
f_c-1/T_c
f_c
f_c+1/T_c
$d_1(t)$
$c_1(t)$
$\cos(2\pi f_c t)$
f_c-1/T
f_c+1/T
1/Tc

FDMA & OFDMA

- FDMA

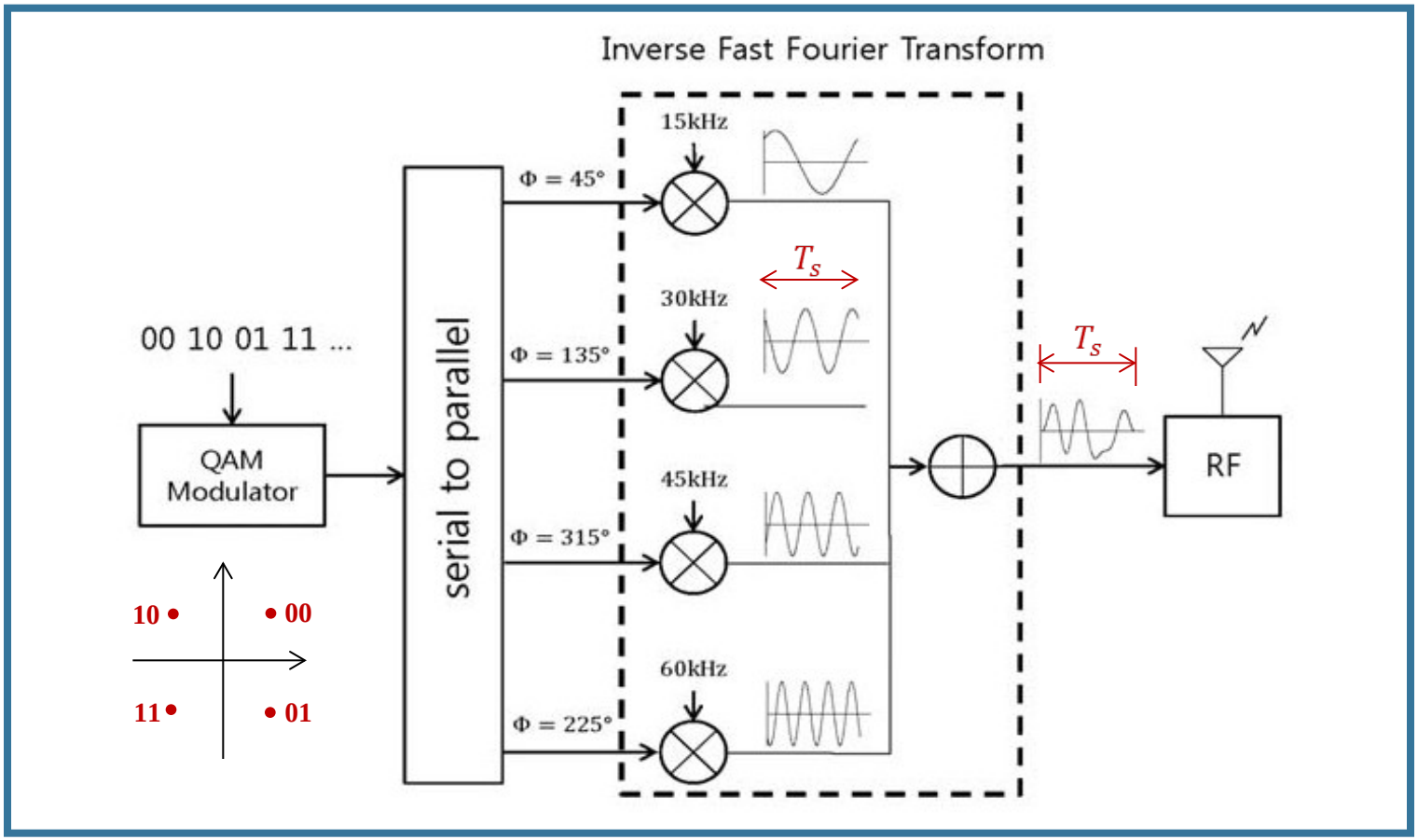


- OFDMA



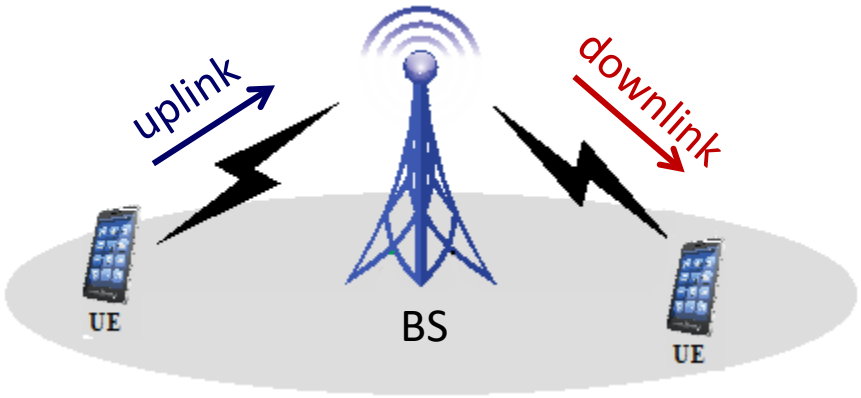
$$\Delta f = {}^{1}/_{T_s}$$

OFDM

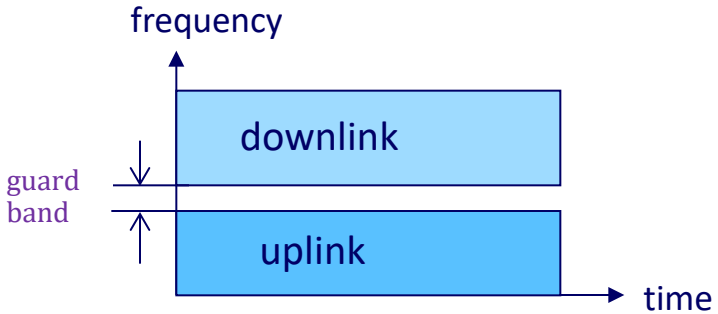


OFDM symbol time: $T_s = {}^{1}/_{\Delta f} = {}^{1}/_{15\times10^3} = 66.7\mu s$

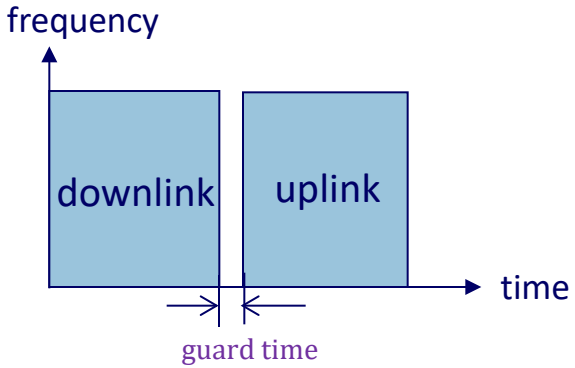
Duplexing Mode



- Frequency Division Duplexing (FDD)



