Computer Networks I

Multiplexing

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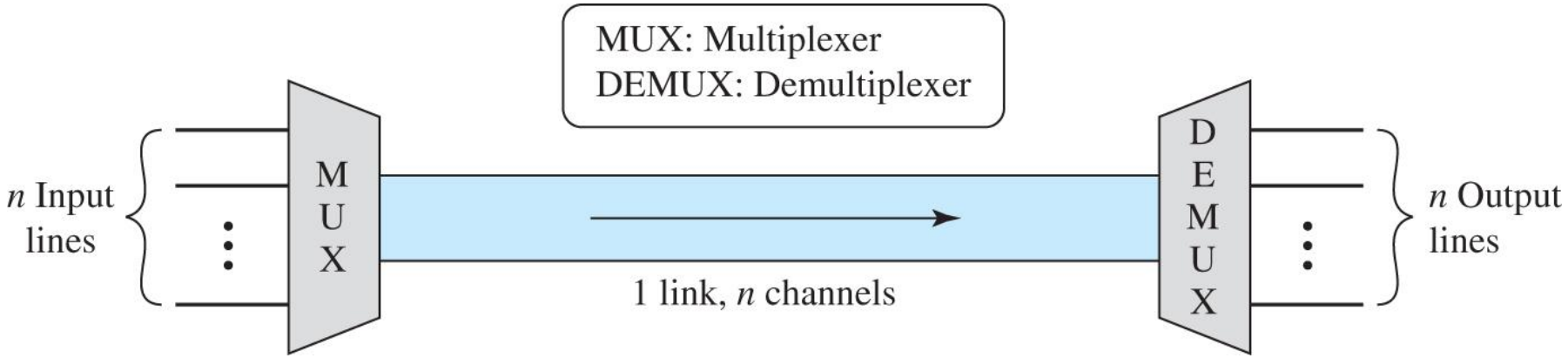
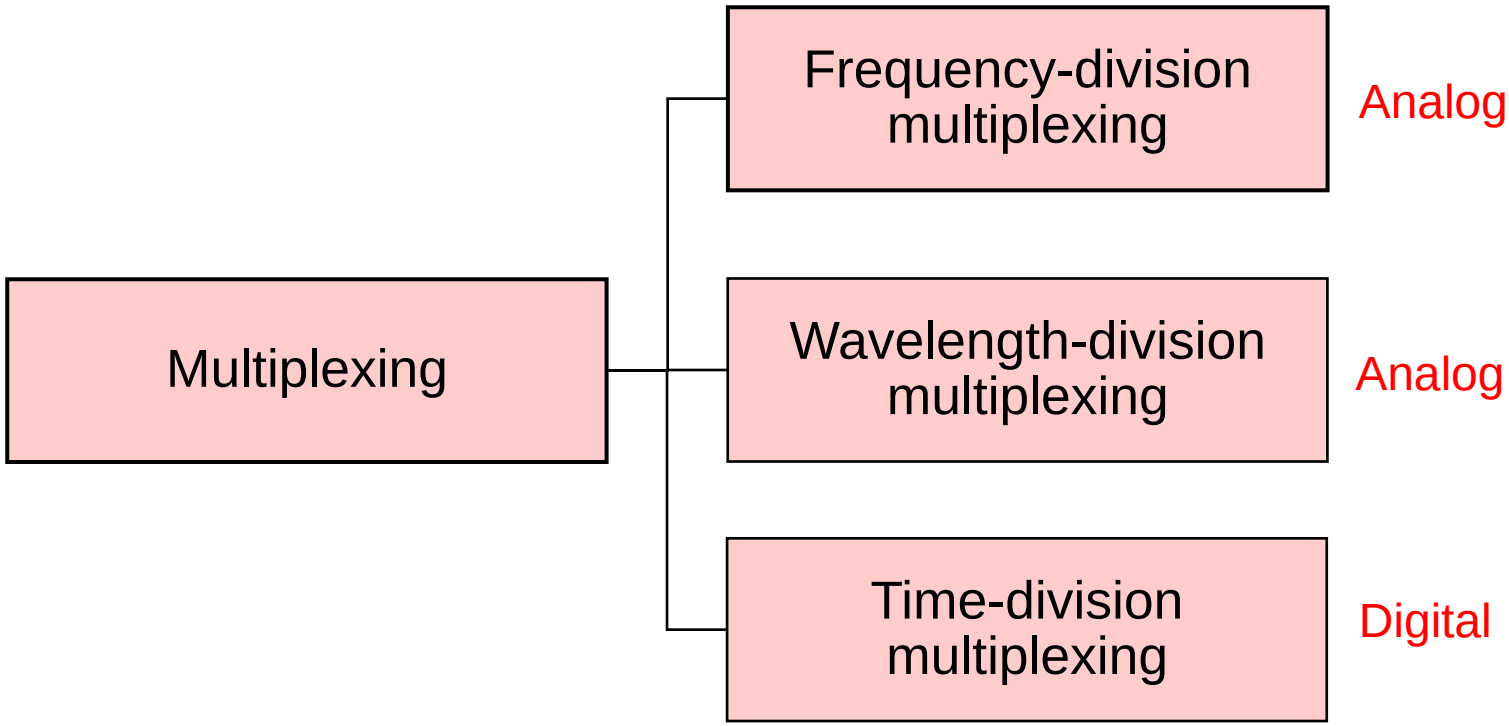
Multiplexing

- Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link
- **Multiplexer** (MUX): A device that combines several signals into a single signal
- **Demultiplexer** (DEMUX): A device that performs the inverse operation

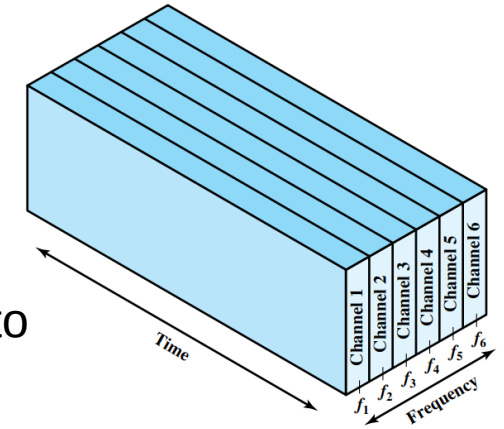


Multiplexing

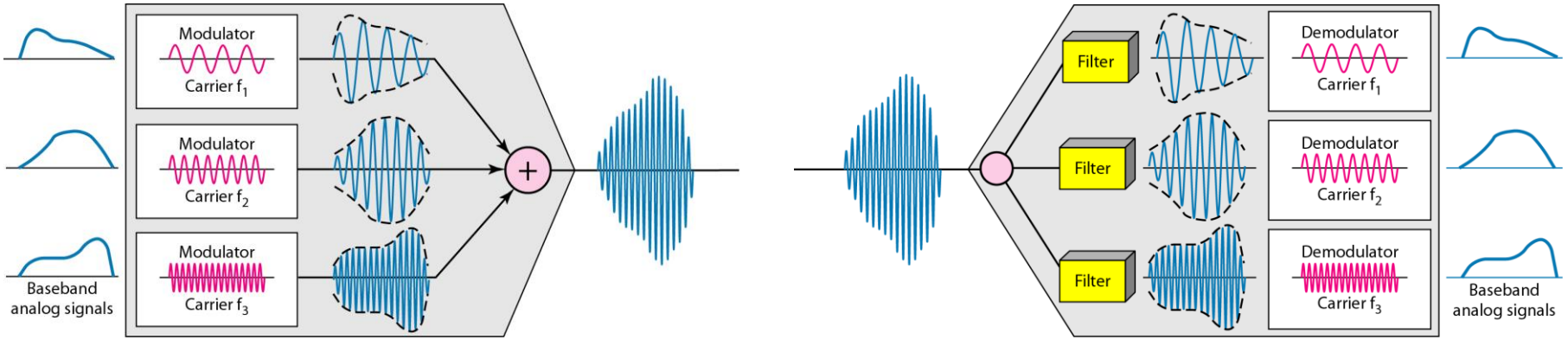


Frequency Division Multiplexing

