Lecture 8

Link Protocol Performance, Bit Stuffing, Multiplexing

Data Link Performance Issues

- Performance is computed as a measure of the how efficiently a transmitter and receiver make use of the communications capacity of a give line (medium).
- We want to know how much of the potential capacity of the line a protocol can actually use.
- This is called utilization, and it varies based on the flow control and error control mechanisms used.
- First, let's review these mechanisms.

Stop and Wait

- Source transmits frame
- After reception, destination indicates willingness to accept another frame in acknowledgement
- Source must wait for acknowledgement before sending another frame
- 2 kinds of errors:
  - Damaged frame at destination
  - Damaged acknowledgement at source

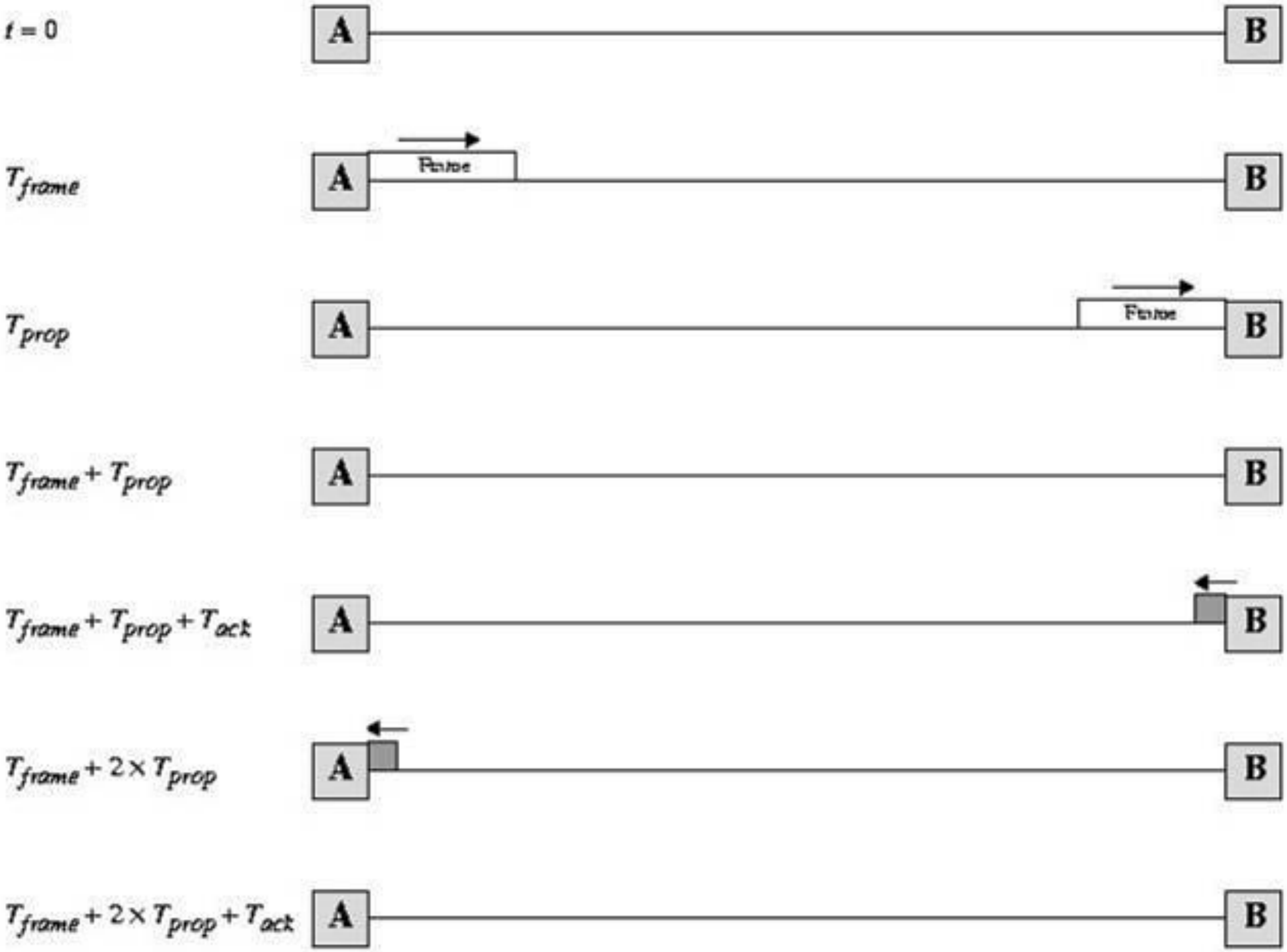


Figure 11.4 Stop-and-Wait Link Utilization

Error-Free Stop and Wait

$T = T_{frame} + T_{prop} + T_{proc} + T_{ack} + T_{prop} + T_{proc}$

T_{frame} = time to transmit frame

T_{prop} = propagation time

T_{proc} = processing time at station

T_{ack} = time to transmit ack

Assume T_{proc} and T_{ack} relatively small

Error-Free Stop and Wait (2)