- Time Division Duplexing (TDD)

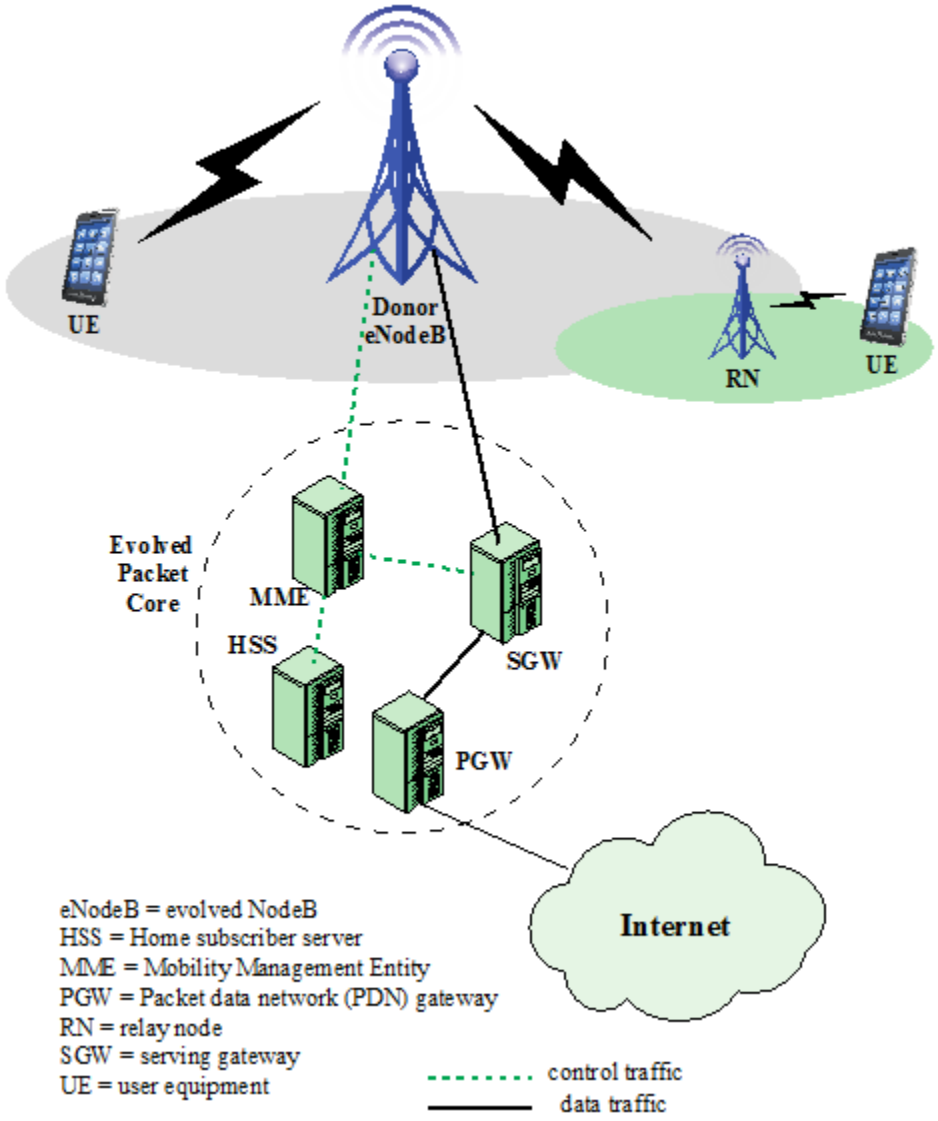


LTE (Long Term Evolution)

All IP Core Networks

Access Network

Core Network



Performance Requirements of LTE and LTE-Advanced

System Performance		LTE	LTE-Advanced
Peak rate	Downlink	100Mbps@20MHz	1Gbps@100MHz
	Uplink	50Mbps@20MHz	500Mbps@100MHz
Delay	Idle to connected	< 100 ms	< 50 ms
	Dormant to active	< 50 ms	< 10 ms
Peak Spectral efficiency	Downlink	5bps/Hz@2x2	30bps/Hz@8x8
	Uplink	2.5bps/Hz@1x2	15bps/Hz@4x4
Mobility		Up to 350 km/h	Up to 350 ~ 500 km/h

Antennas

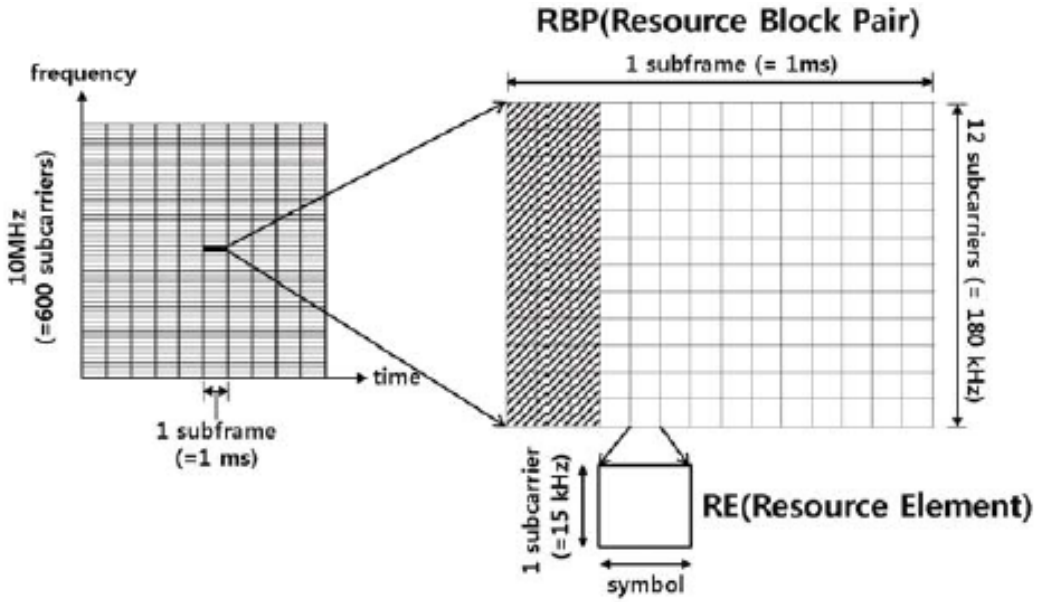
LTE-Overview

- Channel Bandwidth
  - Release-8 bandwidth set
    - 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz, 20MHz
    - Occupied bandwidth: 1.08MHz, 2.7MHz, 4.5MHz, 9MHz, 13.5MHz, 18MHz
  - Release-10
    - 5 channel aggregation (a maximum bandwidth of 100 MHz)
- Duplexing:
  - FDD, TDD
- MAC
  - Downlink: OFDMA
  - Uplink: SC-FDMA

LTE-FDD Downlink (1)

