Chapter 5

Multiple Access Techniques for Wireless Communications

Contents of Chapter 5

1. Introduction to Multiple Access
2. FDMA, TDMA and CDMA
3. Packet Radio
4. Capacity of Cellular Systems

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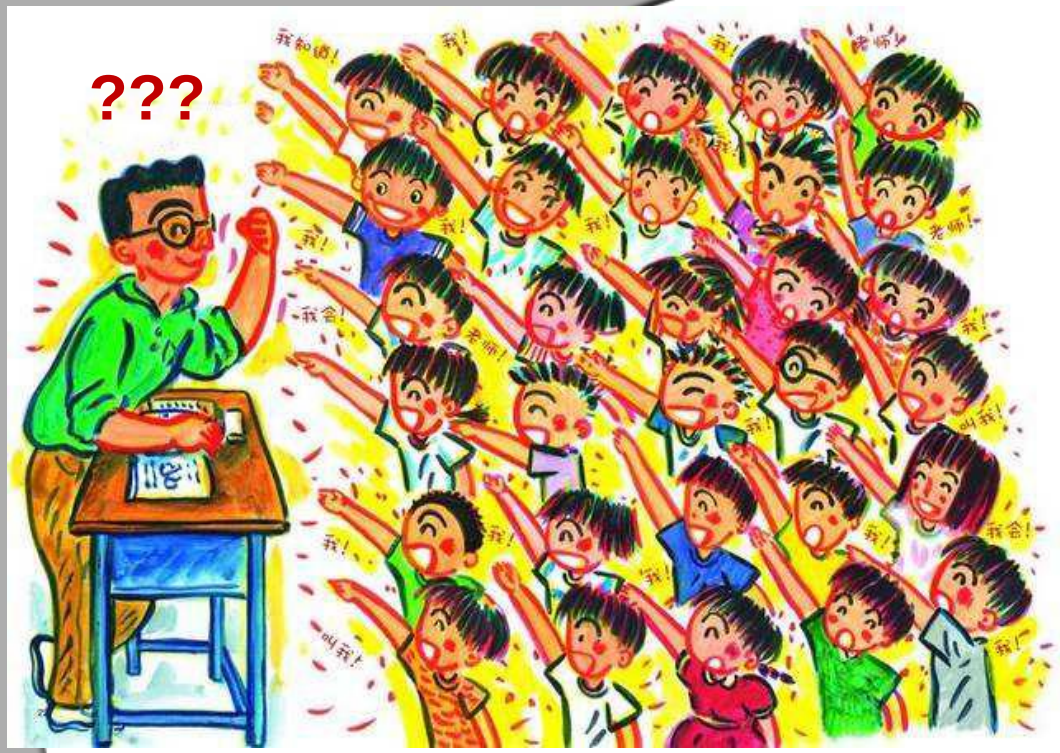
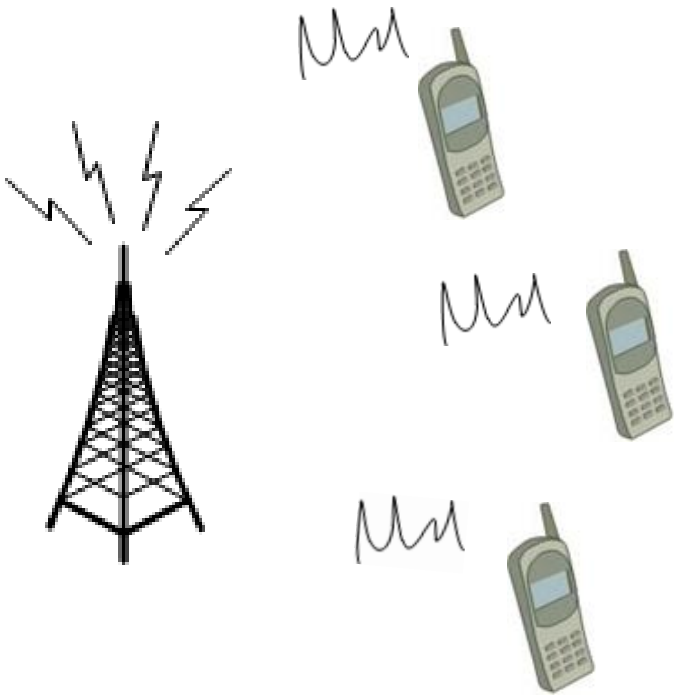
Multiple Access





***Multiple Access* : enables efficient sharing of channels for multiple users.**

What is multiple access ?

- 多址（**MA:Multiple Access**）技术的本质是在共享通信资源的基础上，使系统中各个用户能够实现有效的互通互联的技术。互通互联的有效性指的是在保证用户通信的前提下尽可能地提高信道的使用效率。

Multiple access

According to whether there are collisions in channels, the multiple access techniques can be classified into:

- Non-collision multiple access
- Collision multiple access

Multiple access

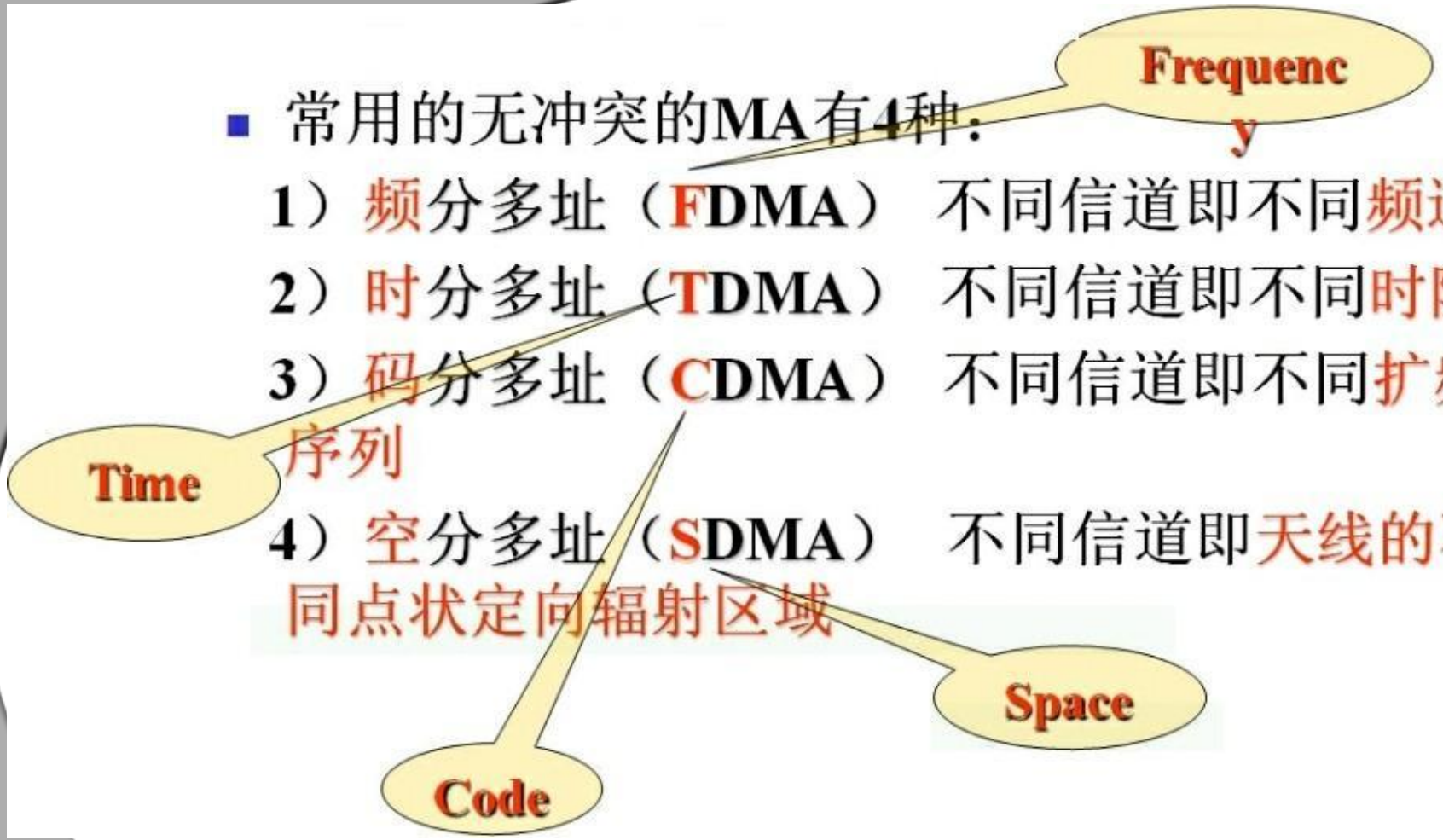
- 常用的无冲突的MA有4种：

1）频分多址（FDMA） 不同信道即不同频道

2）时分多址（TDMA） 不同信道即不同时隙

3）码分多址（CDMA） 不同信道即不同扩频序列

4）空分多址（SDMA） 不同信道即天线的不同点状定向辐射区域



Multiple access

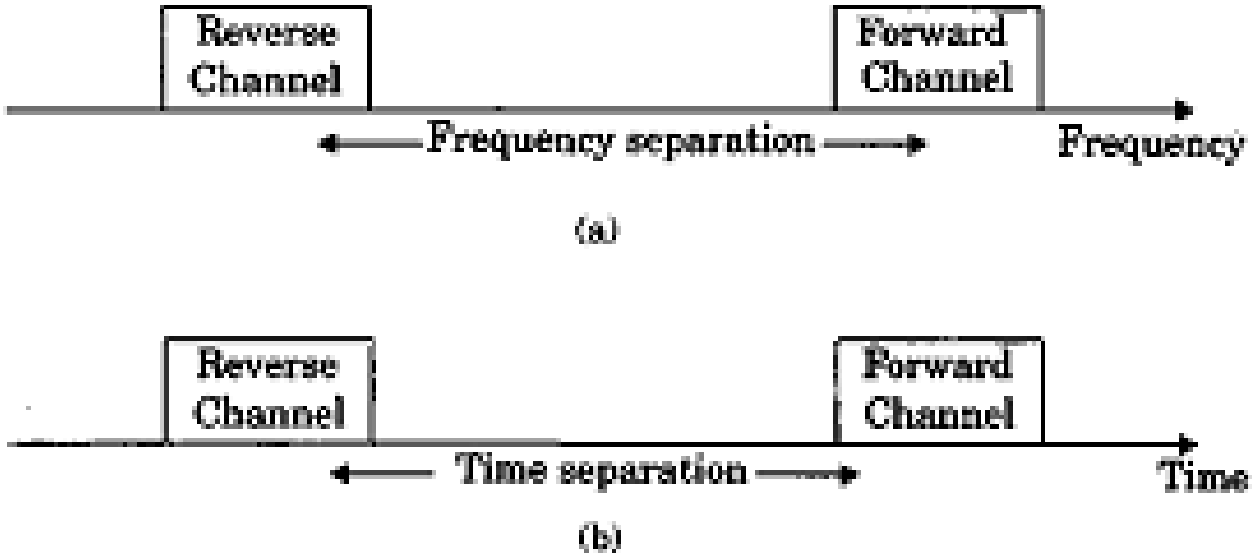
- 常用的允许冲突的MA方式包括：
  1）纯ALOHA（Pure ALOHA）
  2）时隙ALOHA（Slotted ALOHA）
  3）载波侦听多址（CSMA）

