# ΕΠΛ 427:
# ΚΙΝΗΤΑ ΔΙΚΤΥΑ ΥΠΟΛΟΓΙΣΤΩΝ
# (MOBILE NETWORKS)

**Δρ. Χριστόφορος Χριστοφόρου**

**Πανεπιστήμιο Κύπρου - Τμήμα Πληροφορικής**

Spread Spectrum Techniques (Τεχνικές Διασποράς Φάσματος)

# Topics Discussed



- Spread Spectrum Techniques
- Code Division Multiple Access (CDMA)

# Spread Spectrum Techniques Τεχνικές Διασποράς Φάσματος



- Spread Spectrum techniques **use a transmission bandwidth** that is **several orders of magnitude greater** than **the required bandwidth to spread the data (**Χρησιμοποιούν ένα εύρος ζώνης πολύ μεγαλύτερο από αυτό που πραγματικά χρειάζεται για διασπείρουν τα δεδομένα**).**

# Spread Spectrum Techniques
# Τεχνικές Διασποράς Φάσματος



- **Each bit** of the data that we want to transmit is **encoded** using **a sequence of digits (chips)** known as a **Spreading Code** → Κάθε bit των δεδομένων που θα διαδοθούν κωδικοποιείται χρησιμοποιώντας μια ακολουθία ψηφίων (τα ψηφία αυτά ονομάζονται **chips**) η οποία είναι γνωστή ως ο **Κώδικας Διασποράς**.
  - **Each bit (0 or 1)** that will be transmitted by the transmitter in the specific channel is encoded using the same **Spreading Code.**
  - During Spreading, data bit 0 is represented as -1 and data bit 1 is represented as +1.

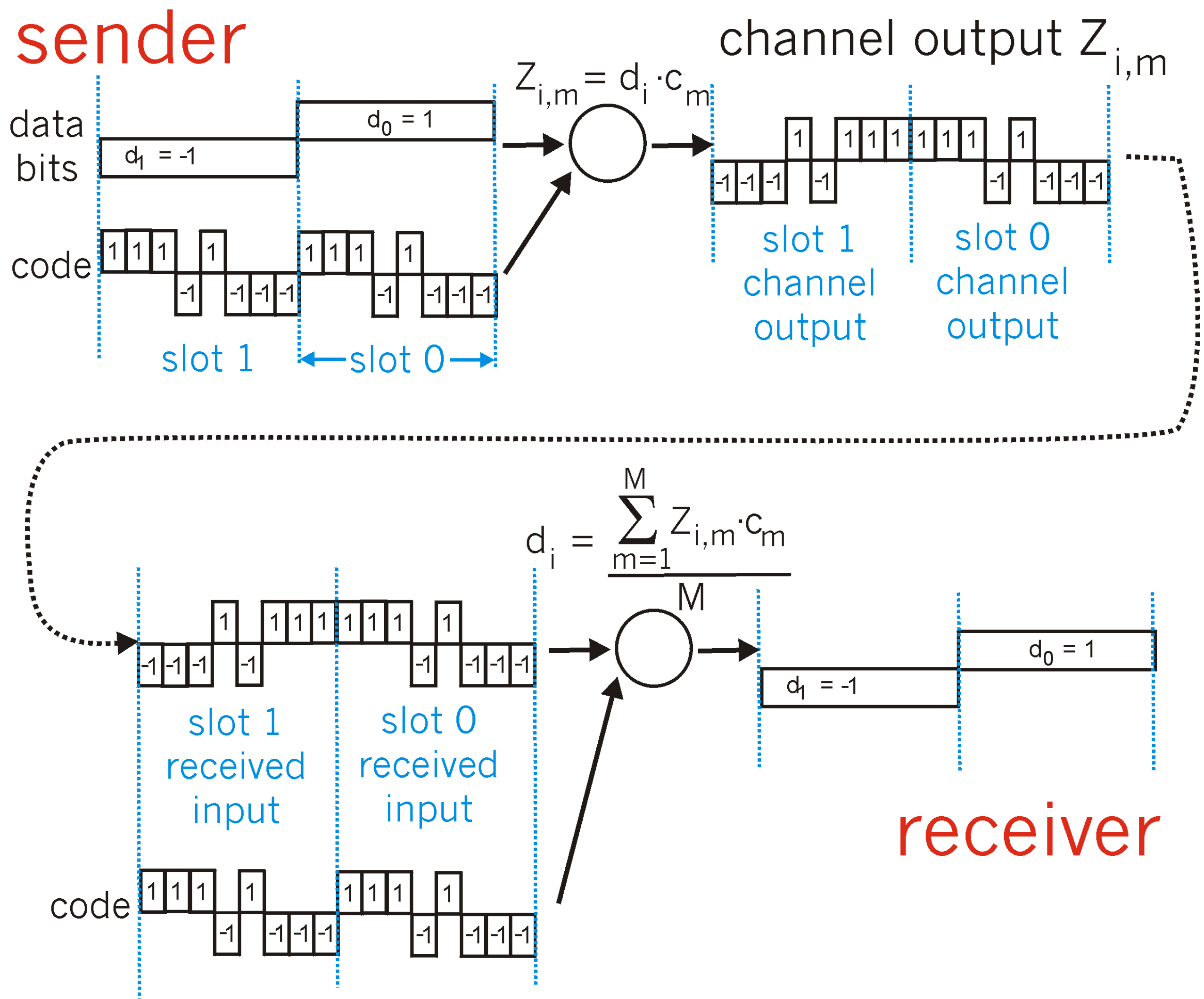
# Spread Spectrum Techniques
# Τεχνικές Διασποράς Φάσματος



Data bit 0 → -1

Data bit 1 → +1

**During Spreading, data bit 0 is represented as -1 and data bit 1 is represented as +1.**



# Spread Spectrum Techniques
# Τεχνικές Διασποράς Φάσματος



**Example:** We want to transmit **Data = (0, 1)** using the **Spreading Code = (1, 1, 1, -1, 1, -1, -1, -1)**

- Data = (-1, +1)

  Data bit 0 → -1

  Data bit 1 → +1

- **Bit 0** will be encoded and transmitted using the following **chip sequence**:
  - (-1).(1, 1, 1, -1, 1, -1, -1, -1) = **(-1, -1, -1, 1, -1, 1, 1, 1)**
- **Bit 1** will be encoded and transmitted using the following **chip sequence**:
  - (+1). (1, 1, 1, -1, 1, -1, -1, -1) = **(1, 1, 1, -1, 1, -1, -1, -1)**

# Spread Spectrum Techniques
# Spreading and Despreading



## Example: Spreading

| Step | Encode Sender (Spreading) |
|---|---|
| 0 | Spreading Code (SC) = (1, 1, 1, -1, 1, -1, -1, -1),<br>Data = (0, 1) → Data' (-1, +1) |
| 1 | Encode (Spread) Data' = ( (-1 . SC), (+1 . SC) ) =<br>((-1, -1, -1, 1, -1, 1, 1,1), (1, 1, 1, -1, 1, -1, -1,-1)) |
| 2 | Spread Data = (-1, -1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, -1, -1, -1) |

Data bit 0 → -1

Data bit 1 → +1

# Spread Spectrum Techniques
# Spreading and Despreading



- **The Receiver** will use the **same Spreading Code** to Despread (Decode) the chip sequence received.
- Example: The Receiver receives the chip sequence

  (-1, -1, -1, 1, -1, 1, 1, 1)

- Decoding of the chip sequence (applying dot product) using the Spreading Code (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) =
  - = (-8)

| | |
|---|---|
| If **decoded data < 0** | → Data bit **0** |
| If **decoded data > 0** | → Data bit **1** |
| If **decoded data == 0** | → **No data** |

