EEEN3008J: Advance wireless communications

Cellular Wireless Networks II

Dr Avishek Nag

(avishek.nag@ucd.ie)

Outline of the Last Lecture

- Cellular Network Introduction
- Concept of Frequency Reuse
- Cellular System Architecture
- Handoff and Power Control
- Traffic Engineering
  - Erlang B formula

$$P = \frac{\frac{A^N}{N!}}{\sum_{x=0}^{N} \frac{A^x}{x!}}$$

where

A = offered traffic, erlangs

N = number of servers

P = probability of blocking (grade of service)

Problem 1

Consider a 7-cell system covering an area of 3100 km^2. The traffic in the seven cells is as follows:

Cell number	1	2	3	4	5	6	7
Traffic (Erlangs)	30.8	66.7	48.6	33.2	38.2	37.8	32.6

Each user generates an average of 0.03 Erlangs of traffic per hour, with a mean holding time of 120 s. The system consists of a total of 395 channels and is designed for a grade of service of 0.02.

a. Determine the number of subscribers in each cell.
b. Determine the number of calls per hour per subscriber.
c. Determine the number of calls per hour in each cell.
d. Determine the number of channels required in each cell. *Hint:* You will need to extrapolate using Table P1
e. Determine the total number of subscribers.
f. Determine the average number of subscribers per channel.
g. Determine the subscriber density per km^2.
h. Determine the total traffic (total Erlangs).
i. Determine the Erlangs per km^2.
j. What is the radius of a cell?

Table P1

	Capacity (Erlangs) for Grade of Service of				
Number of Servers (N)	**P = 0.02 (1/50)**	**P = 0.01 (1/100)**	**P = 0.005 (1/200)**	**P = 0.002 (1/500)**	**P = 0.001 (1/1000)**
1	0.02	0.01	0.005	0.002	0.001
4	1.09	0.87	0.7	0.53	0.43
5	1.66	1.36	1.13	0.9	0.76
10	5.08	4.46	3.96	3.43	3.09
20	13.19	12.03	11.10	10.07	9.41
24	16.64	15.27	14.21	13.01	12.24
40	31.0	29.0	27.3	25.7	24.5
70	59.13	56.1	53.7	51.0	49.2
?	66.7				
100	87.97	84.1	80.9	77.4	75.2

$$P = \frac{\dfrac{A^N}{N!}}{\displaystyle\sum_{x=0}^{N} \frac{A^x}{x!}}$$

where

A = offered traffic, erlangs

N = number of servers

P = probability of blocking (grade of service)

Erlang B Formula Calculator

Solution to Problem 1

a. Number of subscribers = Traffic/0.03

Cell number	1	2	3	4	5	6	7
Subscribers	1026.7	2223.3	1620.0	1106.7	1273.3	1260.0	1086.7

b. Number of calls per hour per subscriber = $\lambda = A/h = 0.03/(120/3600) = 0.9$

c. Multiply results of part (a) by 0.9

Cell number	1	2	3	4	5	6	7
Calls per hour	924	2001	1458	996	1146	1134	978

d. The table in the problem statement gives the value of A. Use $P = 0.02$. Find N.

Cell number	1	2	3	4	5	6	7
Channels	40	78	59	43	48	48	42

e. Total number of subscribers = the sum of the values from part (a) = 9597

f. From (d), the total number of channels required = 358
Average number of subscribers per channel = 9597/358 = 26.8

g. Subscriber density = 9597/3100 = 3.1 subscribers per km^2

h. Total traffic = the sum of the values from table in the problem statement = 287.9

i. Erlangs per km^2 = 287.9/3100 = 0.09

j. The area of a hexagon of radius R is $A = 1.5R^2\sqrt{3}$. For A = 3100/7 = 442.86 km^2 we have R = 13 km

First-Generation Analog

- Advanced Mobile Phone Service (AMPS)
  - In North America, two 25-MHz bands allocated to AMPS
    - One for transmission from base to mobile unit
    - One for transmission from mobile unit to base
  - Each band split in two to encourage competition
  - Frequency reuse exploited

AMPS Operation

- Subscriber initiates call by keying in phone number and presses send key
- MTSO verifies number and authorizes user
- MTSO issues message to user' s cell phone indicating send and receive traffic channels
- MTSO sends ringing signal to called party
- Party answers; MTSO establishes circuit and initiates billing information
- Either party hangs up; MTSO releases circuit, frees channels, completes billing

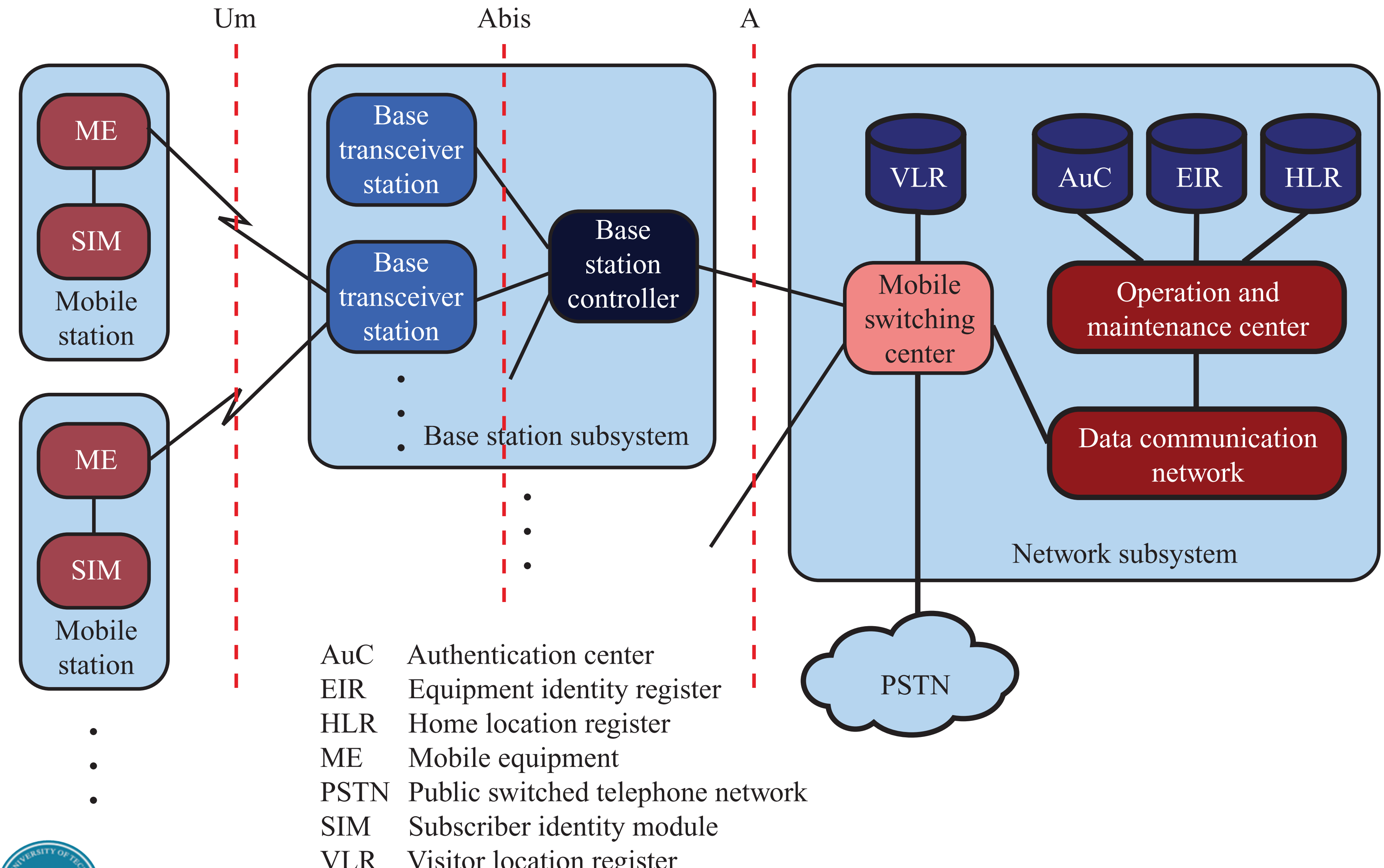
Differences Between First and Second Generation Systems

- Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
  - Using FDMA/TDMA or CDMA
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users

Global System for Mobile Communications (GSM)

- FDMA/TDMA approach
- Developed to provide a common second-generation technology for Europe
  - Over 6.9 billion subscriber units by the end of 2013
- Mobile station communicates across the Um interface (air interface) with base station transceiver in the same cell as mobile unit
- Mobile equipment (ME) – physical terminal, such as a telephone or PCS
  - ME includes radio transceiver, digital signal processors and subscriber identity module (SIM)
- GSM subscriber units are generic until SIM is inserted
  - SIMs roam, not necessarily the subscriber devices

GSM Architecture



Base Station Subsystem (BSS)

- BSS consists of base station controller and one or more base transceiver stations (BTS)
- Each BTS defines a single cell
  - Includes radio antenna, radio transceiver and a link to a base station controller (BSC)
- BSC reserves radio frequencies, manages handoff of mobile unit from one cell to another within BSS, and controls paging

Network Subsystem (NS)

- NS provides link between cellular network and public switched telecommunications networks
  - Controls handoffs between cells in different BSSs
  - Authenticates users and validates accounts
  - Enables worldwide roaming of mobile users
- Central element of NS is the mobile switching center (MSC)

Mobile Switching Center (MSC) Databases

- Home location register (HLR) database – stores information about each subscriber that belongs to it
- Visitor location register (VLR) database – maintains information about subscribers currently physically in the region
- Authentication center database (AuC) – used for authentication activities, holds encryption keys
- Equipment identity register database (EIR) – keeps track of the type of equipment that exists at the mobile station

GSM Radio Link

- Combination of FDMA and TDMA
- 200 kHz carriers
- Each with a data rate of 270.833 kbps
- 8 users share each carrier

Generalized Packet Radio Service (GPRS)