—— **Packet Radio：分组无线电**

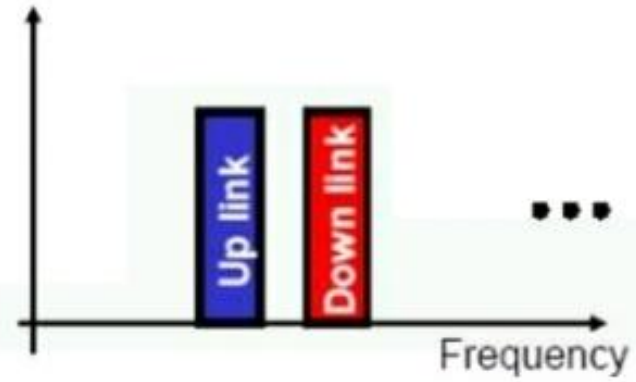
Duplexing

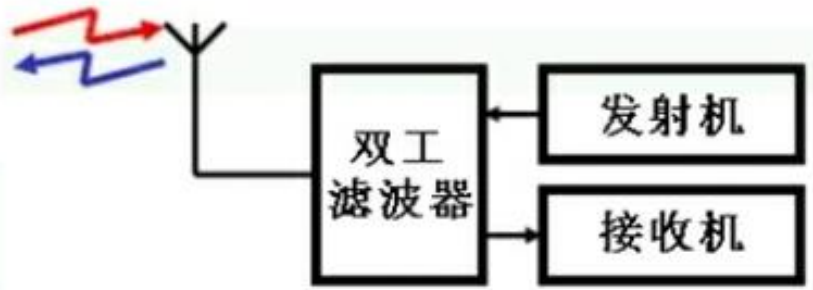
Frequency domain techniques : FDD

Time domain techniques : TDD



FDD systems

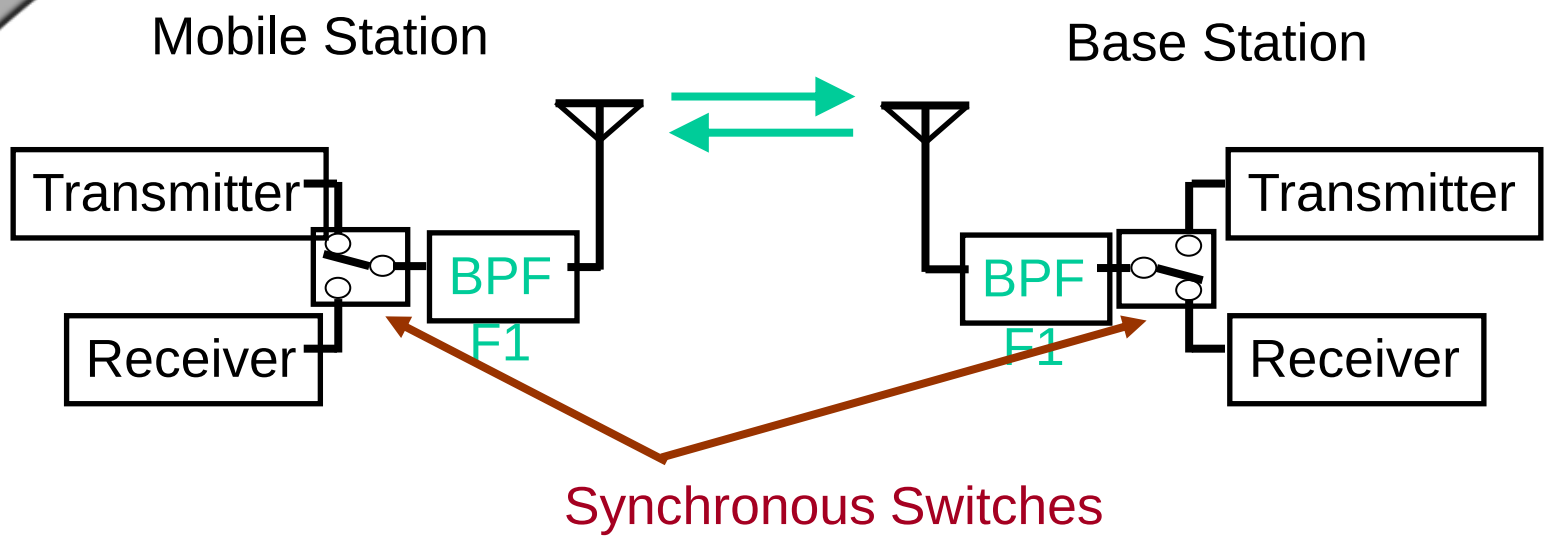




FDD提供了更为复杂的全双工实现方案（要使用双工滤波器）。

它可以用于连续传输。

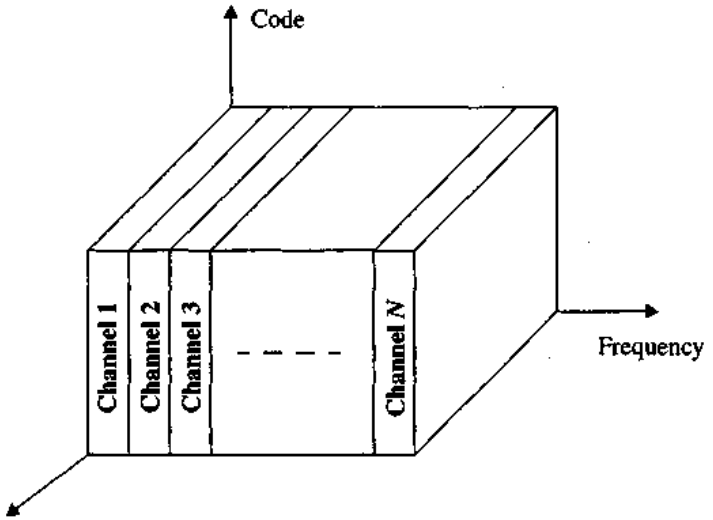
TDD systems



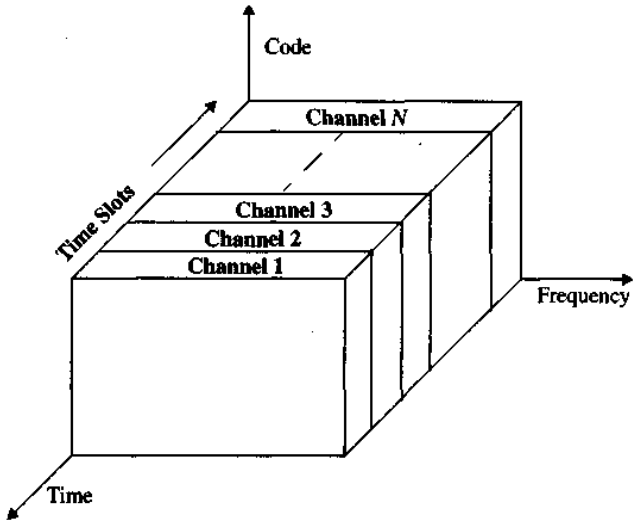
TDD提供了复杂度较低的全双工实现方案（使用双工开关）

但不能用于连续传输

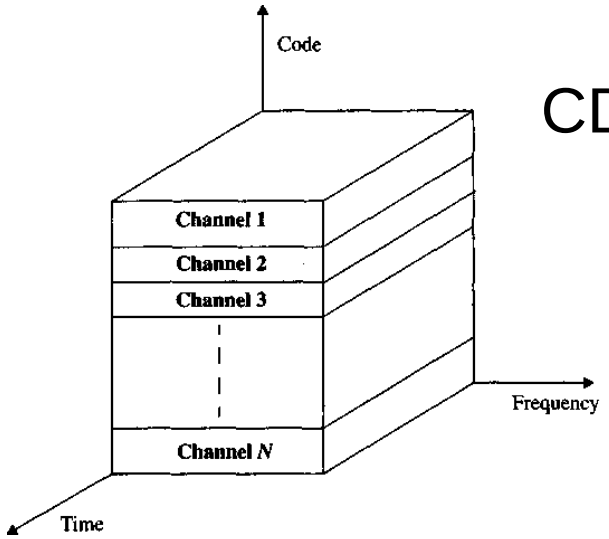
FDMA



TDMA



CDMA



Multiple ascess technologies used in different wireless systems

Cellular Systems	MA Technique
AMPS (Advanced Mobile Phone system)	FDMA / FDD
GSM (Global System for Mobile)	TDMA / FDD
IS – 95 (U.S Narrowband Spread Spectrum)	CDMA / FDD
WCDMA	CDMA / FDD,CDMA/TDD
TD-SCDMA	CDMA / TDD
Cdma2000	CDMA / FDD

Chapter 5

1. Introduction to Multiple Access
2. **FDMA, TDMA and CDMA**
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FDMA

(PP.450)

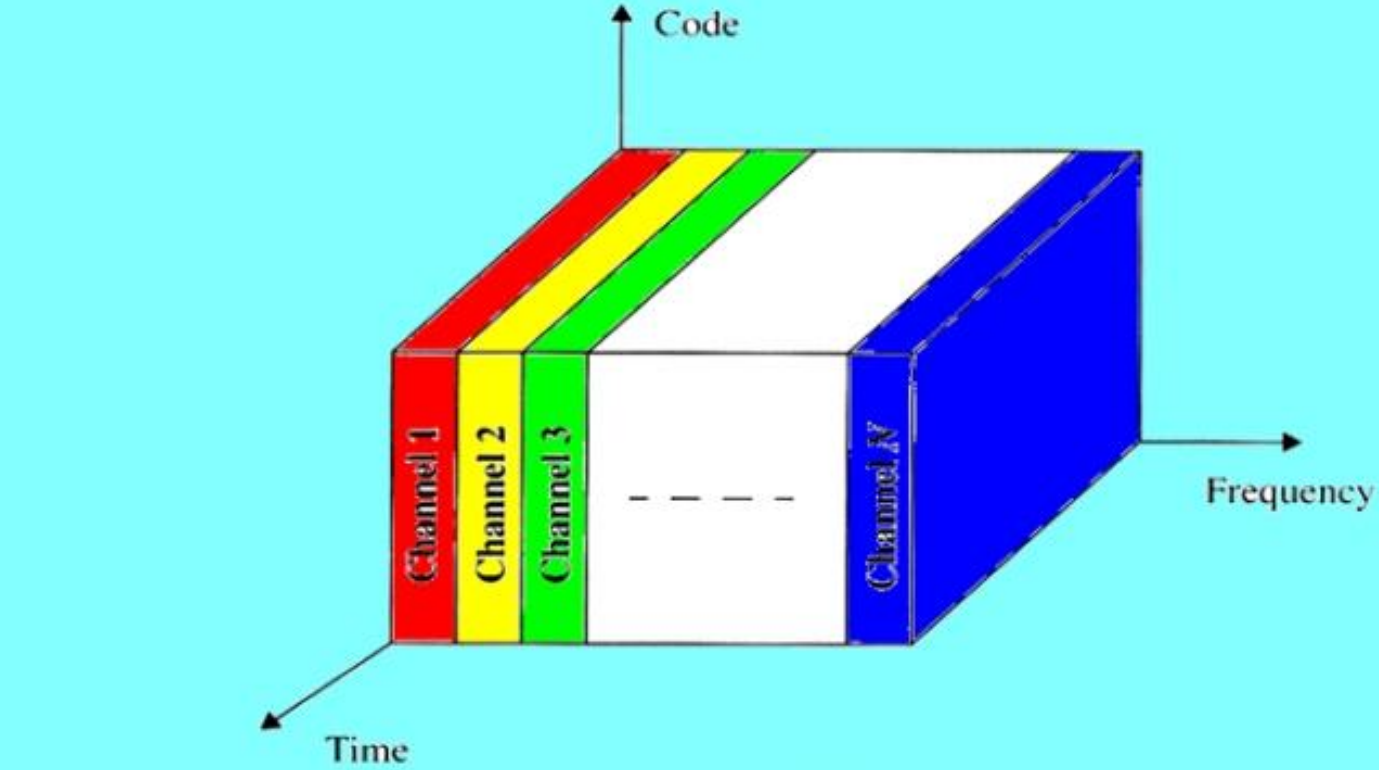


图 9.2 FDMA 中，不同的信道就是不同的频道

FDMA

Separation of the whole spectrum into smaller frequency bands

A channel gets a certain band of the spectrum for the whole time

- Each user is allocated a unique frequency band or channel.

  These channels are assigned on demand to users who request service.

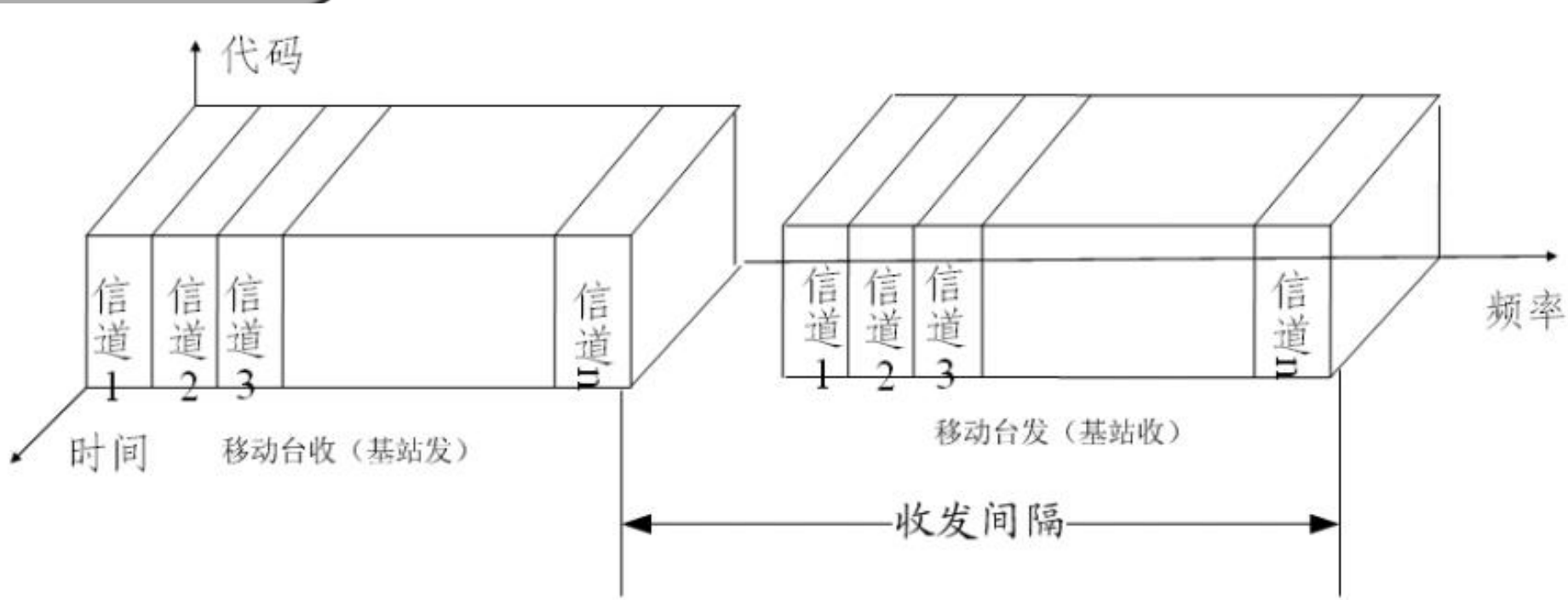
- The bandwidth of FDMA channels is narrow (30 KHz) since it supports only one call/ carrier.

- ISI is low since the symbol time is large compared to average delay spread ➔ No equalization is required.

