Computer Network and Distributed Systems

Spread Spectrum

Why Spread Spectrum ?

- In wired communication a narrowband signal is good enough to carry users data.

- But in wireless or mobile communication air being the medium of transmission, user data gets corrupt due to interference.

Spread Spectrum address this issue

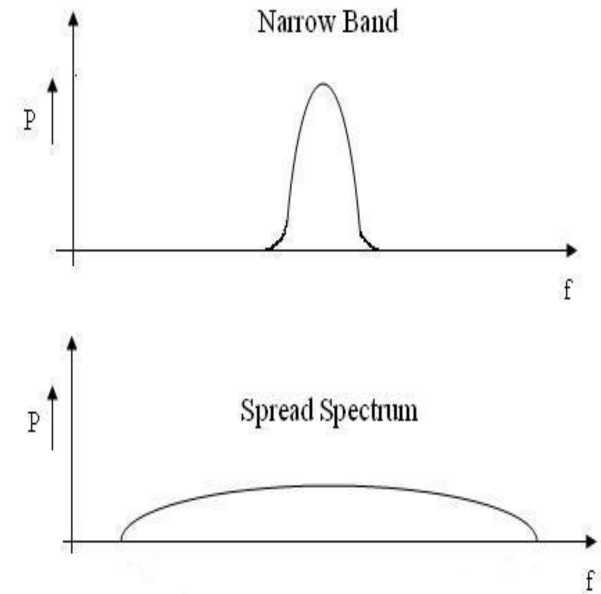
Principles of Spread Spectrum

- The basic principle of Spread Spectrum is to spread the bandwidth of the information signal to a it's several orders of magnitude **greater** than the minimum required signal bandwidth

- It converts the information signal as noise like signal. And noise like signals are less susceptible to narrowband interference

- Spread signals are much wider, they are transmitted in lesser power density.

- Lesser power means lesser energy, lesser interference and greater capacity



Feature of Spread Spectrum

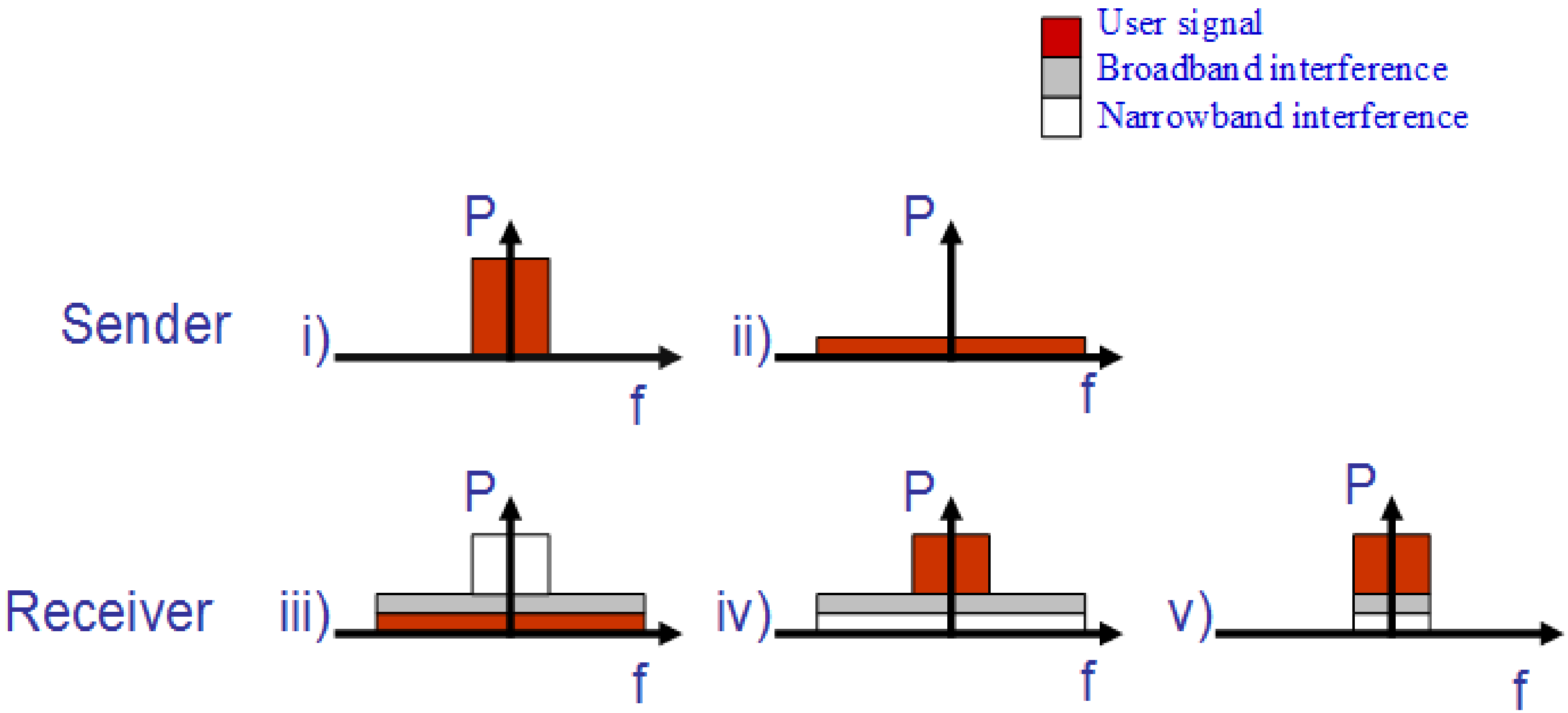
- Frequency range of the transmitted signal is deliberately varied, resulting in a much greater bandwidth than the signal would have if its frequency were not varied. Variation is done according to spreading sequences

