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Data Communication
Discussion
Chapter 9
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CHAPTER 9

SPREAD SPECTRUM

Spread Spectrum is an important form of encoding for wireless communications. In spread spectrum (SS), we combine signals from different sources to fit into a larger bandwidth, but our goals are to prevent **eavesdropping and jamming**.

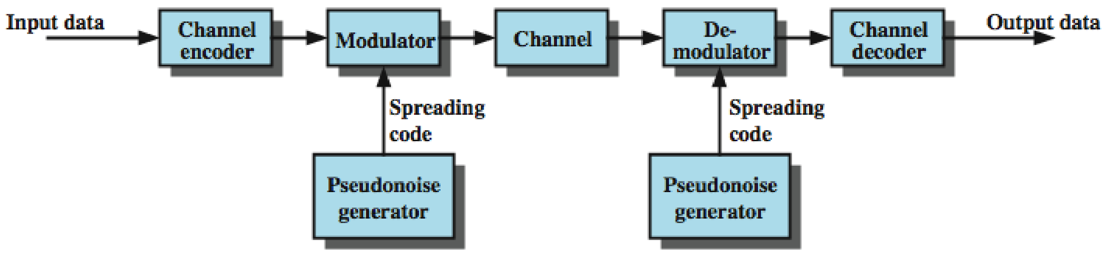


Figure 9.1 General Model of Spread Spectrum System

A signal that occupies a bandwidth of B, is spread out to occupy a bandwidth of Bss. All signals are spread to occupy the same bandwidth Bss. The bandwidth is wider after the signal has been encoded using spread spectrum.(Bss >> B).

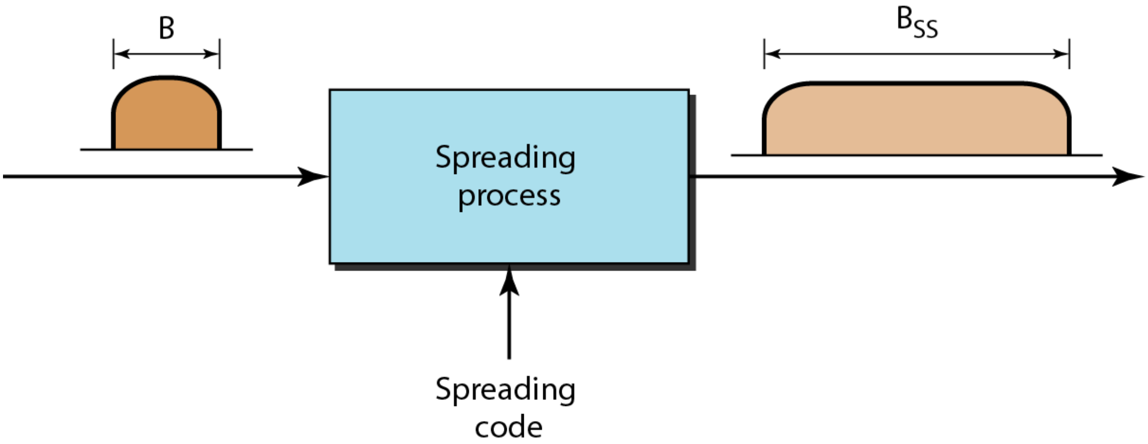


Figure 9.2 Spread Spectrum

Example:

9.1 Assume we wish to transmit a 56-kbps data stream using spread spectrum.

a. Find the channel bandwidth required to achieve a 56-kbps channel capacity when SNR = 0.1, 0.01, and 0.001.

b. In an ordinary (not spread spectrum) system, a reasonable goal for bandwidth efficiency might be **1 bps/Hz**. That is, to transmit a data stream of 56 kbps; a bandwidth of 56 kHz is used. In this case, what is the minimum SNR that can be endured for transmission without appreciable errors? Compare to the spread spectrum case.

Solution:

a) $C = B \log_2 (1 + SNR)$.

For SNR = 0.1, B= $\boxed{0.41 \text{ MHz}}$

For SNR = 0. 01, B = $\boxed{3.9 \text{ MHz}}$

For SNR = 0.001, B = $\boxed{38.84 \text{ MHz}}$

Thus, to achieve the desired SNR, the signal must be spread so that 56 KHz is carried in *very large bandwidths.*

b. For 1 bps/Hz=(C / B), the equation $C = B \log_2 (1 + SNR)$ becomes

$\log_2 (1 + SNR) = 1$.

$\boxed{SNR = 1}$. Thus a far higher SNR is required without spread spectrum.

Spread Spectrum Approaches are:

1. Frequency-hopping spread spectrum.

2. Direct sequence spread spectrum.

Frequency-hopping spread spectrum: is a form of spread spectrum in which the signal is broadcast over a seemingly random series of radio frequencies, hopping from frequency to frequency at fixed intervals.