$T \approx T_{frame} + 2T_{prop}$

Throughput = $1/T = 1/(T_{frame} + 2T_{prop})$ frames/sec

Utilization U is ratio of time to transmit data T_{frame} and the total time to send the data and get the response $T_{frame} + 2T_{prop}$

$$U = \frac{T_{frame}}{T_{frame} + 2T_{prop}} = \frac{1}{1 + 2a}$$

where $a = T_{prop} / T_{frame}$

The Parameter a

$$a = \frac{\text{propagation time}}{\text{transmission time}} = \frac{d/V}{L/R} = \frac{Rd}{VL}$$

where

- d = distance between stations
- V = velocity of signal propagation
- L = length of frame in bits
- R = data rate on link in bits per sec

Rd/V ::= bit length of the link

a ::= ratio of link bit length to the length of frame

Stop-and-Wait Link Utilization

- If T_{prop} large relative to T_{frame} then throughput reduced
- If propagation delay is long relative to transmission time, line is mostly idle
- Problem is only one frame in transit at a time
- Stop-and-Wait rarely used because of inefficiency

Error-Free Sliding Window ARQ

- Case 1: $W \geq 2a + 1$
  - Ack for frame 1 reaches A before A has exhausted its window
- Case 2: $W < 2a + 1$
  - A exhausts its window at $t = W$ and cannot send additional frames until $t = 2a + 1$