- Power of the spread signal is the same as of the narrowband signal, resulting in a lower power spectral density (due to the higher bandwidth)

- Spread spectrum is very bandwidth **inefficient** for a single user

- But many users can **simultaneously** use the same bandwidth without significantly interfering with one another

Effects of spreading and interference



Classification

Direct Sequence Spread Spectrum (DSSS)

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- ❑Signal is spread before modulating it onto a carrier
- ❑ Each symbol is represented by a number of chips, resulting in a signal with a larger range of frequencies but with redundant data
- ❑ Spread signal is modulated onto a carrier signal with fixed carrier frequency

Frequency Hopping Spread Spectrum (FHSS)

- ❑ Signal is spread during modulation
- ❑ Carrier frequency is rapidly changed according to a hopping sequence

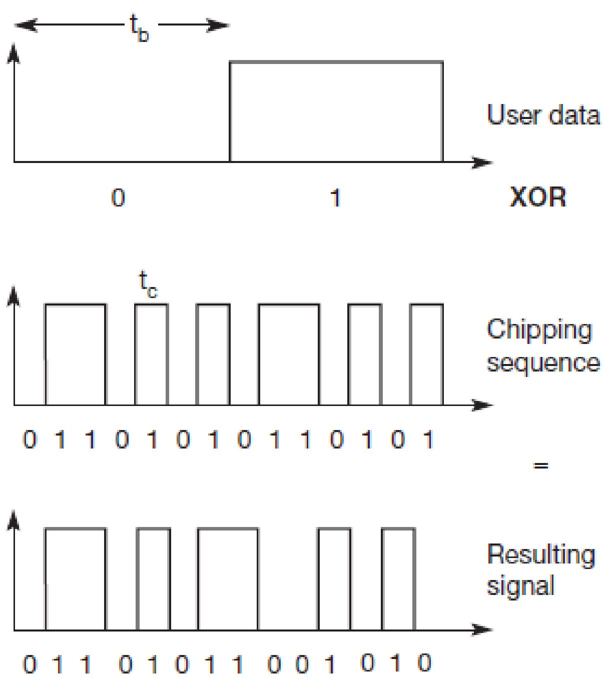
Direct Sequence Spread Spectrum (DSSS)

- DSSS systems take a user bit stream and perform an (XOR) with a so-called chipping sequence (the code) and transmit

- While each user bit has a duration tb, the chipping sequence consists of smaller pulses, called chips, with a duration tc.