# Spread Spectrum Techniques
# Spreading and Despreading



## Example: Despreading

| Step | Decode Receiver (Despreading) |
|---|---|
| 0 | **Spreading Code (SC)= (1, 1, 1, -1, 1, -1, -1, -1)**<br>**Received Spread Data (RSD) = (-1, -1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, 1, -1, -1, -1)** |
| 1 | **Decode = RSD . SC =**<br>**((-1, -1, -1, 1, -1, 1, 1, 1), (1, 1, 1, -1, 1, -1, -1, -1)) . (1, 1, 1, -1, 1, -1, -1, -1) =**<br>**((-1-1-1-1-1-1-1-1), (1, 1, 1, 1, 1, 1, 1,1))** |
| 2 | **Decoded Data' = ( -8 , 8 ) → Data (0, 1)** |

If **decoded data < 0** → Data bit **0**

If **decoded data > 0** → Data bit **1**

If **decoded data == 0** → **No data**

# Spread Spectrum Techniques
# Spreading Factor & Processing Gain



- As illustrated in the previous example, after despreading **the amplitude** of the signal **increases** by a **factor of 8** (**analogous to the length of the Spreading Code → this is called the Spreading Factor (SF)**)
- This effect is termed **'Processing Gain'** and is a **fundamental aspect** (είναι ένα θεμελιώδες στοιχείο) of all **Spread Spectrum** systems.

$$\textbf{Processing Gain}_{(dB)} = 10 \log_{10} (SF)$$

# Spread Spectrum Techniques
# Spreading Factor & Processing Gain



- In the previous example the **Processing Gain is 9dB** (**10 x $\log_{10}$(8)**) → This means that the **signal energy** can be **increased by 9dB** after despreading.

- Thus, assuming that the **minimum SNIR required by the Receiver (Demodulator) for decoding the signal correctly** is **5dB**, the **SNIR that the signal can have before despreading** is therefore **5 dB minus** the **Processing Gain** (i.e., **5dB – 9dB = – 4 dB**).

- **In other words, the signal power, can be 4 dB under the interference or thermal noise power, and the Receiver (Demodulator) can still decode the signal correctly.**

# Spread Spectrum Techniques Spreading Factor & Processing Gain



- The **number of chips that will be used (i.e., the length of the Spreading Code)** to spread one bit of data is defined by the **Spreading Factor**.
- The Spreading Factor is given by:

$$Spreading\_Factor = \frac{Chip\_Rate}{Bit\_Rate}$$

# Spread Spectrum Techniques
# Spreading Factor & Processing Gain



- Using **W-CDMA** (Wideband-Code Division Multiple Access, which is used in 3G Networks) we have **5Mhz** carrier bandwidth and a **Chip Rate of 3.84 Mcps** to Spread the data.
  - Note: **CDMA** uses a carrier bandwidth of **1.25 MHz** and a **Chip Rate of 1.22Mcps.**
- Thus, if we transmit a video clip with **Bit Rate of 128Kbps** the **Spreading Factor** will be:

$$Spreading\_Factor = \frac{3{,}840{,}000 chips/\sec}{128{,}000 bits/\sec} = 30$$

- **Each bit** will be **spread** using a **Spreading Code of length 30**.
- **Processing Gain = 10 x log$_{10}$(30) = 14.77 dB**

# Spread Spectrum Techniques
# Spreading Factor & Processing Gain



- **Processing Gain** allows the **received signal power** to be **under the interference or thermal noise power (i.e., improves reception)**, and the **Receiver can still detect the signal**.
  - **Detection of a Spread signal** is **difficult without knowledge** of the **Spreading Code**.
  - Spread Spectrum systems **originated** in **military applications** as it is very **difficult to interfere with** (πολύ δύσκολα παρεμβάλλεται) and **difficult to identify the signal** (πολύ δύσκολα αναγνωρίζεται η πληροφορία που μεταφέρει το σήμα) **without knowing** the **Spreading Code**.

# Spread Spectrum Techniques Advantages



- **Several advantages** can be gained from this **apparent waste of spectrum (από αυτή την προφανή "σπατάλη" του φάσματος)** by this approach:
  - The signals **gains immunity from various kinds of noise and interference** (Τα σήματα αποκτούν μεγαλύτερη ανοσία στο θόρυβο και στις παρεμβολές) – Due to the **Processing Gain** that can be achieved
    - The earliest applications of spread spectrum were military, where it was used for its **immunity to jamming** (ανοσία σε θόρυβο και παρεμβολές με σκοπό το μπλοκάρισμα των καναλιών).

# Spread Spectrum Techniques Advantages

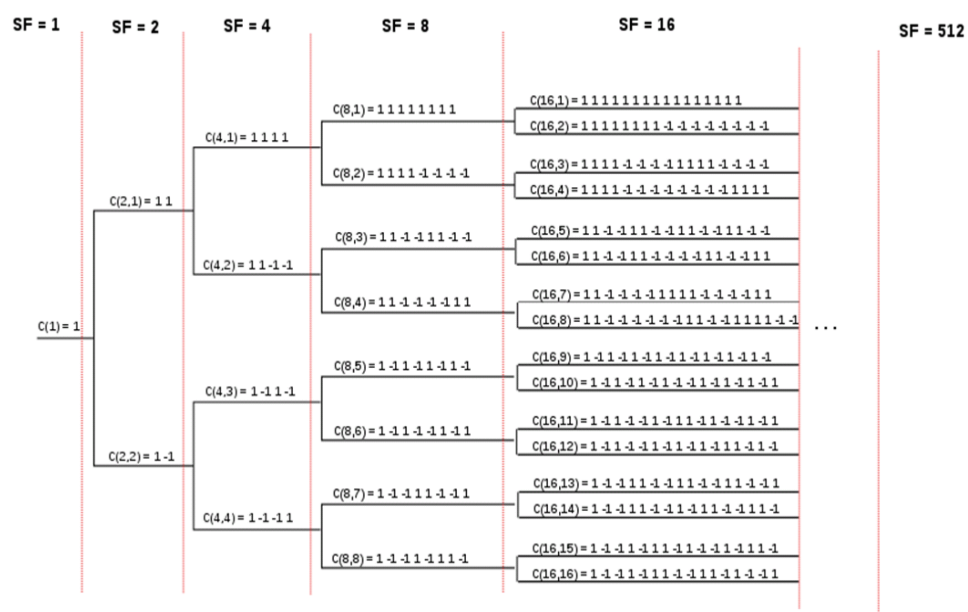


- It can also be used **for hiding and encrypting signals** (Χρησιμοποιούνται για **απόκρυψη** και **κρυπτογράφηση** των σημάτων).
  - Only a recipient who **knows the spreading code can recover the encoded** information.
- **Several users can independently use the same bandwidth at the same time** with **very little interference**.
  - This property is **used in cellular telephony applications (e.g., in UMTS Networks)**, with a technique known as **Code Division Multiple Access (CDMA)**.

# Code Division Multiple Access (CDMA)



- Divides up a radio channel **not by frequency** (as in FDMA), **not by time** (as in TDMA), but instead by using **Code Sequences (Spreading Codes)** for **each user**.
- **Guard Spaces (For keeping the different channels independent)** are realized **by using codes** with the necessary ‘distance’ in code space, e.g., **Orthogonal Codes**.
- These codes are derived from an **Orthogonal Variable Spreading Factor (OVSF)** code tree, and **each user is given a different, unique code**.

