Chapter Five

Making Connections Efficient: Multiplexing and Compression

Data Communications and Computer Networks: A Business User's Approach

Eighth Edition

After reading this chapter, you should be able to:

- Describe frequency division multiplexing and list its applications, advantages, and disadvantages
- Describe synchronous time division multiplexing and list its applications, advantages, and disadvantages
- Outline the basic multiplexing characteristics of T-1 and SONET/SDH telephone systems
- Describe statistical time division multiplexing and list its applications, advantages, and disadvantages

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After reading this chapter, you should be able to (continued):

- Cite the main characteristics of wavelength division multiplexing and its advantages and disadvantages
- Describe the basic characteristics of discrete multitone
- Cite the main characteristics of code division multiplexing and its advantages and disadvantages
- Apply a multiplexing technique to a typical business situation

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After reading this chapter, you should be able to (continued):

- Describe the difference between lossy and lossless compression
- Describe the basic operation of run-length, JPEG, and MP3 compression

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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

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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

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Frequency Division Multiplexing (continued)

- Each channel is assigned a set of frequencies and is transmitted over the medium
- A corresponding multiplexor, or demultiplexor, is on the receiving end of the medium and separates the multiplexed signals
- A common example is broadcast radio

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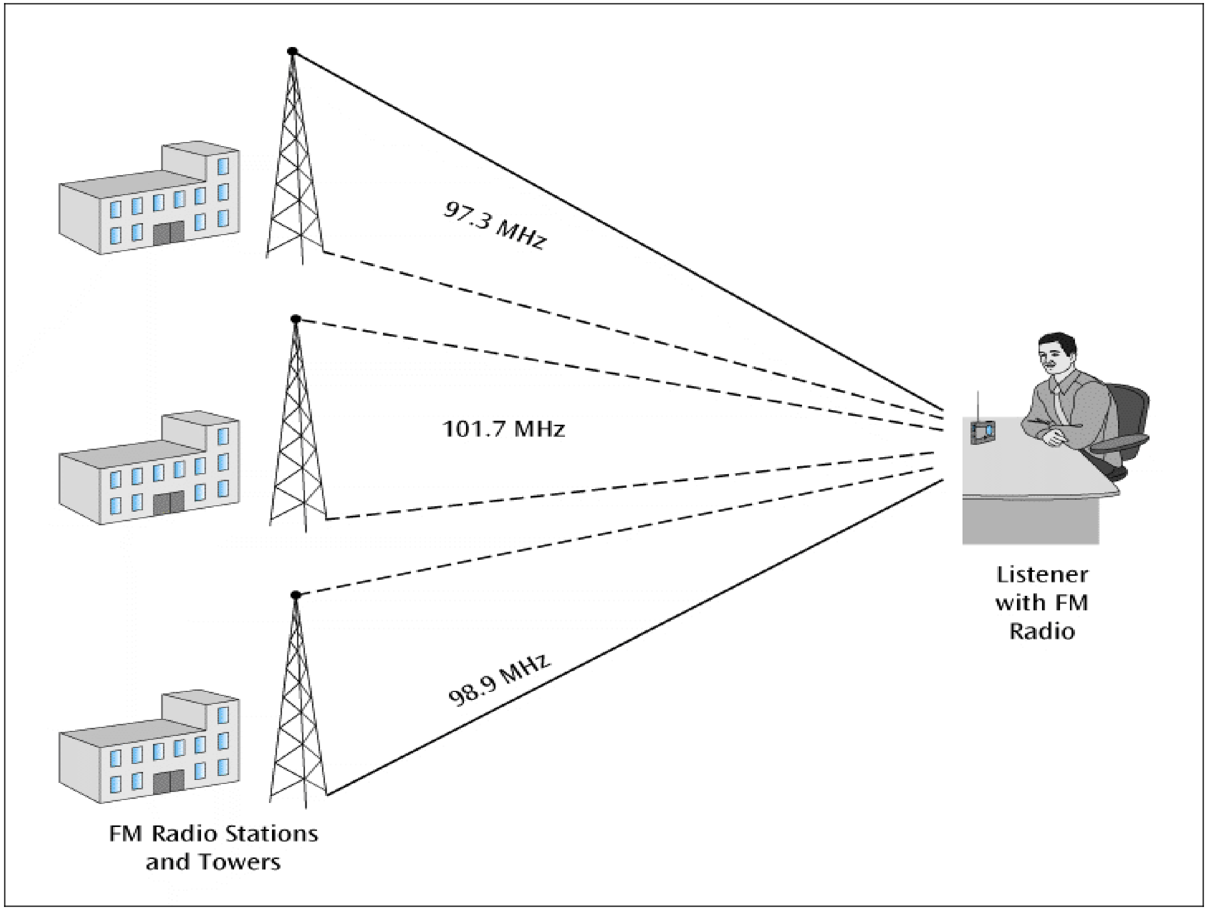
Frequency Division Multiplexing (continued)

Figure 5-1
Simplified example of frequency division multiplexing



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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

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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

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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

