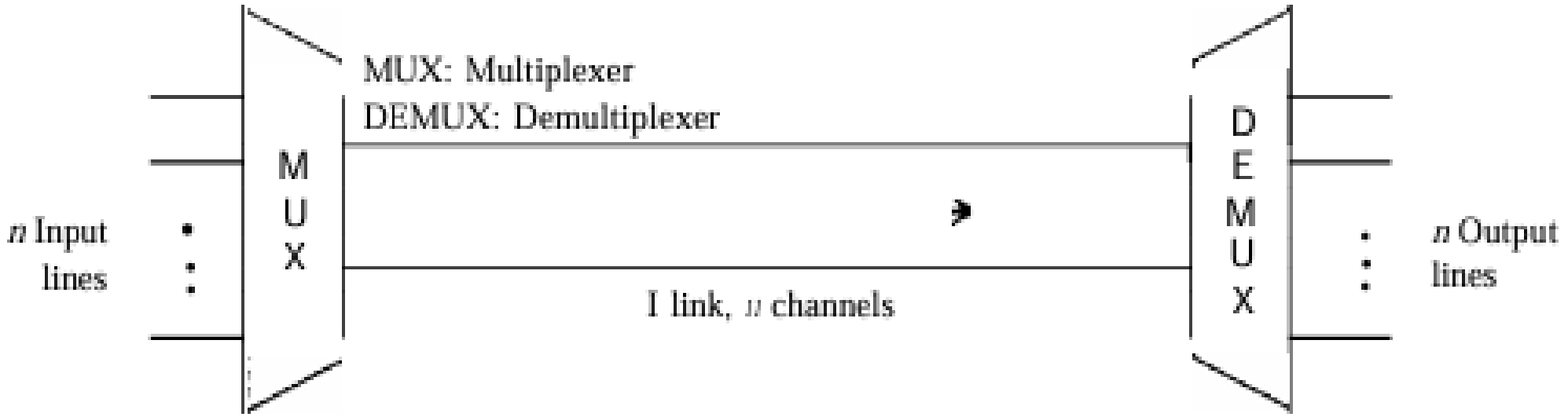
# Data Communication & Networks

Chapter 2: Multiplexing (Behrouz Forouzan & Tanenbaum)