❖ Downlink Frame Format

- 15 kHz subcarrier spacing
- 10 ms frame, 10 subframes/frame, 2 slots/subframe, 7 OFDM symbols/slot, 14 OFDM symbols/subframe
- Resource Element (RE): one subcarrier and one OFDM symbol time
- Resource Block (RB): 12 subcarriers and one slot time
- Resource Block Pair (RBP): 12 subcarriers and one subframe



LTE-FDD Downlink (2)

❖ Downlink Channels

- PDSCH (Physical downlink shared channel)
  - Carries user specific data
- PDCCH (Physical Downlink Control Channel)
  - Carries control info
- PCFICH (Physical Control Format Indicator Channel)
  - It carries the number of symbols that can be used for control channels (PDCCH and PHICH).
- PHICH (Physical HARQ Indication Channel)
  - Carries H-ARQ Feedback for the received PUSCH (0: ACK, 1: NAK)
- PBCH (Physical Broadcast Channel)
  - It carries only the MIB (Master Information Block).
- PSS/SSS (Primary Synchronization Signal/Secondary SS)
  - Used for Downlink Frame Synchronization

LTE-FDD Downlink (3)

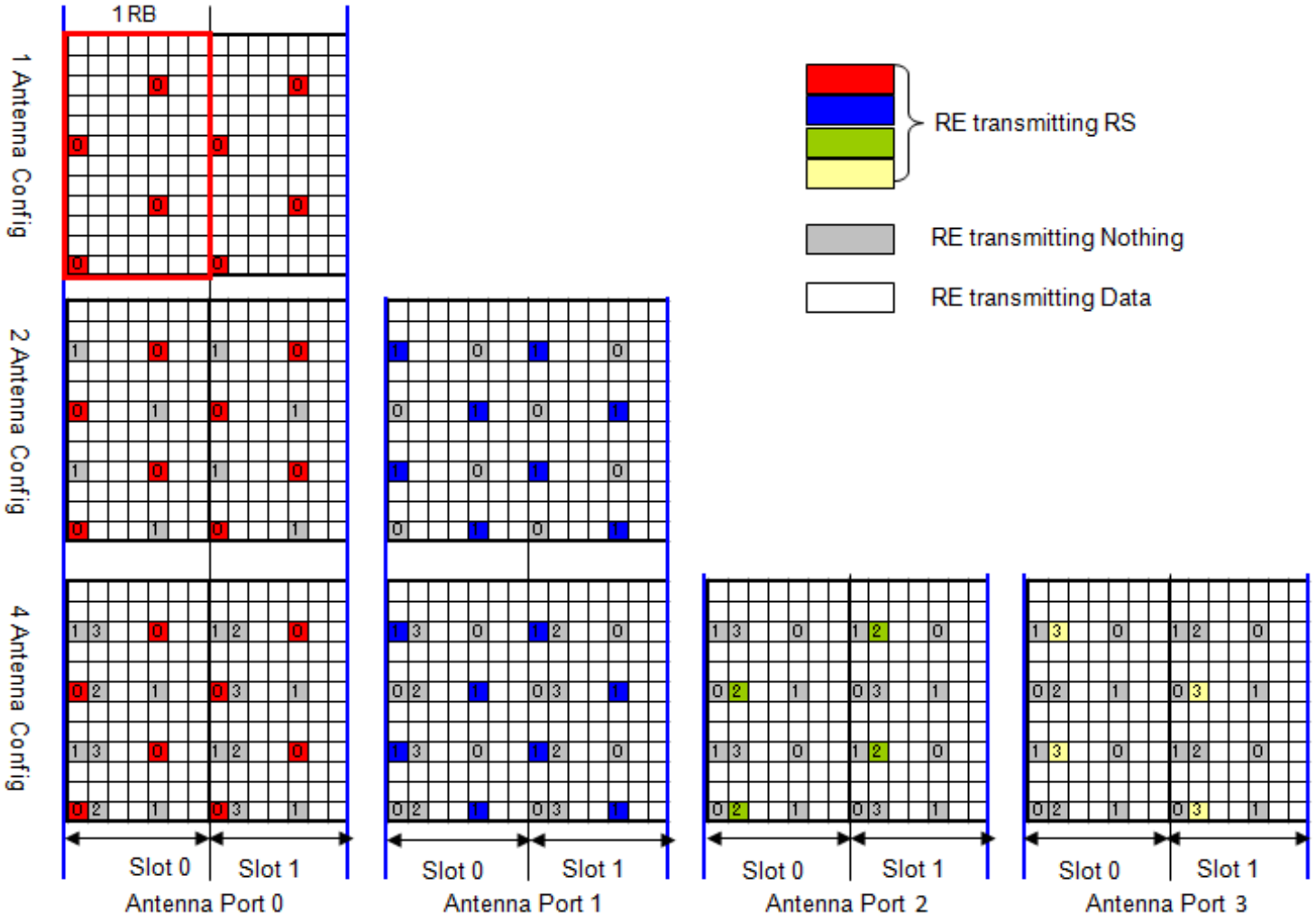
- PDCCH
  - Mapped to the first L (1, 2, or 3) OFDM symbols in each downlink subframe
  - Carries DCIs (Downlink resource scheduling, Uplink power control instructions , Uplink resource grant , Indication for paging or system information)
  - Modulation Scheme is QPSK.
  - Multiple PDCCH can be assigned in single subframe and UEs do blind decoding of all the PDCCHs.
- PDSCH
  - Carries user specific data (DL Payload).
  - Carries Random Access Response Message.
  - It is using AMC with QPSK, 16 QAM, 64 QAM, 256 QAM modulation scheme (This modulation scheme is determined by MCS carried by DCI)
- PCFICH
  - It carries the number of symbols used for control channels (PDCCH and PHICH).
  - It is 16 data subcarriers of the first OFDM symbol of each downlink subframe.
  - The exact position of PCFICH is determined by cell ID and bandwidth

LTE-FDD Downlink (4)

- PHICH
  - H-ARQ feedback channel
- PBCH
  - It carries only the MIB (Master Information Block).
  - It is using QPSK.
  - Mapped to centered around DC subcarrier in subframe 0.
  - Mapped to Resource Elements which is not reserved for transmission of reference signals, PDCCH or PCHICH
- PSS/SSS
  - Mapped to 6 RBs (72 subcarriers), centered around the DC subcarrier in slot 0 (subframe 0) and slot 10 (subframe 5).
  - Used for Downlink Frame Synchronization
  - One of the critical factors determining Physical Cell ID

