

Chapter 10

Cellular Wireless Networks

Introduction (1/2)

- **Wireless Network:**
 - Physical link between nodes: wireless channel
- **Mobile Network:**
 - User mobility support with portable devices
- **wireless channel**
 - Medium: radio frequency band
 - Radio propagation:
 - Severe fading
 - Time-varying channel quality

⇒ Hostile transmission environment



Cellular Antenna

Introduction (2/2)

- Radio frequency

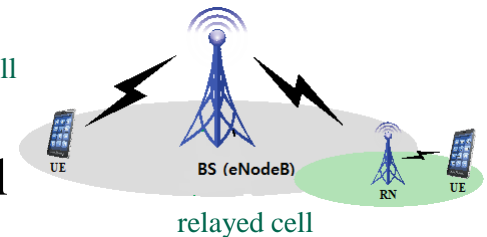
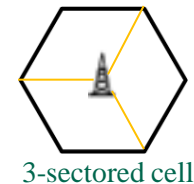
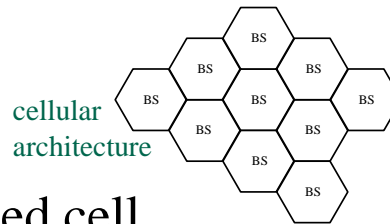
- Scarce resource
- Time-varying channel quality → dynamic channel capacity
- should utilize very efficiently
 - cellular system, multiple access, radio resource management

$$C = B \log_2(1 + \frac{S}{I+N})$$

↑ channel bandwidth ↑ channel quality (time varying)

- Cellular system

- Spectrum reuse
- Sectorized cell, relay-assisted cell
- Heterogeneous system: macrocell, microcell, picocell



- Multiple access scheme

- Efficient resource sharing among users in a cell
- FDMA, TDMA, CDMA, OFDMA, and hybrids (OFDMA+TDMA)

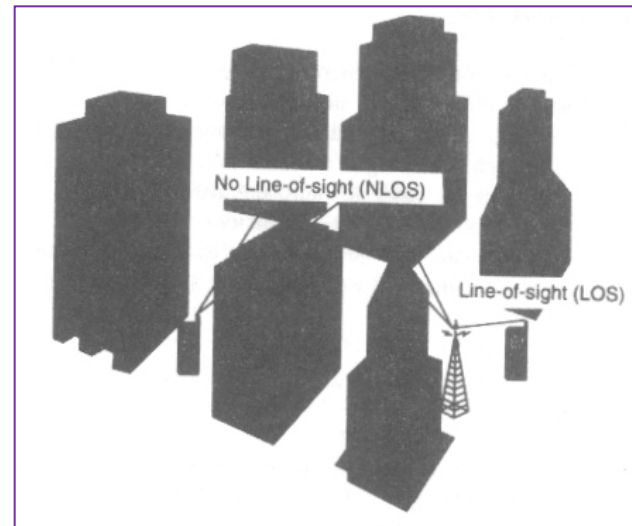
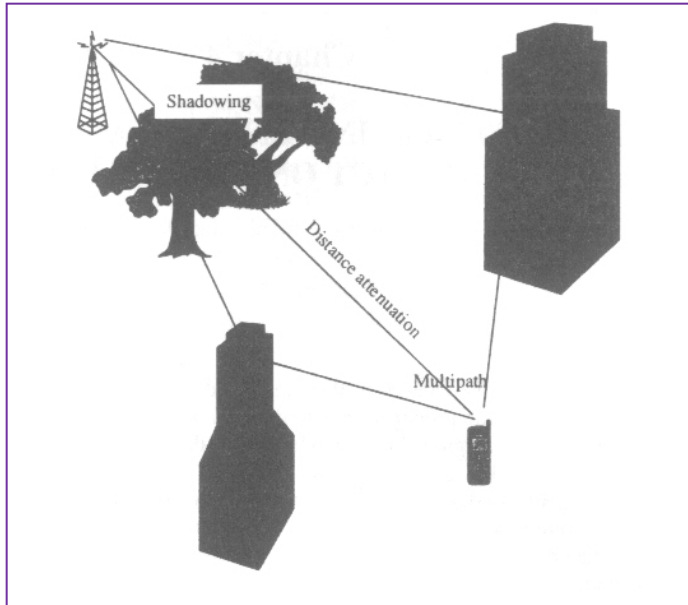
Radio channel

- Signal Fading

- path loss: large-scale component
- shadowing: medium-scale slow varying component
- multipath fading: small-scale fast varying component

Signal fading

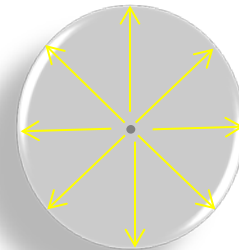
$$\text{SINR: } \frac{\text{received signal power}}{\text{Interference and noise power}}$$



Path Loss & Shadowing

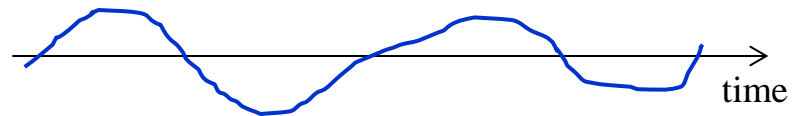
- Path loss

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



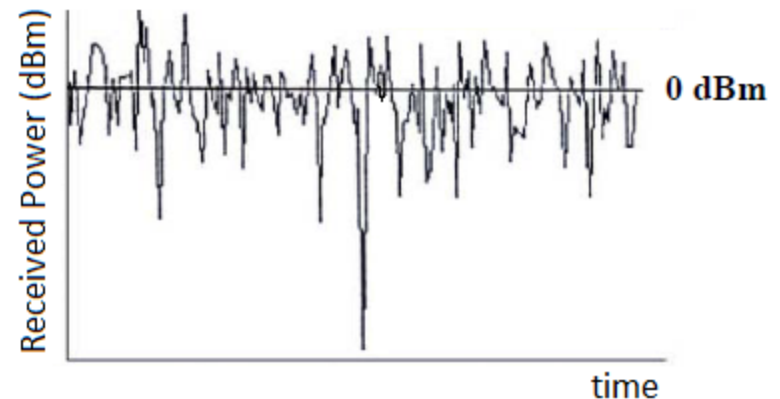
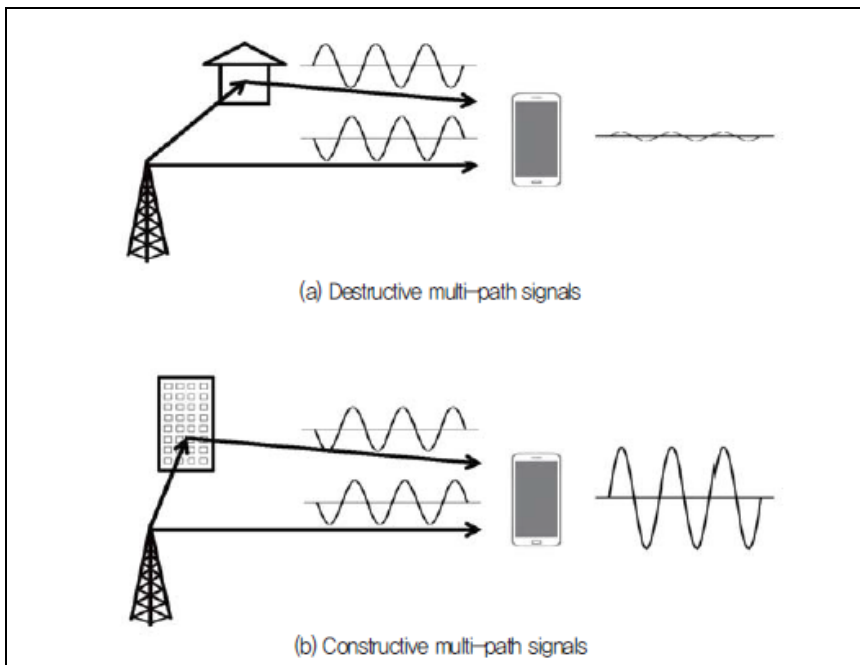
- Shadowing

- Caused by obstacles between transmitter and receiver that absorb power
 - Log-normal distribution

