Introduction

- Under simplest conditions, medium can carry only one signal at any moment in time
- For multiple signals to share a medium, medium must somehow be divided, giving each signal a portion of the total bandwidth
- Current techniques include:
  - Frequency division multiplexing
  - Time division multiplexing
  - Code division multiplexing

Multiplexing, or muxing, is a way of sending multiple signals or streams of information over a communications link at the same time in the form of a single, complex signal.

Frequency Division Multiplexing

- Assignment of nonoverlapping frequency ranges to each "user" or signal on a medium
  - Thus, all signals are transmitted at the same time, each using different frequencies
- A multiplexor accepts inputs and assigns frequencies to each device

Frequency Division Multiplexing (continued)

- Analog signaling is used in older systems; discrete analog signals in more recent systems
- Broadcast radio and television, cable television, and cellular telephone systems use frequency division multiplexing
- This technique is the oldest multiplexing technique
- Since it involves a certain level of analog signaling, it may be susceptible to noise

Time Division Multiplexing

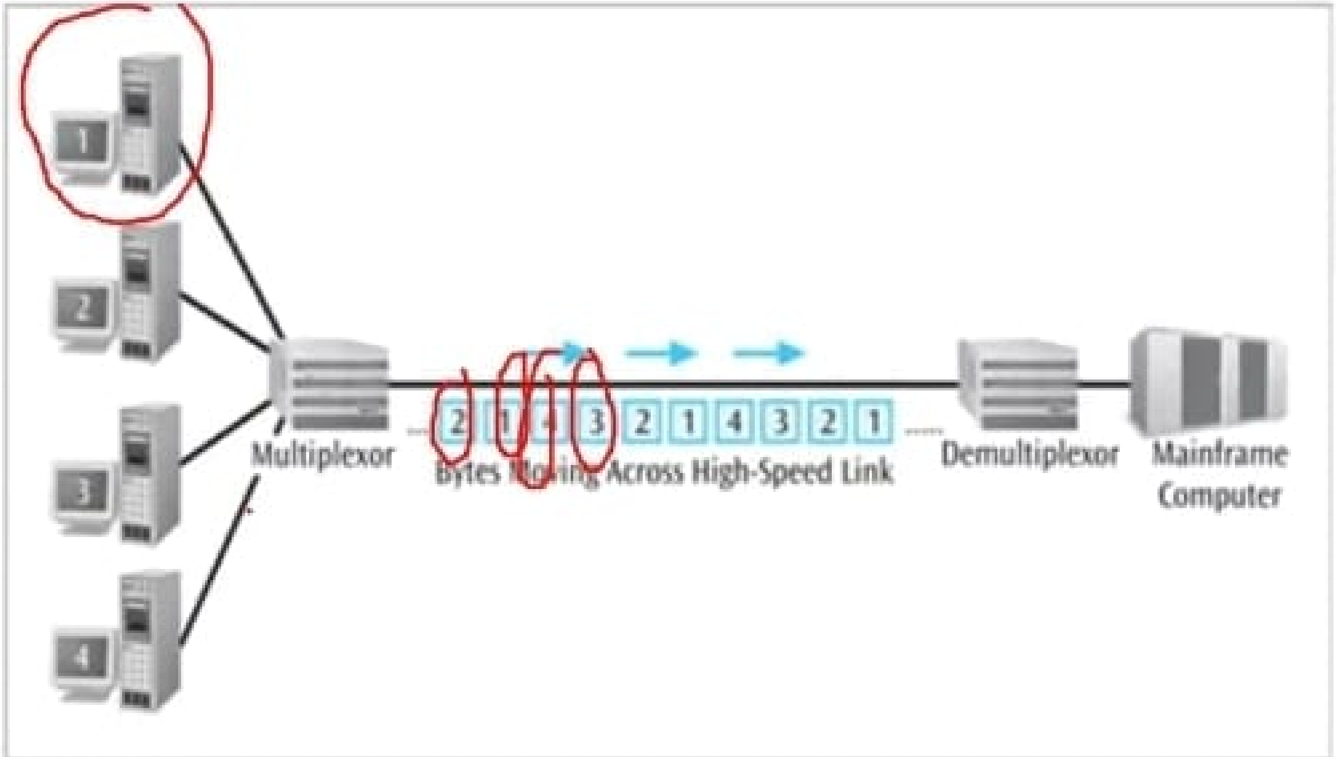
- Sharing of the signal is accomplished by dividing available transmission time on a medium among users
- Digital signaling is used exclusively
- Time division multiplexing comes in two basic forms:
  - Synchronous time division multiplexing
  - Statistical time division multiplexing