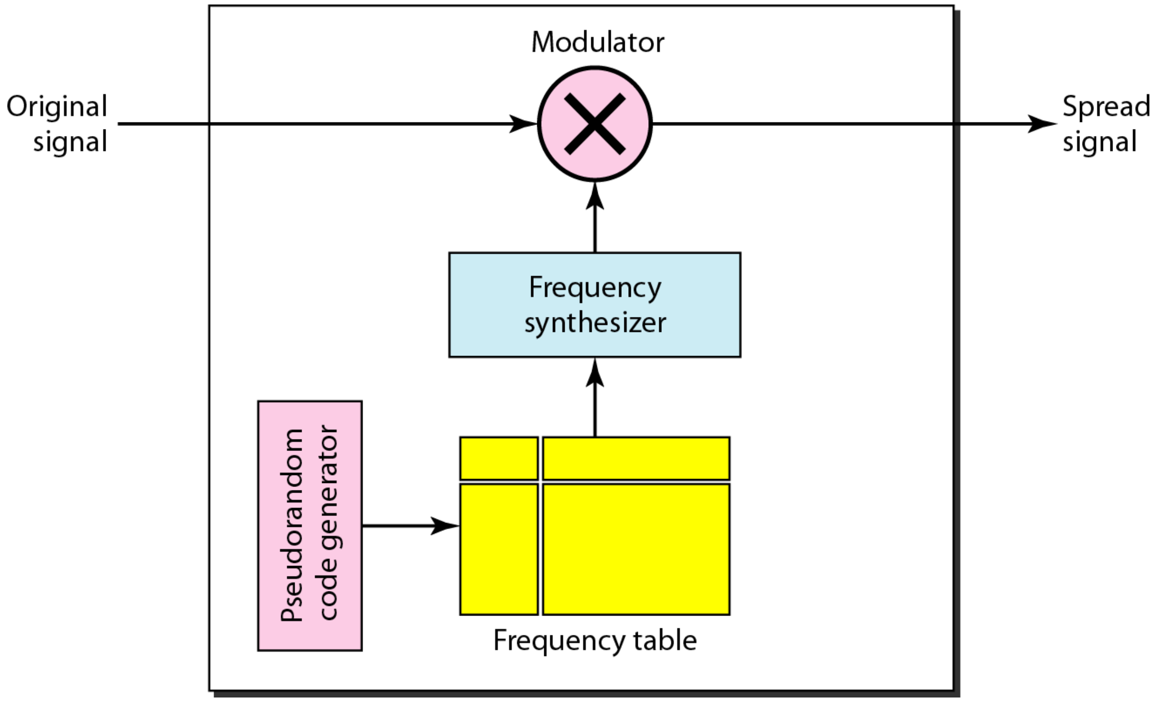


Figure 9.3 Frequency hopping spread spectrum (FHSS)