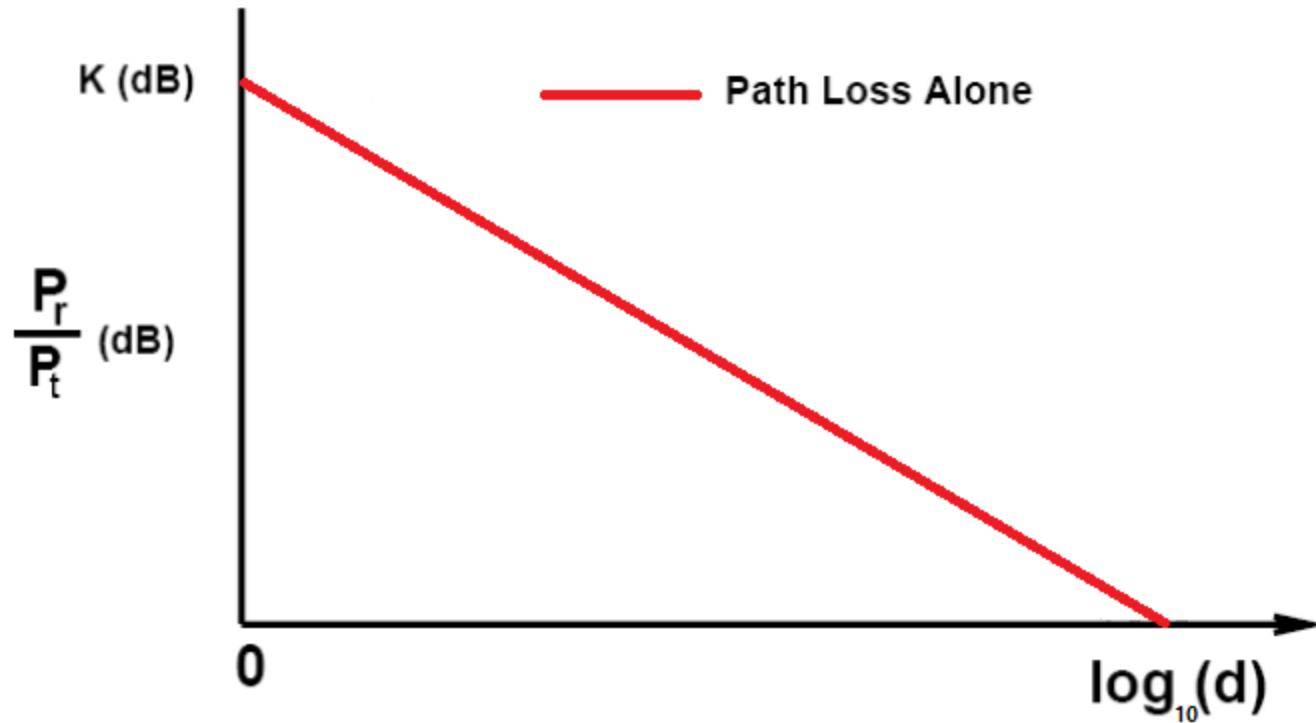


Multipath fading

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

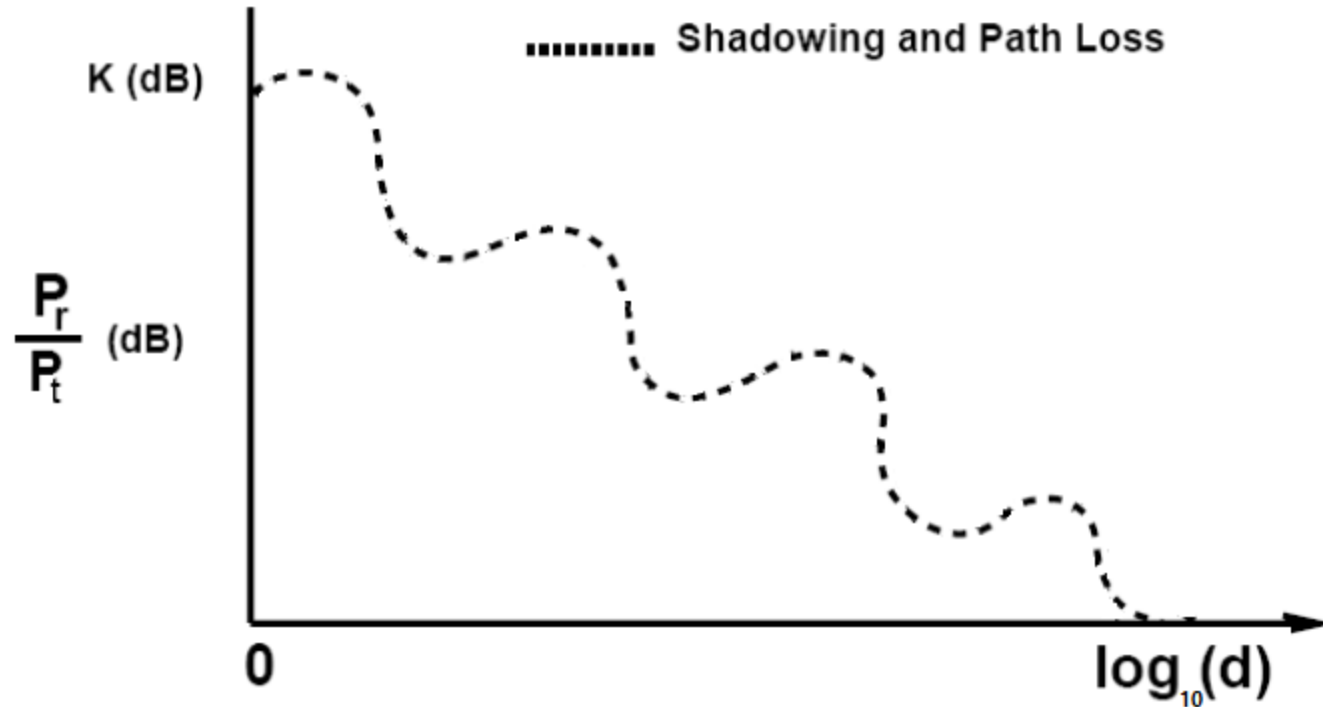


Channel Model

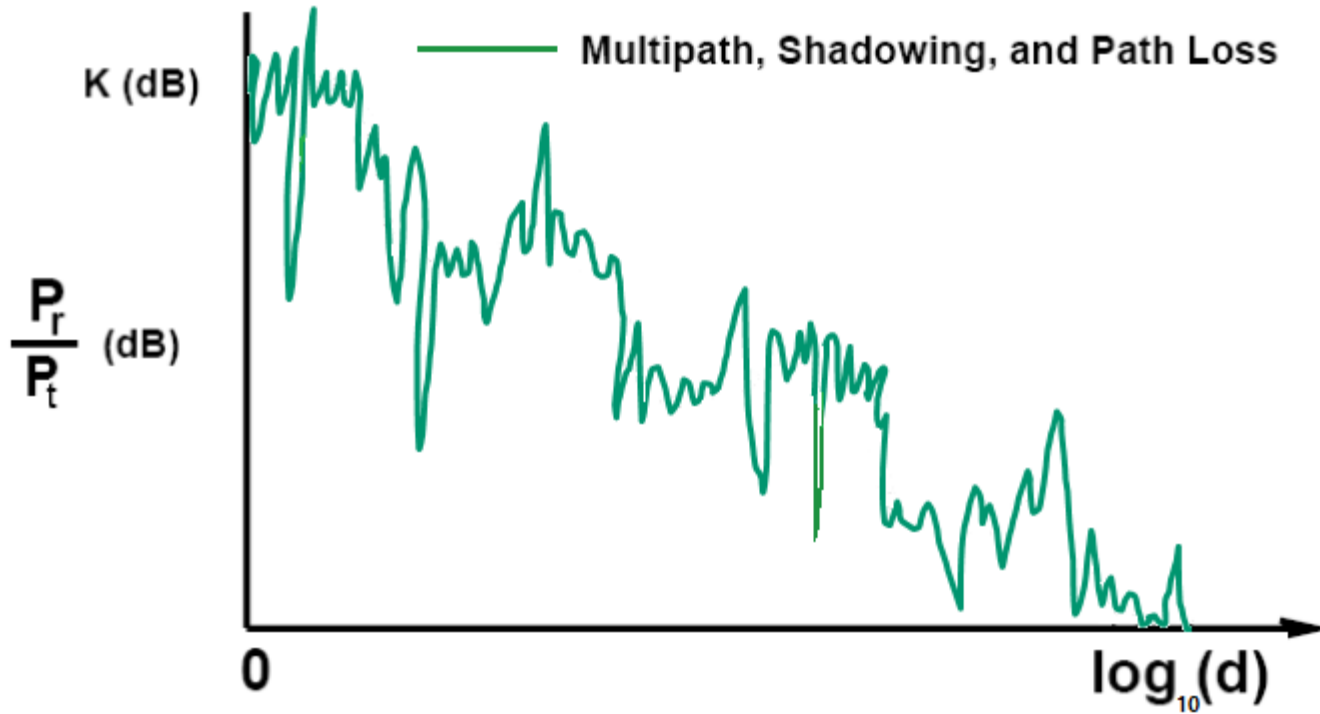


$$\frac{P_r}{P_t} = K d^{-e} \Rightarrow \underbrace{10 \log_{10} \frac{P_r}{P_t}}_{\frac{P_r}{P_t} \text{ (dB)}} = 10 \log_{10} K d^{-e} = \underbrace{10 \log_{10} K}_{K \text{ (dB)}} - 10e \log_{10} d$$

Channel Model

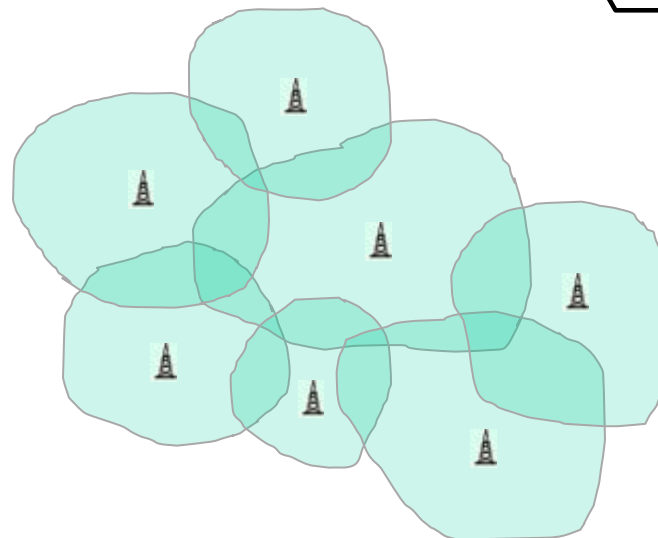
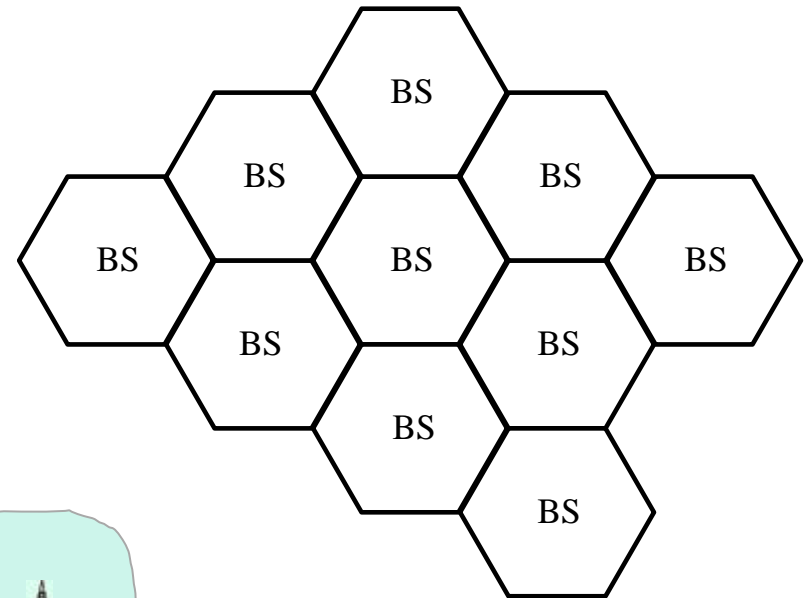


Channel Model



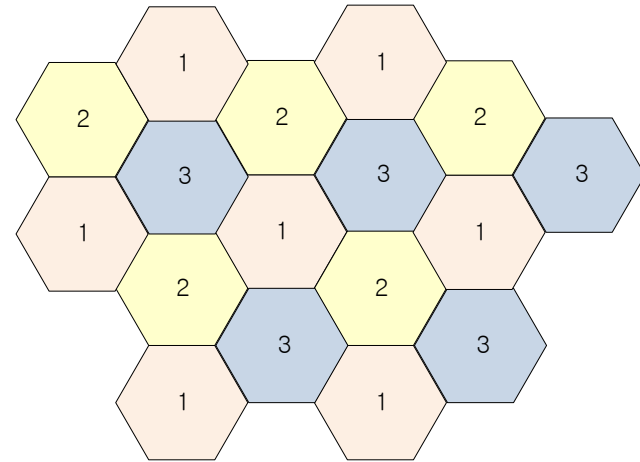
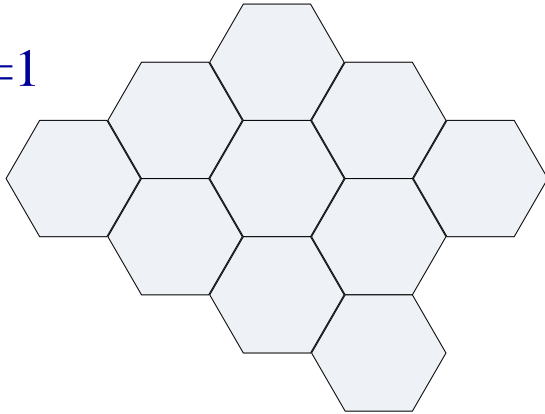
Cellular Architecture

- The service area is divided into several small areas, called cells
- Each cell is served by a base station
- Wider service area with more cells
- Frequency (band) reuse
 - => the increased capacity
 - => Power control (intercell interference)
- Movement Management
 - Location management
 - Handover



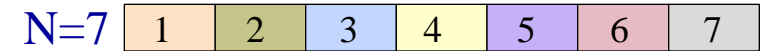
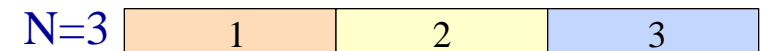
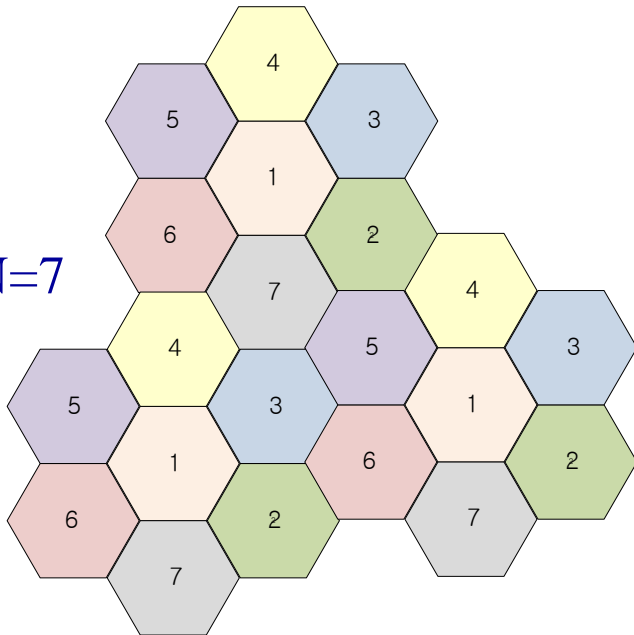
Reuse Factor

N=1



N=3

N=7



Bandwidth per cell

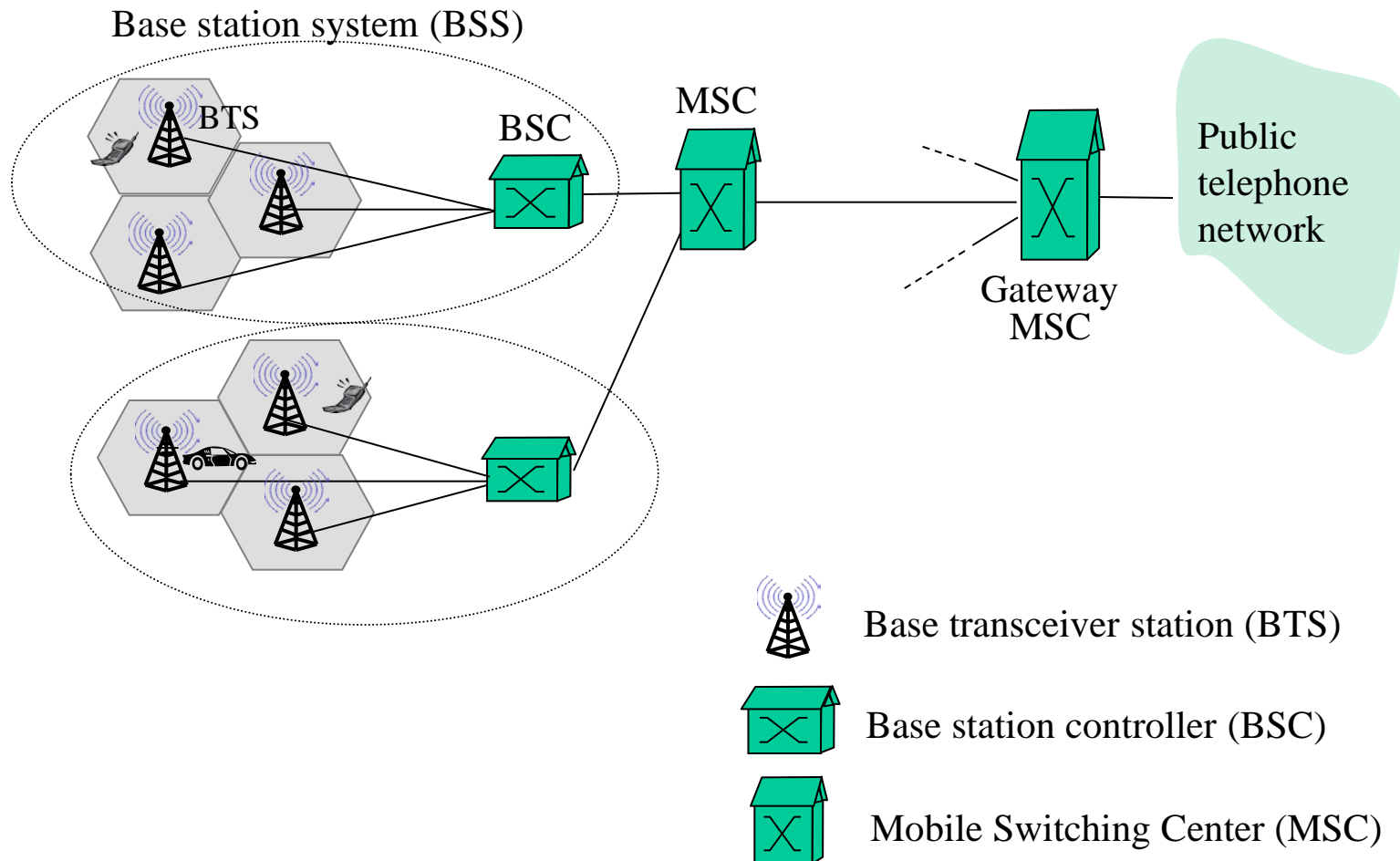
Movement Management

- Location management
 - To deliver connection request to appropriate moving mobiles
 - Location update
 - Paging
- Handover
 - When an MS moves into other cell during connection
 - Change of serving BS