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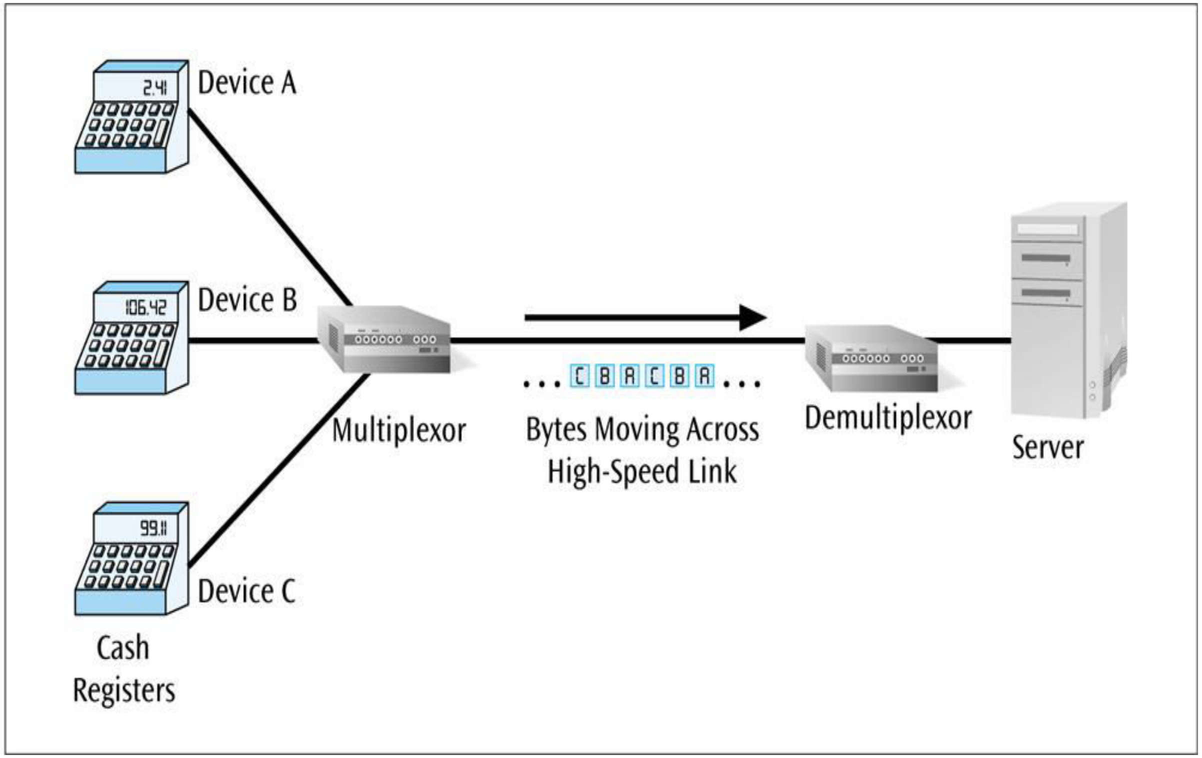
Synchronous Time Division Multiplexing (continued)

Figure 5-2 Several cash registers and their multiplexed stream of transactions



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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

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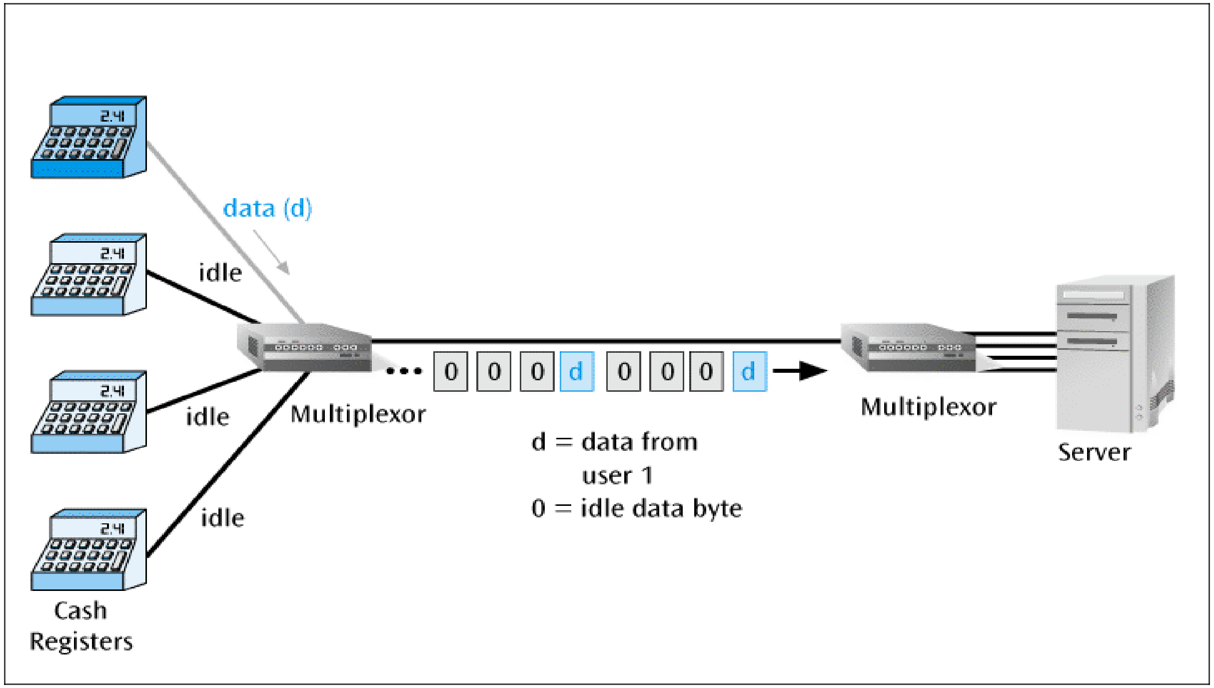
Synchronous Time Division Multiplexing (continued)

Figure 5-3

Multiplexor transmission stream with only one input device transmitting data



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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

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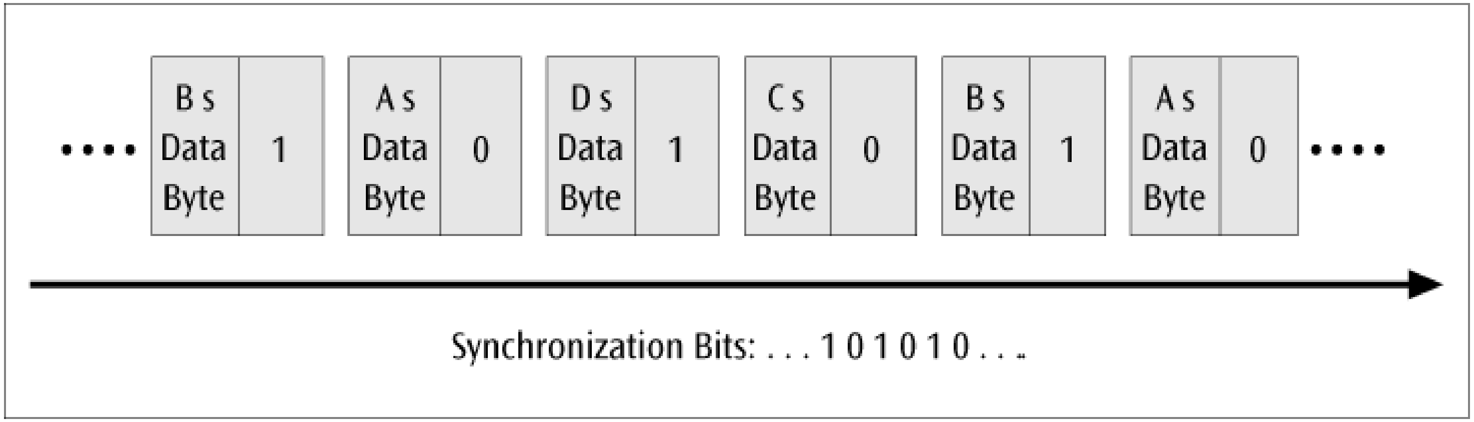
Synchronous Time Division Multiplexing (continued)