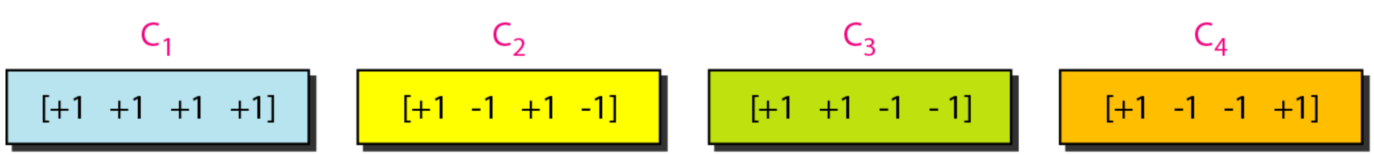


# Code Division Multiple Access



## Orthogonal Codes

- Orthogonal codes have a **cross-correlation equal to zero**; in other words, they **do not interfere with each other**
- Their **dot product** (*operation of vectors*) is **equal to zero**
- An example of orthogonal codes (vectors) is provided below:
  - C1 = (1, 1, 1, 1),
  - C2 = (1, -1, 1, -1),
  - C3 = (1, 1, -1, -1),
  - C4 = (1, -1, -1, 1),
- These vectors (codes) will be **assigned to individual users** and are called the **Spreading Codes**



# Code Division Multiple Access



- **Orthogonal Codes Examples:**
  - Question 1: Is SC1 = (1, -1, 1, -1) and SC2 = (1, 1, -1, -1), orthogonal?
  - Answer 1: For these two Spreading Codes to be orthogonal their dot product (SC1 . SC2) must be equal to 0.

$$(1, -1, 1, -1) \cdot (1, 1, -1, -1) = (+1 -1 -1 +1) = 0$$

Their dot product is equal to 0, therefore these two Spreading Codes are orthogonal

# Code Division Multiple Access



- **Orthogonal Codes Examples:**
  - Question 2: Is SC1 = (1, -1, 1, -1) and SC2 = (1, -1, -1, -1), orthogonal?
  - Answer 2: For these two Spreading Codes to be orthogonal their dot product (SC1 . SC2) must be equal to 0.

$$(1, -1, 1, -1) \cdot (1, -1, -1, -1) = (+1 +1 -1 +1) = +2$$

Their dot product is not equal to 0, therefore these two Spreading Codes are NOT orthogonal

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



- Each user is associated with a different Spreading Code, say **C**
- **During the Spreading of the Data bits:**
  - **Data bit 0** will be represented as **-1**
  - **Data bit 1** will be represented as **+1**
- For example:
  - **C = (1, -1, -1, 1)** (this is the **Spreading Code** and in this case the **Spreading Factor** is equal with **4**)
  - The **Data Bit Stream** (1, 0, 1, 1) would correspond to (C, -C, C, C)
  - The **Spread Data** will be:
    - ((1, -1, -1, 1), (-1, 1, 1, -1), (1, -1, -1, 1), ( 1, -1, -1, 1)).

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



- **Example of encoding (Spreading) and decoding (Despreading) a signal**
  - "**Sender 1**" has a
    - Spreading Code ($C_1$) = (1, -1, -1, 1)
    - Data ($D_1$) = (1, 0, 1, 1), and
  - "**Sender 2**"
    - Spreading Code ($C_2$) = (1, 1, -1, -1)
    - Data ($D_2$) = (0, 0, 1, 1), and
  - Both senders **transmit simultaneously**

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



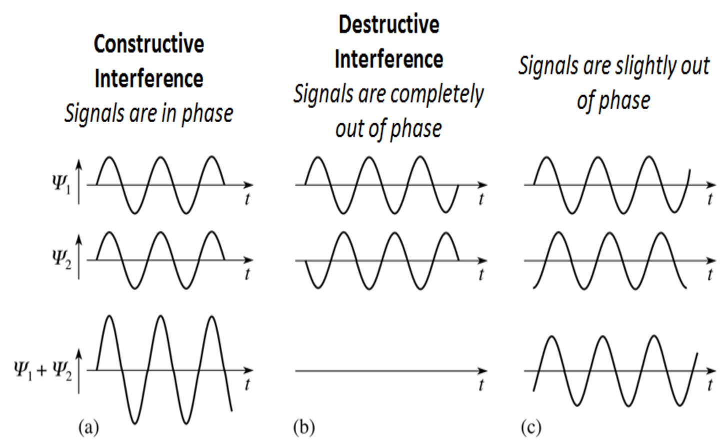
| Step | Encode Sender 1 (Spreading) |
|---|---|
| 0 | $C_1 = (1, -1, -1, 1)$, $D_1 = (1, 0, 1, 1)$ |
| 1 | Encode 1 = $(C_1, -C_1, C_1, C_1)$ = $((1, -1, -1, 1),(-1, 1, 1, -1),(1, -1, -1, 1),(1, -1, -1, 1))$ |
| 2 | Spread Signal 1 = $(1, -1, -1, 1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, -1, 1)$ |

| Step | Encode Sender 2 (Spreading) |
|---|---|
| 0 | $C_2 = (1, 1, -1, -1)$, $D_2 = (0, 0, 1, 1)$ |
| 1 | Encode 2 = $(-C_2, -C_2, C_2, C_2)$ = $((-1, -1, 1, 1),(-1, -1, 1, 1), (1, 1, -1, -1), (1, 1, -1, -1))$ |
| 2 | Spread Signal 2 = $(-1, -1, 1, 1, -1, -1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1)$ |

# Code Division Multiple Access -
## Example of Spreading and Despreading a Signal



- *The physical properties of interference say that if two signals at a point are in phase, they will "add up" to give twice the amplitude of each signal, but if they are out of phase, they will "subtract" and give a signal that is the difference of the amplitudes.*




- *Because Signal 1 and Signal 2* ***are transmitted at the same time using the same frequency band****, we'll add them together to model the* ***raw signal*** *in the air. This raw signal may be called an* ***Interference Pattern****.*
- **Interference Pattern**:

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | 0 | -2 | 0 | 2 | -2 | 0 | 2 | 0 | 2 | 0 | -2 | 0 | 2 | 0 | -2 | 0 |

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



- **Question:** How does a Receiver make sense of this Interference Pattern?

- **Answer:** The receiver **knows the Spreading Codes of the senders.** Using these Spreading Codes on the received interference pattern can extract an intelligible signal for any known sender.

