MODULE 12: Network Components and Access Technologies

Lecture 12.2
Physical Layer

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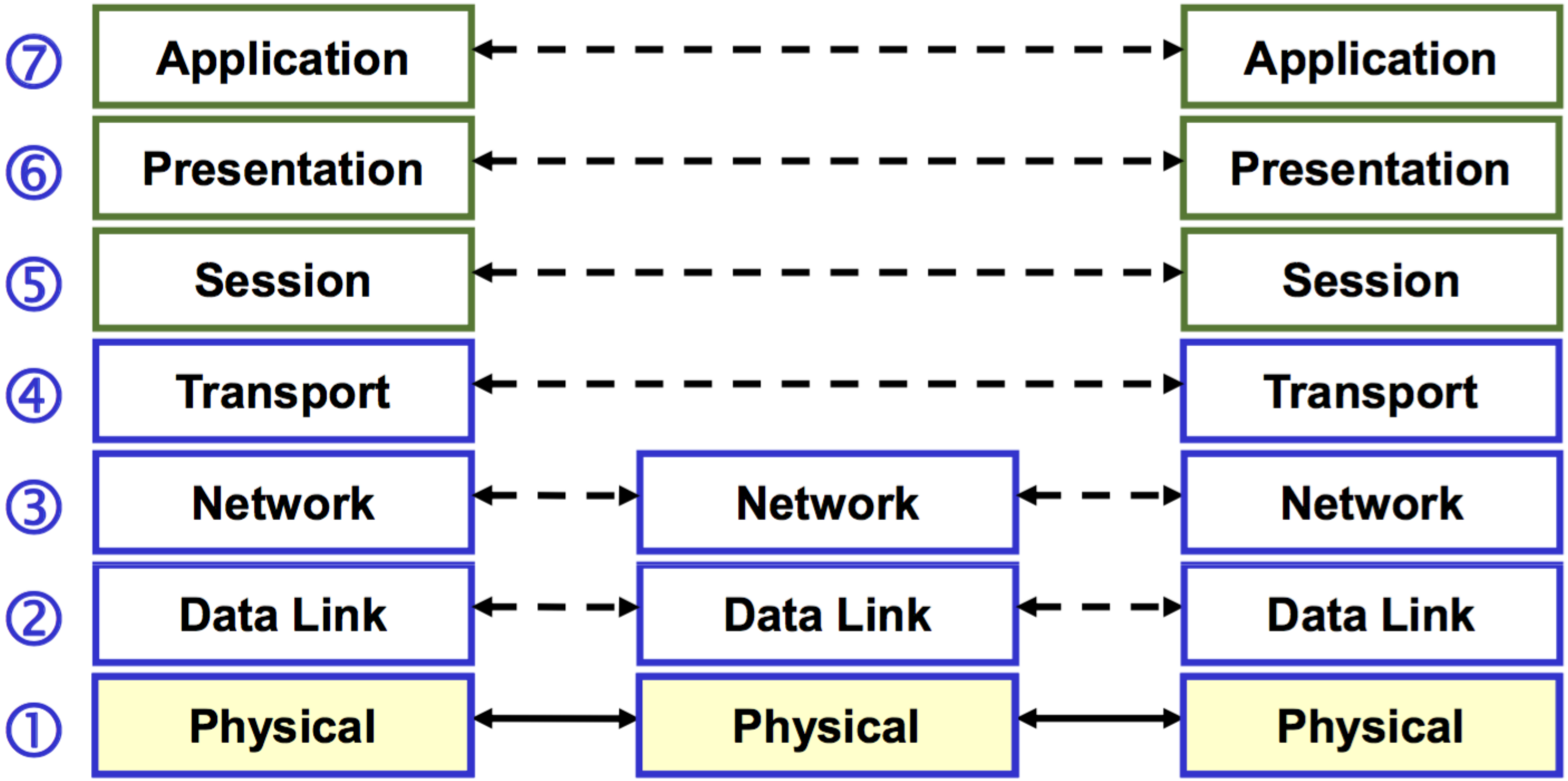
Lecture 12.2 Objectives

- Describe the concepts of analog versus digital communication
- Show how a bit string can be encoded using NRZ-L, NRZI, and 4B/5B-NRZI codes
- Identify the factors that affect capacity
- Describe the characteristics of transmission media, including twisted pair, coaxial cable, fiber, and wireless media
- Differentiate between grades of twisted pair
- Describe the concept of a digital transmission hierarchy, and describe the concept in the context of T-Carrier (E- Carrier) and SONET (SDH) optical carrier hierarchy