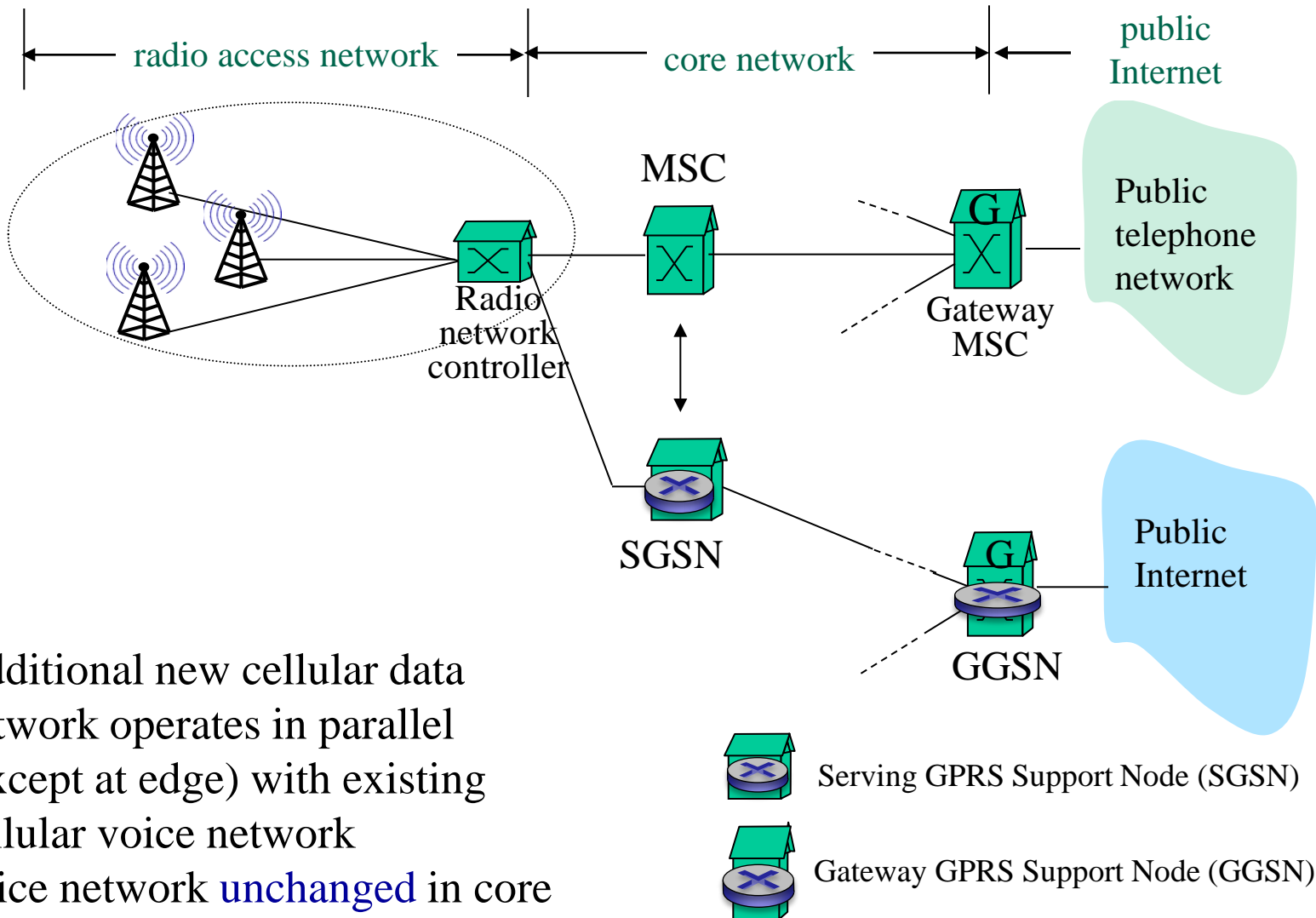
Cellular Networks Generation

	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

2G (voice) network architecture



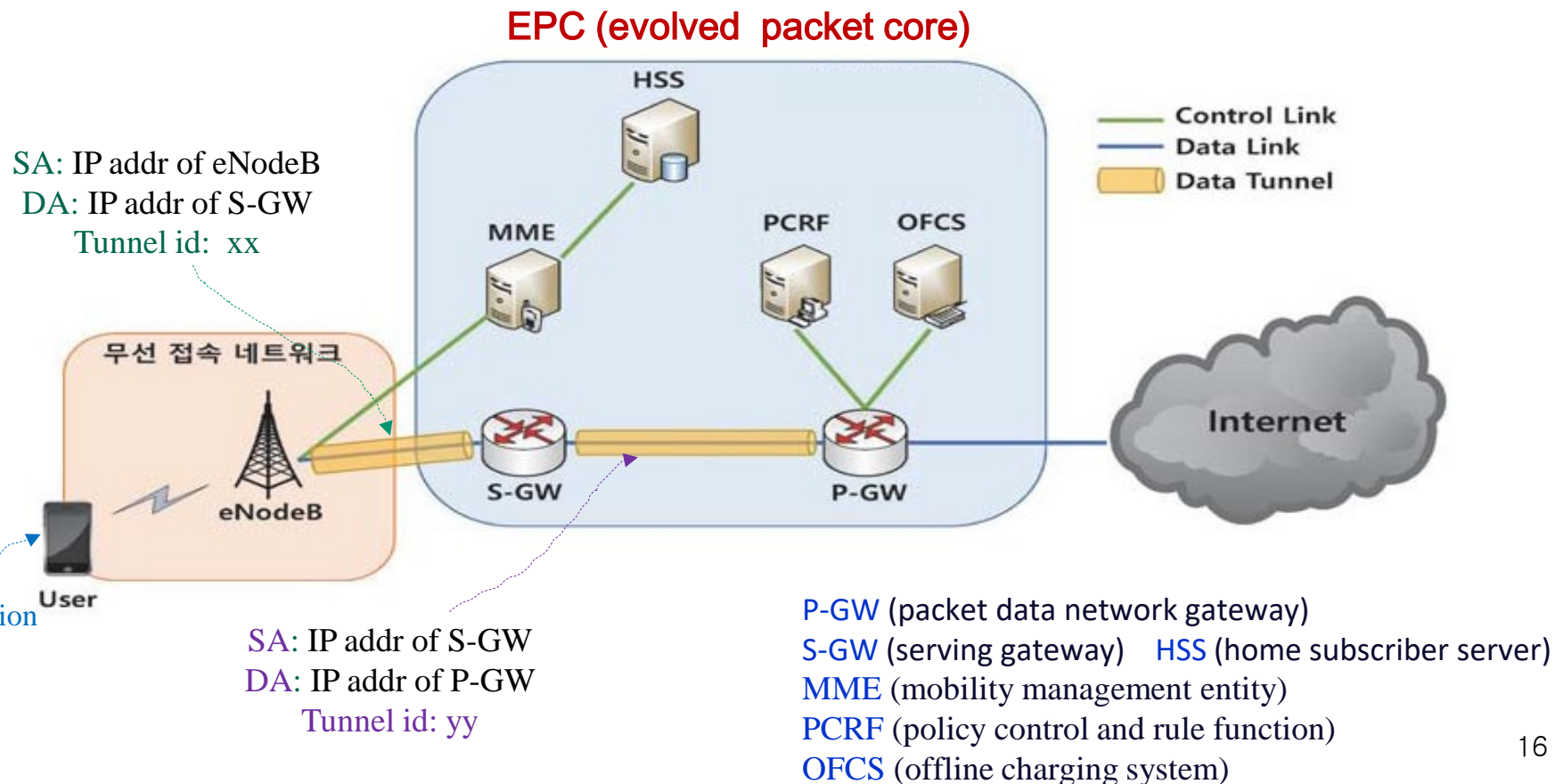
3G (voice+data) network architecture



- Additional new cellular data network operates in parallel (except at edge) with existing cellular voice network
- voice network **unchanged** in core

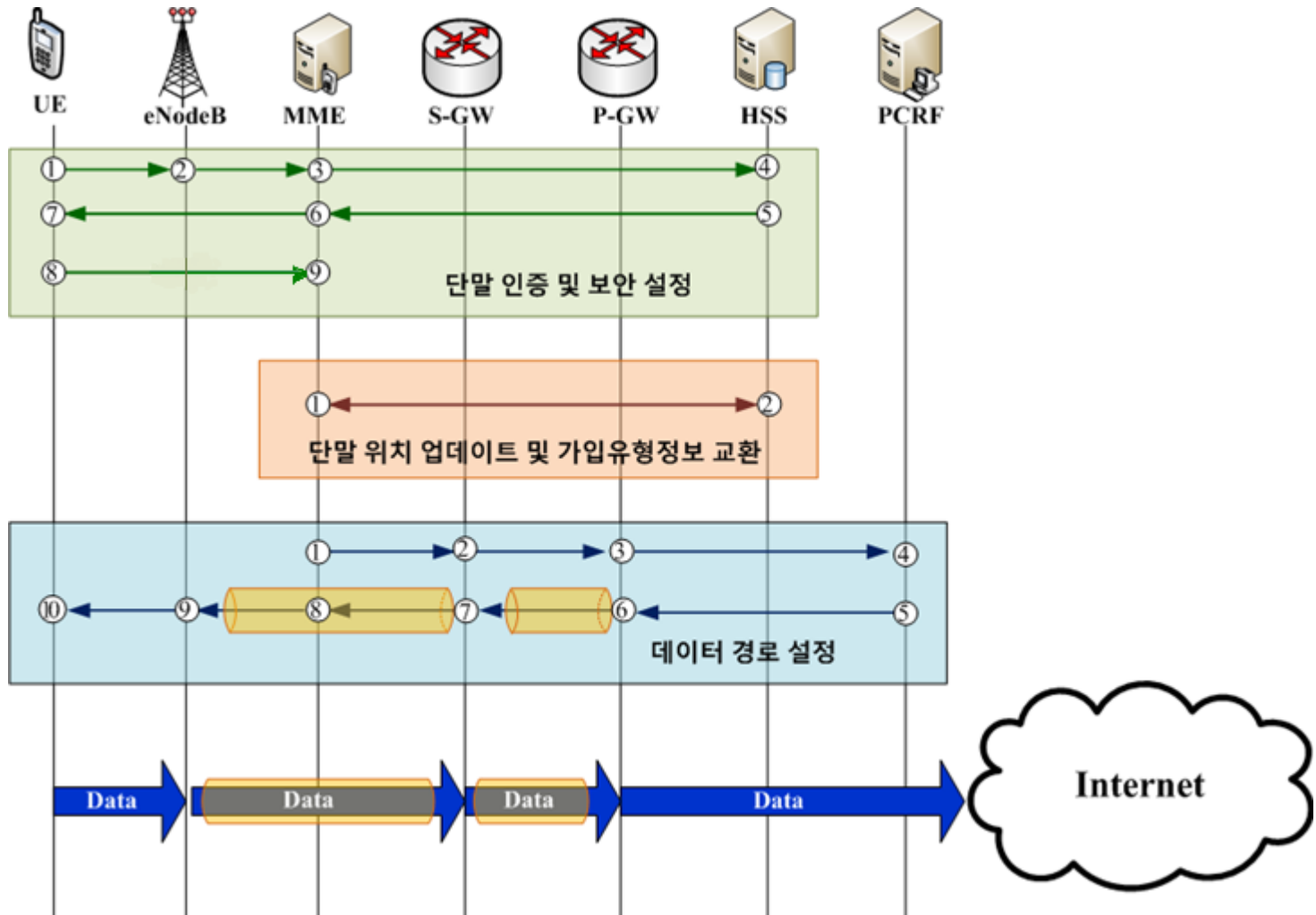
4G: differences from 3G

- all IP core: IP packets tunneled (through core IP network) from base station to gateway (each eNodeB and each gateway have its fixed IP addr)
- no separation between voice and data – all traffic carried over IP core



Evolved Packet Core (2)

Communication Procedure



Communication Procedure (1)

- 단말인증 및 보안 설정

- Step ① ~ ③

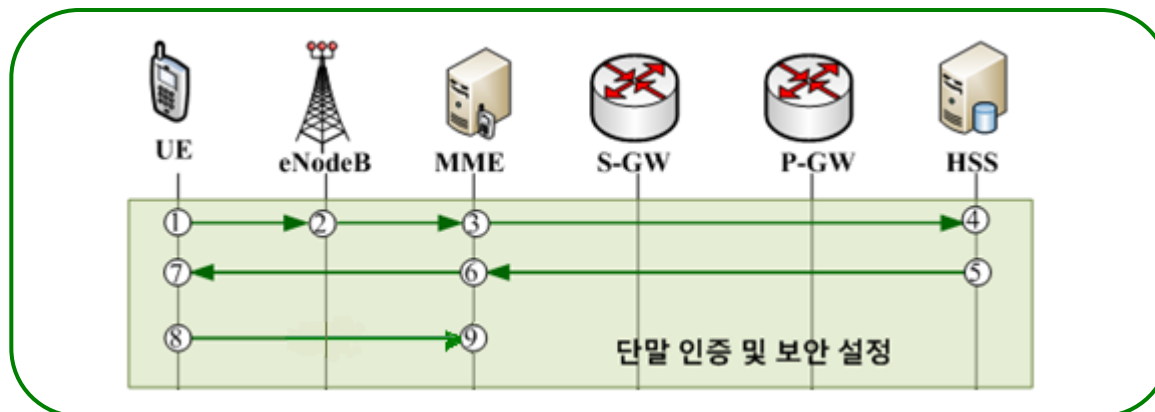
UE는 인증을 위해 USIM에 저장된 가입자 정보를 eNodeB를 통해 MME로 보낸다.

- Step ③ ~ ⑥

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

- Step ⑥ ~ ⑨

정보가 일치하면 MME는 무선링크 보안에 대한 인증절차를 수행한다



Communication Procedure (2)

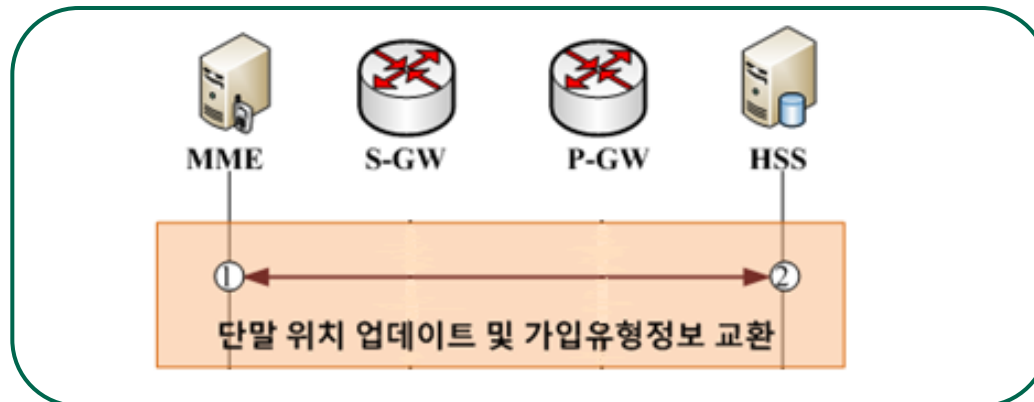
- 단말 위치 갱신 및 가입유형 정보 교환

- Step ①

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

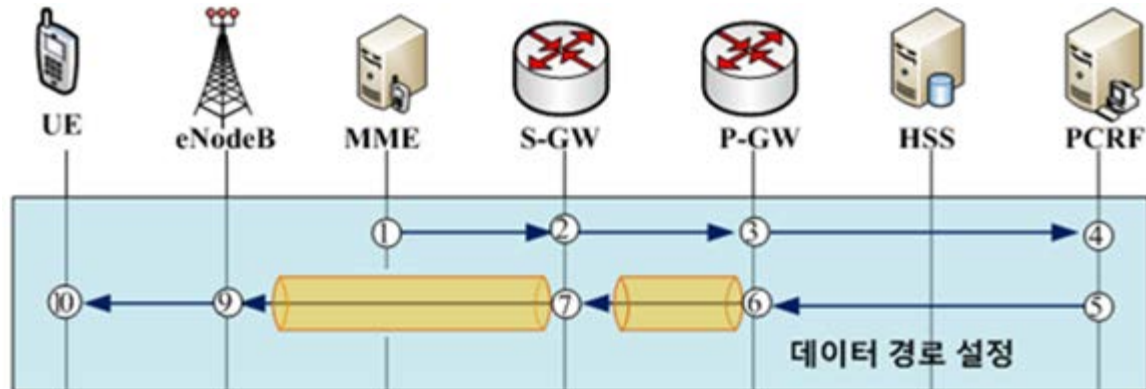
- Step ②

HSS는 MME에게 사용자의 가입유형 정보(어느 서비스에 가입했고 그에 따라 어떤 속도로 인터넷 접속을 지원해야 하는지에 대한 정보)를 전달.
이 정보는 EPC에서의 데이터경로를 설정할 때 사용된다.