FDMA

- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.
- The FDMA mobile unit uses duplexers.
- FDMA requires tight RF filtering to minimize adjacent channel interference.
- Nonlinear Effects in FDMA: Intermodulation frequency

FDMA & FDD



Example 9.2

(PP.328)

- 如果为一家美国AMPS蜂窝系统运营商的每个单工波段分配了12.5MHz，并且如果系统带宽B_t为12.5MHz，分配频谱时的保护带宽B_{guard}为10KHz，信道带宽B_c为30KHz，求FDMA系统中的有效信道数。
- 解：FDMA系统中有效信道数为

$$N = (B_t - 2B_{guard}) / B_c$$

$$= 12.5*10^6 - 2(10*10^3)/30*10^3 = 416$$

TDMA

(PP.328)

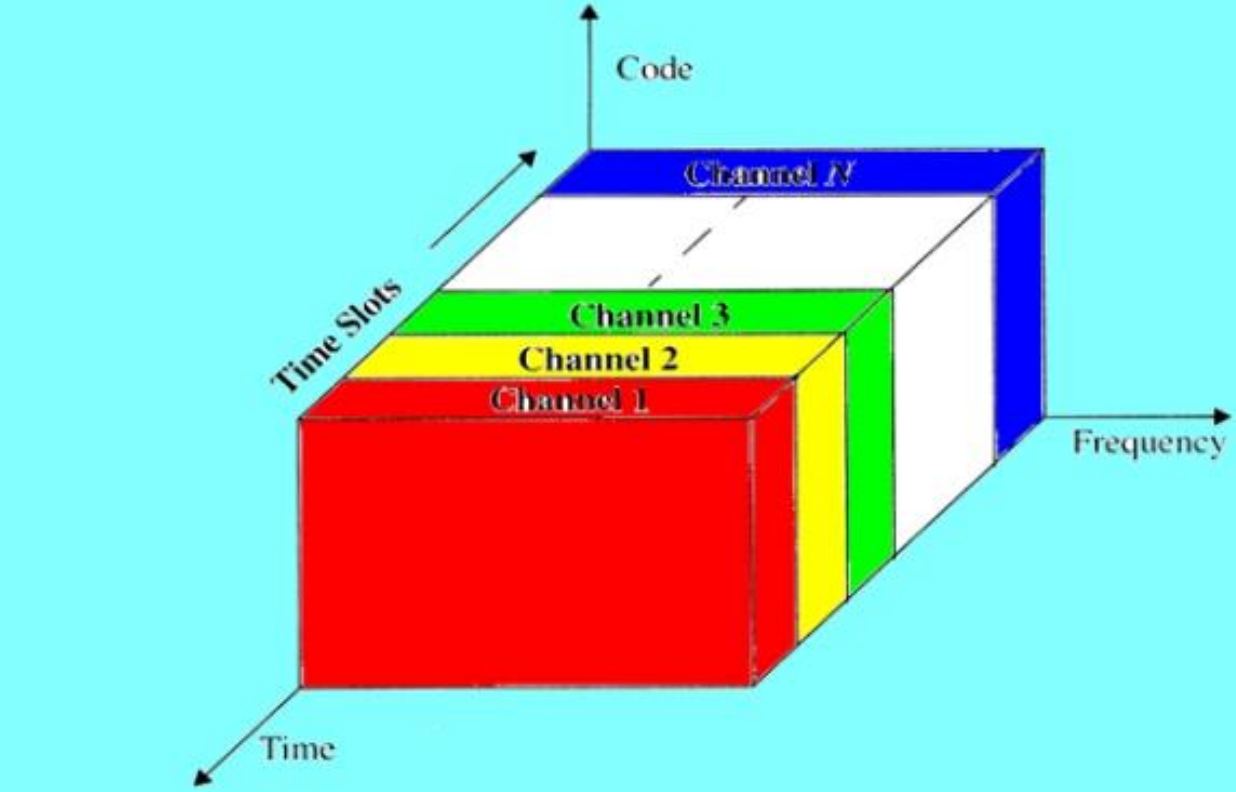


图 9.3 TDMA 中，一个信道就是一个周期性重复的时隙（Time Slot）

TDMA

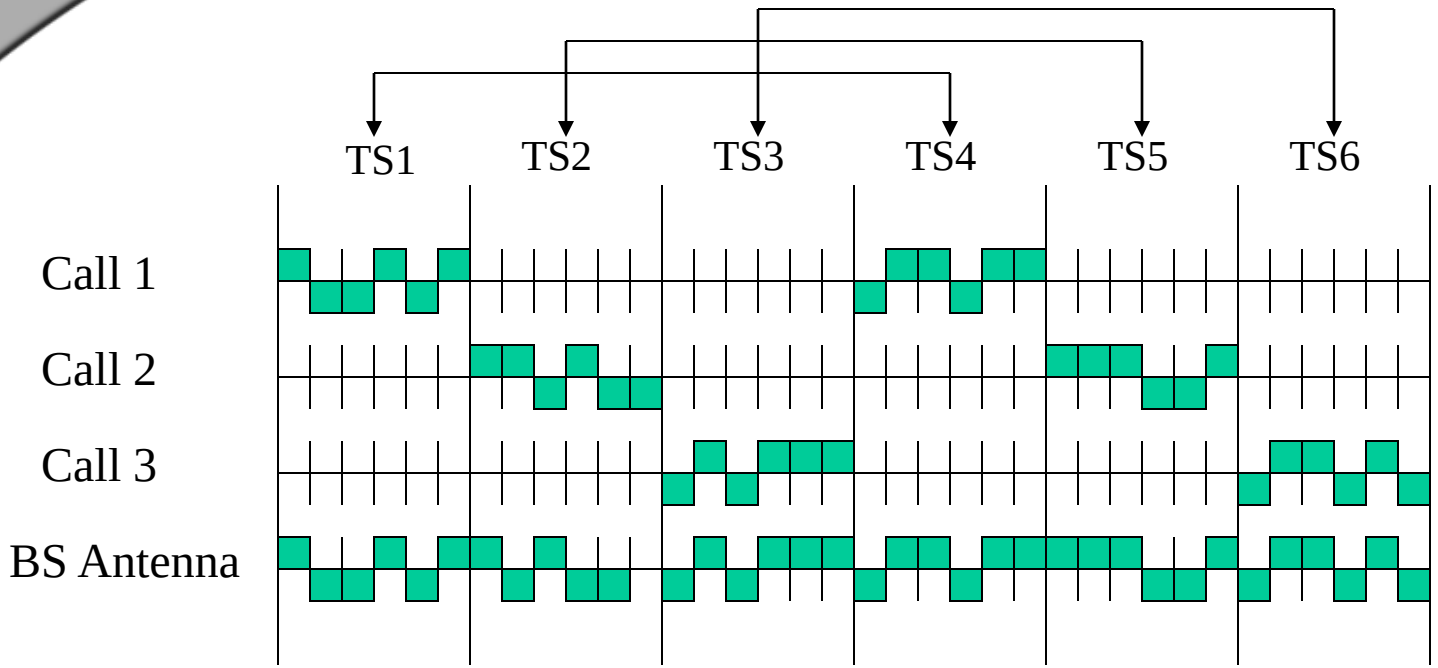
TDMA systems divide the radio resource into time slots and each user is allowed to either transmit or receive in each time slots.

Each user occupies a cyclically repeating time slots.

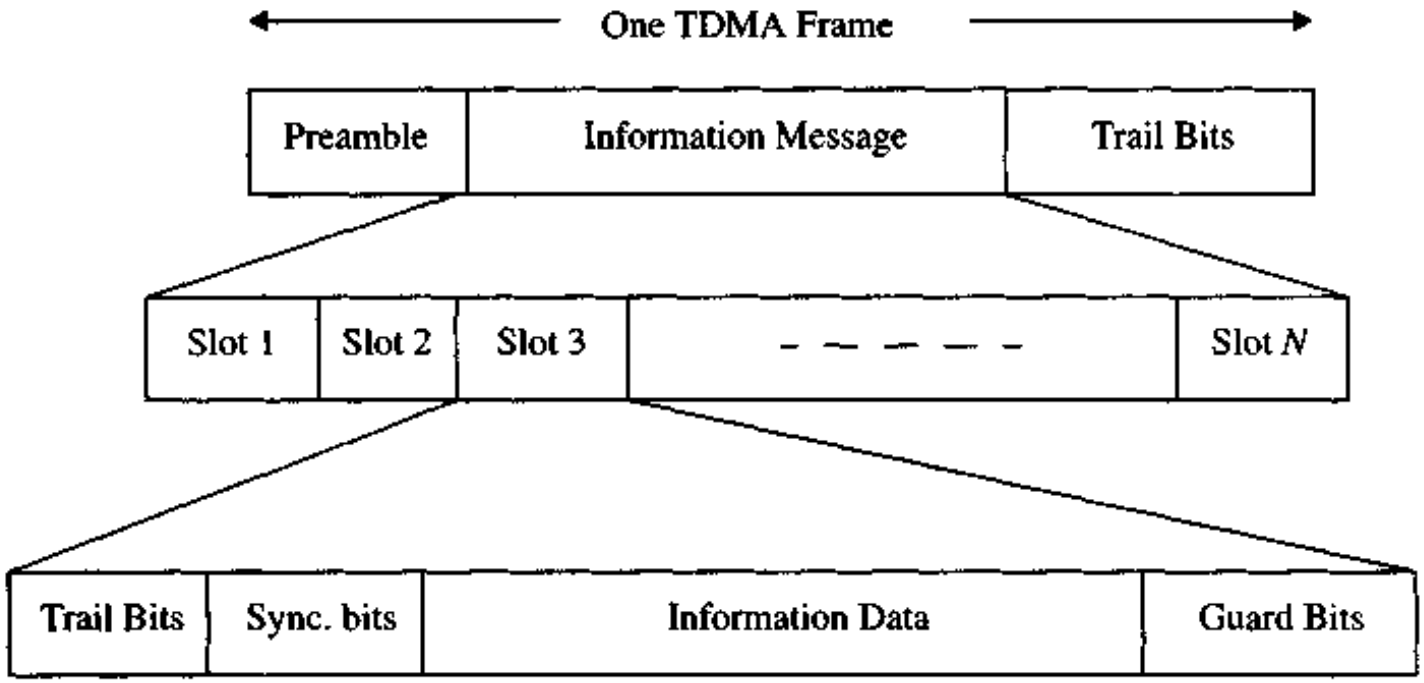
Disadvantages:

- precise synchronization necessary

TDMA



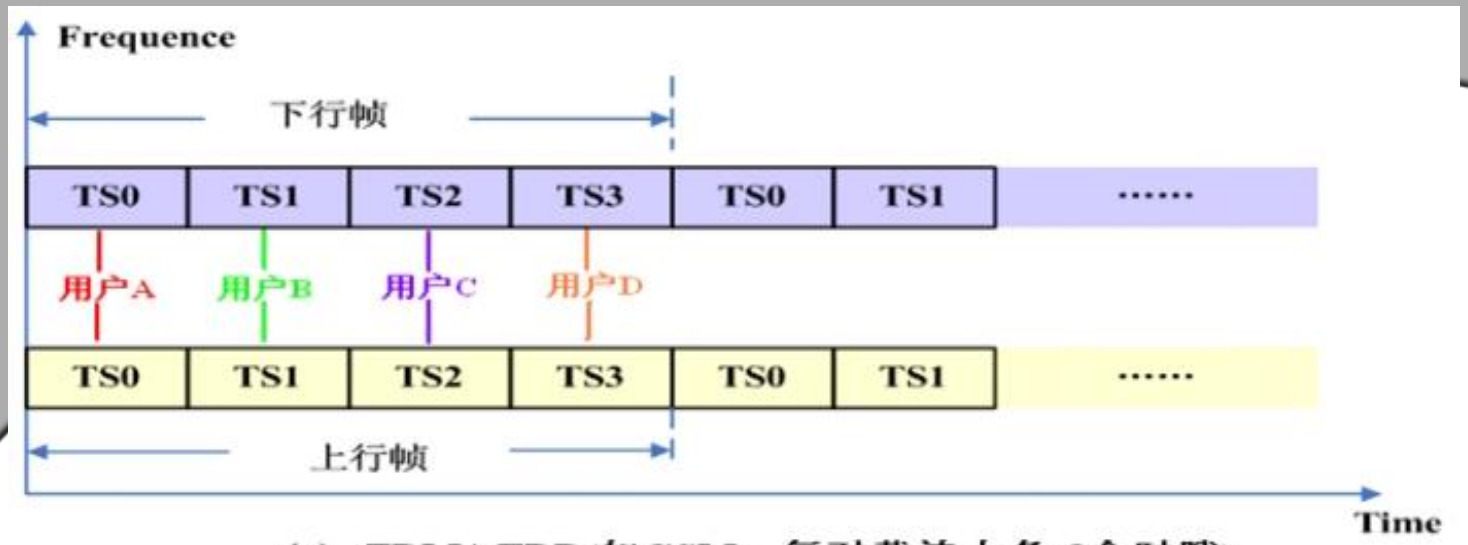
TDMA
(PP.454)



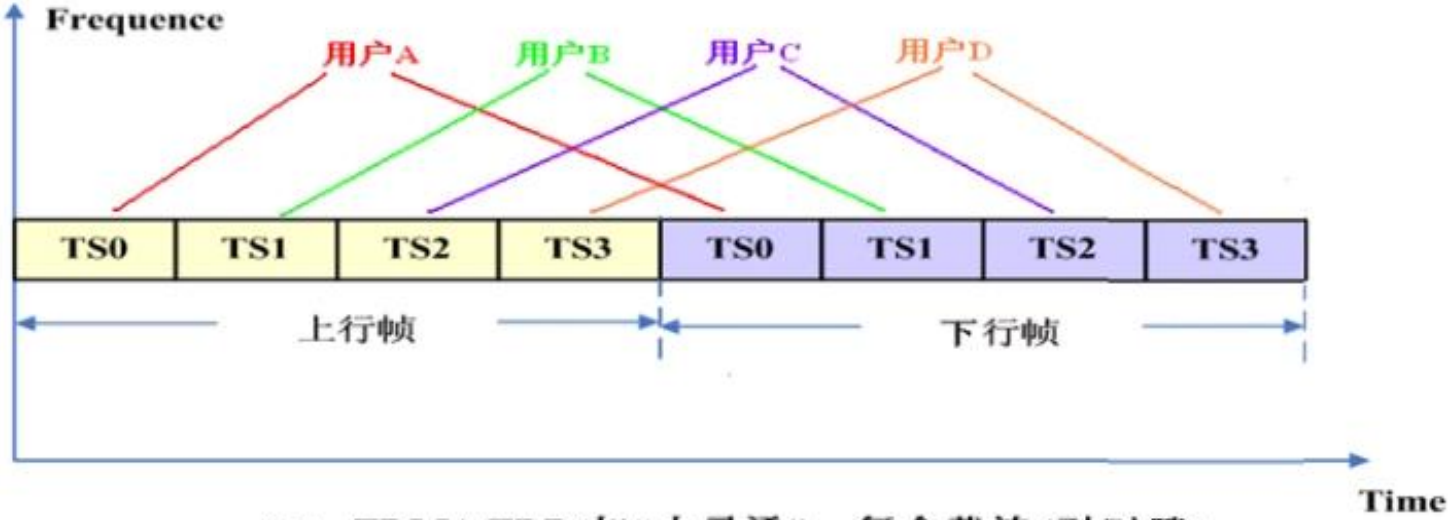
Utilized only in digital systems !!!