- The **spreading factor s = tb/tc** determines the bandwidth of the resulting signal.

- If the original signal needs a bandwidth **w**, the resulting signal needs **s*w** after spreading



Direct Sequence Spread Spectrum (DSSS) Contd

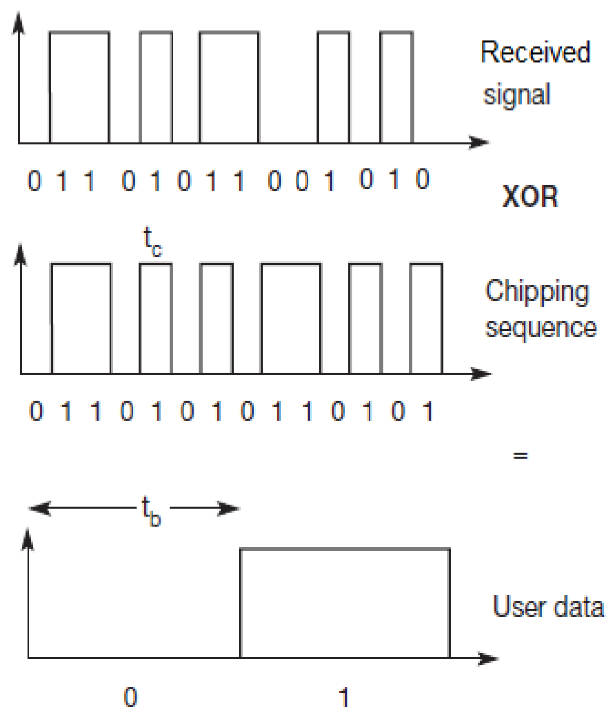
•Spreading Factor/Gain (Process Gain) = Chip Rate / Data Rate

❑In every system, the chip rate is fixed, hence data rate varies based on the size of spreading code

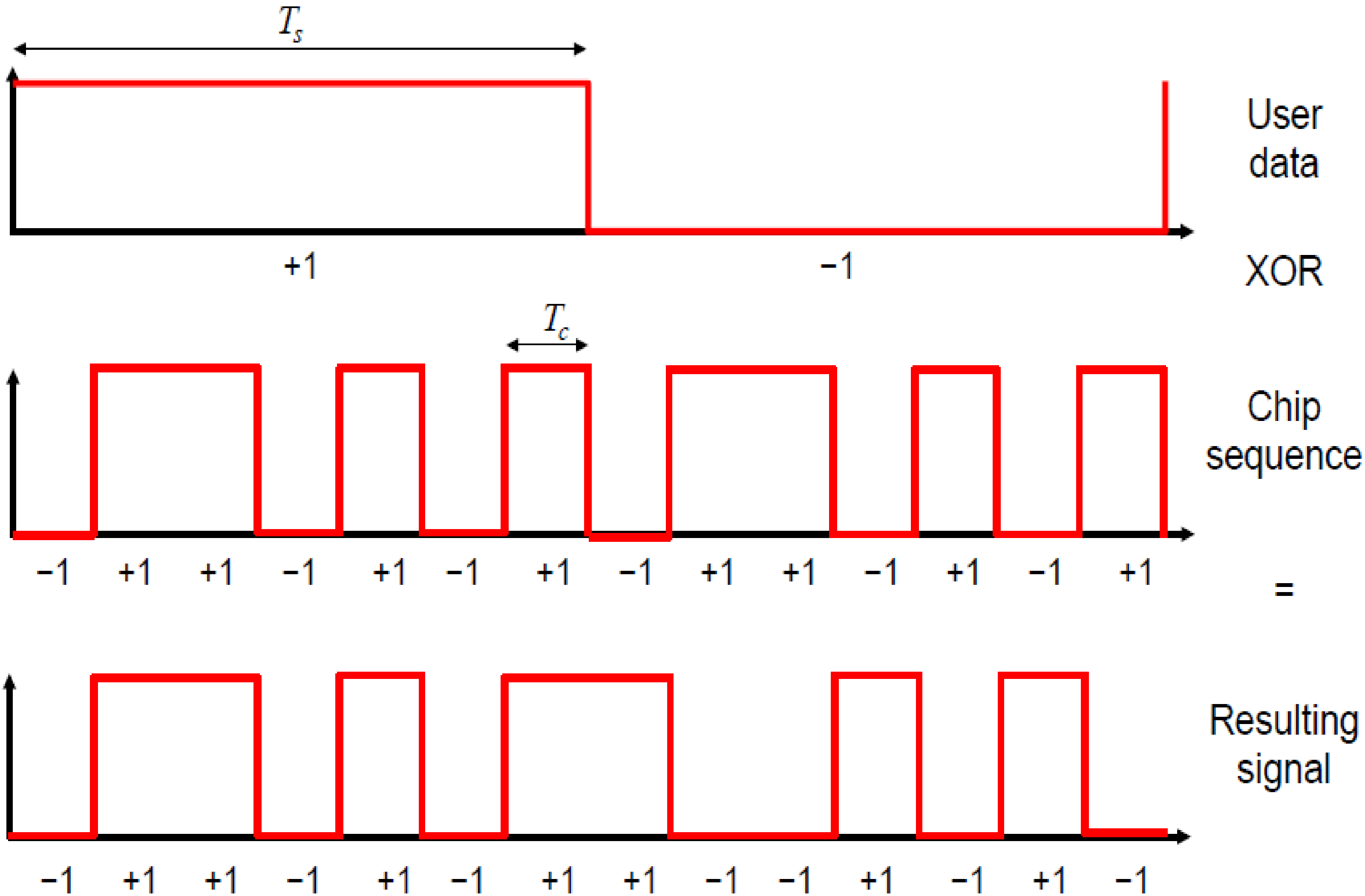
❑Such that higher the size of the code used for spreading, lower the data rate achieved.