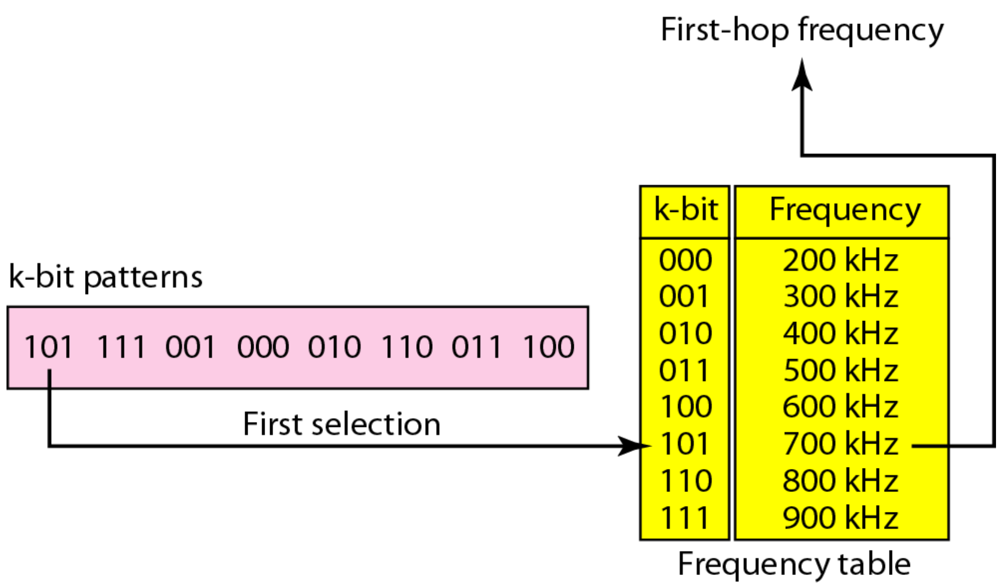


Figure 9.4 Frequency selection in FHSS

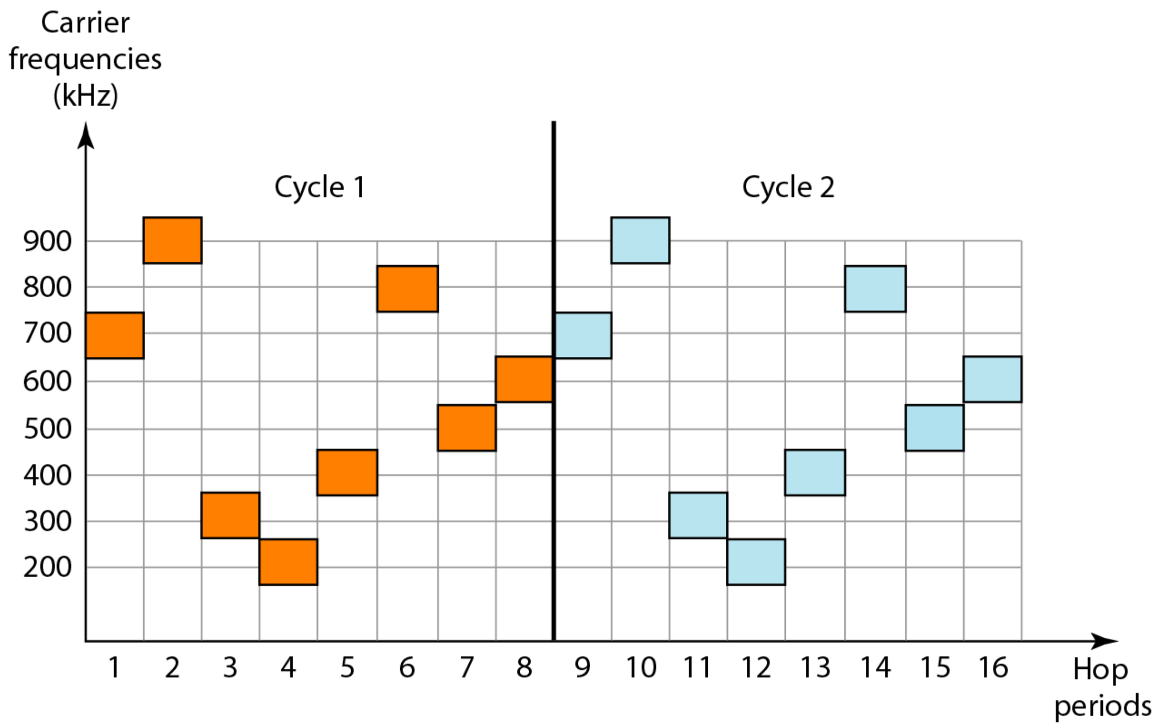


Figure 9.5 FHSS cycles

Examples:

1. What is the minimum number of bits in a PN sequence if we use FHSS with a channel bandwidth of B =4 KHz and B_{ss} =100 KHz?

Solution:

The number of hops = 100 KHz/4 KHz = 25.

So we need $\log_2 25 = 4.64 \approx$ $\boxed{\textbf{5 bits}}$

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 possible hops?

b. What is number of finished cycles per time of PN?

Solution:

a. $2^4 =$ $\boxed{\textbf{16 hops}}$

b. (64 bits/s) / 4 bits = $\boxed{\textbf{16 cycles/s}}$

3. A pseudorandom number generator uses the following formula to create a random series:

$$N_{i+1} = (5 + 7N_i) \bmod 17 - 1$$

In which N_i defines the current random number and N_{i+1} defines the next random number. The term mod means the value of the remainder when dividing $(5 + 7N_i)$ by 17. Find the random numbers.

Solution:

i=0 $\longrightarrow$ $N_1 = (5 + 7N_0) \bmod 17 - 1 = 11$, where $N_0 = 1$

i=1 $\longrightarrow$ $N_2 = (5 + 7*11) \bmod 17 - 1 = 13$

i=2 $\longrightarrow$ $N_3 = (5 + 7*13) \bmod 17 - 1 = 10$

i=3 $\longrightarrow$ $N_4 = (5 + 7*10) \bmod 17 - 1 = 6$

i=4 $\longrightarrow$ $N_5 = (5 + 7*6) \bmod 17 - 1 = 12$

i=5 $\longrightarrow$ $N_6 = (5 + 7*12) \bmod 17 - 1 = 3$

i=6 $\longrightarrow$ $N_7 = (5 + 7*3) \bmod 17 - 1 = 8$

i=7 $\longrightarrow$ $N_8 = (5 + 7*8) \bmod 17 - 1 = 9$

i=8 $\longrightarrow$ $N_9 = (5 + 7*9) \bmod 17 - 1 = -1$, Now we stop because we have a negative value.