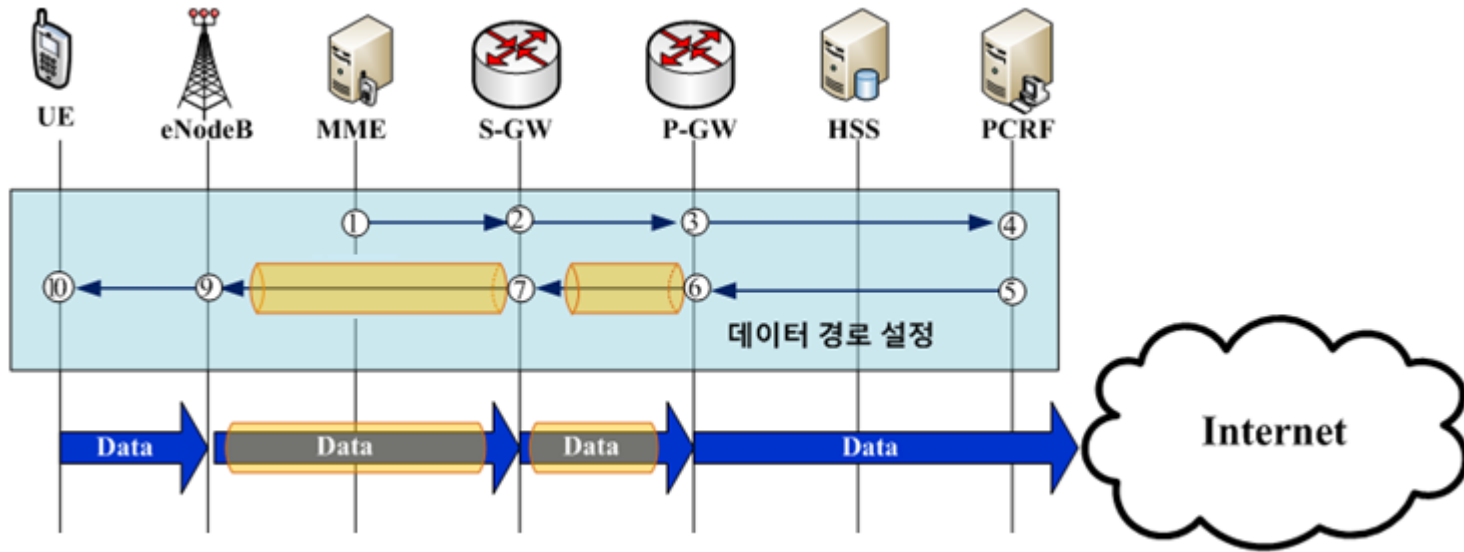


Communication Procedure (3)

- 단말의 데이터 경로 설정 (단말이 외부인터넷에 접속하는 경우에만 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.



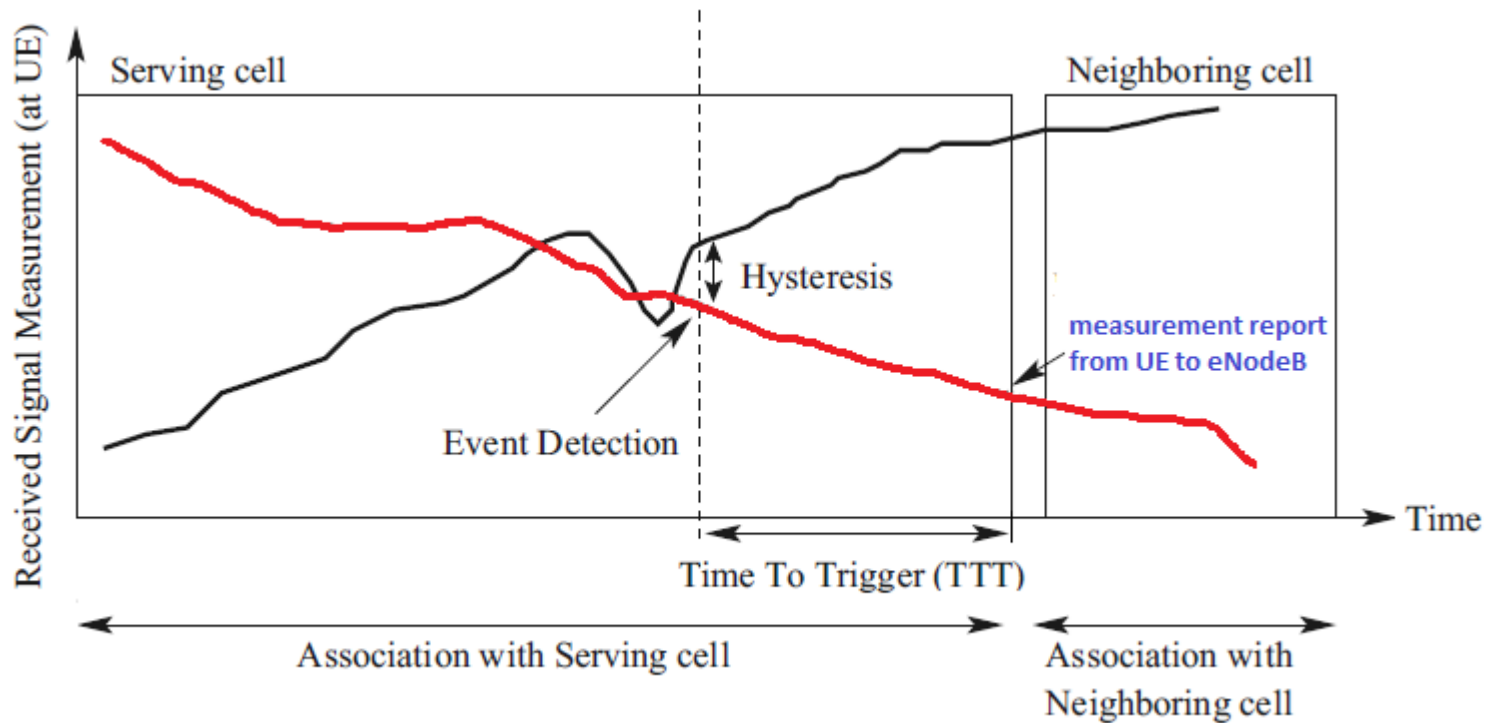
Communication Procedure (4)



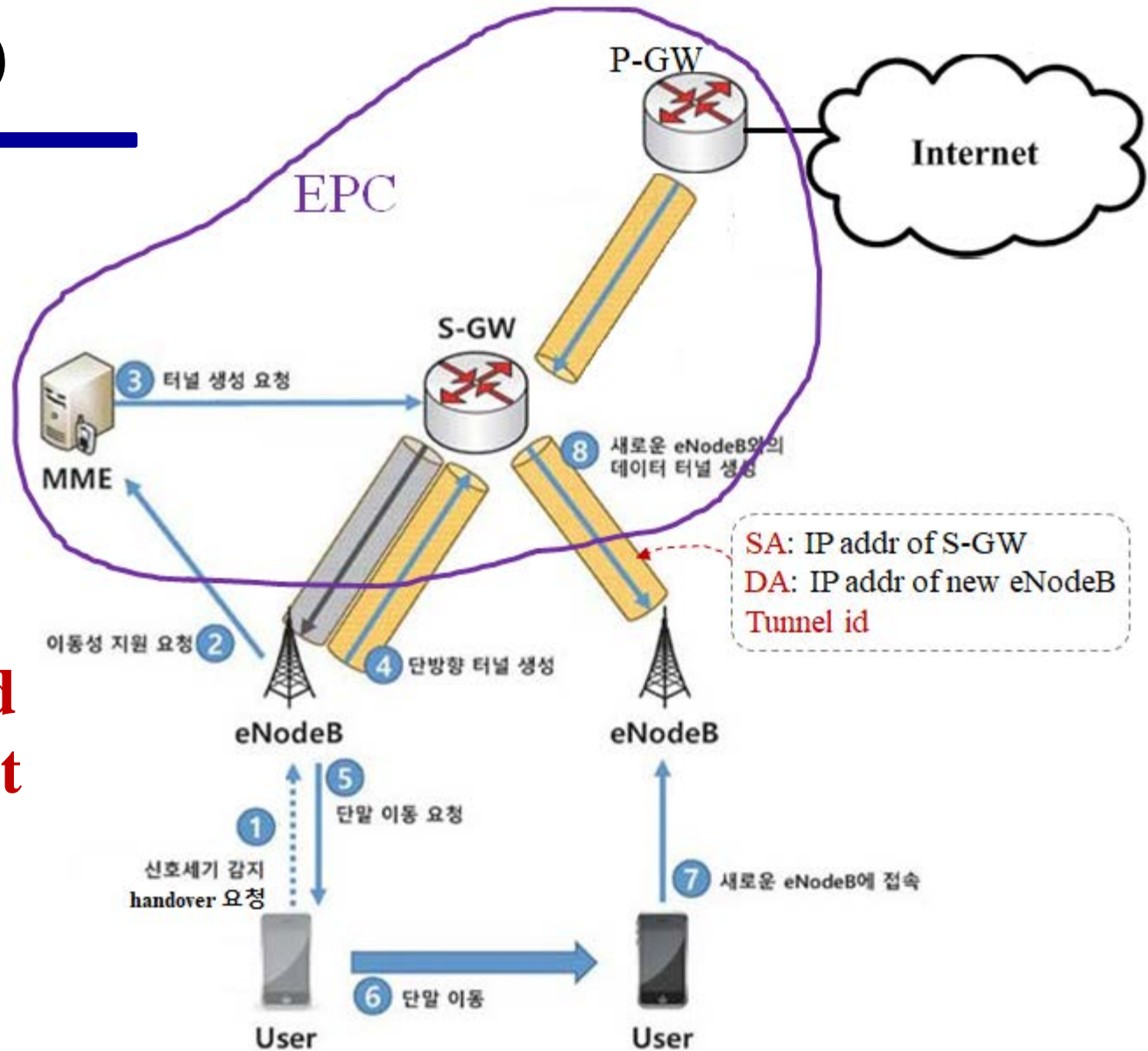
- Step ⑥ ~ ⑨
할당된 IP 주소와 데이터터널 성능에 적용할 정책들이 P-GW, S-GW, eNodeB로 차례로 전달되며 데이터 전달을 위한 터널을 형성한다.
- Step ⑩
eNodeB는 네트워크 사용 준비가 완료되었다는 메시지를 UE에게 보낸다.

Handover (1)

- Handover Triggering
 - Measurement Report



Handover (2)



Tunneling-based Mobility Support

IP address of UE is not changed

Performance Requirements of LTE, LTE-A

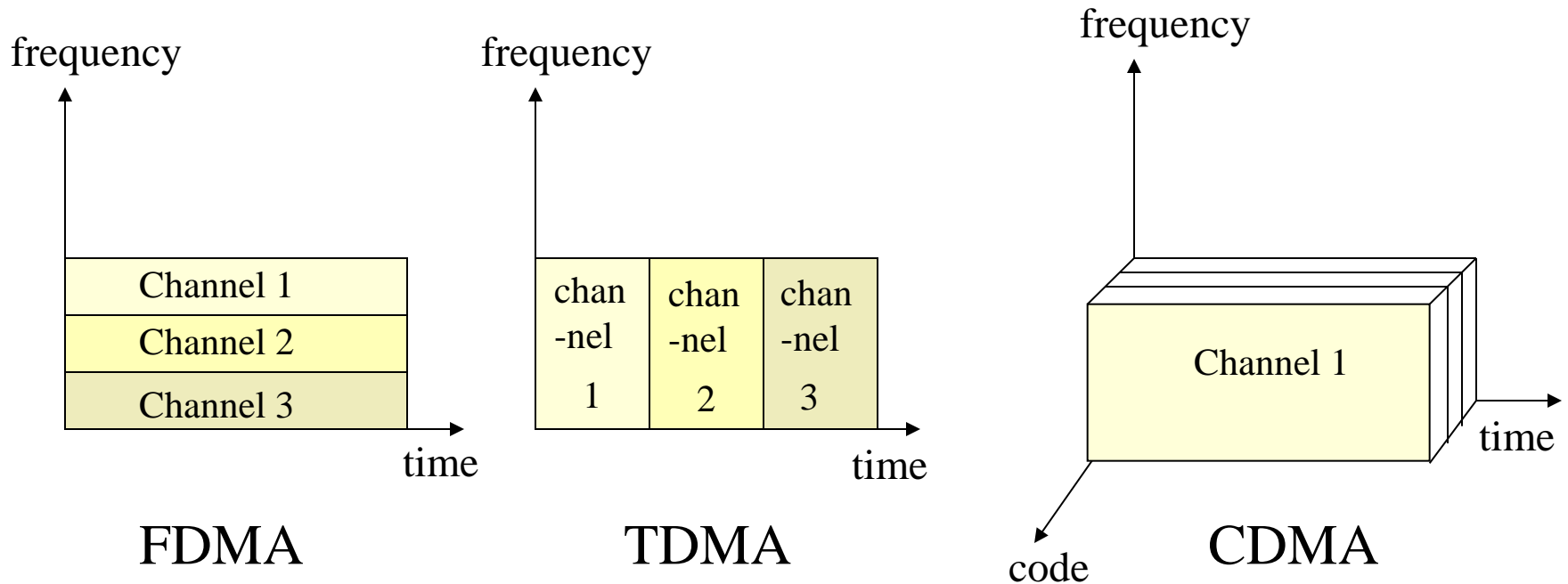
System Performance		LTE	LTE-Advanced
Peak rate	Downlink	100Mbps@20MHz	1Gbps@100MHz
	Uplink	50Mbps@20MHz	500Mbps@100MHz
Delay	Idle to connected	< 100 ms	< 50 ms
	Dormant to active	< 50 ms	< 10 ms
Peak Spectral efficiency	Downlink	5bps/Hz@2x2	30bps/Hz@8x8
	Uplink	2.5bps/Hz@1x2	15bps/Hz@4x4
Mobility		Up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