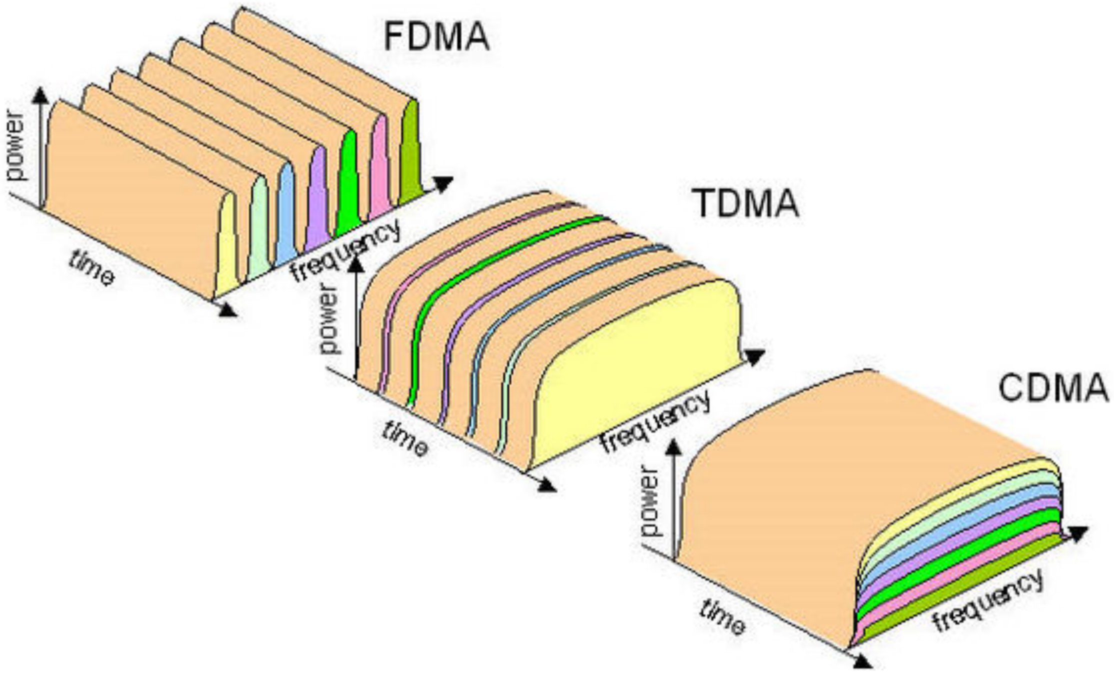
- Phase 2 of GSM
- Provides a datagram switching capability to GSM
  - Instead of sending data traffic over a voice connection which requires setup, sending data, and teardown
  - GPRS allows users to open a persistent data connection
  - Also has a new system architecture for data traffic
  - 21.4 kbps from a 22.8 kbps gross data rate
  - Can combine up to 8 GSM connections
    - Overall throughputs up to 171.2 kbps

Enhanced Data Rates for GSM Evolution (EDGE)

- The next generation of GSM
  - Not yet 3G, so called "2.5G" by some
- Three-fold increase in data rate
  - Up to 3 bits/symbol for 8-PSK from 1 bit/symbol for GMSK for GSM.
  - Max data rates per channel up to $22.8 \times 3 = 68.4$ kbps per channel
  - Using all eight channels in a 200 kHz carrier, gross data transmission rates up to 547.2 kbps became possible
    - Actual throughput up to 513.6 kbps.
- A later release of EDGE (3GPP Release 7) increased downlink data rates over 750 kbps and uplink data rates over 600 kbps

Spread Spectrum

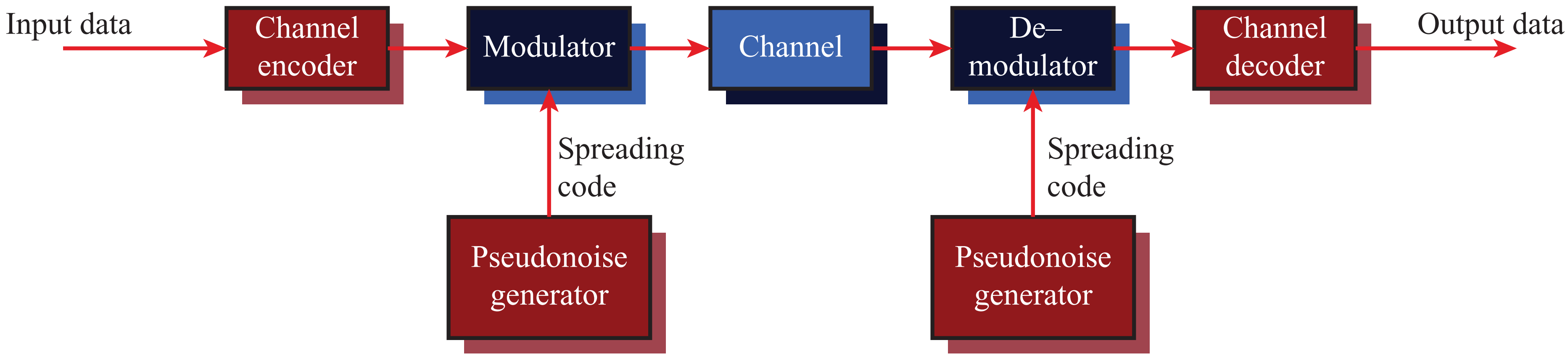
Before we study 3G we will have a look at spread spectrum and CDMA.

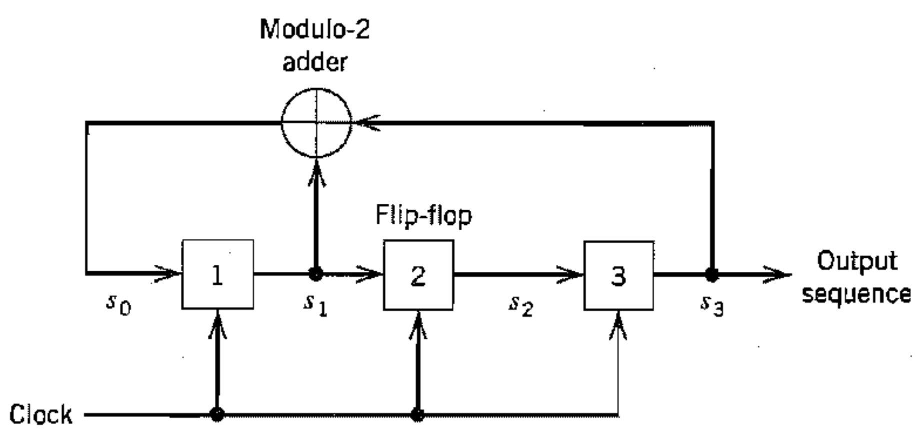


Spread Spectrum

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - Spreading code or spreading sequence
  - Generated by pseudonoise, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted

General Model of Spread Spectrum Digital Communication System

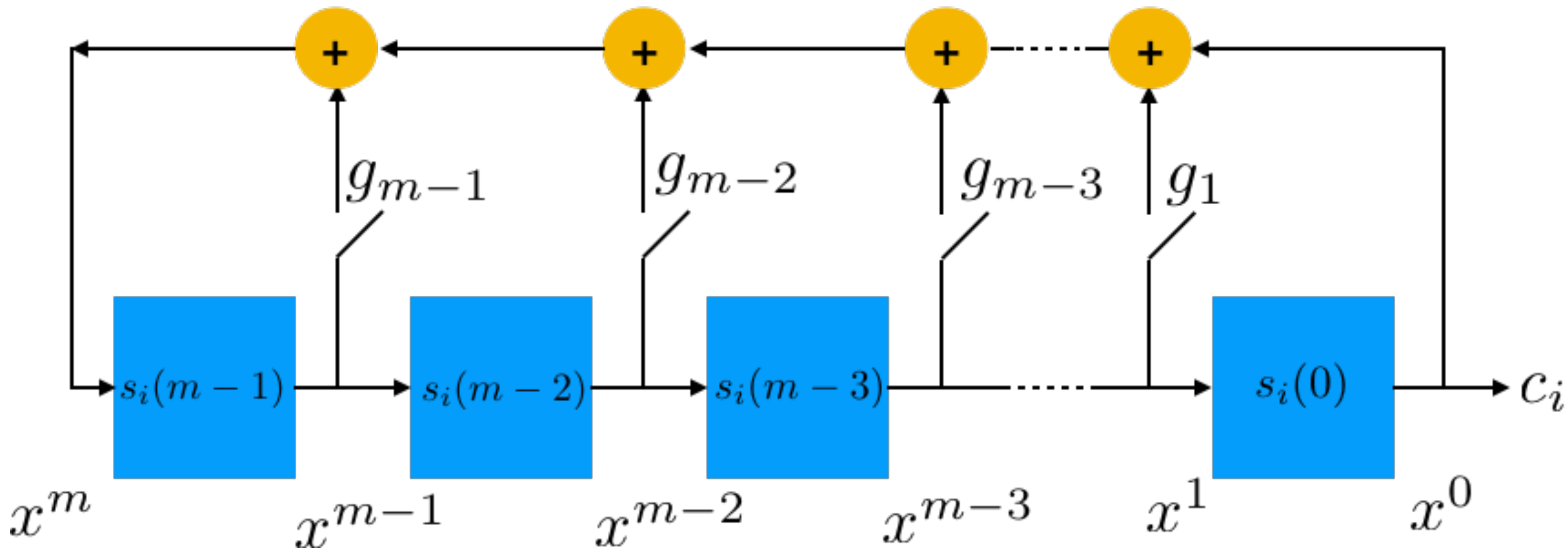




0011101**0011101**0011101

Source: http://tjeyamy.blogspot.tw/2012/05/pseudo-random-sequence-generator-in.html