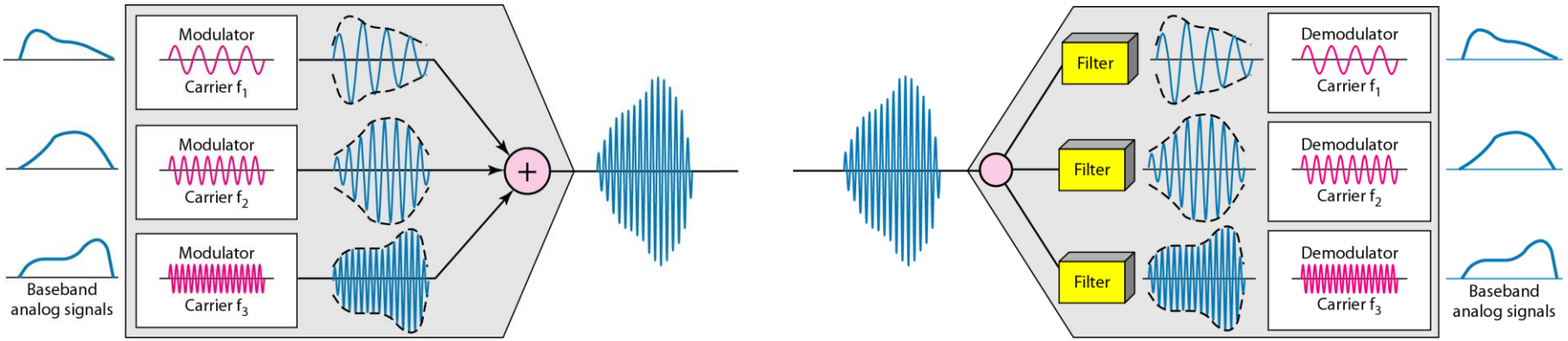
FDM

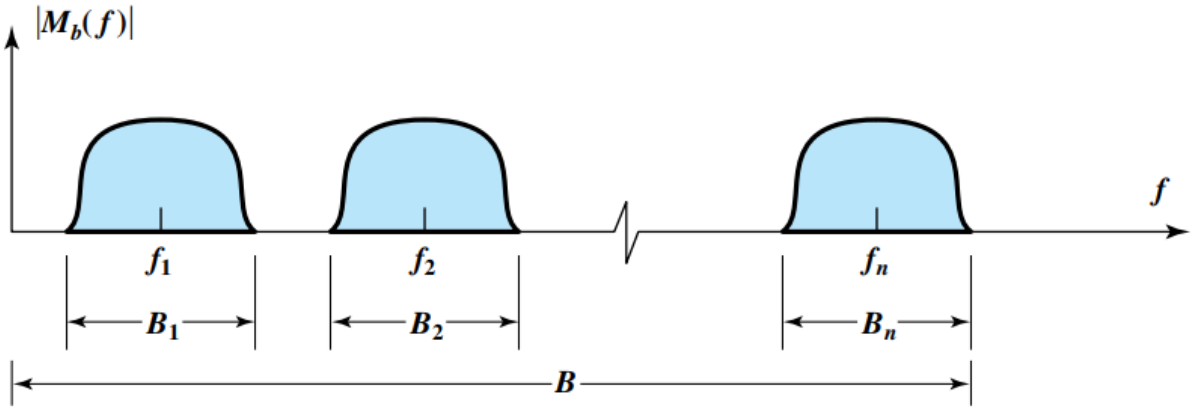


- Each signal is allocated a different frequency band
- Usually used with analog signals
- Modulation equipment is needed to move each signal to the required frequency band (channel)
- Multiple carriers are used, each is called sub-carrier