Random numbers are $\boxed{11, 13, 10, 6, 12, 3, 8, 9}$

4. (Q9.2) An FHSS system employs a total bandwidth of Ws = 400 MHz and an individual channel bandwidth of 100 Hz. What is the minimum number of PN bits required for each frequency hop?

Solution:

# of hops = $(400*10^6) / 100 = 4*10^6$

The minimum number of PN bits = $\lceil \log_2 (4 \times 10^6) \rceil = \boxed{22 \text{ bits}}$

Slow and Fast FHSS

- Commonly use multiple FSK (MFSK) , MFSK uses $M = 2^L$ different frequencies to encode the digital input L bits at a time.
- Total MFSK bandwidth $W_d = 2^L f_d$
- Total FHSS bandwidth $W_s = 2^k W_d$

- have frequency shifted every T_c seconds
- duration of signal element is T_s seconds

Slow FHSS = multiple signal elements per hop; has $T_c \geq T_s$, ($T_c = 2T_s = 4T$).

Fast FHSS = multiple hops per signal element; has $T_c < T_s$, ($T_s = 2T_c = 2T$).

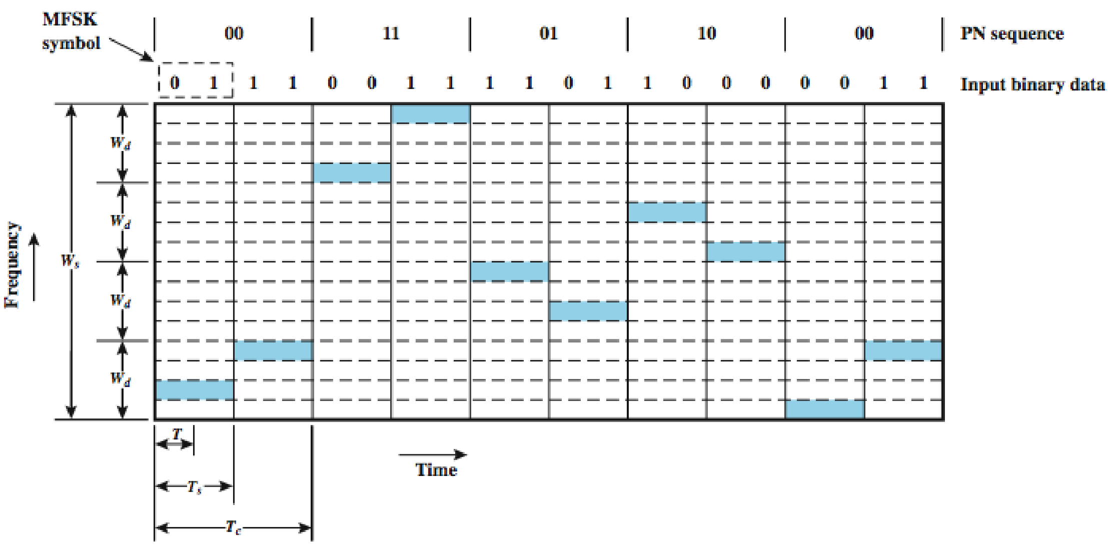


Figure 9.6 Slow MFSK FHSS(M = 4, k = 2)

