Mobile Communication Networks

Spread Spectrum Communications

Note: Some slides and/or pictures in the following are adapted from slides ©2010 AAU, Bettstetter - Mobile and Wireless Systems; ©2012 TUB, Schiller - Telematics, Mobile Communications; and adapted from books: ©2004 Stallings - Wireless Communications & Networks (2ed); ©2003 Schiller: Mobile Communications (2ed); ©2008 Eberspächer et al - GSM – Architecture, Protocols, and Services (3ed)

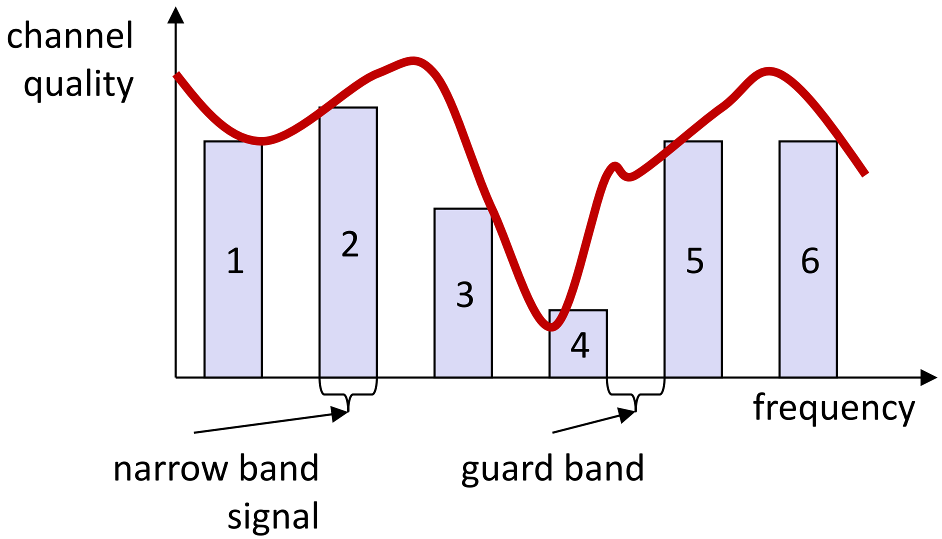
Questions:

- How to cope with (time varying) frequency selective fading?
- How to cope with narrow-band interference?
  (unintentional or jamming)
- Is it possible to send at the same time and at the same frequency? Why would I want that?

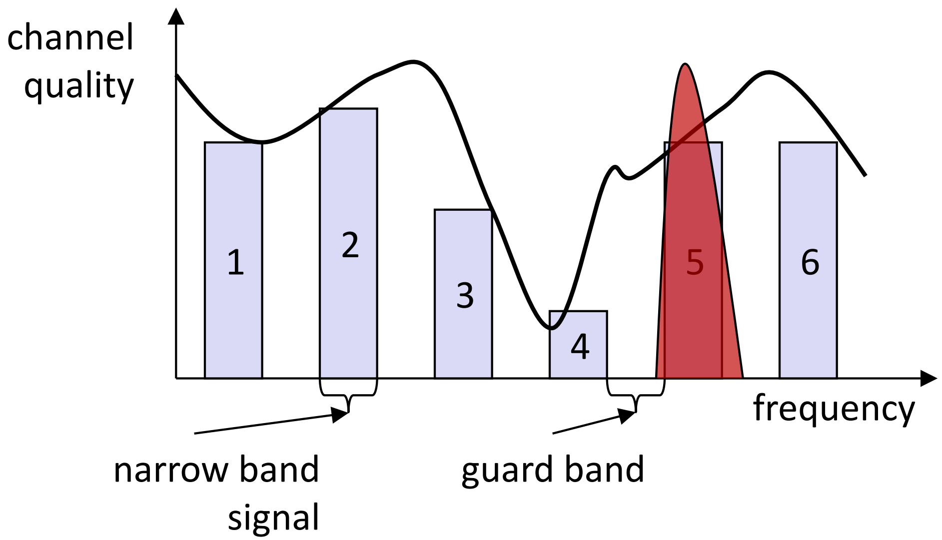
Possible solutions:

- Frequecy Hopping Spread Spectrum
- Direct Sequence Spread Spectrum

frequency selective fading and Jamming



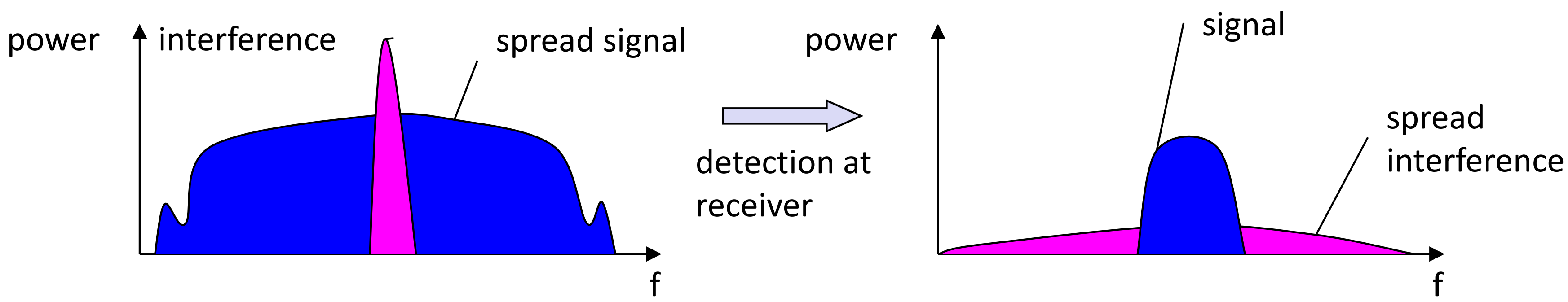
Frequency selective fading



Jamming

Spread Spectrum Communications

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal over a wide frequency interval, much higher than the minimum required bandwidth of the signal, using a special code
  - protection against narrowband interference
  - make the signals less susceptible to interference and more difficult to intercept



- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof
- Alternatives: Direct Sequence, Frequency Hopping

Frequency Hopping Spread Spectrum

Frequency Hopping Spread Spectrum

Frequency Hopping Spread Spectrum

US Patent „Secret Communications System“ (# 2,292,387, 1942)

- “Secret communication systems involving the use of carrier waves of different frequencies ... useful in the remote control of ... torpedoes” intended to make it harder for enemies to detect or to jam.
- Frequency hopping (88 frequencies)

The patent was rediscovered in the 1950s.

Hedy Lamarr (*1913 Vienna, †2000 Florida, actress)

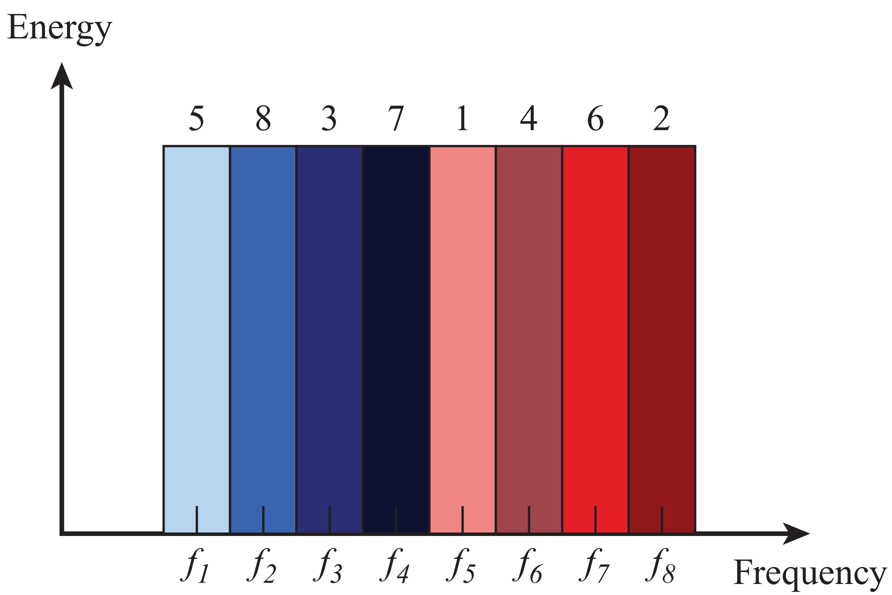
Frequency Hopping Spread Spectrum

Hedy Lamarr (*1913 Vienna, †2000 Florida, actress)

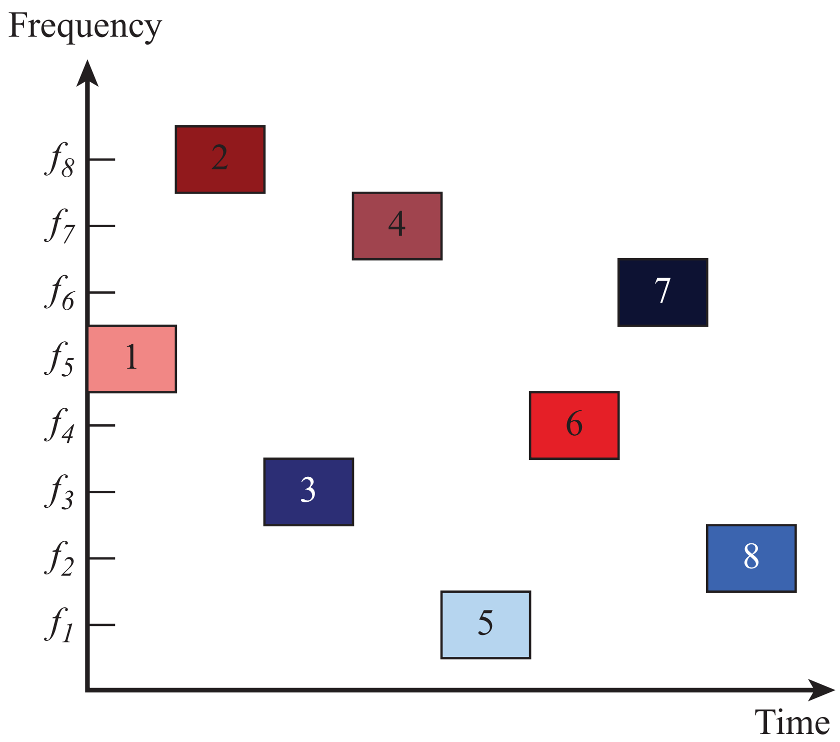
"Avant garde composer George Antheil and Golden Age actress Hedy Lamarr were granted US Patent 2,292,387 on August 11, 1942 for their Secret Communication System for use in radio guided torpedoes.

Their approach was unique in that frequency coordination was done with paper player piano rolls - a novel approach which was never put in practice."

