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WIRED-NETWORK TECHNOLOGIES/PROTOCOLS

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CONTENTS

Network Classification and Requirements

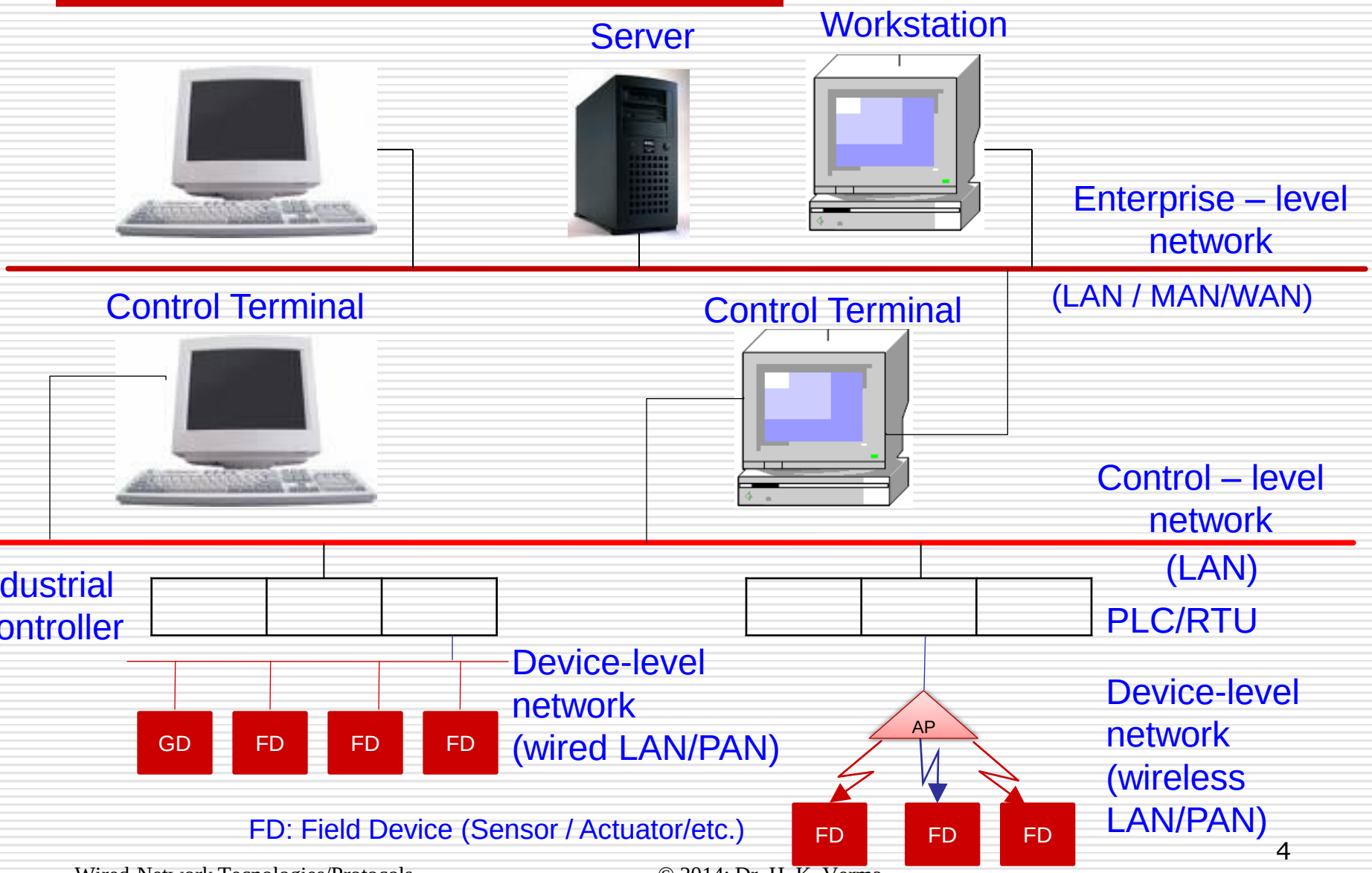
A. Business Data Networks

- High data rates

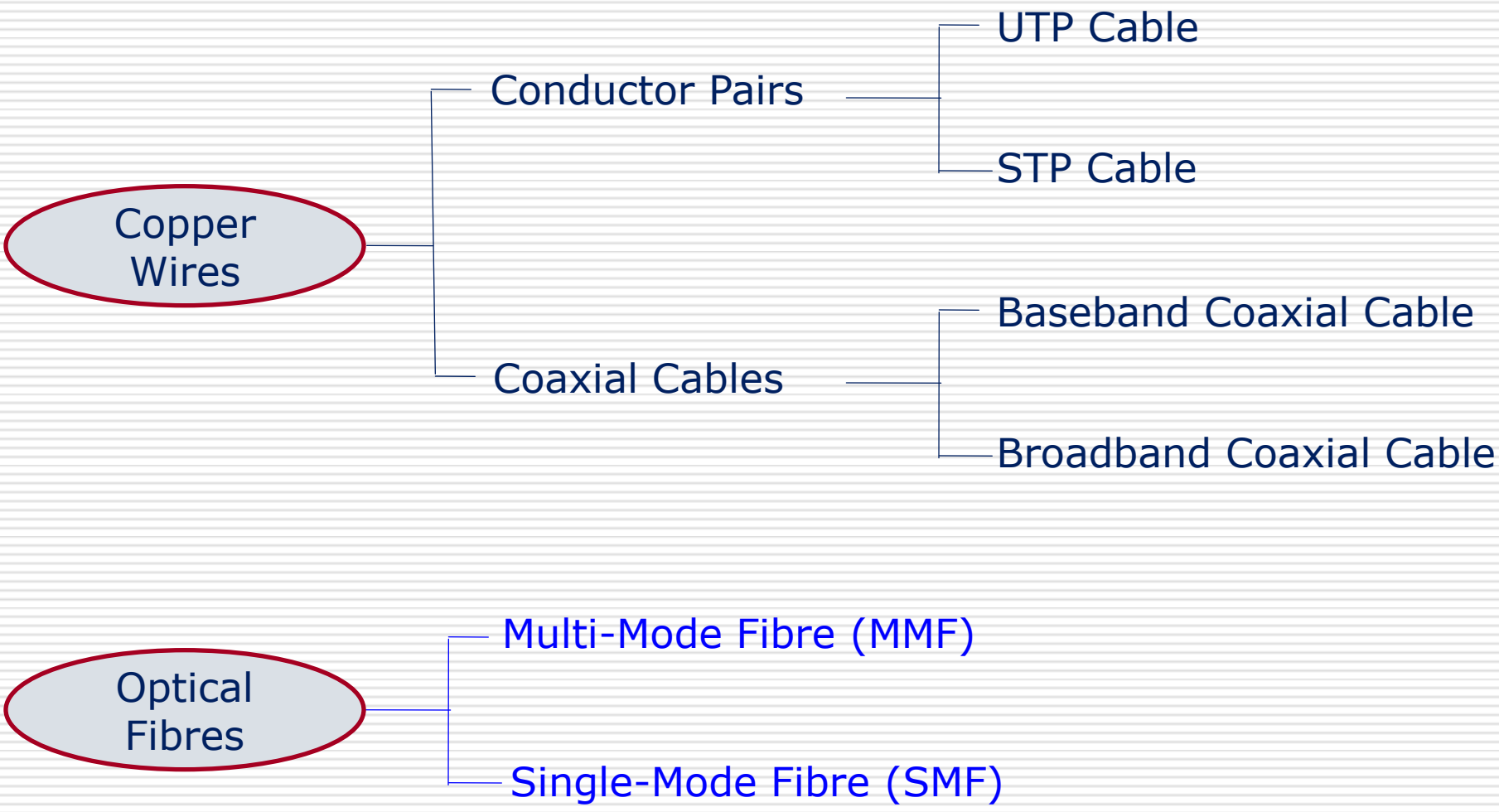
B. Industrial Data Networks

- Enterprise-level network
  - High data rates
- Control-level network
  - High data rates
- Device-level network
  - Low data rates
  - Low latency
  - High security
  - Low Power Consumption (for WSN)

Hierarchy of Industrial Data Networks



"Wire" Transmission Media



Conductor Pairs

- UTP Cable
  - Low capacity, inexpensive, low skill required
  - Old LANs with voice-grade Cat-3, now Cat-5, Cat-6 & Cat-7
  - Most popular for copper-cable LANs inside buildings
- STP Cable
  - Higher capacity than UTP, more expensive
  - Competes with Cat-5, Cat-6 & Cat-7 UTP cables

Coaxial Cables

- Baseband Coaxial Cable
  - Digital signalling
  - Higher capacity than UTP
  - More expensive than UTP
  - Difficult to work with
- Broadband Coaxial Cable
  - Analog signalling

Optical Fibre Cable (OFC)

- Transmission Modes
  - MMF: Short cable lengths, low data rates
  - SMF: Long cable lengths, high data rates
- Sizes (Core dia)
  - 62.5 µm, MMF
  - 50 µm, MMF
  - 10 µm, MMF
- Wavelengths
  - 850 nm, MMF
  - 1310 nm, SMF
  - 1550 nm, SMF

