9

Data Communication

Week 9 Spread Spectrum

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Spread Spectrum

- Spread spectrum is an important form of encoding for wireless communications.
- The spread spectrum technique was developed initially for military and intelligence requirements. The essential idea is to spread the information signal over a wider bandwidth to make jamming and interception more difficult.
- The first type of spread spectrum developed is known as frequency hopping. A more recent type of spread spectrum is direct sequence. Both of these techniques are used in various wireless communications standards and products.

Frequency Hopping Spread Spectrum (FHSS)

Direct Sequence Spread Spectrum (DSSS)

Concept of Spread Spectrum

- Figure below highlights the key characteristics of any spread spectrum system. Input is fed into a channel encoder that produces an analog signal with a relatively narrow bandwidth around some center frequency. This signal is further modulated using a sequence of digits known as a spreading code or spreading sequence. Typically, but not always, the spreading code is generated by a pseudonoise, or pseudorandom number, generator. The effect of this modulation is to increase significantly the bandwidth (spread the spectrum) of the signal to be transmitted. On the receiving end, the same digit sequence is used to demodulate the spread spectrum signal. Finally, the signal is fed into a channel decoder to recover the data.

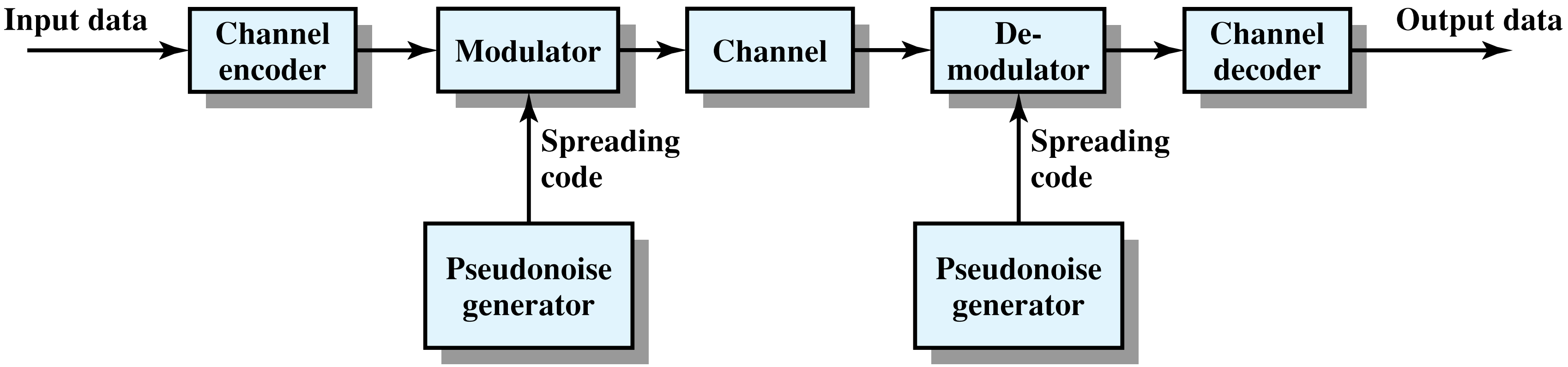
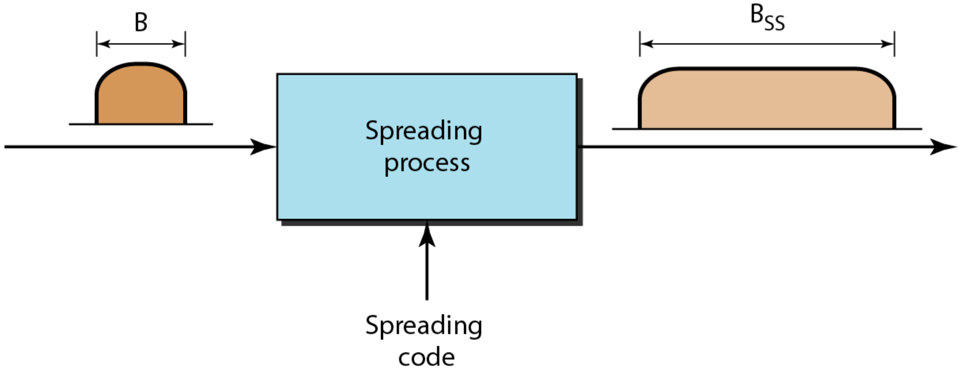


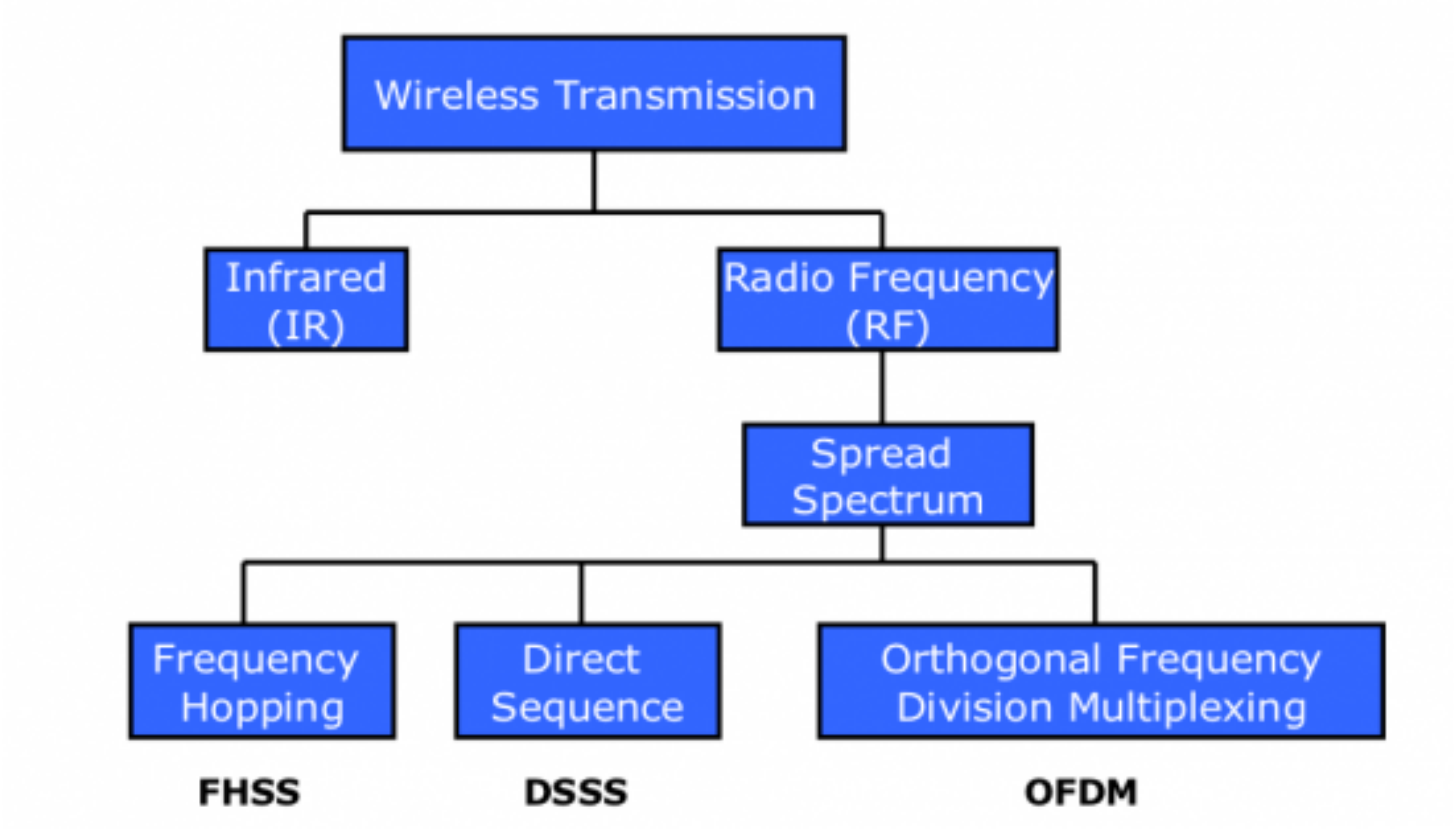
Figure 9.1 General Model of Spread Spectrum Digital Communication System