Figure 5-4
Transmitted frame with added synchroni-zation bits



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T-1 Multiplexing

- The T-1 multiplexor stream is a continuous series of frames
- Note how each frame contains the data (one byte) for potentially 24 voice-grade telephone lines, plus one sync bit
- It is possible to combine all 24 channels into one channel for a total of 1.544 Mbps

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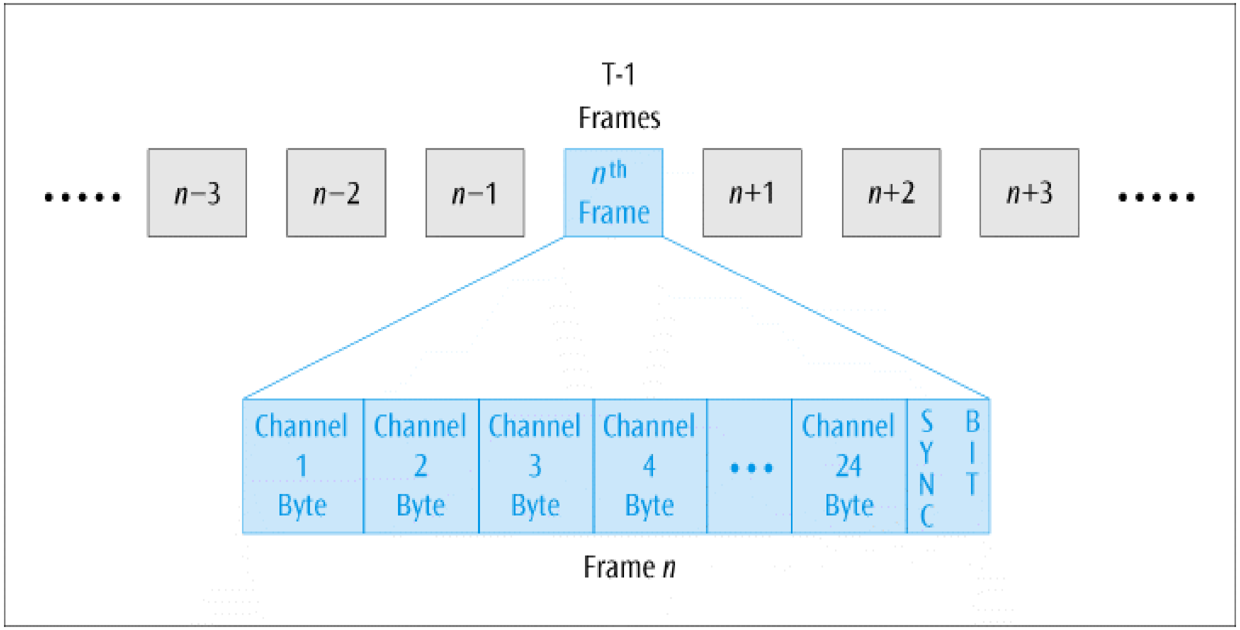
T-1 Multiplexing (continued)

Figure 5-4
T-1 multiplexed data stream



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SONET/SDH Multiplexing

- Similar to T-1, SONET incorporates a continuous series of frames
- SONET is used for high-speed data transmission
- Telephone companies have traditionally used a lot of SONET but this may be giving way to other high-speed transmission services
- SDH is the European equivalent to SONET

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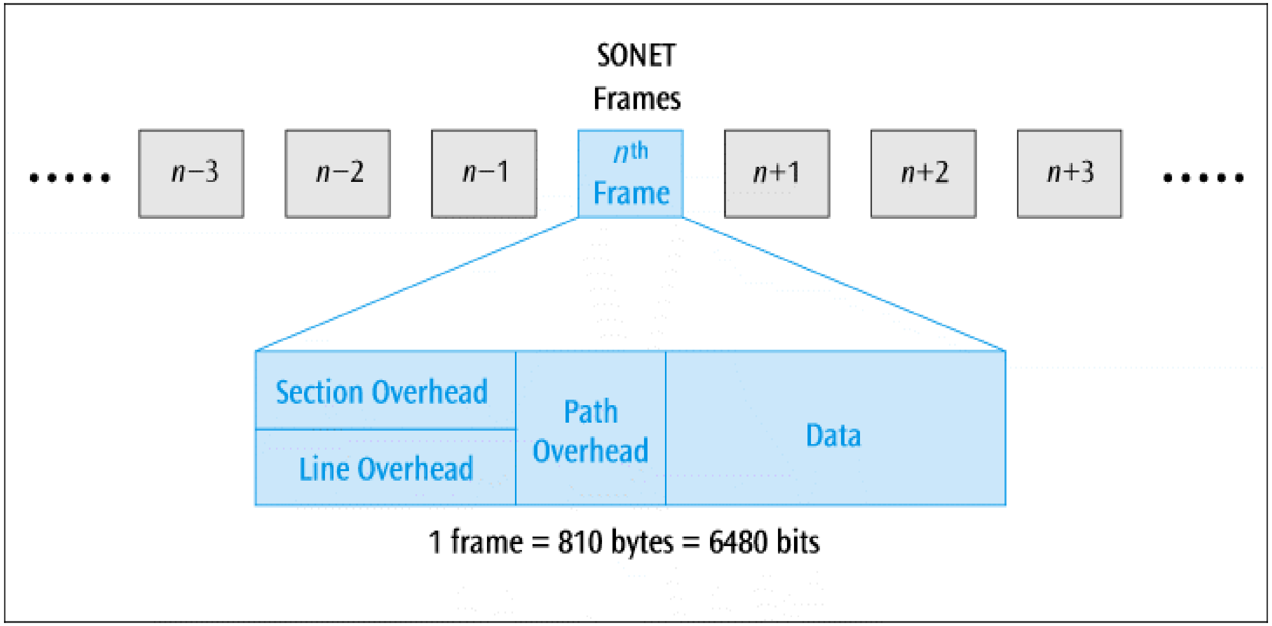
SONET/SDH Multiplexing (continued)

Figure 5-6

SONET STS-1 frame layout



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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