OSI Seven-Layer Reference Model



Physical Layer Functionality

- The physical (PHY) layer provides a virtual link for transmitting a sequence of bits between any pair of nodes joined by a physical communication channel – a “virtual bit pipe”
- Defines physical interface, signaling, cabling, connectors, etc.
- There may be variations at the physical level for a basic data link protocol
  - IEEE 802.3 (Ethernet) offers an historical example: 10Base5 (thick wire), 10Base2 (thin wire), 10BaseT (twisted pair)

Digital Communications

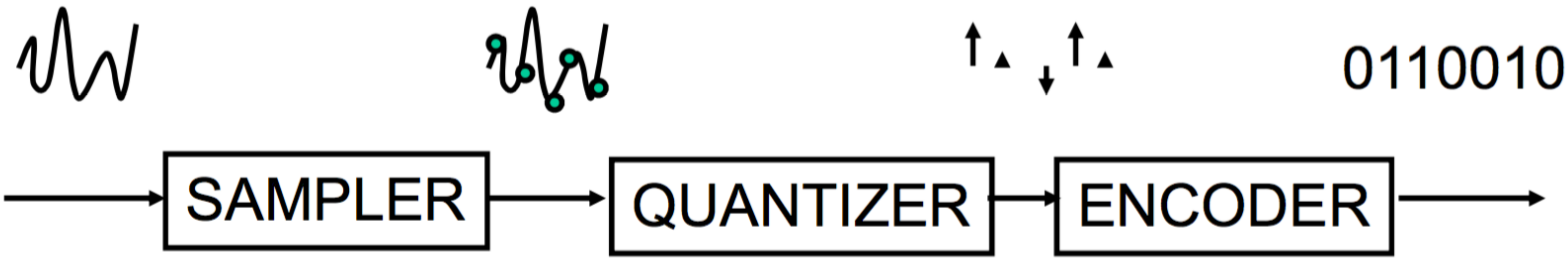
- Contemporary communications are dominated by digital communications
- Advantages of digital transmission include:
    - Data integrity
    - Efficient capacity utilization
    - Security

Analog Versus Digital Data

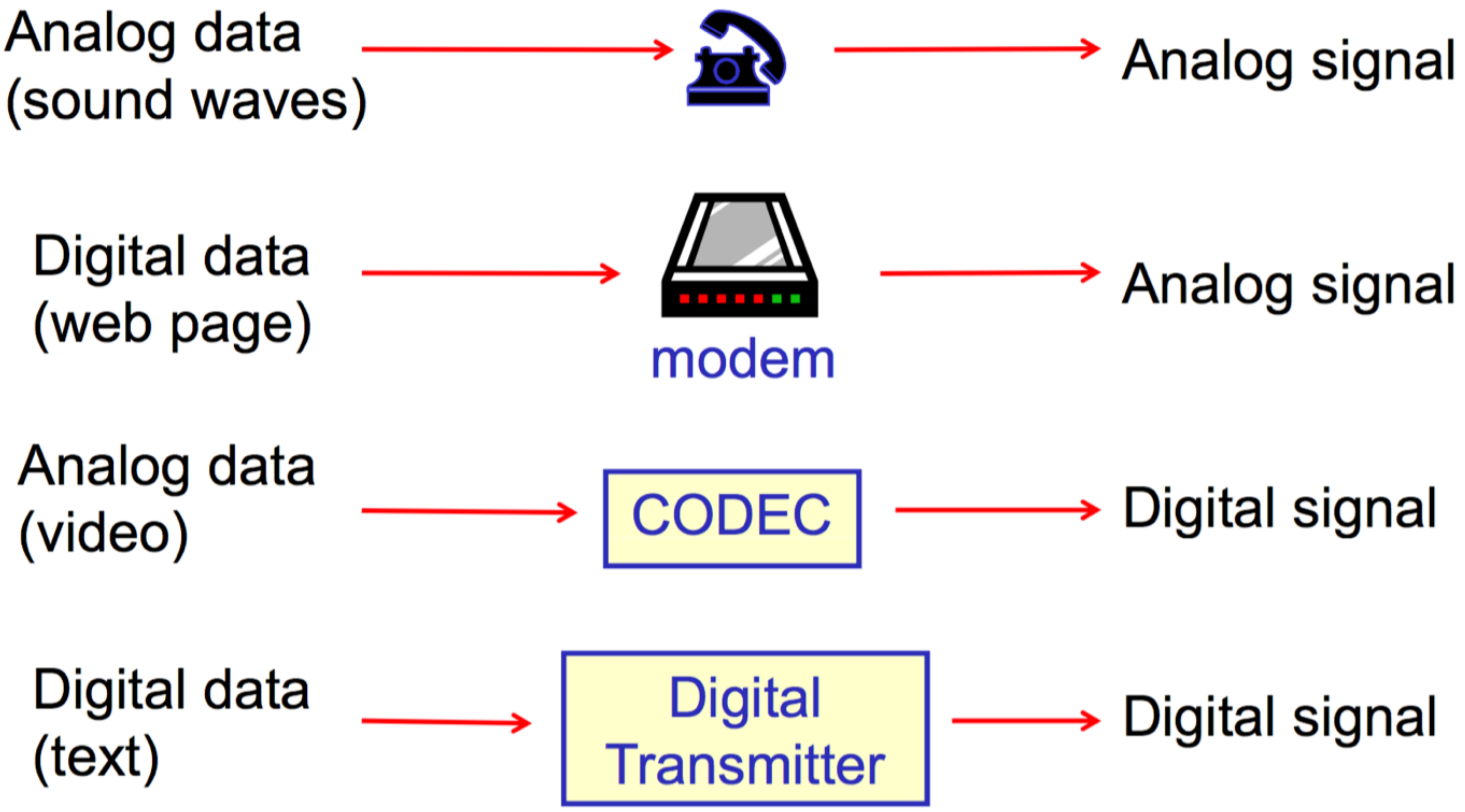
- Analog data – take on continuous values
  - Examples include speech and (traditional) video
  - Generally, occupy limited frequency spectrum
- Digital data – take on discrete values
  - Examples include text and integers
  - ASCII (American Standard Code for Information Interchange) represents characters by a 7-bit pattern
  - Analog data such as speech and video are often digitized – represented by discrete values