Spread Spectrum

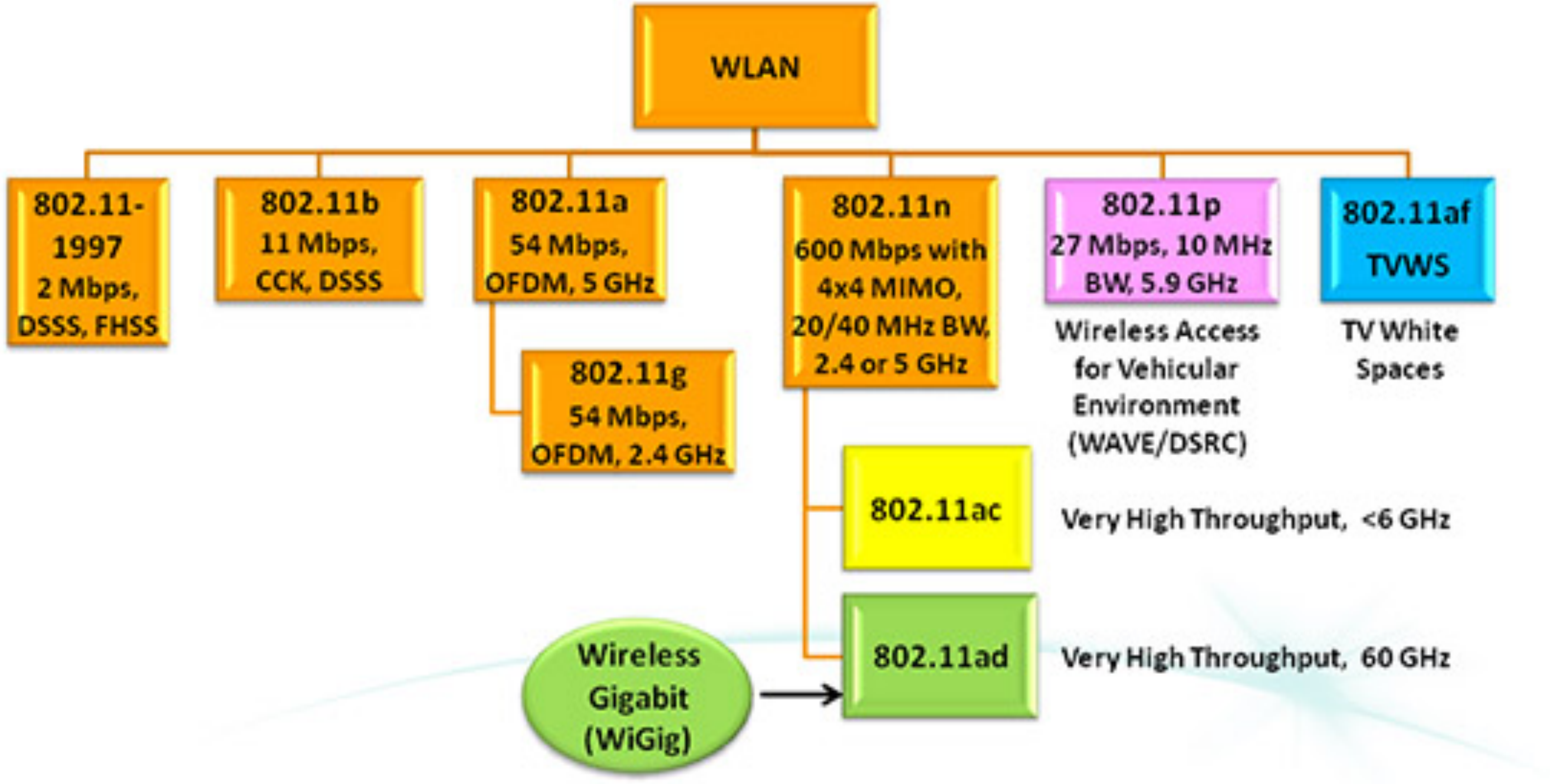
- Spread spectrum is designed to be used in wireless applications (LANs and WANs)
- In this type of application, we have some concerns that outweigh bandwidth efficiency.
- In wireless applications, all stations use air (or a vacuum) as the medium for communication. Station must be able to share this medium without interception by an eavesdropper and without being subject to jamming from malicious intruder.
- To achieve these goals, spread spectrum techniques add redundancy; the spread the original spectrum needed for each station.
- If the required bandwidth for each station is **B**, spread spectrum expand it to Bss. The expanded bandwidth allows the source to wrap its message in a protective envelope for a more secure transmision.