Number of time slots (TS) depends on technology

TDMA/FDD & TDMA/TDD



(a) TDMA/FDD(如GSM，每对载波上各 8个时隙)



(b) TDMA/TDD(如“小灵通”，每个载波4对时隙)

TDMA

- TDMA shares the single carrier frequency with several users, where each user makes use of non-overlapping timeslots.
- Data Transmission for user of TDMA system is discrete bursts
  - The result is low battery consumption, power save.
  - Handoff process is simpler, since it is able to listen for other base stations during idle time slots.
- Since different slots are used for T and R, duplexers are not required.
- Equalization is required, since transmission rates are generally very high as compared to FDMA channels.

TDMA & FDMA

Combination of both methods

A channel gets a certain frequency band for a certain amount of time

Example: GSM

PP.330 Example7.3 :

GSM采用FDMA和TDMA的混合技术。将可用频带890-915MHz等间隔（200kHz）分成125个载频，每个载频又分成8个时隙，每个时隙为一个信道，总计为1000个信道。

Example

(PP. 330)

If GSM uses a frame structure where each frame consists of eight time slots, and each time slot contains 156.25 bits, and data is transmitted at 270.833 kbps in the channel, find (a) the time duration of a bit, (b) the time duration of a slot, (c) the time duration of a frame, and (d) how long must a user occupying a single time slot wait between two successive transmissions.

Solution :

(a) The time duration of a bit, $T_b = \frac{1}{270.833 \text{ kbps}} = 3.692 \ \mu s.$

(b) The time duration of a slot, $T_{slot} = 156.25 \times T_b = 0.577$ ms.

(c) The time duration of a frame, $T_f = 8 \times T_{slot} = 4.615$ ms.

(d) A user has to wait 4.615 ms, the arrival time of a new frame, for its next transmission.

SSMA (Spread Spectrum MA)

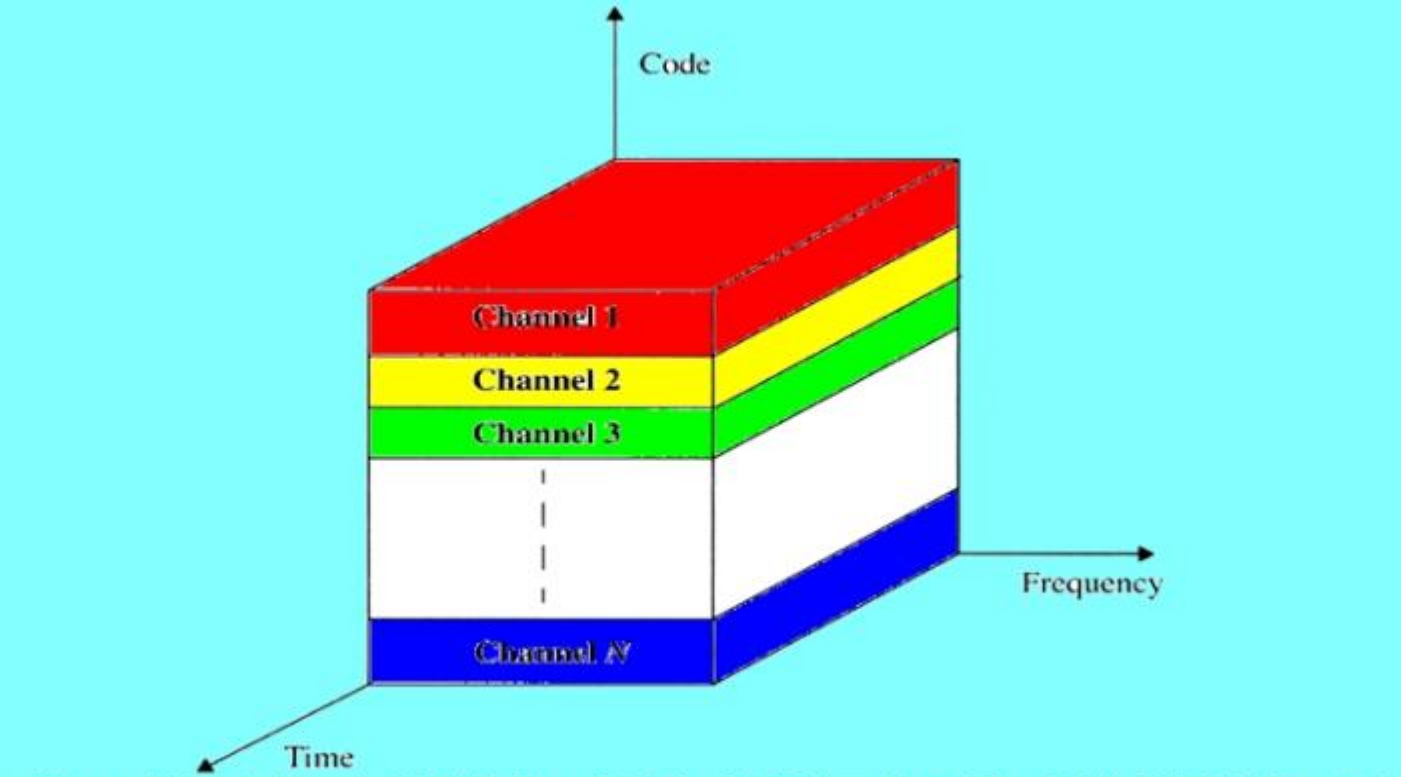


图9.5 扩谱多址：向每个信道（用户）分配唯一的PN码，跟其他用户的PN码正交或者近似正交

PN码 (Pseudo-Noise Code)

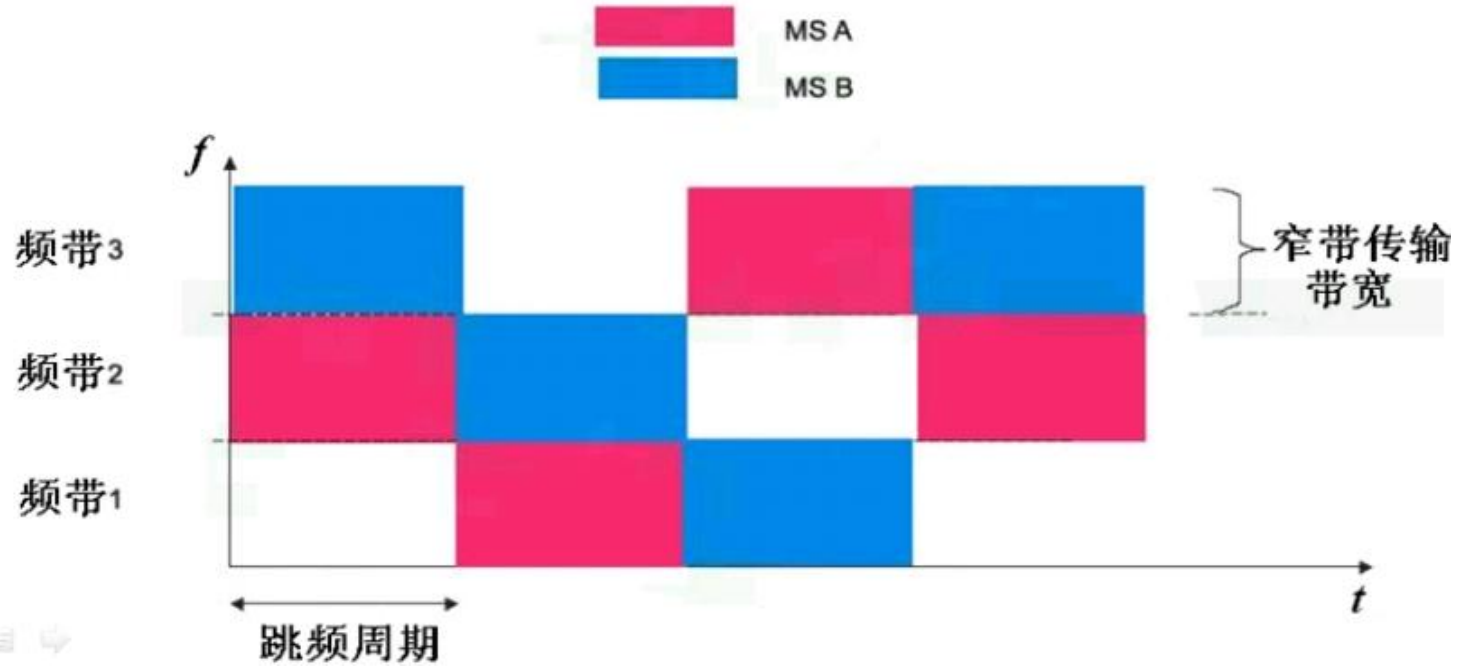
SSMA

- Spread Spectrum modulation spreads signal bandwidth to a bandwidth that is several orders of magnitude wider than the signal bandwidth
- Two spectrum spread methods
  - Frequency Hopping Spread Spectrum (FHSS)
  - Direct Sequence Spread Spectrum (DSSS)

FHMA

Discrete changes of carrier frequency

- sequence of frequency changes determined via pseudo random number sequence



FHMA

Advantages

- frequency selective fading and interference limited to short period
- simple implementation
- uses only small portion of spectrum at any time

Disadvantages

- not as robust as DSSS

DSMA(CDMA)

Each channel has a unique code

All channels use the same spectrum at the same time

–bandwidth efficient

–no coordination and synchronization necessary

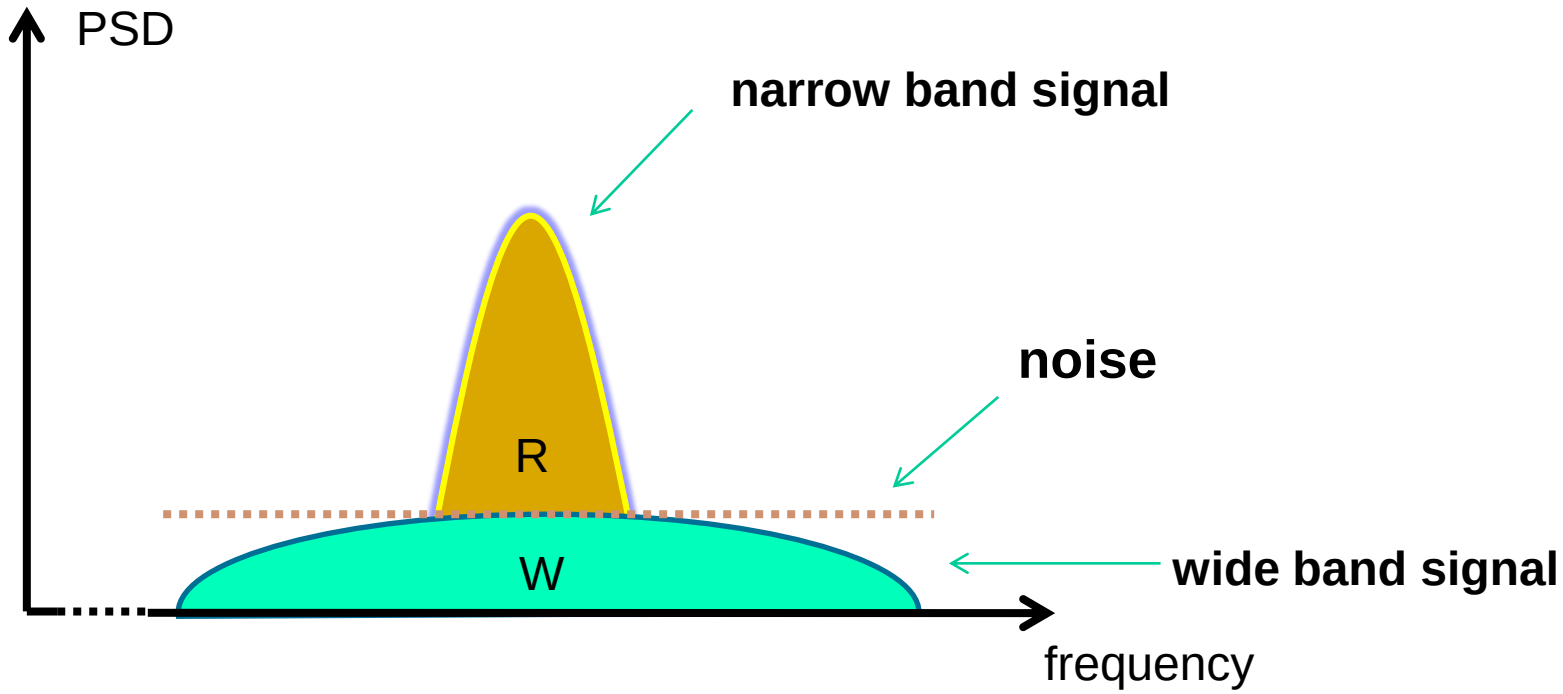
Implemented using spread spectrum technology

Is it too wasteful ?