Frequency Hopping Spread Spectrum (FHSS)



(a) Channel assignment



(b) Channel use

Signal hops from frequency to frequency at fixed intervals

Frequency Hopping Spread Spectrum

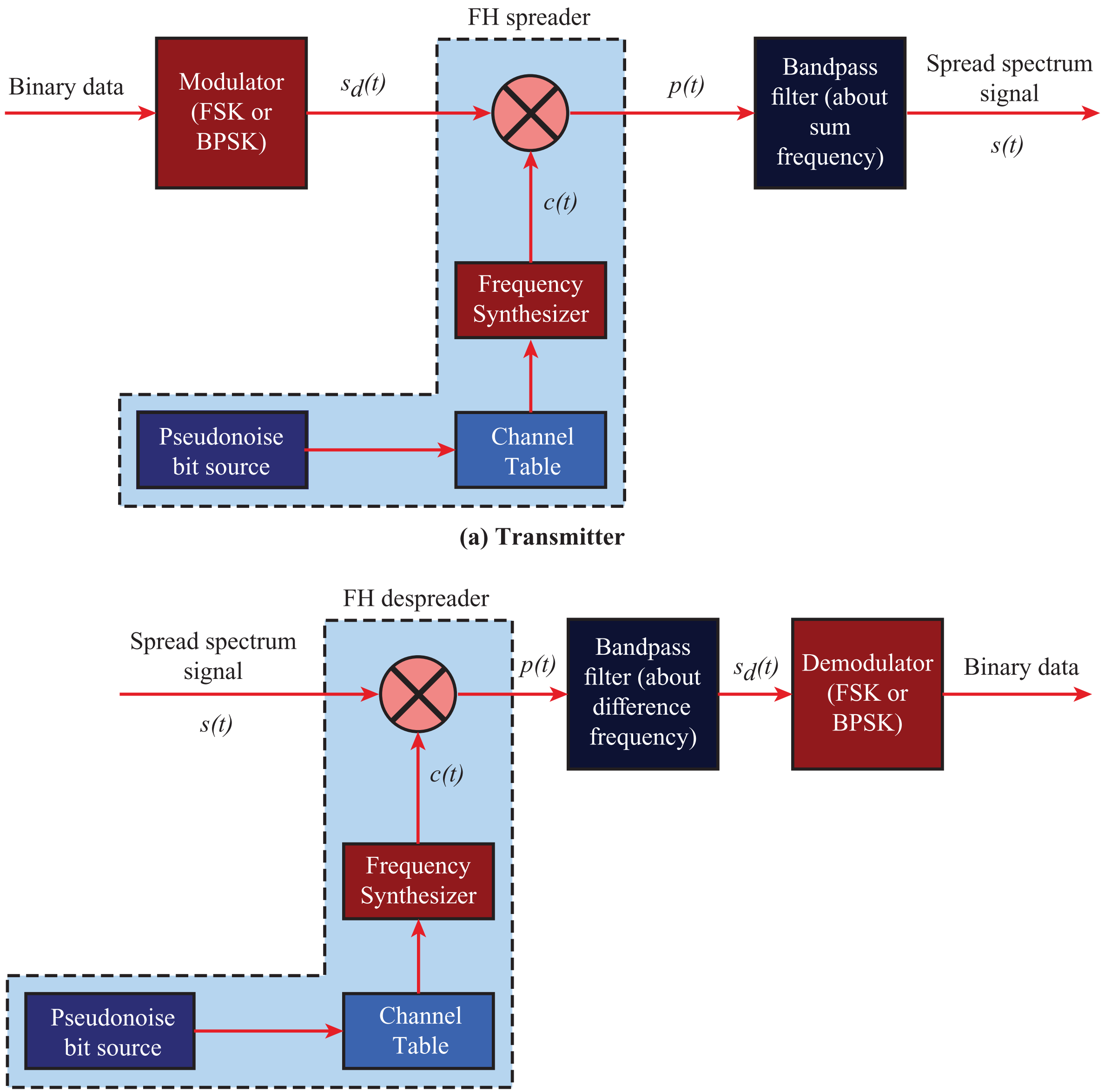
- Signal is broadcast over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
  - Transmitter operates in one channel at a time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

Frequency Hopping Spread Spectrum

- Channel sequence dictated by spreading code
- 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

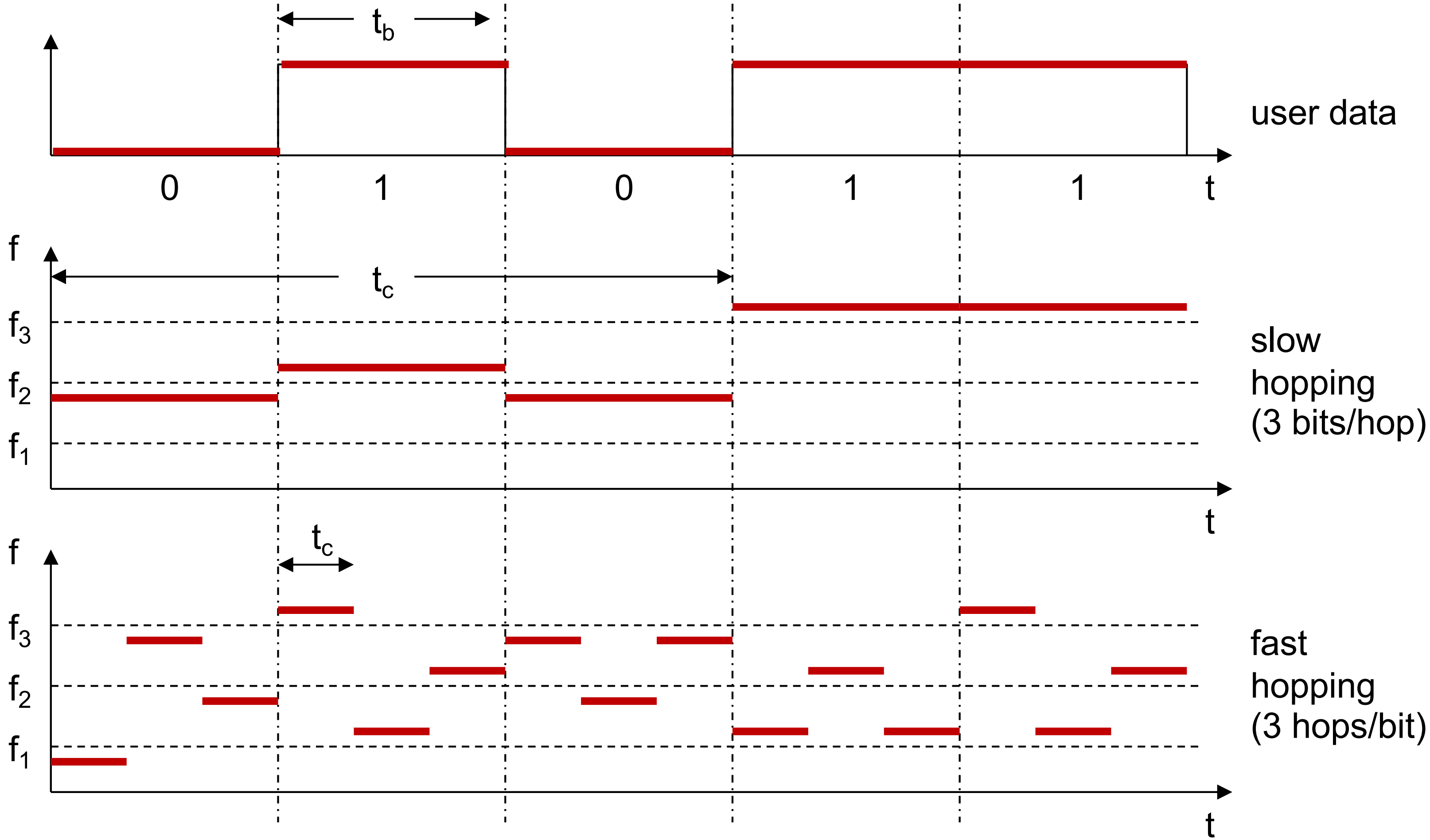
FHSS Transmitter / Receiver



(a) Transmitter

(b) Receiver

FHSS – slow vs fast hopping



t_b: bit duration t_c: hop duration (or chipping duration)

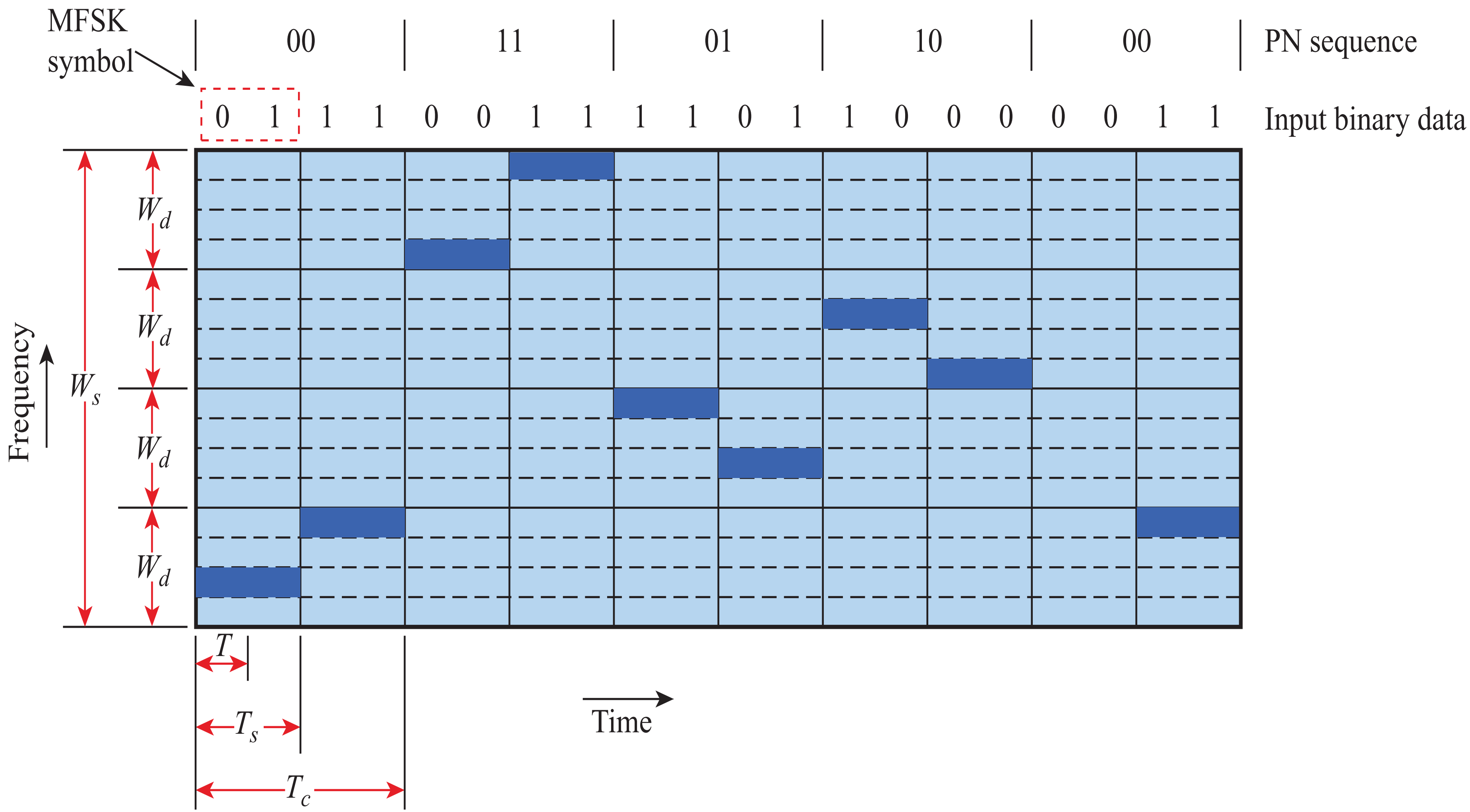
FHSS using MFSK

- 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 (or symbol): $T_s = LT$ seconds (L = # bits/symbol)

- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
- $T_c < T_s$ - fast-frequency-hop spread spectrum