Wireless Transmission



IEEE 802.11 Standards Evolution

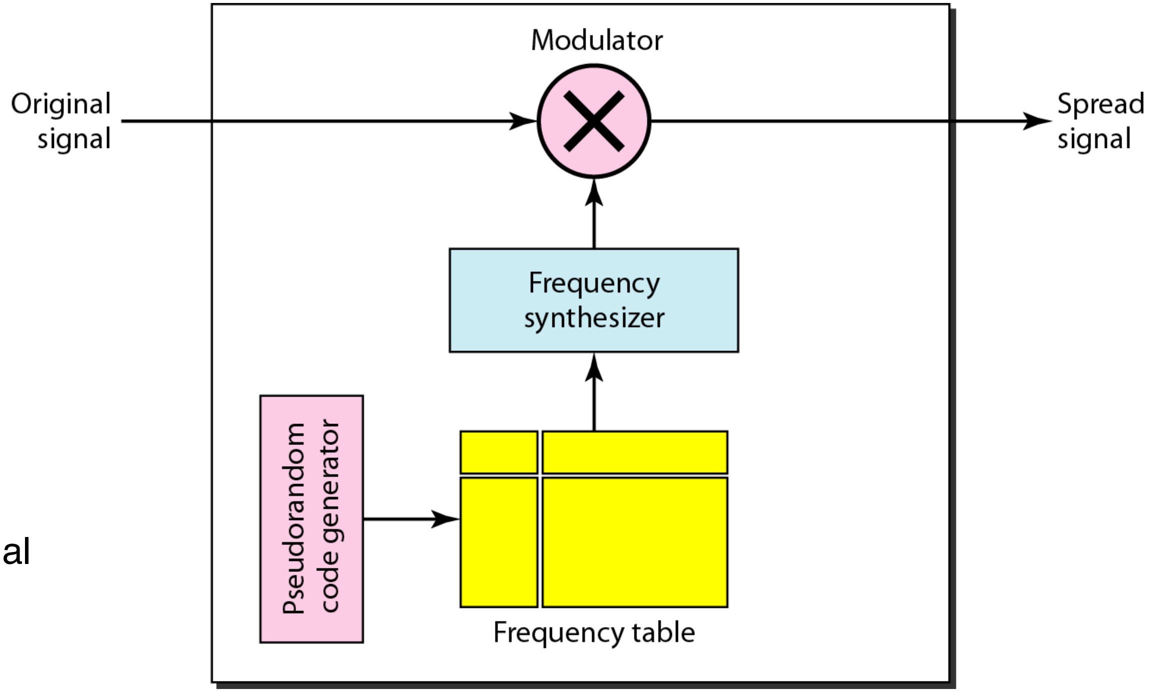


DSRC = Dedicated Short-Range Communications

Frequency Hopping

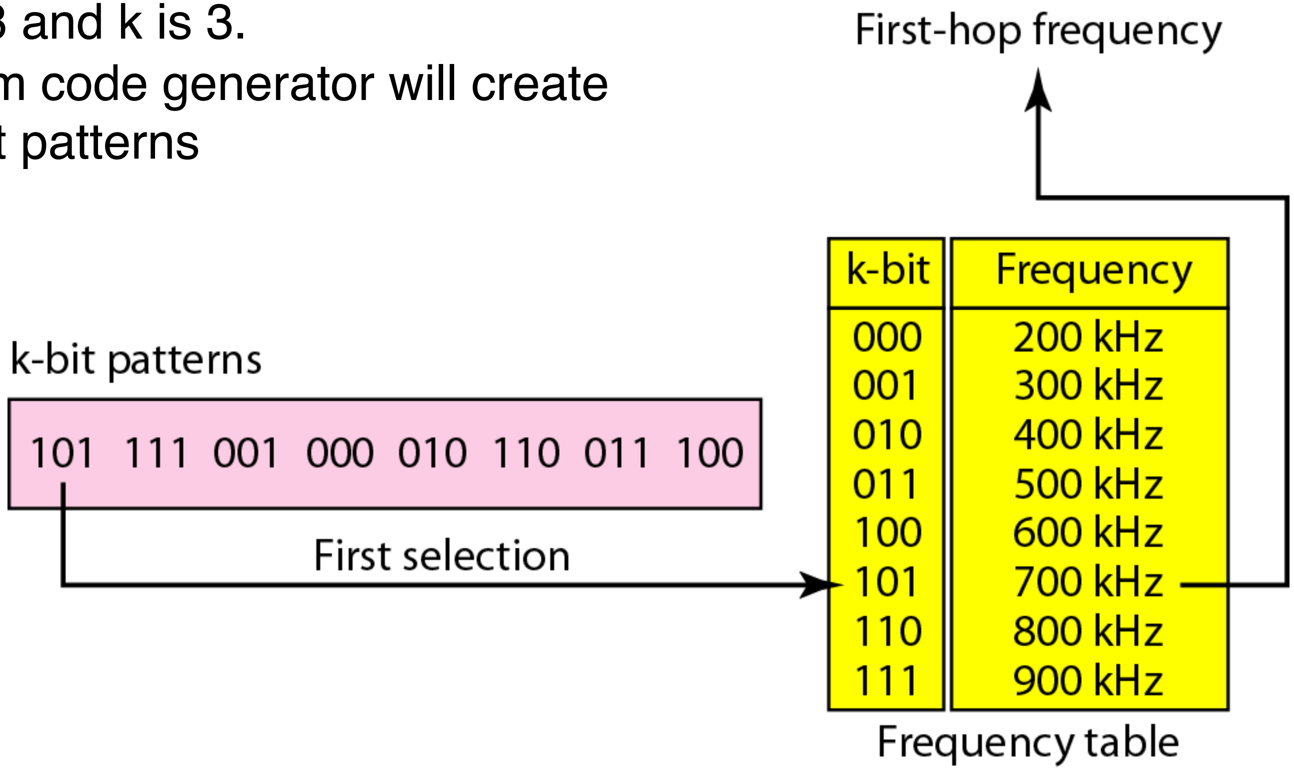
- The Frequency Hopping Spread Spectrum (FHSS) technique uses M different carrier frequencies that are modulated by the source signal.
- At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency. Although the modulation is done using one carrier frequency at a time, M frequencies are used in the long run. The bandwidth occupied by a source after spreading is $B_{FHSS} >> B$.