❑At receiver, it takes the received chip stream and perform an (XOR) with a chipping sequence (the code) and generates the original user bit stream

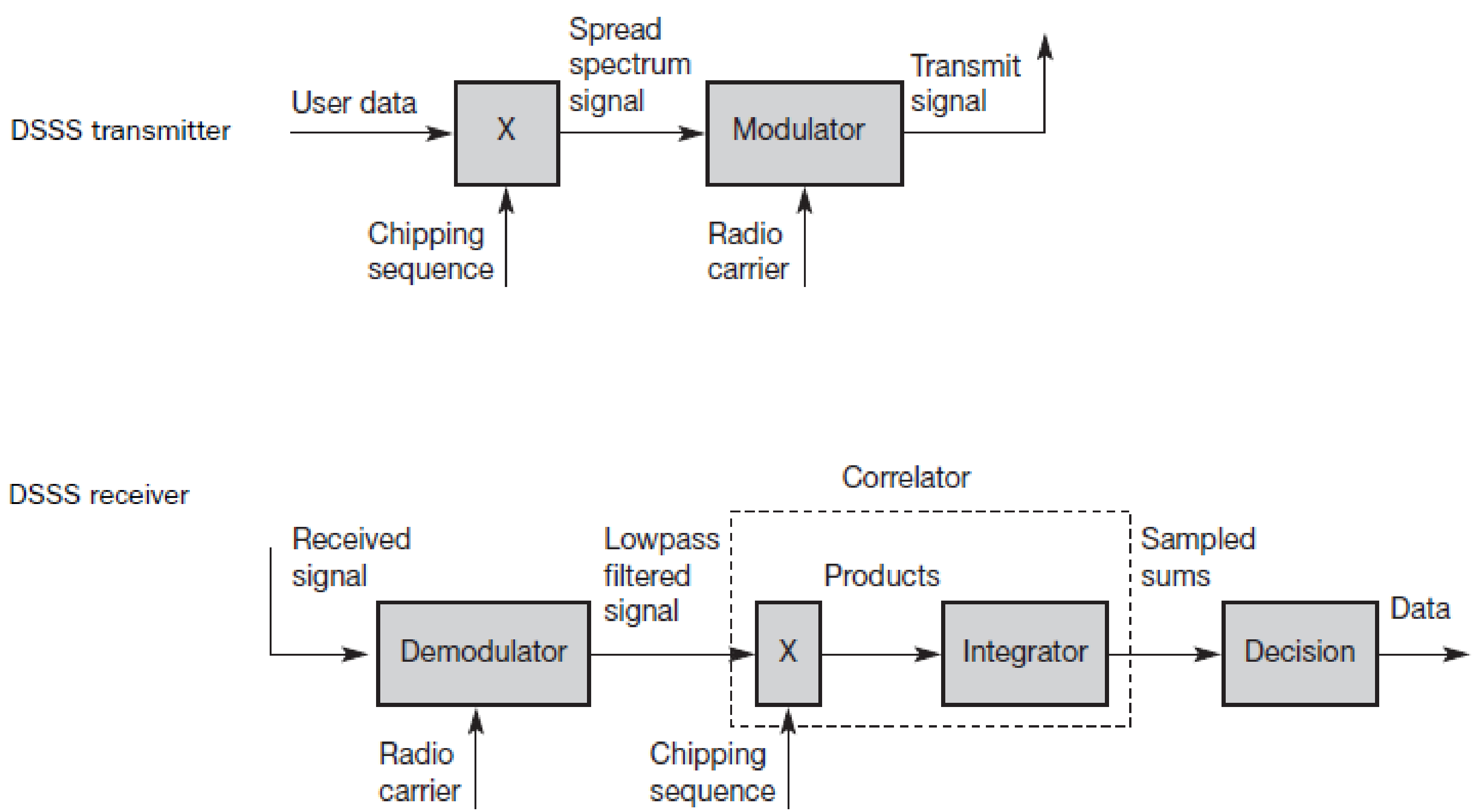
❑Hence sender and receiver has to be exact synchronization