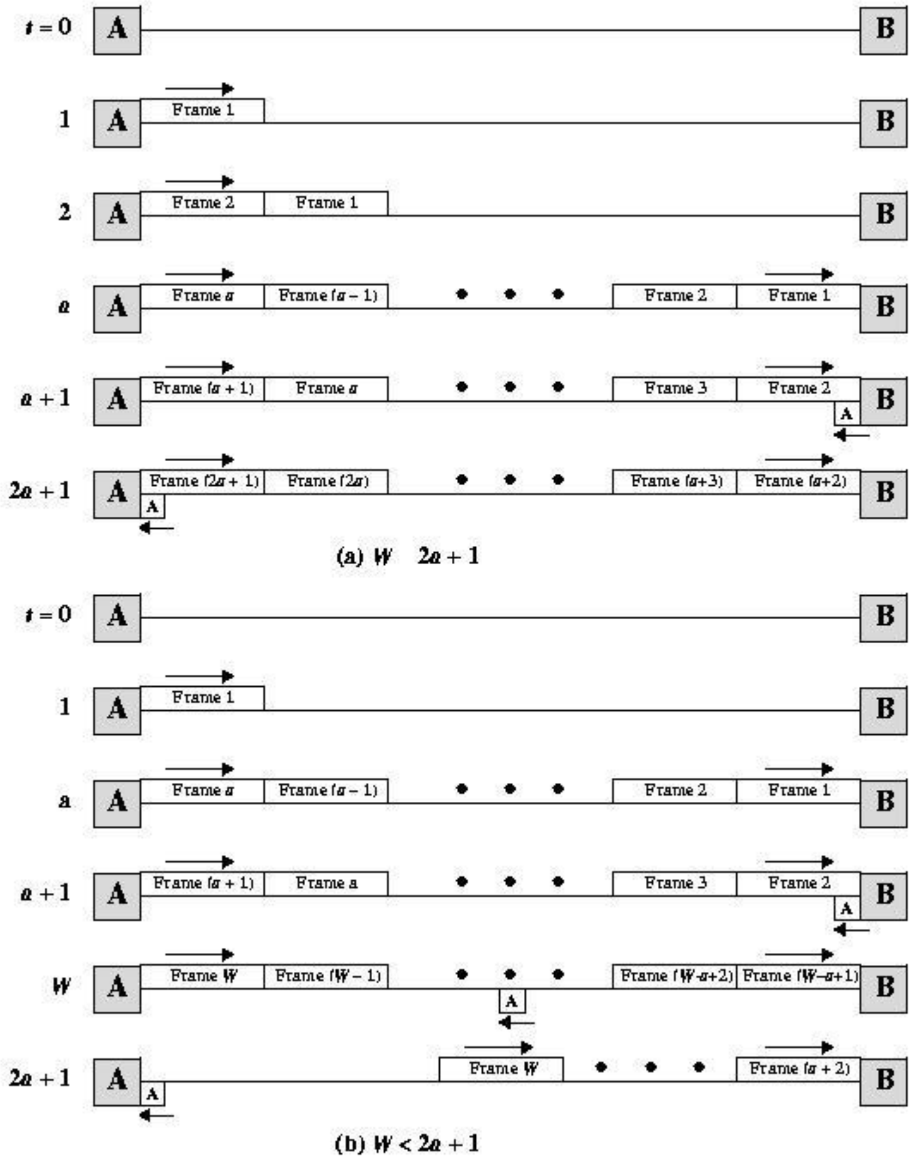


Figure 11.10 Timing of Sliding-Window Protocol

Normalized Throughput

$$U = \begin{cases} 1 & \text{for } W \geq 2a + 1 \\ \dfrac{W}{2a + 1} & \text{for } W < 2a + 1 \end{cases}$$

Stop-and-Wait ARQ with Errors

P = probability a single frame is in error

$$N_x = \frac{1}{1 - P}$$

= average number of times each frame must be transmitted due to errors

$$U = \frac{1}{N_x\,(1 + 2a)} = \frac{1 - P}{(1 + 2a)}$$

Selective Reject ARQ

$$U = \begin{cases} 1 - P & \text{for} \quad W \geq 2a + 1 \\ \dfrac{W(1 - P)}{2a + 1} & \text{for} \quad W < 2a + 1 \end{cases}$$

Go-Back-N ARQ

$$U = \frac{1 - P}{1 + 2aP} \quad \text{for} \quad W \geq 2a + 1$$

$$U = \frac{W(1 - P)}{(2a + 1)(1 - P + WP)} \quad \text{for} \quad W < 2a + 1$$

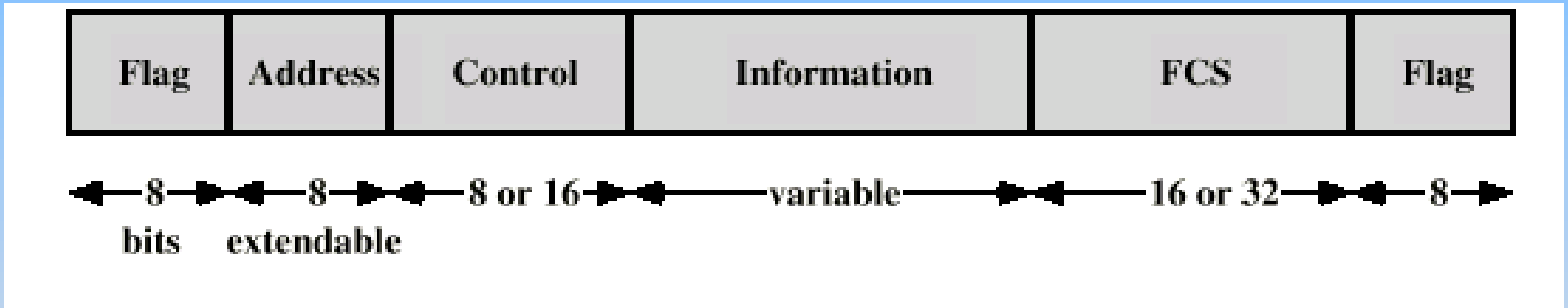
High-Level Data Link Control

- HDLC is the most important data link control protocol
- Widely used which forms basis of other data link control protocols

Frame Structure

- Synchronous transmission
- All transmissions in frames
- Single frame format for all data and control exchanges

Frame Structure Diagram



Flag Fields

- Delimit frame at both ends
- 01111110
- May close one frame and open another
- Receiver hunts for flag sequence to synchronize
- Bit stuffing used to avoid confusion with data containing 01111110
  - 0 inserted after every sequence of five 1s
  - If receiver detects five 1s it checks next bit
  - If 0, it is deleted
  - If 1 and seventh bit is 0, accept as flag
  - If sixth and seventh bits 1, sender is indicating abort