FDM


Modulator
Carrier f_1
Modulator
Carrier f_2
Modulator
Carrier f_3
Baseband analog signals
Filter
Filter
Filter
Demodulator
Carrier f_1
Demodulator
Carrier f_2
Demodulator
Carrier f_3
Baseband analog signals

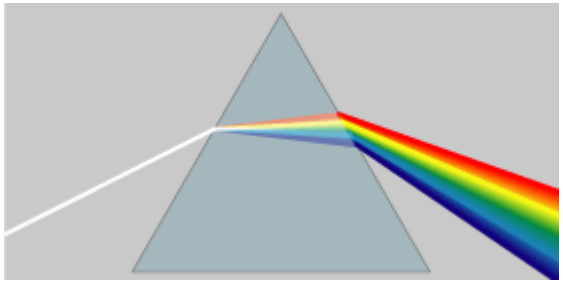

$|M_b(f)|$
f
f_1
f_2
f_n
B_1
B_2
B_n
B

FDM

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

Wavelength Division Multiplexing

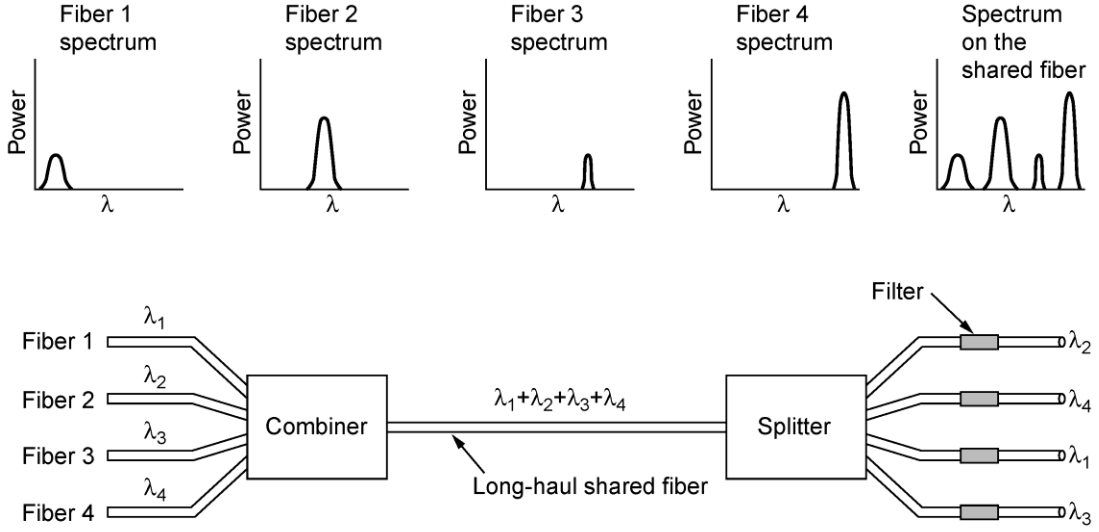
WDM



Src:https://commons.wikimedia.org/wiki/File:Prism_rainbow_schema.png

- WDM is conceptually the same as FDM
  - Multiplexing and demultiplexing involve light signals transmitted through fiber-optic channels

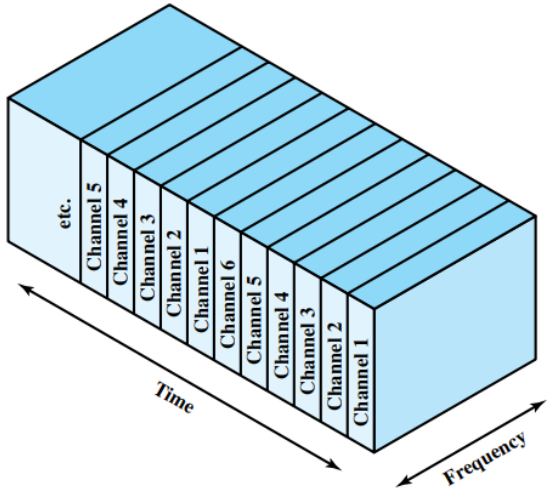
- Combining and splitting of light sources can be handled by a prism