Antennas



Multiple Access Scheme

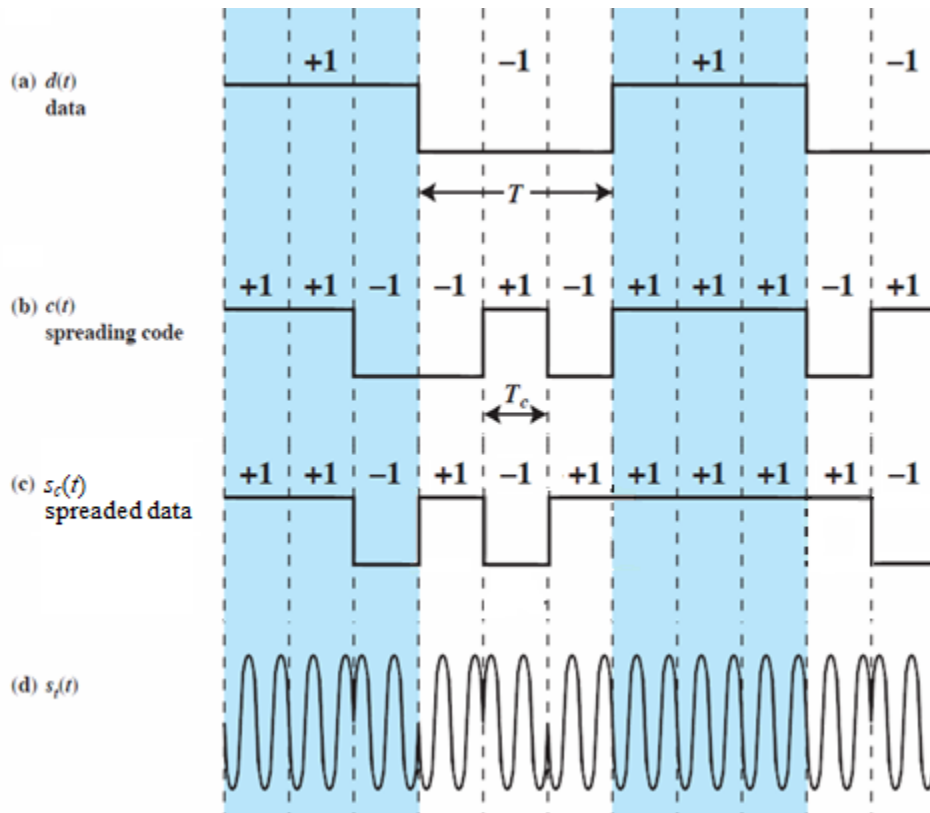
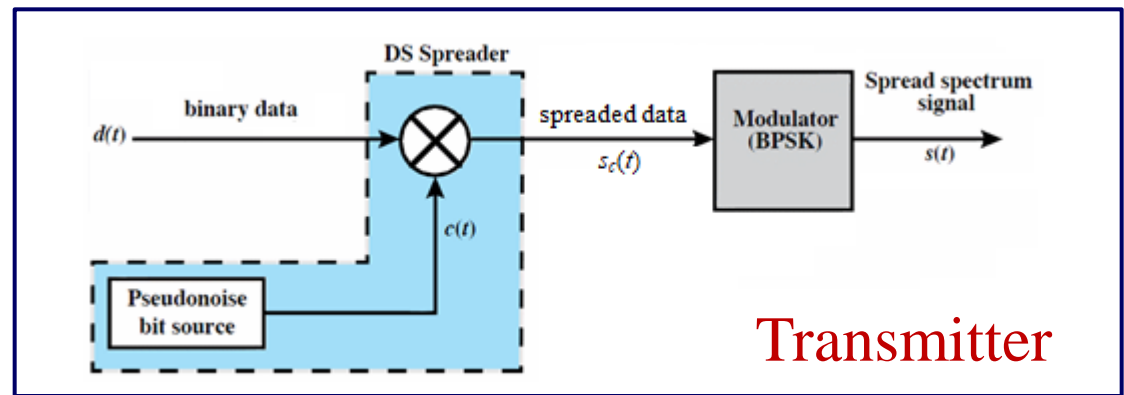
- FDMA: frequency division multiple access
- TDMA: time division multiple access
- CDMA: code division multiple access
- OFDMA: orthogonal FDMA



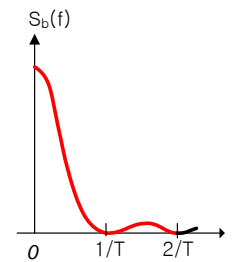
Spread Spectrum & CDMA

- Spread Spectrum
 - Developed initially for military application
 - Spread the information signal over a wider bandwidth
 - Types
 - Frequency hopping (FHSS) : BLE
 - Direct sequence (DSSS)
- Motivation for Spread Spectrum
 - Anti-jamming
 - Low Probability of Intercept
 - Secure Communication (Privacy)
 - Protection against channel fading/interference signal: WiFi
 - Multiple Access: CDMA

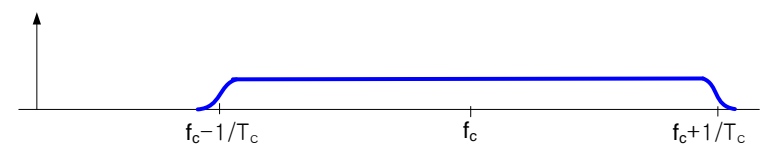
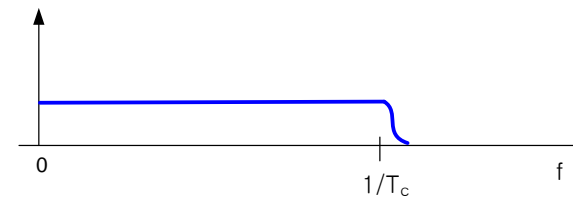
DSSS (1)



time domain



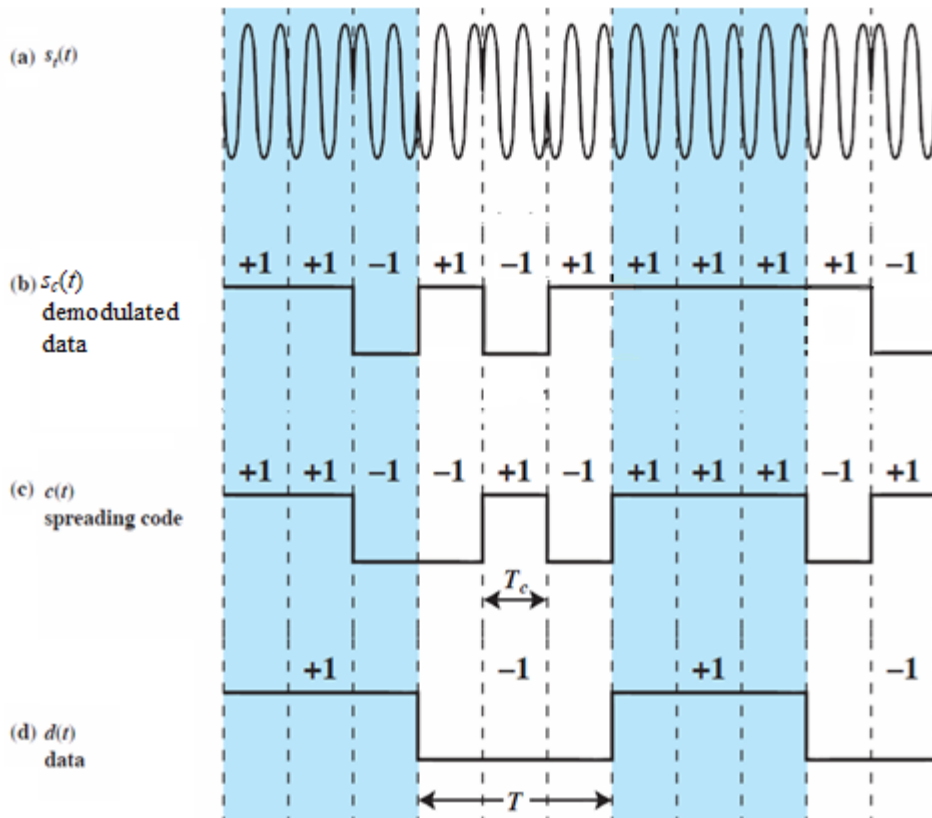
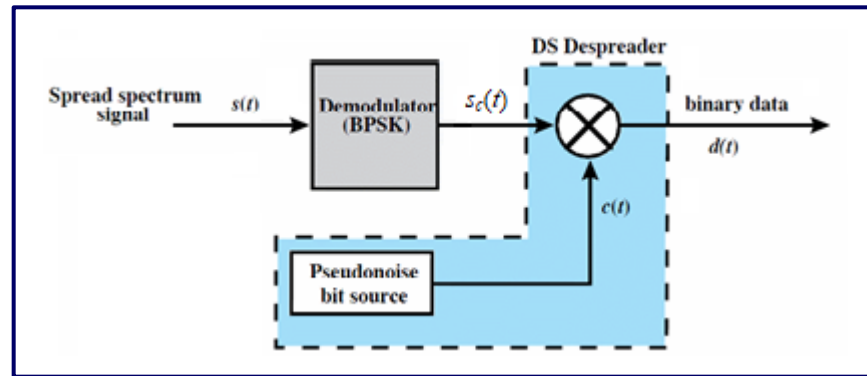
Spreading spectrum



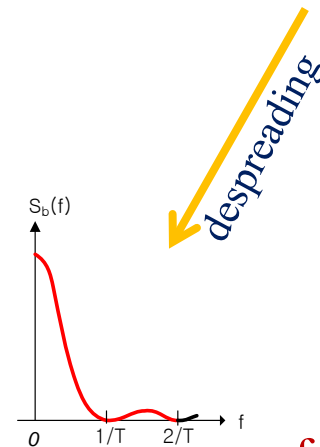
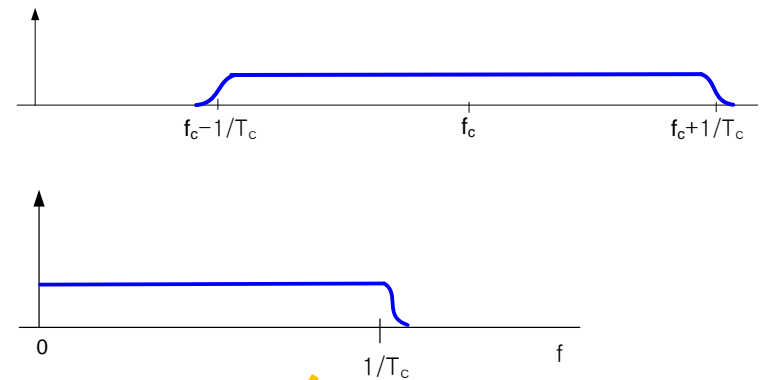
frequency domain

DSSS (2)

Receiver

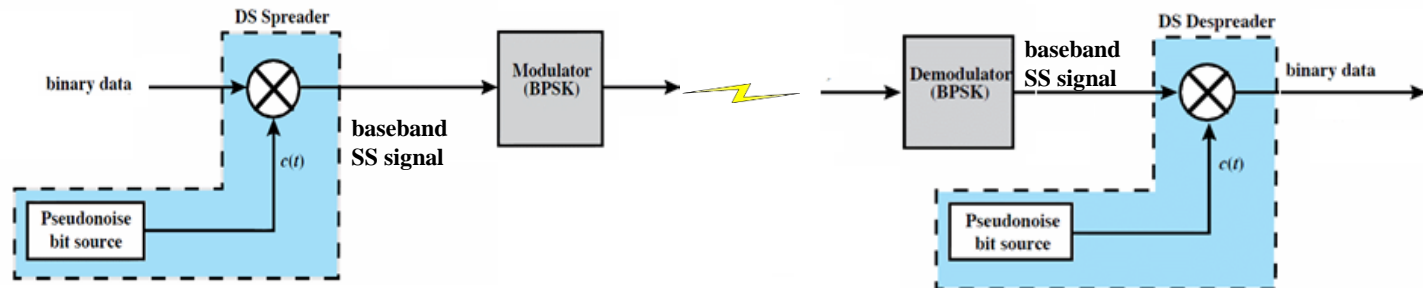


time domain

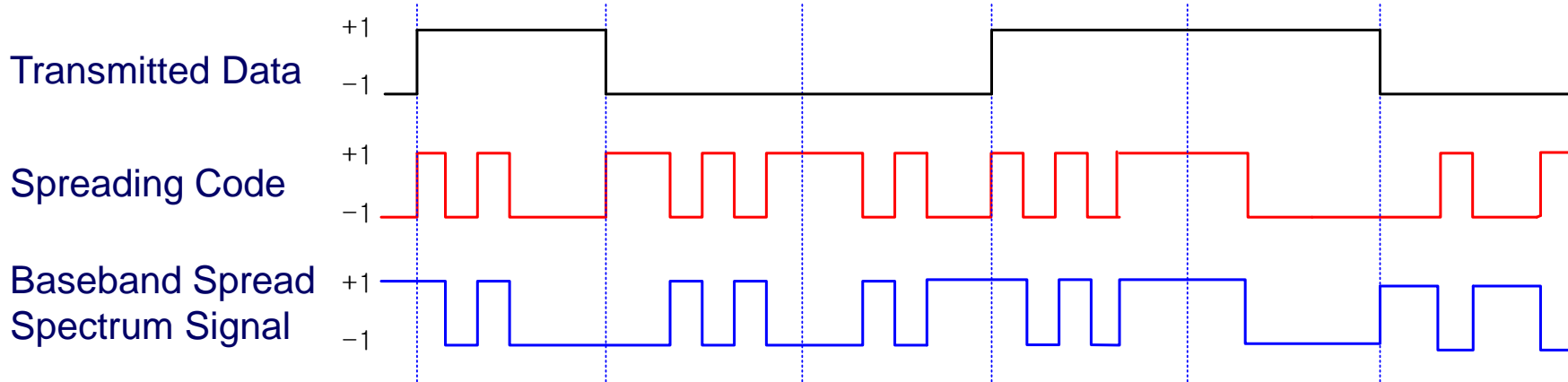


frequency domain

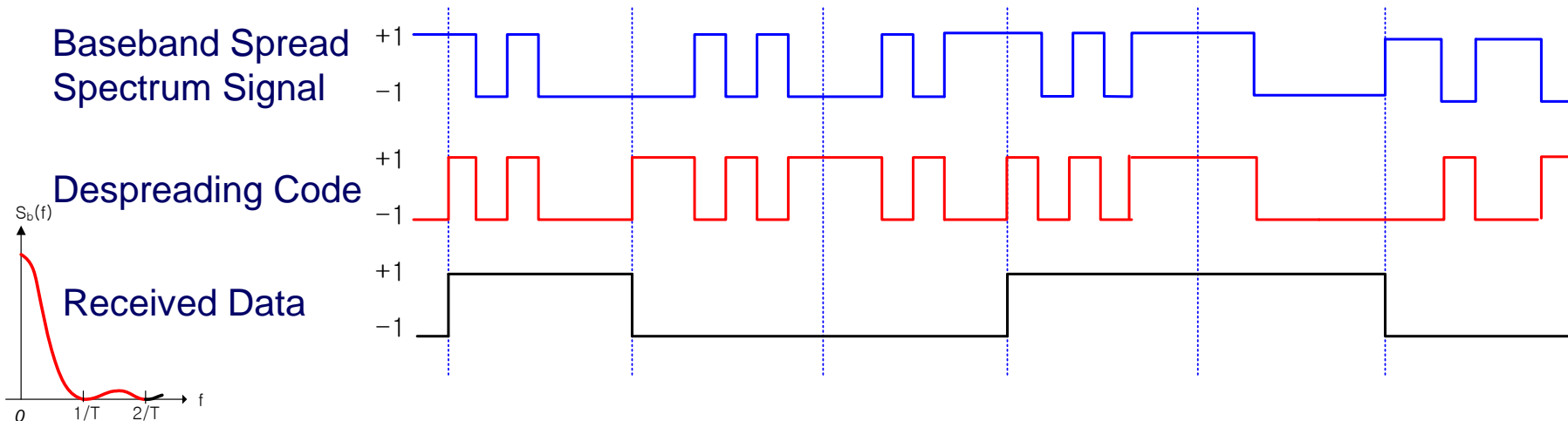
DSSS (3)