PN Sequence

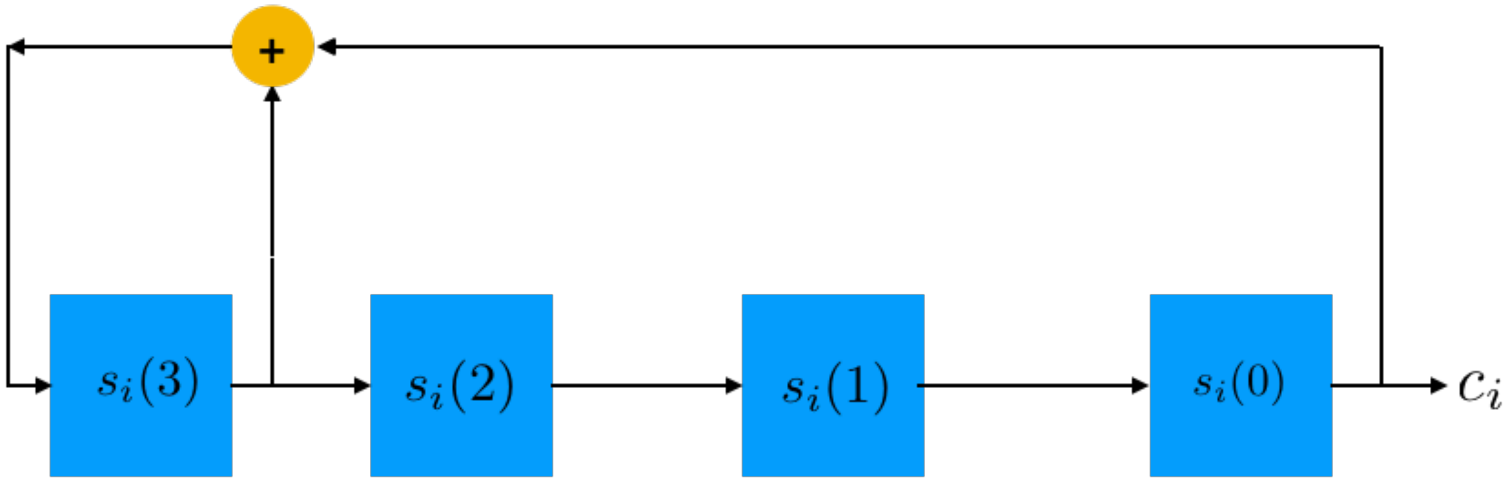


$$g(x) = g_m x^m + g_{m-1}x^{m-1} + \cdots + g_1 x + g_0$$

Output sequence recurrence condition according to g(x)

$$c_{i+m} = g_{m-1}c_{i+m-1} + g_{m-2}c_{i+m-2} + \cdots + g_1 c_{i+1} + c_i \qquad \pmod 2$$

PN Sequence: Shift-Register Implementation



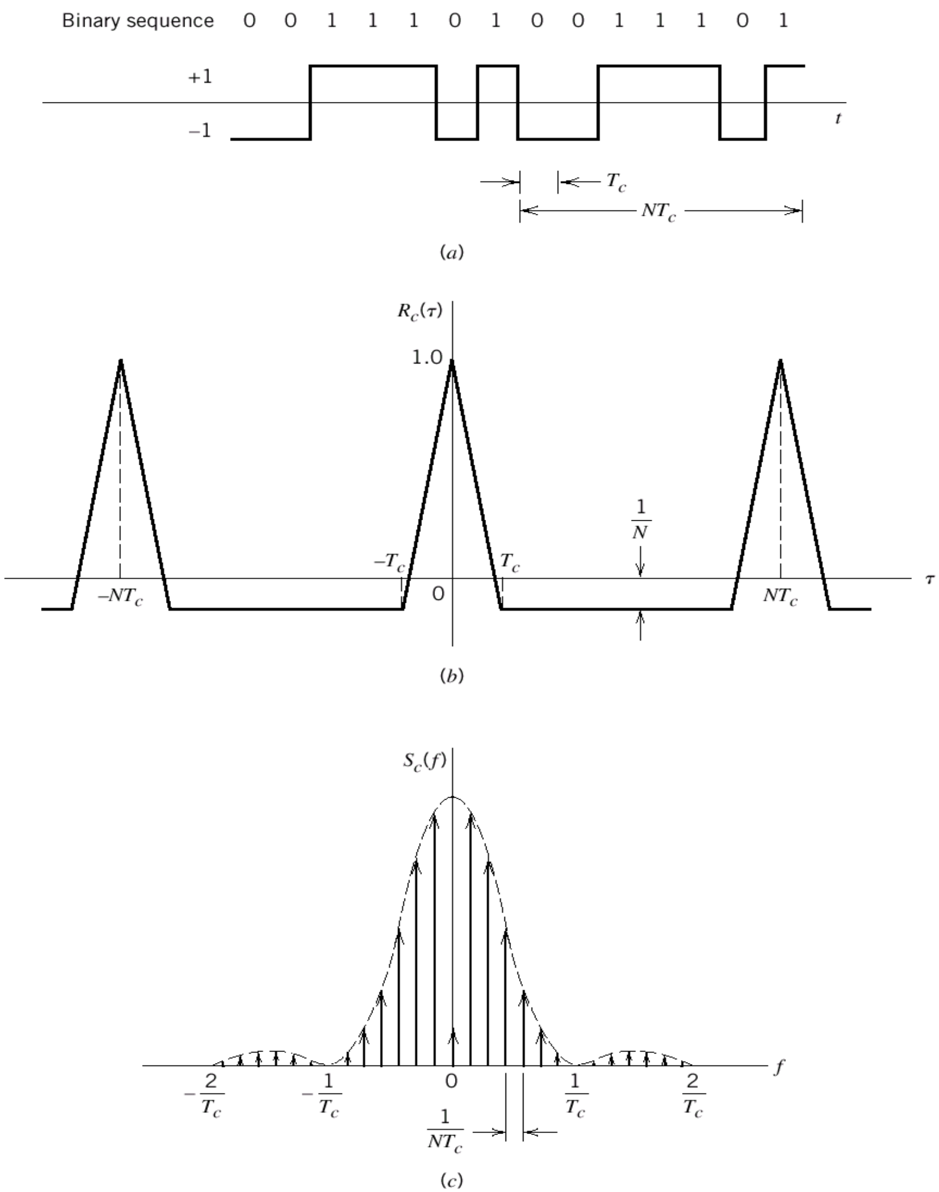
$$\boxed{g(x) = x^4 + x^3 + 1.}$$

$$\boxed{g_4 = 1, g_3 = 1, g_2 = 0, g_1 = 0, g_0 = 1}$$

$$\boxed{s_i(3) = 1,\ s_i(2) = 0,\ s_i(1) = 0,\ \text{and}\ s_i(0) = 1}$$

Using the recurrence relation above and setting $c_0 = 1, c_1 = 0, c_2 = 0, c_3 = 1$ we get $c_4 = g_3c_3 + g_2c_2 + g_1c_1 + c_0 = 1 + 0 + 0 + 1 = 0$ continuing in this manner we get: $c_5 = g_3c_4 + g_2c_3 + g_1c_2 + c_1 = 0 + 0 + 0 + 0 = 0$ $c_6 = 0,\ c_7 = 1,\ c_8 = 1,\ c_9 = 1, c_{10} = 1, c_{11} = 0, c_{12} = 1, c_{13} = 0$ $c_{14} = 1$, and $c_{15} = 1$. Therefore the sequence is $1, 0, 0, 1, 0, 0, 0, 1, 1, 1, 1, 0, 1, 0, 1, 1$ and the period is 15.

PN Sequence



(*a*) Waveform of PN sequence for length *m* = 3 or period *N* = 7.

(*b*) Autocorrelation function.

(*c*) Power spectral density.

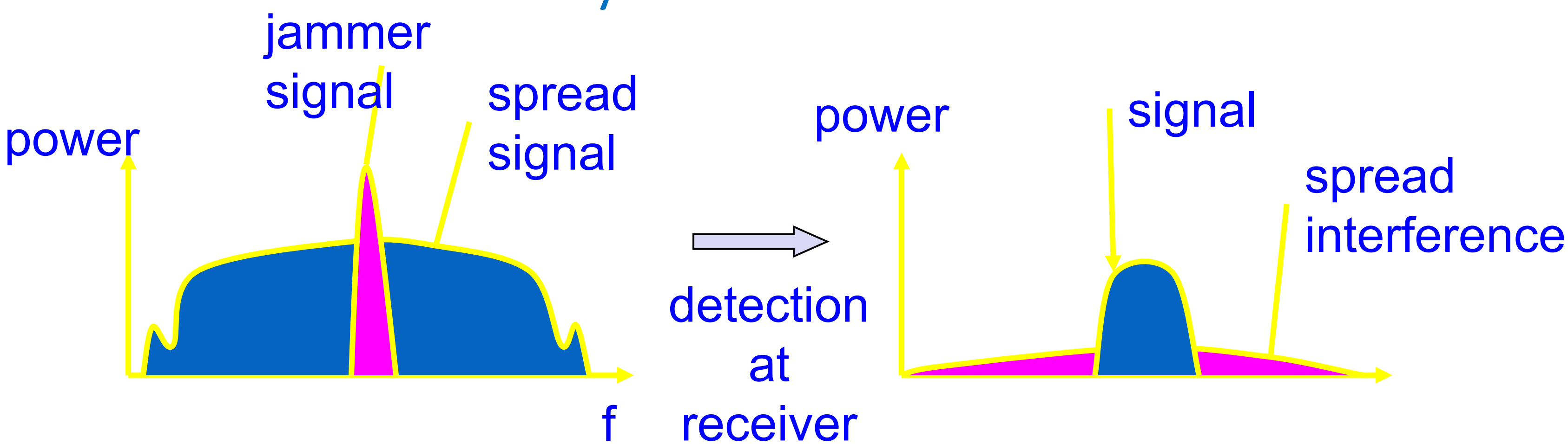
Courtesy: Huseyin Bilgekul, Eastern Mediterranean Univ.