A pseudorandom code generator, called pseudorandom noise (PN), creates a *k* but pattern for every hopping periosd Th. Frequency table uses the pattern to find the frequency to be used for this hopping period and passes it to the frequency synthesizer. The frequency synthesizer creates a carrier signal of that frequency, and the source signal modulates the carrier signal.



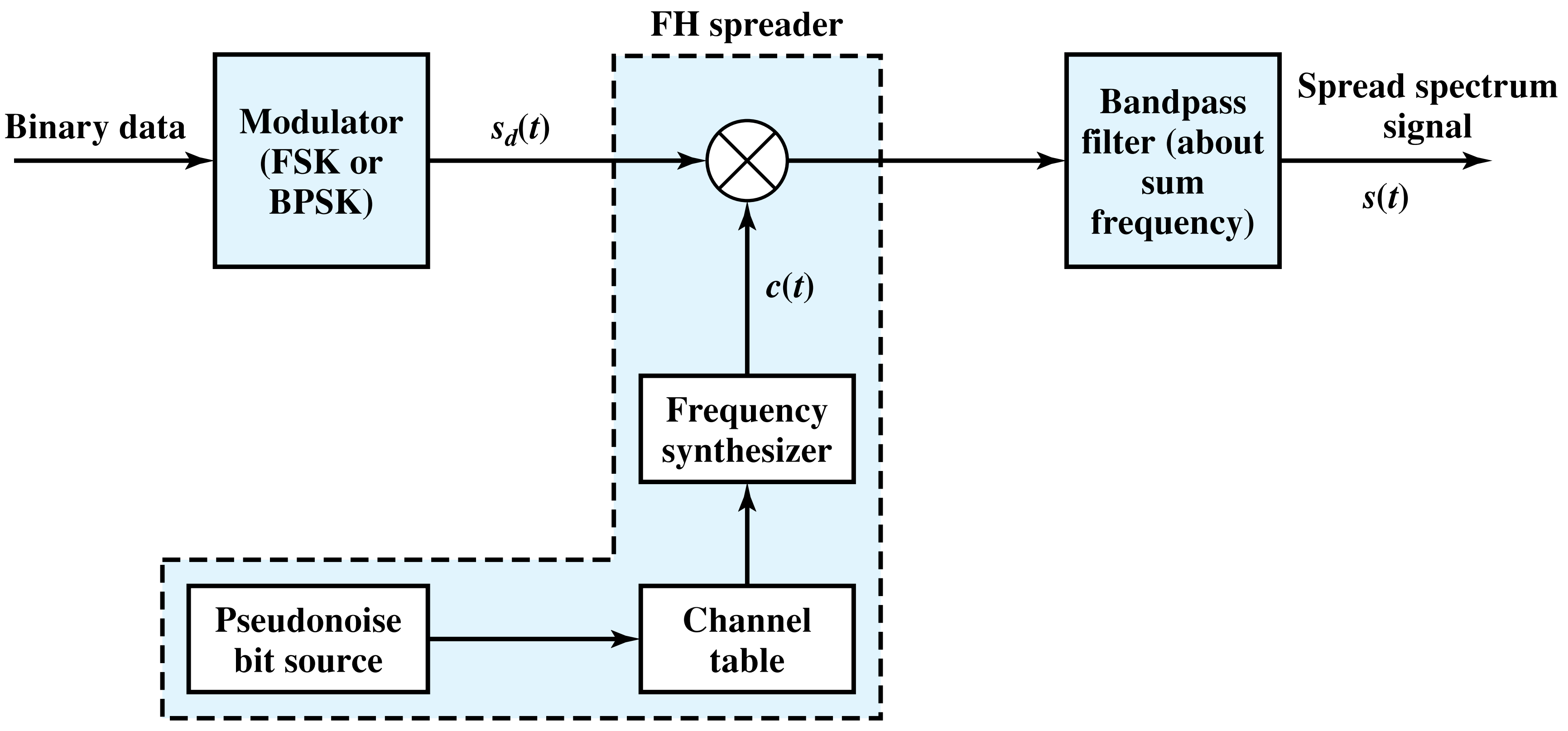
Frequency Selection is FHSS

Suppose we have decided to have eight hopping frequencies. This is extremely low for real applications and is just for illustration.
In this case, M is 8 and k is 3.
The pseudorandom code generator will create eight different 3-bit patterns



