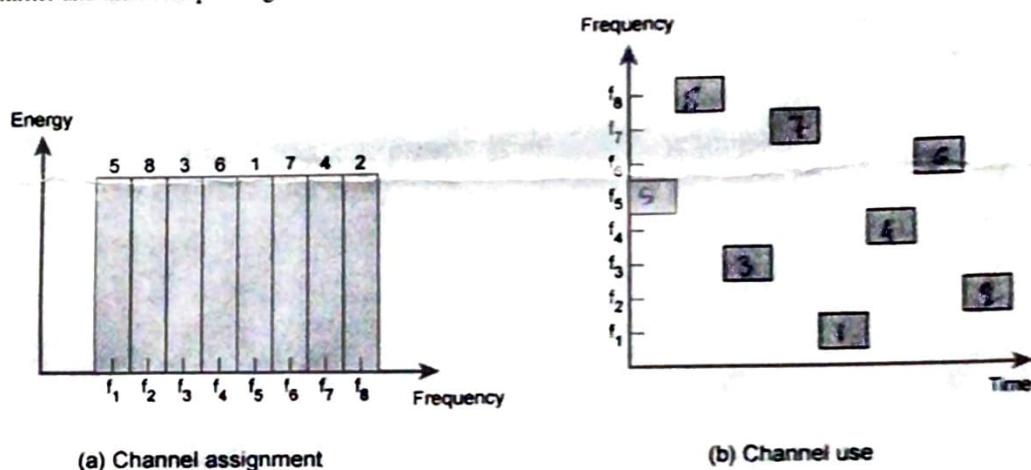# FREQUENCY HOP SPREAD SPECTRUM

Another common method to spread the transmission spectrum of a data signal is to (pseudo) randomly hop the data signal over different carrier frequencies. This spreading method is called frequency hop spread spectrum (FH-SS). Usually, the available band is divided into non-overlapping frequency bins. The data signal occupies one and only one bin for a duration Tc and hops to another bin afterward. When the hopping rate is faster than the symbol rate, the FH scheme is referred to as fast hopping. Otherwise, it is referred to as slow hopping. A typical FH-SS transmitter and the corresponding receiver are shown in Figures respectively.

(a) Channel assignment   (b) Channel use

Frequency hopping entails the transmission carrier frequency hopping between available channels within the spread-spectrum band. A narrow spectral band and an individual carrier frequency at the centre of the band define each transmitted channel. Successive carrier frequencies are chosen in accordance with the pseudo-random phases of the spreading code sequence. There are two widely used FH schemes: (1) Fast frequency hopping where one complete, or a fraction of the data symbol, is transmitted within the duration between carrier hops. Consequently, for a binary system, the frequency hopping rate may exceed the data bit rate. (2) On the other hand, in a slow frequency hopping system, more than one symbol is transmitted in the interim time between frequency hops. Figure illustrates how the carrier frequency hops with time. Let time duration between hops be Th and data bit duration be denoted by Tb, then:

$$Th \leq Tb \text{ for fast hopping (1.22)}$$
$$Th > Tb \text{ for slow hopping (1.23)}$$

P

The basic FH modulation system, depicted in Figure comprises a digital phase or frequency shift keying modulator and a frequency synthesizer. The latter generates carrier frequencies according to the pseudo-random phases of the spreading code sequence that is then mixed with the data carrier to originate the FH signal.