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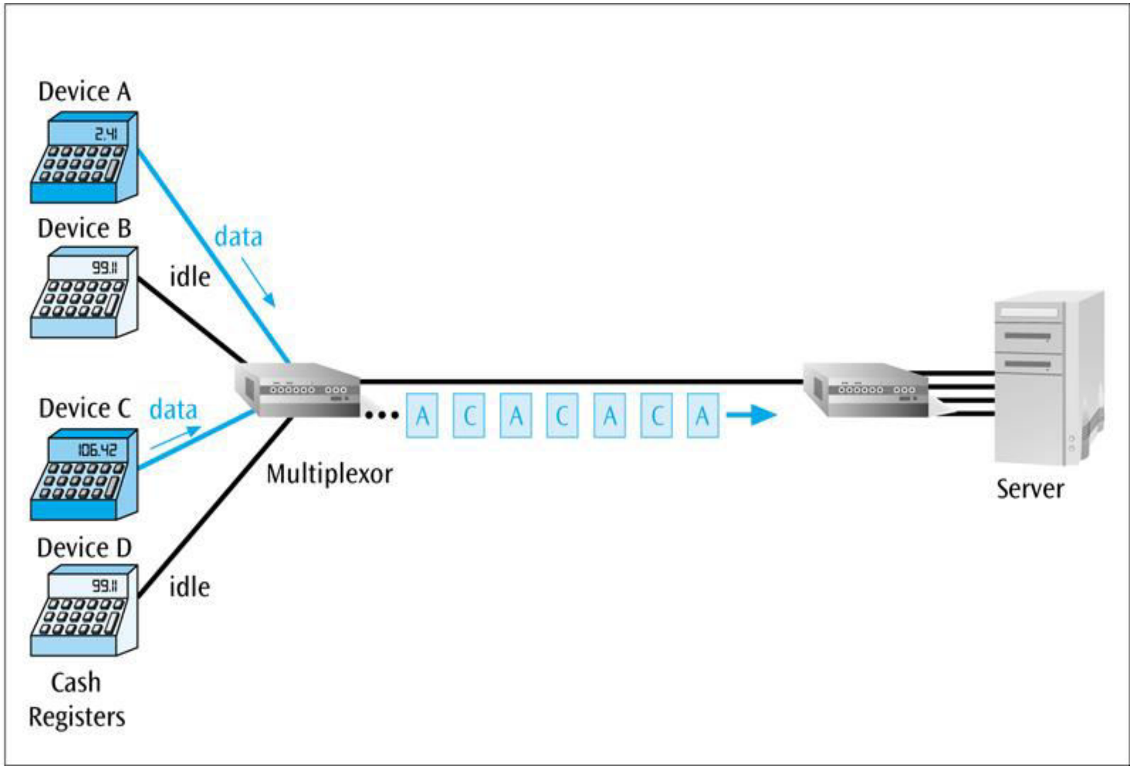
Statistical Time Division Multiplexing (continued)

Figure 5-7 Two stations out of four transmitting via a statistical multiplexor



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Statistical Time Division Multiplexing (continued)

- A statistical multiplexor accepts the incoming data streams and creates a frame containing the data to be transmitted
- To identify each piece of data, an address is included

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Statistical Time Division Multiplexing (continued)

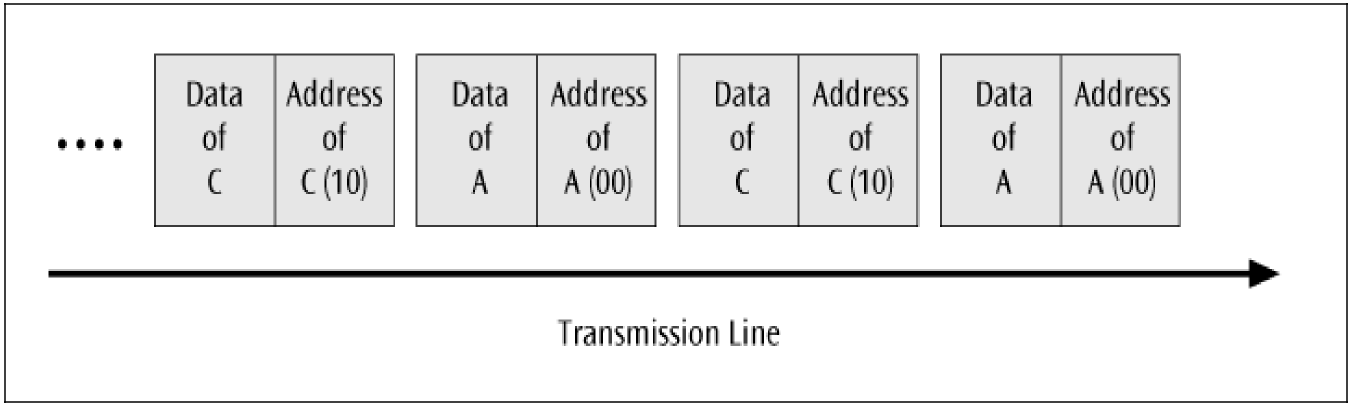

Figure 5-8
Sample address and data in a statistical multiplexor output stream

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Statistical Time Division Multiplexing (continued)

- If the data is of variable size, a length is also included

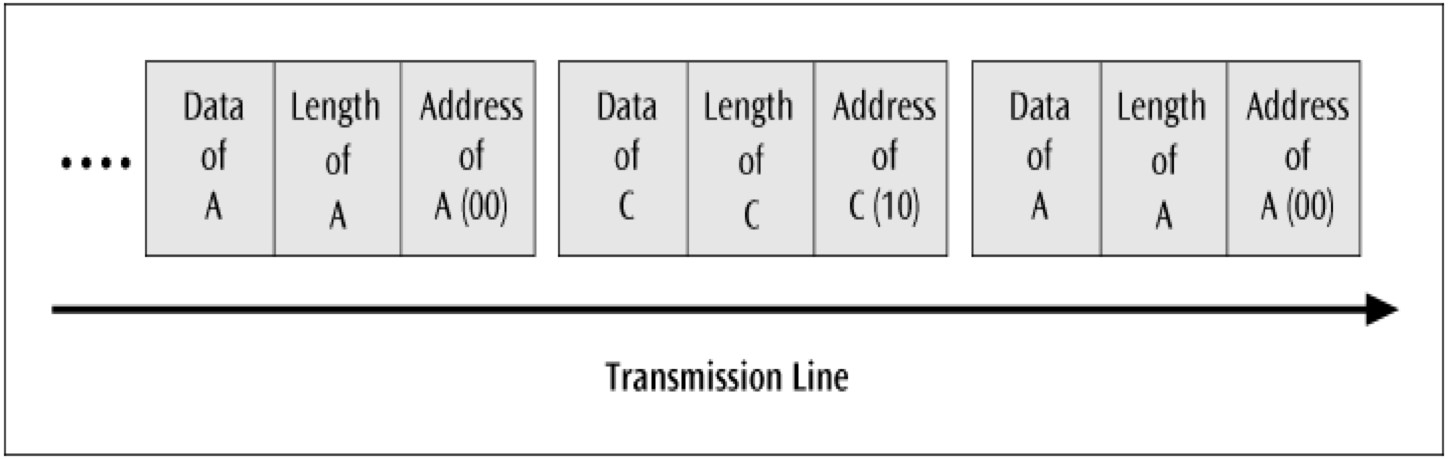

Figure 5-9
Packets of address, length, and data fields in a statistical multiplexor output stream