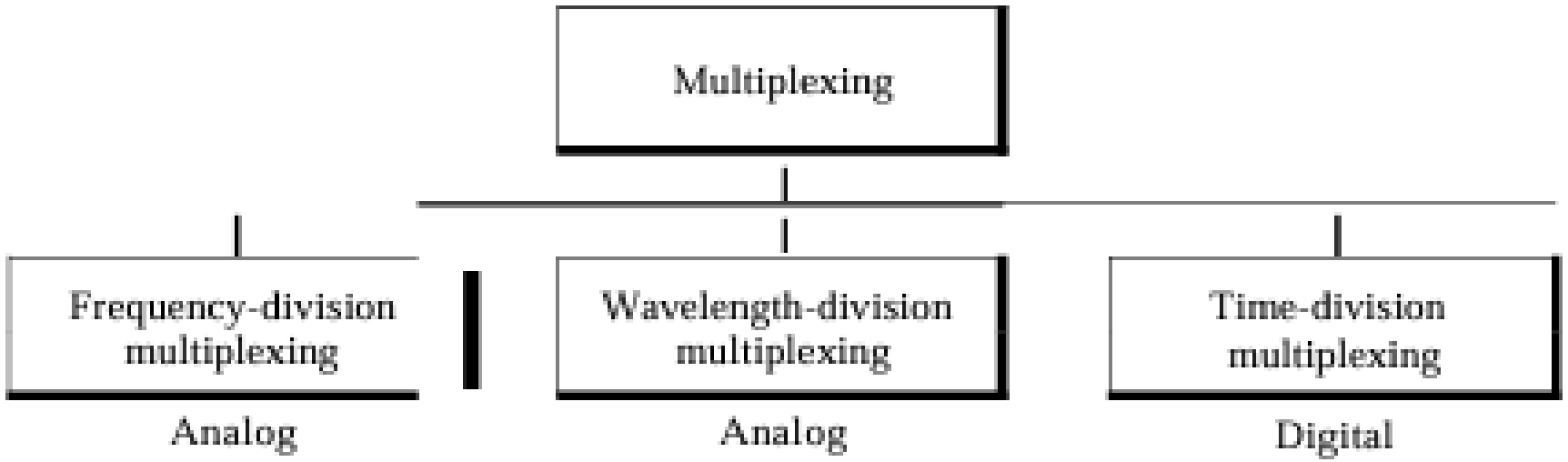
# Multiplexing

Figure 6.1 *Dividing a link into channels*



# Multiplexing

Figure 6.2 *Categories of multiplexing*

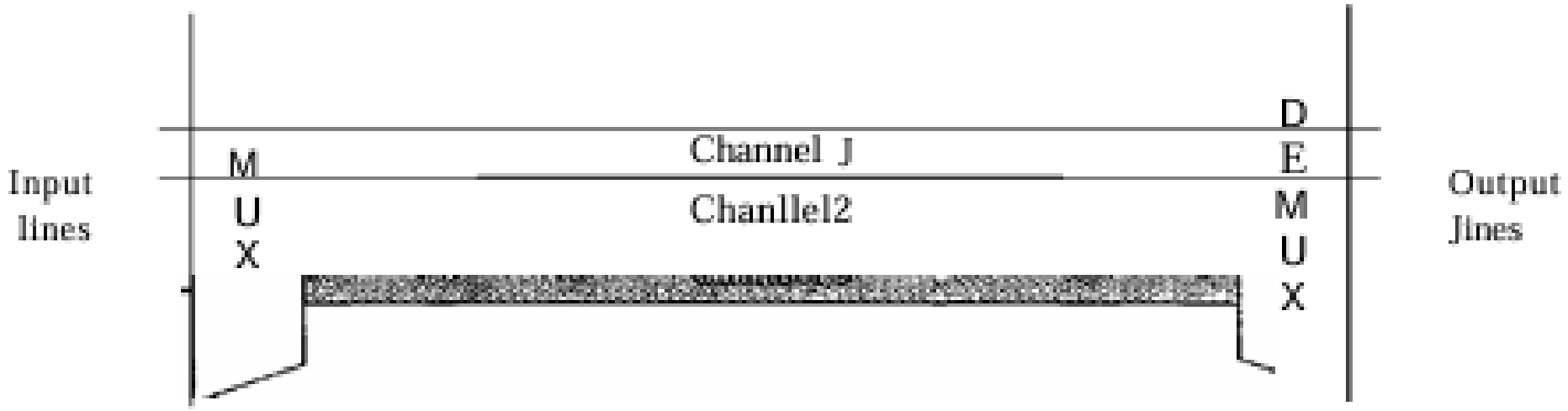



Although some textbooks consider *carrier division multiple access* (COMA) as a fourth multiplexing category, we discuss COMA as an access method (see Chapter 12).

# Multiplexing: Frequency Division Multiplexing

- Step 1: In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link.
- Channels can be separated by strips of unused bandwidth called guard bands to prevent signals from overlapping.