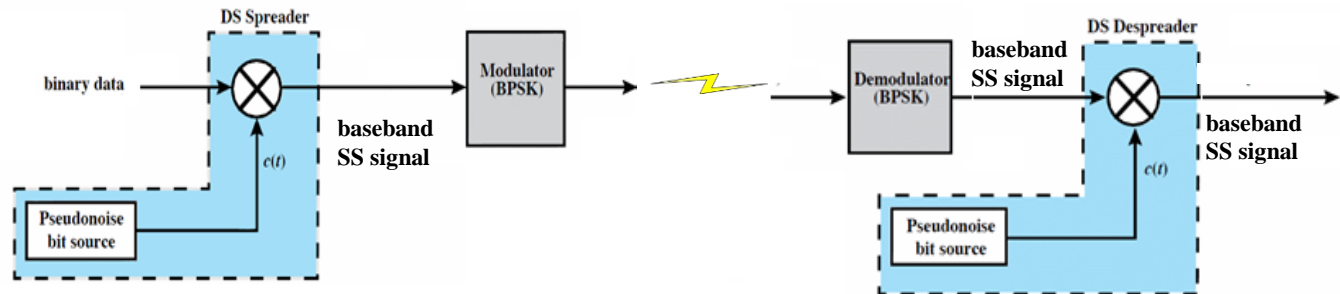
Transmitter



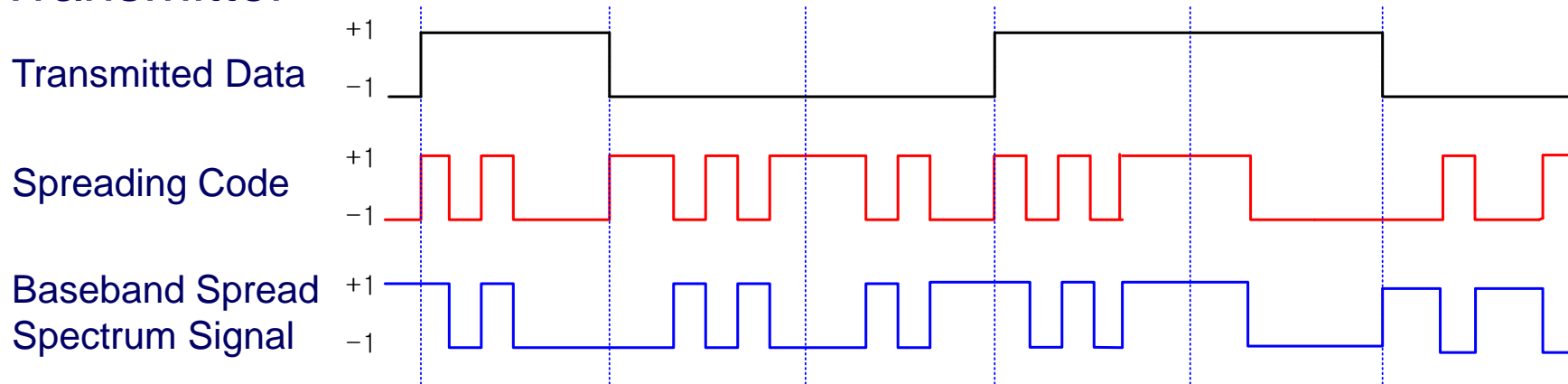
Receiver 1 (same spreading code)



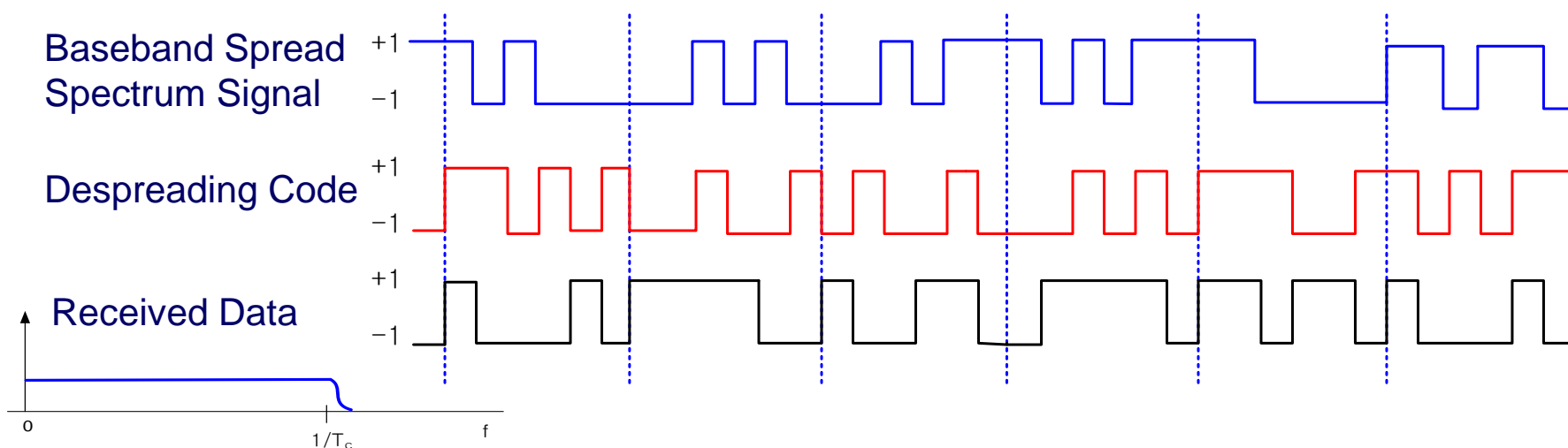
DSSS (4)



Transmitter

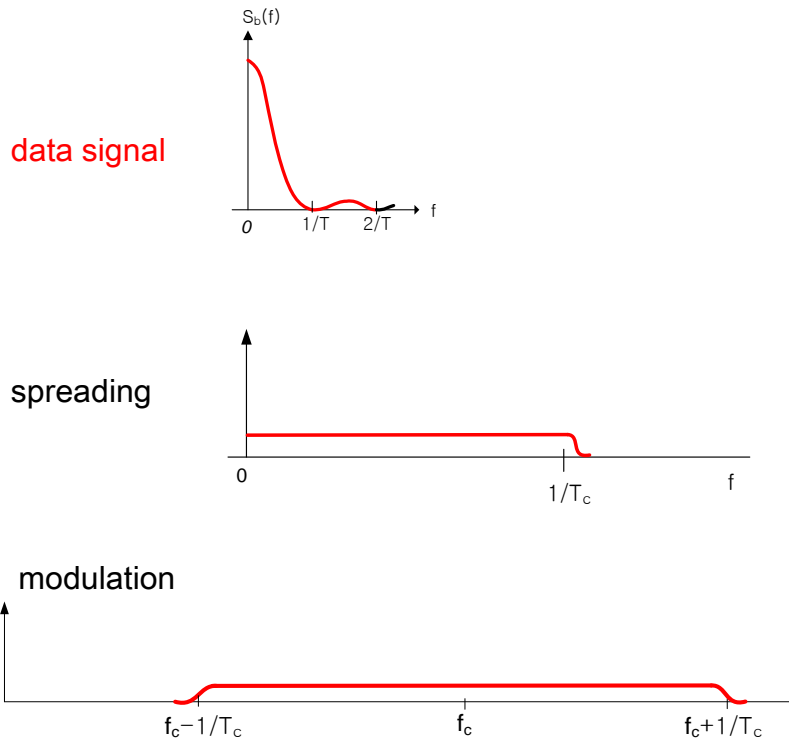


Receiver 2 (different spreading code)

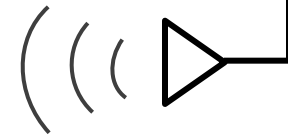
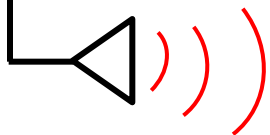
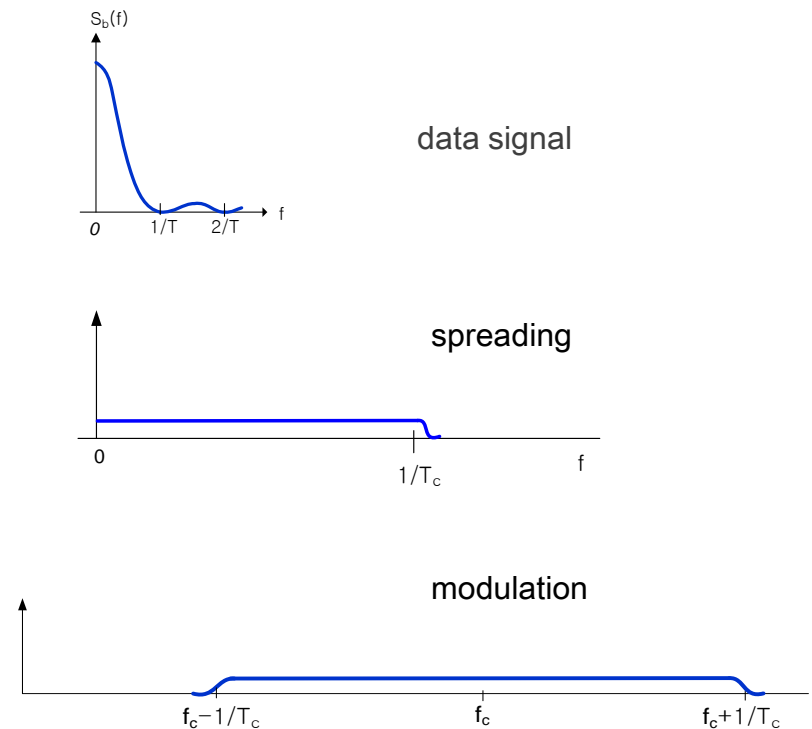


Interference in CDMA System (1)

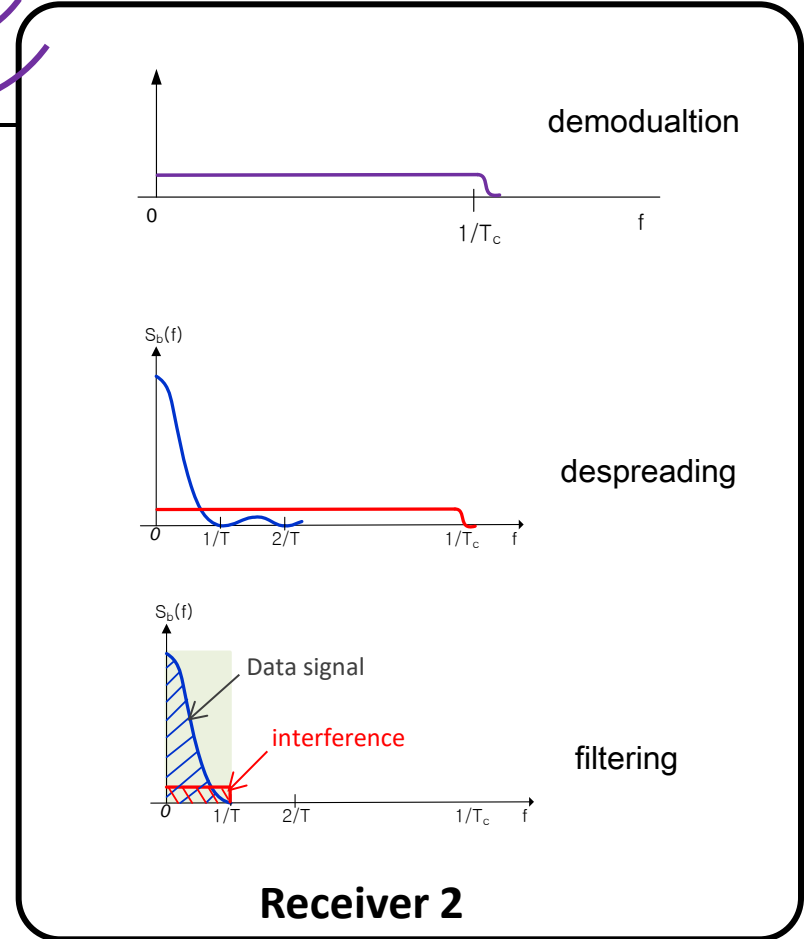
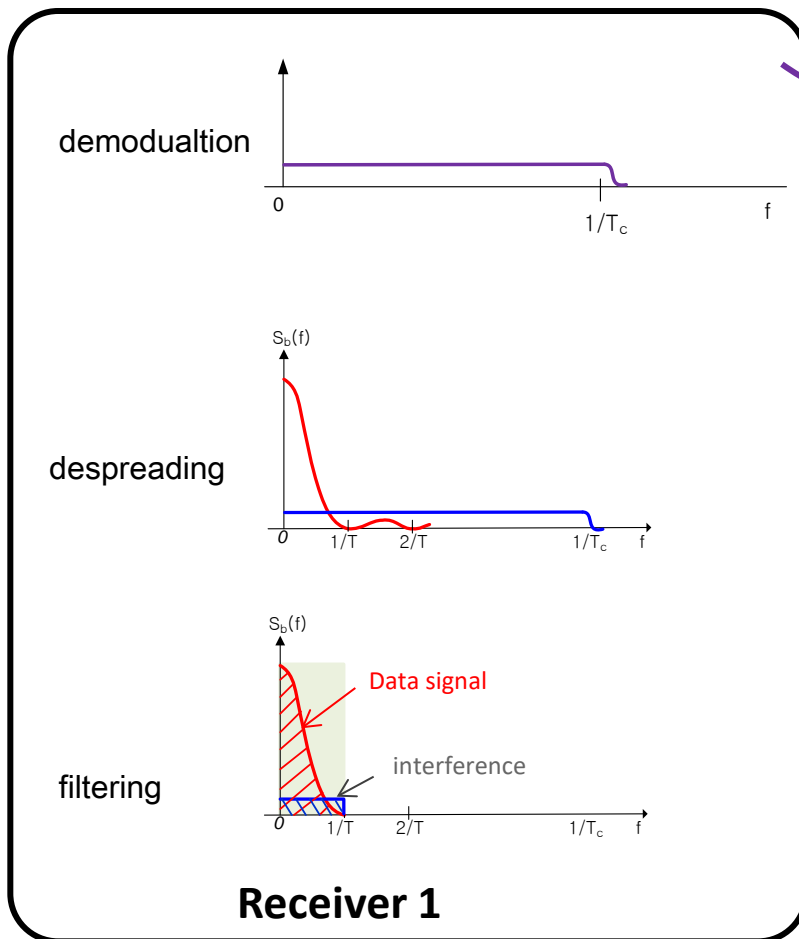
Transmitter 1