Bit Stuffing

- Example with possible errors

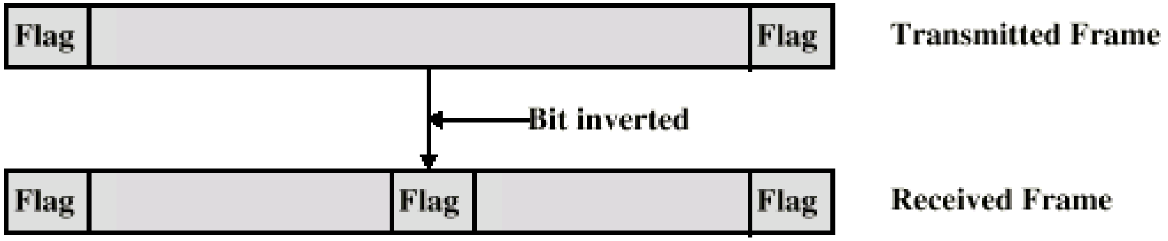
Original Pattern:

111111111111011111101111110

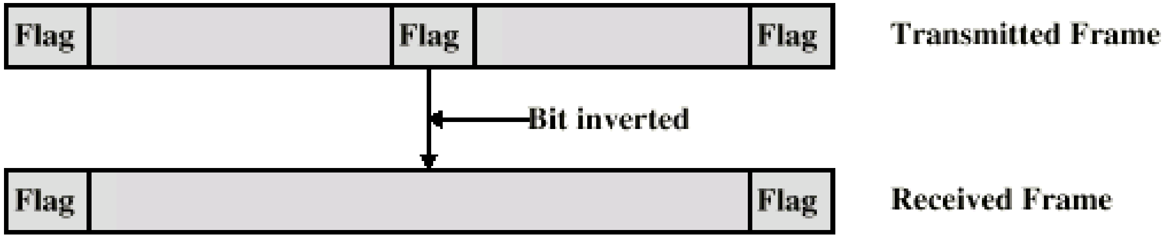
After bit-stuffing

1111101111101101111101011111010

(a) Example

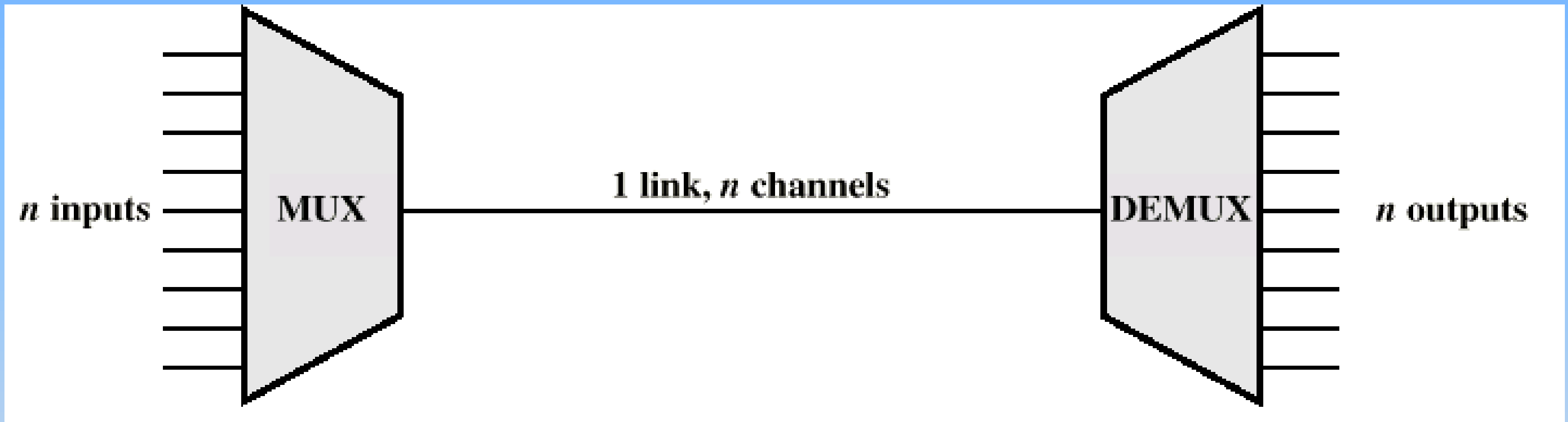


(b) An inverted bit splits a frame in two



(c) An inverted bit merges two frames