DSSS Spreading with a Chip Sequence (bipolar representation)



DSSS Transmission and Reception process



Correlation of Code Sequences

Correlation:

- Concept of determining how much similarity one set of data has with another
- Correlation is defined with a range of between -1 and 1 with the following meanings

Correlation Value	Interpretation
1	The second sequence matches the first sequence exactly
0	There is not relation at all between the two sequences
-1	The two sequences are mirror images of each other

Note: A spread spectrum sequence should have good correlation properties

Correlation of Code Sequences Contd

Auto Correlation:

Correlation of a code sequence **Ci** of N elements with all phase shifts of itself

$$\Phi_{ii}[n] = \frac{1}{N}\sum_{m=1}^{N} c_i[m]c_i[m+n]$$

$$\text{with } n = 1..N$$

Cross Correlation:

Correlation of two code sequences Ci and Cj

$$\Phi_{ij}[n] = \frac{1}{N}\sum_{m=1}^{N} c_i[m]c_j[m+n]$$

$$\text{with } n = 1..N$$

Auto-correlation

- A code has a good auto-correlation if the inner product with itself is large and its inner product with the same, but shifted code is small
- Good auto-correlation is essential to achieve synchronization between sender and receiver

Example: **Barker code** +1,-1,+1,+1,-1,+1,+1,+1,-1,-1,-1

n	$c_i[0], c_i[0+n]$	$\Phi_{ii}[n]$
0	(+1, −1,+1,+1, −1,+1,+1,+1, −1, −1, −1) (+1, −1,+1,+1, −1,+1,+1,+1, −1, −1, −1)	1
1	(+1, −1,+1,+1, −1,+1,+1,+1, −1, −1, −1) (−1,+1,+1, −1,+1,+1,+1, −1, −1, −1,+1)	-1/11
2	(+1, −1,+1,+1, −1,+1,+1,+1, −1, −1, −1) (+1,+1, −1,+1,+1,+1, −1, −1, −1,+1, −1)	-1/11
...	...	...