Digitization of Analog Data

- Analog data (e.g., speech) can be digitized
- The digitization process involves sampling, quantizing and encoding



Digital and Analog Data and Signals



Analog Versus Digital Transmission

- Analog transmission – used to transmit analog signals without regard for content
  - Amplifiers are used to boost the energy level of the signal (also the noise)
- Digital transmission – transmission is concerned with the content of the signal (at the 1/0 or symbol level)
  - Repeaters periodically re-generate the signal

CHECK POINT

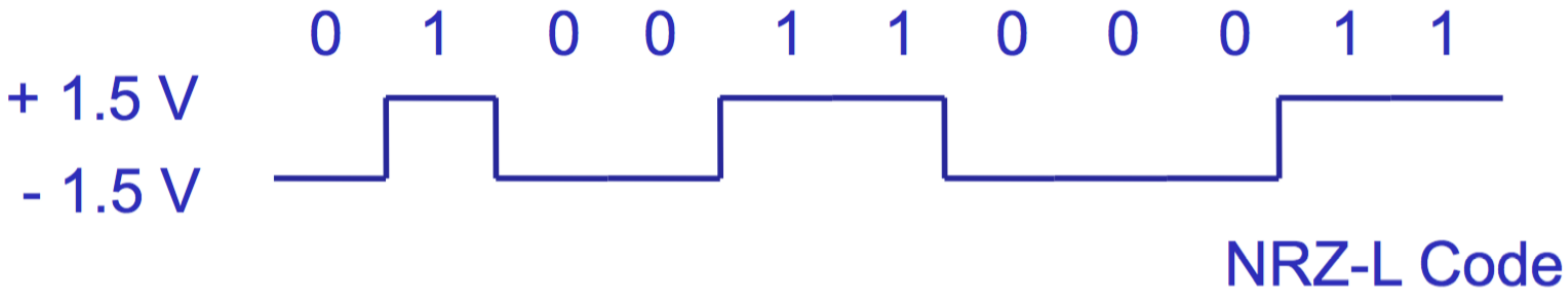
As a checkpoint of your understanding, please pause the video and make sure you can do the following:

- Describe the concepts of analog versus digital communication

If you have any difficulties, please review the lecture video before continuing.