Synchronous Time Division Multiplexing

- The original time division multiplexing
- The multiplexor accepts input from attached devices in a round-robin fashion and transmits the data in a never -ending pattern
- T-1 and SONET telephone systems are common examples of synchronous time division multiplexing

Synchronous Time Division Multiplexing (continued)

Figure 5-2
Sample output stream generated by a synchronous time division multiplexor



Synchronous Time Division Multiplexing (continued)

- If one device generates data at faster rate than other devices, then the multiplexor must either sample the incoming data stream from that device more often than it samples the other devices, or buffer the faster incoming stream
- If a device has nothing to transmit, the multiplexor must still insert something into the multiplexed stream

Synchronous Time Division Multiplexing (continued)

- So that the receiver may stay synchronized with the incoming data stream, the transmitting multiplexor can insert alternating 1s and 0s into the data stream

Synchronous Time Division Multiplexing (continued)

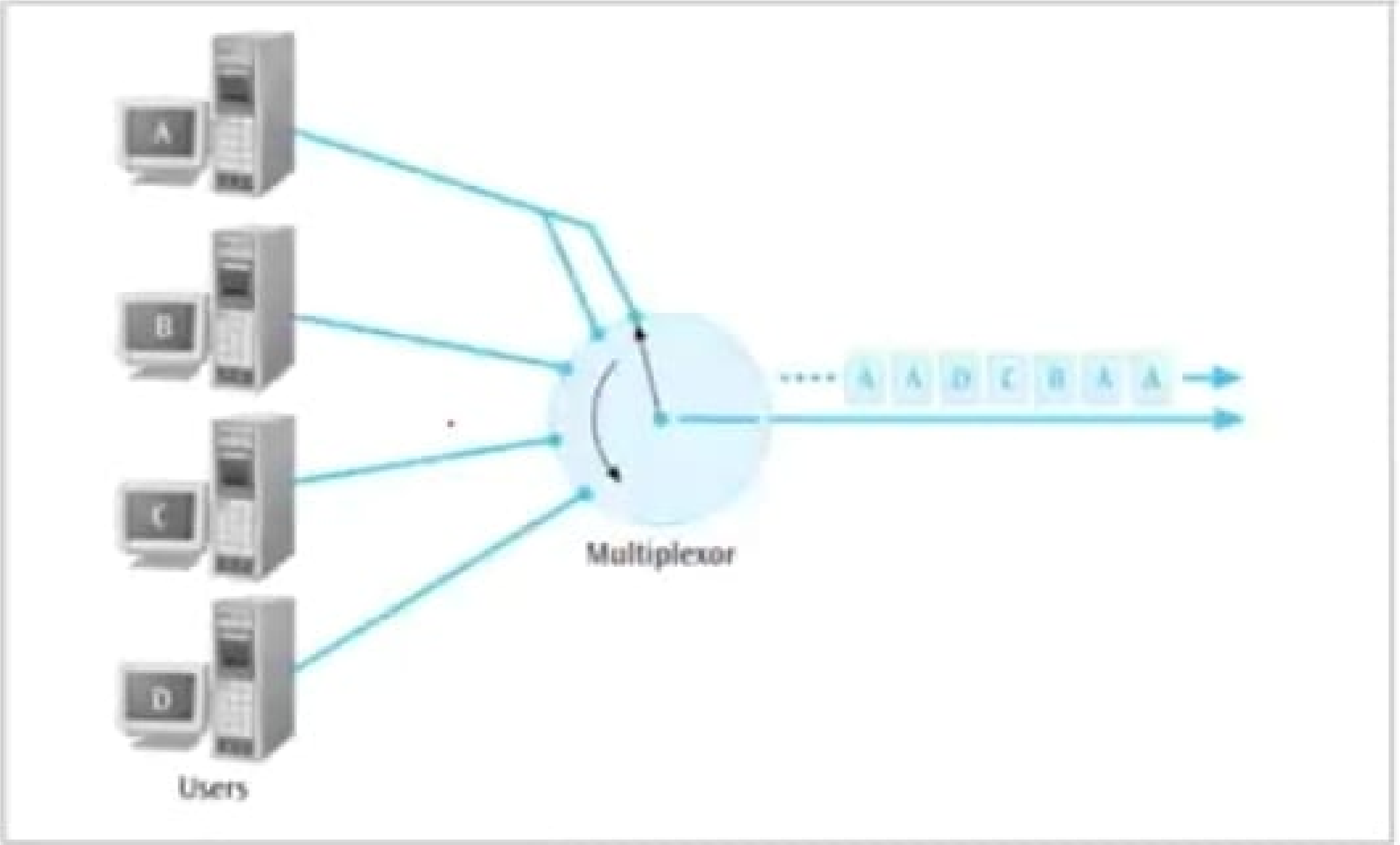


Figure 5-3
A synchronous time division multiplexing system that samples device A twice as fast as the other devices

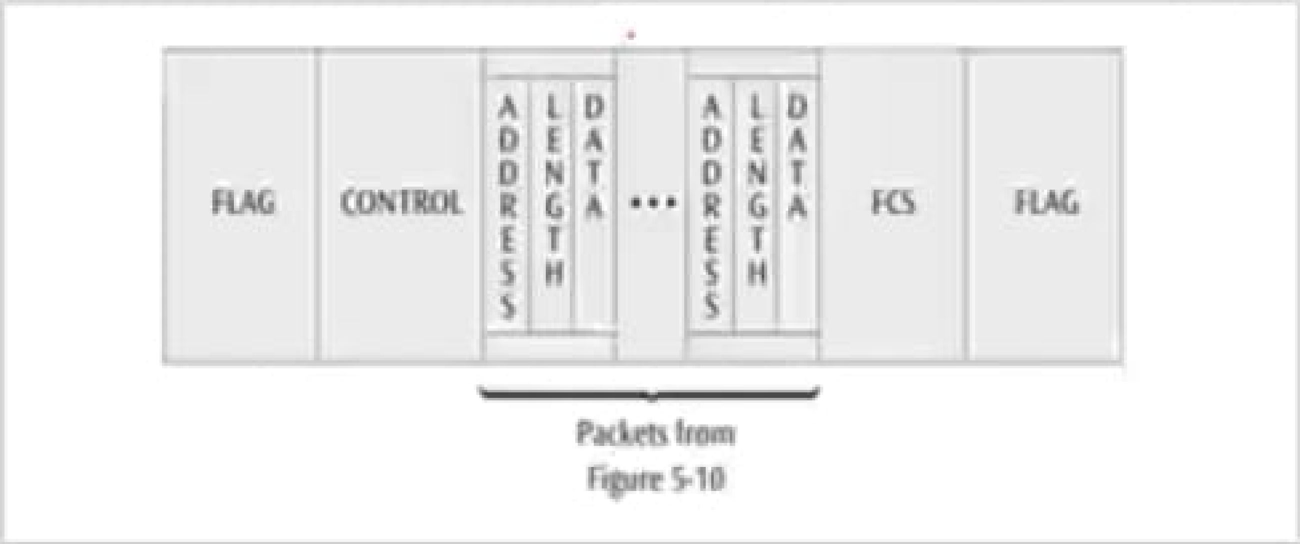
Statistical Time Division Multiplexing

- A statistical multiplexor transmits the data from active workstations only
- If a workstation is not active, no space is wasted in the multiplexed stream

Statistical Time Division Multiplexing (continued)

- More precisely, the transmitted frame contains a collection of data groups

Figure 5-11
Frame layout for the information packet transferred between statistical multiplexors



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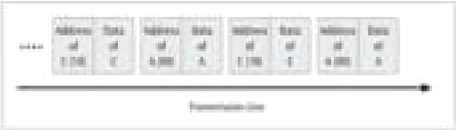
Statistical Time Division Multiplexing (continued)



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No Notes

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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

Code Division Multiplexing (continued)