Spread Spectrum

- On receiving end, digital sequence is used to demodulate the spread spectrum signal
- Signal is fed into a channel decoder to recover data

Spread Spectrum

- What can be gained from apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion
  - Can be used for hiding and encrypting signals
  - Several users can independently use the same higher bandwidth with very little interference

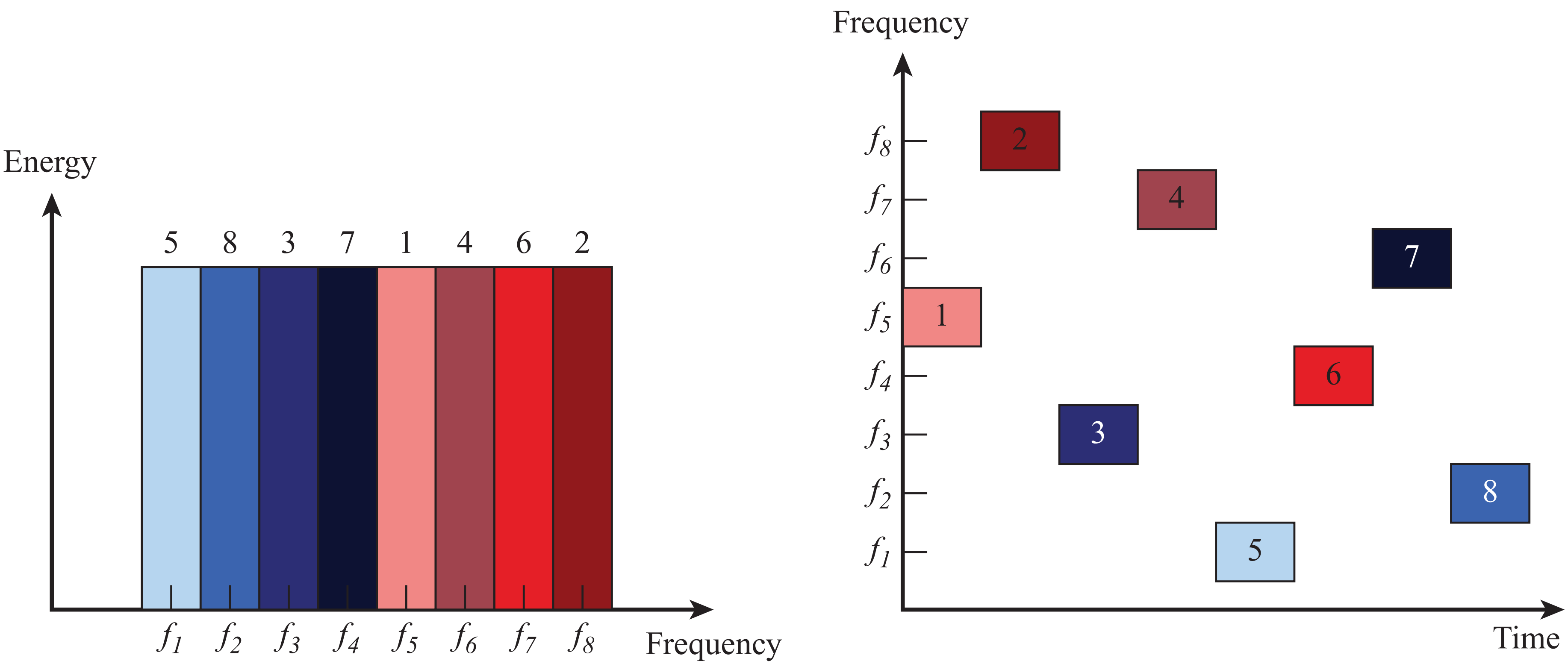


Courtesy: Huseyin Bilgekul, Eastern Mediterranean Univ.

Frequency Hopping Spread Spectrum (FHSS)

- Signal is broadcast over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
  - Transmitter operates in one channel at a time
  - Bits are transmitted using some encoding scheme
  - At each successive interval, a new carrier frequency is selected

Frequency hopping

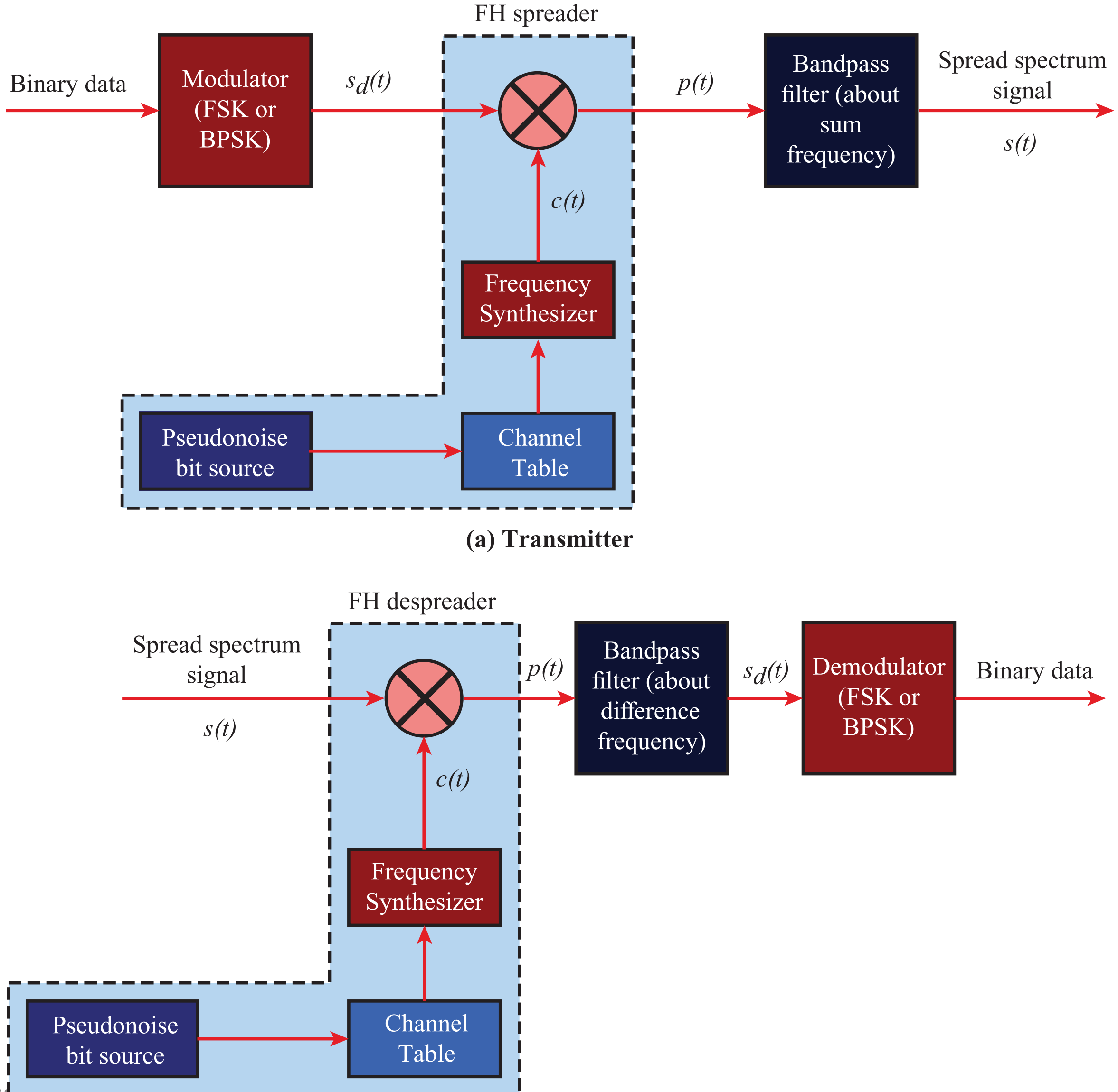


(a) Channel assignment **(b) Channel use**

Frequency Hopping Spread Spectrum

- Channel sequence dictated by spreading code (PN sequence)
- Receiver, hopping between frequencies in synchronization with transmitter, picks up message
- Advantages
  - Eavesdroppers hear only unintelligible blips
  - Attempts to jam signal on one frequency succeed only at knocking out a few bits