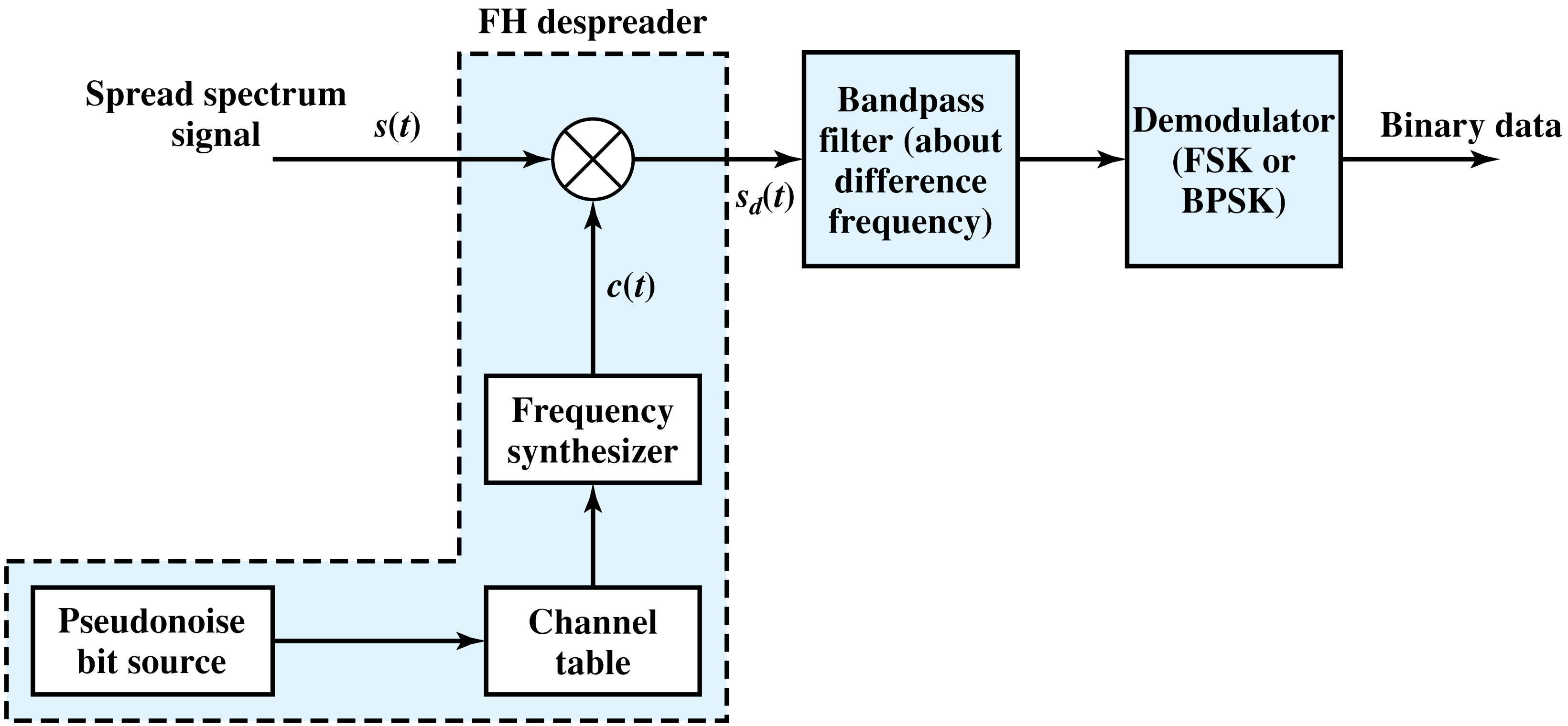
k-bit	Frequency
000	200 kHz
001	300 kHz
010	400 kHz
011	500 kHz
100	600 kHz
101	700 kHz
110	800 kHz
111	900 kHz

