Wireless Medium Access Control and CDMA, 3G and 4G Communication

Lesson 07

Frequency Hopping Spread Spectrum

Spread spectrum (DSSS and FHSS)

- A transmission technique that provides a
- Direct sequence spread spectrum (DSSS) for novel solution to the spectral efficiency
- Frequency hopping spread spectrum (FHSS) for novel solution to the spectral efficiency and interference problem

Spread spectrum

- Systems use FH Spread spectrum
- Signals with hop between the frequencies f_{c0}, $f_{c0} + f_s$, $f_{c0} + 2f_s$, …, $f_{c0} + (n–2)f_s$, $f_{c0} + (n–1)f_s$

Spread spectrum

- Spectrum widens by a factor of *n*
- Spread between f_{c0} and $f_{c0} + (n–1)f_s$, where *n* is the number of chipping frequencies used and f_s is symbol frequency (symbol/s, number of symbols chipped/s)
- The spread in the present case = $n \times f_s$

FHSS (Frequency hopping spread spectrum) technique

- One frequency at an instance in a hopping sequence as per the code used
- Hopping sequence is randomly designed for each code
- Code (3, 10, 0, 9, 7) means first hop interval frequency is 3rd hopping frequency, second is 10th, 3rd is 0th, fourth 9th and fifth the 7th
- Frequency spreads between f_{c0} and f_{c0} + (n–1) .f_s for 0th, 1st,…, (n–1)th hop frequency

FHSS (Frequency hopping spread spectrum) technique

- The frequency spread– between f_{c0} and $f_{c0} + (n–1) .f_s$ for 0^{th}, 1^{st},…, (n–1)th hop frequency

FHSS difference from DSSS

- FHSS bandwidth during transmission at each given instant of time is just equal to the inter-channel separation
- The DSSS bandwidth for transmission at each instant is equal to the full assigned spread spectrum

FHSS difference from DSSS

- Signal radio carrier band is a narrow band, but the frequencies span over the spread spectrum during a complete sequence of hopping
- Each frequency channel is separated by a guard space

FHSS

- Symbol in a hop interval is transmitted using FHSS
- The channel frequency used for transmission at a given hop interval is as per the hop sequence defined by the code

N HOPPING FREQUENCY SIGNALS

- $s_0\ (t) \ = (S_0/\sqrt{n}) \times \sin\ (2\pi \times f'_c \times t + \phi_{t0}),$
- $s_1\ (t) \ = (S_0/\sqrt{n}) \times \ \sin\ (2\pi \times (f'_c + f_s) \times \ t + \phi_{t0}),$
- $s_{n-1}(t) = (S_0/\sqrt{n}) \times \ \sin\ \{2\ \pi \times (f'_c + (n-1)\ f_s) \times \ t + \phi_{t0}\}$

N HOPPING FREQUENCIES

- $f_0 = f'_c$
- $f_{1} = f'_c + f_s$
- $f_{n-1} = f'_c + (n-1)\ f_s) \times\ t + \phi_{t0}$

FHSS

- A symbol in FHSS using the code transmits as such after hopping sequence of frequencies when transmitting the symbol 0 and using the code’s complement when transmitting 1

FSSS

- XORing between the user-signal symbols and hopping frequency signal
- The hopping sequence in transmitted frequencies are used as per the code

XORing

- B XORed with each of the *n* symbols of code
- XORing– if B = 1 and S = 1 or B = 0 and S = 0 then the amplitude is $-S_0$, else it is S_0

XORing

- i_{th} hopping frequency signal in q^{th} sequence— The second term after the multiplication sign $[(s0/\sqrt{n}) \sin \{2\pi .(f_{c0} + i. f_s + B .f_m) .t + \phi_{t0}\}]$ where B = 0 or 1
- First term $[(B .XOR. S_{i-1})$ for the q^{th} hopping sequence]— the operation performed at the spreader