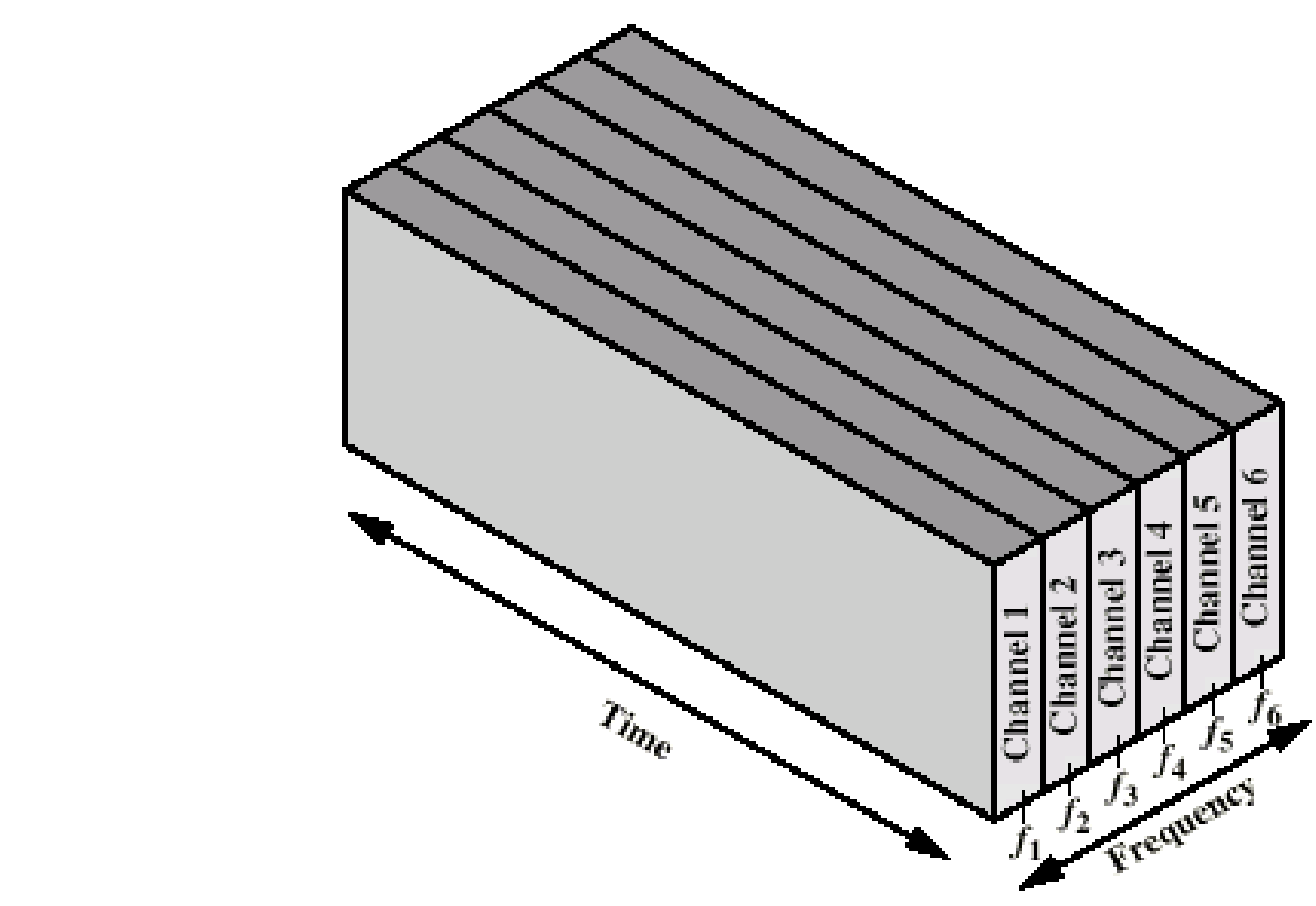
Multiplexing



Frequency Division Multiplexing

- FDM
- Useful bandwidth of medium exceeds required bandwidth of channel
- Each signal is modulated to a different carrier frequency
- Carrier frequencies separated so signals do not overlap (guard bands)
- e.g. broadcast radio
- Channel allocated even if no data