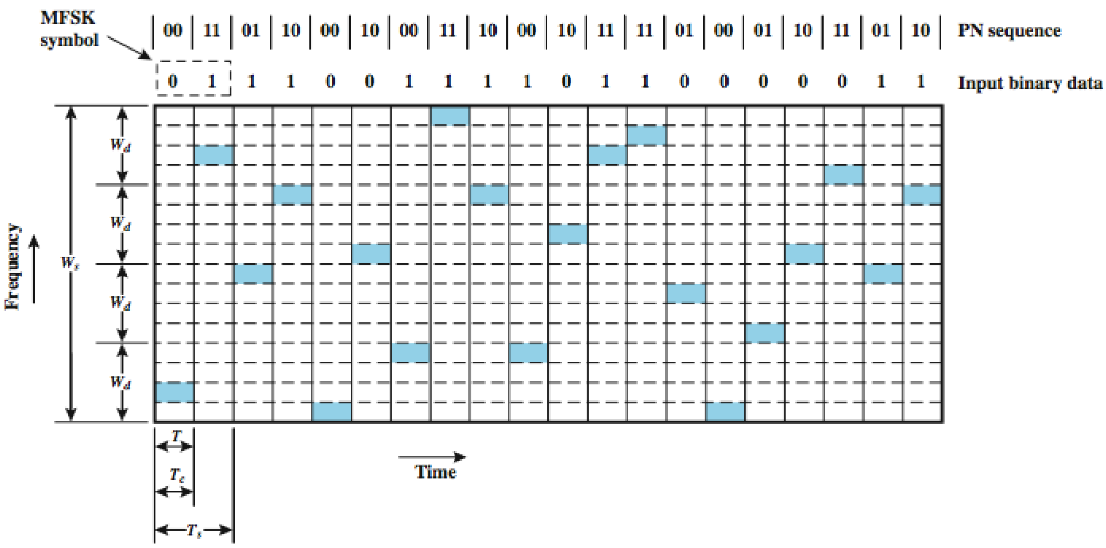


Figure 9.6 Fast MFSK FHSS (M = 4, k = 2)

Examples:

1. (Q9.4) The following table illustrates the operation of FHSS system for one complete period of the PN sequence.

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Input data	0	1	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	0	1	0
Frequency	f_1		f_3		f_{23}		f_{22}		f_8		f_{10}		f_1		f_3		f_2		f_2	
PN sequence	001				110				011				001				001			

a. What is the period of the PN sequence, in terms of bits in the sequence?
b. The system makes use of a form of FSK. What form of FSK is it?
c. What is the number of bits per signal element (symbol)?
d. What is the number of FSK frequencies?
e. What is the length of a PN sequence per hop?
f. Is this a slow or fast FH system?
g. What is the total number of possible carrier frequencies?
h. Show the variation of the base, or demodulated, frequency with time.

Solution:

a) Period of the PN sequence is 15
b) MFSK
c) L = 2
d) $M = 2^L = 2^2 = 4$
e) k = 3
f) Slow FHSS
g) $2^k = 2^3 = 8$
h) We have 4 FSK Frequencies ($f_0 - f_3$)
for $f_{23} \longrightarrow$ 23 mod 4 = 3 $\longrightarrow$ So $f_{23} = f_3$

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Input data	0	1	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	0	1	0
Frequency	f_1		f_3		f_3		f_2		f_0		f_2		f_1		f_3		f_2		f_2	

2. (Q9.5) The following table illustrates the operation of FHSS system using the same PN sequence as previous questions

Time	0	1	2	3	4	5	6	7	8	9	10	11
Input data	0	1	1	1	1	1	1	0	0	0	1	0
Frequency	f_1	f_{21}	f_{11}	f_3	f_3	f_3	f_{22}	f_{10}	f_0	f_0	f_2	f_{22}
PN sequence	001	110	011	001	001	001	110	011	001	001	001	110

Time	12	13	14	15	16	17	18	19
Input data	0	1	1	1	1	0	1	0
Frequency	f_9	f_1	f_3	f_3	f_{22}	f_{10}	f_2	f_2
PN sequence	011	001	001	001	110	011	001	001

a. What is the period of the PN sequence?
b. The system makes use of a form of FSK. What form of FSK is it?
c. What is the number of bits per signal element?

d. What is the number of FSK frequencies?
e. What is the length of a PN sequence per hop?
f. Is this a slow or fast FH system?
g. What is the total number of possible carrier frequencies?
h. Show the variation of the base, or demodulated, frequency with time.

Solution:

a) Period of the PN sequence is 15
b) MFSK
c) L = 2
d) $M = 2^L = 2^2 = 4$
e) k = 3
f) FAST FHSS
g) $2^k = 2^3 = 8$
h) We have 4 FSK Frequencies ($f_0 - f_3$)
for $f_{22} \longrightarrow 22 \bmod 4 = 2 \longrightarrow$ So $f_{22} = f_2$

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Input data	0	1	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	0	1	0
Frequency	f_1		f_3		f_3		f_2		f_0		f_2		f_1		f_3		f_2		f_2	

Direct sequence spread spectrum: is a form of spread spectrum in which each bit in the original signal is represented by multiple bits in the transmitted signal, using a spreading code.

For an N-bit spreading code, the bit rate after spreading (usually called the chip rate) is N times the original bit rate.