FHSS frequency signals after hopping with symbol B

- Hopping sequence (i, j, …, p)
- s_0 (t) = $(S_0/\sqrt{n})$ (B.XOR.S_0) sin {2π [f'_c + (i .f_s) + B . f_m] .t + ϕ_{t0}) } in time interval t = 0 to t_{hop}
- s_1 (t) = $(S_0/\sqrt{n})$ (B.XOR.S_1) sin {2π [f'_c + (j .f_s) + B . f_m] .t + ϕ_{t0}) } in time interval t = t_{hop} to 2.t_{hop}

FHSS frequency signals after hopping with symbol B

- $s_{n-1}(t) = (S_0/\sqrt{n})\ (B.XOR.S_{n-1})\ .\sin\{2\pi\ [f'_c + (p\ .f_s) + B\ .\ f_m]\ .t + \phi_{t0})\ \}$ in time interval $t = (n-1)\ .t_{hop}$ to $n\ .t_{hop}$

FHSS frequencies after hopping with symbol B

- Hopping sequence (i, j, …, p)
- $f_0 = f'_c + i\,.f_s + B\,.\,f_m$ in time interval $t = 0$ to t_{hop}
- $f_1\,(t) \quad = f'_c + (j\,.f_s) + B\,.\,f_m$ in time interval $t = t_{hop}$ to $2.t_{hop}$
- $f_{n-1}\,(t) \quad = f'_c + (p\,.f_s) + B\,.\,f_m$ in time interval $t = t_{hop}$ to $2.t_{hop}$

q^{th} Hopping-Sequence

- S_q ($0 < q < n - 1$), is the in the sequence (code), f_s is symbol frequency and f_{hop} is the number of hopping sequences per second
- $t_{hop} = f_{hop}^{-1}$ and $f_{spread} = (n-1) \times f_s$

Fast FHSS

- Interval during a hop, $t_{hop} << t_s$
- During a symbol period a large number of frequency hops take place

Advantage of fast FHSS

- Even if a few channel frequencies are faded at the receiver due to narrow band interference, the symbol is received correctly
- The synchronization of fast FHSS between the BTS and WS is more complex than that of slow FHSS