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



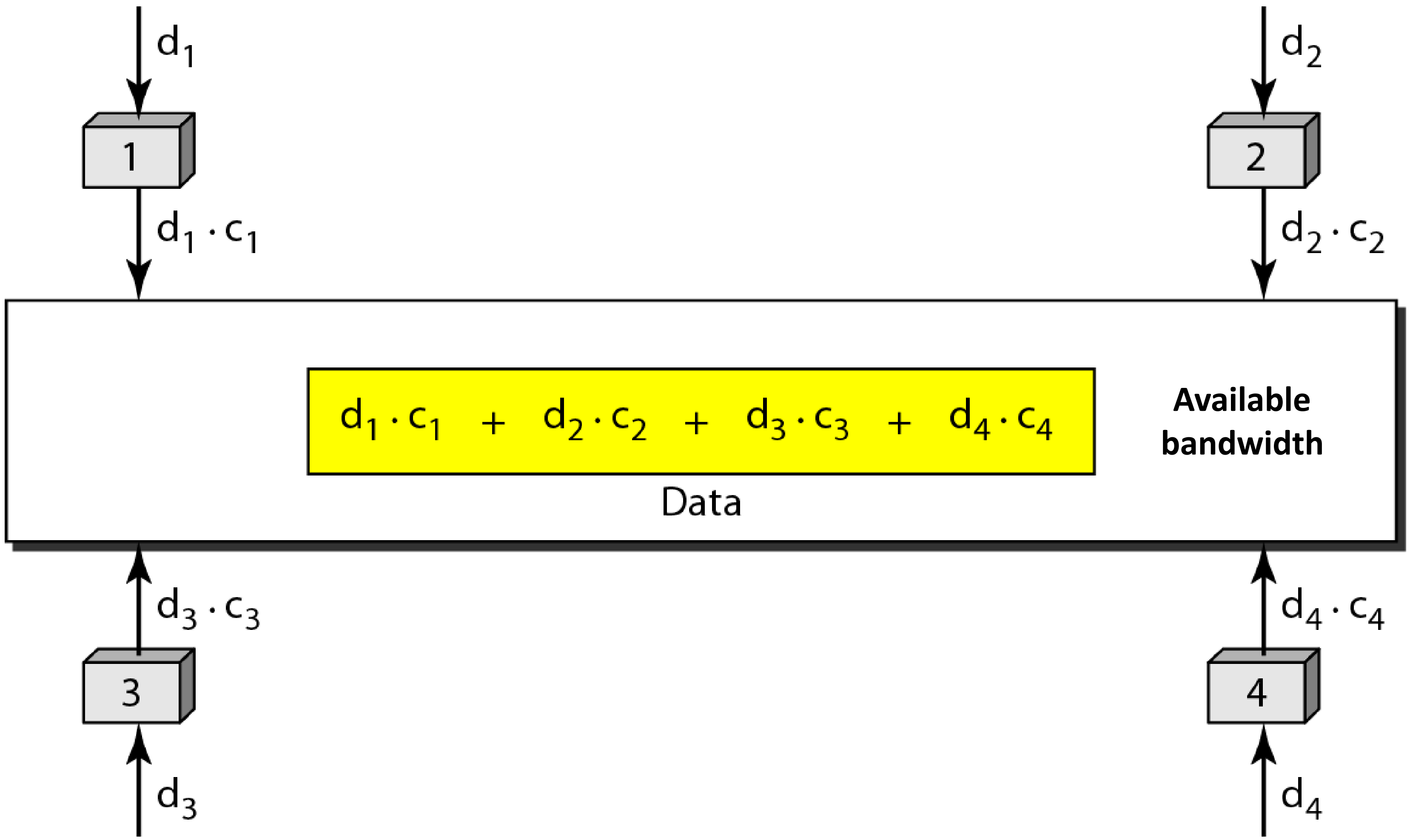
| Step | Decode Sender 1 (Despreading) |
|---|---|
| 0 | $C_1 = (1, -1, -1, 1)$,<br>**Interference Pattern = (0, -2, 0 ,2, -2, 0, 2, 0, 2, 0, -2, 0, 2, 0, -2, 0)** |
| 1 | Decode 1 = Interference_Pattern . $C_1$ =<br>**((0, -2, 0, 2), (-2, 0, 2, 0), (2, 0, -2, 0), (2, 0, -2, 0))**.(1, -1, -1, 1) =<br>((0 + 2 + 0 + 2), (-2 + 0 - 2 + 0), (2 + 0 + 2 + 0), (2 + 0 + 2 + 0)) |
| 2 | **Data 1 = (4, -4, 4, 4) = (1, 0, 1, 1)** |

| Step | Decode Sender 2 (Despreading) |
|---|---|
| 0 | $C_2 = (1, 1, -1, -1)$,<br>**Interference Pattern = (0, -2, 0 , 2, -2, 0, 2, 0, 2, 0, -2, 0, 2, 0, -2, 0)** |
| 1 | Decode 1 = Interference_Pattern . $C_2$ =<br>**((0, -2, 0, 2),(-2, 0, 2, 0),(2, 0, -2, 0),(2, 0, -2, 0))**.(1, 1, -1, -1) =<br>((0 - 2 + 0 - 2), (-2 + 0 - 2 + 0), (2 + 0 + 2 + 0), (2 + 0 + 2 + 0)) |
| 2 | **Data 2 =(-4, -4, 4, 4) = (0, 0, 1, 1)** |