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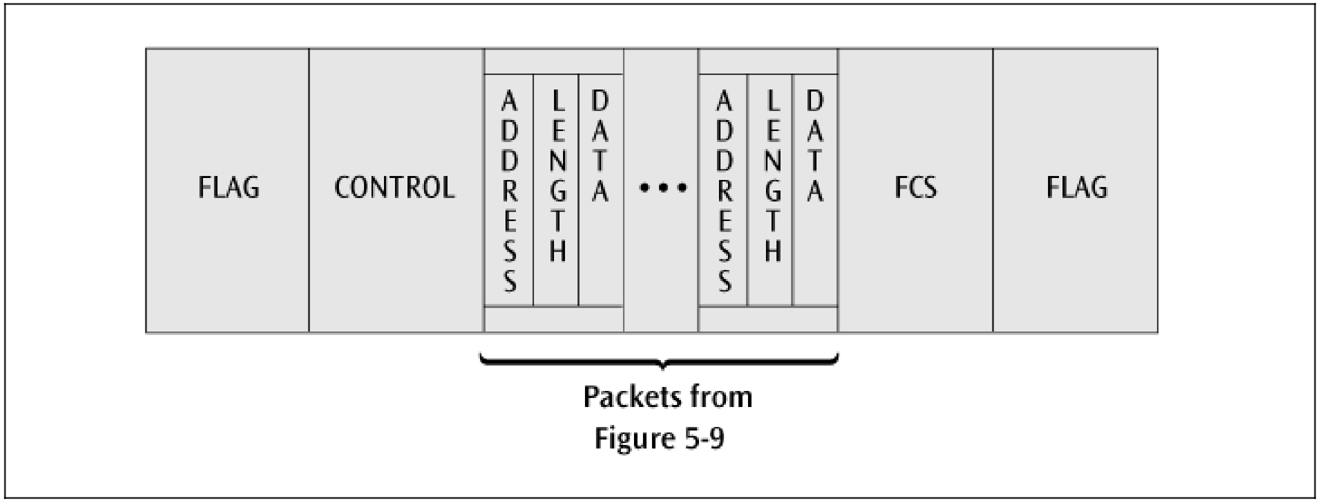
Statistical Time Division Multiplexing (continued)

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

Figure 5-10

Frame layout for the information packet transferred between statistical multiplexors



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Wavelength Division Multiplexing

- Wavelength division multiplexing multiplexes multiple data streams onto a single fiber-optic line
- Different wavelength lasers (called lambdas) transmit the multiple signals

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Wavelength Division Multiplexing (continued)

- Each signal carried on the fiber can be transmitted at a different rate from the other signals
- Dense wavelength division multiplexing combines many (30, 40, 50 or more) onto one fiber
- Coarse wavelength division multiplexing combines only a few lambdas

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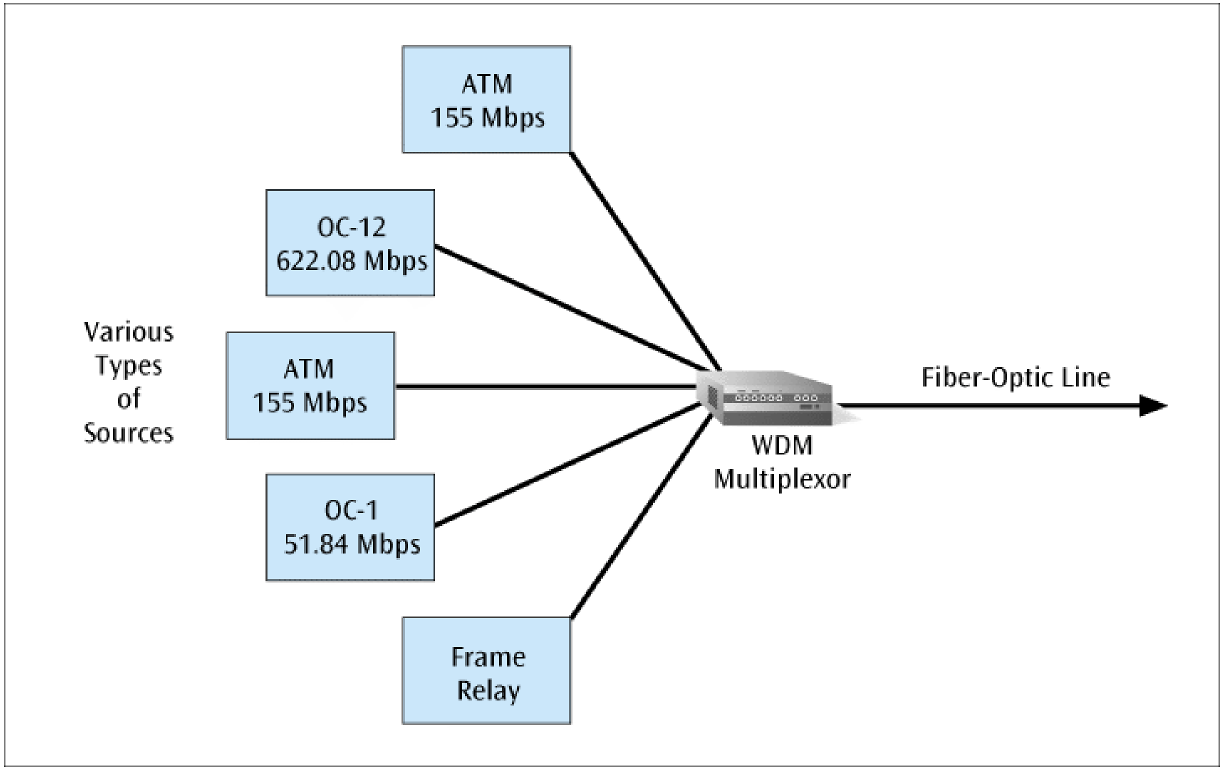
Wavelength Division Multiplexing (continued)