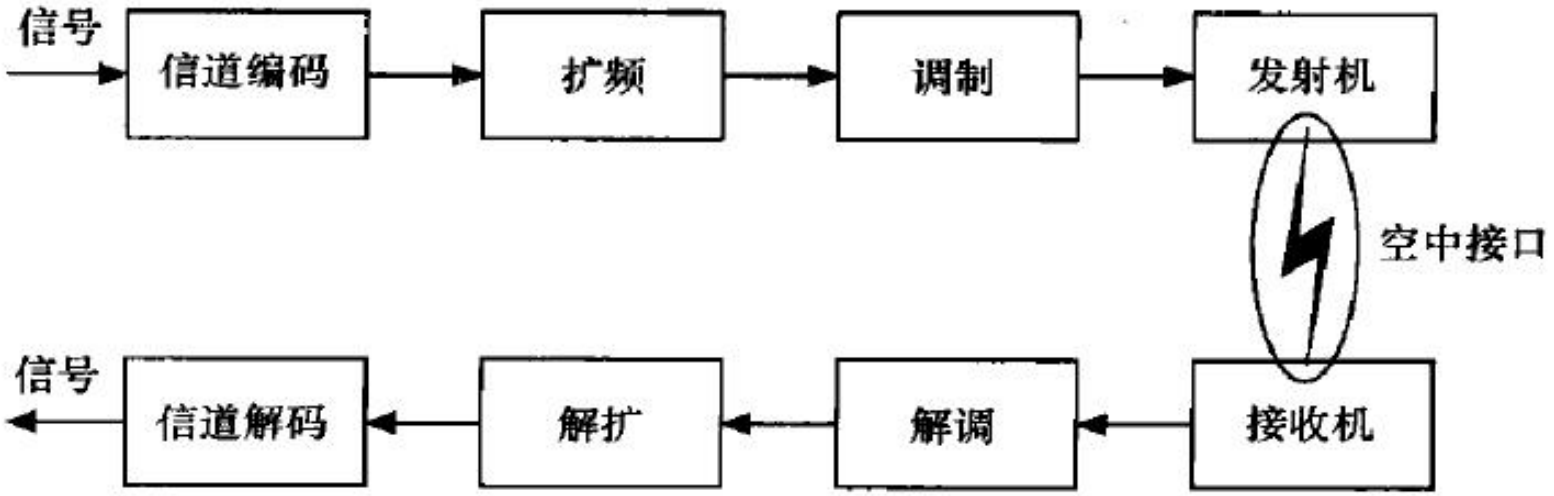
Spread Spectrum

Shannon's capacity : $C = B\log_2(1+S/N)$

Given C, B ↑ → S/N ↓

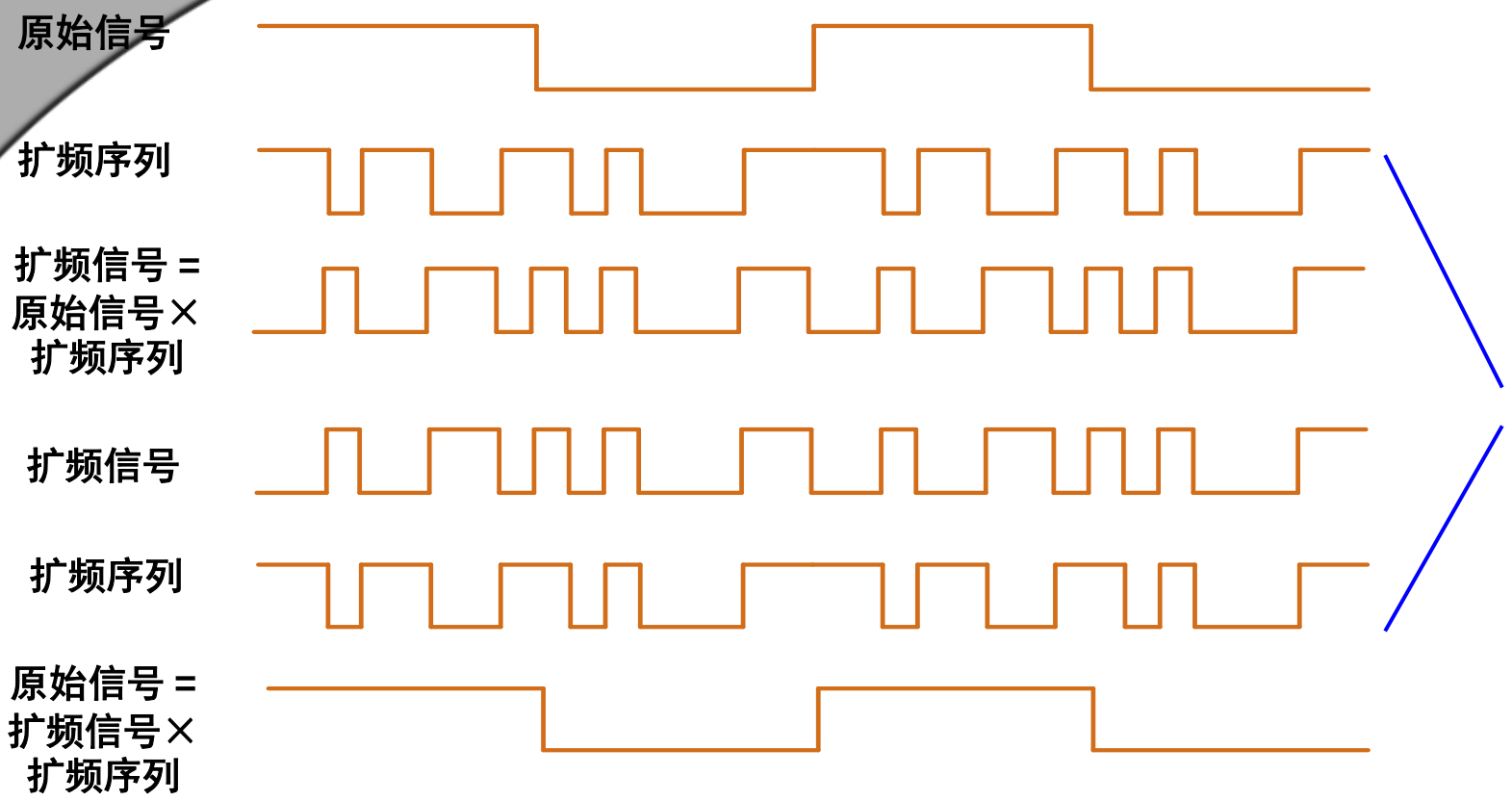


CDMA



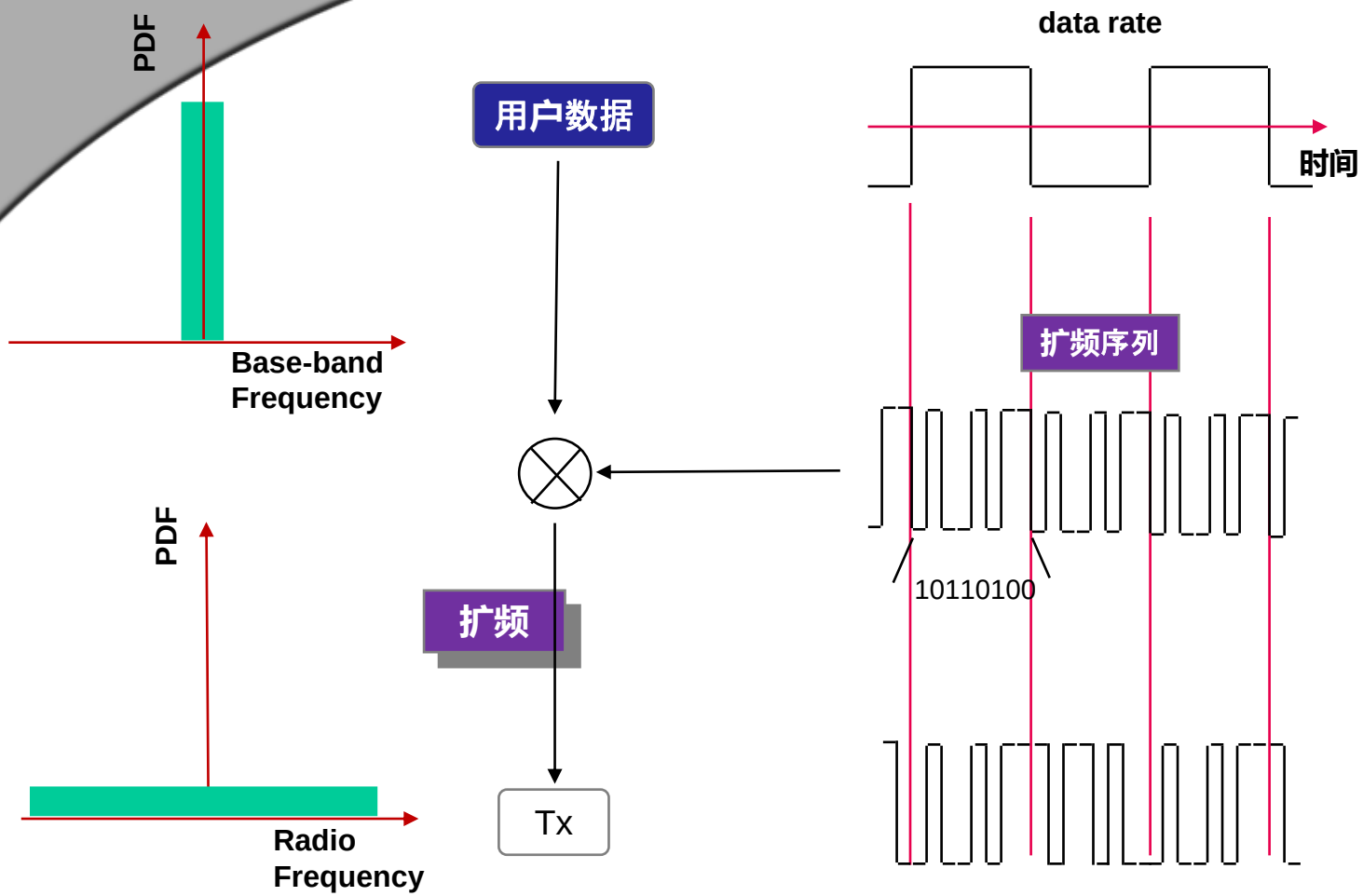
Spreading and despreading

扩频：

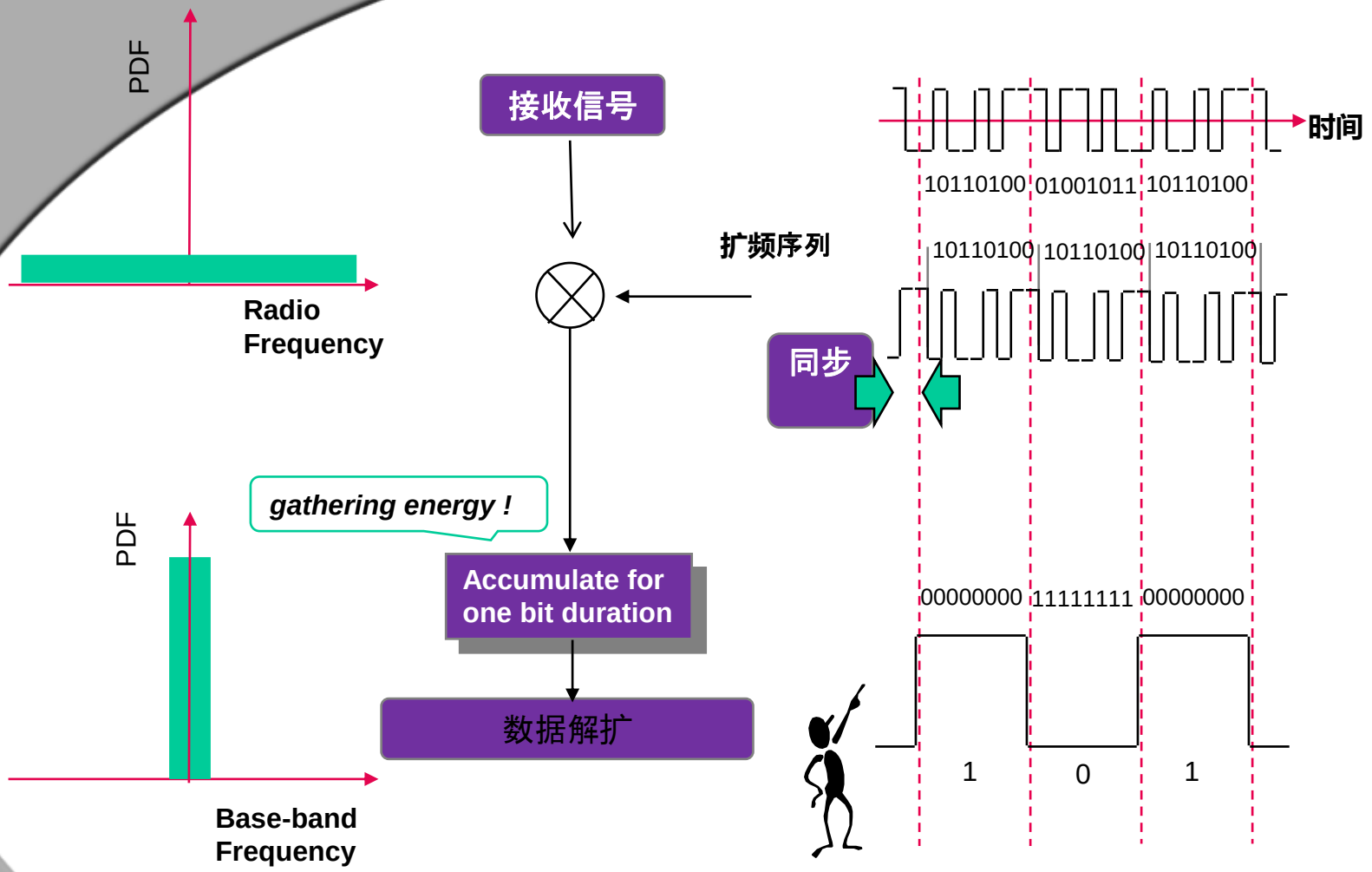


How to spread in a CDMA system?