Transmitter 2

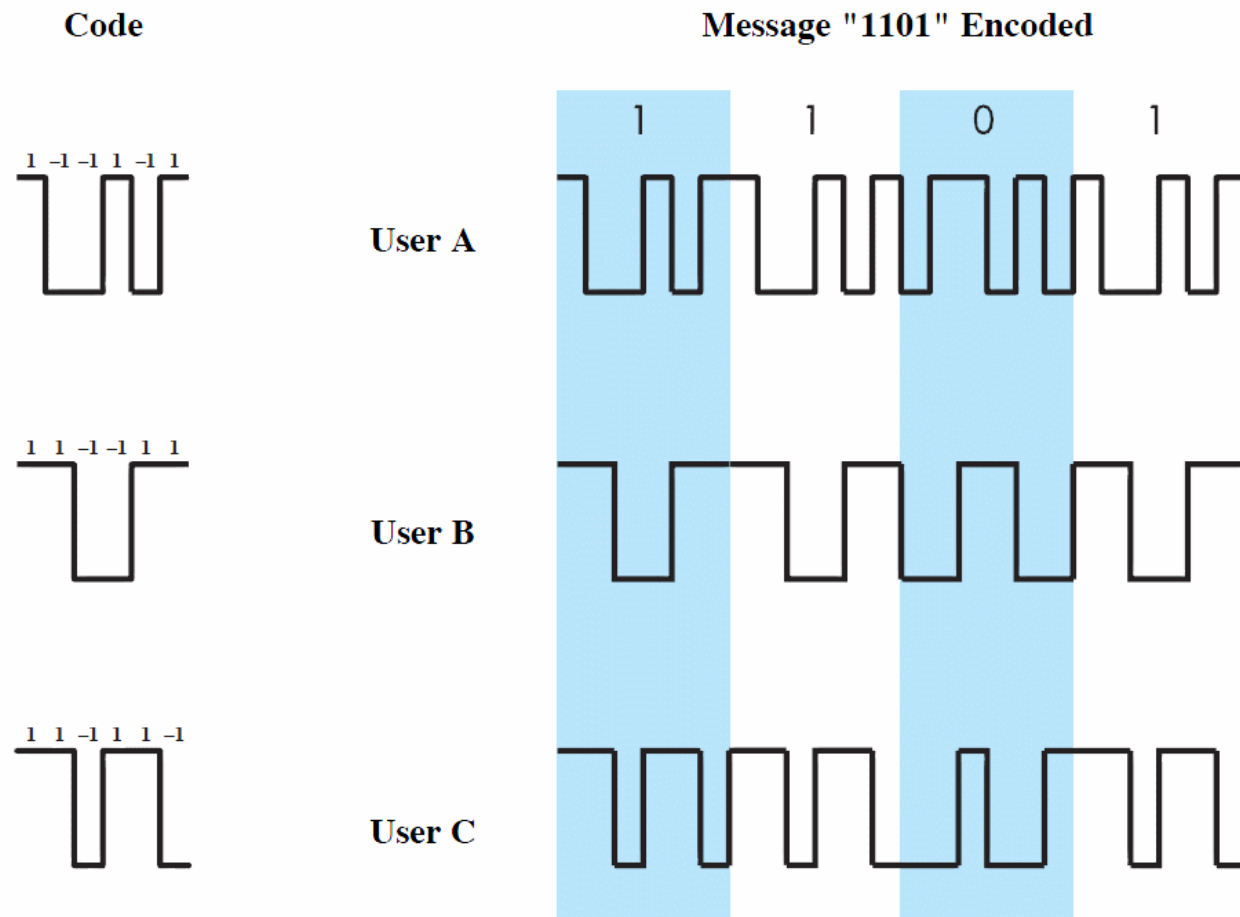


Interference in CDMA System (2)

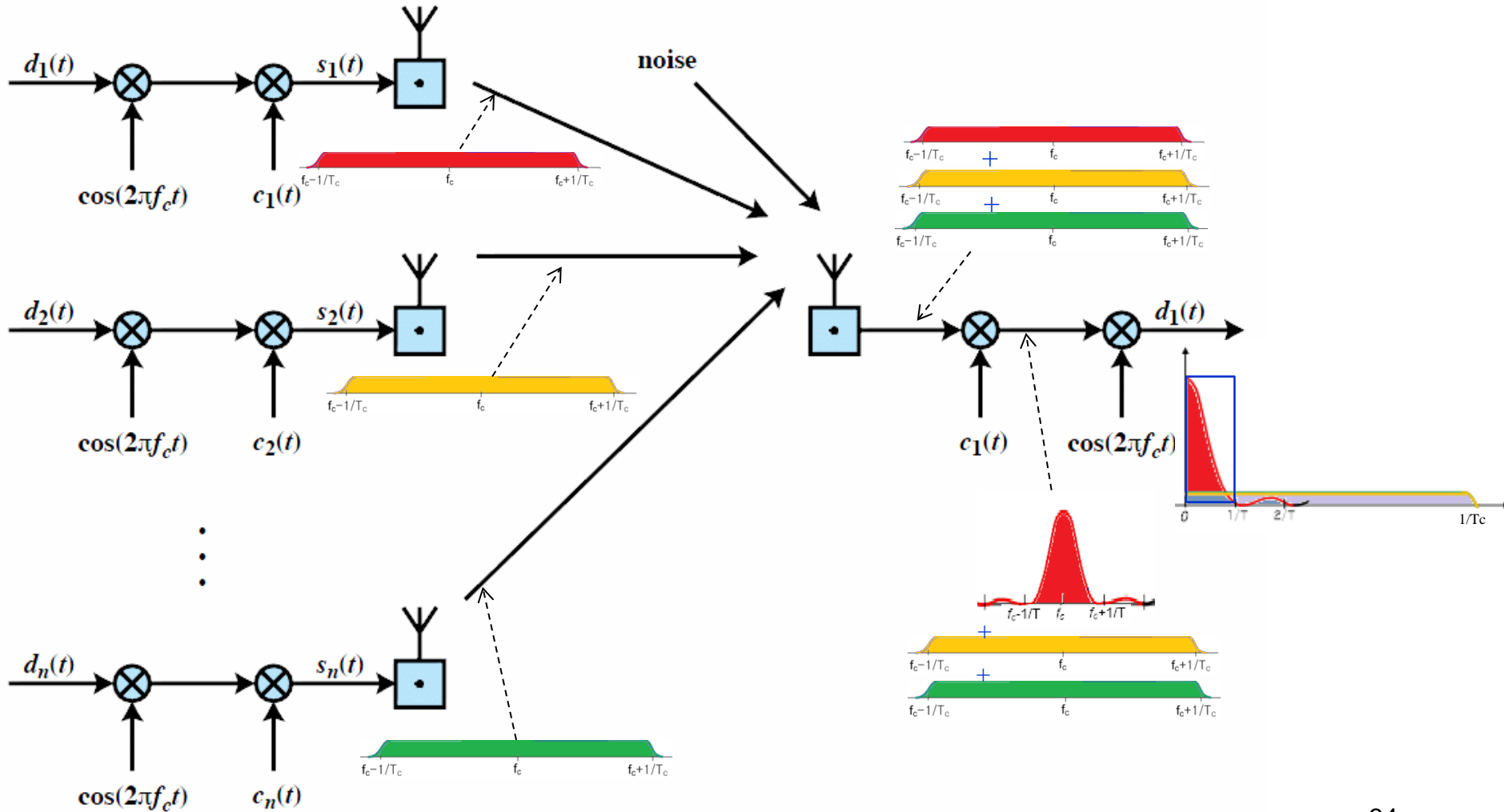


Code Division Multiple Access (1/2)

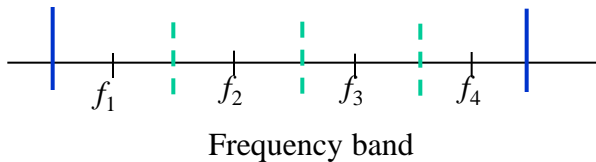
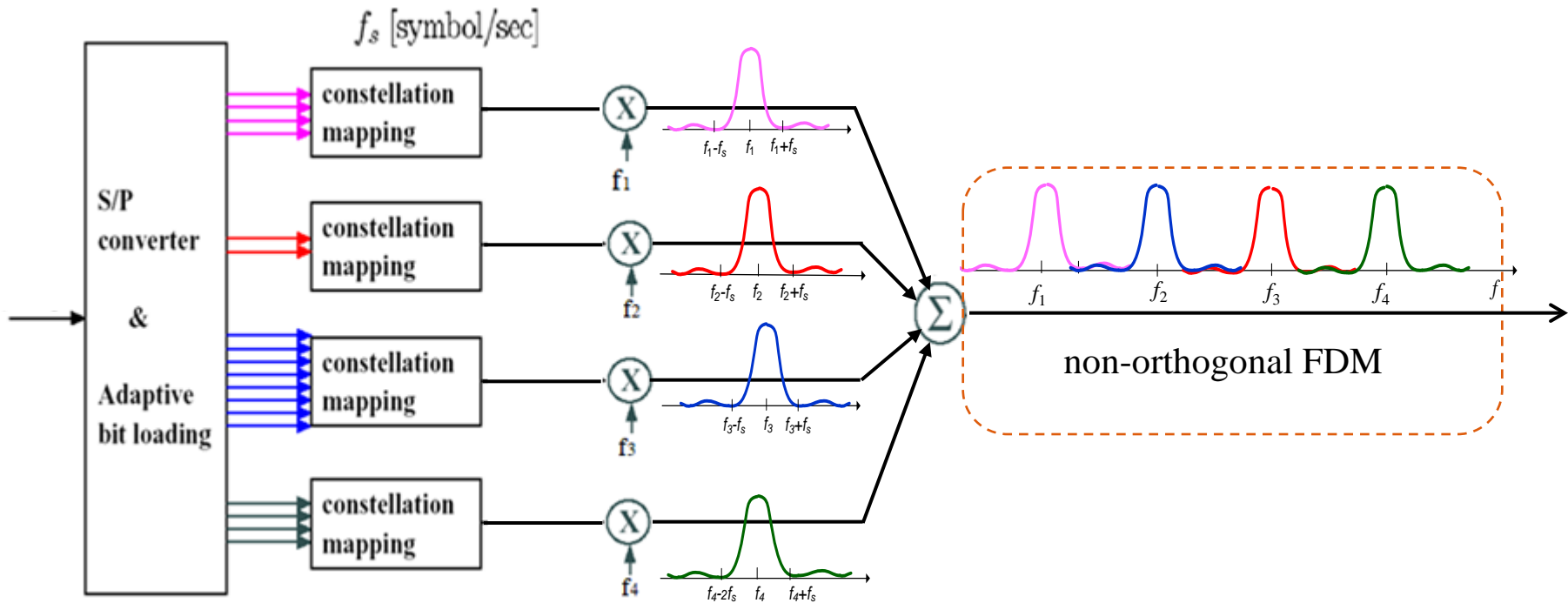
- Different code to each user



Code Division Multiple Access (2/2)



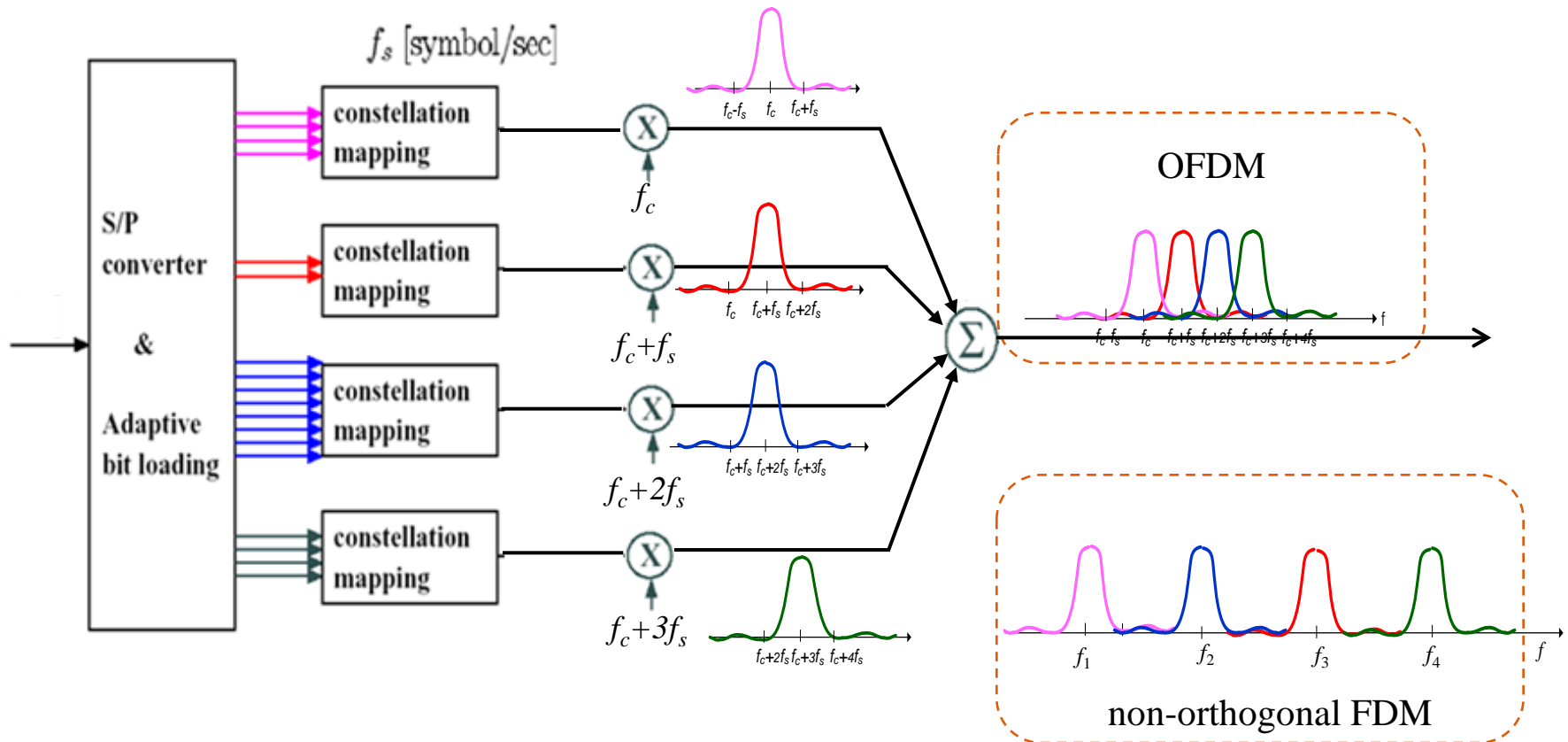
Non-orthogonal FDM



$$\left. \begin{array}{l} f_s \text{ constellation symbols/second} \\ \text{one constellation symbols per } T_s \end{array} \right\} T_s = \frac{1}{f_s}$$