Non-Return to Zero (NRZ) Line Coding

- Some coding scheme is needed to encode symbols (e.g., “1” and “0”) during transmission – NRZ is a simple example
- Constant voltage level during the transmission of a bit
- Examples of NRZ-L (level) coding:
  - 0 V to represent a “0”, 3 V to represent a “1”
  - -1.5 V to represent a “0”, +1.5 V to represent a “1”

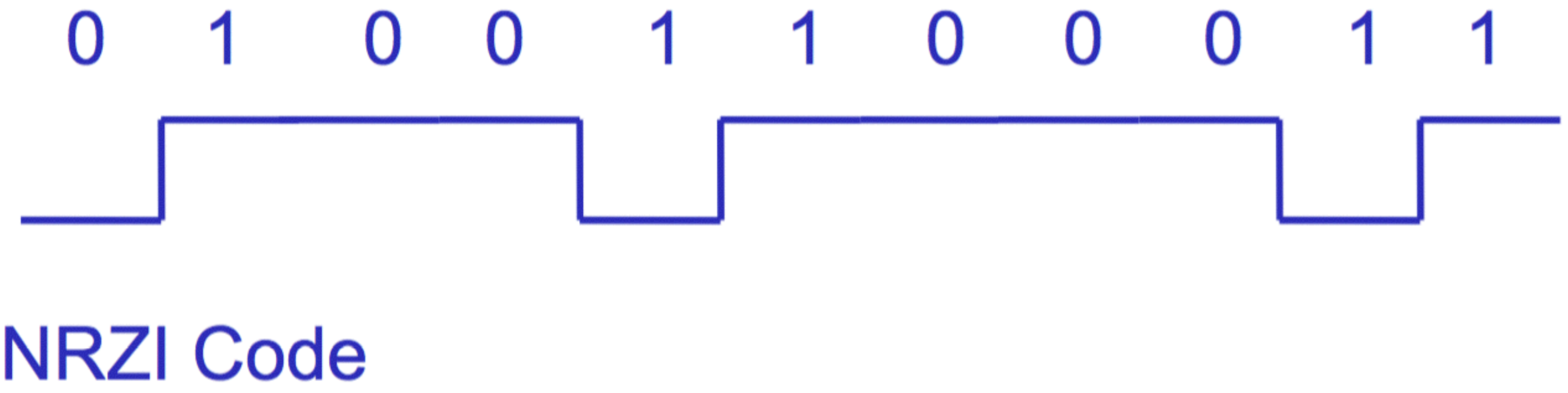


NRZ Line Coding (cont’d)

- Advantages
  - Simplicity
  - Makes efficient use of bandwidth
- Problems
  - Lack of synchronization capabilities (transitions not ensured)
  - DC (direct current) wander if the number of 0’s and 1’s is unbalanced

Non-Return to Zero, Invert on Ones

- NRZI (Non-return to zero, invert on ones) – a variation of NRZ
- A transition indicates a “1”, absence of transition a “0” (differential encoding)
- More reliable detection in the presence of noise
- Does not depend upon correct sensing of polarity (unlike NRZ-L)



4B/5B-NRZI Block Coding

- Each 4 bits of data are encoded into a symbol with 5 code bits (a code group) – 80% efficiency
- Advantages
  - Synchronization – 5-bit patterns chosen to guarantee no more than 3 0’s in a row
  - Bits are further encoded using NRZI for better reception reliability
- Some symbols reserved for control use
- Accepted in practice
  - 100BASE-X
  - Fiber Distributed Data Interface (FDDI) LANs

4B/5B Code Groups

4-bit input	5-bit code	NRZI pattern
0000	11110	
0001	01001	
0010	10100	
0011	10101	
0100	01010	
0101	01011	
0110	01110	
0111	01111	
1000	10010	
1001	10011	

4-bit input	5-bit code	NRZI pattern
1010	10110	
1011	10111	
1100	11010	
1101	11011	
1110	11100	
1111	11101	
idle	11111	

There are other control patterns and Invalid codes

CHECK POINT

As a checkpoint of your understanding, please pause the video and make sure you can do the following:

- Show how a bit string can be encoded using NRZ-L, NRZI, and 4B/5B-NRZI codes

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Link Capacity

- One wants to transmit as much information as possible using as little frequency bandwidth as possible with as few errors as possible
- Reducing bandwidth (the range of frequencies that need to be in the transmitted signal) can:
  - Reduce the cost of media and components
  - Reduce radio frequency spectrum use in wireless communications
- Reducing the number of errors leads to:
  - Delivery of more correct information
  - Reduces the need for error coding and/or retransmission

Capacity Limits

- “Capacity is the maximum rate at which we can send information over the channel and recover the information at the output with vanishing low probability of error.”*
- Shannon’s Theorem provides an upper bound on link capacity

$$C = B\log_2(1+\frac{S}{N})$$

Achievable capacity

Available bandwidth (Hz)

Signal-to-noise ratio (SNR)