发送端

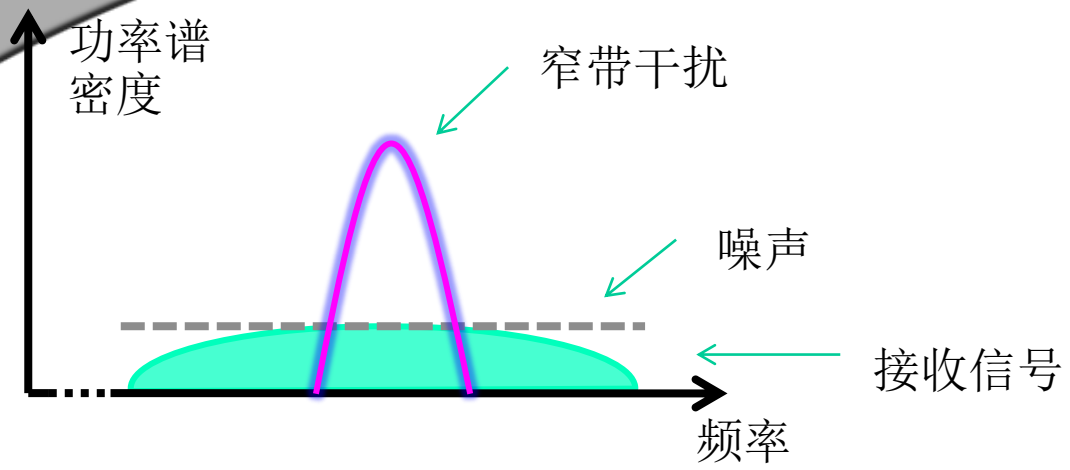


接收端

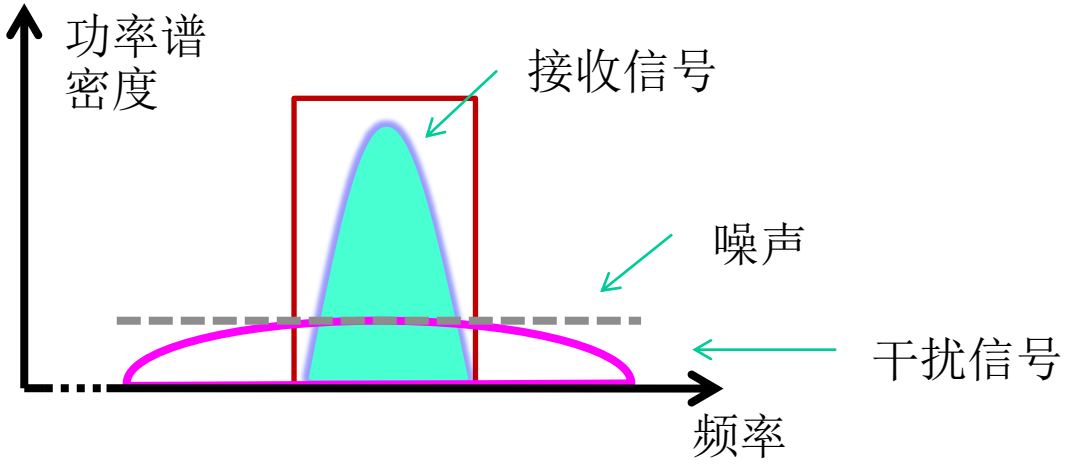

PDF
Radio
Frequency
接收信号
扩频序列
同步
时间
10110100 01001011 10110100
10110100 10110100 10110100
gathering energy !
Accumulate for
one bit duration
数据解扩
PDF
Base-band
Frequency
00000000 11111111 00000000
1
0
1

Confront the narrow bandwidth interference

解扩前

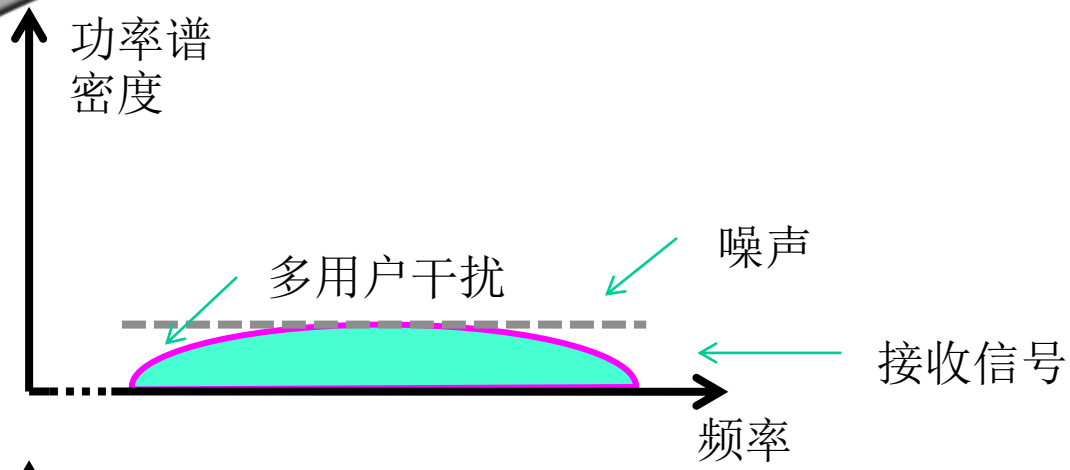


解扩后

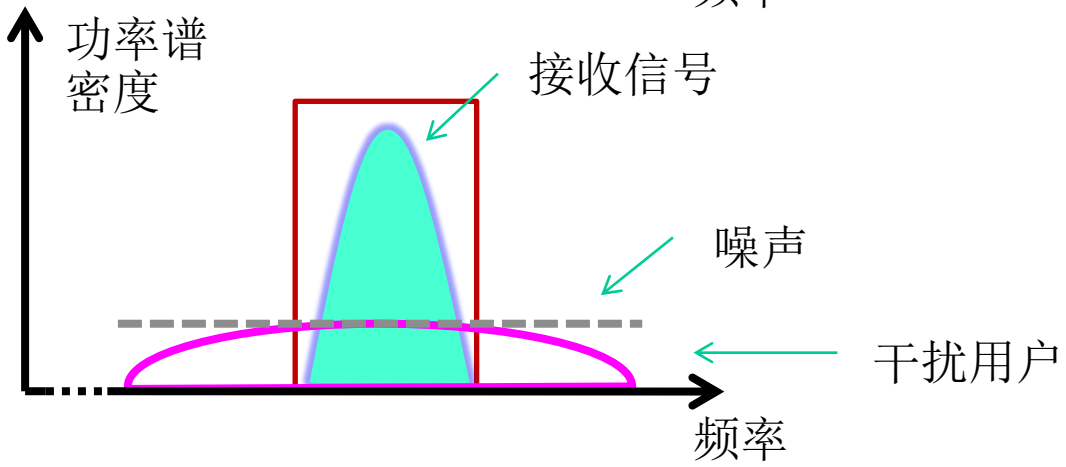


Confront the multi-user interference

解扩前



解扩后

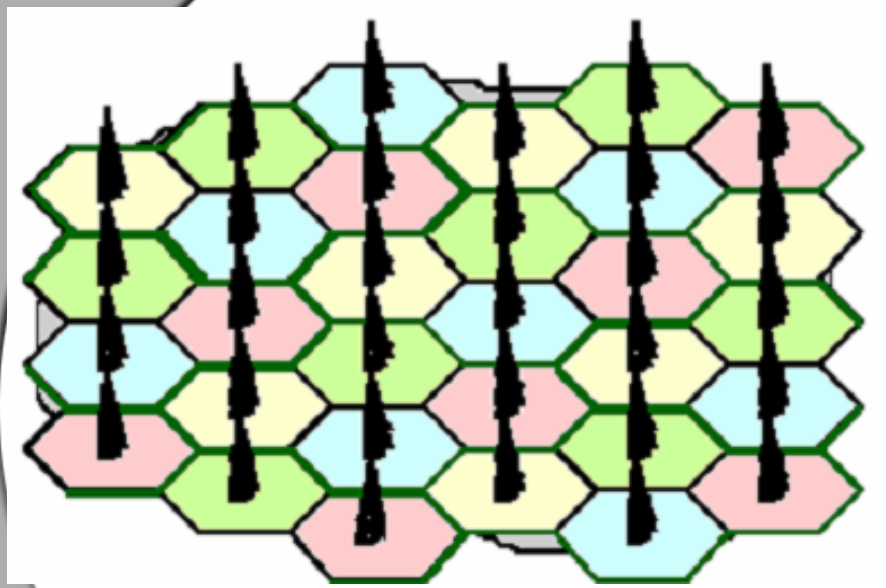


CDMA

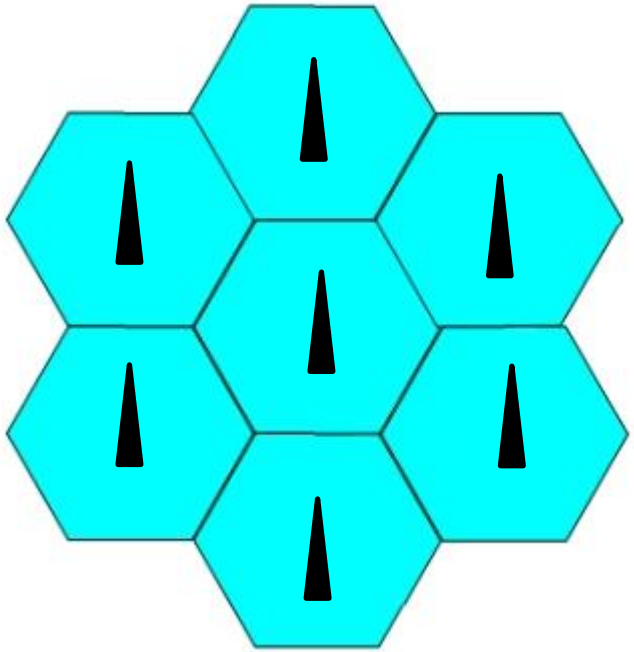
- CDMA can adopt same-frequency networking scheme.
- Since CDMA uses co-channel cells, it can use macroscopic spatial diversity to provide soft handoff.
- Unlike TDMA or FDMA, CDMA has a soft capacity limit.
- Self-jamming is a problem in CDMA system.
- The near-far problem occurs at a CDMA receiver if an undesired user has a high detected power as compared to the desired user.
- CDMA power control
- A RAKE receiver can be used to improve reception by collecting time delayed versions of the required signal .