Fast FHSS

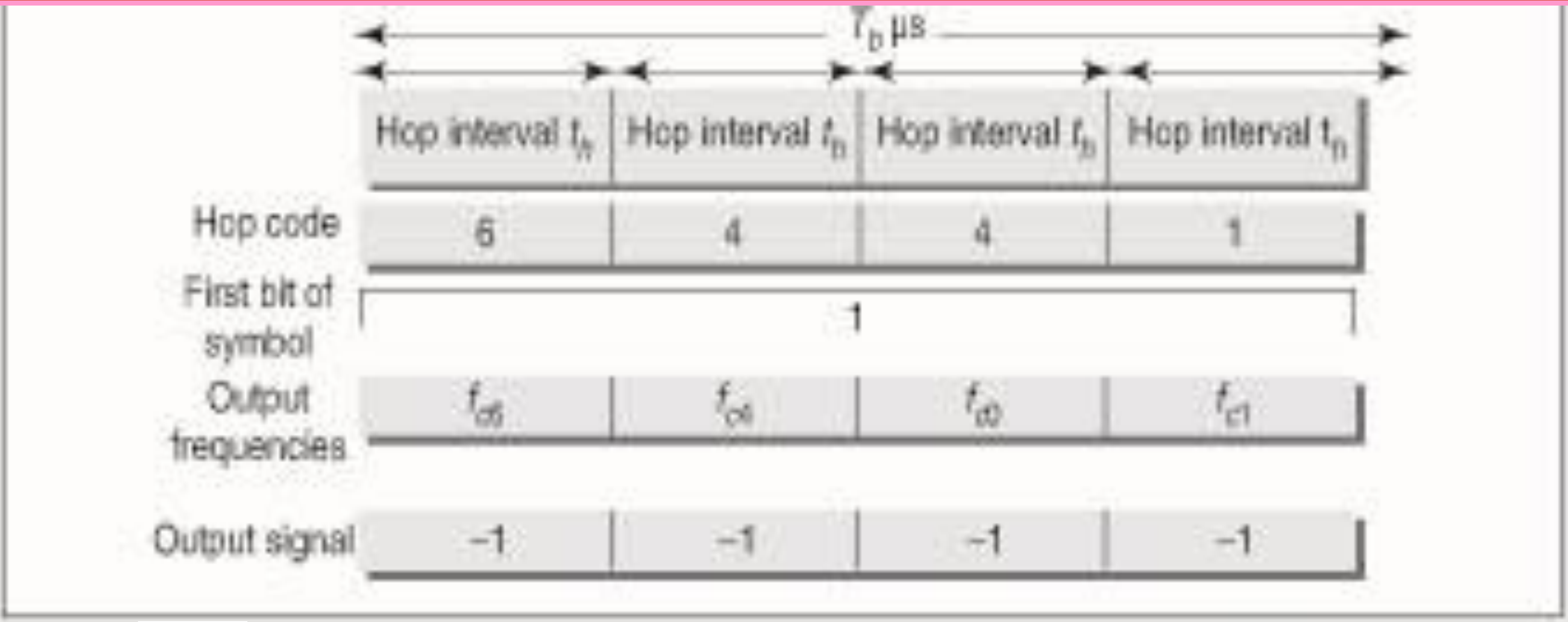


Figure Fast hopping FHSS when symbol 1001 is transmitted in four times period relative to hop intervals t_h ($T_b = 4\ t_h$) using hopping sequence (6, 4, 0, 1, 5, 3, 7, 2)

Slow FHSS

- FHSS spectrum in which the interval during a hop, $t_{hop} >> t_s$ (where $t_s = f_s^{-1}$)
- A number of symbols get transmitted during a channel hop period

Advantage of Slow FHSS

- Even if one of the hopped frequency signal is faded at the receiver due to narrow band interference, the other symbols are received correctly

Slow FHSS Example

- Assume that out of 78 channels, the 35th channel is affected by interference
- Then the signals from the 35th channel are rejected
- Transmitter later retransmits these symbols at another channel frequency
- If FHSS is not used, then even retransmission does not help, because that channel will fade again