FHSS Transmitter



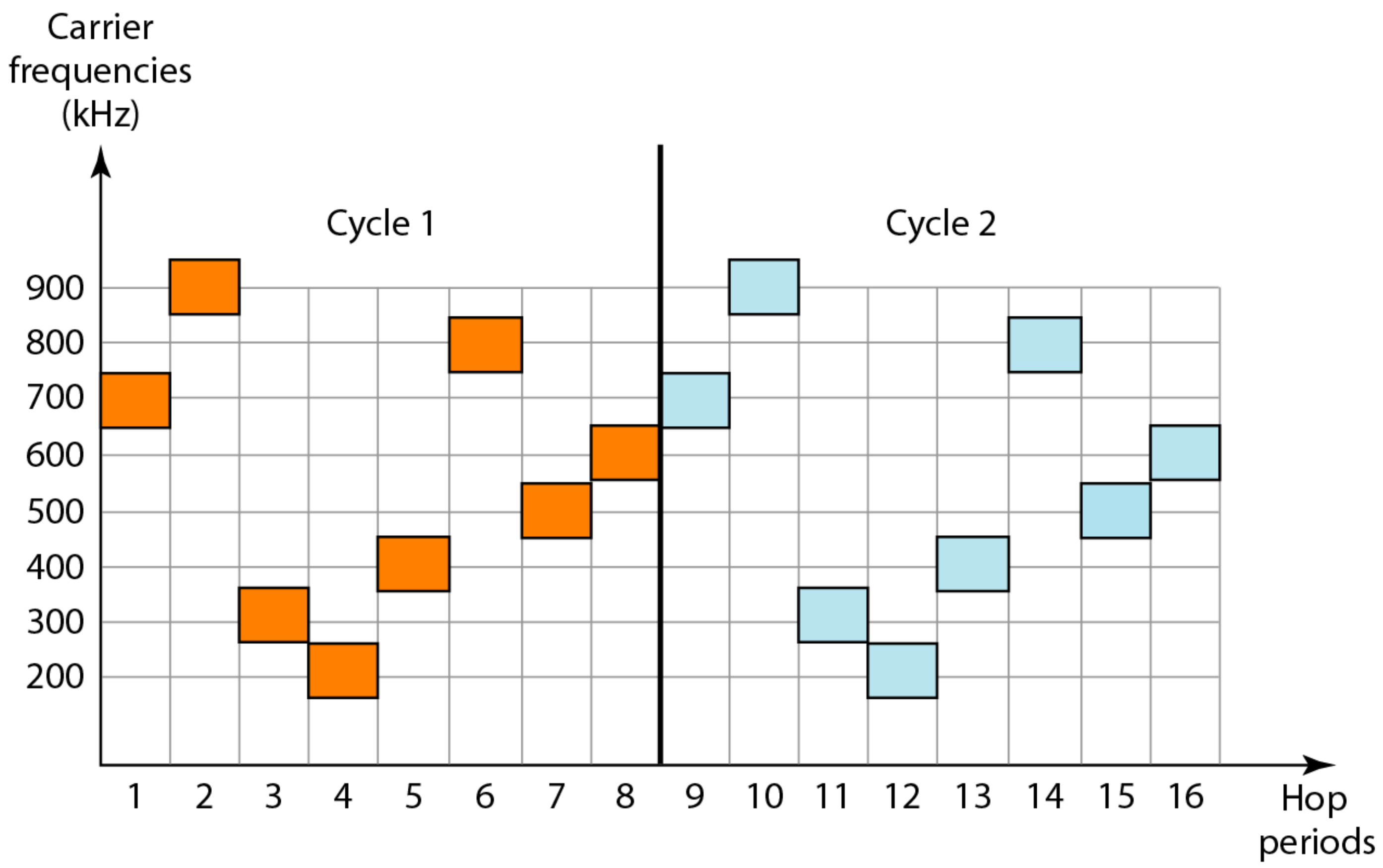
(a) Transmitter

FHSS Receiver



(b) Receiver

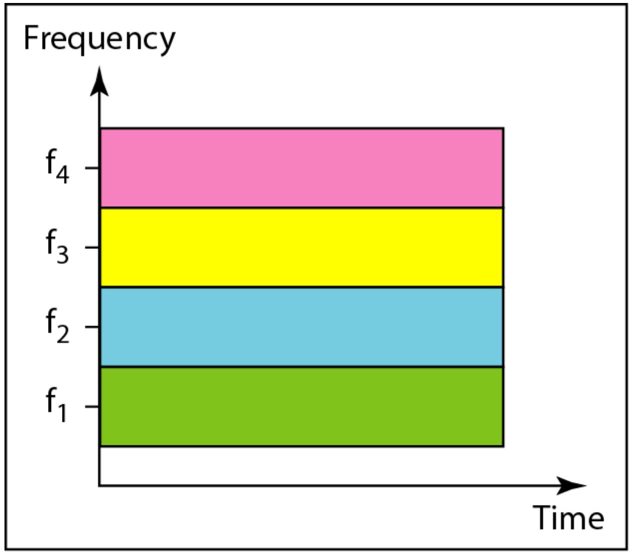
FHSS Cycles



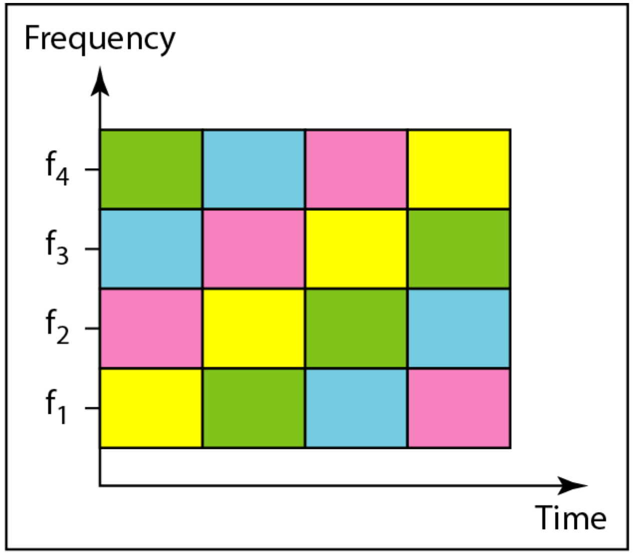
- It can be shown that this scheme can accomplish the previously mentioned goals. If there are many k-bit patterns and the hopping period is short, a sender and receiver can have privacy. If an intruder tries to intercept the transmitted signal, she can only access a small piece of data because he/she does not knot the spreading sequence to adapt herself to the next hop. The scheme has also an antijamming effect. A malicious sender may be able to send noise to jam the signal for one hopping period (randomly), but not for the whole period.

Bandwidth Sharing

- If the number of hopping frequencies is M, we can multiplex M channels into one by using the same Bss Bandwidth. This is possible because a station uses just one frequency in each hopping period; M-1 other frequency can be used by other M-1 stations. In other words, M different station can be use the same Bss if an appropriate modulation technique such as multiple FSK (MSK) is used. FHSS is similar to FDM.
- example four channels using FDM and four channel using FHSS. In FDM, each station uses 1/M of the bandwidth, but the allocation is fixed; in FHSS, each station uses 1/M of the bandwidth, but the allocation changes hop to hop.