Time Division Multiplexing

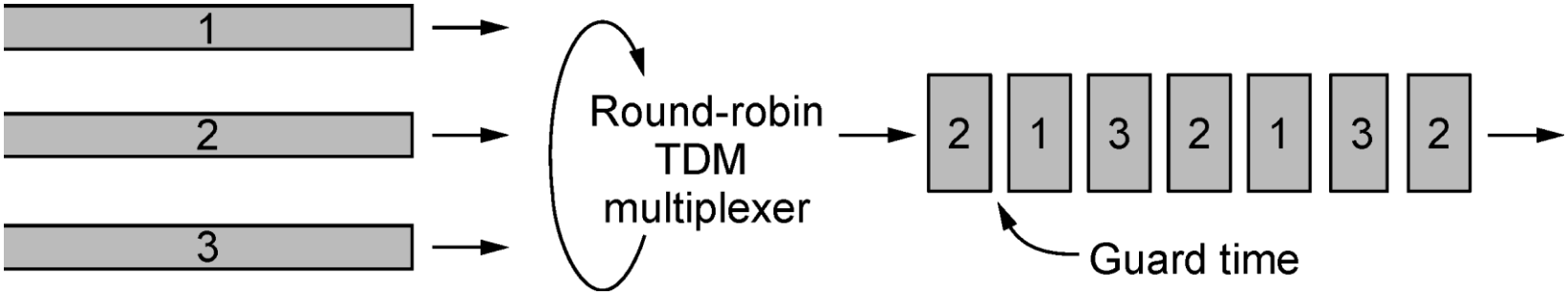
TDM

- User takes turns
  - Each one periodically get the entire bandwidth



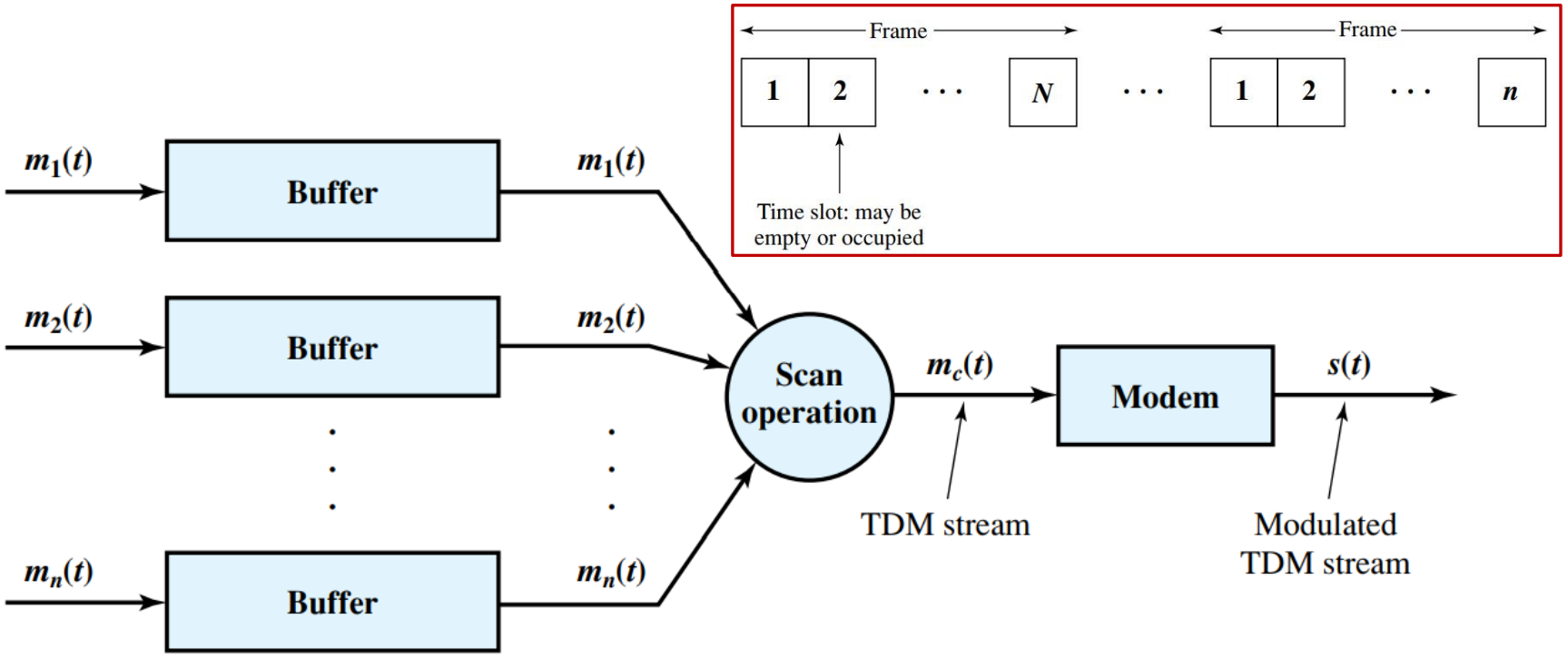
❑TDM:

- Synchronous TDM
- Asynchronous TDM



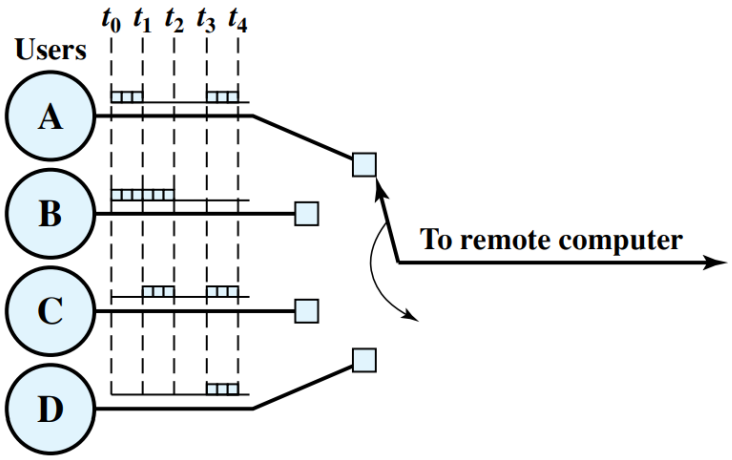
Synchronous TDM

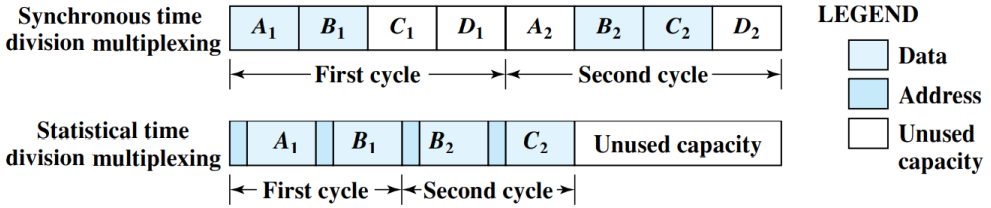
- Multiplexer allocates exactly the same time slot to each device at all times, whether or not a device has anything to transmit
  - Data rate of the link is n times faster