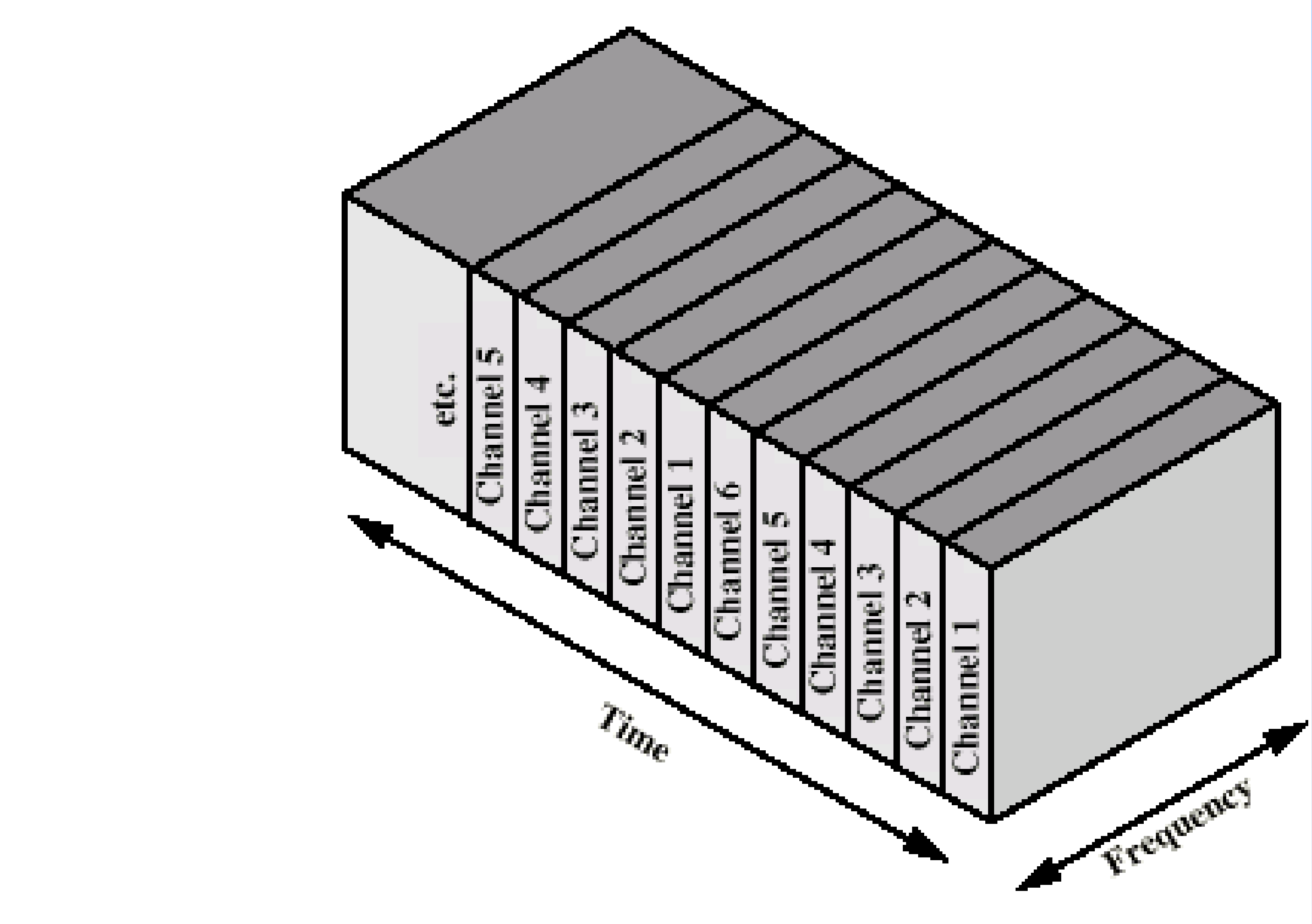
Frequency Division Multiplexing Diagram



Synchronous Time Division Multiplexing

- Data rate of medium exceeds data rate of digital signal to be transmitted
- Multiple digital signals interleaved in time
- May be at bit level of blocks
- Time slots preassigned to sources and fixed
- Time slots allocated even if no data
- Time slots do not have to be evenly distributed amongst sources

Time Division Multiplexing



Statistical TDM

- In Synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- Multiplexer scans input lines and collects data until frame full
- Data rate on line lower than aggregate rates of input lines