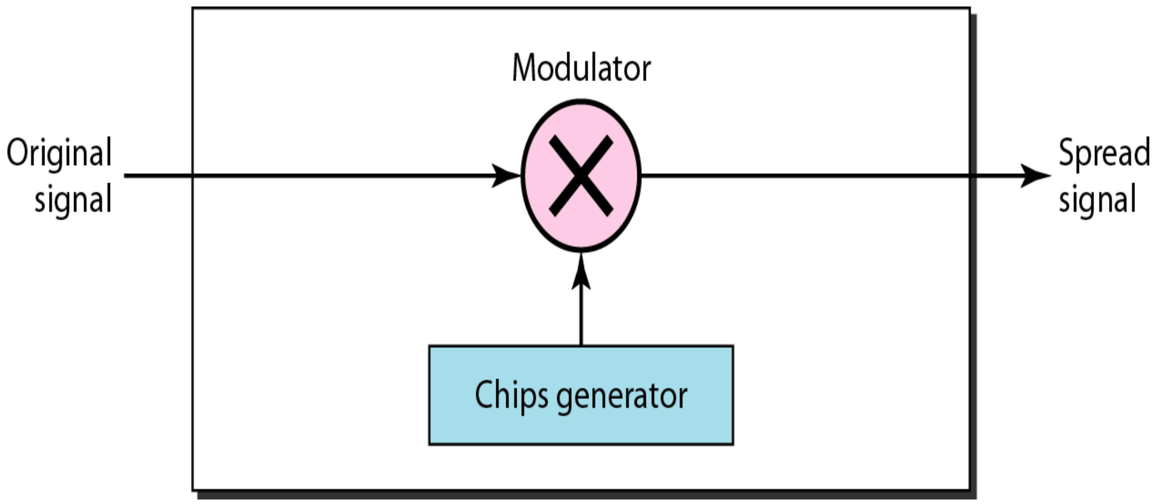


Figure 9.7 Direct Sequence Spread Spectrum

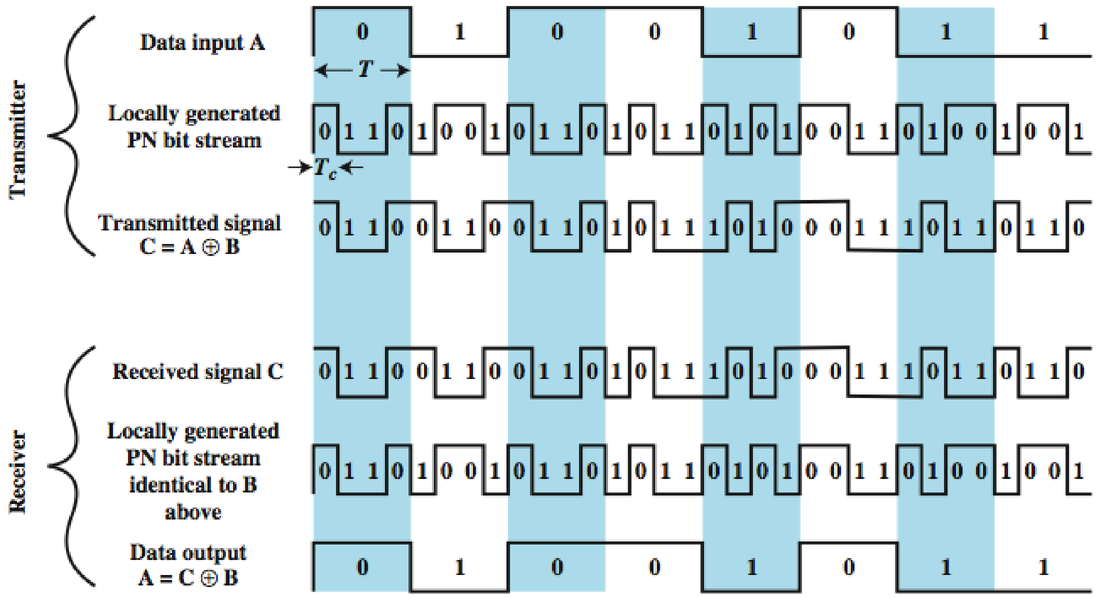


Figure 9.8 Direct Sequence Spread Spectrum Example

In Figure 9.9, the spreading code is 11 bits chip (Barker chip) with 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 larger than the bandwidth of the original signal.

(Spread signal = Original signal * Spreading code)