# Code Division Multiple Access

## Example of Spreading and Despreading a Signal

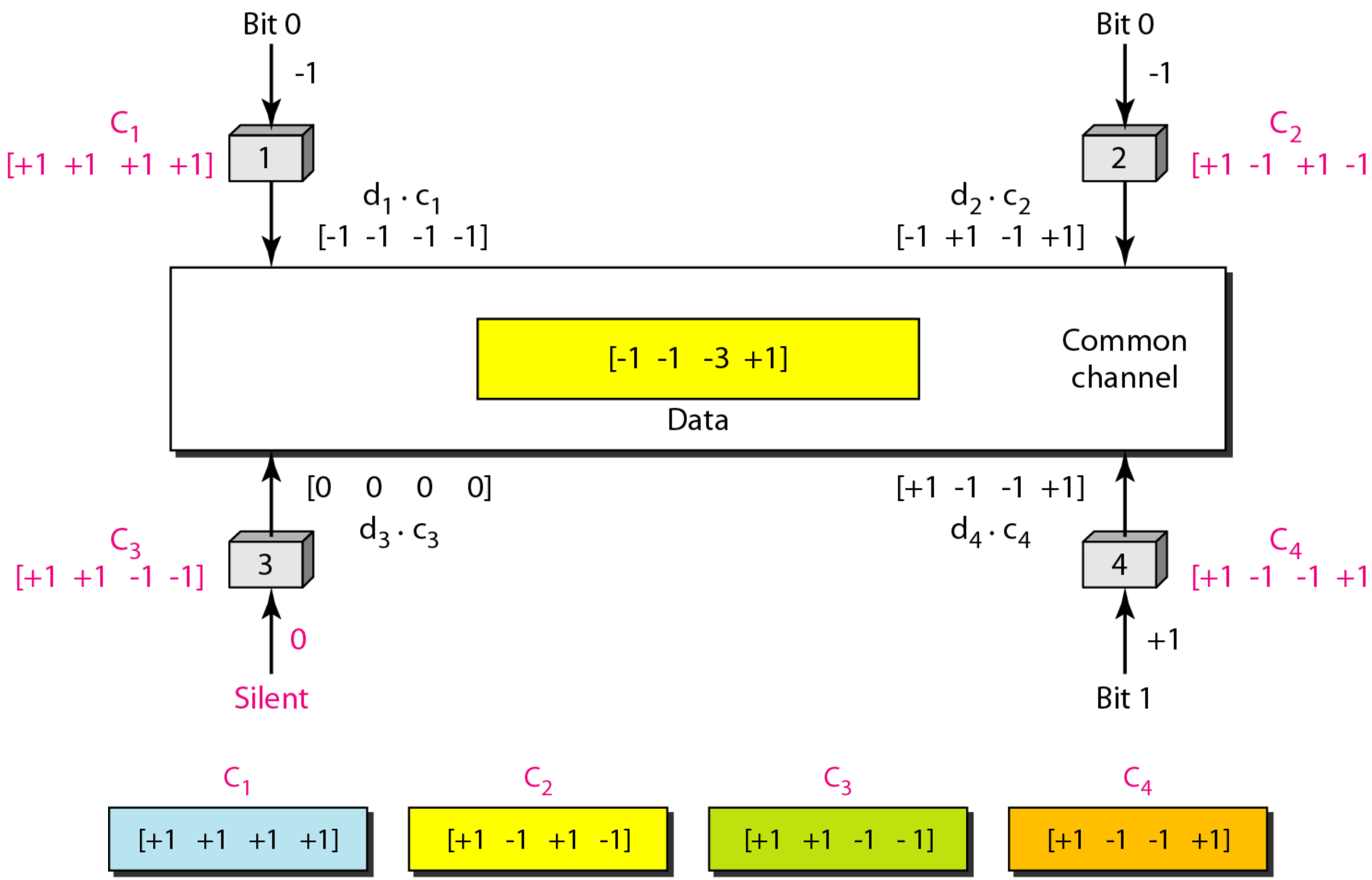




# Code Division Multiple Access -

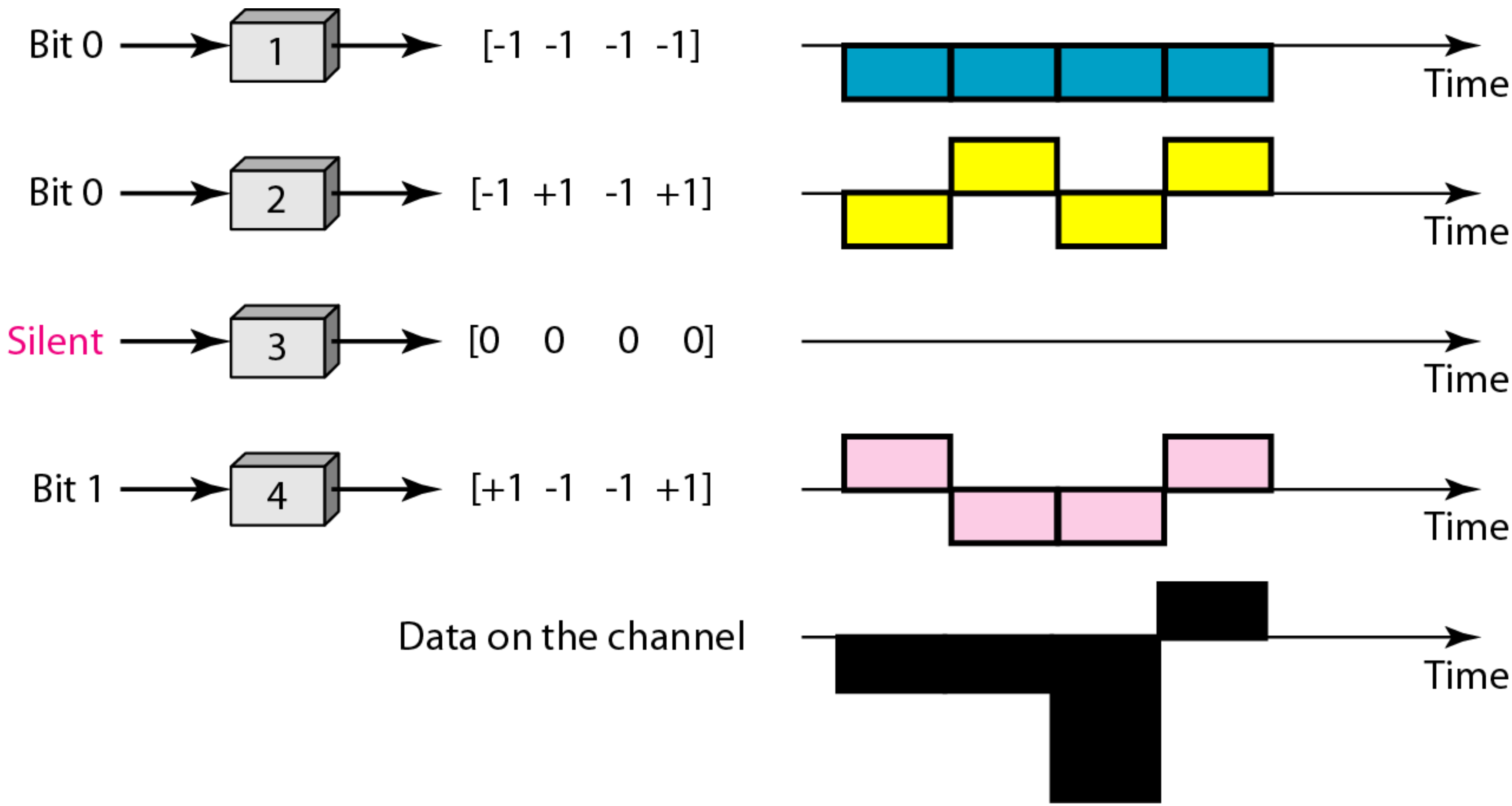
## Example of Spreading and Despreading a Signal





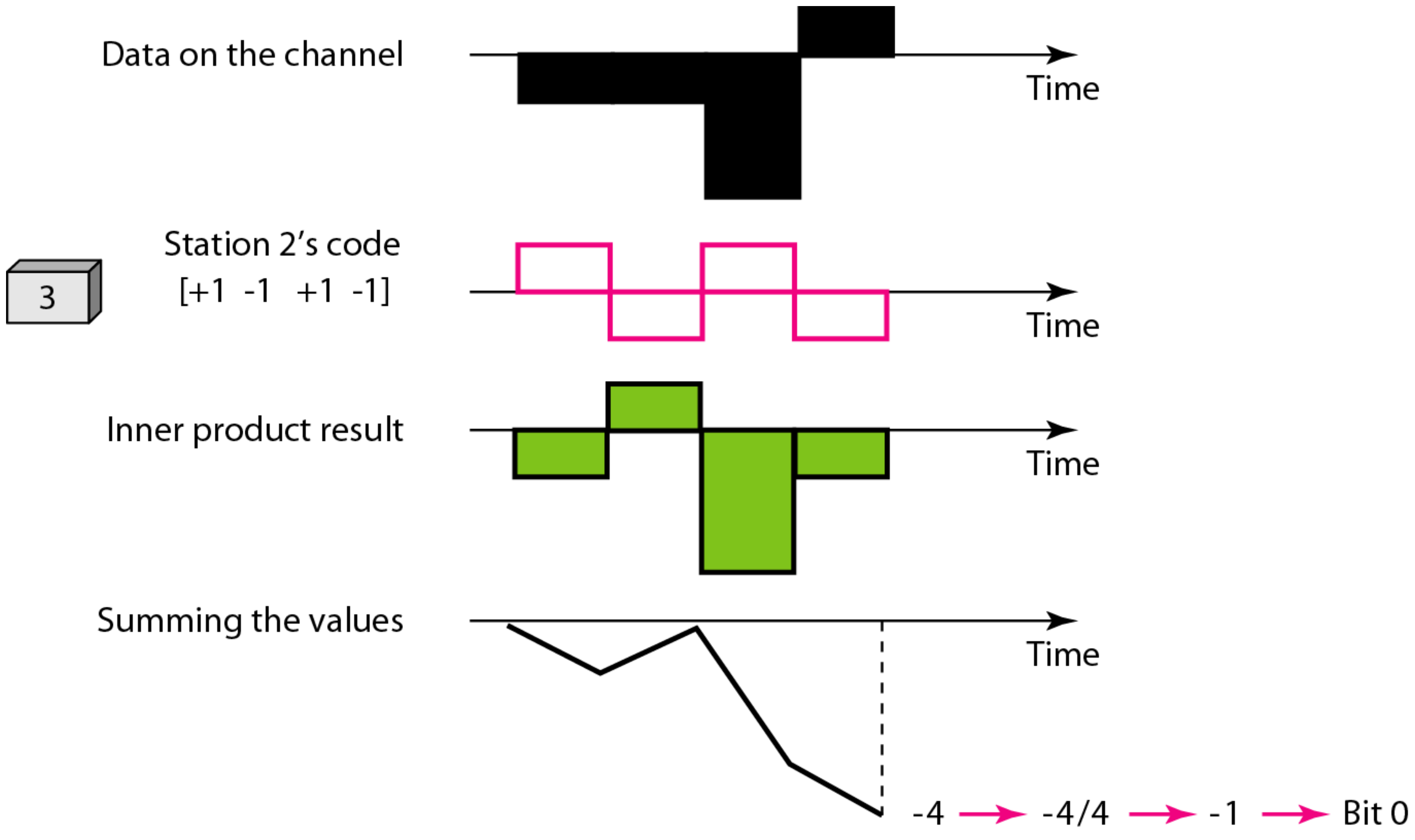
# Code Division Multiple Access - Example of Spreading and Despreading a Signal