* Cover & Thomas, *Elements of Information* Theory, Wiley, 1991

Capacity and Media

- The available bandwidth and signal-to-noise ratio depend, in part, on the physical media
- Example types of media
  - Copper twisted pair
  - Coaxial cable
  - Optical fiber
  - Radio Frequency (wireless) media
  - Free-space optical media
  - Infrared media

Twisted Pair Media

- Two wires twisted together
- 26 to 16 gauge, one twist every 2 to 6 inches
- Twist minimizes interference from other wire pairs

Response time, τ

$$\tau = \left(\frac{DK}{4Z_0}\right)^2$$

- D is length of the line, Z_0 is characteristic impedance, K is a constant depending on line parameters
- Data rate is inversely proportional to response time
- So, data rate is inversely proportional to the square of line length D

Grades of Twisted-Pair Wiring

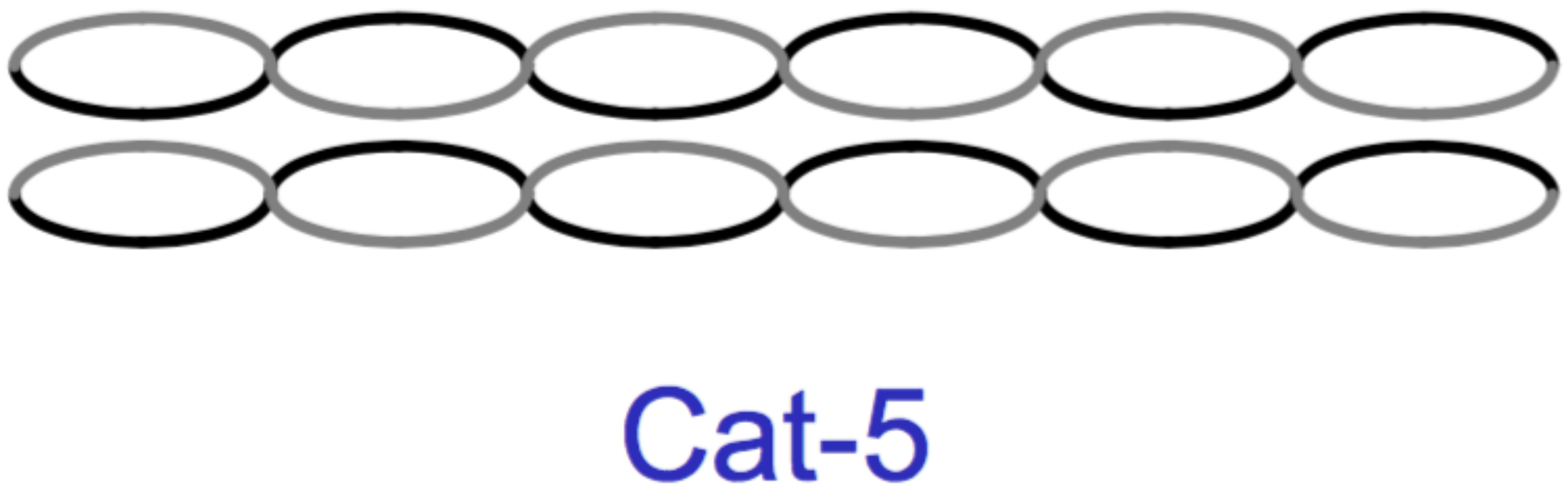
- Category 3 – voice-grade unshielded twisted pair (UTP)
  - 22 to 26 gauge
  - Data rates up to 10 Mbps (10-Mbps 10BaseT Ethernet)
- Category 4 – UTP for data transmission
  - Increased number of twists
  - Data rates up to 20 Mbps