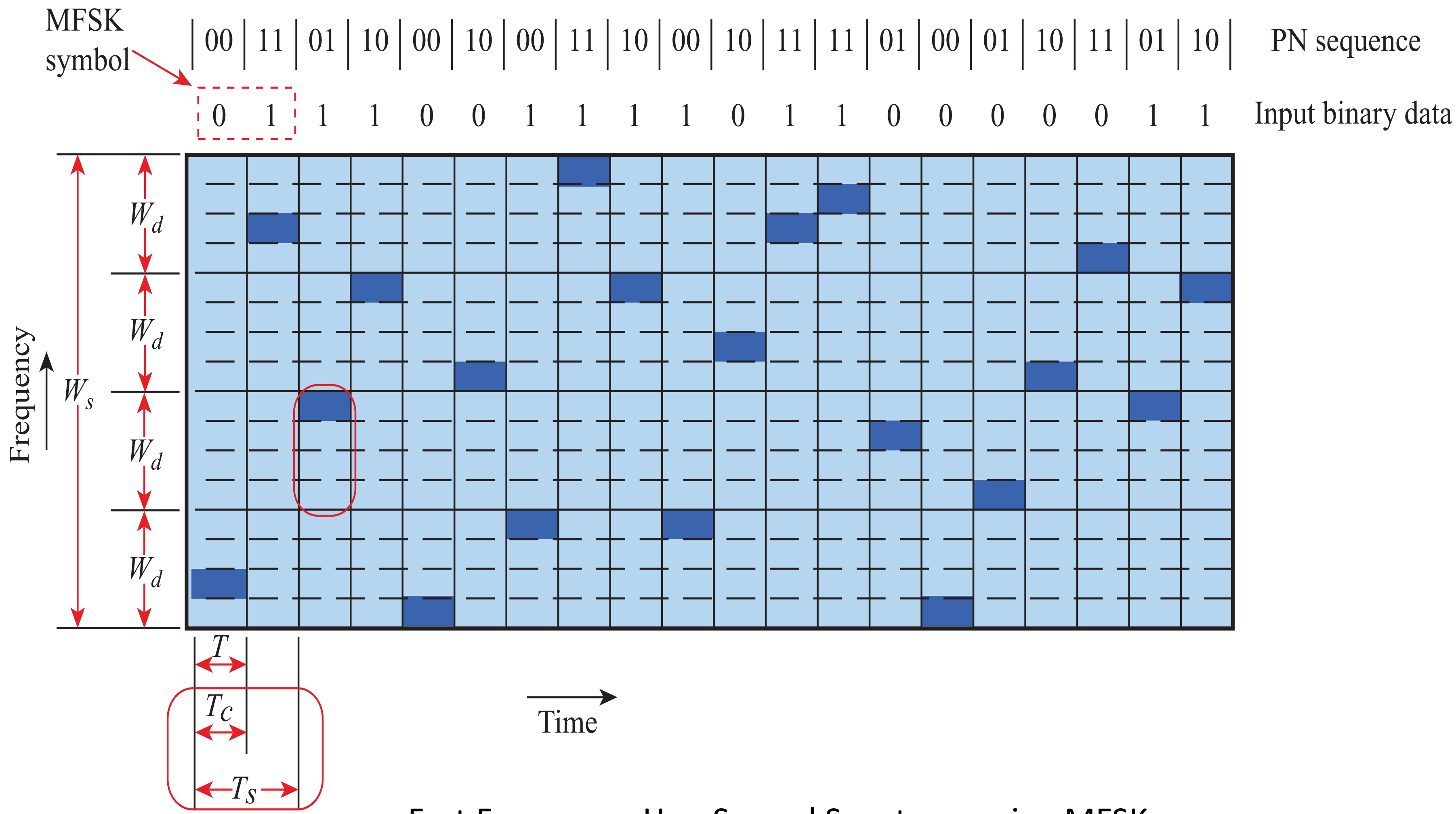
FHSS using MFSK – slow hopping



Slow-Frequency-Hop Spread Spectrum using MFSK

M=4, PN sequence with k=2 (2^2 FHSS bands), 2 symbols/hop

FHSS using MFSK – fast hopping



Fast Frequency-Hop Spread Spectrum using MFSK

M=4, PN sequence with k=2 (2^2 FHSS bands), 2 hops/symbol

FHSS Performance Considerations

- Large number of frequencies used
  - Used bandwidth *B'* expands to *n*B*

    n – number of frequency bands in FHSS

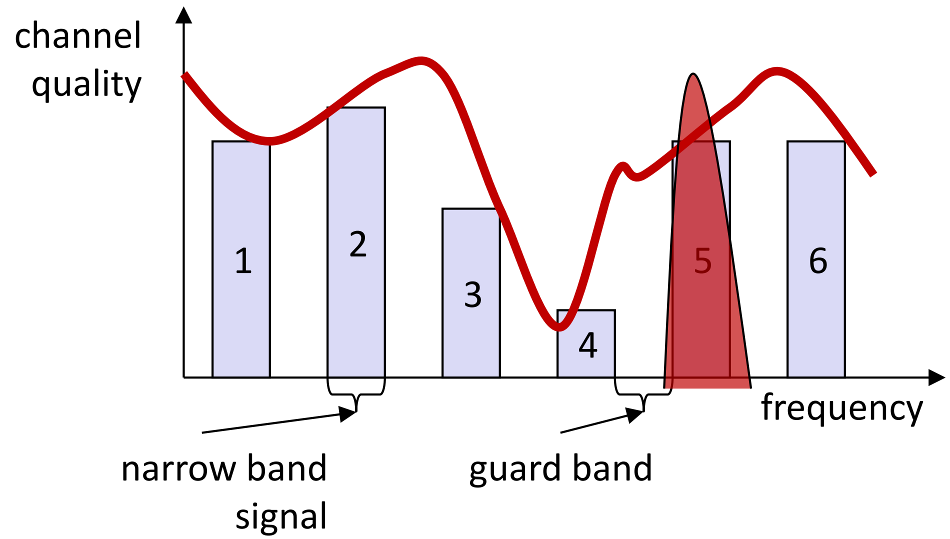
- Results in a system that is quite resistant to jamming
  - Jammer must jam all frequencies
  - With fixed power, this reduces the jamming power in any of the *n* frequency bands by a factor of *1/n*

FHSS - summary

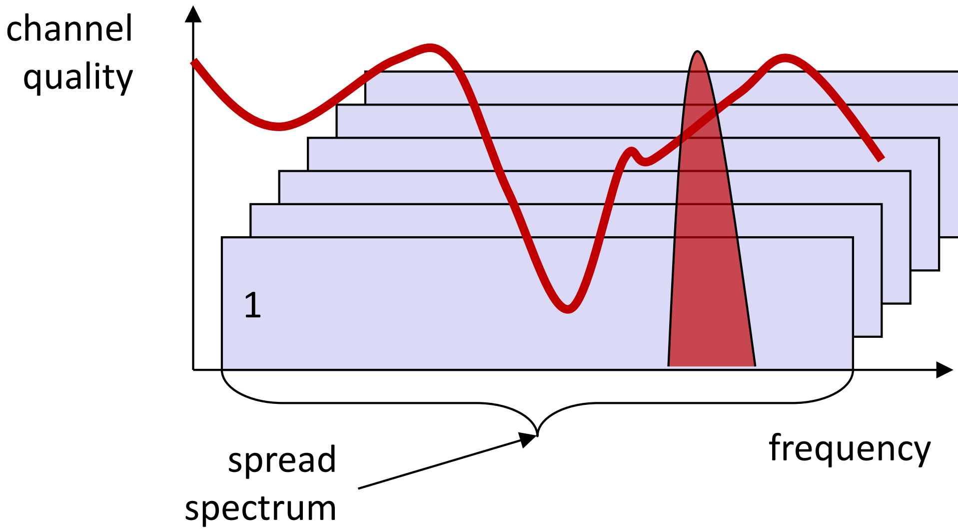
- Discrete changes of carrier frequency
  - sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS *(to be seen later)*
  - simpler to detect

Direct Sequenced Spread Spectrum

frequency selective fading and Jamming



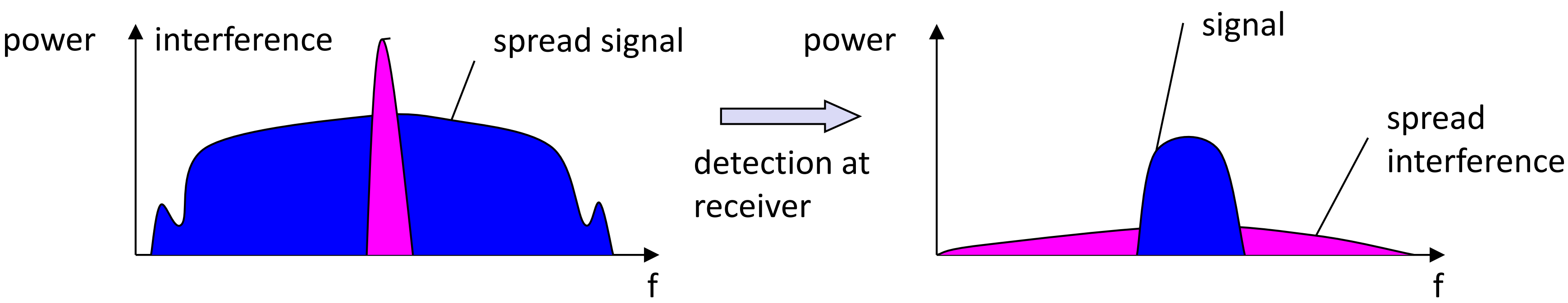
Narrow band channel



Spread spectrum channels

Spread Spectrum Communications

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal over a wide frequency interval, much higher than the minimum required bandwidth of the signal, using a special code
  - protection against narrowband interference
  - make the signals less susceptible to interference and more difficult to intercept



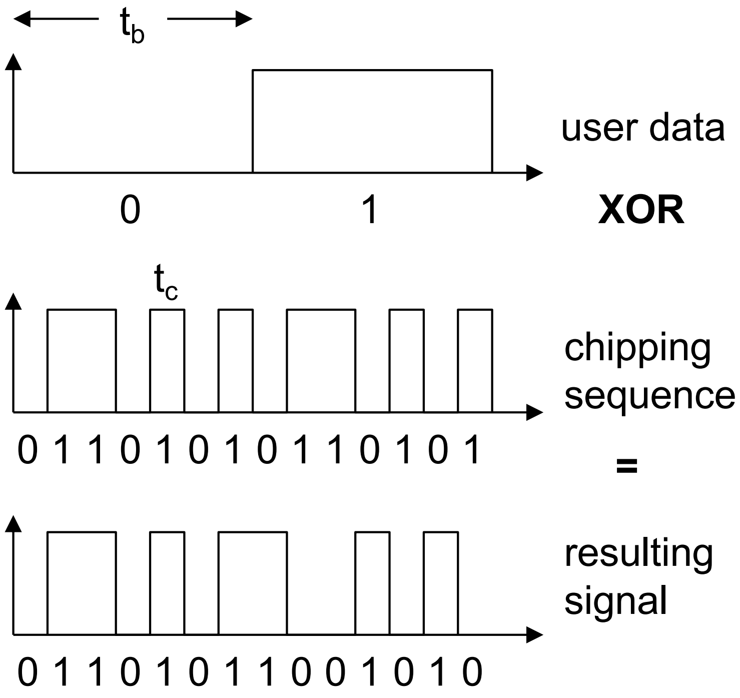
- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof
- Alternatives: Direct Sequence, Frequency Hopping

DSSS (Direct Sequence Spread Spectrum)

- XOR of the signal with pseudo-random number (chipping sequence)
  – many chips per bit (e.g., 128) result in higher bandwidth of the signal

- Advantages
  – reduces frequency selective fading
  – in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover