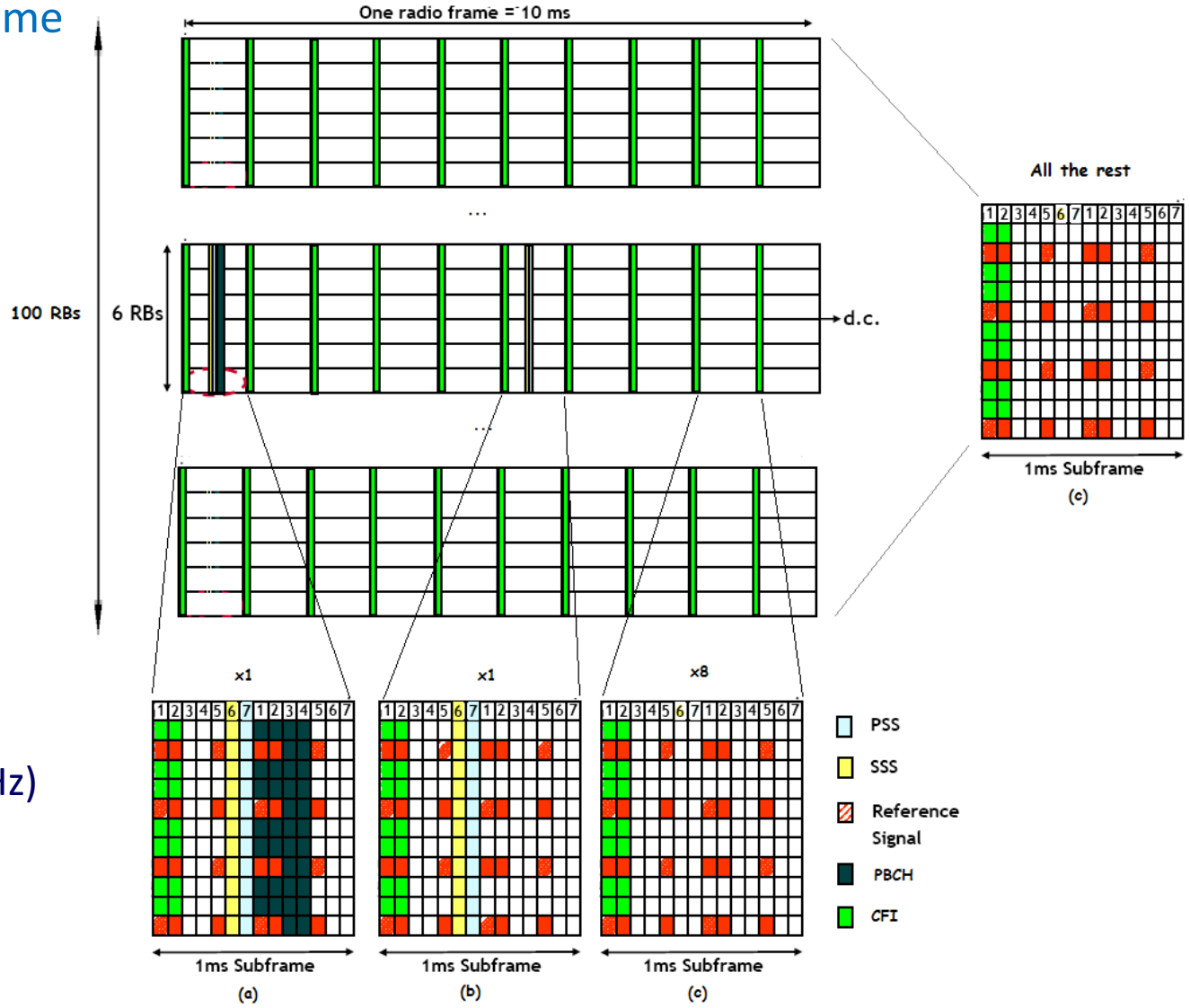
LTE-FDD Reference Signal

- Reference Signals
  - RS received power: used for accessing channel quality



Example: LTE-FDD Downlink Frame

Example Downlink Frame (20MHz)



- RB: 12 carriers (180KHz)
- 100 RBs: 18 MHz
- L = 2
- 4 antennas

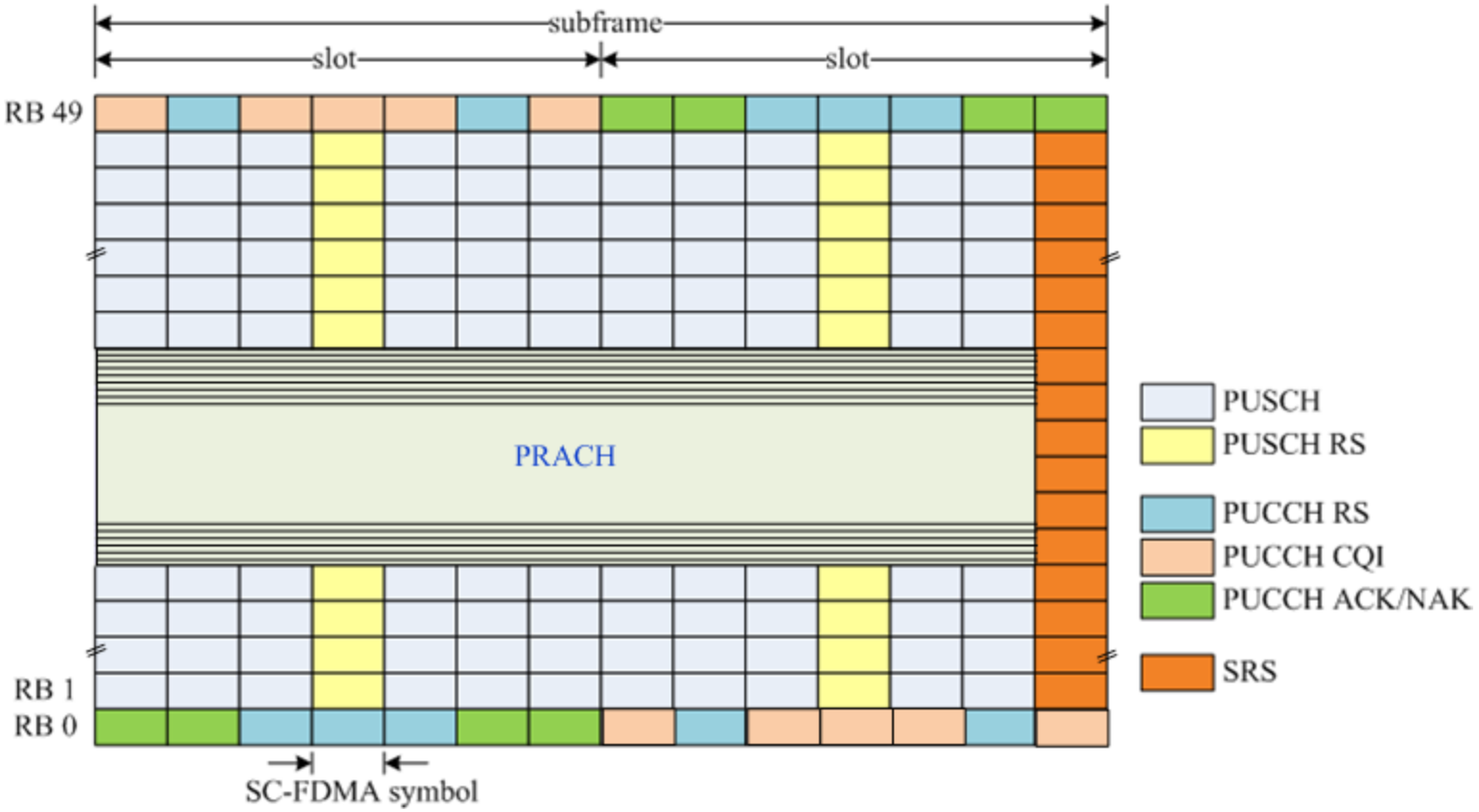
LTE-FDD Uplink (1)