# Code Division Multiple Access - Example of Spreading and Despreading a Signal



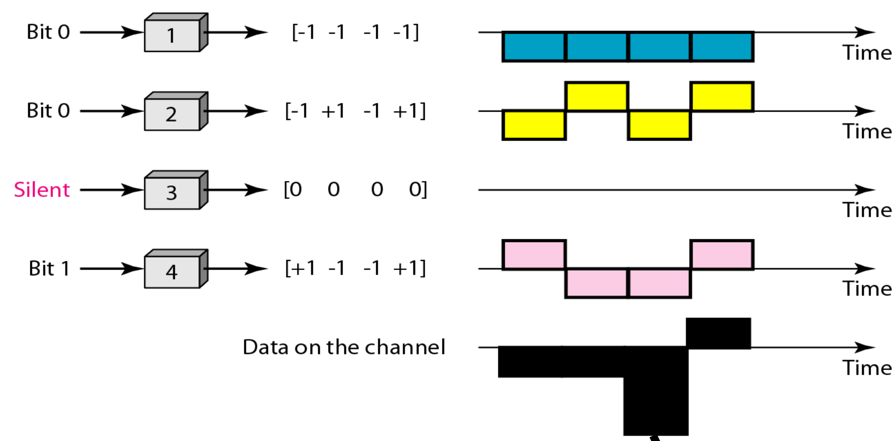


# Code Division Multiple Access -
## Example of Spreading and Despreading a Signal



- **Question:** In the example provided in the previous slides, Station 3 (S3) did not send any data to the channel. What will happen when the receiver, during Despreading, correlates the Spreading Code of S3 on the Interference Patter (i.e., the data on the channel)?

- **Answer:** When the receiver correlates the interference pattern with the Spreading Code of S3, the summing of the values of the despread signal will be equal to 0 → **Thus no data are included in the channel for S3.**




***For example:***

***Interference Pattern: (-1, -1, -3, 1)***

***S3 → $C_3$ = (1, 1, -1, -1)***

***Despreading of S3:***

***(-1, -1, -3, 1) . (1, 1, -1, -1) =***

***= -1 -1 + 3 -1 = -3 + 3 = 0 → No Data***

# Code Division Multiple Access -
## Example of Spreading and Despreading a Signal



- **FOR HOME PRACTICE → Example of encoding (Spreading) and decoding (Despreading) a signal with 4 users →**
  - "**Sender 1**" has a
    - Spreading Code ($C_1$) = (1, 1, 1, 1), Data ($D_1$) = (0, 0)
  - "**Sender 2**"
    - Spreading Code ($C_2$) = (1, -1, 1, -1), Data ($D_2$) = (0, 1)
  - "**Sender 3**"
    - Spreading Code ($C_3$) = (1, 1, -1, -1), Data ($D_3$) = (1, 0)
  - "**Sender 4**"
    - Spreading Code ($C_4$) = (1, -1, -1, 1), Data ($D_4$) = (1, 1)
  - All senders **transmit simultaneously**

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



- **Example of encoding (Spreading) and decoding (Despreading) a signal with 4 users,**
  - **"Sender 1" Spread Signal**:
    - (-1, -1, -1, -1, -1, -1, -1, -1)
  - **"Sender 2" Spread Signal:**
    - (-1, 1, -1, 1, 1, -1, 1, -1)
  - **"Sender 3" Spread Signal:**
    - (1, 1, -1, -1, -1, -1, 1, 1)
  - **"Sender 4" Spread Signal:**
    - (1, -1, -1, 1, 1, -1, -1, 1)

  - **Interference Pattern (We add all the signals together)**
    - **(0, 0, -4, 0, 0, -4, 0, 0)**

# Code Division Multiple Access - Example of Spreading and Despreading a Signal



- **Example of encoding (Spreading) and decoding (Despreading) a signal with 4 users (Interference Pattern: (0, 0, -4, 0, 0, -4, 0, 0))**
-
  - **"Sender 1" Despread Signal ($C_1$ = (1, 1, 1, 1))**
    - ((0, 0, -4, 0), (0, -4, 0, 0)) . (1, 1, 1, 1) = (-4, -4) → **Data (0, 0)**
  - **"Sender 2" Despread Signal** (**$C_2$ = (1, -1, 1, -1)**)
    - ((0, 0, -4, 0), (0, -4, 0, 0)). (1, -1, 1, -1) = (-4, +4) → **Data (0, 1)**
  - **"Sender 3" Despread Signal** (**$C_3$ = (1, 1, -1, -1)**)
    - ((0, 0, -4, 0), (0, -4, 0, 0)) . (1, 1, -1, -1) = (+4, -4) → **Data (1, 0)**
  - **"Sender 4" Despread Signal** (**$C_4$ = (1, -1, -1, 1)**):
    - ((0, 0, -4, 0), (0, -4, 0, 0)) . (1, -1, -1, 1) = (+4, +4) → **Data (1, 1)**

# Code Division Multiple Access



- In contrast with FDMA and TDMA which are **bandwidth and time limited**, CDMA is **interference limited**.
- Because **all users transmit on the same frequency and at the same time, internal interference generated by the users (related to the transmission power used by each one of them)** is the **most significant factor** in **determining system capacity** and **call quality**.
  - **Each user** is a **source of interference to all the other users** in the cell.

# Code Division Multiple Access

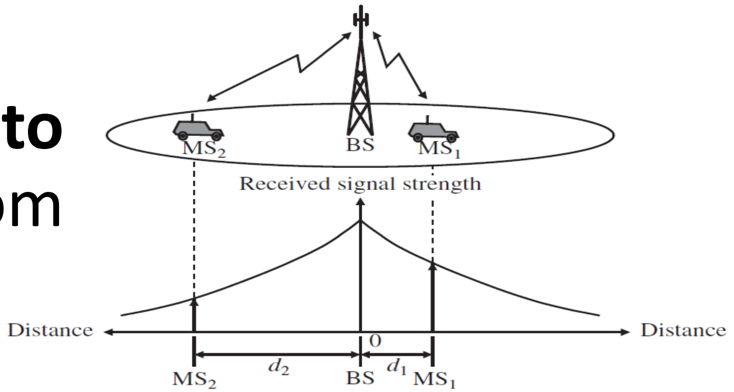


- To increase capacity, the **transmit power for each user** must be **reduced to limit interference**.
- However, **the Received signal power (at the BS) should be enough to maintain the minimum required *SNIR needed by the Receiver, so as to decode the signal (symbol) correctly,*** for a **satisfactory call quality**.
- Thus, the goal is **all MSs' transmitted signals to reach the Base Station and received with about the same signal power (and equal to the minimum required SNIR) from the BS → Otherwise some signals could drown others**.