In the basic FH receiver, shown in Figure (b), the received FH signal is first filtered using a wideband bandpass filter and then mixed with a replica of the FH carrier. The mixer output is applied to the appropriate demodulator. A coherent demodulator may be used when a PSK carrier is received.
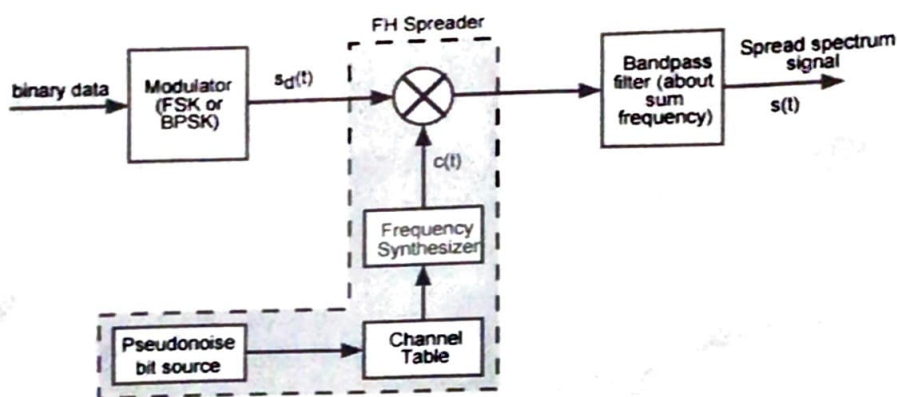
Frequency Hopping Spread Spectrum System (Transmitter)

The incoming signal is multiplied by the signal from the PN generator identical to the one at the transmitter. Resulting signal from the mixer is a binary FSK, which is then demodulated in a "regular" way. Error correction is then applied in order to recover the original signal. The timing synchronization is accomplished through the use of early-late gates, which control the clock frequency
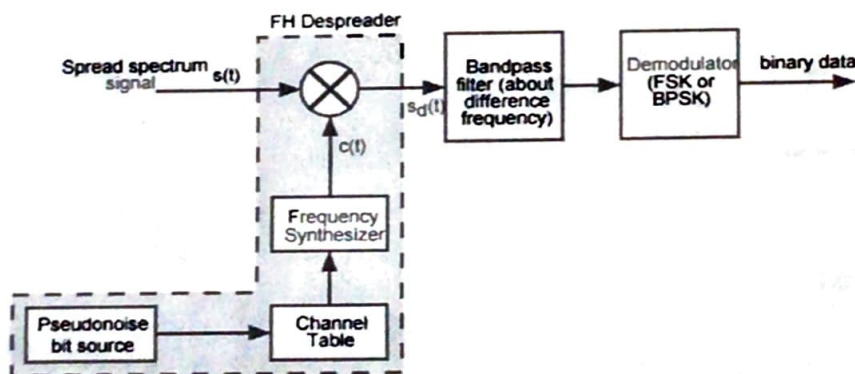

Frequency Hopping Spread Spectrum System (Receiver)

The FH receiver is usually non-coherent. A typical non-coherent receiver architecture is represented in figure.

Slow versus Fast Hopping:

As mentioned earlier, the hop period (also called the chip period Tc) may be greater or less than the symbol duration. The bandwidth expansion factor (and consequently the processing gain) is related only to the number of hop frequencies N, not the hop period. Thus, we are free to choose the hop period based on other considerations. Specifically, the hop frequency should be chosen based on implementation and performance considerations. First let us consider the case where Tc > Ts, which is called slow hopping. Additionally, let us assume that FSK modulation is used. Figure 4.4 plots the frequency occupancy versus time considering both the data modulation and frequency hopping. In this example $Tc = \frac{4Ts}{2}$, or the frequency is hopped every four symbols, N = 6 and M = 4 (Tb = Ts/2). Further, in the figure we have defined B as the bandwidth of the MFSK signal and W as the spread bandwidth. As can be seen, every Ts seconds, the frequency is changed to one of 4 symbols based on the data.