❖ Uplink Channels

- PUCCH
  - Carries control information including channel quality info, acknowledgements, and scheduling requests.
- PUSCH
  - Carries Uplink data that UE tries to send.
  - It can also carries ACK/NACK for the PDSCH the UE received
- PUCCH RS, PUSCH RS
  - Used for channel estimation for PUCCH or PUSCH demodulation
- SRS (Sounding RS)
  - Used to measure the uplink channel quality for channel sensitive scheduling
- PRACH
  - Used to transmit RA preambles

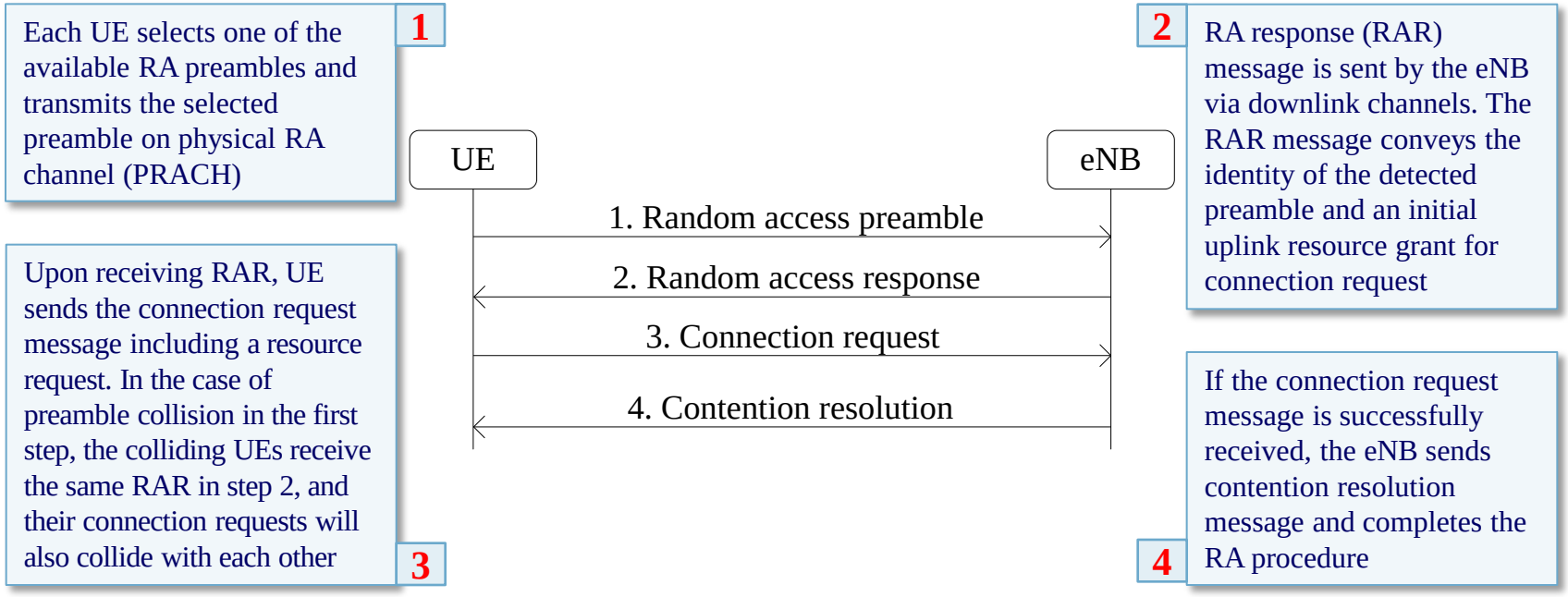
LTE-FDD (4)

❖ Uplink Subframe (10 MHz)



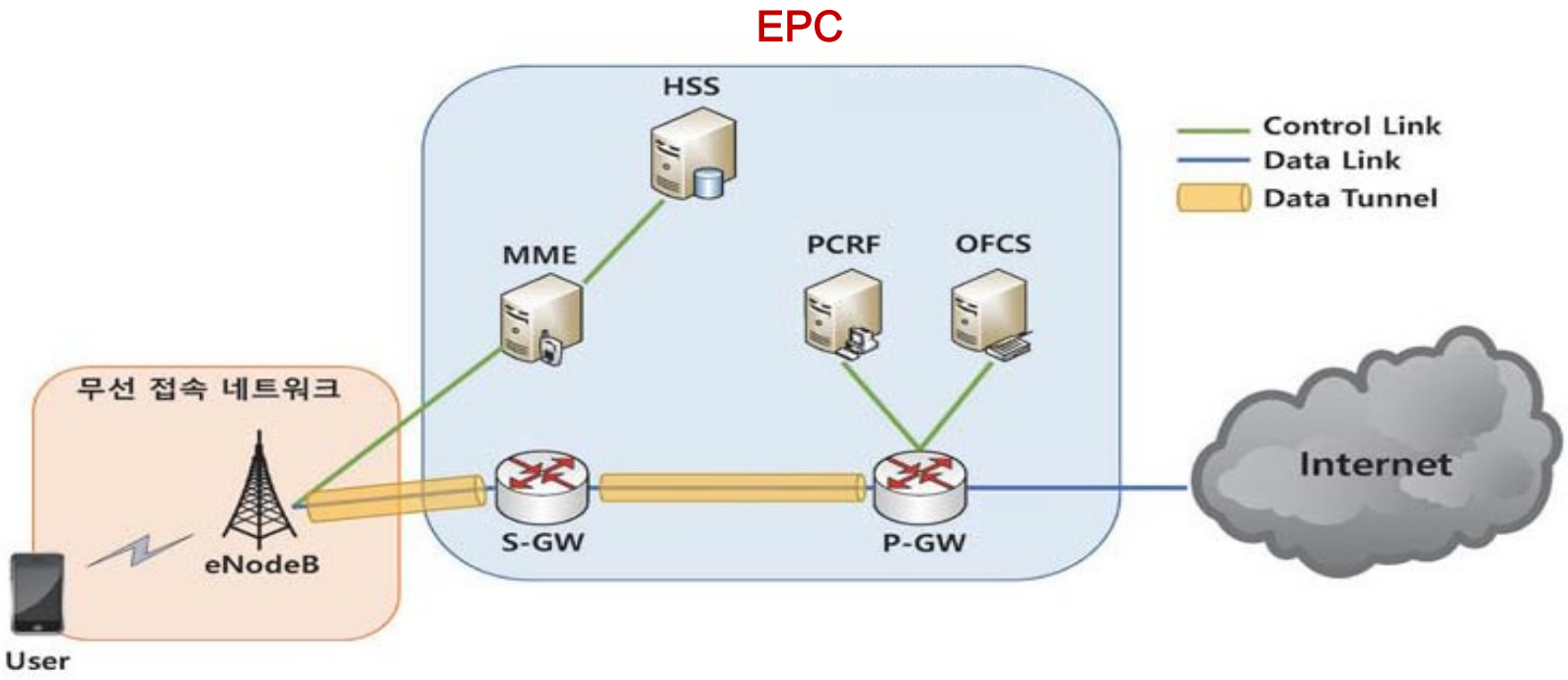
Random Access Protocol

- LTE system adopts a contention-based **random access (RA) technique** for initial access