Figure 6.3 *Frequency-division multiplexing*



# Multiplexing: Frequency Division Multiplexing

**FDM is an analog multiplexing technique that combines analog signals.**

Figure 6.4 *FDM process*

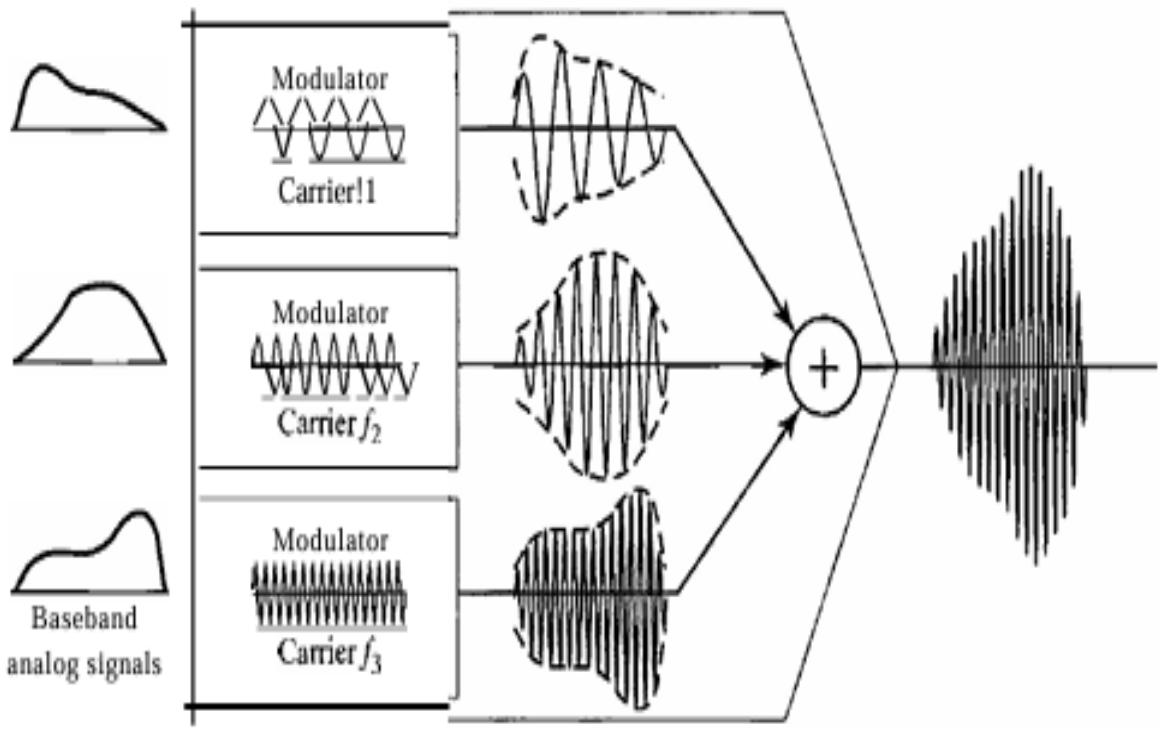
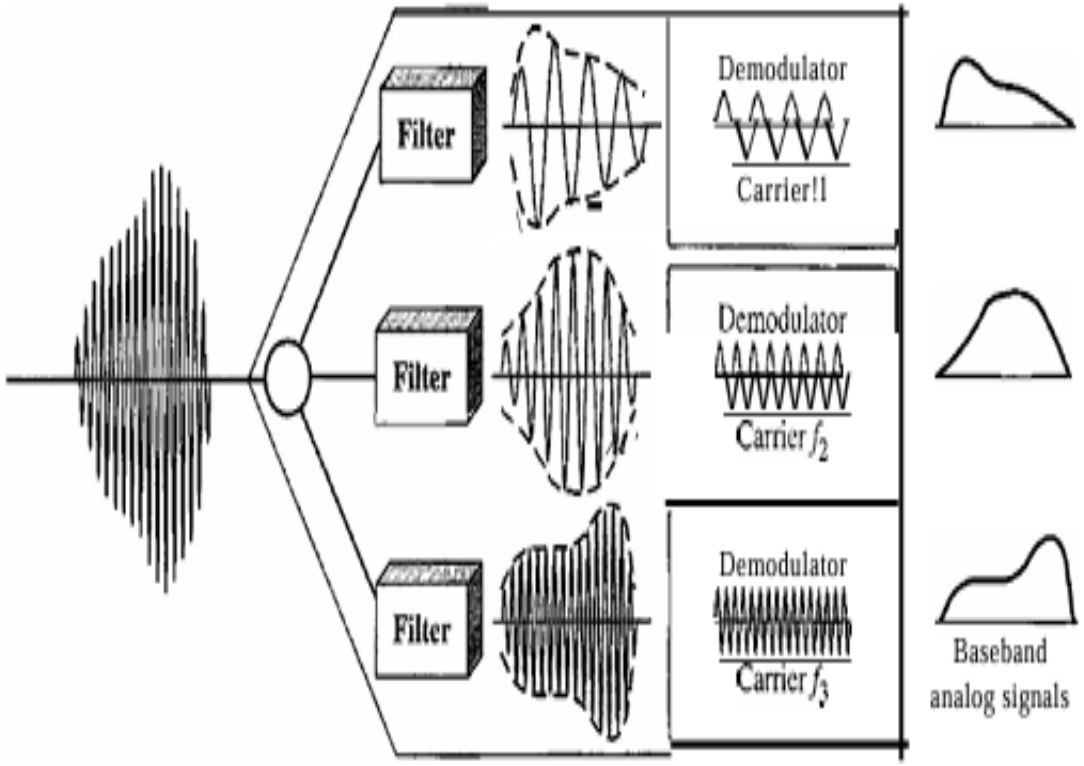