Additionally, every Tc seconds, the center frequency of these symbols is changed based on the frequency hopping pattern. At the receiver the pseudorandom hopping is removed, leaving only the data modulation as shown in Figure. In contrast to slow hopping, with fast frequency hopping Tc < Ts. That is, frequency hopping occurs faster than the modulation. This is depicted in Figure 4.6 where Tc = Ts/2 , N=6, and M=4. In this case coherent modulation is extremely difficult since it would require extremely fast carrier synchronization. Thus, non-coherent FSK is universally used with fast hopping. The despread or de-hopped signal is plotted in Figure 4.5 which shows that the despread data is the same as in slow hopping. Fast hopping, although more difficult to implement, offers some advantages over slow hopping. First, unlike slow hopping, fast hopping provides frequency diversity at the symbol level which provides substantial benefit in fading channels or versus narrowband jamming. Slow hopping can obtain these same benefits through error correction coding as we will see later, but fast hopping offers this benefit before coding is applied, which can provide better performance, especially when punctured codes are used. The down side to fast hopping is that the separate integration periods collected each hop must be combined non-coherently since non-coherent demodulation is used. As a result, a loss in performance is experiences as compared to standard noncoherent FSK modulation.
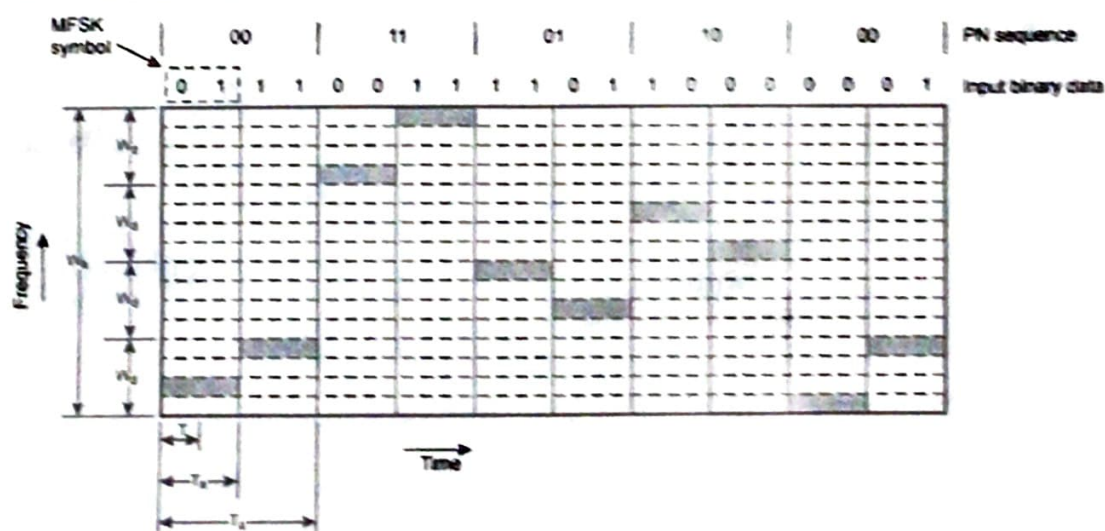
Slow Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)

Coherent: Carrier phase information is required to detect signal
non-coherent: phase information is not required.
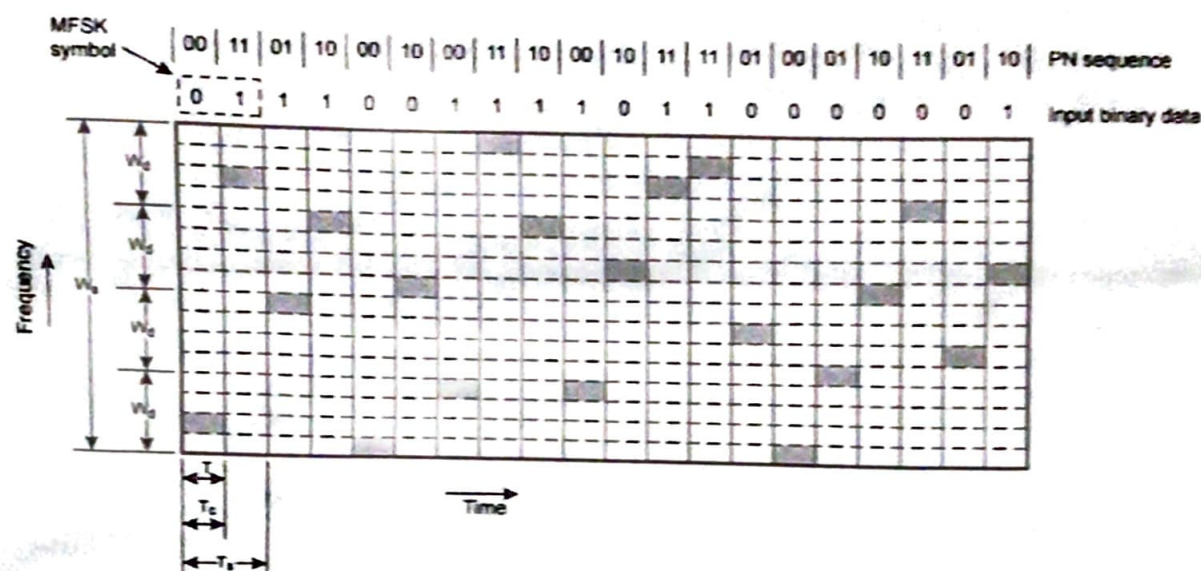
Fast Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)