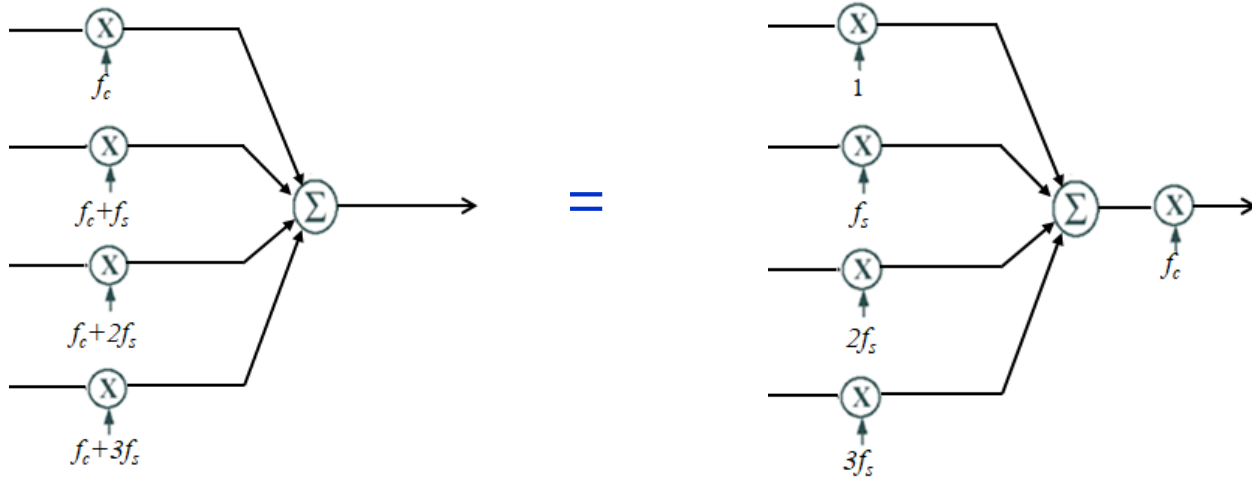
0110111010100001010100000010001001000001010000101 \rightarrow

Orthogonal FDM

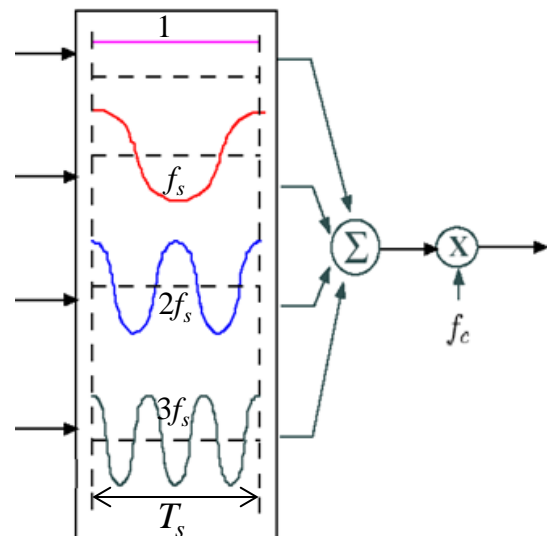


f_s : signaling rate ($1/T_s$)
(constellation symbols/second)

OFDM

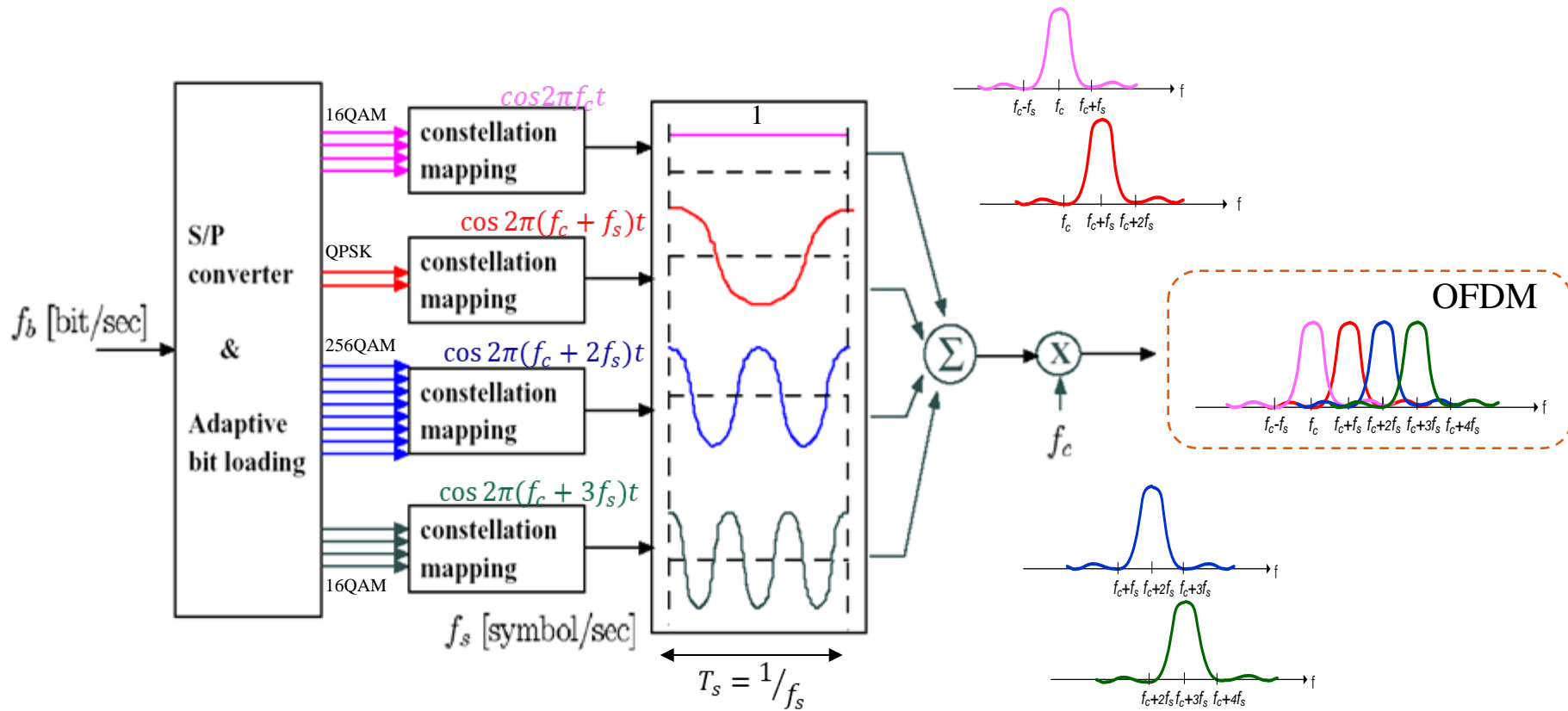


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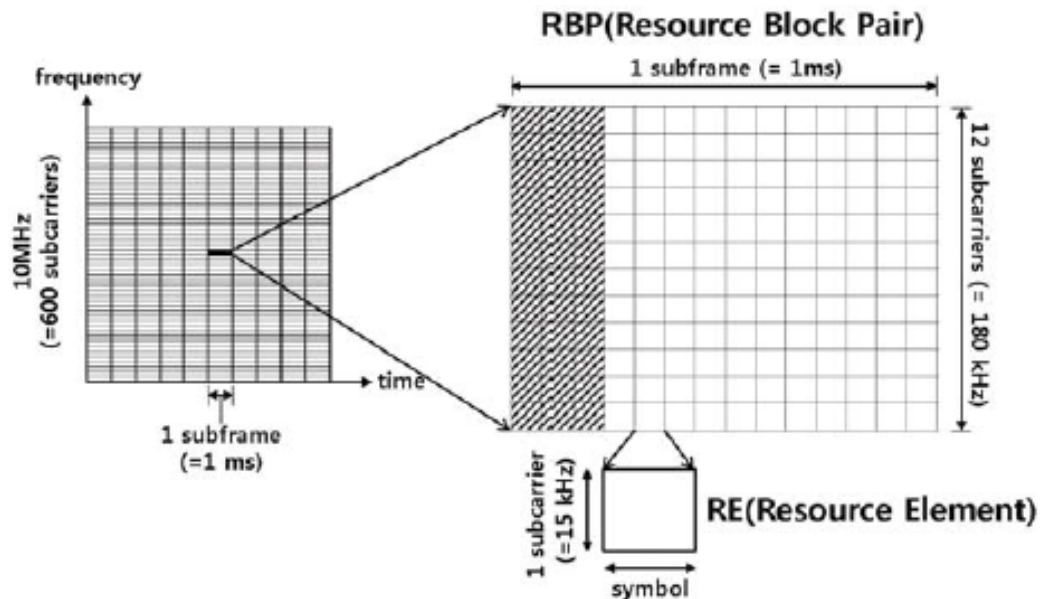
$$T_s = \frac{1}{f_s}$$

OFDM

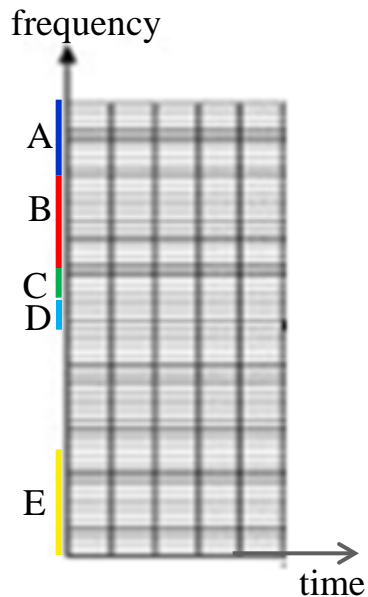
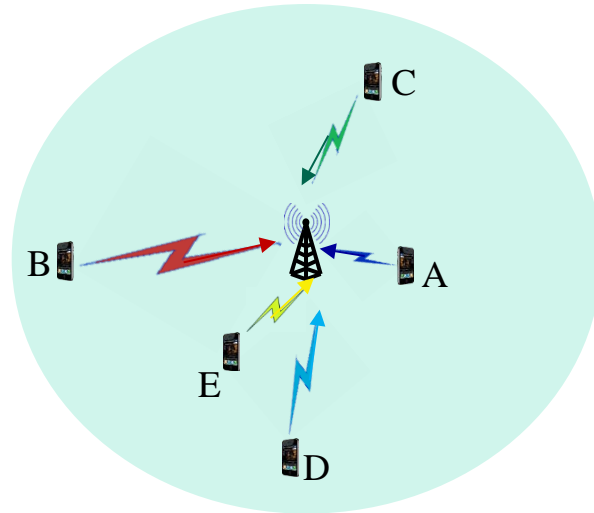


Example: LTE-FDD Downlink

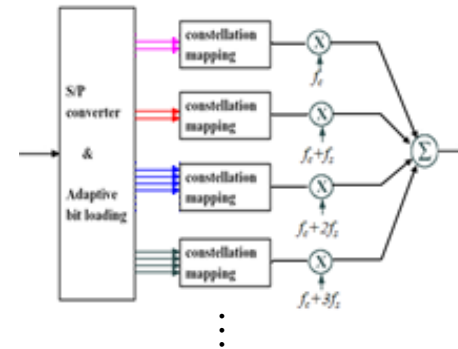
- **Downlink Frame (time) Format**
 - 15 kHz subcarrier spacing
 - 10 ms frame, 10 subframes/frame, 2 slots/subframe, 7 OFDM symbols/slot, 14 OFDM symbols/subframe
 - Resource Element (RE): one subcarrier and one OFDM symbol time
 - Resource Block (RB): 12 subcarriers and one slot time, scheduling unit



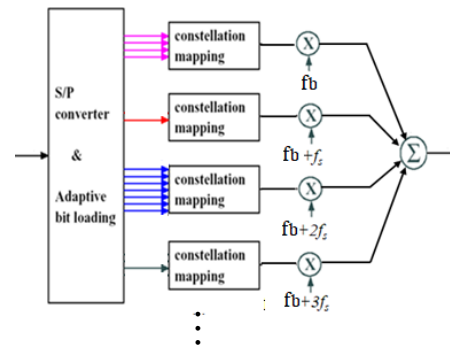
Example of OFDMA in Uplink



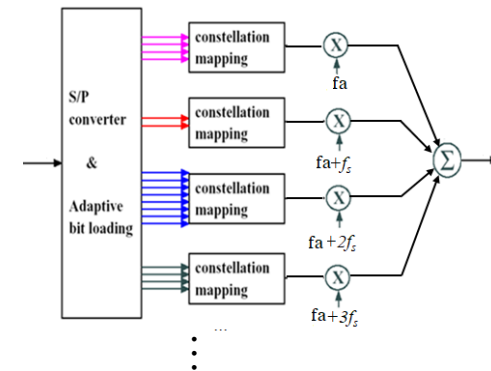
User A



User B



User C



* LTE Uplink MAC: SC-FDMA (not OFDMA)