Evolved Packet Core (1)

Architecture

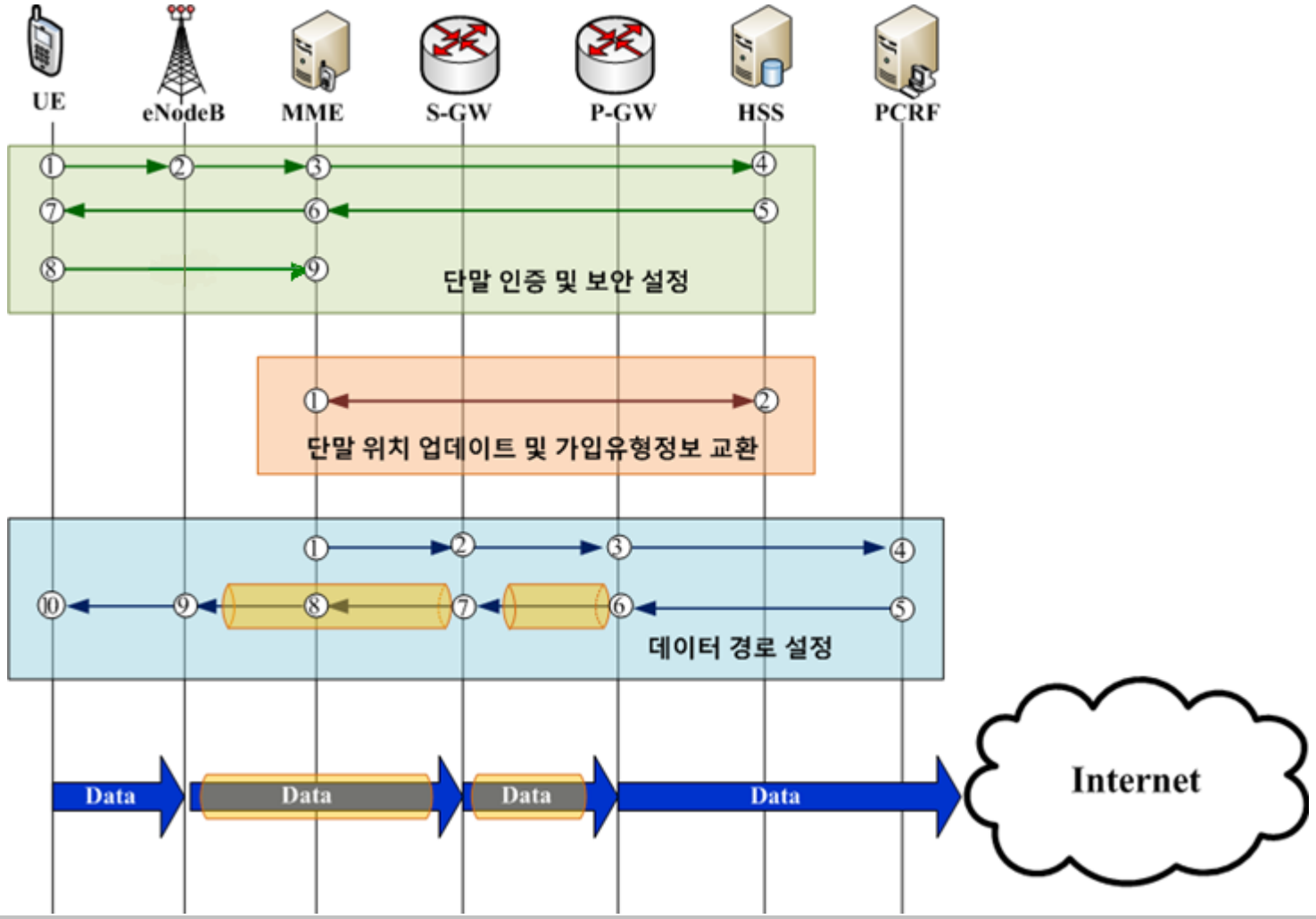


P-GW (packet data network gateway)
S-GW (serving gateway)

MME (mobility management entity)
HSS (home subscriber server)
PCRF (policy control and rule function)
OFCS (offline charging system)

Evolved Packet Core (2)

Communication Procedure



Communication Procedure (1)

❖ 단말인증 및 보안 설정

- Step ① ~ ③

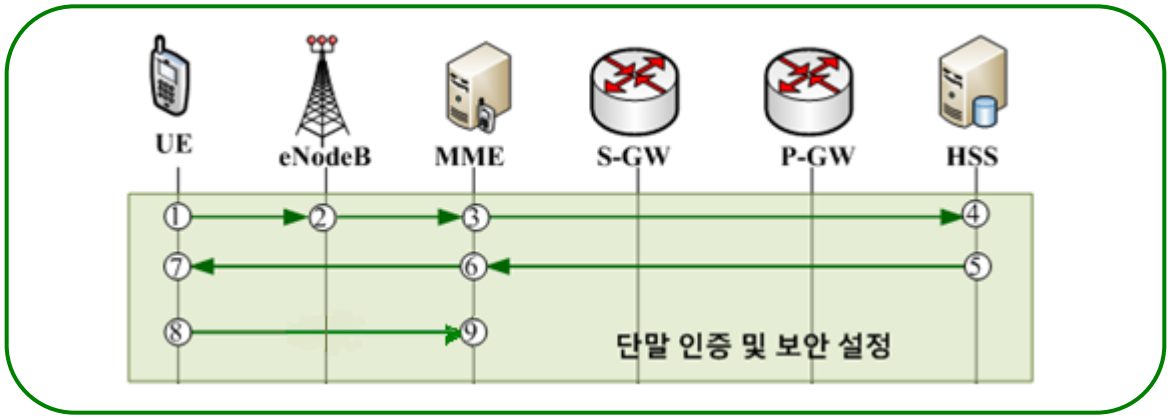
  UE는 USIM에 저장된 가입자 정보를 eNodeB를 통해 MME로 보내 사용자 인증을 받는다

- Step ③ ~ ⑥

  MME는 HSS에 저장되어 있는 가입자 정보를 가져와 UE로부터의 가입자 정보와 일치하는지 확인한다.