The Barker code has good auto-correlation. This is used for spreading in 802.11

Cross-correlation

- Two codes have a low cross-correlation if their product is low for all shift combinations
- Low cross-correlation between a sequence and noise is useful to the receiver in filtering out noise
- Low cross-correlation between two sequences is useful to the receiver to discriminate among signals generated by different users
- If the cross-correlation between two sequences is **0**, the sequences are said to be **full orthogonal**

Cross-correlation between c1 and c2 is 4/8 = 0.5

$$
\begin{array}{cccccccccc}
 & c_1: & +1 & +1 & +1 & +1 & -1 & +1 & +1 & -1 \\
\oplus & c_2: & -1 & +1 & -1 & +1 & +1 & -1 & -1 & +1 \\
\hline
 & & -1 & +1 & -1 & +1 & -1 & -1 & -1 & -1 & =4
\end{array}
$$

*C3 and C4 is are **orthogonal**, because their cross-correlation is 0*

$$
\begin{array}{cccccccccc}
 & c_3: & -1 & -1 & -1 & +1 & +1 & -1 & +1 & +1 \\
\oplus & c_4: & -1 & -1 & +1 & -1 & +1 & +1 & +1 & -1 \\
\hline
 & & +1 & +1 & -1 & -1 & +1 & -1 & +1 & -1 & =0
\end{array}
$$

DSSS CDMA system

CDMA systems use codes with certain characteristics to separate different users in code space and to enable access to a shared medium without interference.

But how to find such good codes ?

These code for a certain user should have a **good auto-correlation** and should be **orthogonal** to other codes (**cross-correlation is 0**)

$$\sum_{k=0}^{M-1} c_i[k] c_i[k] = 1$$

$$\sum_{k=0}^{M-1} c_i[k] c_j[k] = 0 \quad \text{for } i \neq j$$

Note: For CDM, each quence as a spreading code, thereby providing zero cross correlations among all users.

Example of such codes are **Walsh codes, OVSF**(Orthogonal Variable Spreading Factor)

CDMA transmission and reception analogy

Tx 1 : Information Signal **S1**, Spreading Code **C1**. Transmits (**S1.C1**) over the air

Tx 2 : Information Signal **S2**, Spreading Code **C2**. Transmits (**S2.C2**) over the air

From Spreading code's auto-correlation and orthogonal property -

C1.C1 = 1

C2.C2 = 1

C1.C2 = 0

When signal transmitted from two source, over the air it becomes -

(S1.C1 + S2.C2)

Rx 1 : Despreading on reception **(S1.C1 + S2.C2).C1 = S1.C1.C1 + S2.C2.C1 = S1**

Rx 2 : Despreading on reception **(S1.C1 + S2.C2).C2 = S1.C1.C2 + S2.C2.C2 = S2**

Walsh Codes

- Set of Walsh codes of length n consists of the rows of a n×n Hadamard matrix

- Matrix is recursively defined as : $W_1 = (+1) \quad W_{2n} = \begin{pmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{pmatrix}$

  - Where n is the dimension of the matrix and the overscore denotes the logical NOT of the bits in the matrix

Example for n=2,4 :

$$W_2 = \begin{pmatrix} +1 & +1 \\ +1 & -1 \end{pmatrix} \qquad W_4 = \begin{pmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{pmatrix}$$

All users using a set of orthogonal codes must be synchronized, because the cross-correlation between different shifts of Walsh sequences is not zero (refer last two rows of W4 matrix)

IS-95 uses 64x64 Walsh code

Generating chip sequences using Walsh Code

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

$$W_1 = \begin{bmatrix} \mathbf{+1} \end{bmatrix}$$

$$W_2 = \begin{bmatrix} \mathbf{+1} & \mathbf{+1} \\ \mathbf{+1} & \mathbf{-1} \end{bmatrix}$$