Figure 6.5 *FDM demultiplexing example*



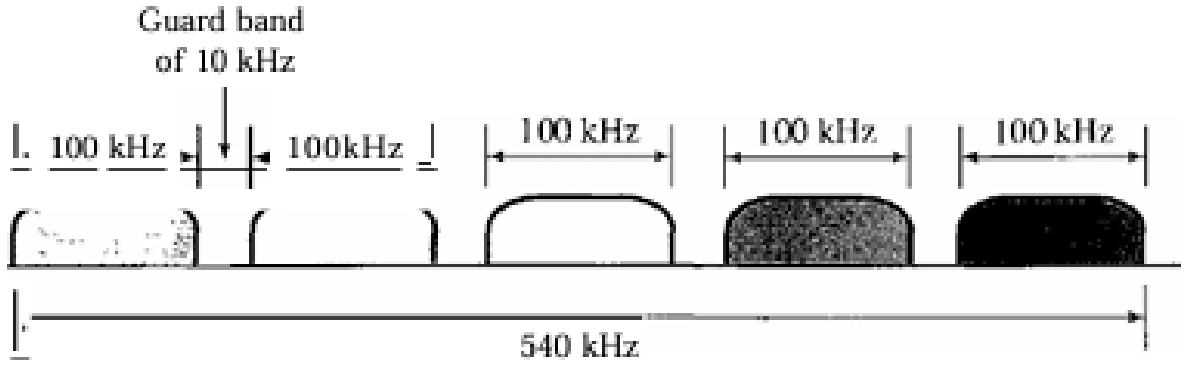
# Multiplexing: Frequency Division Multiplexing

## *Example 6.2*

Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the mini mum bandwidth of the link if there is a need for a guard band of 10kHz between the channels to prevent interference?

- Solution: For five channels, we need at least four guard bands. This means that the required bandwidth is at least 5 x 100 + 4 x 10 = 540kHz