Figure 5-11

Fiber optic line using wavelength division multiplexing and supporting multiple-speed transmissions



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Discrete Multitone

- Discrete Multitone (DMT) – a multiplexing technique commonly found in digital subscriber line (DSL) systems
- DMT combines hundreds of different signals, or subchannels, into one stream
- Interestingly, all of these subchannels belong to a single user, unlike the previous multiplexing techniques

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Discrete Multitone (continued)

- Each subchannel is quadrature amplitude modulated (recall eight phase angles, four with double amplitudes)
- Theoretically, 256 subchannels, each transmitting 60 kbps, yields 15.36 Mbps
- Unfortunately, there is noise, so the subchannels back down to slower speeds

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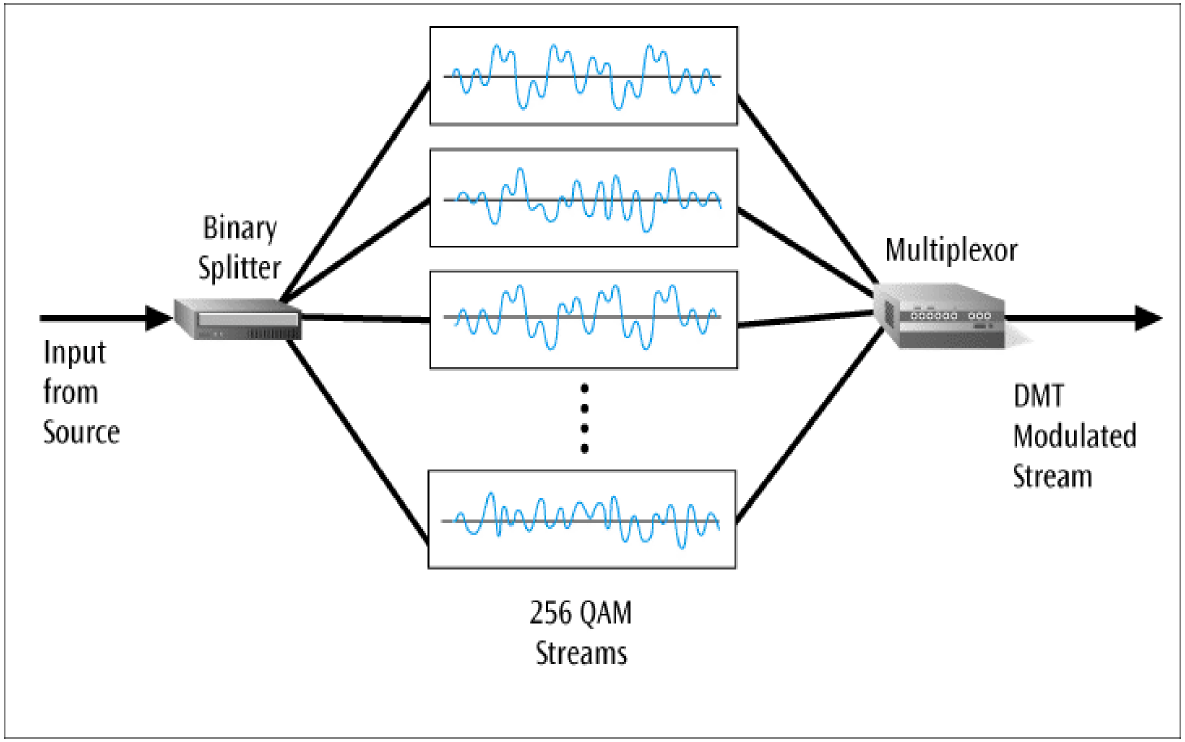
Discrete Multitone (continued)

Figure 5-12

256 quadrature amplitude modulated streams combined into one DMT signal for DSL



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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

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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

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Code Division Multiplexing (continued)

- Receiver gets summed signal, multiplies it by receiver code, 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

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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

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Code Division Multiplexing (continued)

- 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

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Code Division Multiplexing (continued)

- 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

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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

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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

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Compression–Lossless versus Lossy

- Compression is another technique used to squeeze more data over a communications line or into a storage space
  - If you can compress a data file down to one half of its original size, the 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

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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, Lempel-Ziv compression, and FLAC
- Examples of lossy compression include:
  - MPEG, JPEG, and MP3

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Lossless Compression

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

00000000000000100000000011000000000000000000001…11000000000001

^

(30 0s)

14 9 0 20 30 0 11

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Lossless Compression (continued)

- Run-length encoding (continued)
  - Now replace each decimal value with a 4-bit binary value (nibble)
    - Note: If you need to code a value larger than 15, you need to use two consecutive 4-bit nibbles
      - The first is decimal 15, or binary 1111, and the second nibble is the remainder
        - » For example, if the decimal value is 20, you would code 1111 0101 which is equivalent to 15 + 5

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Lossless Compression (continued)

- Run-length encoding (continued)
  - If you want to code the value 15, you still need two nibbles: 1111 0000
    - The rule is that if you ever have a nibble of 1111, you must follow it with another nibble

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Lossy Compression

- Audio and video files do not compress well using lossless techniques
- And we can take advantage of the fact that the human ear and eye can be tricked into hearing and seeing things that aren’t really there
- So let’s use lossy compression techniques on audio and video (just as long as we don’t lose too much of the audio or video!)

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Audio Compression

- Much audio is now compressed - MP3 players found in cell phones and iPod-like devices store and play compressed music
- Audio compression is tricky and hard to describe. For example, a louder sound may mask a softer sound when both played together (so drop the softer sound)
- Some people don’t like compressed audio and prefer to store their music in uncompressed form (such as FLAC), but this takes more storage

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Video Compression

- Video (both still images and moving video) does not compress well using run-length encoding
  - When examining the pixel values in an image, not many are alike
- But what about from frame to frame within a moving video?
  - The difference between video frames is usually very small
  - So what if we just sent the difference between frames?

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Video 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

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MPEG

- MPEG (Motion Picture Experts Group) is a group of people that have created a set of standards that can use these small differences between frames to compress a moving video (and audio) to a fraction of its original size

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Image Compression

- What about individual images?
- For example, a color image can be defined by red/green/blue, or luminance/chrominance/ chrominance, which are based on RGB values (Red, Green, Blue)
- If you have three color values and each is 8 bits, you have 24 bits total (or 2^{24} colors!)