FHSS System



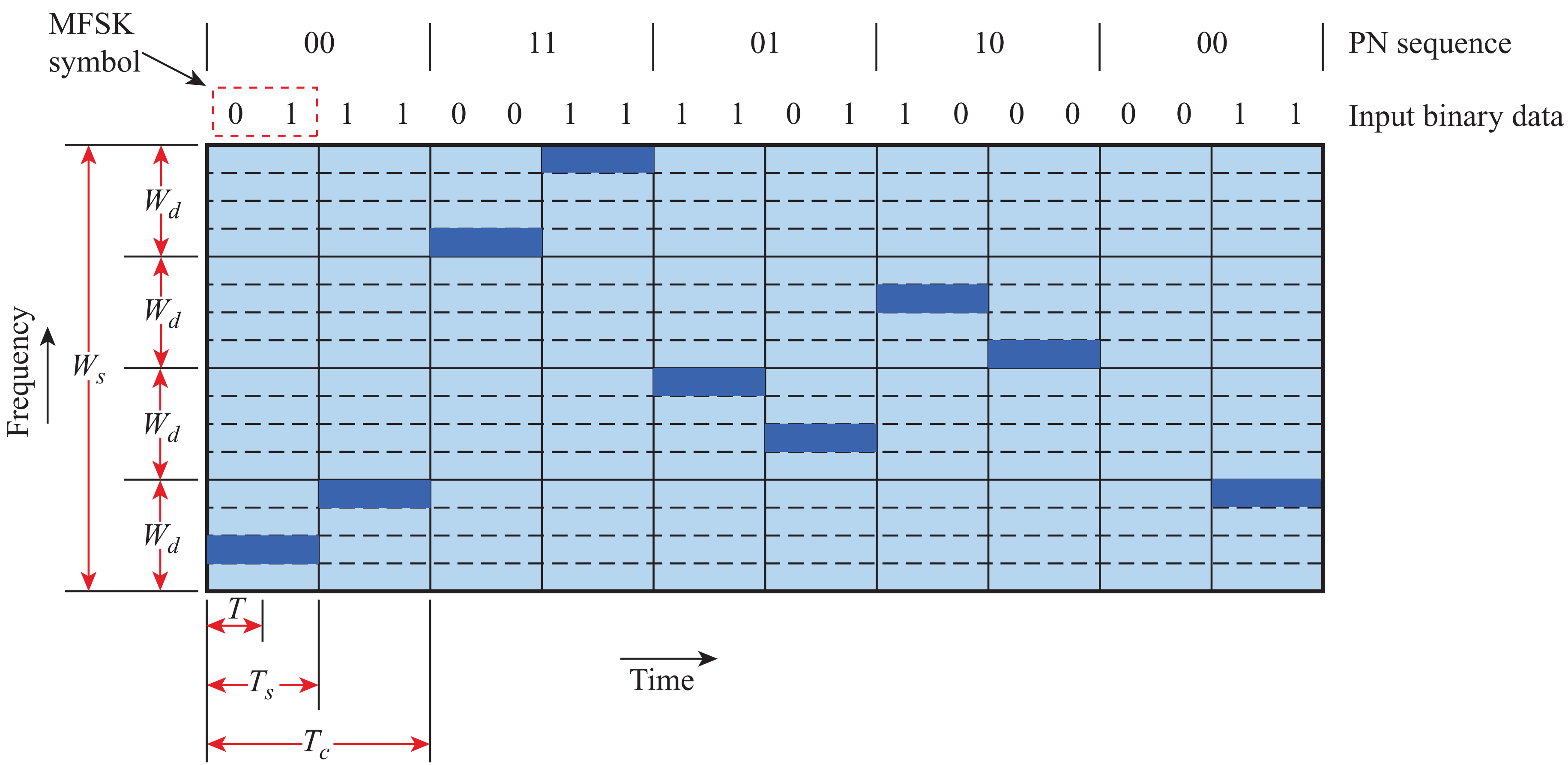
(a) Transmitter

(b) Receiver

FHSS Using MFSK

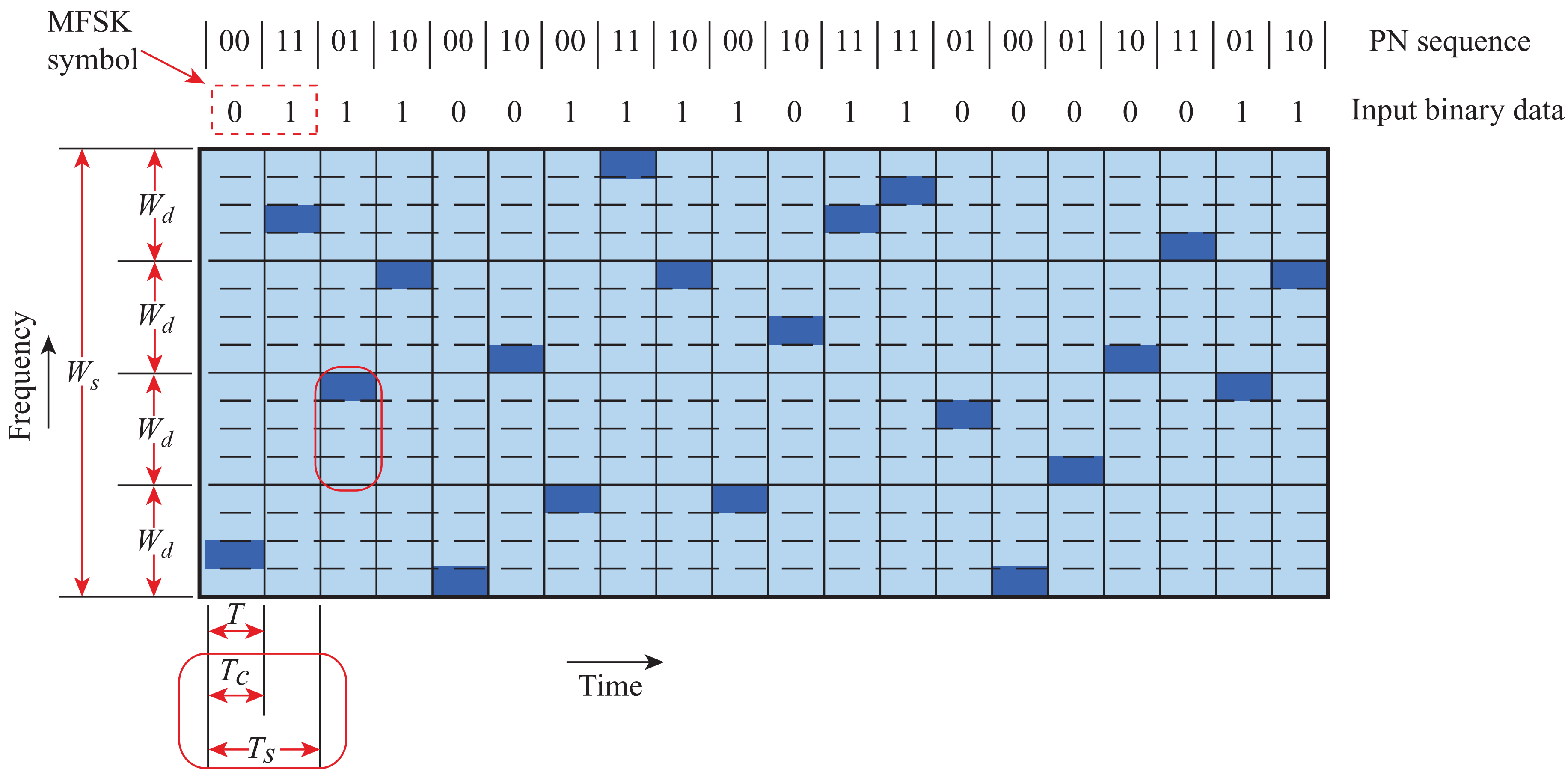
- MFSK signal is translated to a new frequency every T_c seconds by modulating the MFSK signal with the FHSS carrier signal
- For data rate of *R:*
  - duration of a bit: $T = 1/R$ seconds
  - duration of signal element: $T_s = LT$ seconds
- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
- $T_c < T_s$ - fast-frequency-hop spread spectrum

Slow FHSS



MFSK symbol
00
11
01
10
00
PN sequence
0 1 1 1 0 0 1 1 1 1 0 1 1 0 0 0 0 0 1 1
Input binary data
Frequency
W_s
W_d
W_d
W_d
W_d
T
T_s
T_c
Time

Fast FHSS


MFSK symbol
00 | 11 | 01 | 10 | 00 | 10 | 00 | 11 | 10 | 00 | 10 | 11 | 11 | 01 | 00 | 01 | 10 | 11 | 01 | 10
PN sequence
0 1 1 1 0 0 1 1 1 1 0 1 1 0 0 0 0 0 1 1
Input binary data
Frequency
W_s
W_d
W_d
W_d
W_d
T
T_c
T_s
Time