Same-frequency networking

- **All cells use the same frequency.**
- **The frequency reuse factor is 1.**



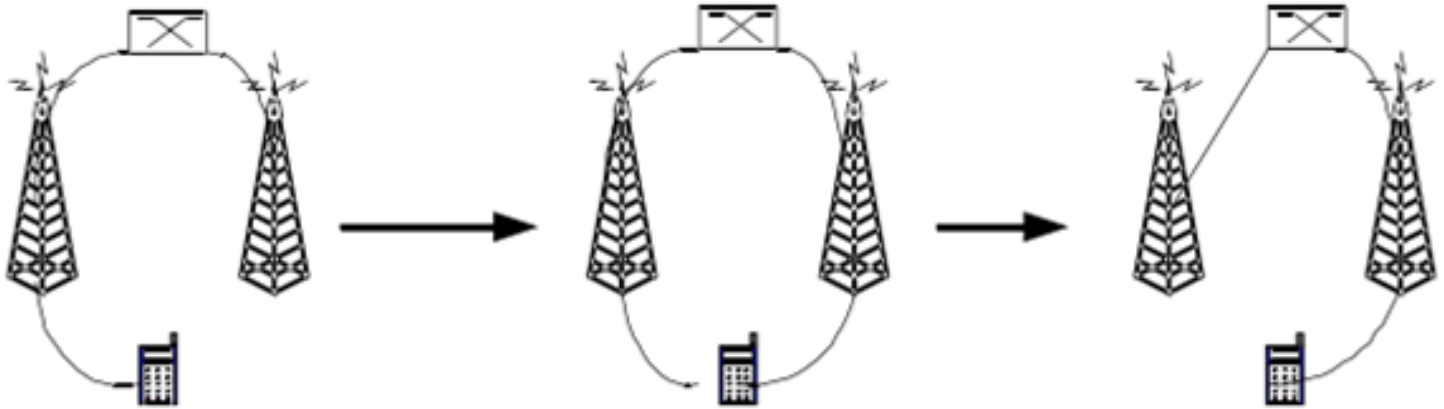
Conventional system



CDMA system

Soft handoff

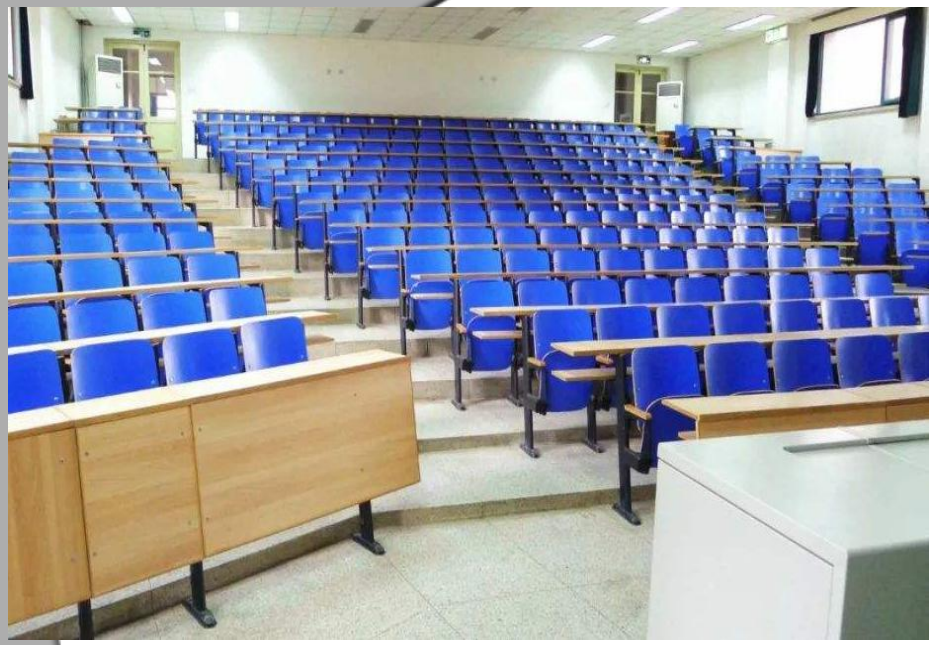
Hard handoff



Soft handoff

Soft capacity

- FDMA : bandwidth limited, CDMA : interference limited.



- Number of users increases ⟹ Link performance of CDMA decreases.

Chapter 5

1. Introduction to Multiple Access
2. FDMA, TDMA and CDMA
3. **Packet Radio**
4. Capacity of Cellular Systems

Packet Radio

- **Packed radio communications use a wireless channel to transmit data in packets.**
- **Many subscribers attempt to access a single channel in an uncoordinated (or minimally coordinated) manner.**

Packet Radio

- High spectral efficiency
- Collisions
- Service: DATA

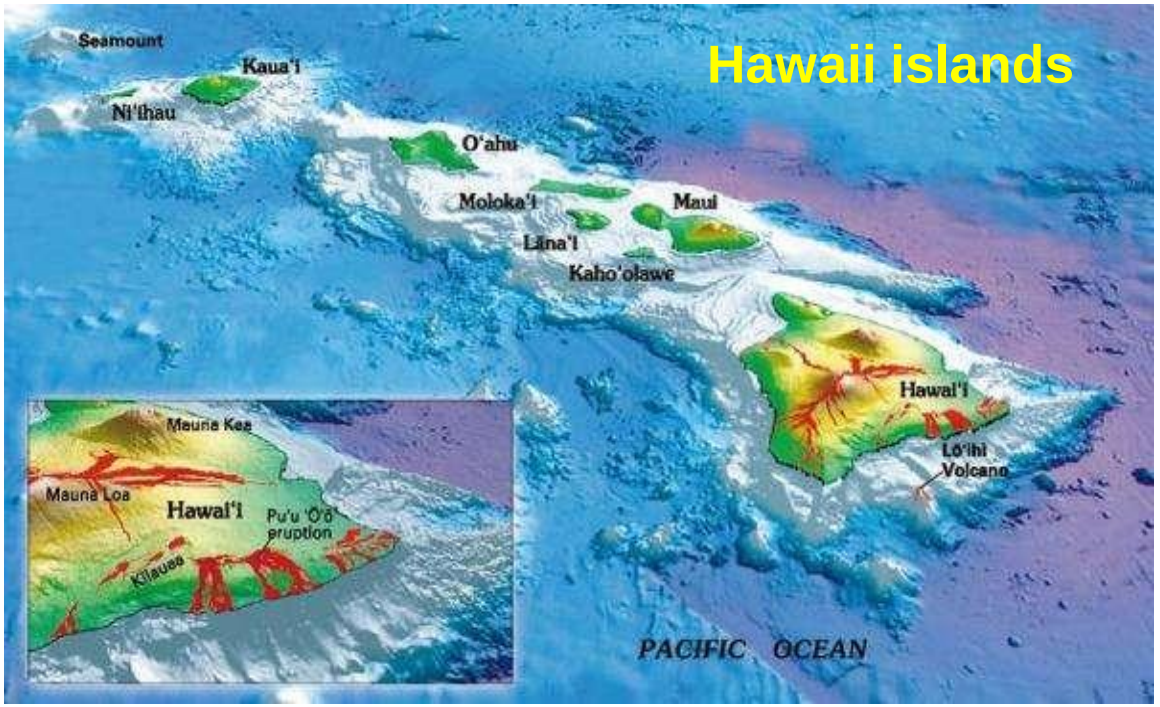
Two indexes :

- Throughput
- Average delay

“ ALOHA Protocol ”

Packet Radio

“ ALOHA Protocol ”



ALOHA Protocol

- **Pure ALOHA**
- **Slotted ALOHA**

Pure ALOHA

- **Transmit whenever a message is ready**
- **Retransmit when there is a collision**

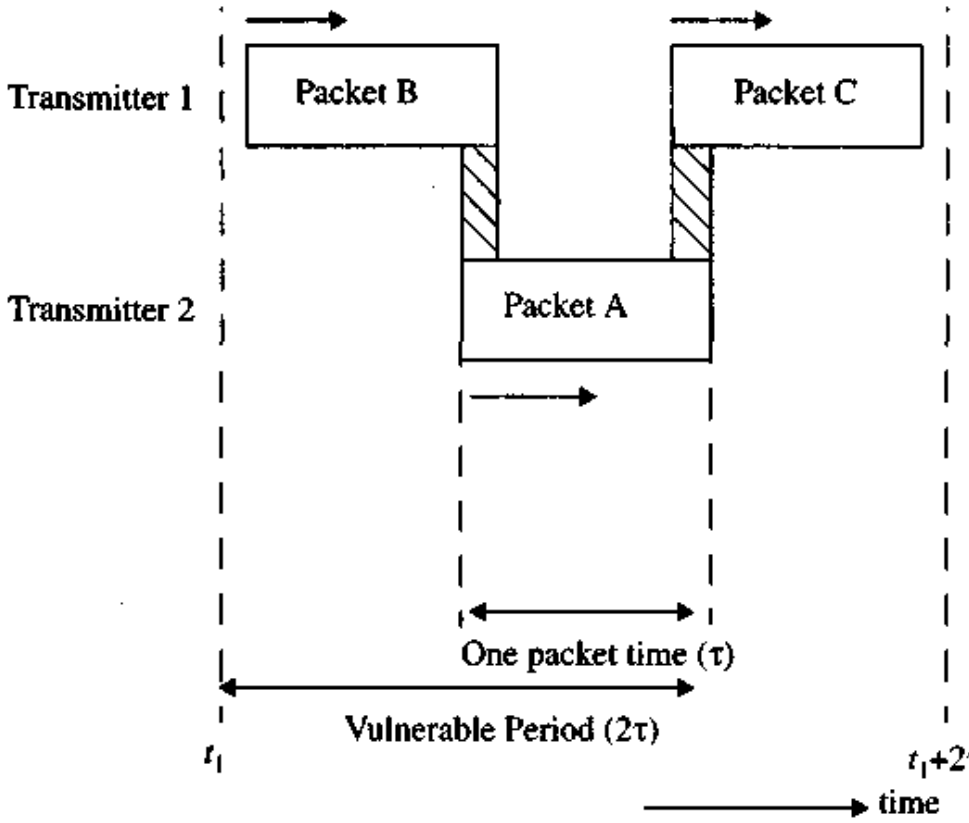
User 1 :

User 2 :

Successful transmission :

Vulnerable Period in the ALOHA Protocol

易损阶段



Packet A will collide with packets B and C because of overlap in transmission time.

Normalized Throughput

归一化吞吐量

Normalized Throughput

Normalized throughput (T) =

Normalized channel traffic (R) ×

Probability of no collision (Pr)

归一化吞吐量 T = 归一化信道业务量 R × 成功发送的概率 Pr

“ T = R × Pr (no collision) ”

Normalized Channel Traffic

Normalized channel traffic *R* :

- **a relative measure of the channel utilization**
- **represents the load of the channel**

$$R = \lambda\tau$$

***R*: Erlangs**

λ : packets / s

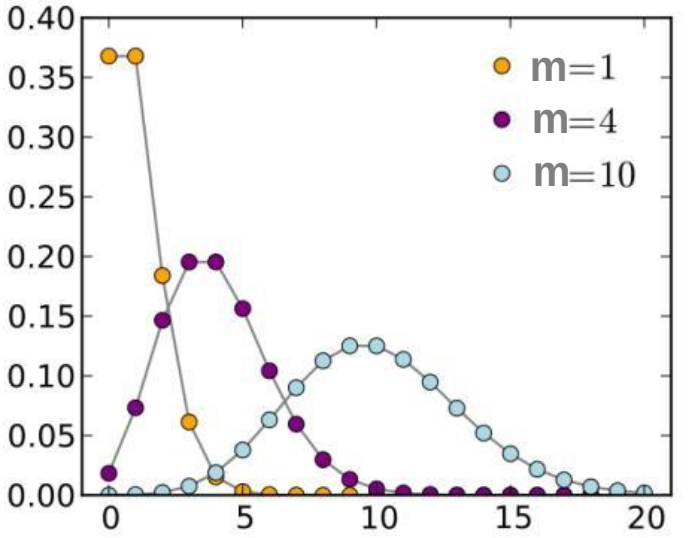
τ : s / packet

Probability of No Collision

Poisson process :

Averagely *m* , actually *x* :

$$\mathrm{P}(x) = \frac{(m)^x}{x!} e^{-m}$$



In vulnerable period *t* , averagely *λt* packets, actually *n* packets :

$$\Pr(n) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \Rightarrow \Pr(n=0) = \frac{(\lambda t)^0}{0!} e^{-\lambda t} = e^{-\lambda t}$$

Pure ALOHA

$$t = 2\tau \rightarrow \Pr(0) = e^{-\lambda t} = e^{-2\lambda\tau} = e^{-2R}$$

“ $T = R \times Pr\,(n = 0)$ ”