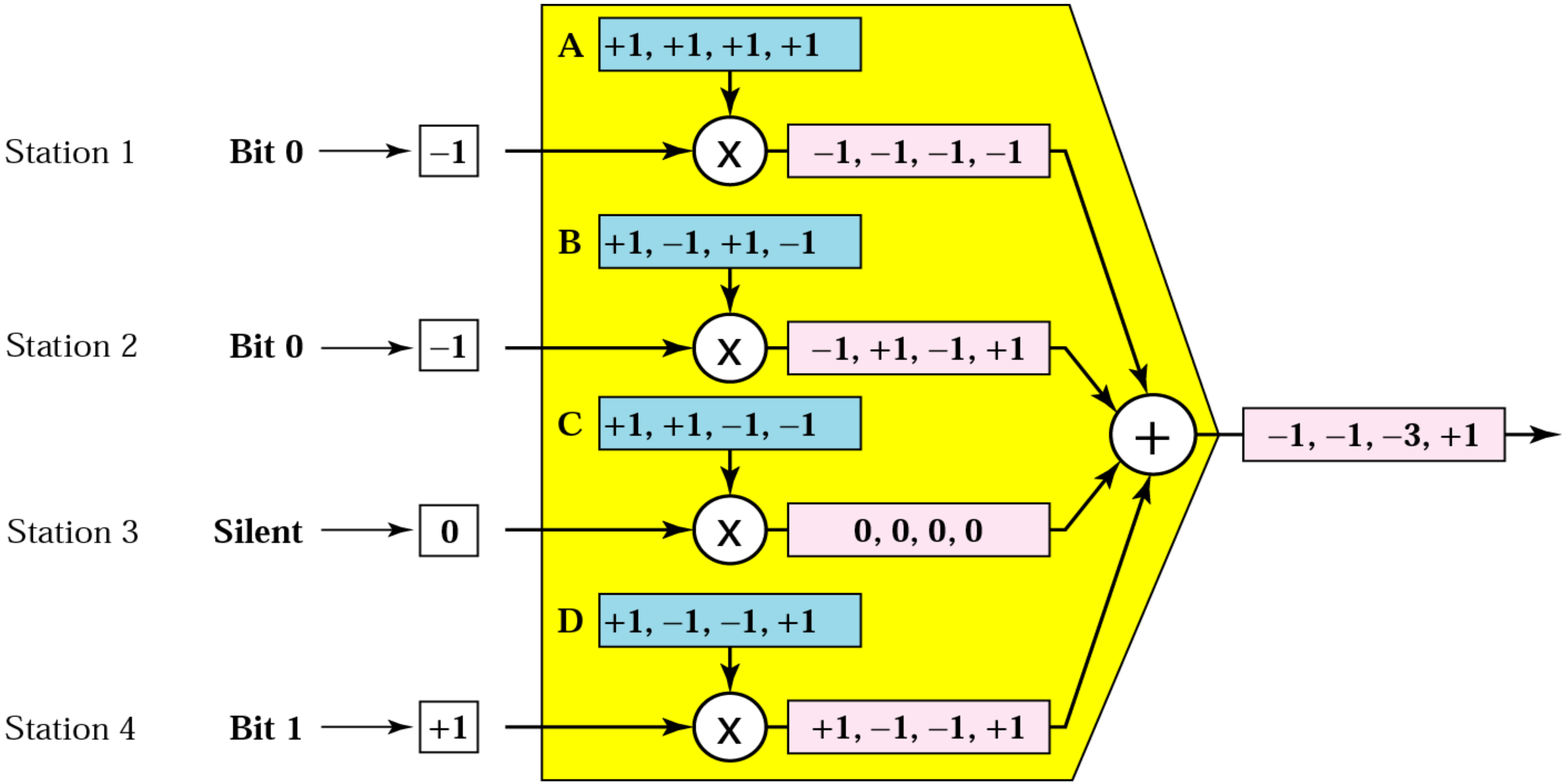
$$W_4 = \begin{bmatrix} \mathbf{+1} & \mathbf{+1} & \mathbf{+1} & \mathbf{+1} \\ \mathbf{+1} & \mathbf{-1} & \mathbf{+1} & \mathbf{-1} \\ \mathbf{+1} & \mathbf{+1} & \mathbf{-1} & \mathbf{-1} \\ \mathbf{+1} & \mathbf{-1} & \mathbf{-1} & \mathbf{+1} \end{bmatrix}$$