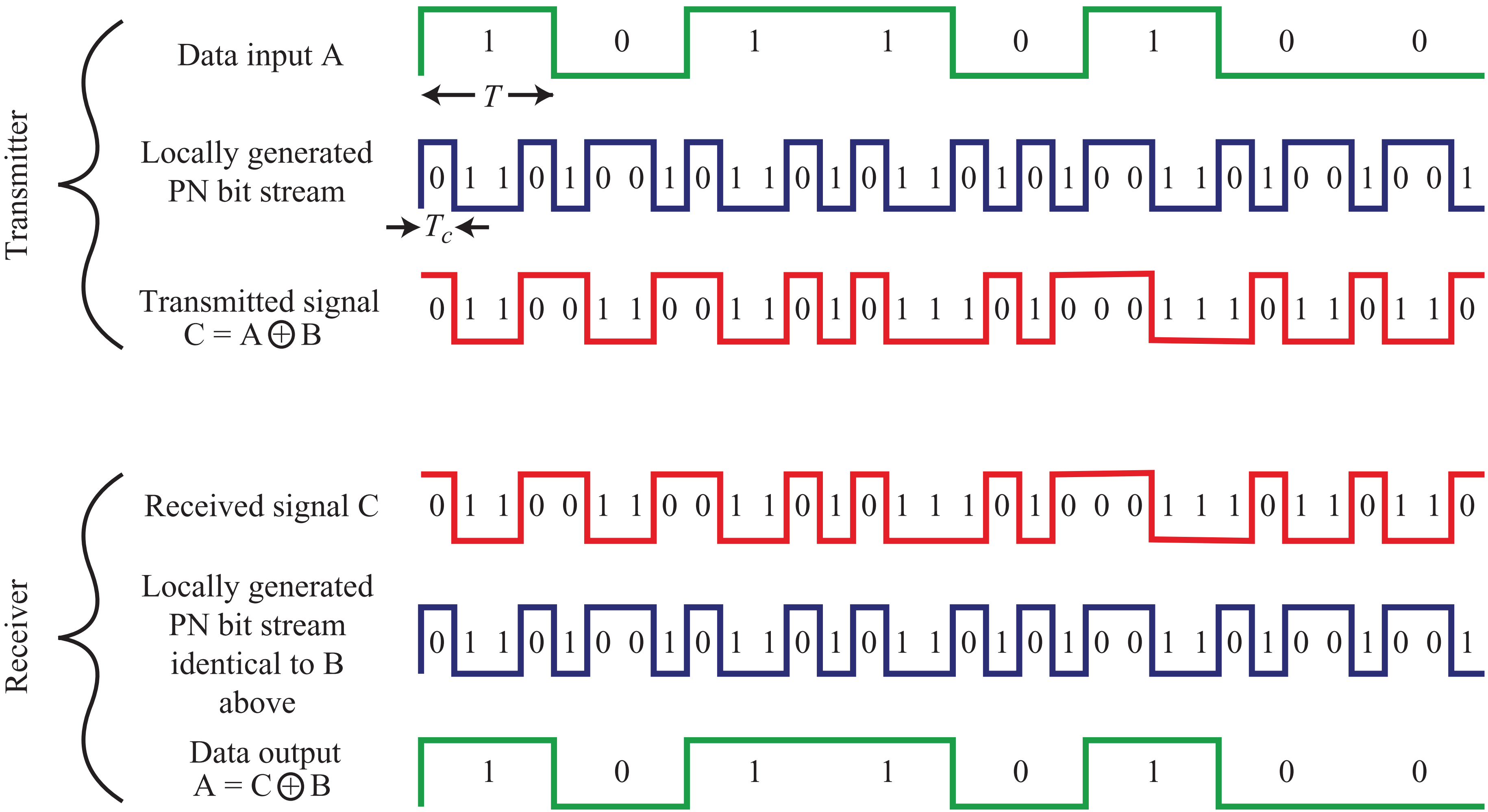
FHSS Performance Considerations

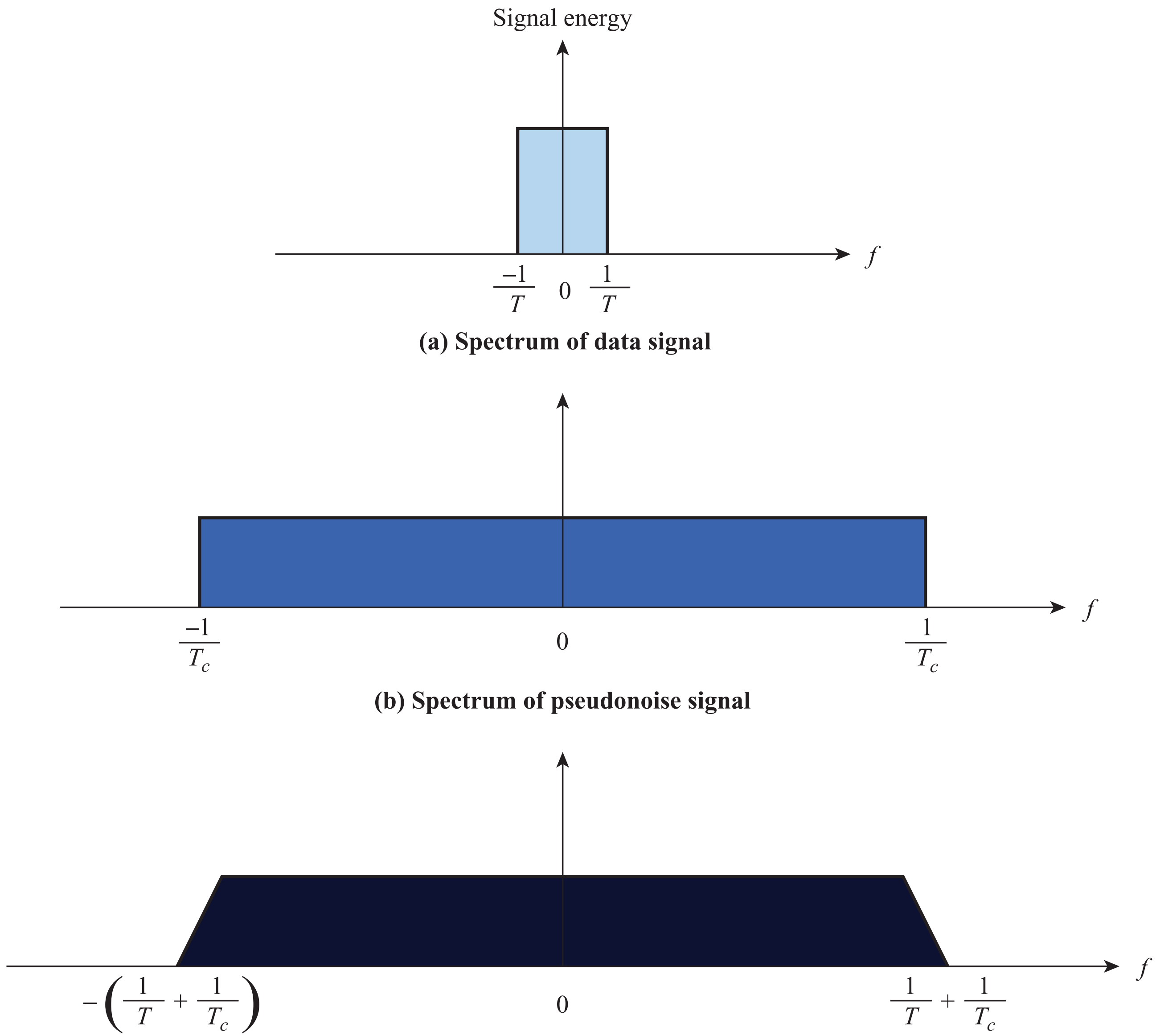
- Large number of frequencies used
- Results in a system that is quite resistant to jamming
  - Jammer must jam all frequencies
  - With fixed power, this reduces the jamming power in any one frequency band

Direct Sequence Spread Spectrum (DSSS)

- Each bit in original signal is represented by multiple bits in the transmitted signal
- Spreading code spreads signal across a wider frequency band
  - Spread is in direct proportion to number of bits used
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR

Example of Direct Sequence Spread Spectrum





(a) Spectrum of data signal

(b) Spectrum of pseudonoise signal

(c) Spectrum of combined signal

Code-Division Multiple Access (CDMA)

- Basic Principles of CDMA
  - D = rate of data signal
  - Break each bit into *k chips*
    - Chips are a user-specific fixed pattern
  - Chip data rate of new channel = kD

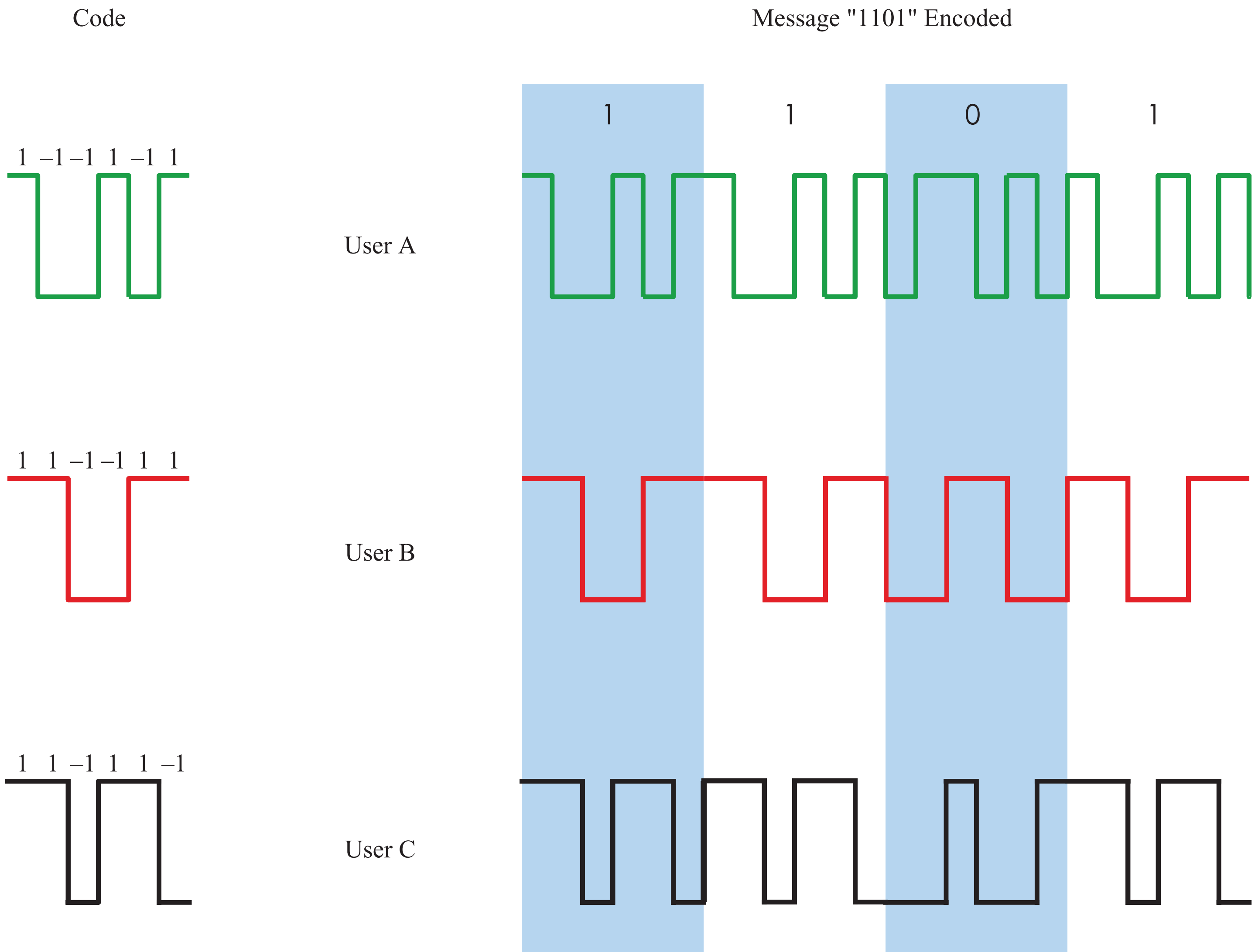
CDMA Example

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

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

- <d1, d2, d3, d4, d5, d6> = received chip pattern
- <c1, c2, c3, c4, c5, c6> = sender's code