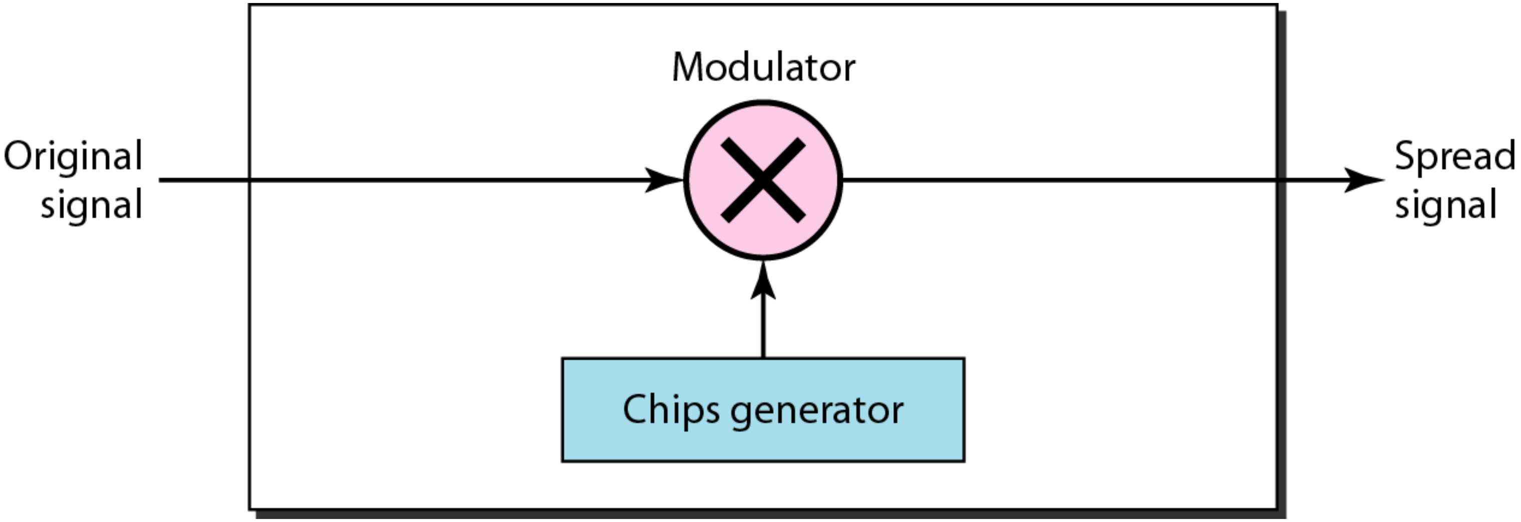
a. FDM



b. FHSS

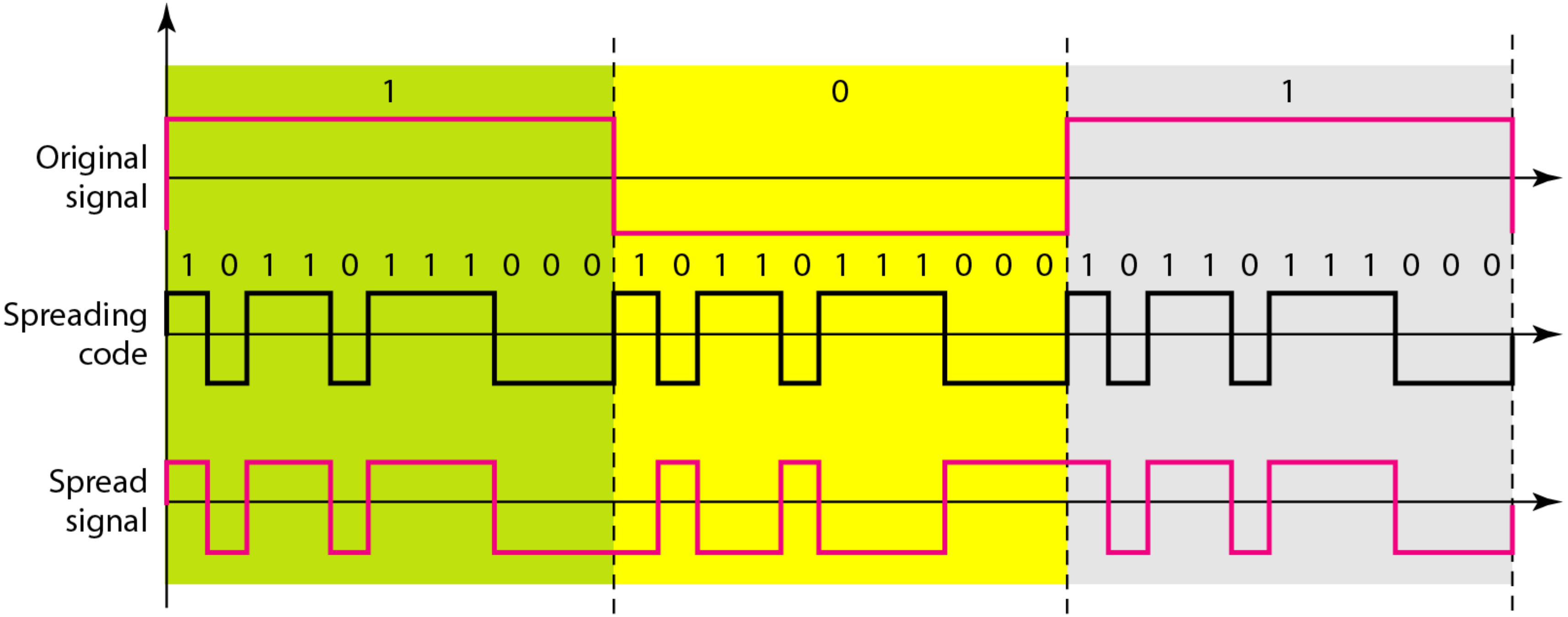
Direct Sequence Spred Spectrum

- The direct sequence spread spectrum (DSSS) technique also expands the bandwidth of the original signal, but the process is different
- In DSSS, we replace each data bit with n bits using a spreading code. In other words, each bit is assigned a code of n bits, called chips, whre the chip rate is n times that of the data bit.

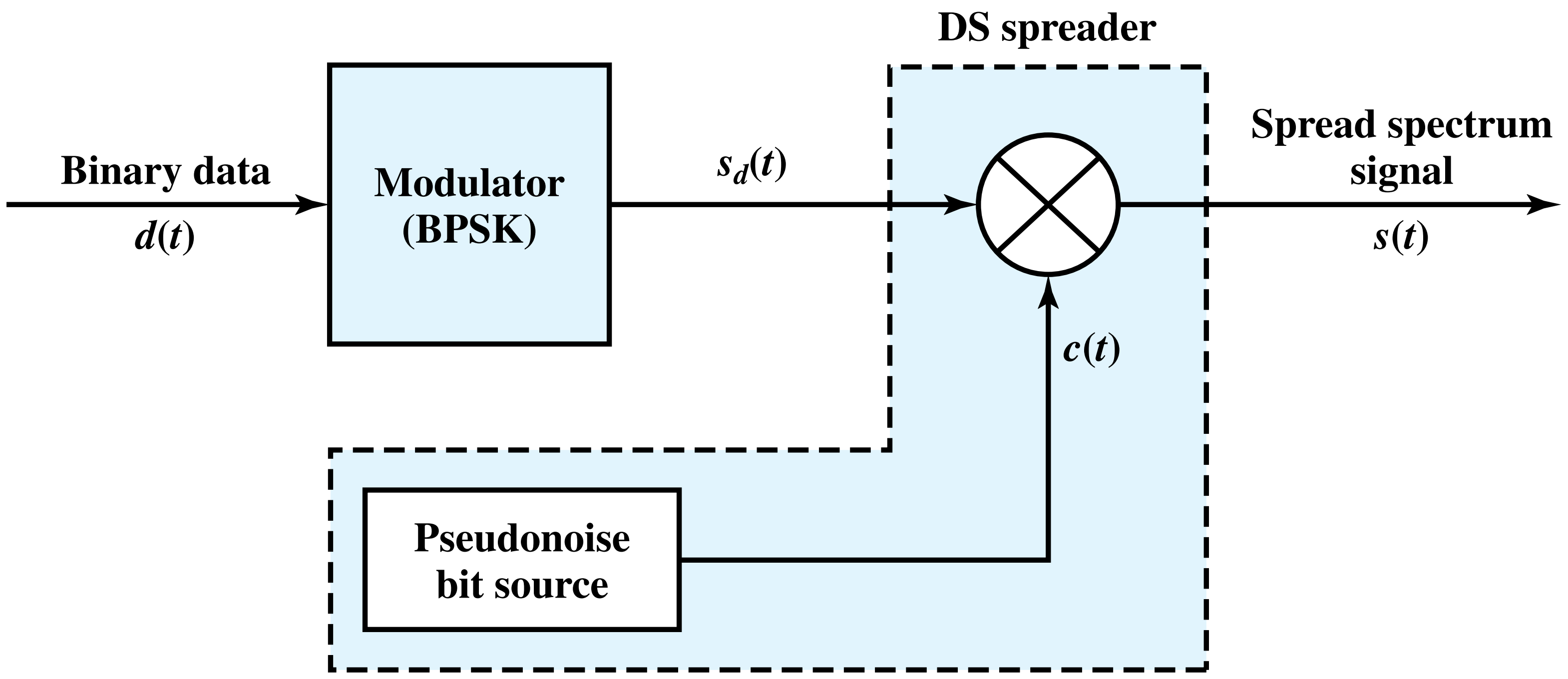


DSSS Example

- In figure, the spreading code is 11 chips having the pattern 10110111000 (in this case). If the original signal rate is N, the rate of the spread signal is 11N. This means that the required bandwidth for the spread signal is 11 times laeger than the bandwidth of the origina signal.
- The spread can provide privacy if the intruder does not know the code. It can also provide immunity against interference if each station uses a different code.