Orthogonal chip sequences

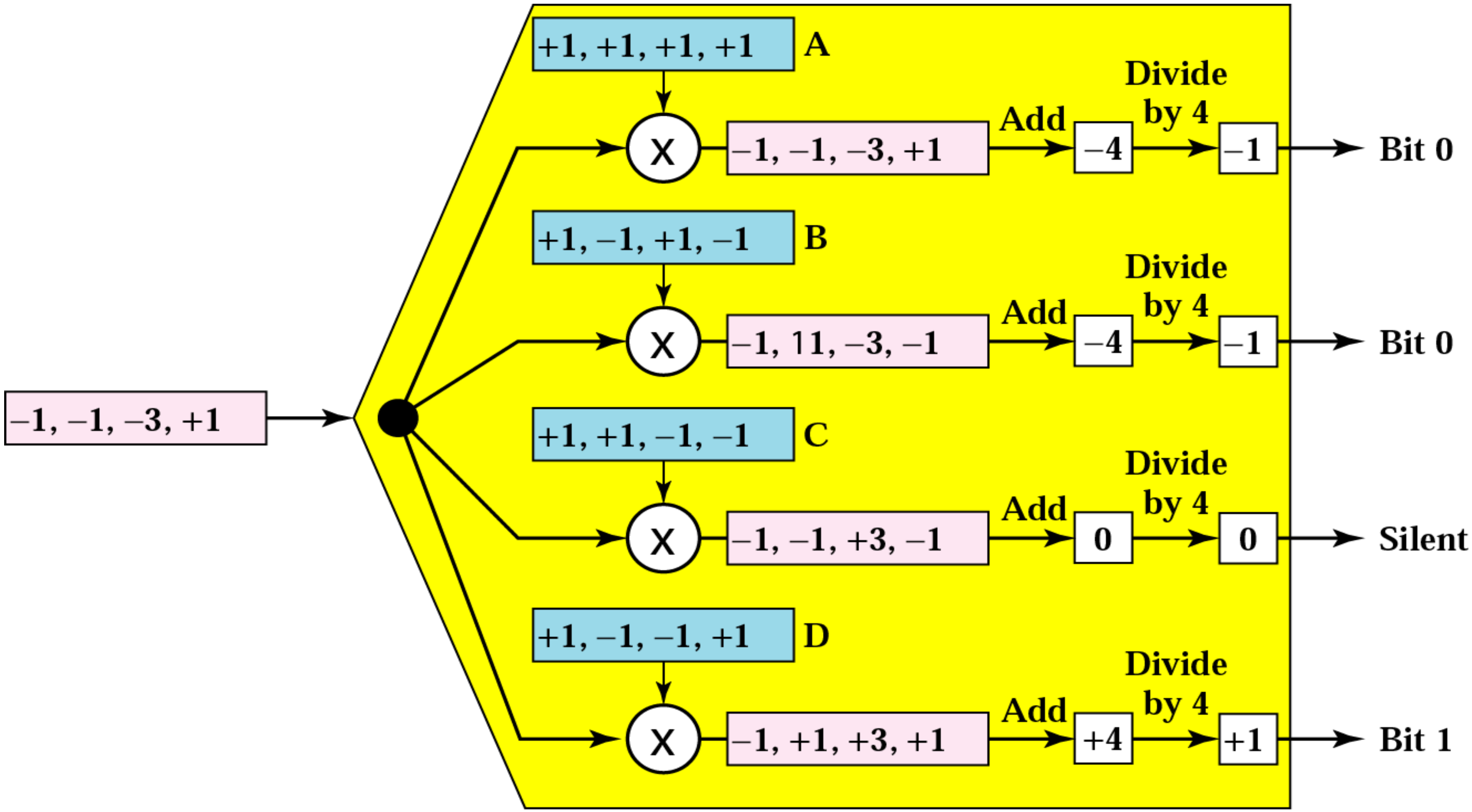
- Encoding rules:
  - If station has to send data bit 0: transmit signal -1
  - If station has to send data bit 1: transmit signal +1
  - If station does not have data to send: transmit signal 0

A	B	C	D
+1, +1, +1, +1	+1, −1, +1, −1	+1, +1, −1, −1	+1, −1, −1, +1

CDMA Multiplexer



CDMA De-Multiplexer



For your study

- ✓ Orthogonal Variable Spreading Factor (OVSF)
- ✓ Frequency Hopping Spread Spectrum (FHSS)

Reference

- *Mobile Communication, Jochen Schiller*
- *Data Communications & Networking, 5th Edition, Behrouz A. Forouzan*