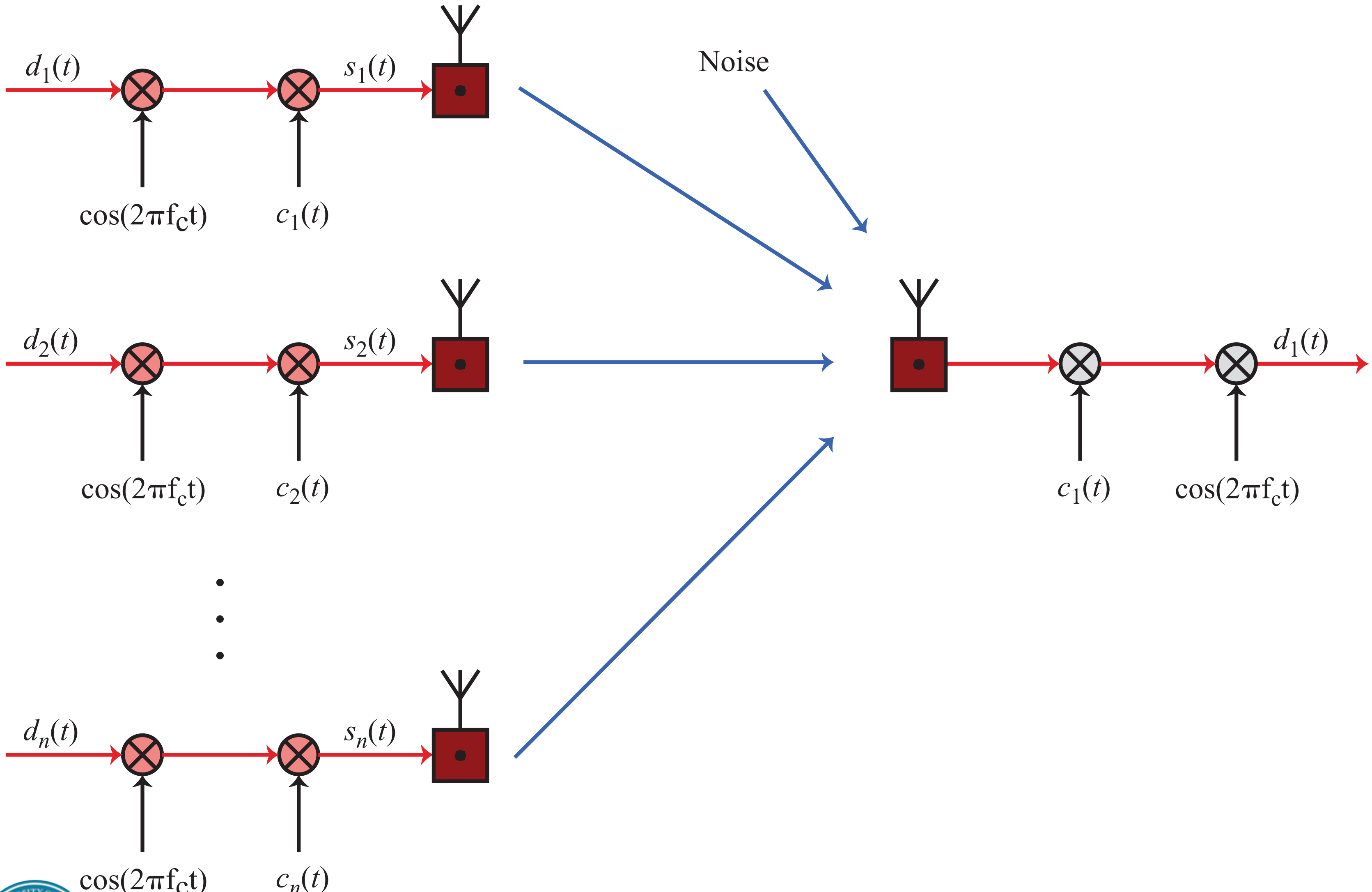
CDMA example



CDMA Example

- User A code = <1, –1, –1, 1, –1, 1>
  - –To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - –To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code = <1, 1, –1, – 1, 1, 1>
  - –To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A's code
  - –(A's code) x (received chip pattern)
    - ➢User A '1' bit: 6 -> 1
    - ➢User A '0' bit: -6 -> 0
    - ➢User B '1' bit: 0 -> unwanted signal ignored

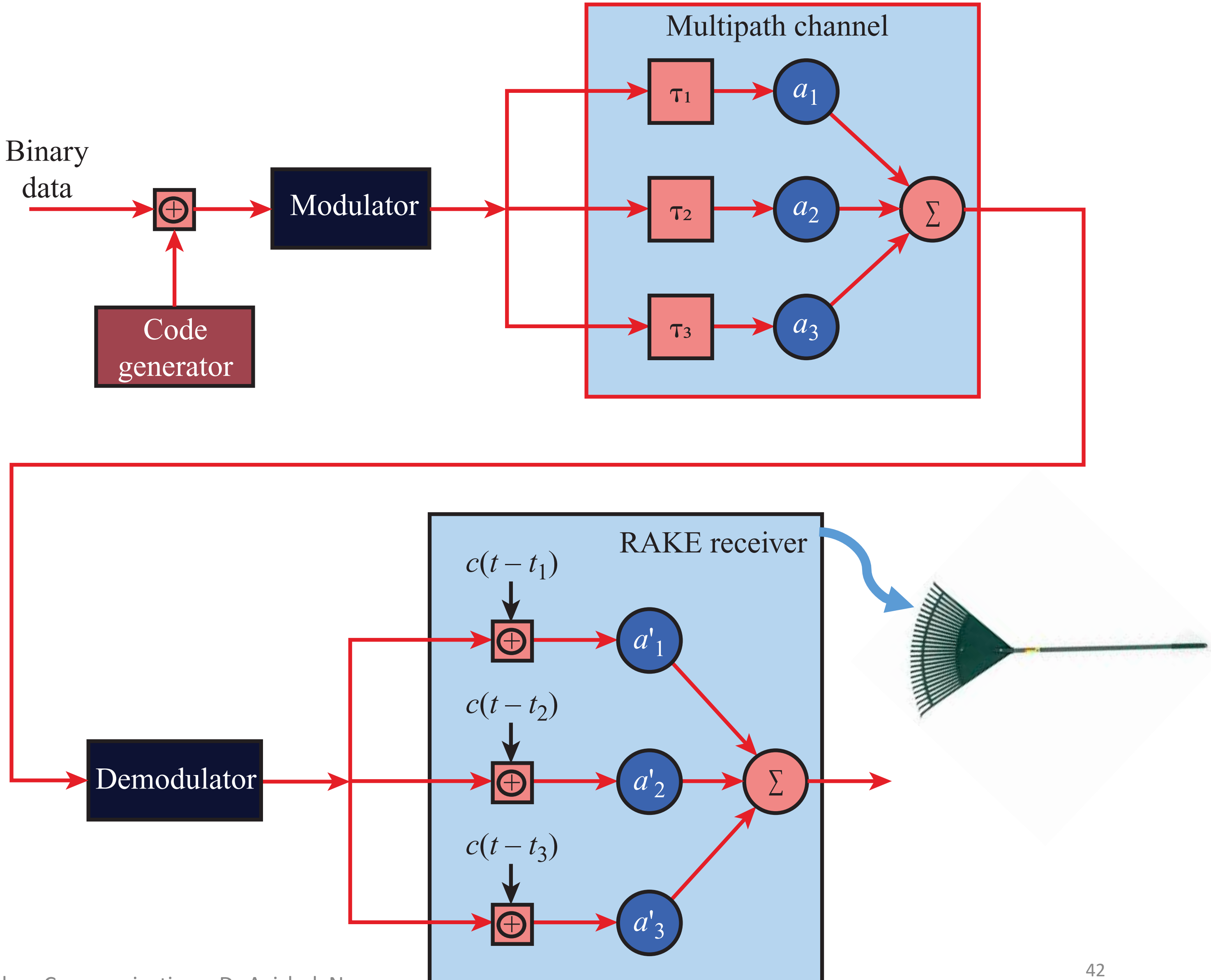
CDMA in a DSSS Environment



Rake receiver

- RAKE receiver
  - –Multiple versions of a signal arrive more than one chip interval apart
  - –RAKE receiver attempts to recover signals from multiple paths and combine them
- This method achieves better performance than simply recovering dominant signal and treating remaining signals as noise

Principle of RAKE Receiver



Categories of Spreading Sequences

- Spreading Sequence Categories
  - PN sequences (pseudonoise)
  - Orthogonal codes
- For FHSS systems
  - PN sequences most common
- For DSSS systems not employing CDMA
  - PN sequences most common
- For DSSS CDMA systems
  - PN sequences
  - Orthogonal codes

Advantages of CDMA for Cellular systems

- Frequency diversity – frequency-dependent transmission impairments have less effect on signal
- Multipath resistance – chipping codes used for CDMA exhibit low cross correlation and low autocorrelation
- Privacy – privacy is inherent since spread spectrum is obtained by use of noise-like signals
- Graceful degradation – system only gradually degrades as more users access the system

Drawbacks of CDMA Cellular

- Self-jamming – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized
- Near-far problem – signals closer to the receiver are received with less attenuation than signals farther away

Mobile Wireless CDMA Design Considerations

- RAKE receiver – when multiple versions of a signal arrive more than one chip interval apart, RAKE receiver attempts to recover signals from multiple paths and combine them
- Soft Handoff – mobile station temporarily connected to more than one base station simultaneously
  - Requires that the mobile acquire a new cell before it relinquishes the old
  - More complex than hard handoff used in FDMA and TDMA schemes

IS-95 Forward Link

- Most widely used CDMA cellular standard is IS-95, used mainly in North America
- Forward link channels
  - Pilot (channel 0) - allows the mobile unit to acquire timing information, provides phase reference and provides means for signal strength comparison
  - Synchronization (channel 32) - used by mobile station to obtain identification information about cellular system
  - Paging (channels 1 to 7) - contain messages for one or more mobile stations
  - Traffic (channels 8 to 31 and 33 to 63) – the forward channel supports 55 traffic channels
    - 9600 or 14,400 bps

ITU’s initial View of Third-Generation Capabilities

- The ITU’s International Mobile Telecommunications for the year 2000 (IMT-2000) initiative
- Voice quality comparable to the public switched telephone network
- 144 kbps data rate available to users in high-speed motor vehicles over large areas
- 384 kbps available to pedestrians standing or moving slowly over small areas
- Support for 2.048 Mbps for office use