# Code Division Multiple Access
# Near Far Problem



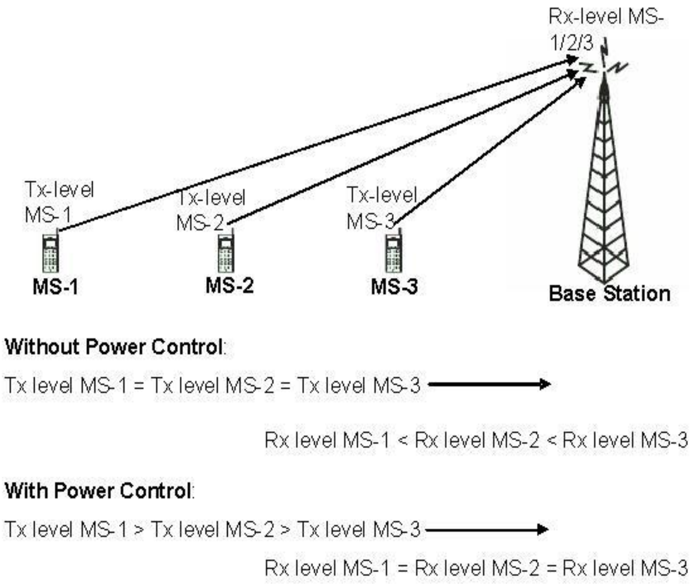
- If all **MSs transmit with the same power**, **signals** transmitted from **MSs closest to the BS** will be **received with much larger power** than **signals** from **MSs further away**.
  - Due to the difference in the **path lengths higher propagation path loss** is **experienced** for **users further away from the BS.**
  - The **received SNIR for signals transmitted from MSs far from the BS will be low**.
- Thus, **signals** from **MSs close to the BS** will **drown out signals** from **MSs far away from the BS.**
- **Solution: Power Control!!!**



# Code Division Multiple Access
# Near Far Problem – Power Control



- **Power control is essential** in order to **maintain the transmission power levels used by the MSs to the lowest level necessary → Reduce interference to the minimum** and **maximize the capacity of the system**.




***One of the main objectives of Power Control is to ensure that the power of all signals received at the BS is almost equal and at a lowest level aiming to reduce the interference to the minimum, however adequate for the Receiver to be able to decode the signal correctly (i.e., received signal SNIR ≈ minimum required SNIR).***

# Ερωτήσεις;

# Additional Slides

# Spread Spectrum Techniques
# Τεχνικές Διασποράς Φάσματος

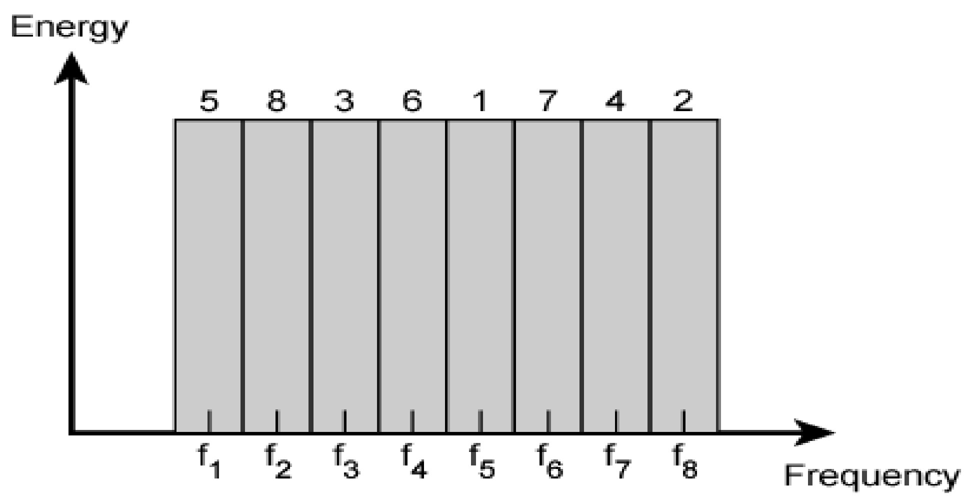


- The first type of spread spectrum developed is known as **Frequency Hopping (FH)**.
- A more recent type of spread spectrum is **Direct Sequence (DS)**.
- Both of these techniques are used in various wireless communications standards and products.

# Frequency Hopping Spread Spectrum (FHSS)



- When using **FHSS**, the available **Frequency Spectrum (bandwidth)** is **divided into channels (**Το διαθέσιμο εύρος ζώνης διαιρείται σε κανάλια μικρότερου εύρους**)**.

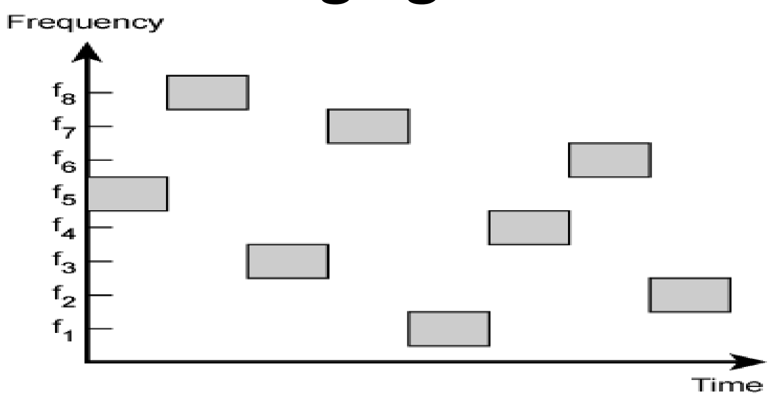



(a) Channel assignment

# Frequency Hopping Spread Spectrum (FHSS)



- **Data are transmitted (spread) on these channels** in a **random pattern (**με ένα τυχαίο μοτίβο**)** (this random pattern is defined by a **Hopping sequence Table) generated by a pseudorandom algorithm known only** to the **Transmitter** and **Receiver**.
  - The **Transmitter** transmits data on one frequency channel **for a certain time**, then **randomly jumping (hopping) to another**, and **transmitting again**.
  - The **Receiver, hopping between frequencies in synchronization (**σε συγχρονισμό**)** with the **Transmitter, picks up the message**.




(b) Channel use

# Frequency Hopping Spread Spectrum (FHSS)



- Because **collocated FHSS networks** follow different random patterns, **multiple systems/networks can operate in close proximity** with a minor possibility of interfering **(**Επειδή συνορεύοντα FHSS δίκτυα **ακολουθούν διαφορετικά τυχαία μοτίβα αναπήδησης** μπορούν να λειτουργήσουν σε κοντινές αποστάσεις με ελάχιστη πιθανότητα να προκαλούν παρεμβολές το ένα στο άλλο**)**.
- If interference is present **on one channel**, **data** transmission is blocked **(i.e., the data is lost)**.
  - The **Transmitter** and the **Receiver** will **'hop' to the next channel** in the Hopping Sequence Table and the Transmitter will resend the data again.

# Frequency Hopping Spread Spectrum (FHSS)



- **Advantages of FHSS**:
  - **Allows a number of FHSS systems/networks to operate in close proximity in the same geographic area** with a **minor possibility of interfering**.
  - **Eavesdroppers that do not know the hopping sequence** will **“hear” only unintelligible blips (ακατανόητους στιγμιαίους ήχους)**.
  - **Attempts to jam the signal** on **one frequency channel** will **affect only a few bits**.

# Frequency Hopping Spread Spectrum (FHSS)



- **Disadvantages of FHSS**:
  - It has a relatively **low transfer limit**, since only a specific amount of information can be sent over any given frequency channel (e.g., in the case of Bluetooth only 1 MHz of bandwidth can be used to spread the data at each hop)
  - There is **no built in redundancy** or **error checking**, which means that **once there is a certain critical limit of 'bad' channels**, **FHSS becomes nearly unusable →** Too many bits come out corrupted.