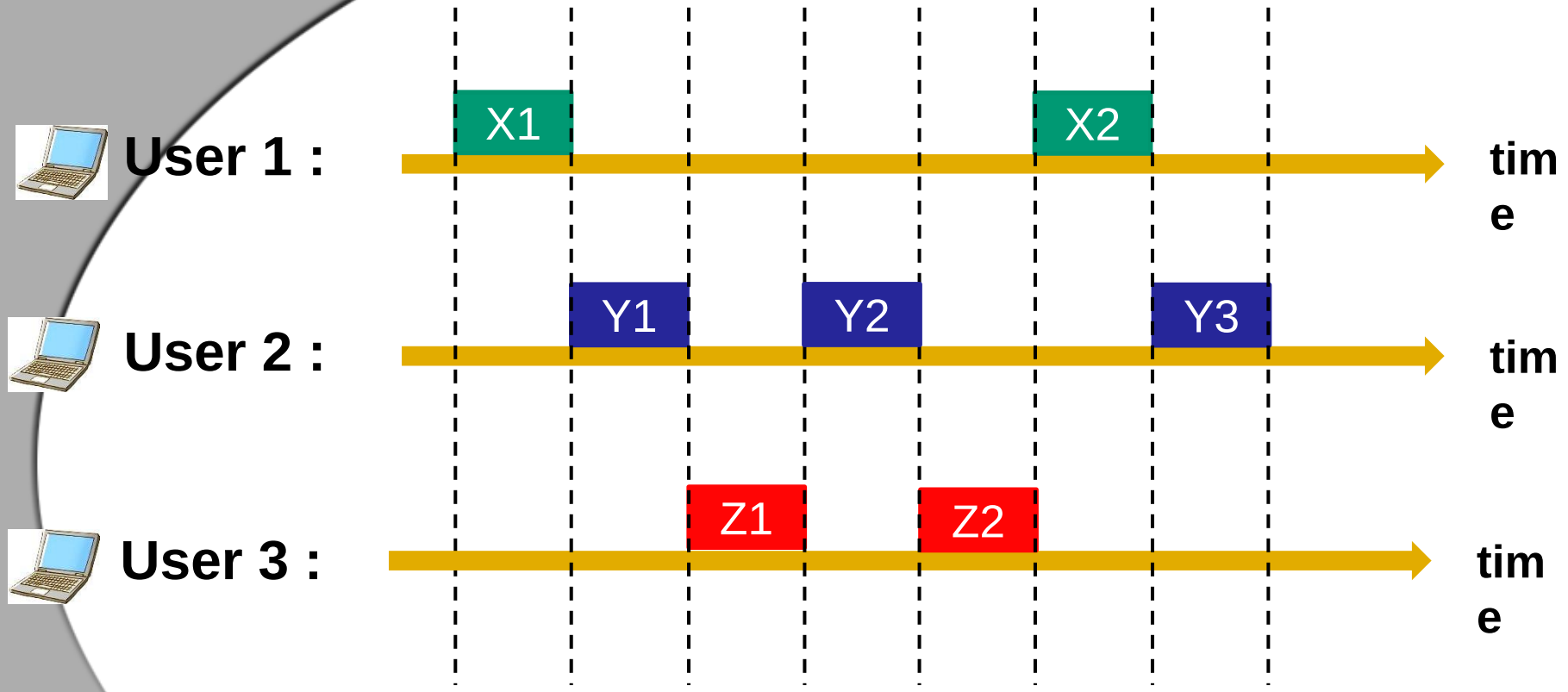
$$\boxed{T = Re^{-2R}}$$

R = 0.5, T_{max} = 0.1839

ALOHA Protocol

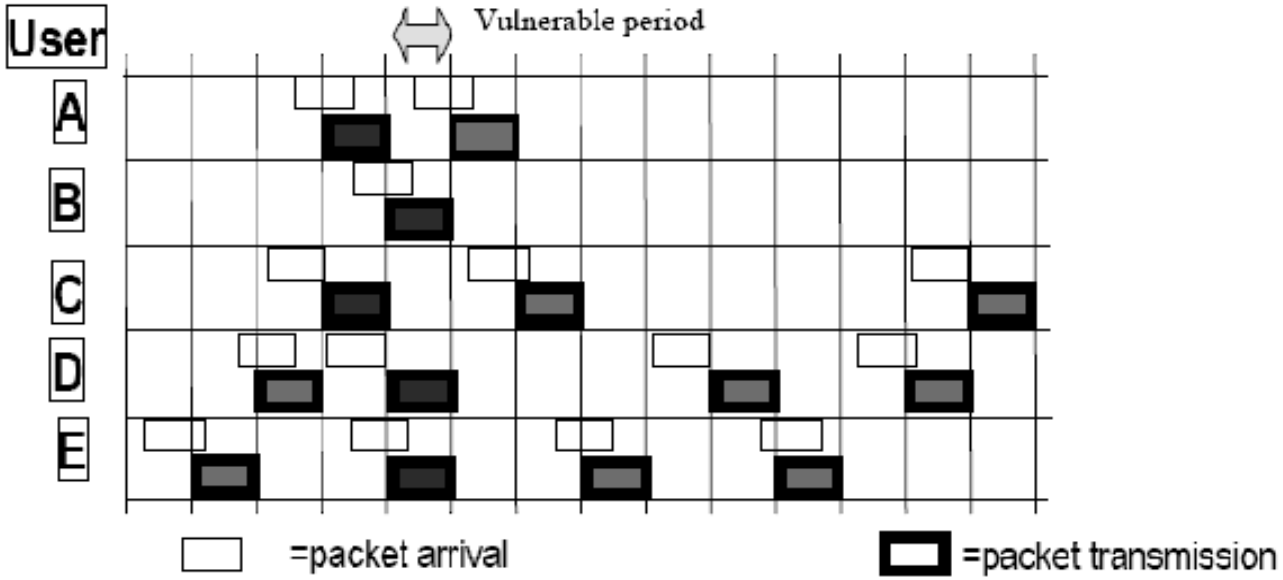
- Pure ALOHA
- **Slotted ALOHA**

Slotted ALOHA

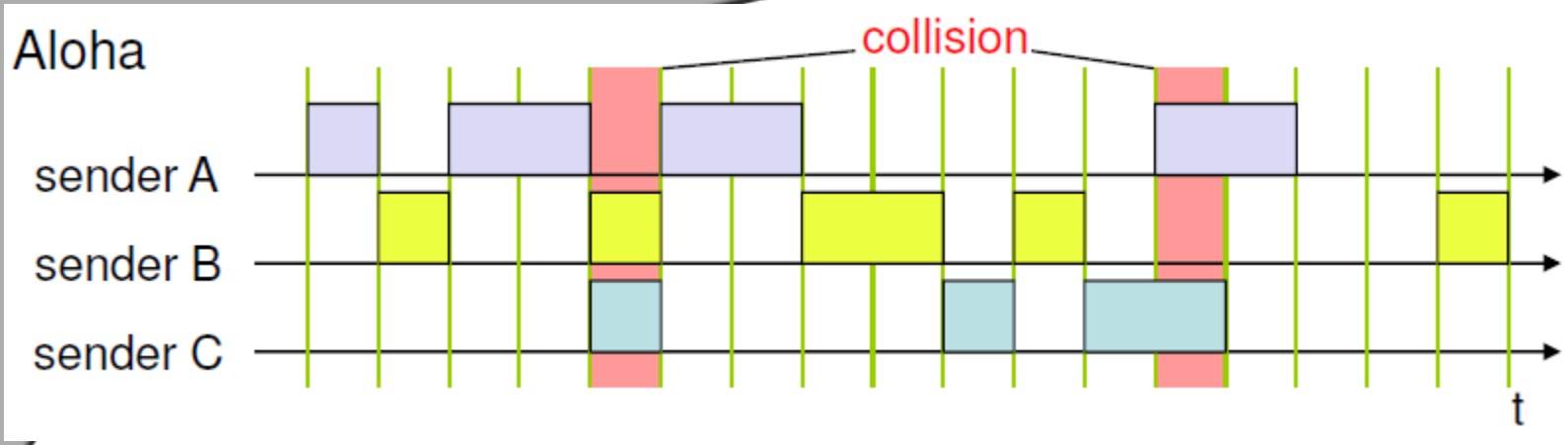


Slotted Aloha

- **Time is divided into equal time slots**
- **Transmit only at the beginning of a time slot**
- **Avoid partial collisions**
- **Increase delay, and require synchronization**



Slotted Aloha



vulnerable period $t = \tau$

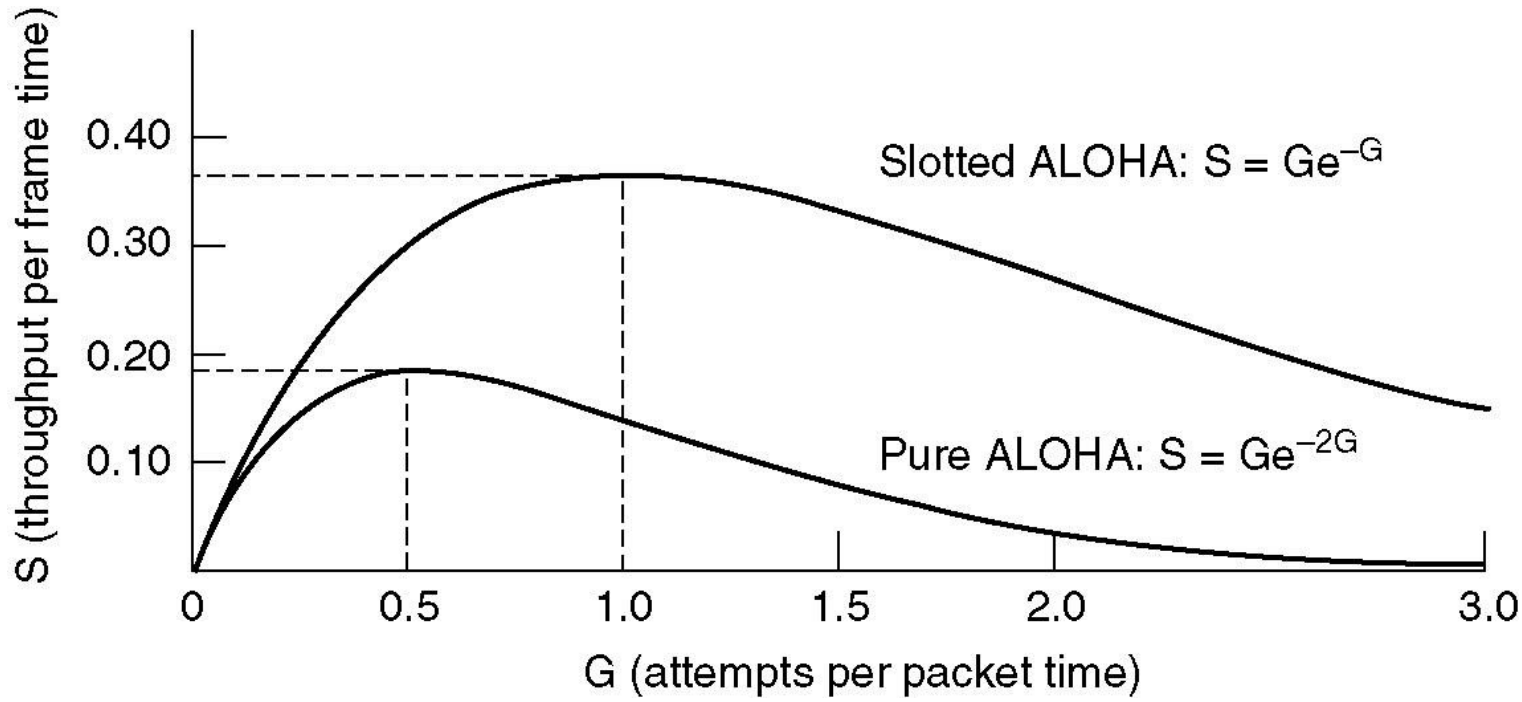
$$\Pr(n=0) = \frac{(R)^n}{n!} e^{-R} \mid n=0 \quad = e^{-R}$$

$$T = Re^{-R}$$

R=1，Maximum Channel efficiency T_{max}=0.3679

Slotted Aloha

Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length)



Thinking

Not listen before talk :

- **Pure ALOHA - Random Access**
- **Slotted ALOHA - Scheduled Access**

How to improve efficiency ?

Listen before talk :

CSMA : Carrier Sense Multiple Access

CSMA

(PP.340)

Improvement : sense the carrier before access the medium

CSMA: Start transmission only if no transmission is ongoing

CSMA/CD: CD = Collision Detection. Stop ongoing transmission if a collision is detected (Used in IEEE 802.3).

CSMA/CA: CA = Collision Avoid.(Used in IEEE 802.11)

Chapter 5

1. Introduction to Multiple Access
2. FDMA, TDMA and CDMA
3. Packet Radio
4. **Capacity of Cellular Systems**

Capacity of Cellular Systems

Channel capacity for a radio system is defined as the maximum number of channels or users that can be provided in a fixed frequency band ➔ spectrum efficiency of wireless system.

For a Cellular System

$m = B_t / (B_{Ch} * N)$

B_t = Total allocated spectrum for the system

B_{Ch} = Channel bandwidth

N= Number of cells in frequency reuse pattern

Capacity of Digital Cellular CDMA

Capacity of FDMA and TDMA system is bandwidth limited. Capacity of CDMA system is interference limited.

The link performance of CDMA increases as the number of users decreases.

CDMA

$$SNR = \frac{S}{(N-1)S} = \frac{1}{(N-1)}$$

Bit energy-to-noise ratio：

$$\frac{E_b}{N_0} = \frac{S/R}{(N-1)(S/W)} = \frac{W/R}{N-1}$$ ★

$$N = 1 + \frac{W/R}{E_b/N_0}$$ ★

$$\frac{E_b}{N_0} = \frac{W/R}{(N-1)+(\eta/S)} \qquad N = 1 + \frac{W/R}{E_b/N_0} - (\eta/S)$$

W/R : processing gain —— “处理增益”

Antenna Sectorization:

A cell site with 3 antennas, each having a beamwidth of 120 degree. This increase the capacity.

Monitoring of Voice activity:

Each transmitter is switched off during period of no voice activity. Voice activity is denoted by a factor α.

Eb/N_0' within a sector

$$\frac{E_b}{N_0'} = \frac{W/R}{(N_s - 1)\alpha + (\eta/S)}$$

$$N_s = 1 + \frac{1}{\alpha}\left[\frac{W/R}{\frac{E_b}{N_0'}}\right]$$

Example

PP.348

If W = 1.25 MHz, R= 9600 bps, and a minimum acceptable E_b/N_o is 10 dB, determine the maximum number of users that can be supported in a single cell CDMA system using

(a) omni directional base station antennas and no voice activity detection.

(b) 3 sectors at base station and a = 3/8. Assume the system is interference limited.

“ E_b/N_0要用非dB值”

$$N = 1 + \frac{1.25 \times 10^6 / 9600}{10} = 1 + 13.02 = 14$$

$$N_s = 1 + \frac{1}{0.375}\left[\frac{1.25 \times 10^6 / 9600}{10}\right] = 35.7$$

Therefore $N = 3*35.7 = 107$ users/ cell.

Summary

1. Introduction to Multiple Access
2. FDMA, TDMA and CDMA
3. Packet Radio : T and R
4. Capacity of Cellular Systems :

Capacity of CDMA $\frac{E_b}{N_0'} = \frac{W/R}{(N_s - 1)\alpha + (\eta/S)}$

Exercises

1. The US Digital Cellular TDMA system uses a 48.6 kbps data rate to support three users per frame. Each user occupies two of the six time slots per frame. What is the raw data rate provided for each user ?

Exercises

2. In an unslotted ALOHA system the packet arrival times form a Poisson process having a rate of 10^3 packets/sec. If the bit rate is 10 Mbps and there are 1000 bits/packet, find

(a). the normalized throughput of the system, and

(b). the number of bits per packet that will maximize the throughput.

(c). repeat (b) for a slotted ALOHA system.

Exercises

3. In an omnidirectional (single-cell, single-sector) CDMA cellular system, $E_b/N_0 = 20dB$ is required for each user. If 100 users, each with a baseband data rate of 13 kbps, are to be accommodated, (a) determine the minimum channel bit rate of the spread spectrum chip sequence. Ignore voice activity considerations. (b) repeat the problem for the case where voice activity is considered and is equal to 40%. (c) repeat the problem for the case of a tri-sectored CDMA system. Include the effects of voice activity, where it is assumed that each user is active 40% of the time.