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Image Compression (continued)

- Consider a VGA screen is 640 x 480 pixels
  - 24 bits x 640 x 480 = 7,372,800 bits – Ouch!
  - We need compression!

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Image Compression (continued)

- JPEG (Joint Photographic Experts Group)
  - Compresses still images
  - Lossy
  - JPEG compression consists of 3 phases:
    - Discrete cosine transformations (DCT)
    - Quantization
    - Run-length encoding

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JPEG (continued)

- JPEG Step 1 – DCT
  - Divide image into a series of 8x8 pixel blocks
  - If the original image was 640x480 pixels, the new picture would be 80 blocks x 60 blocks (next slide)
  - If B&W, each pixel in 8x8 block is an 8-bit value (0-255)
  - If color, each pixel is a 24-bit value (8 bits for red, 8 bits for blue, and 8 bits for green)

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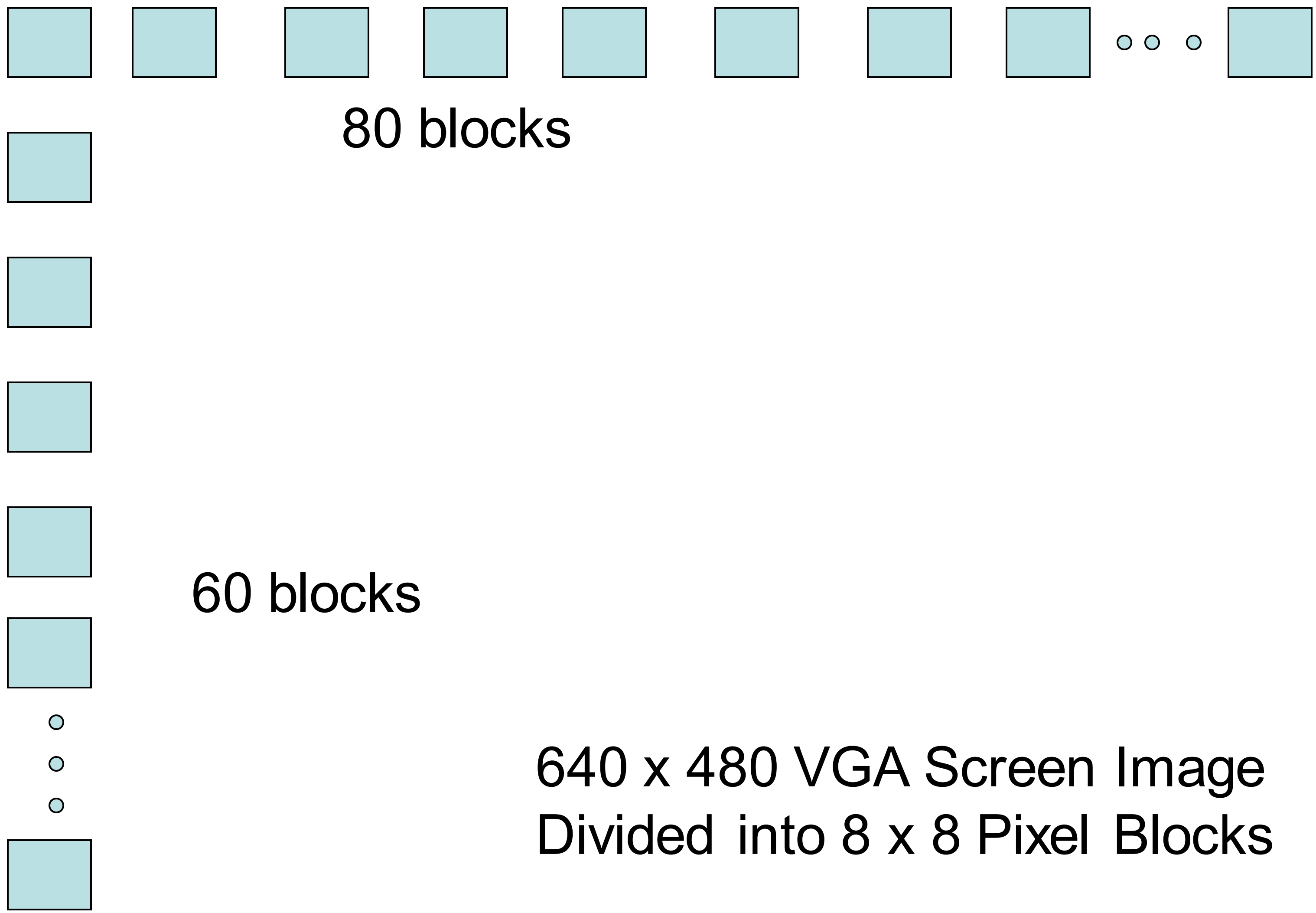
JPEG (continued)



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JPEG (continued)

- JPEG Step 1 – DCT (continued)
  - So what does DCT do?
    - Takes an 8x8 matrix (P) and produces a new 8x8 matrix (T) using cosines
    - T matrix contains a collection of values called spatial frequencies
    - These spatial frequencies relate directly to how much the pixel values change as a function of their positions in the block

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JPEG (continued)

- JPEG Step 1 – DCT (continued)
  - An image with uniform color changes (little fine detail) has a P matrix with closely similar values and a corresponding T matrix with many zero values
  - An image with large color changes over a small area (lots of fine detail) has a P matrix with widely changing values, and thus a T matrix with many non-zero values (as shown on next slide)

120	80	110	65	90	142	56	100
40	136	93	188	90	210	220	56
95	89	134	74	170	180	45	100
9	110	145	93	221	194	83	110
65	202	90	18	164	90	155	43
93	111	39	221	33	37	40	129
55	122	52	166	93	54	13	100
29	92	153	197	84	197	83	83

Original pixel values (P matrix)

652	32	-40	54	-18	129	-33	84
111	-33	53	9	123	-43	65	100
-22	101	94	-32	23	104	76	101
88	33	211	2	-32	143	43	14
132	-32	43	0	122	-48	54	110
54	11	133	27	56	154	13	-94
-54	-69	10	109	65	0	17	-33
199	-18	99	98	22	-43	8	32

Values (T matrix) after the cosine transformation has been applied (note larger values in upper-left)

JPEG (continued)