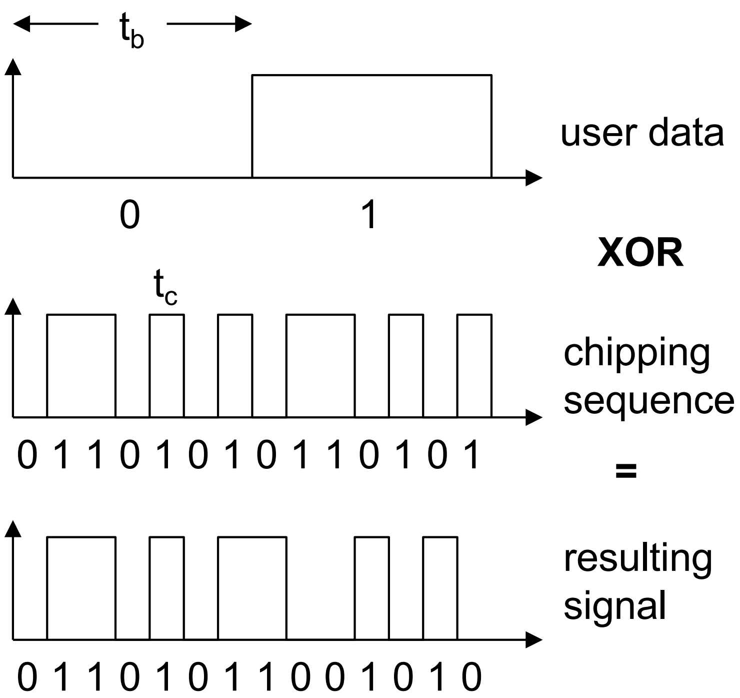
- Disadvantages
  – precise power control necessary



t_b: bit period
t_c: chip period

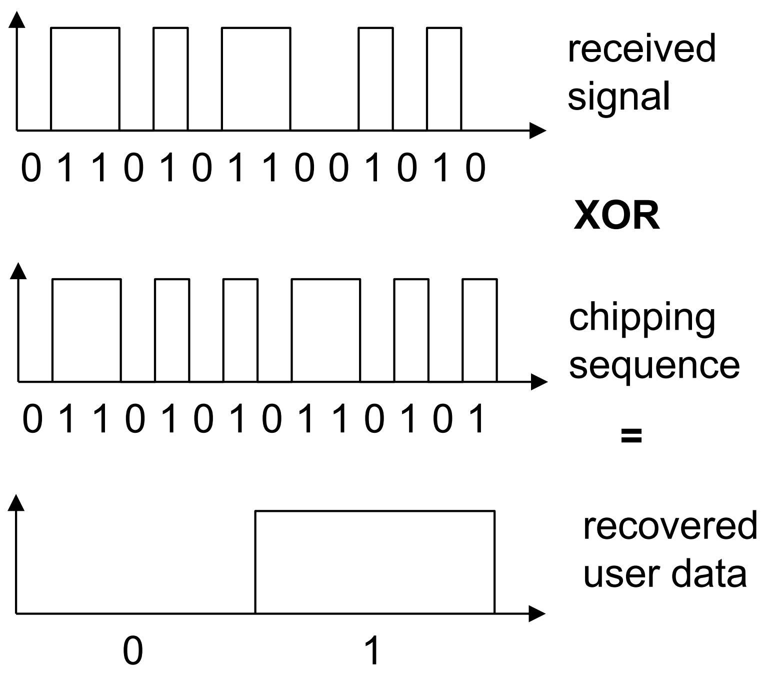
DSSS (Direct Sequence Spread Spectrum)

Transmitter:



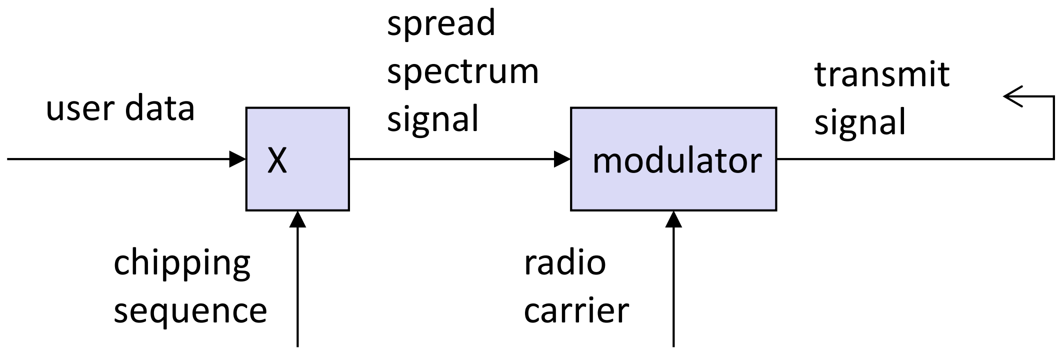
t_b: bit period
t_c: chip period

Receiver:

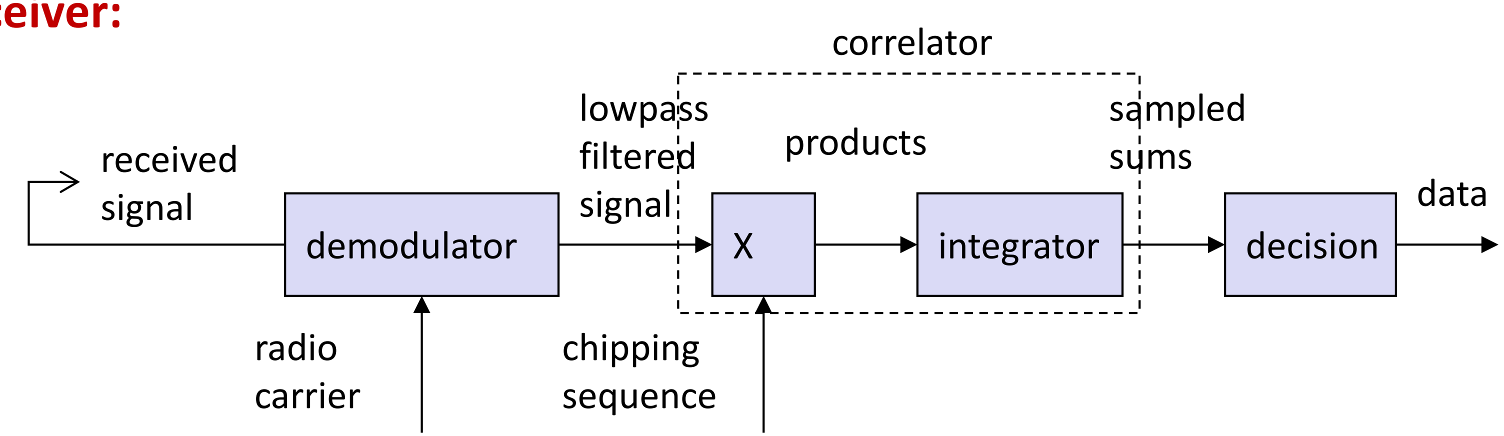


DSSS System

Transmitter:



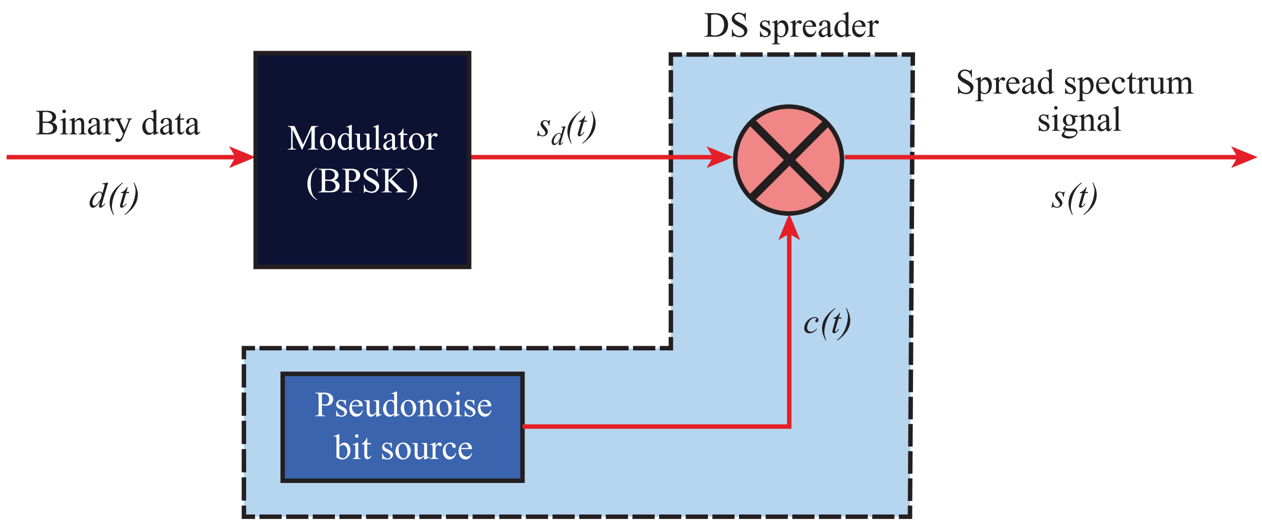
Receiver:



[Schiller2003]

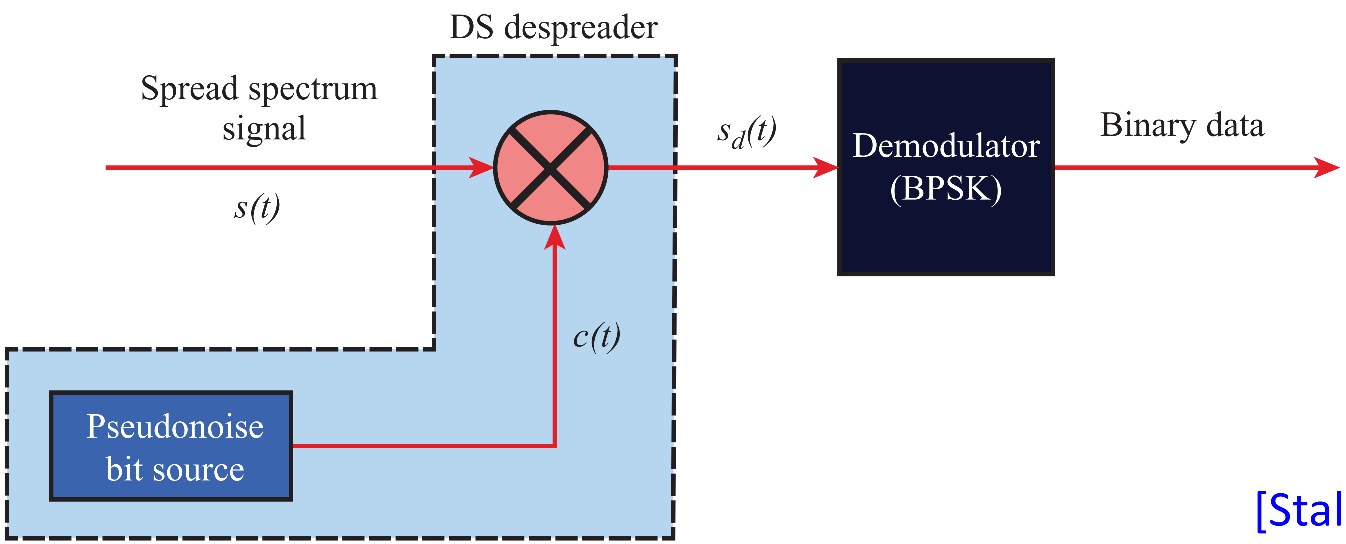
DSSS System (alternative design) using BPSK

Transmitter:



(a) Transmitter

Receiver:

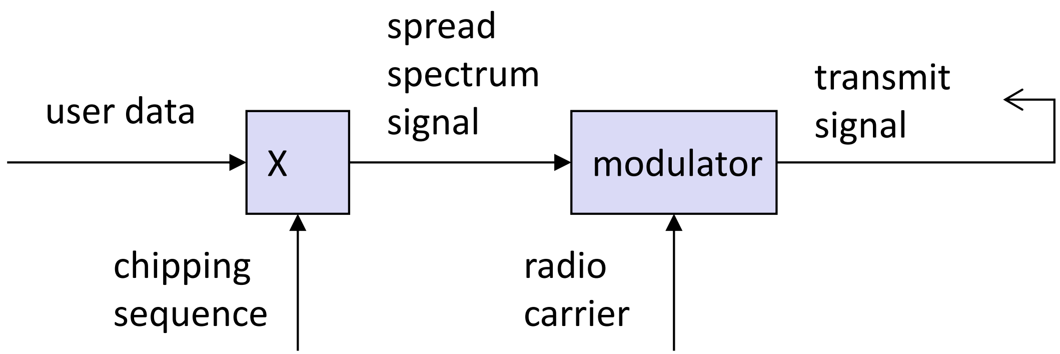


(b) Receiver

[Stallings2016]