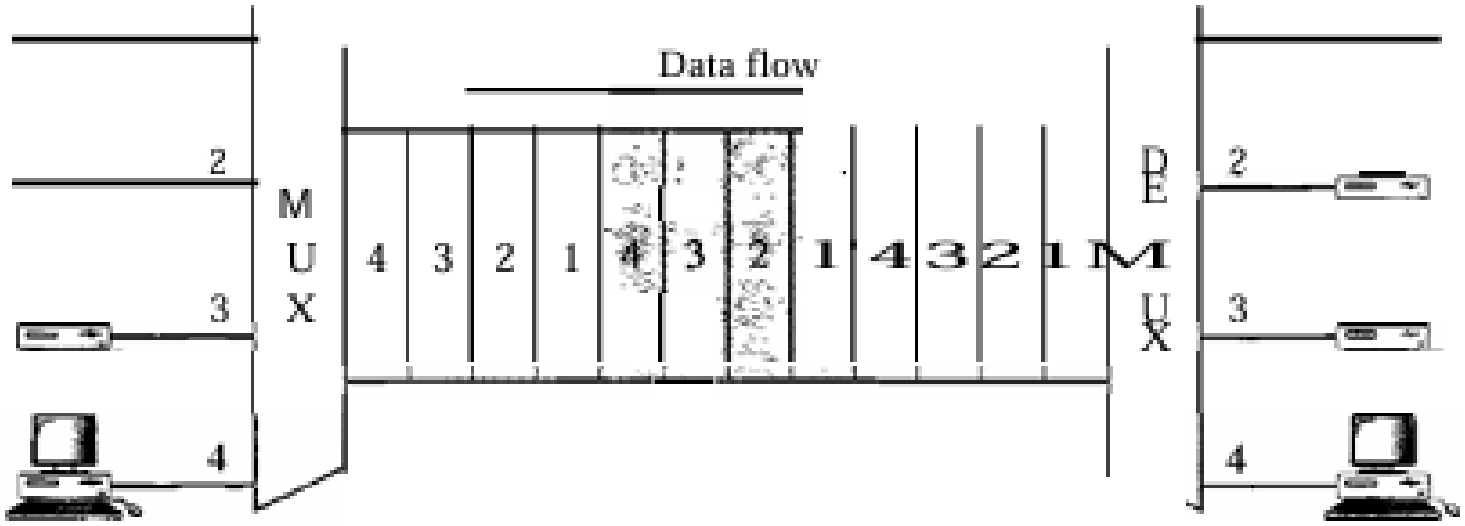
Figure 6.7 *Example 6.2*



# Multiplexing: Time Division Multiplexing

- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link

Figure 6.12 *TDM*

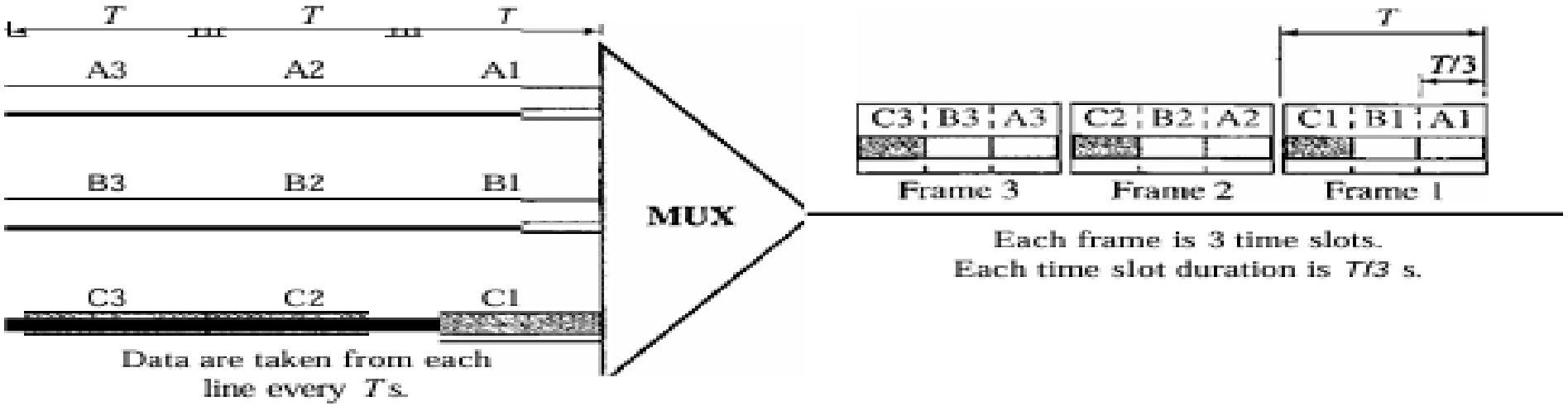


# Multiplexing: Time Division Multiplexing

TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

We can divide TDM into two different schemes: synchronous and statistical. We first discuss synchronous TDM and then show how statistical TDM differs. In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.