- Step ⑥ ~ ⑨

  MME는 무선링크 보안에 대한 인증절차를 수행한다



Communication Procedure (2)

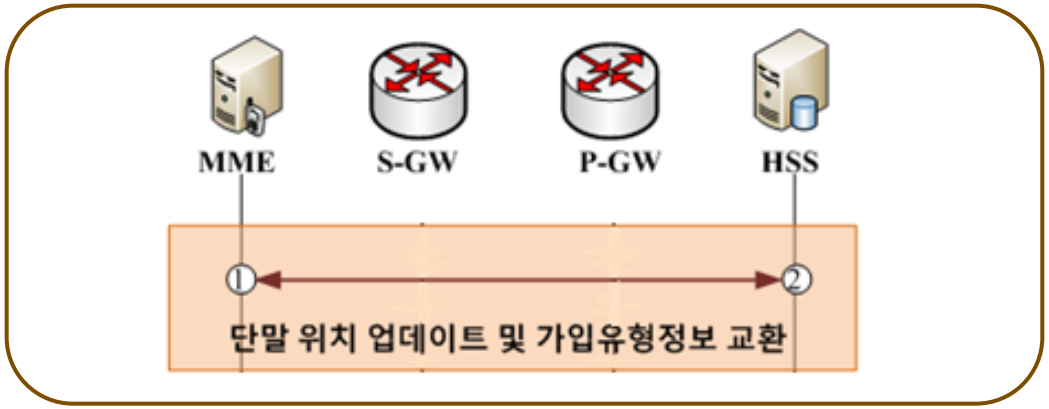
❖ 단말 위치 갱신 및 가입유형 정보 교환

- Step ①

  MME는 UE의 현 위치를 HSS에게 전달하고 HSS는 UE 위치 정보를 update한다.

- Step ②

  HSS는 MME에게 사용자의 가입유형 정보(어느 서비스에 가입했고 그에 따라 어떤 속도로 인터넷 접속을 지원해야 하는지에 대한 정보)를 전달.



Communication Procedure (3)

❖ 단말의 데이터 경로 설정

- Step ① ~ ②

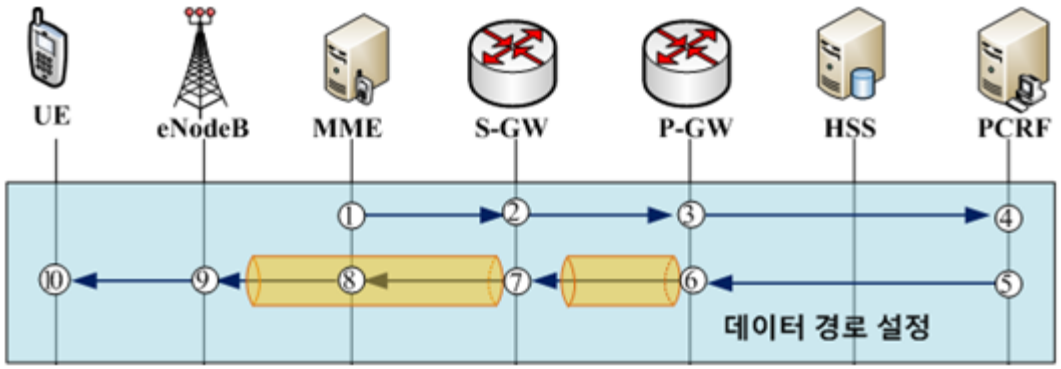
  MME는 S-GW 선택하여 해당 UE에 대한 경로설정을 요청한다.
  S-GW는 P-GW를 찾아 해당 단말의 경로설정을 요청한다

- Step ③

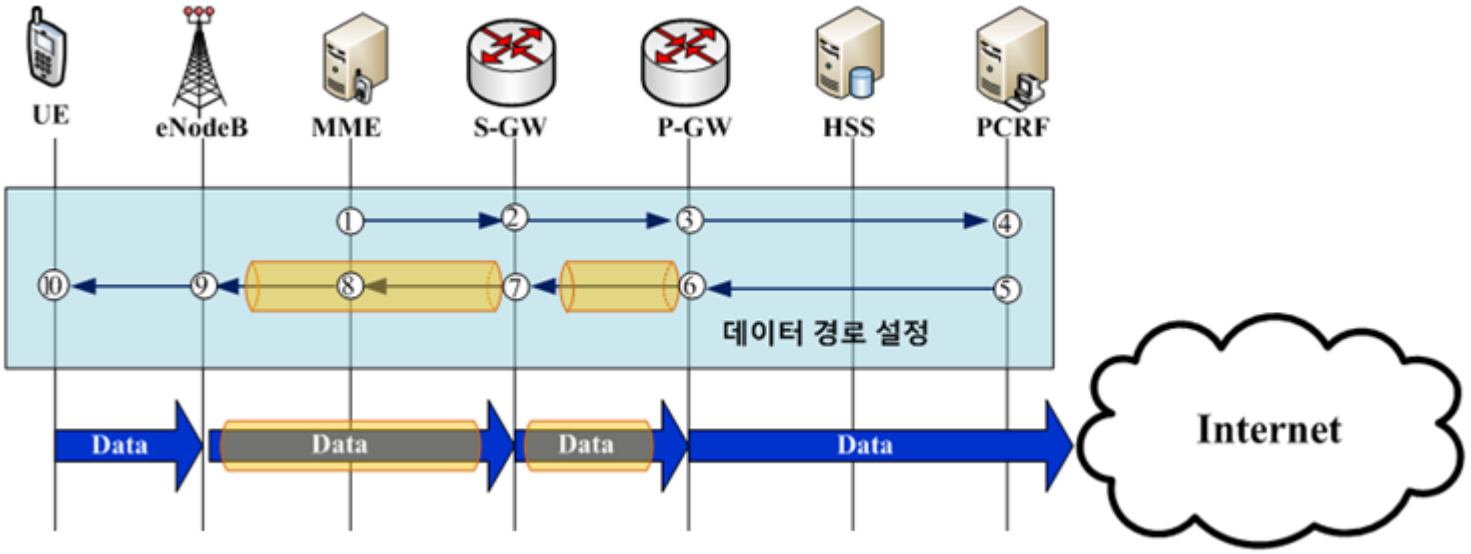
  P-GW는 단말의 경로설정 요청을 수신하면 외부로의 통신을 위해 단말에 IP를 할당한다.

- Step ④ ~ ⑥

  P-GW는 PCRF로부터 받은 사용자의 가입상품 정보를 따른 서비스 품질정책을 적용한다.