<u>Processing Gain:</u>

As discussed in the previous chapter, processing gain is a measure which provides a short-hand description of the benefits of a particular spread spectrum format. Like with DS/SS there are multiple definitions available in the literature with subtle differences. As with DS/SS we will formally define processing gain as the ratio of the bandwidth to the bit rate

$$PG = W/R_b \quad (1.24)$$

while we will define the number of non-overlapping frequency bands available for hopping as the bandwidth expansion factor N. However, note that in most cases of interest, the two will be equivalent and the processing gain will be equal to the common definition PG = N.

College of Computer & Information Science
Northeastern University
CS 6710: Wireless Networks

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Handout 5
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Sample Solution to Problem Set 2

1. (6 points) Number of quantization levels in PCM

Consider an audio signal with frequency components in the range 300 to 3000 Hz. Suppose we generate a PCM signal with 6000 samples per second.

(a) What is the number of uniform quantization levels needed to achieve an SNR of 30 dB?

SNR_{dB} equals $6.02n + 1.76$ dB. So we obtain $n \geq (30 - 1.76)/6.02 \geq 4.69$. That is we need $n \geq 5$, implying 32 quantization levels.

(b) What data rate is required?

With 6000 samples per second and 5 bits per sample, we obtain a data rate of 30000 bps.

2. (12 points) FHSS Consider an MFSK scheme with carrier frequency f_c equal to 250 kHz, difference frequency f_d equal to 25KHz, and M equal to 8 (L equal to 3 bits).

(a) Make a frequency assignment for each of the eight possible 3-bit data combinations.

Here is one possible frequency assignment:

String	Frequency (kHz)
000	75
001	125
010	175
011	225
100	275
101	325
110	375
111	425

We wish to apply FHSS to this MFSK scheme with $k = 2$; that is, the system will hop among four different carrier frequencies. Suppose the data rate is R bps, so the duration of a bit is $T = 1/R$ seconds.

(b) Consider a slow FHSS with T_c (the period at which the MFSK carrier frequency changes) being $2T_s$, where T_s is the duration of a signal element. Show the sequence of frequencies used, and the times the frequency changes occur, for transmitting the bit string 011110001.

Let f_{ij} denote the frequency associated with the jth string of the ith carrier frequency, where $0 \leq i < 4$, and $0 \leq j < 8$. Thus, for example, if the ith carrier frequency is F kHz, then f_{ij} equals $F + (j - 4) \cdot 50 + 25$ kHz.

Under slow FHSS with $T_c = 2T_s$, frequency hops occur every 2 signal elements, so 6 bits.