Statistical TDM

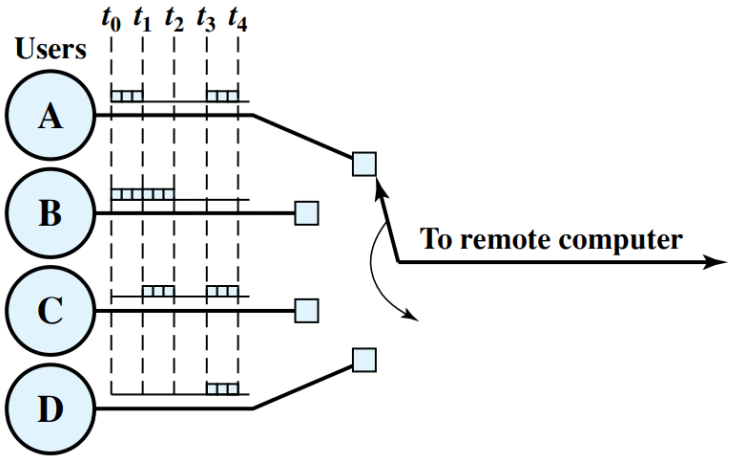
- In synchronous TDM it is often the case that many of the time slots in a frame are wasted
- Asynchronous time-division multiplexing, or statistical time-division multiplexing, is designed to avoid this type of waste

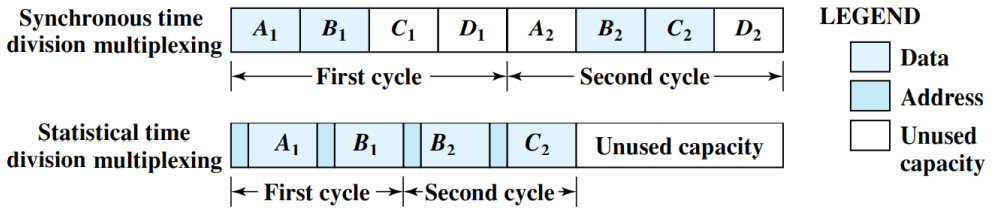




Statistical TDM

- Line data rate can be lower than input lines rates
- Overhead per slot for statistical TDM because each slot carries an address as well as data
- May have problems during peak periods
  - Must buffer inputs





Code Division Multiple Access

CDMA

$$A = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$$
$$B = (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1)$$
$$C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$$
$$D = (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$$

All chip sequences are orthogonal

$$S \bullet T = \frac{1}{m}\sum_{i=1}^{m} S_i T_i = 0 \qquad S \bullet \overline{T} = 0$$

$$S \bullet S = \frac{1}{m}\sum_{i=1}^{m} S_i S_i = \frac{1}{m}\sum_{i=1}^{m} S_i^2 = \frac{1}{m}\sum_{i=1}^{m} (\pm 1)^2 = 1$$

CDMA

$$A = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$$
$$B = (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1)$$
$$C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$$
$$D = (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$$

$X = A + \overline{B} + C = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$

CDMA

$$A = (-1\ -1\ -1\ +1\ +1\ -1\ +1\ +1)$$
$$B = (-1\ -1\ +1\ -1\ +1\ +1\ +1\ -1)$$
$$C = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$$
$$D = (-1\ +1\ -1\ -1\ -1\ -1\ +1\ -1)$$

$X = A+B+\bar{C}+D = (-2\ \ -2\ 0\ -2\ 0\ -2\ +4\ 0)$

CDMA

- Proof:
  - Let's consider the case of $S = (A + \overline{B} + C)$

$$S \bullet C = (A + \overline{B} + C) \bullet C = A \bullet C + \overline{B} \bullet C + C \bullet C$$
$$= 0 + 0 + 1 = 1$$

- One significant assumption is that, the chips are synchronized in time at the receiver
  - Asynchronous CDMA

- Used in cellular networks, satellites and cable networks

Summary

- Different multiplexing techniques discussed:
  - Frequency division multiplexing
  - Wavelength division multiplexing
  - Time division multiplexing
    - Synchronous TDM
    - Asynchronous TDM