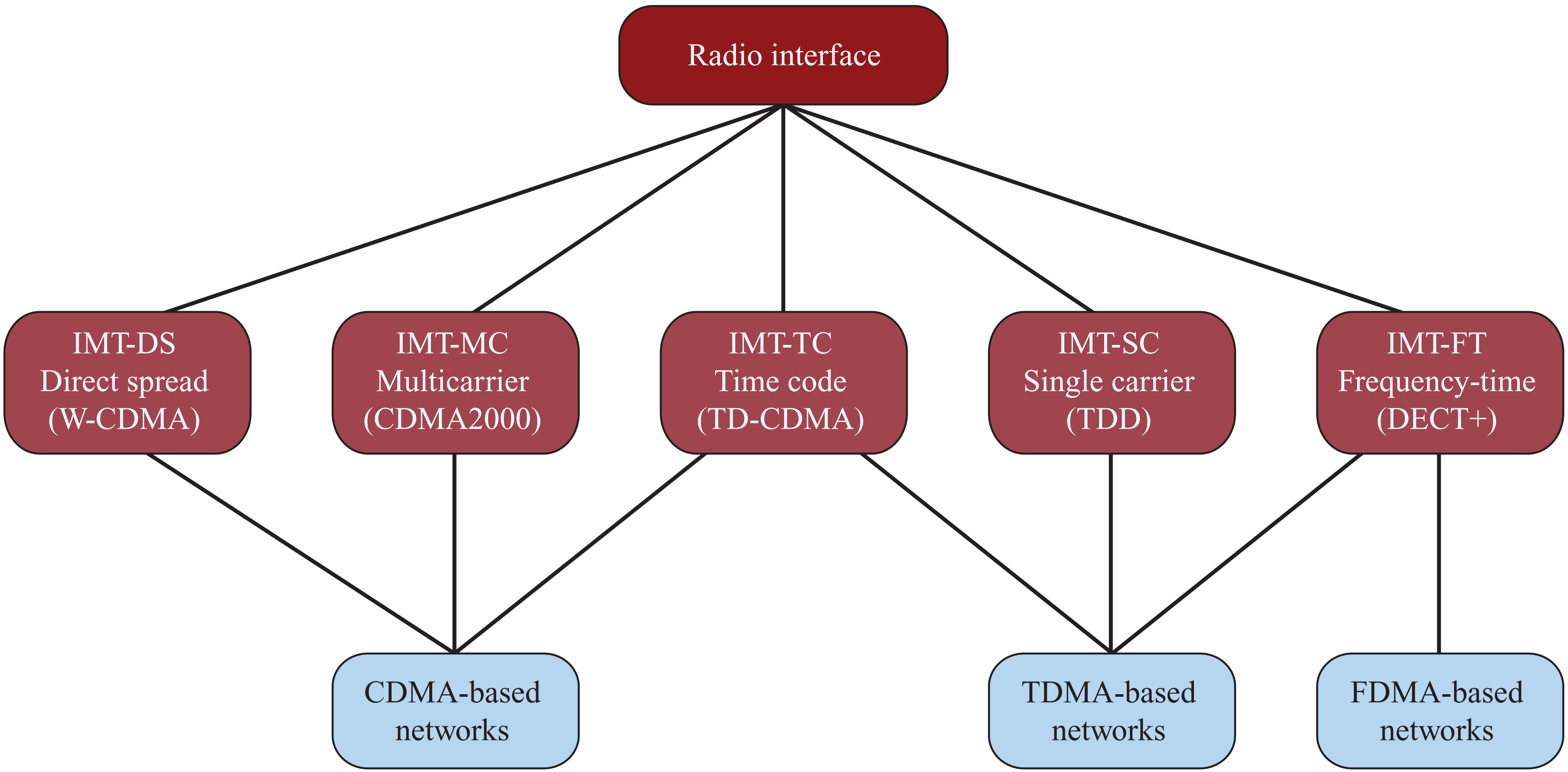
ITU's initial View of Third-Generation Capabilities

- Symmetrical / asymmetrical data transmission rates
- Support for both packet switched and circuit switched data services
- An adaptive interface to the Internet to reflect efficiently the common asymmetry between inbound and outbound traffic
- More efficient use of the available spectrum in general
- Support for a wide variety of mobile equipment
- Flexibility to allow the introduction of new services and technologies

Alternative interfaces

- Five alternatives for smooth evolution from 1G and 2G systems
- Two most prevalent
  - Wideband CDMA (WCDMA)
  - CDMA2000
- Both based on CDMA
- Similar to but incompatible with each other

ITM-2000 terrestrial radio interfaces



CDMA Design Considerations

- Bandwidth – limit channel usage to 5 MHz
- Chip rate – depends on desired data rate, need for error control, and bandwidth limitations; 3 Mcps or more is reasonable
- Multirate – advantage is that the system can flexibly support multiple simultaneous applications from a given user and can efficiently use available capacity by only providing the capacity required for each service

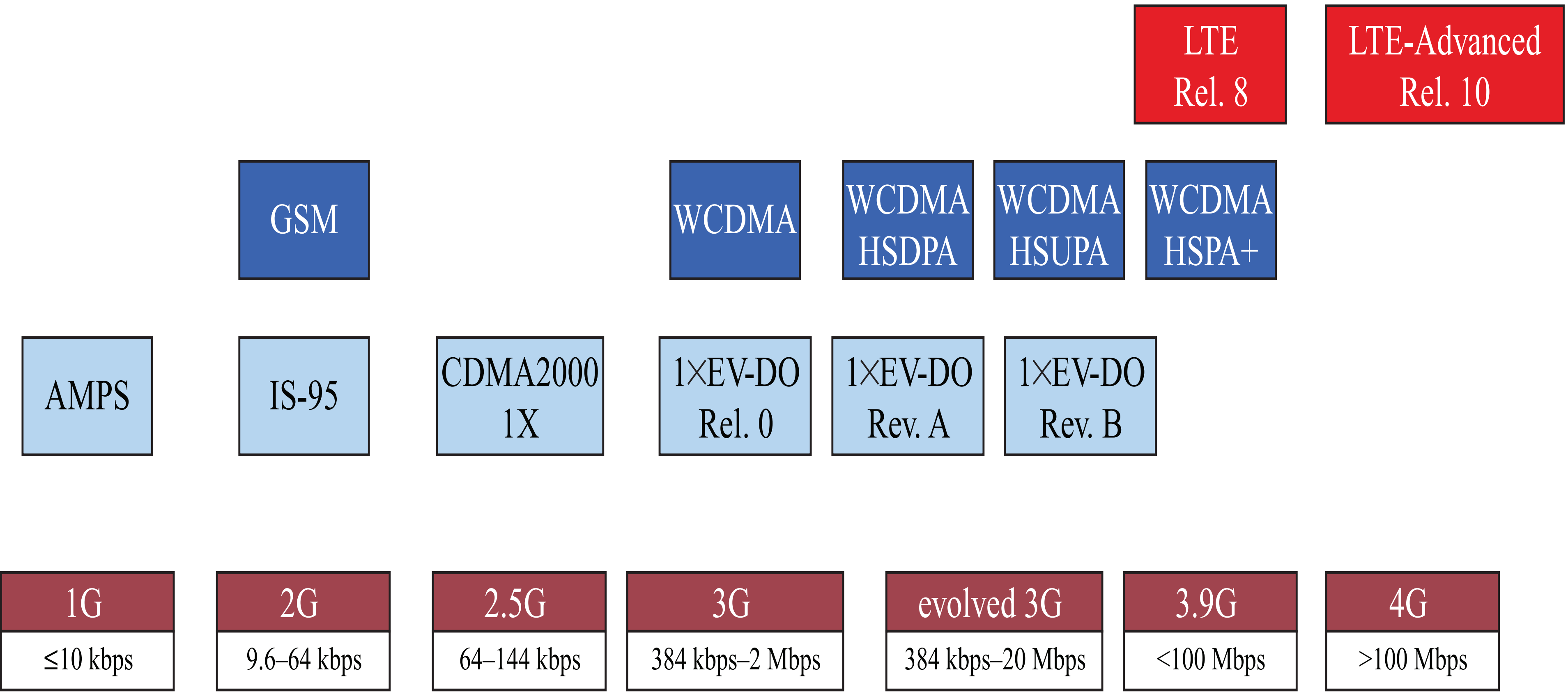
WCDMA and UMTS

- WCDMA is part of a group of standards from
  - IMT-2000
  - Universal Mobile Telephone System (UMTS)
  - Third-Generation Partnership Project (3GPP) industry organization
- 3GPP originally released GSM
  - Issued Release 99 in 1999 for WCDMA and UMTS
  - Subsequent releases were “Release 4” and onwards
  - Many higher layer network functions of GSM were carried over to WCDMA

WCDMA and UMTS

- 144 kbps to 2 Mbps, depending on mobility
- High Speed Downlink Packet Access (HSDPA)
  - Release 5
  - 1.8 to 14.4 Mbps downlink
  - Adaptive modulation and coding, hybrid ARQ, and fast scheduling
- High Speed Uplink Packet Access (HSUPA)
  - Release 6
  - Uplink rates up to 5.76 Mbps
- High Speed Packet Access Plus (HSPA+)
  - Release 7 and successively improved in releases through Release 11
  - Maximum data rates increased from 21 Mbps up to 336 Mbps
  - 64 QAM, 2×2 and 4×4 MIMO, and dual or multi-carrier combinations
- 3GPP Release 8 onwards introduced Long Term Evolution (LTE)
  - Pathway to 4G, Chapter 14

Evolution of cellular wireless systems



CDMA2000 and EV-DO

- CDMA2000 first introduced 1xRTT (Radio Transmission Technology)
  - 1 times the 1.2288 Mcps spreading rate of a 1.25 MHz IS-95 CDMA channel
  - Not 3G, so considered by some as "2.5G"
- Evolution-Data Only (1×EV-DO)
  - Also 1×EV-DV (data/voice) which never succeeded
  - 1×EV-DO Release 0
    - ➢ 2.4 Mbps uplink, 153 kbps downlink
    - ➢ Only using 1.25 MHz of 5 MHz required of CDMA
  - 1×EV-DO Release A
    - ➢ 3.1 Mbps downlink, 1.8 Mbps uplink, QoS
  - 1×EV-DO Release B
    - ➢ 5 MHz bandwidth, 14.7 Mpbs uplink, 5.4 Mbps downlink
- EV-DO uses only IP, but VoIP can be used for voice

CDMA2000 1XEV-Do configuration elements