DSSS System

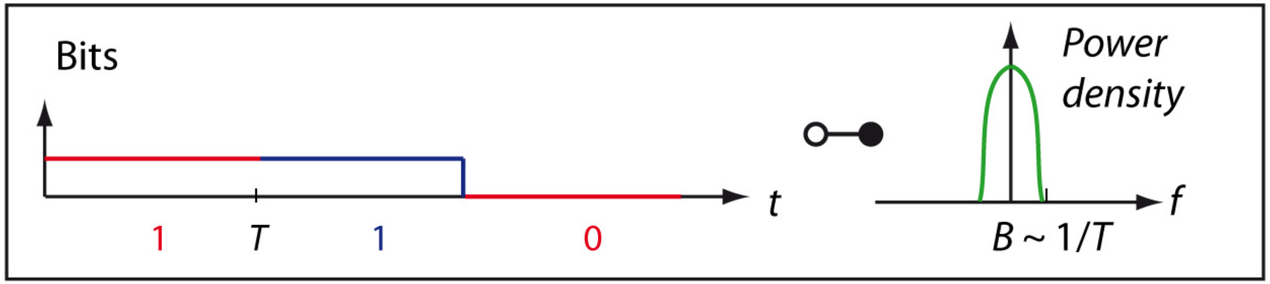
Transmitter:



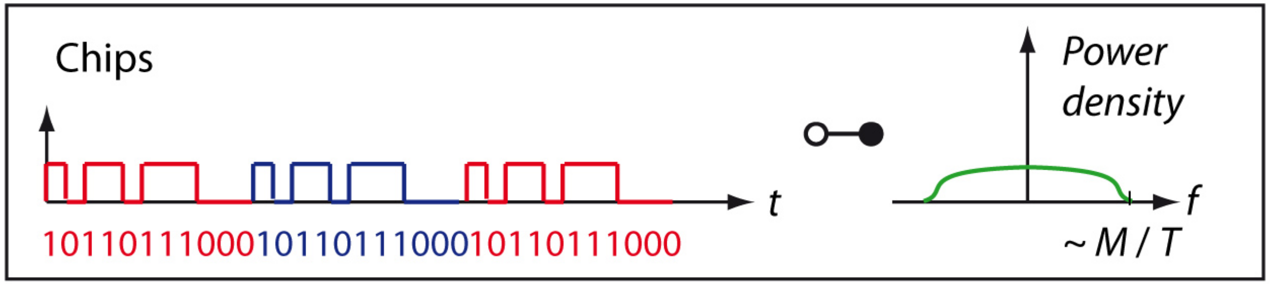
transmitter

Direct Sequence Spread Spectrum (DSSS)

Original Data Bits

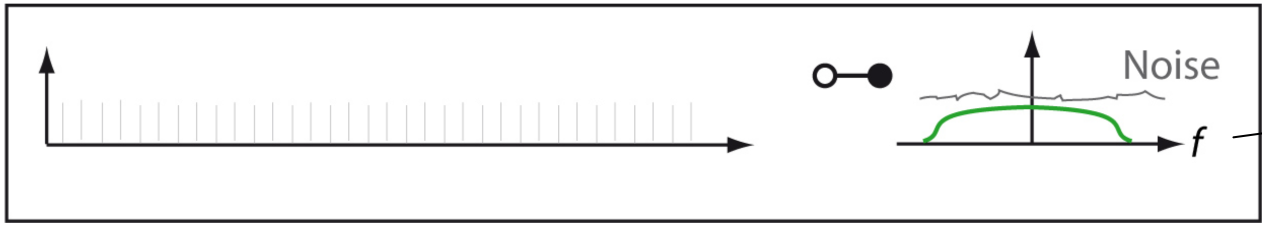


Spreading Code

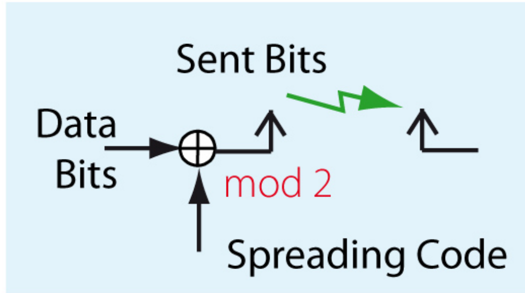


Barker Code (length $M = 11$ bits)

Sent Bits



Sender Concept



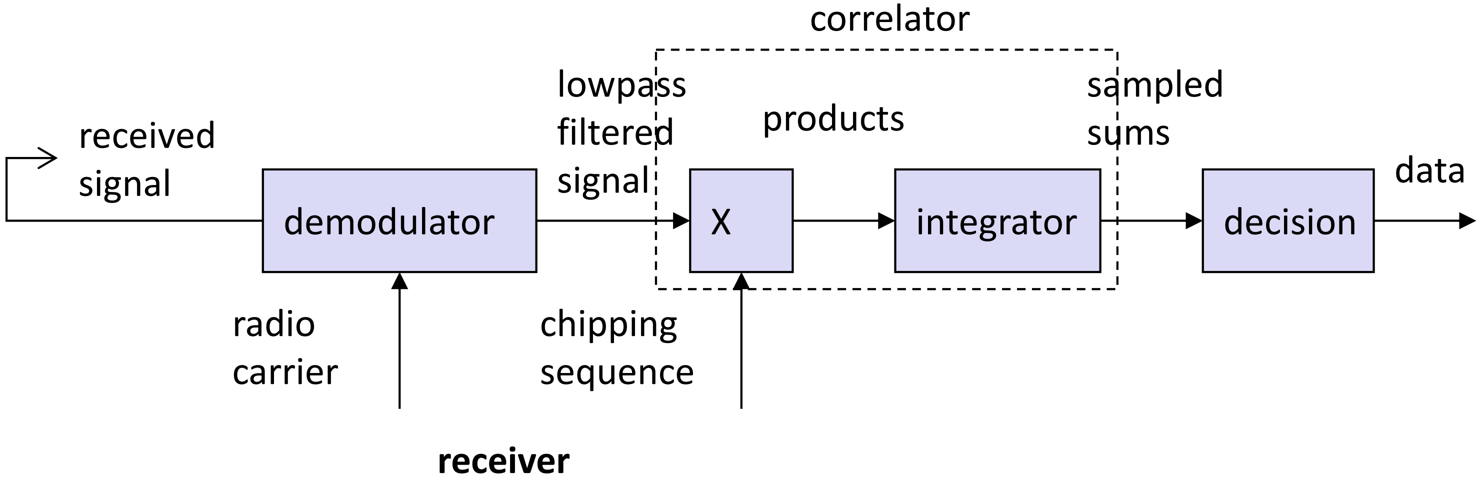
The ***spreading factor M*** is the ratio of the bandwidth of the sent bits to that of the original data bits.

The ***power spectral density*** of the sent bits is very small; it decreases by a factor of *M* and can even fall below that of the ambient noise.

The signal is hidden below the noise

DSSS System

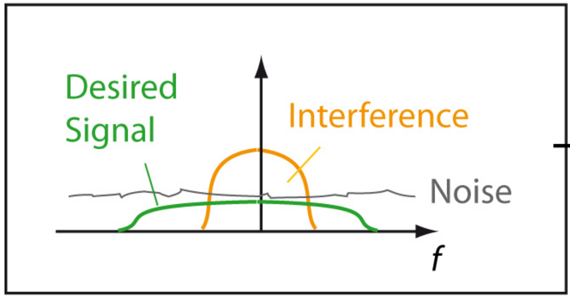
Receiver:



Direct Sequence Spread Spectrum (DSSS)

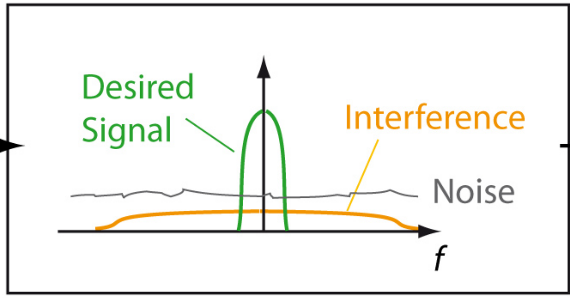
Receiver Concept

Received Signal



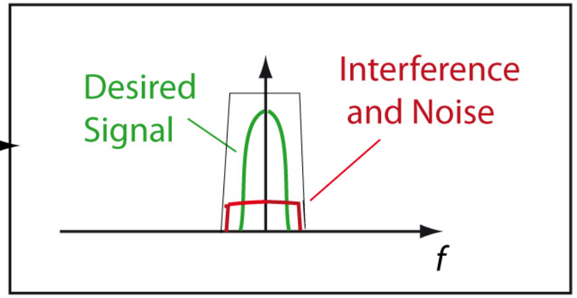
The received signal contains, in addition to the desired signal, also noise and possibly interfering signals from other devices or technologies.

De-Spread Signal



The receiver reverts the spreading operation. It correlates the received signal with the same spreading code as used at the sender. This de-spreads the desired signal, while it spreads signals of narrowband interferers. The bandwidth of noise and wideband interferers which used a different speading code at the sender and noise are not significantly affected.