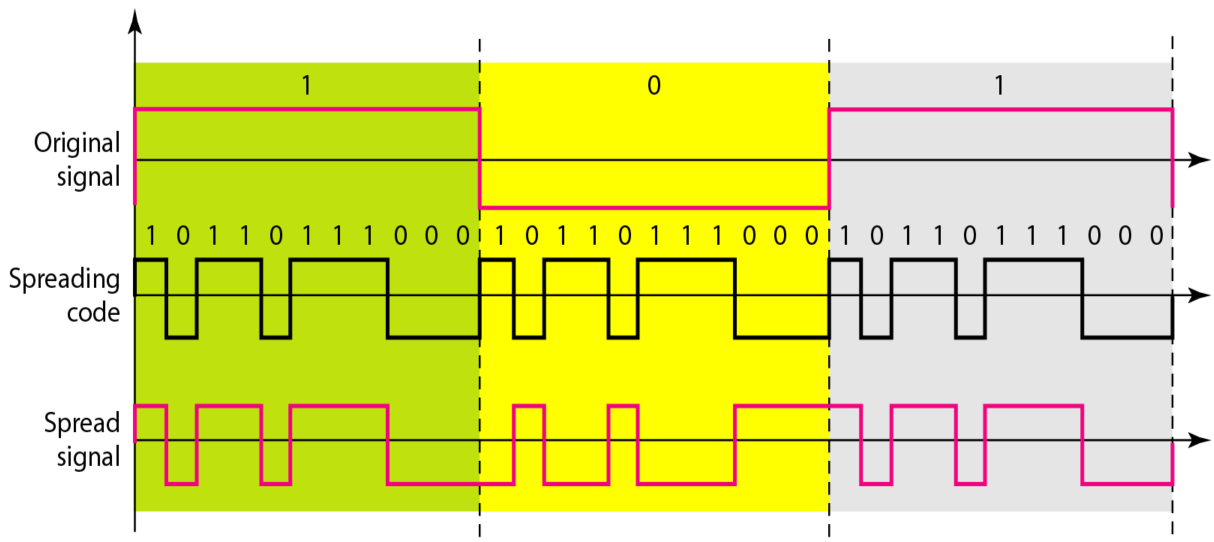


Figure 9.9 DSSS example

Example:

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?

Solution:

The Barker chip is 11 bits, which means that it increases the bit rate 11 times.

A voice channel of 64 kbps needs $\longrightarrow$ 11 × 64 kbps = 704 kbps.

This means that the bandpass channel can carry:

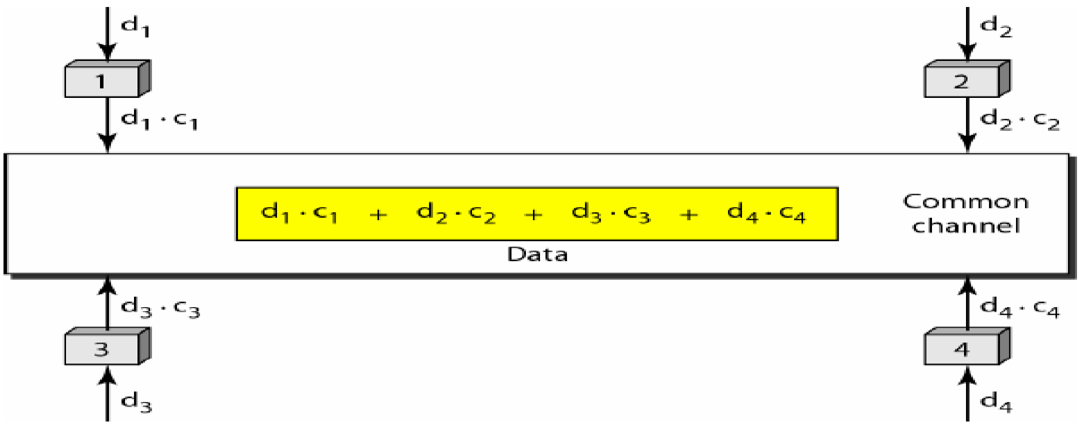
(10 Mbps) / (704 kbps) ≈ **14 channels.**

Code Division Multiple Access (CDMA)

- a multiplexing technique used with spread spectrum
- given a data signal rate D
- break each bit into *k* chips according to a fixed chipping code specific to each user
- resulting new channel has chip data rate *kD* chips per second
- can have multiple channels superimposed

Code division multiple access exploits the nature of spread spectrum transmission to enable multiple users to independently use the same bandwidth with very little interference.

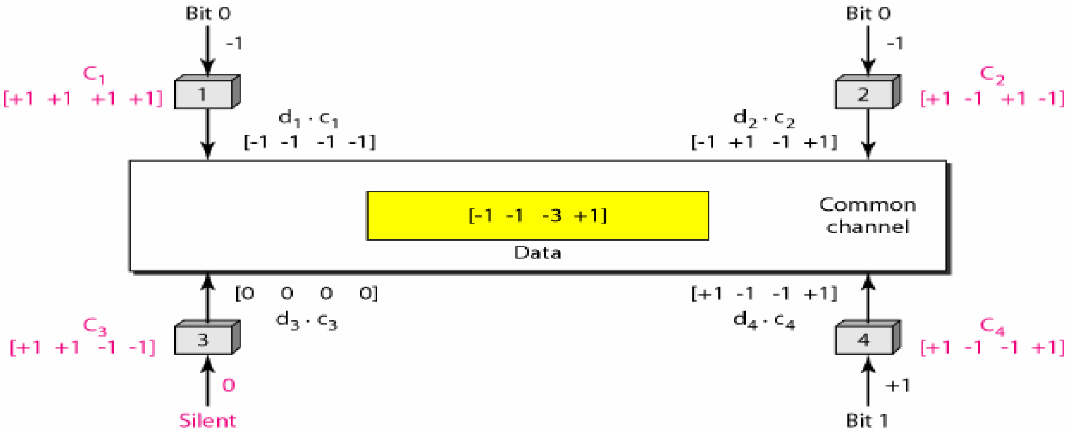
CDMA allows multiple users to transmit over the same wireless channel using spread spectrum. Each user uses a different spreading code. The receiver picks out one signal by matching the spreading code.