Cat-3

Cat-4

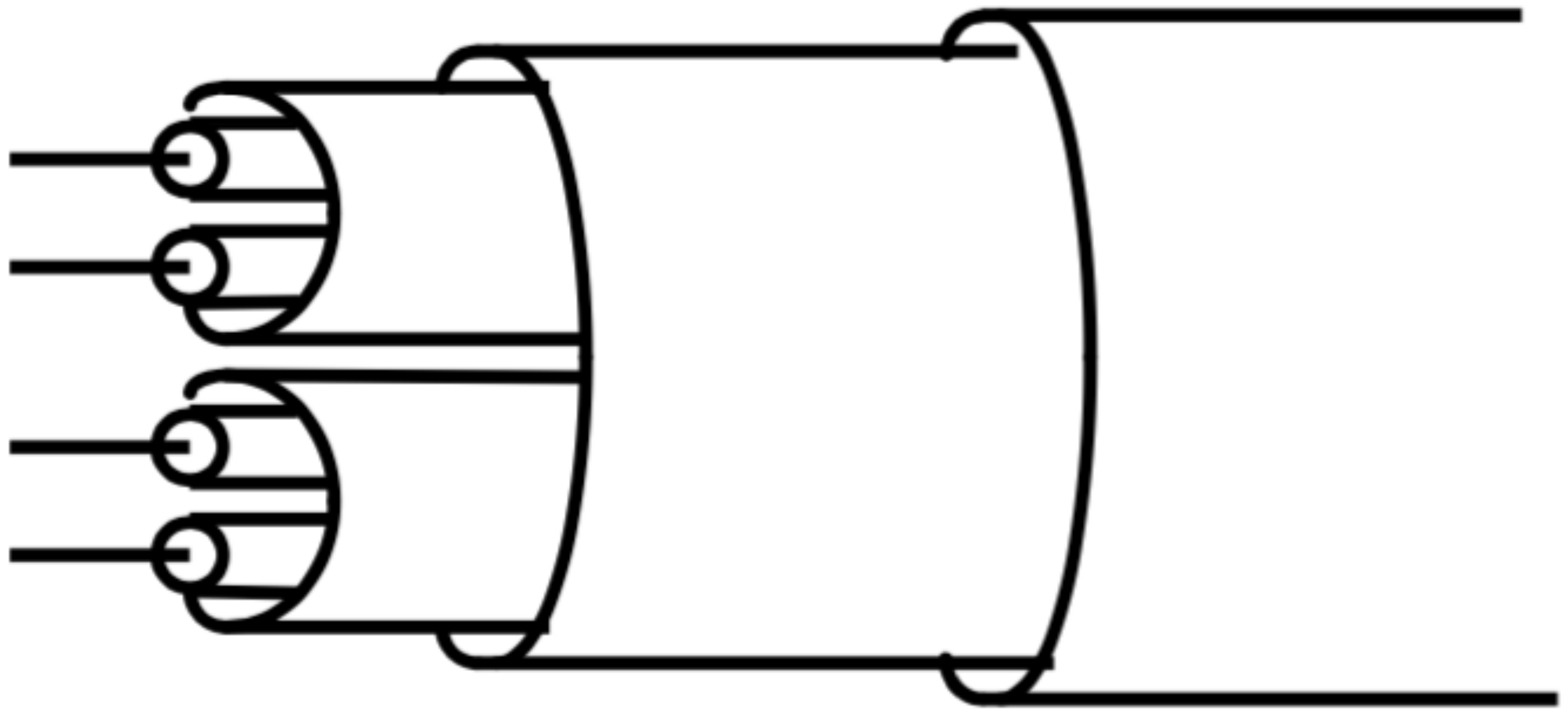
Grades of Twisted-Pair Wiring (cont'd)

- Category 5 – data-grade UTP
  - 2 wire pairs
  - Data rates beyond 100 Mbps (100-Mbps Fast Ethernet, 125-Mbps FDDI, 155-Mbps ATM)



Grades of Twisted-Pair Wiring (cont'd)

- Type 1 – shielded twisted pair (STP)
  - Two pairs
  - Conductive shielding or wire braided mesh around each pair
  - Another conductive shielding around both pairs
  - Data rate of 16 Mbps (16 Mbps Token Ring)



CHECK POINT

As a checkpoint of your understanding, please pause the video and make sure you can do the following:

- Identify the factors that affect capacity
- Describe the characteristics of twisted pair media