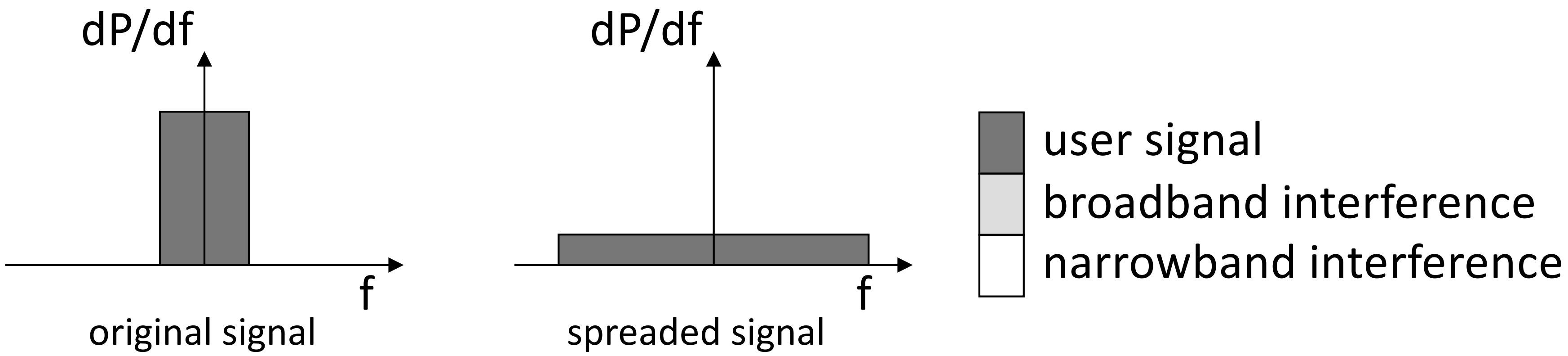
Original Signal



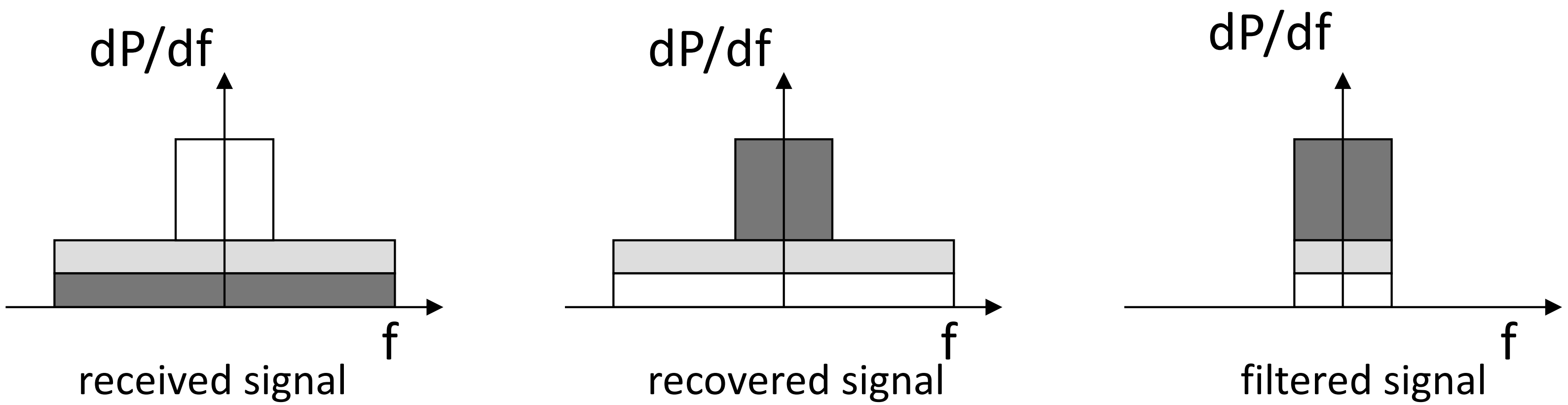
A subsequent low pass filter of band-width $1/T$ filters out the high frequencies of the inferferers and noise. The power of noise and interferers is reduced by $1/M$. The remaining interference and noise power is small compared to the power of the desired, original signal.

Effects of spreading and interference

Sender



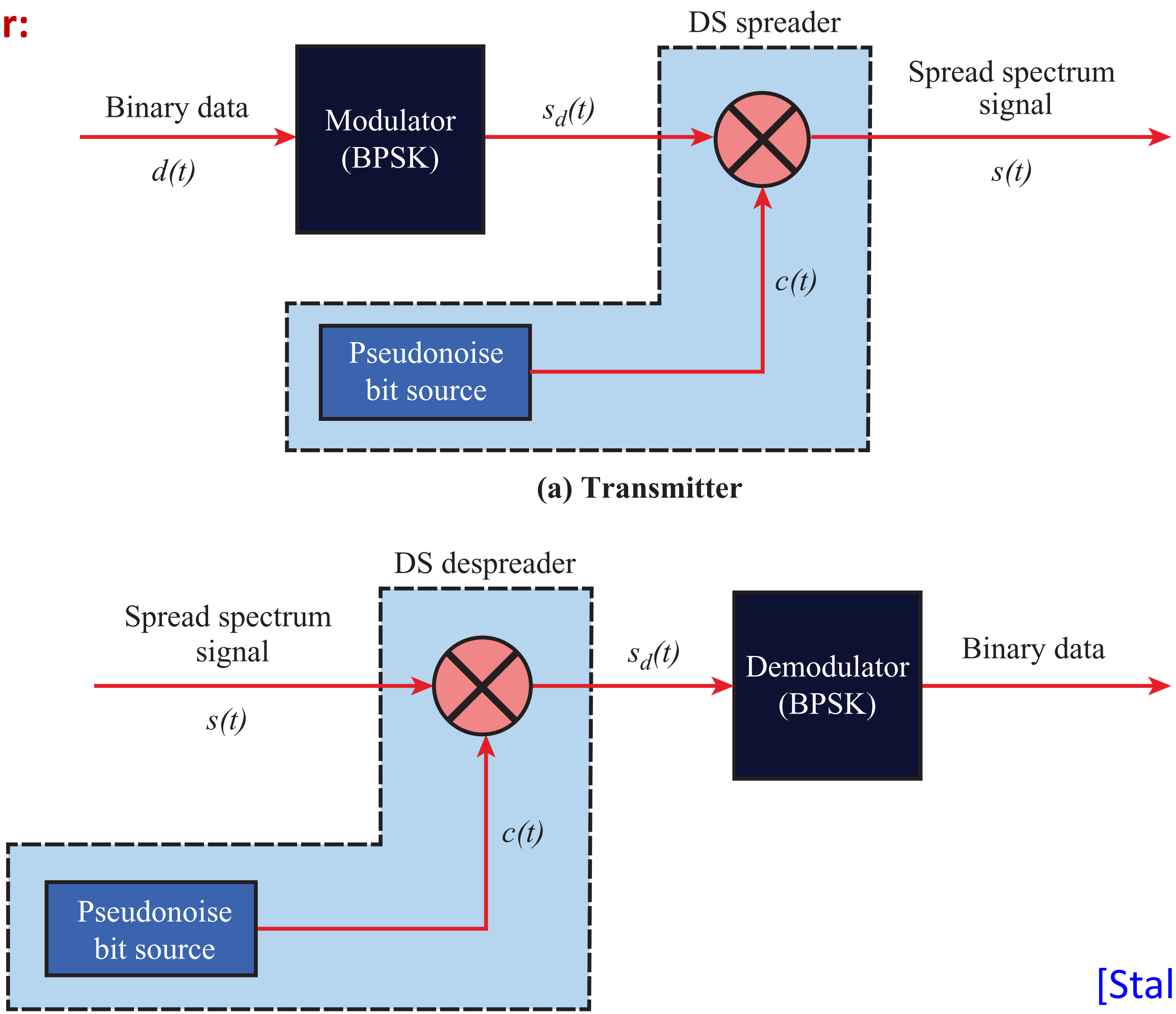
Receiver



DSSS System (alternative design) using BPSK

Transmitter:

Receiver:



(a) Transmitter

(b) Receiver

[Stallings2016]

DSSS Using BPSK

Multiply BPSK signal,

$$s_d(t) = A\, d(t) \cos(2\pi f_c t)$$

by $c(t)$ (chipping sequence) to get

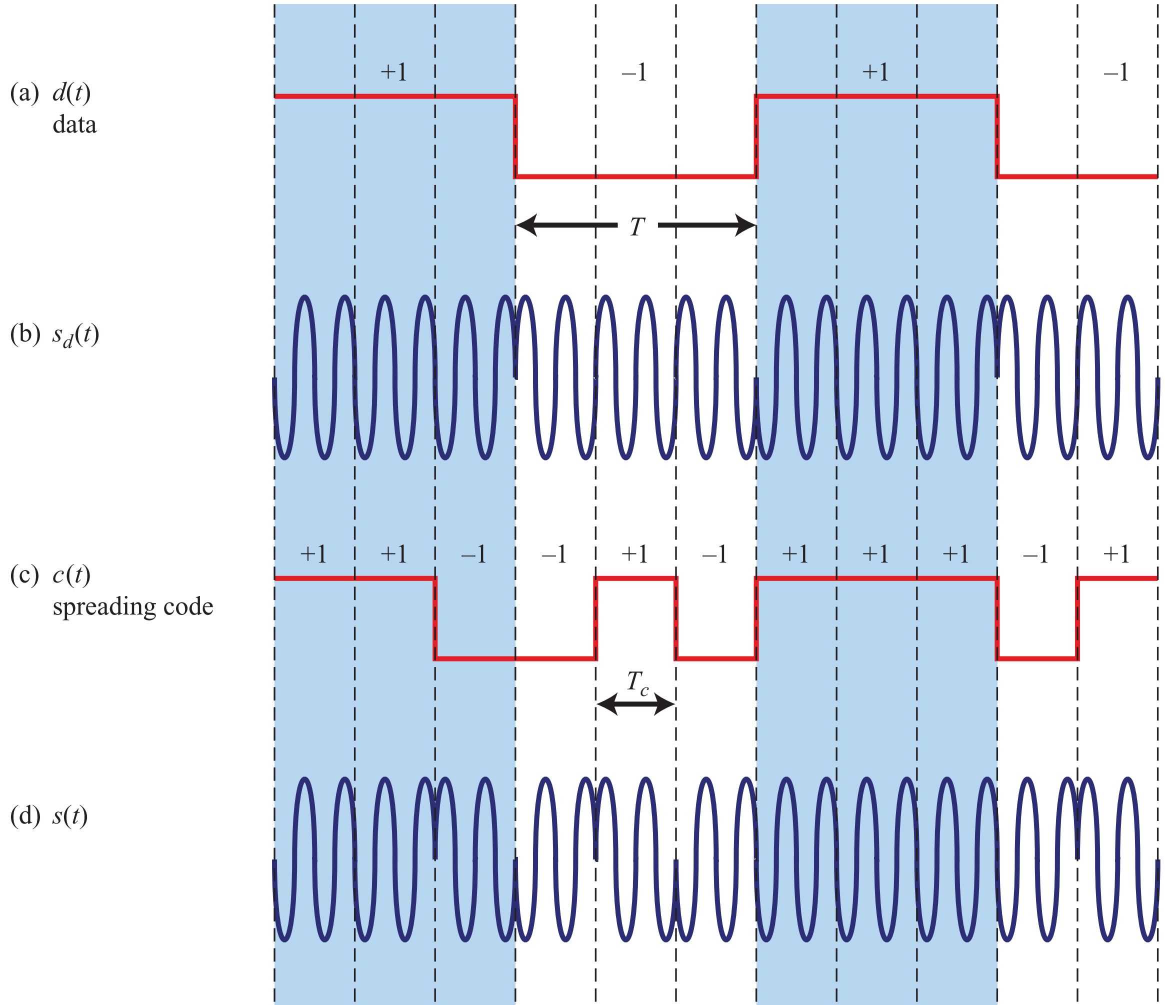
$$s(t) = A\, d(t)c(t) \cos(2\pi f_c t)$$

- A = amplitude of signal
- f_c = carrier frequency
- d(t) = discrete function (data) [+1, -1]
- c(t) = discrete function (chipping sequence) [+1, -1]