# Frequency Hopping Spread Spectrum (FHSS)



- Due to the **need for rapidly switching** between different channels **(hardware complexity)**, and the **low data transfer limitation**, FHSS is **not widely implemented** in today's **WLAN or cellular systems,** however **Bluetooth (WPAN) does use FHSS.**
  - Bluetooth divides the available bandwidth into **79 channels** of **1Mhz** each.
    - The first channel starts at 2,402 MHz and continues up to 2,480 MHz in 1 MHz steps.
  - It performs **1600 hops per second →** ~0.625 ms per time slot

# Direct Sequence Spread Spectrum (DSSS)

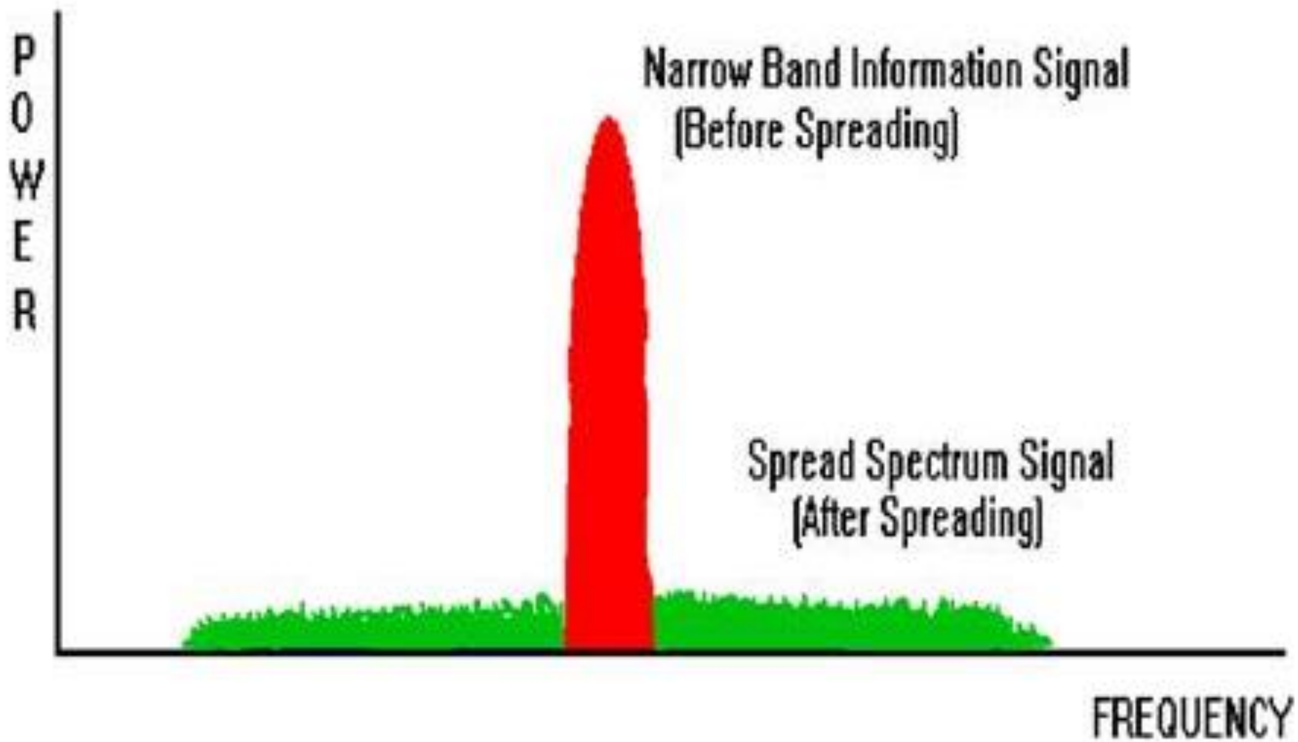


- The **DSSS** encoder **spreads the data** across **a broad range of frequencies (**διασπείρει τα δεδομένα σε ένα ευρύ φάσμα συχνοτήτων**; usually in the whole available bandwidth)** using the **Spreading Code**.
  - The **higher the Bandwidth (and thus the higher the Chip Rate that can be used)** to spread the data, **the larger the Spreading Code** → Thus the **higher the Processing Gain** that can be achieved and thus **lower power density is required during transmission**!
  - The Receiver **uses the same Spreading Code** to **decode the data**.

# Direct Sequence Spread Spectrum (DSSS)



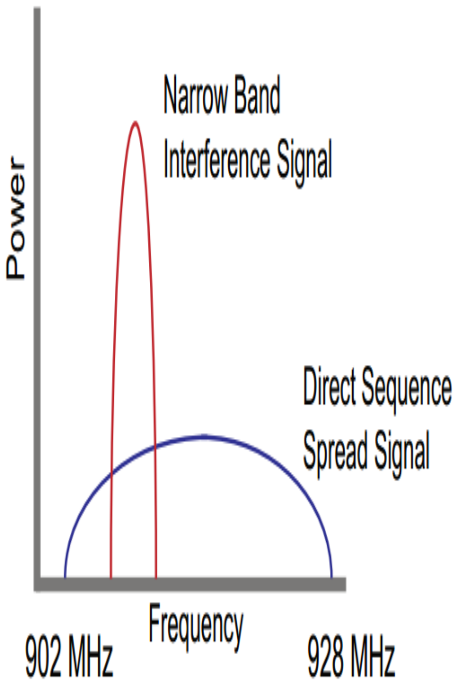
- Compared to Narrowband transmissions, DSSS transmissions uses a **much** **lower power density** **(power/frequency) to send the data.**



# Direct Sequence Spread Spectrum (DSSS)



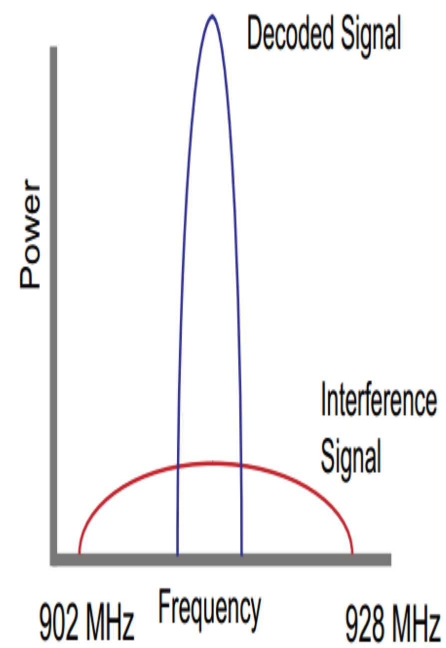
- At the Receiver, **Narrowband interference affects only** **a small part of the DSSS signal**.
- *Στο Receiver, παρεμβολές οι οποίες επηρεάζουν ένα μικρό κομμάτι του εύρους ζώνης που διασπείρεται το σήμα θα επηρεάσουν ένα μικρό κομματι του διασπαρμένου σήματος.*



# Direct Sequence Spread Spectrum (DSSS)



- When the **DSSS signal** is **decoded back** to its original **state**, the **narrowband interference** picked up during transmission is **decoded to a lower power density signal** thereby **reducing its effects** and thus **ignored (filtered) by the Receiver (Due to Processing Gain)**
- Όταν το DSSS σήμα αποκωδικοποιηθεί στην αρχική του κατάσταση, το σήμα ενισχύεται (με βάση το **Processing Gain**) και **οι παρεμβολές που επηρέαζαν το μικρό εύρος συχνοτήτων του διασπαρμένου ελαχιστοποιούνται και** στο τέλος **αγνοούνται από τον Receiver.**



# Direct Sequence Spread Spectrum (DSSS)



- As the **whole available bandwidth is used** to spread the data, **DSSS achieves better Processing Gain than FHSS** (**Spreading Codes with higher length can be used**)
  - Thus, **better resistance to Interference** and moreover **improved reception at the Receiver.**
  - **Better resistance to intended** or **unintended jamming (**Καλύτερη ανοχή σε σκόπιμες ή μη παρεμβολές η θόρυβο για να μπλοκάρουν το σήμα)
  - **Lower levels of transmission power required** to send a signal and thus:
    - **Less battery consumption** in the Mobile Terminal
    - **Less Interference** caused in the System