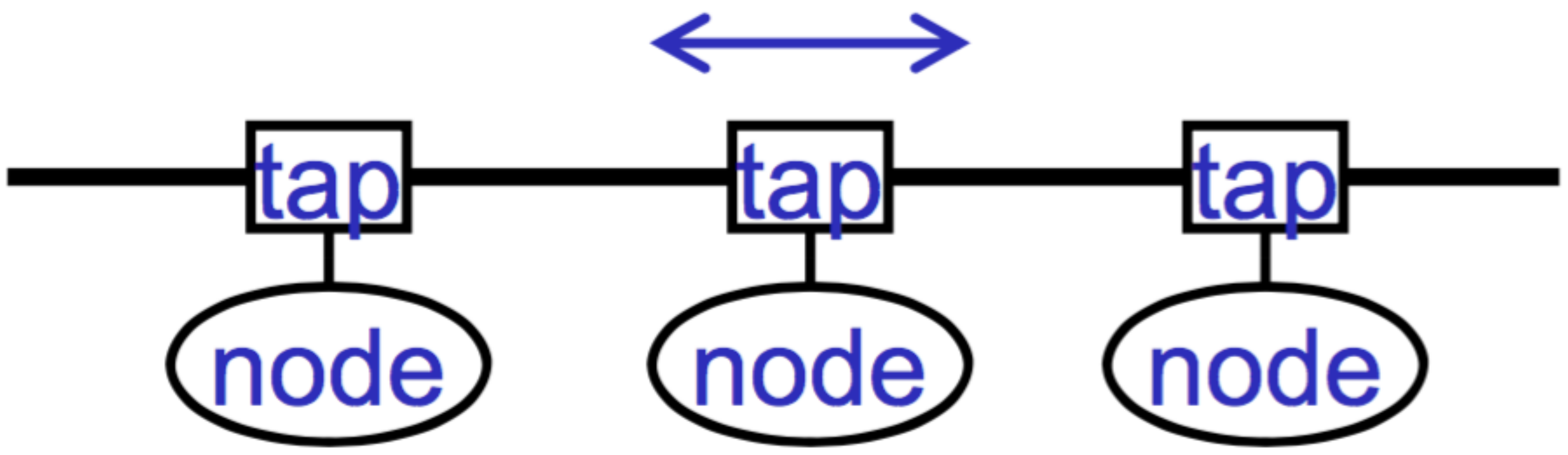
If you have any difficulties, please review the lecture video before continuing.

Coaxial Cable

- Coaxial cable versus twisted pair
  - Coax supports higher data rate, has lower errorr ates, allows longer distances between nodes
  - Coax is more expensive – cable, connectors, installation
  - Types: baseband and broadband
- Baseband
  - Data rates to 20 Mbps at distances of up to 2 km can be provided with low-cost cable using baseband signaling
  - Baseband signals are in just one frequency band and travel in both directions

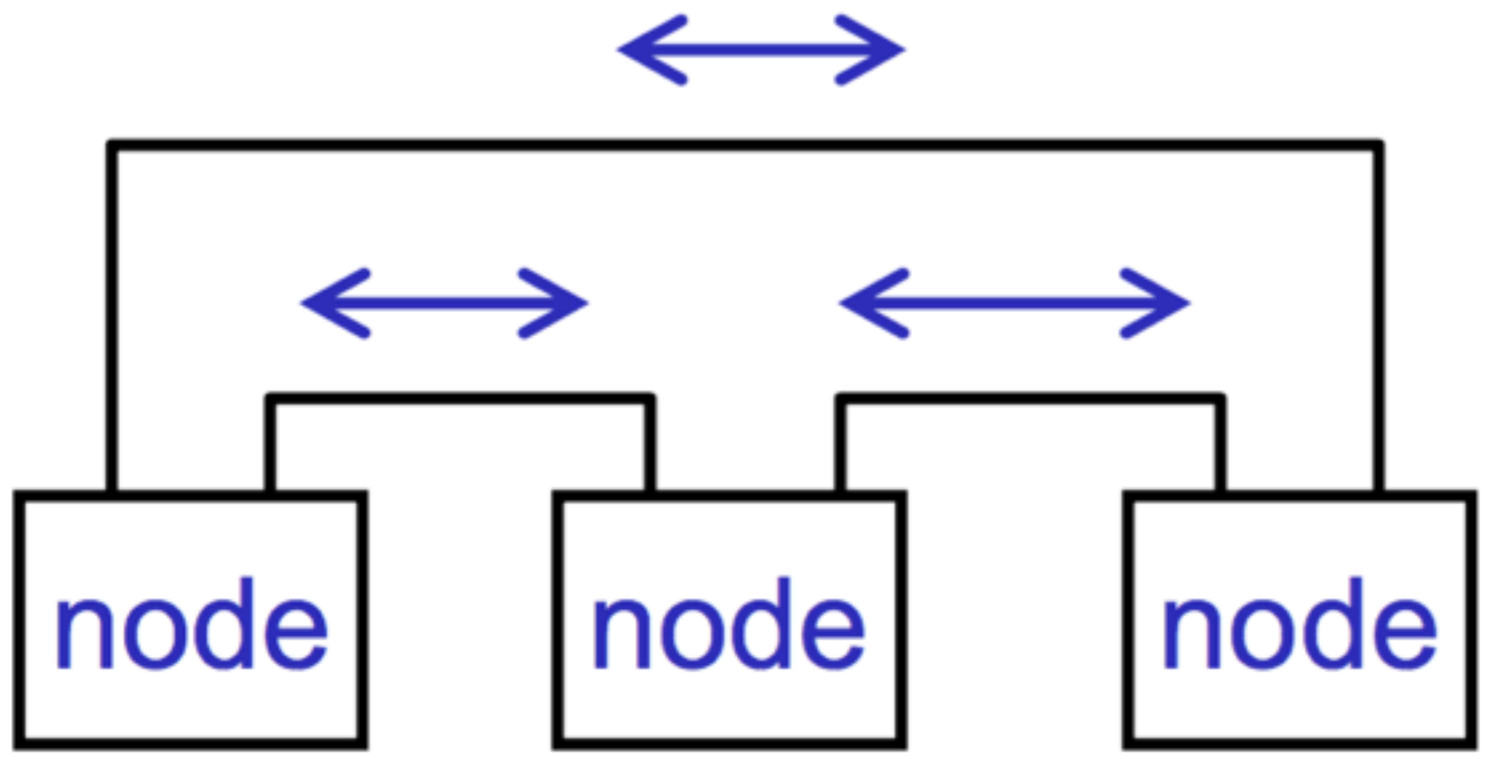
Coaxial Cable (cont'd)