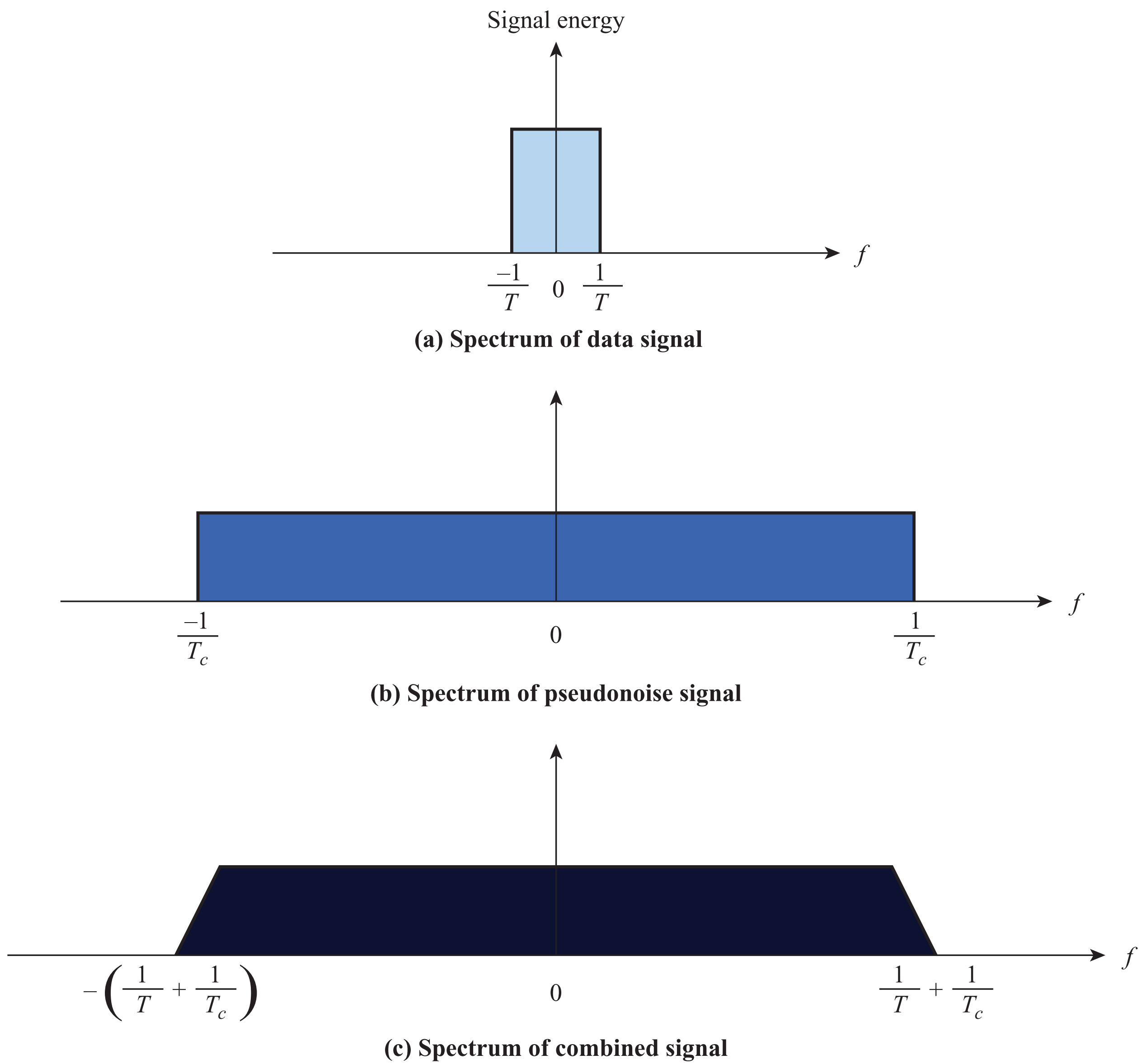
At receiver, incoming signal multiplied by $c(t)$

– Since $c(t) \times c(t) = 1$, incoming signal is recovered

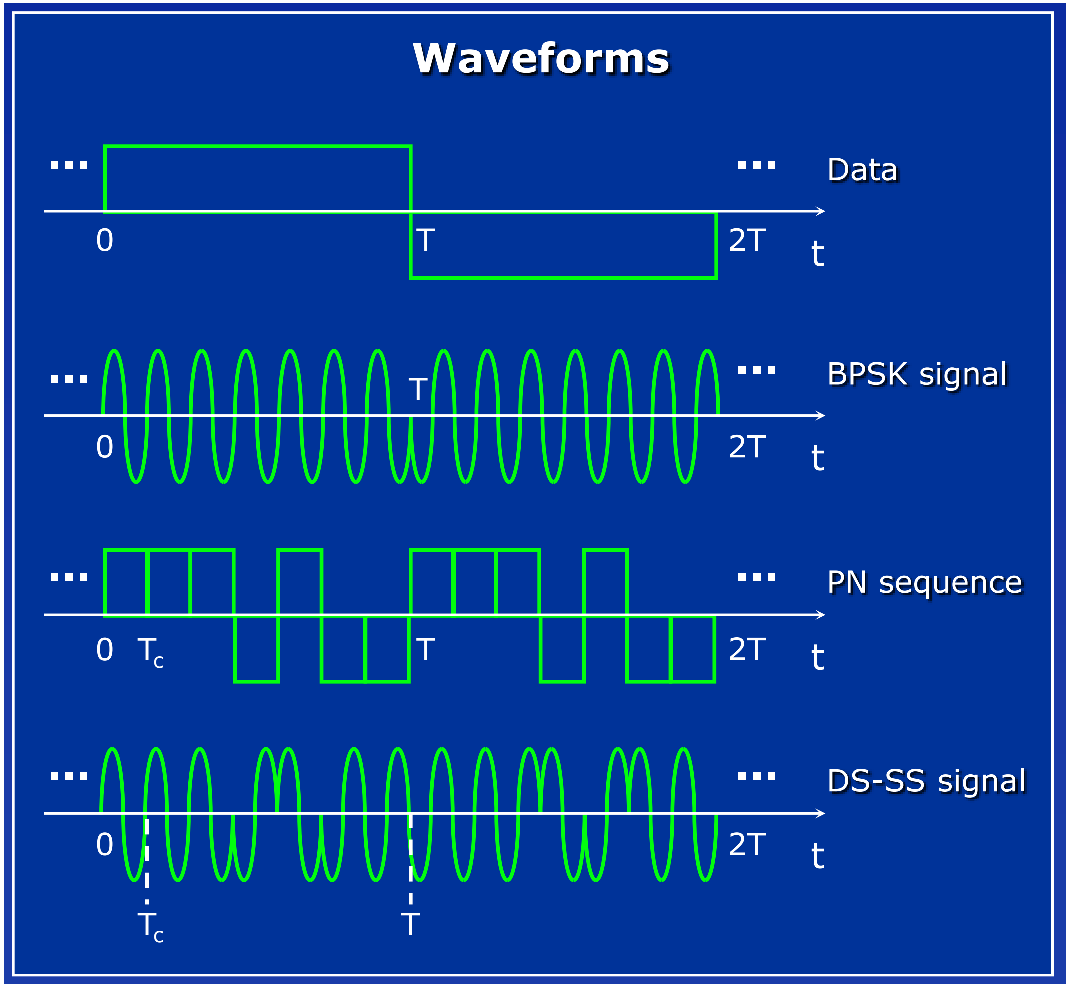
DSSS Using BPSK

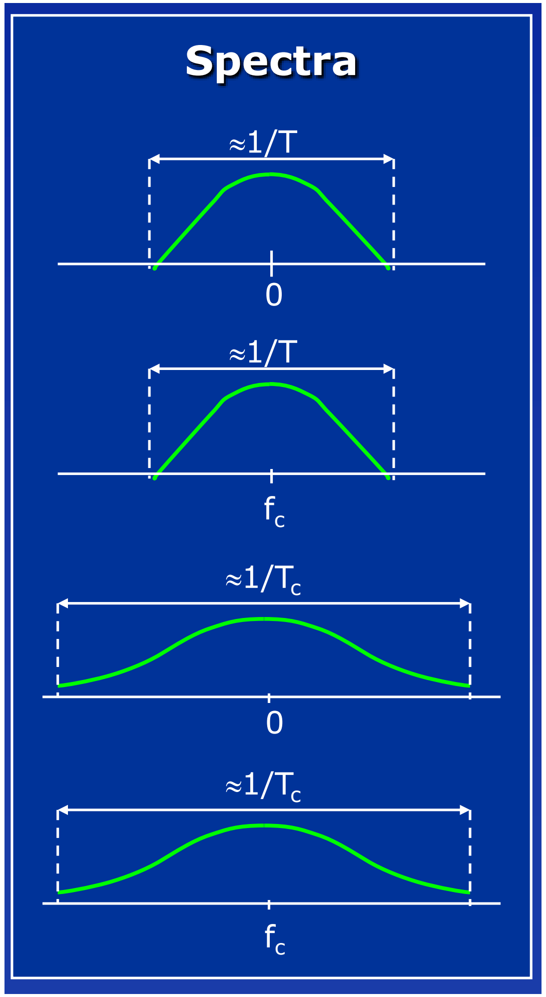


Spectrum of DSSS Signal

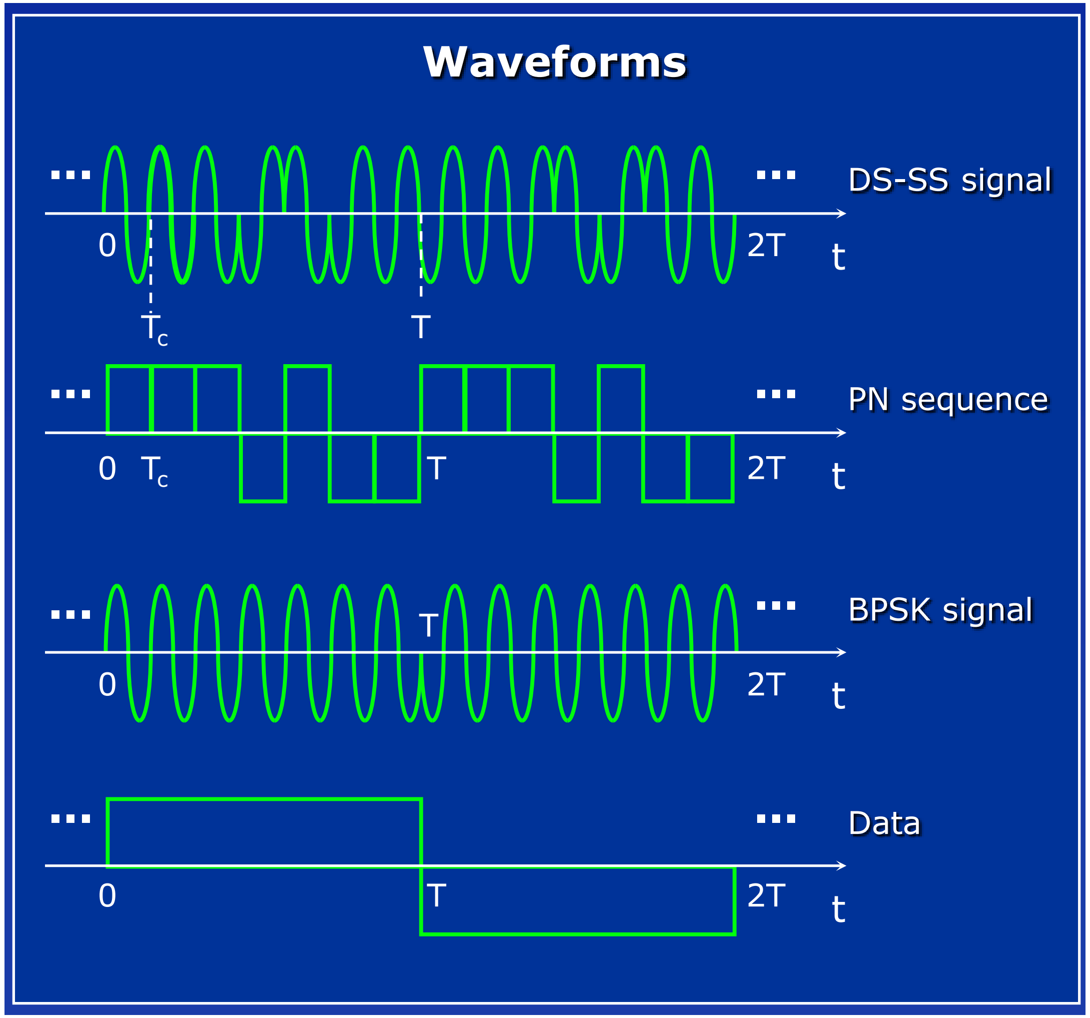


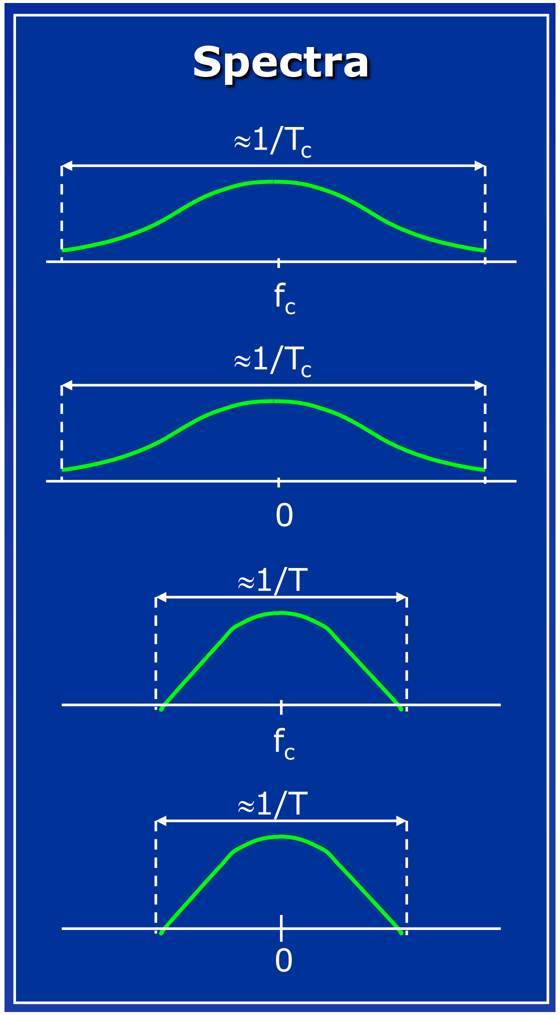
DSSS Transmitter using BPSK





DSSS Receiver using BPSK





Code Division Multiple Access (CDMA)