Slow FHSS

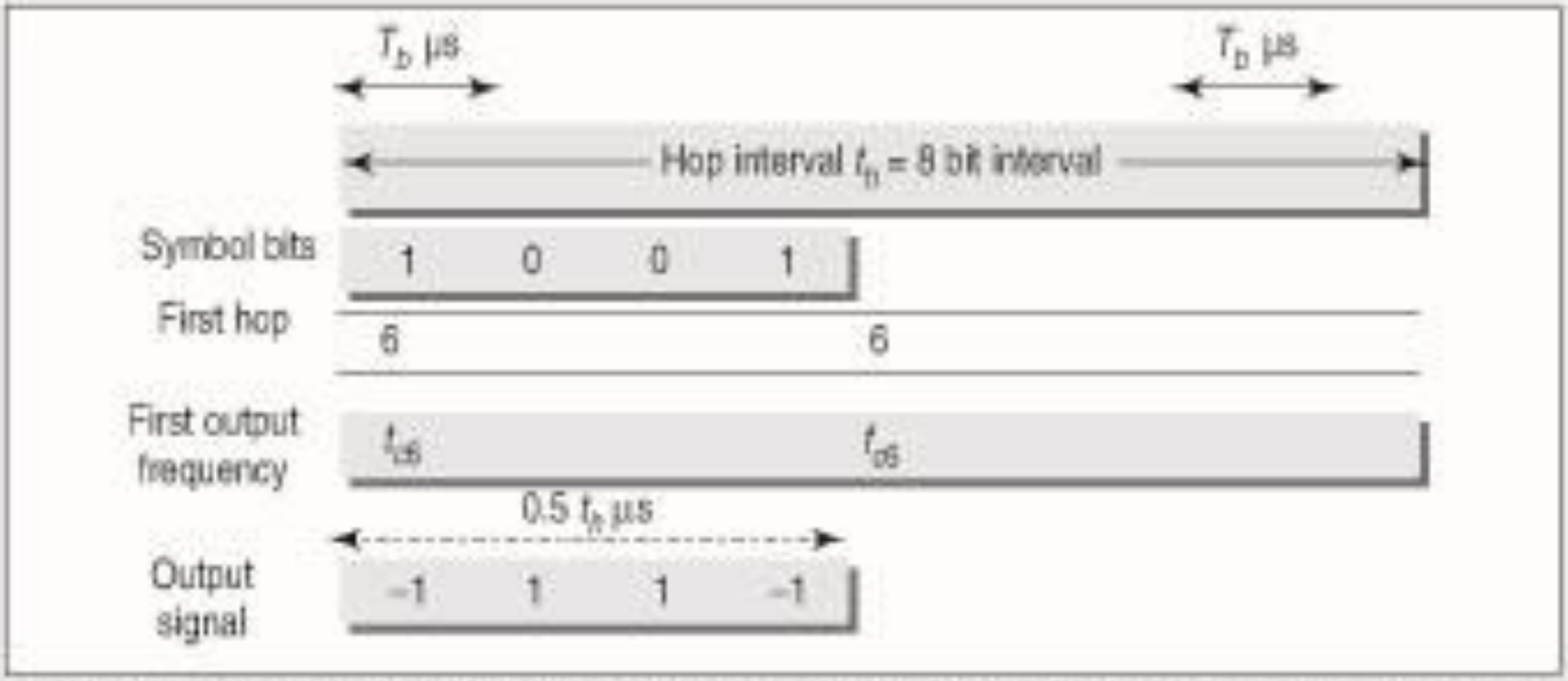
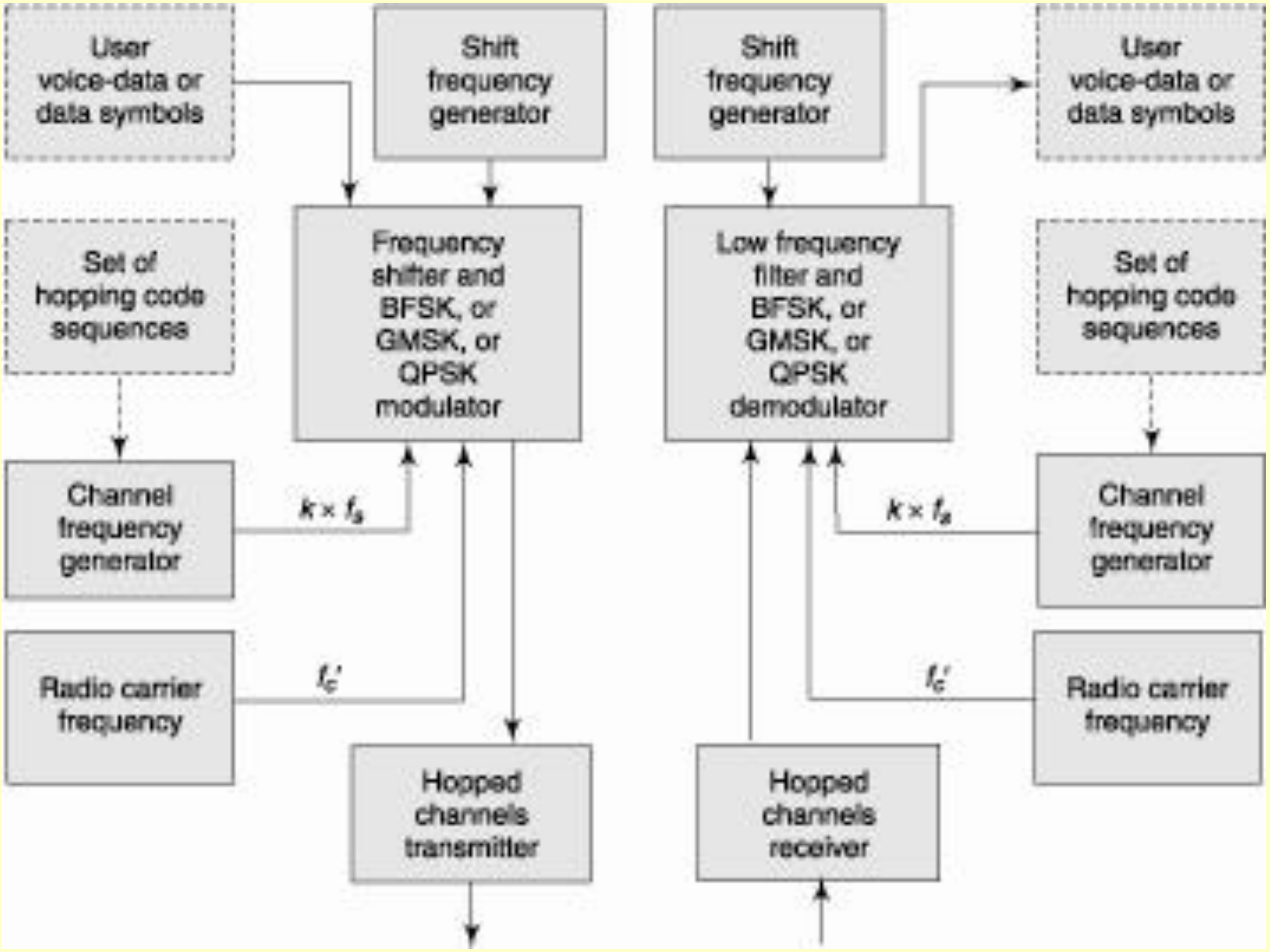