Communication Procedure (4)



- Step ⑦ ~ ⑨

  할당된 IP 주소와 데이터터널 성능에 적용할 정책들이 P-GW, S-GW, eNodeB로 차례로 전달되며 데이터 전달을 위한 터널을 형성한다

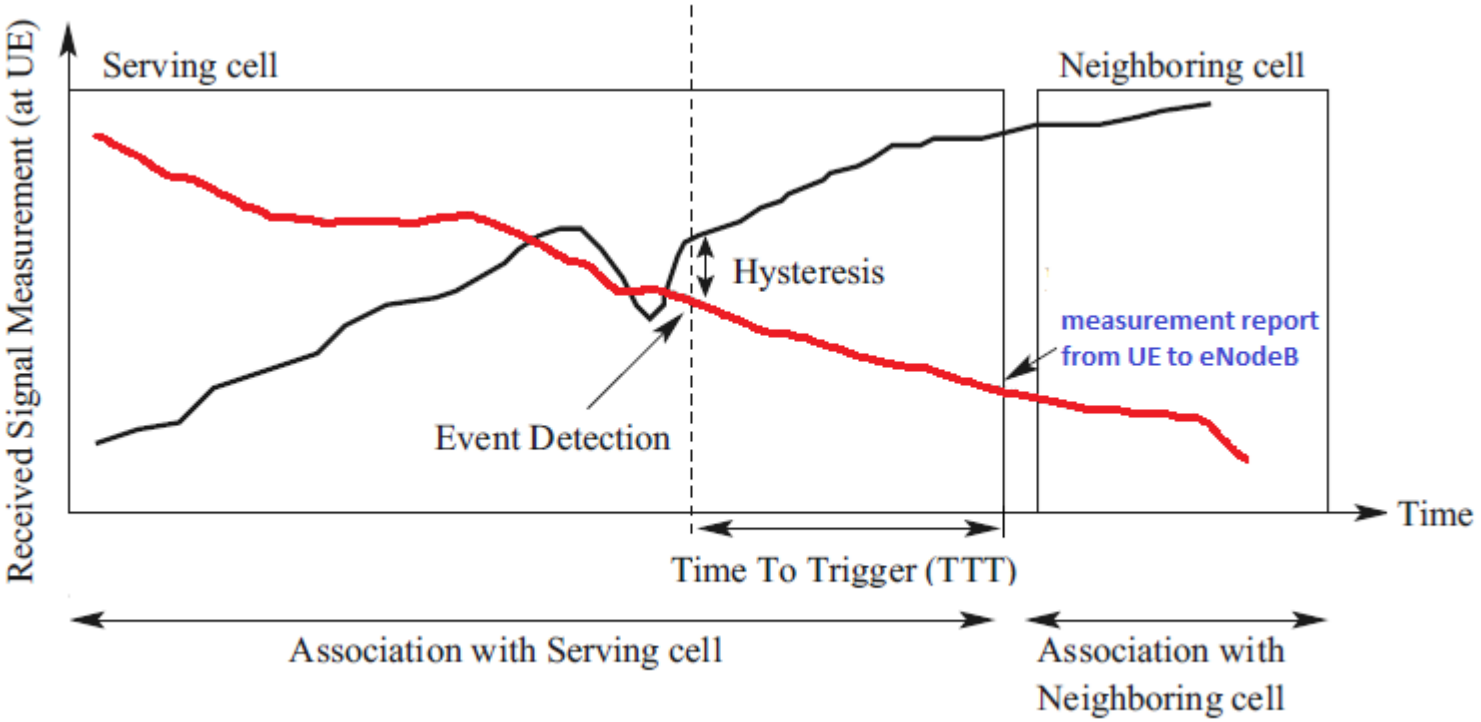
- Step ⑩

  eNodeB는 네트워크 사용 준비가 완료되었다는 메시지를 UE에게 보낸다.

Handover (1)

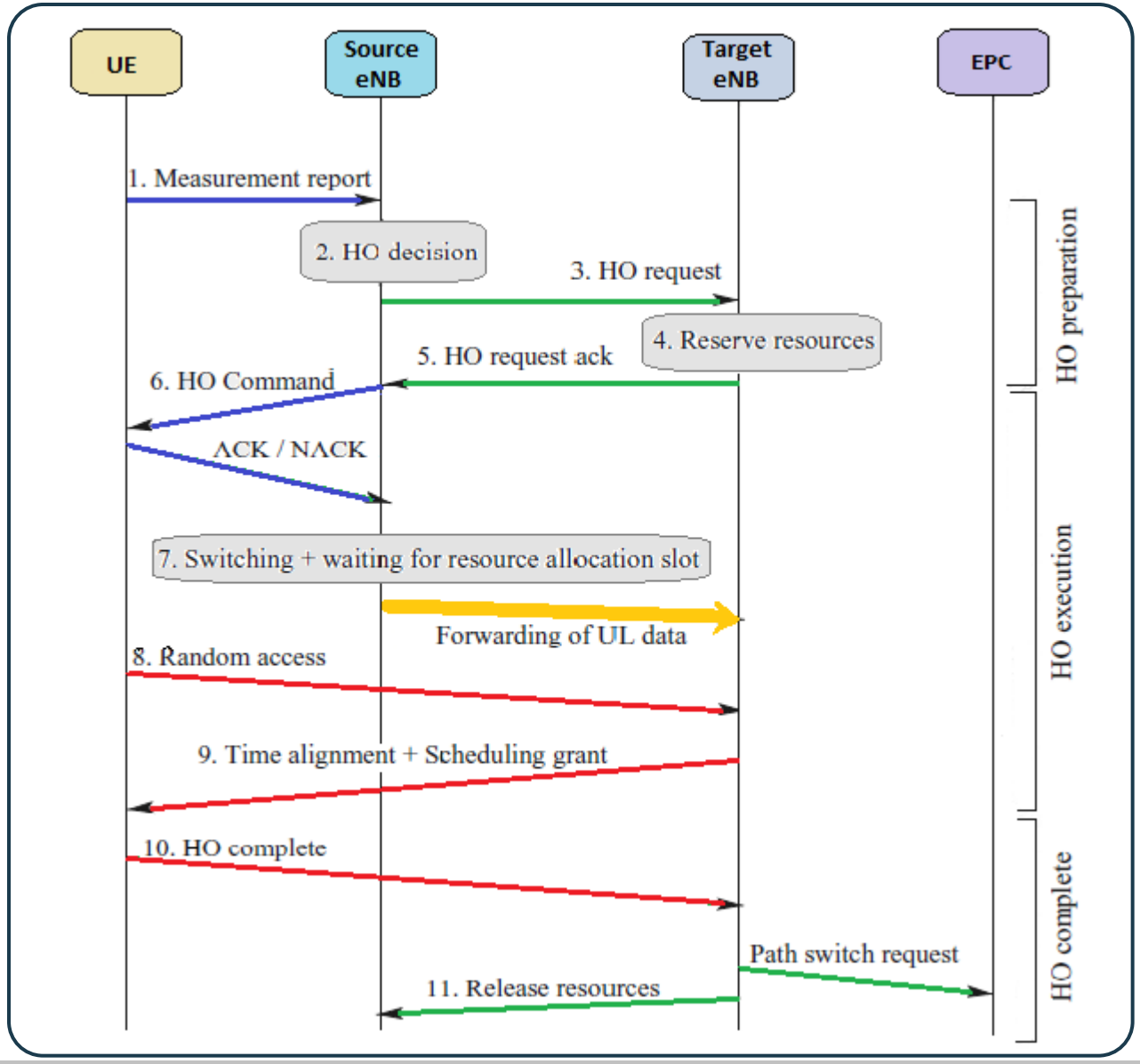
❖ Handover Triggering

- Measurement Report



Handover (2)

Message Flow



Handover (3)

Tunneling–based Mobility Support