- 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

Code Division Multiplexing (continued)

- 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

Code Division Multiplexing (continued)

- Example (continued)
  - Base station decode for Mobile B:
    - Signal received: -1, +1, +1, +3, -3, -1, -1, +1
    - Mobile B'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 0

Comparison of Multiplexing Techniques

Table 5-3

Advantages and disadvantages of multiplexing techniques

Multiplexing Technique	Advantages	Disadvantages
Frequency Division Multiplexing	Simple Popular with radio, TV, cable TV All the receivers, such as cellular telephones, do not need to be at the same location	Noise problems due to analog signals Wastes bandwidth Limited by frequency ranges
Synchronous Time Division Multiplexing	Digital signals Relatively simple Commonly used with T-1, SONET	Wastes bandwidth
Statistical Time Division Multiplexing	More efficient use of bandwidth Frame can contain control and error information Packets can be of varying size	More complex than synchronous time division multiplexing
Wavelength Division Multiplexing	Very high capacities over fiber Signals can have varying speeds Scalable	Cost Complexity
Discrete Multitone	Capable of high transmission speeds	Complexity, noise problems
Code Division Multiplexing	Large capacities Scalable	Complexity Primarily a wireless technology

Compression–Lossless versus Lossy

- Compression is another technique used to squeeze more data over a communications line
  - If you can compress a data file down to one half of its original size, file will obviously transfer in less time
- Two basic groups of compression:
  - Lossless – when data is uncompressed, original data returns
  - Lossy – when data is uncompressed, you do not have the original data

Compression–Lossless versus Lossy (continued)

- Compress a financial file?
  - You want lossless
- Compress a video image, movie, or audio file?
  - Lossy is OK
- Examples of lossless compression include:
  - Huffman codes, run-length compression, and Lempel-Ziv compression
- Examples of lossy compression include:
  - MPEG, JPEG, MP3

Lossy Compression

- Relative or differential encoding
  - Video does not compress well using run-length encoding
  - In one color video frame, not much is alike
  - But what about from frame to frame?
    - Send a frame, store it in a buffer
    - Next frame is just difference from previous frame
    - Then store that frame in buffer, etc.

7:05 4G 30%

Lossy Compression (continued)

5 7 6 2 8 6 6 3 5 6
6 5 7 5 5 6 3 2 4 7
8 4 6 8 5 6 4 8 8 5
5 1 2 9 8 6 5 5 6 6
First Frame

5 7 6 2 8 6 6 3 5 6
6 5 7 6 5 6 3 2 3 7
8 4 6 8 5 6 4 8 8 5
5 1 3 9 8 6 5 5 7 6
Second Frame

0 0 0 0 0 0 0 0 0 0
0 0 0 1 0 0 0 0 -1 0
0 0 0 0 0 0 0 0 0 0
0 0 1 0 0 0 0 0 1 0
Difference

Adam Zubair

Adam 20059... yusuf Atobar...

Lossy Compression (continued)

- Image Compression
  - One image (JPEG) or continuous images (MPEG)
  - A color picture can be defined by red/green/blue, or luminance/chrominance/chrominance which are based on RGB values
    - Either way, you have 3 values, each 8 bits, or 24 bits total (2^{24} colors!)

Lossless Compression

- Run-length encoding
  - Replaces runs of 0s with a count of how many 0s.

000000000000001000000000110000000000000000000001…110000000000001

^

(30 0s)

14 9 0 20 30 0 11

Business Multiplexing In Action (continued)

- Possible solutions
  - Connect each terminal to the mainframe computer using separate point-to-point lines
  - Connect all the terminals to the mainframe computer using one multipoint line
  - Connect all the terminal outputs and use microwave transmissions to send the data to the mainframe
  - Collect all the terminal outputs using multiplexing and send the data to the mainframe computer using a conducted line

Business Multiplexing In Action

- XYZ Corporation has two buildings separated by a distance of 300 meters
- A 3-inch diameter tunnel extends underground between the two buildings
- Building A has a mainframe computer and Building B has 66 terminals
- List some efficient techniques to link the two buildings

Business Multiplexing In Action (continued)

Figure 5-15
Buildings A and B and the 3-inch-diameter tunnel connecting the buildings