- Broadband
  - Higher data rates or distances provided with more expensive cable using broadband signaling
  - Broadband restricts signals in any given frequency band to travel in just one direction



Optical Fiber

- Optical fiber versus coaxial cable and twisted pair
  - Even higher data rates and longer distances
  - Multimode fiber for shorter distances between nodes, single mode fiber for longer distances
  - More expensive
- Light travels in just one direction, so topology is constrained versus coaxial cable



Wireless Media

- Signals in free space represent an unbounded media, versus the bounded media of twisted pair wires, coaxial cable, and optical fiber
- Examples
  - Radio and television broadcast
  - Cellular telephony systems
  - Satellite
  - Land mobile radio
  - IEEE 802.11 wireless local area networks (Wi-Fi)
  - Bluetooth
  - Zigbee

Wireless Media (cont'd)

- Subject to impairments such as path loss, fading, shadowing, multipath, noise, and interference
- Wireless links provide:
    - Mobile and nomadic access
    - Convenience of installation

Digital Hierarchy

- For circuit-switched systems and time-division multiplexed systems, different connections or sessions may need different capacities
- A common approach is to define a base capacity of X bits per second
  - 64 Kbps is common since this was used for voice coding (with some control) in digital telephony transmission systems
- A digital hierarchy can allocate capacity at certain multiples of X, for example 4X or 1024X
- Multiplexing and de-multiplexing is well structured

T-Carrier Hierarchy

- T-Carrier (North America) and E-Carrier (Europe) systems realize the Plesiochronous Digital Hierarchy (PDH)
- T-Carrier hierarchy
  - DS0 can carry a voice call
  - DS1 is 24 DS0 signals (1.544 Mbps)
  - DS2 is 4 DS1 signals (6.312 Mbps)
  - DS3 is 7 DS2 signals (44.736 Mbps)
- “DS” represents the basic signal, while “T” represents the service carrying the DS signal
  - Example: T3 service provides a 44.736-Mbps link
- There are variations and caveats!

Optical Carrier Hierarchy

- The Synchronous Optical Network (SONET) hierarchy (North America) and the Synchronous Digital Hierarchy (SDH) (Europe) are for synchronous optical transmission
- SONET hierarchy
    - Base is 51.84 - Mbps STS-1 signal (OC-1)
    - Three STS-1 signals gives STS-3 signal of 155.52 Mbps
    - STS-12, STS-48…

CHECK POINT

As a checkpoint of your understanding, please pause the video and make sure you can do the following:

- Describe the characteristics of coaxial cable, fiber, and wireless media
- Describe the concept of a digital transmission hierarchy, and describe the concept in the context of T-Carrier (E- Carrier) and SONET (SDH) optical carrier hierarchy

If you have any difficulties, please review the lecture video before continuing.

Summary

- Text, image, voice, audio, and video can be represented in digital form
- Digital data can be transmitted as an analog signal and vice versa
- NRZ-L, NRZI, and 4B/5B-NRZI codes are examples of line coding methods used in the digital transmission of data
- Shannon's theorem can be used to calculate the capacity of a transmission system

Summary (contd.)

- Twisted pair, coaxial cable, and fiber are types of wired media used in communications
- The three types of wired media above are listed in order of cost, support for higher data rates and longer distances
- Wireless networks have become increasingly prevalent in the past decade
- T-carrier systems and SONET systems are examples of digital transmission hierarchies

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