Suppose PN sequence for generating the frequency hops starts with the sequence $\underset{0\ 3}{\underline{0011}}$. Then the frequencies used would be the following:

$$f_{03}, f_{06}, f_{31},$$

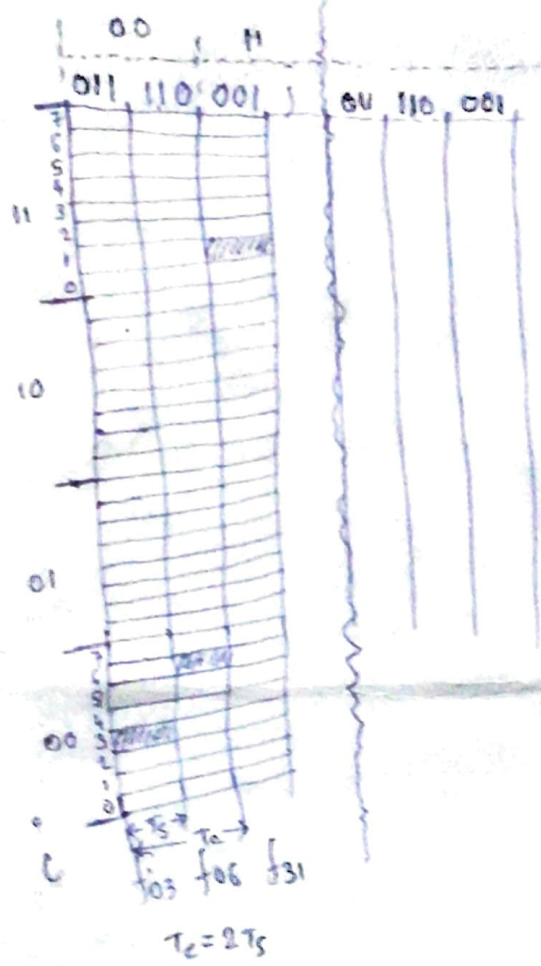where frequency changes occur every T_s time units.

(c) Consider a fast FHSS with T_s being $4T_c$. Show the sequence of frequencies used, and the times the frequency changes occur, for transmitting the bit string ~~(   )~~ $\underset{3\quad 1\quad 6}{011\ 001\ 110}$.

As above, let f_{ij} denote the frequency associated with the jth string of the ith carrier frequency, where $0 \le i < 4$, and $0 \le j < 8$.

Under fast FHSS with $T_s = 4T_c$, frequency hops occur every $T_s/4$ time units.

Suppose the PN sequence is $\underset{0\ 3\ 1\ 3\ 0\ 4\ 2\ 1\ 0\ 1\ 3\ 3}{\underline{001101110010110100011111}}$. Then, the frequencies used would be the following:

$$\underset{T_s^3/4\ \text{time units}}{\underline{f_{03}, f_{33}, f_{13}, f_{33}, f_{01}, f_{21}, f_{31}, f_{11},}} \underset{6}{\underline{f_{06}, f_{16}, f_{36}, f_{36},}}$$

frequency changes occur every $T_s/4$ time units.

Top left labels: 00 11 011 110 001 011 110 001

Left axis numbers: 7 6 5 4 3 2 1 0, labels 11, 10, 01, 00

$\leftarrow S \rightarrow$ $T_c \rightarrow$

$f_{03}\ f_{06}\ f_{31}$

$T_c = 2 T_s$

Top right labels: 00 11 01 11 0010 11 01 00 01 11 11 110 001

Right axis labels: 11, 10, 01, 00

$T_c\ T_c T_c\ T_c$

$\leftarrow T_s \rightarrow$

$T_s = 4 T_c$

fast

$f_{03}\ f_{33}\ f_{13}\ f_{33}\ f_{06}\ f_{26}\ f_{36}\ f_{16}$

$f_{01}\ f_{11}\ f_{31}\ f_{31}$

slow
FM

MFSK: one signal element
= 3 bit
$L = 3,\ M = 8$

$k = 2$

System will hop among
4 different carrier
frequencies.