- JPEG Step 2 -Quantization
  - The human eye can't see small differences in color
  - So take T matrix and divide all values by 10
    - Will give us more zero entries
      - More 0s means more compression!
    - But this is too lossy
    - And dividing *all* values by 10 doesn't take into account that upper left of matrix has more weight
    - So divide T matrix by a matrix like the following:

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JPEG (continued)

1	4	7	10	13	16	19	22
4	7	10	13	16	19	22	25
7	10	13	16	19	22	25	28
10	13	16	19	22	25	28	31
13	16	19	22	25	28	31	33
16	19	22	25	28	31	33	36
19	22	25	28	31	34	37	40
22	25	28	31	34	37	40	43

If we divide the T matrix by the above matrix, we might get something like the next slide:

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JPEG (continued)

652	8	-5	5	-1	8	0	3
27	-4	5	0	7	-2	2	4
-3	10	7	2	1	4	3	3
8	2	13	0	-1	5	1	0
10	-2	2	0	4	-1	1	3
3	0	6	1	2	4	0	-2
-2	-3	0	3	2	0	0	0
9	0	3	3	0	-1	0	0

The resulting matrix Q after cosine transformation and quantization

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JPEG (continued)

- JPEG Step 3 – Run-length encoding
  - Now take the quantized matrix Q and perform run-length encoding on it
    - But don't just go across the rows
      - Longer runs of zeros if you perform the run-length encoding in a diagonal fashion

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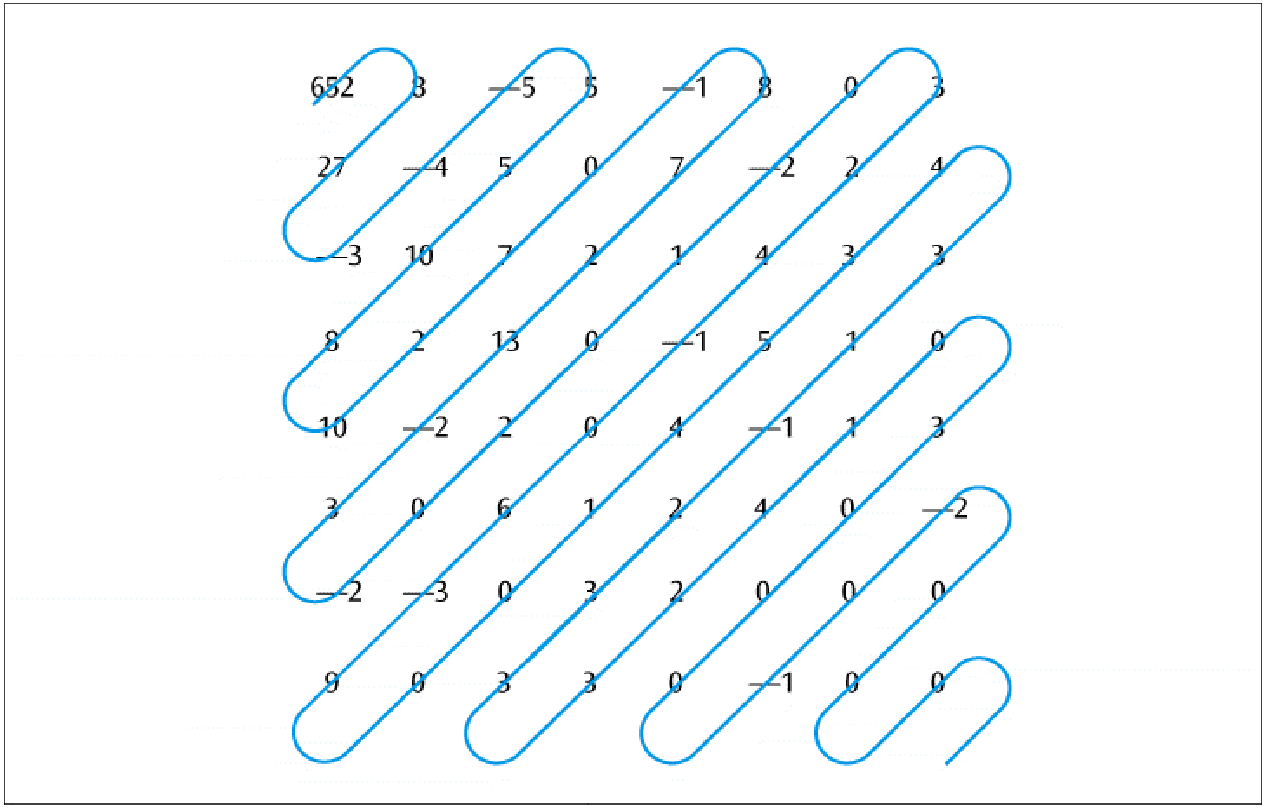
JPEG (continued)

Figure 5-13

Run-length encoding of a JPEG image



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JPEG (continued)

- How do you get the image back?
  - Undo run-length encoding
  - Multiply matrix Q by matrix U yielding matrix T
  - Apply similar cosine calculations to get original P matrix back

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Business Multiplexing In Action

- Bill’s Market has 10 cash registers at the front of their store
- Bill wants to connect all cash registers together to collect data transactions
- List some efficient techniques to link the cash registers

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Business Multiplexing In Action (continued)

- Possible solutions
  - Connect each cash register to a server using point-to-point lines
  - Transmit the signal of each cash register to a server using wireless transmissions
  - Combine all the cash register outputs using multiplexing, and send the multiplexed signal over a conducted-medium line

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Summary

- For multiple signals to share a single medium, the medium must be divided into multiple channels
- Frequency division multiplexing involves assigning nonoverlapping frequency ranges to different signals
  – Uses analog signals
- Time division multiplexing of a medium involves dividing the available transmission time on a medium among the users
  – Uses digital signals

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Summary (continued)

- Synchronous time division multiplexing accepts input from a fixed number of devices and transmits their data in an unending repetitious pattern
- Statistical time division multiplexing accepts input from a set of devices that have data to transmit, creates a frame with data and control information, and transmits that frame
- Wavelength division multiplexing involves fiber-optic systems and the transfer of multiple streams of data over a single fiber using multiple, colored laser transmitters
- Discrete multitone is a technology used in DSL systems

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Summary (continued)

- Code division multiplexing allows multiple users to share the same set of frequencies by assigning a unique digital code to each user
- Compression is a process that compacts data into a smaller package
- Two basic forms of compression exist: lossless and lossy
- Two popular forms of lossless compression include run-length encoding and the Lempel-Ziv compression technique
- Lossy compression is the basis of a number of compression techniques

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