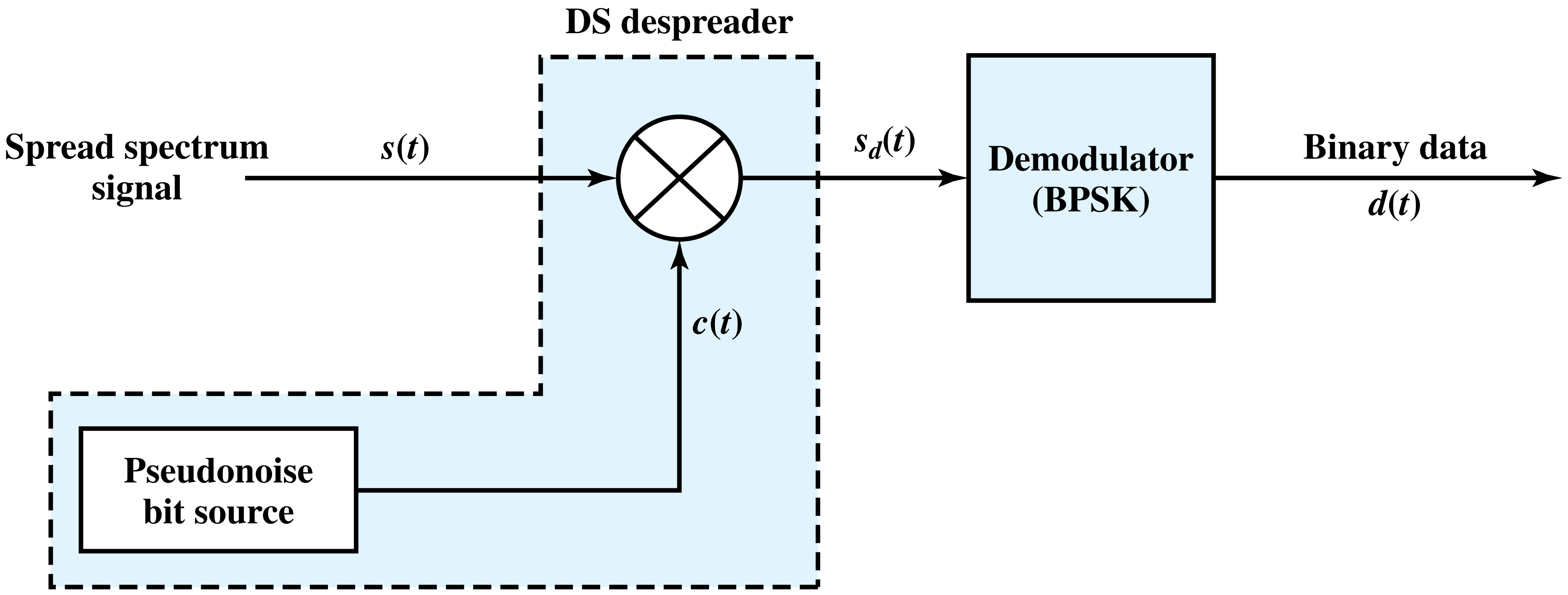


DSSS Transmitter



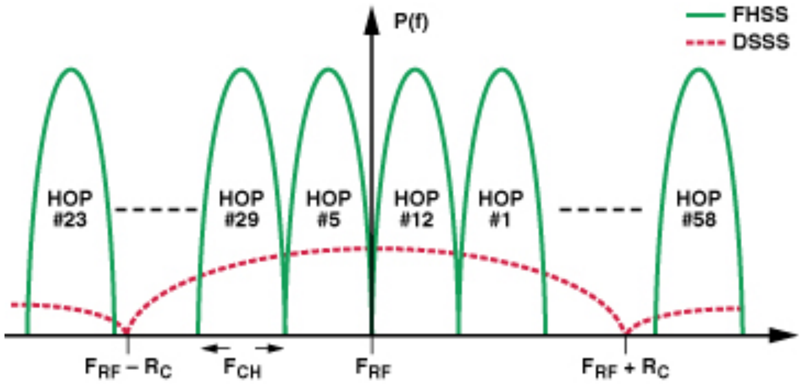
(a) Transmitter

DSSS Receiver



(b) Receiver

- Few examples of systems using DSSS modulation include IEEE 802.15.4 (WPAN), IEEE 802.11 (WLAN), and GPS.
- The main advantages of DSSS are:
    1. Interference resilience – The essence of the interference-rejection capability of DSSS is that the useful signal gets multiplied twice (spread and despread) by the PRN code while any interferers are multiplied just once (spread).
    2. Low power spectral density – Introducing minimal interference with existing narrow-band systems.
    3. Security – Very resistant to jamming because of spreading/despreading.
    4. Mitigation of multipath effects



Frequency spectra for FHSS and DSSS.

FHSS Simulation Video

Summary

- Bandwidth utilization is the use of available bandwidth to achieve specific goals. Efficiency can be achieved by using multiplexing; privacy and antijamming can be achieved by using spreading.
- In spread spectrum (SS), we combine signals from different sources to fit into a larger bandwidth. Spread spectrum is designed to be used in wireless applocaions in which station must be able to share the medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder.
- The frequency hopping spread spectrum (FHSS) techniques uses M different carrier frequencies that are modulated by the source signal. At one moment, the signal modulates one carrier frequncy; at the next moment, the signal modulates another carrier frequency.
- The direct sequence spread spectrum (DSSS) technique expands the bandwidth of a signal by replacing each data bit with n bits using a spreading code. In other words, each bit it is assigned a code of n bits, called chips.

Exercise

1. What is the minimum number of bits in a PN sequence if we use FHSS with a channel bandwidth of B=4KHz and Bss = 100 KHz?
2. An FHSS system uses a 4-bit PN sequence. If the bit rate of the PN is 64 bits per second, answer the following questions:
    a. What is the total number of posible hops?
    b. What is the time needed to finish a complete cycle of PN?
3. We have a digital medium with a data rate of 10 Mbps. How many 64-kbps voice channels can be carried by this medium if we use DSSS with the Barker sequence?