Code Division Multiple Access (CDMA)

- used in several wireless broadcast channels (cellular, satellite, etc.) standards

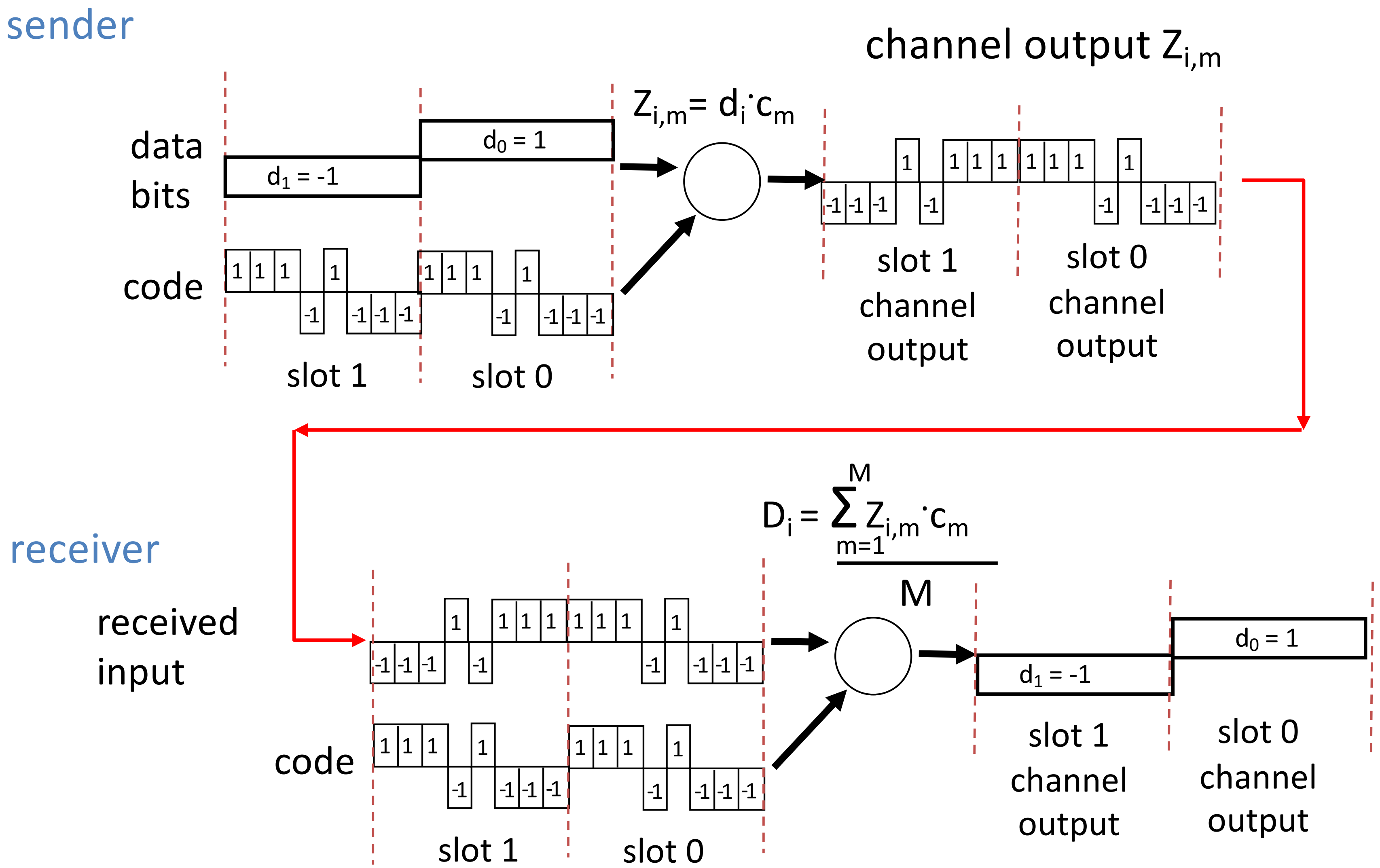
- unique “code” assigned to each user; i.e., code set partitioning

- all users share same frequency, but each user has own “chipping” sequence (i.e., code) to encode data

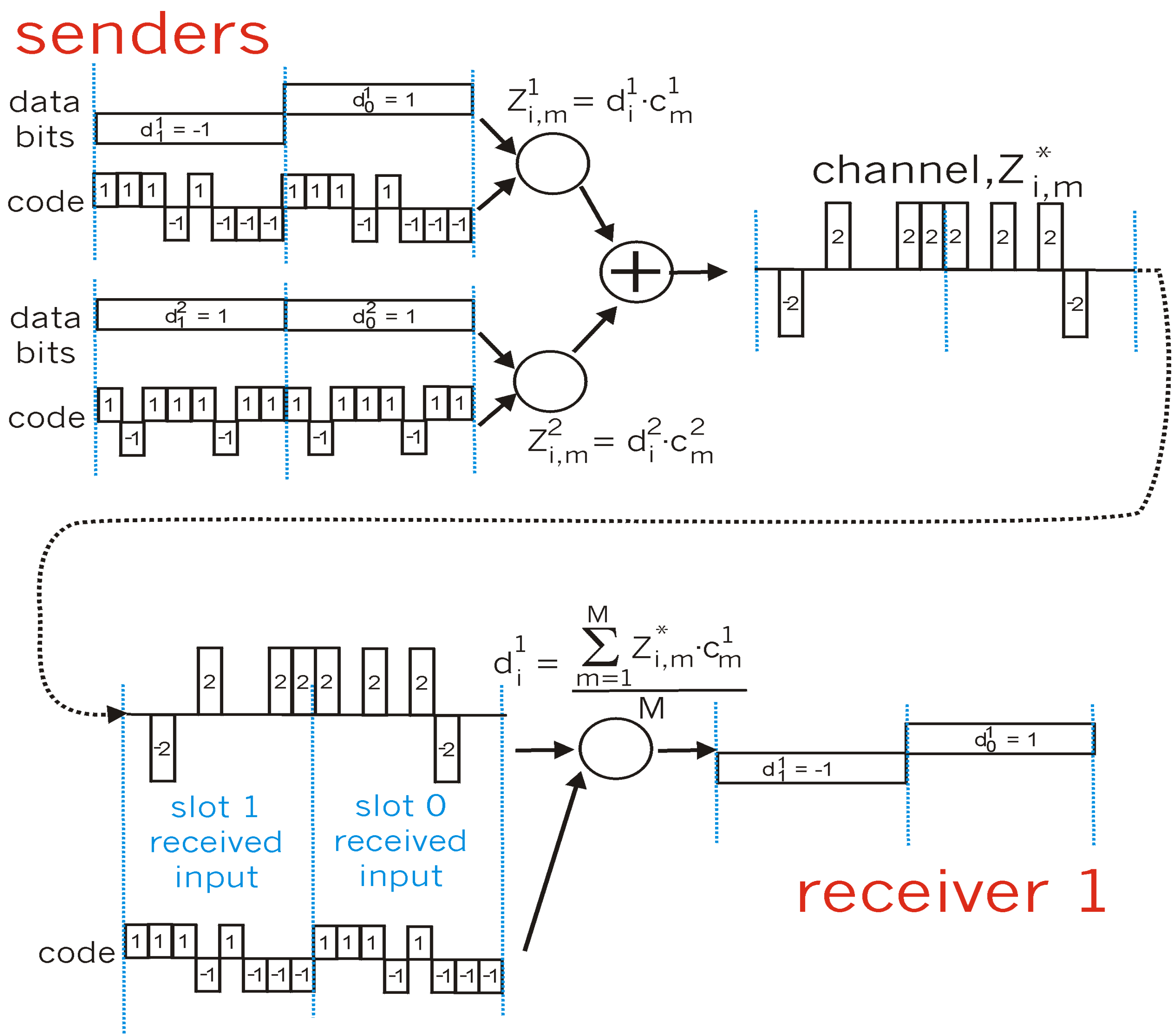
Code Division Multiple Access (CDMA)

- encoded signal = (original data) X (chipping sequence)
- decoding: inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

CDMA Encode/Decode



CDMA: two-sender interference



Exercises

- Consider de example of the previous slide:
  - Draw the reception diagram for receiver 2
  - Code 1 and Code 2 are orthogonal? Why?
  - Does the scheme tolerate errors in the received signal? To which extent?

    Suggestion: determine the decoded signal for the case where the received signal has 1, 3, and 5 errors

PN Sequences

- PN generator produces periodic sequence that appears to be random
- PN Sequences
  - Generated by an algorithm using initial seed
  - Sequence isn’t statistically random but will pass many test of randomness
  - Sequences referred to as pseudorandom numbers or pseudonoise sequences
  - Unless algorithm and seed are known, the sequence is impractical to predict

Categories of Spreading Sequences

- Spreading Sequence Categories
  - PN sequences
  - 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 DSSS

- Resistance to frequency-selective fading
- Resistance to intended or unintended jamming
- Reduced signal/background-noise level hampers interception
- Use of RAKE receivers in presence of multipath propagation can boost received signal

Advantages of DSSS

- In cellular networks (with CDMA):
  - Allows simultaneous transmissions of different users using the same frequency band (and distinct codes)
  - base stations can use the same frequency range
  - several base stations can detect and recover the signal
  - soft handover (to be seen later…)
  - However: IT DEMANDS PRECISE POWER CONTROL

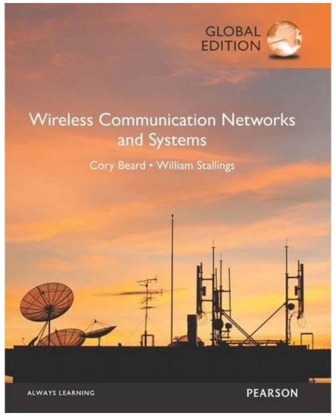
Disavantages

- Synchronization: proper operation requires synchronization or alignment of transmitter and receiver spreading/de-spreading codes.

- Precise power control in CDMA

- Processing power

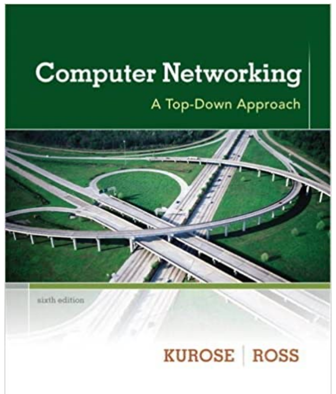
Literature



Wireless Communication Networks and Systems,

C. Beard and W. Stallings, Prentice Hall

- Chap 9



Computer Networking: A Top-down Approach, 5th or 6th edition, J. Kurose and K. Ross, Addison-Wesley

- Chap 7