**Figure 6.13** *Synchronous time-division multiplexing*

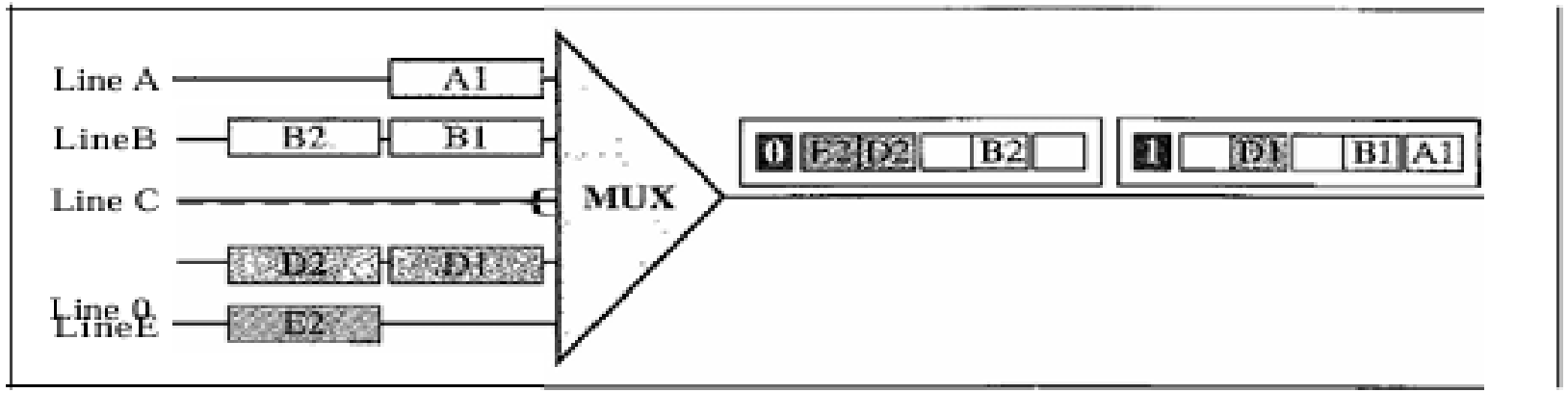


# Multiplexing: Time Division Multiplexing

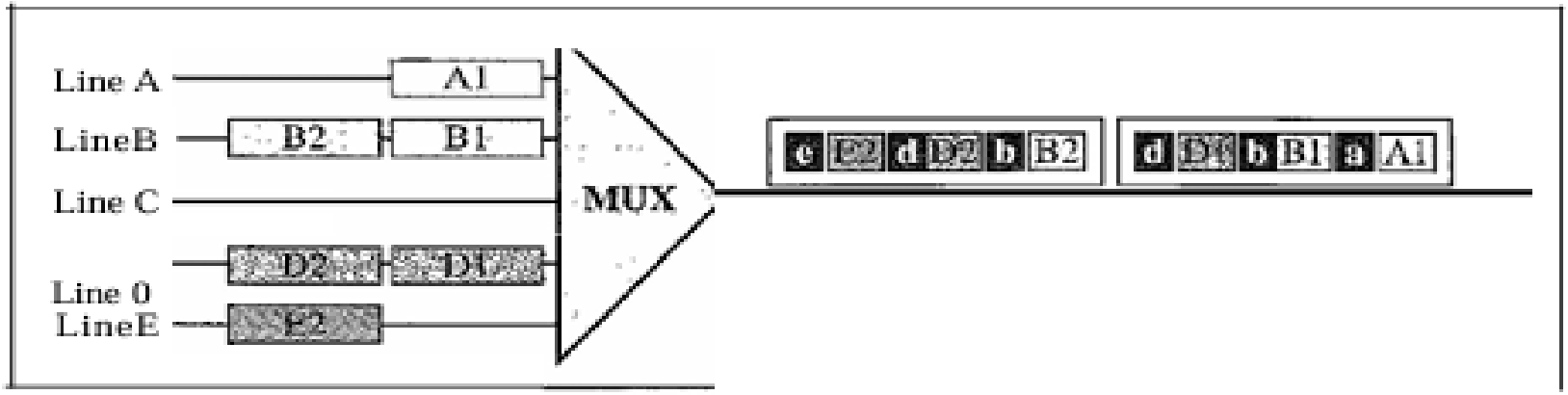
In synchronous TDM, the data rate of the link is $n$ times faster, and the unit duration is $n$ times shorter.

# Multiplexing: Time Division Multiplexing

Figure 6.26 *TDM slot comparison*




a. Synchronous TDM




b. Statistical TDM

# Multiplexing: Code Division Multiplexing

## Code Division Multiplexing

- Also known as code division multiple access
- An advanced technique that allows multiple devices to transmit on the same frequencies at the same time
- Each mobile device is assigned a unique 64-bit code

# Multiplexing: Code Division Multiplexing

- To send a binary 1, a mobile device transmits the unique code
- To send a binary 0, a mobile device transmits the inverse of the code
- To send nothing, a mobile device transmits zeros

# Multiplexing: Code Division Multiplexing

- Receiver gets summed signal, multiplies it by

- Station code and adds up the resulting values
  - Interprets as a binary 1 if sum is near +64
  - Interprets as a binary 0 if sum is near -64

# Multiplexing: Code Division Multiplexing

- For simplicity, assume 8-bit code
- Example
  - Three different mobile devices use the following codes:
    - Mobile A: 11110000
    - Mobile B: 10101010
    - Mobile C: 00110011
  - Assume Mobile A sends a 1, B sends a 0, and C sends a 1
  - Signal code: 1-chip = +N volt; 0-chip = -N volt

# Multiplexing: Code Division Multiplexing

- Example (continued)
  - Three signals transmitted:
    - Mobile A sends a 1, or 11110000, or ++++----
    - Mobile B sends a 0, or 01010101, or -+-+-+-+
    - Mobile C sends a 1, or 00110011, or --++--++
  - Summed signal received by base station: -1, +1, +1, +3, -3, -1, -1, +1

# Multiplexing: Code Division Multiplexing

- Example (continued)
  - Base station decode for Mobile A:
    - Signal received: -1, +1, +1, +3, -3, -1, -1, +1
    - Mobile A's code: +1, +1, +1, +1, -1, -1, -1, -1
    - Product result: -1, +1, +1, +3, +3, +1, +1, -1
  - Sum of Products: +8
  - Decode rule: For result near +8, data is binary 1