Data representation

Data bit 0 → -1 | Data bit 1 → +1 | Silence → 0

Encoding and decoding



Now imagine station 3, which we said is silent, is listening to station 2. Station 3 multiplies the total data on the channel by the code for station 2, which is

[+1 -1 +1-1], to get:

$$[-1 -1 -3 +1] \cdot [+1 -1 +1 -1] = -4/4 = -1 \text{ ...... bit 0}$$

Example:

Consider a CDMA system in which users A and B have codes (-1 1-11-11-11) and (-1-111-1-111) respectively.

(a) Show the output at the receiver if A transmits a data 1 and B does not transmit;

Solution:

$d_a \cdot c_a$ = +1 * [-1 1-11-11-11] = [-1 1-11-11-11] = Data

Output at receiver = $c_a \cdot$ Data = [-1 1-11-11-11] · [-1 1-11-11-11] = $\boxed{8}$

(b) Show the output at the receiver if A transmits a data 0 and B does not transmit;

Solution:

$d_a \cdot c_a$ = -1 * [-1 1-11-11-11] = [1 -11-11-11-1] = Data

Output at receiver = $c_a \cdot$ Data = [-1 1-11-11-11] · [1 -11-11-11-1] = $\boxed{-8}$

(c) Show the output at the receiver if A transmits a data bit 1 and B transmits a data bit 1. Assume the received power from both A and B is the same.

Solution:

A output (data = 1)	–1	1	–1	1	–1	1	–1	1	
B output (data = 1)	–1	–1	1	1	–1	–1	1	1	
Received	–2	0	0	2	–2	0	0	2	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	2	0	0	2	2	0	0	2	=8

(d) Show the output at the receiver if A transmits a data bit 0 and B transmits a data bit 1. Assume the received power from both A and B is the same.

Solution:

A output (data = 0)	1	–1	1	–1	1	–1	1	–1	
B output (data = 1)	–1	–1	1	1	–1	–1	1	1	
Received	0	–2	2	0	0	–2	2	0	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	0	–2	–2	0	0	–2	–2	0	=–8

(e) Show the output at the receiver if A transmits a data bit 1 and B transmits a data bit 0. Assume the received power from both A and B is the same.

Solution:

A output (data = 1)	–1	1	–1	1	–1	1	–1	1	
B output (data = 0)	1	1	–1	–1	1	1	–1	–1	
Received	0	2	–2	0	0	2	–2	0	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	0	2	2	0	0	2	2	0	=8

(f) Show the output at the receiver if A transmits a data bit 0 and B transmits a data bit 0. Assume the received power from both A and B is the same.

Solution:

A output (data = 0)	1	–1	1	–1	1	–1	1	–1	
B output (data = 0)	1	1	–1	–1	1	1	–1	–1	
Received	2	0	0	–2	2	0	0	–2	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	–2	0	0	–2	–2	0	0	–2	=–8

(g) Show the output at the receiver if A transmits a data bit 1 and B transmits a data bit 1. Assume the received power from B is twice the received power from A. This can be represented by showing the received signal component from A as consisting of elements of magnitude 1(+1, -1) and the received signal component from B as consisting of elements of magnitude 2(+2, - 2).

Solution:

A output (data = 1)	–1	1	–1	1	–1	1	–1	1	
B output (data = 1)	–2	–2	2	2	–2	–2	2	2	
Received	–3	–1	1	3	–3	–1	1	3	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	3	–1	–1	3	3	–1	–1	3	=8

(h) Show the output at the receiver if A transmits a data bit 0 and B transmits a data bit 1. Assume the received power from B is twice the received power from A.

Solution:

A output (data = 0)	1	–1	1	–1	1	–1	1	–1	
B output (data = 1)	–2	–2	2	2	–2	–2	2	2	
Received	–1	–2	2	1	–1	–3	3	–1	
Receiver codeword	–1	1	–1	1	–1	1	–1	1	
Multiplication	1	–2	–2	1	1	–3	–3	–1	=–8