Figure 4.9 Slow hopping FHSS when symbol 1001 is transmitted in 32 times period relative to hop intervals t_h(t_h = 8T_b) using hopping sequence (6, 4, 0, 1, 5, 3, 7, 2)

FHSS TRANSMITTER AND RECEIVER



FHSS Transmitter

- A hopping sequence for the WS or BTS channel is fed to generate frequency channels as per the hopped channels for the FHSS modulator
- The channel frequency (hopped frequency signal) and carrier frequency are inputs to the modulator
- The output of the modulator is sent to the FHSS transmitter

FHSS Receiver

- The input demodulated
- Given to the low-frequencies filter to separate the $f'_c + (k \times f_s)$ carriers
- The output of the filter unit is user voice-data or data symbols

FHSS Examples

- The Bluetooth protocol uses FHSS.
- An example of a hopping sequence is that of the IEEE standard 802.11 wireless-LAN—The transmitter transmits a set of three sequences. Hopping sequences are not repeated in the three sequences.

78 Channels

- Each of three sequences consists of 26 channels
- Total of 78 channels
- The LAN specification is that frequency channel separations, f_s = 1 MHz and basic radio carrier frequency, f_{c0}= 2.4 GHz

Spread spectrum bandwidth

- If the hop cycle frequency is f_{hop}, then, the hopping interval, $t_{hop} = f_{hop}^{-1}$
- A set of three sequences with 26 channels
- 78 equations representing the signals from the 1st to the 78th hop
- 78 channels
- f_s inter-channel separation = 1 MHz
- Spread spectrum bandwidth = 78 MHz

Summary

- Frequency hops from one value to another in FHSS after each hopping interval t_{hop}
- Hopping frequency sequence is the code used for transmission
- n-channels and frequency spread = $n \times t_{hop}$
- Slow and fast FHSSs
- FHSS Transmitter and receiver

End of Lesson 07

Frequency Hopping Spread Spectrum