Advantages & Disadvantages of OFC

- Advantages
  - Electromagnetic isolation
  - Very high capacity
- Disadvantages
  - High cost
  - High skill required
- Application
  - Most common for backbone connections
  - Penetrating fast into LANs as costs of fibre cable & components are coming down and data rates are going up

Important Technologies/Protocols for Wired Data Networks

For Business Networks

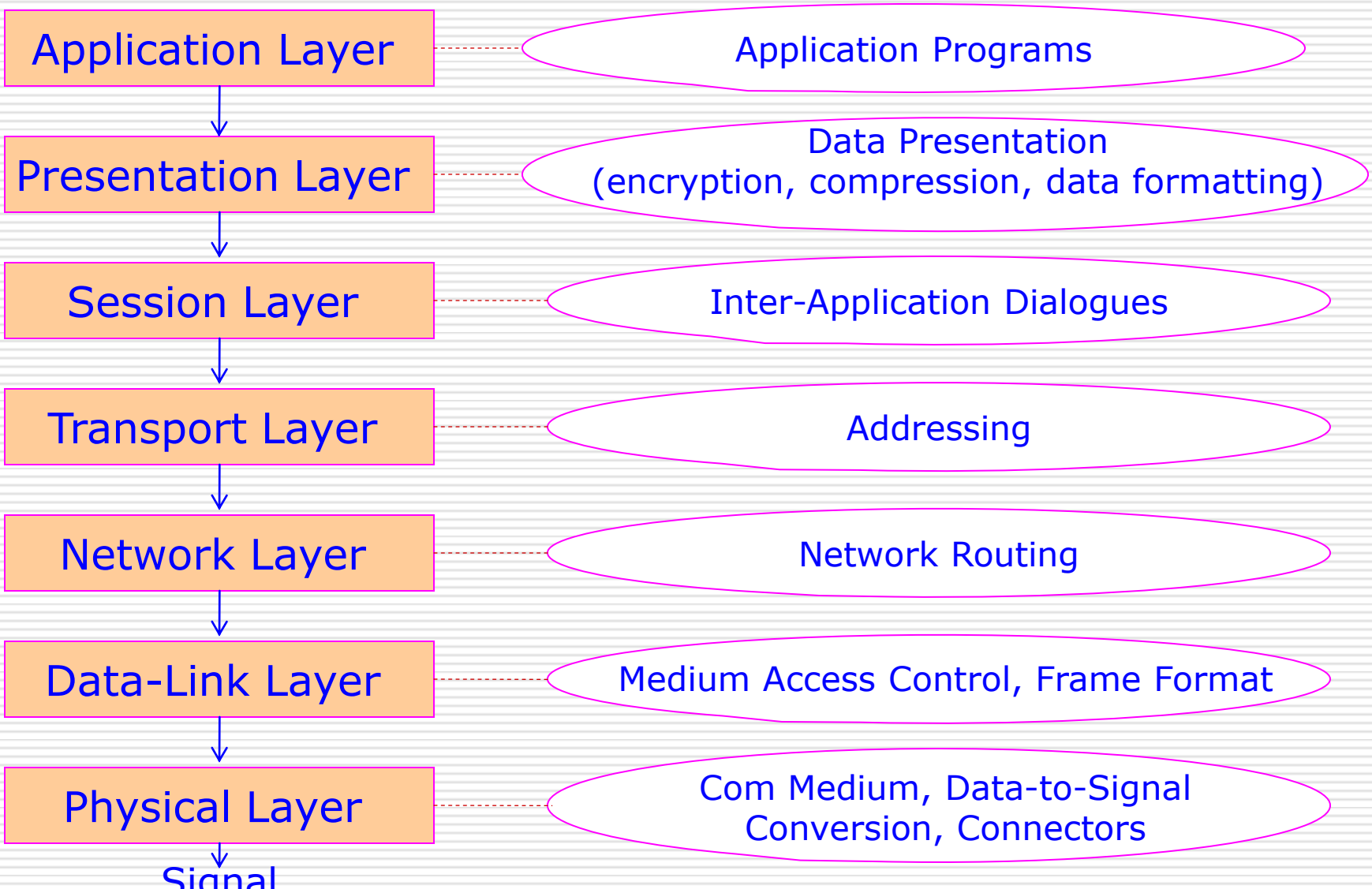
For Industrial Networks

1. Ethernet
2. RS-422
3. RS-485
4. Modbus
5. Foundation Fieldbus
6. HART (Highway Addressable Remote Transmitter
7. CAN Bus (Controller Area Network)
8. Profibus (Process Field Bus)
9. LON (Local Operation Network)
10. BAC-Net (Building Automation Control Network)
11. EHS (European Home System)

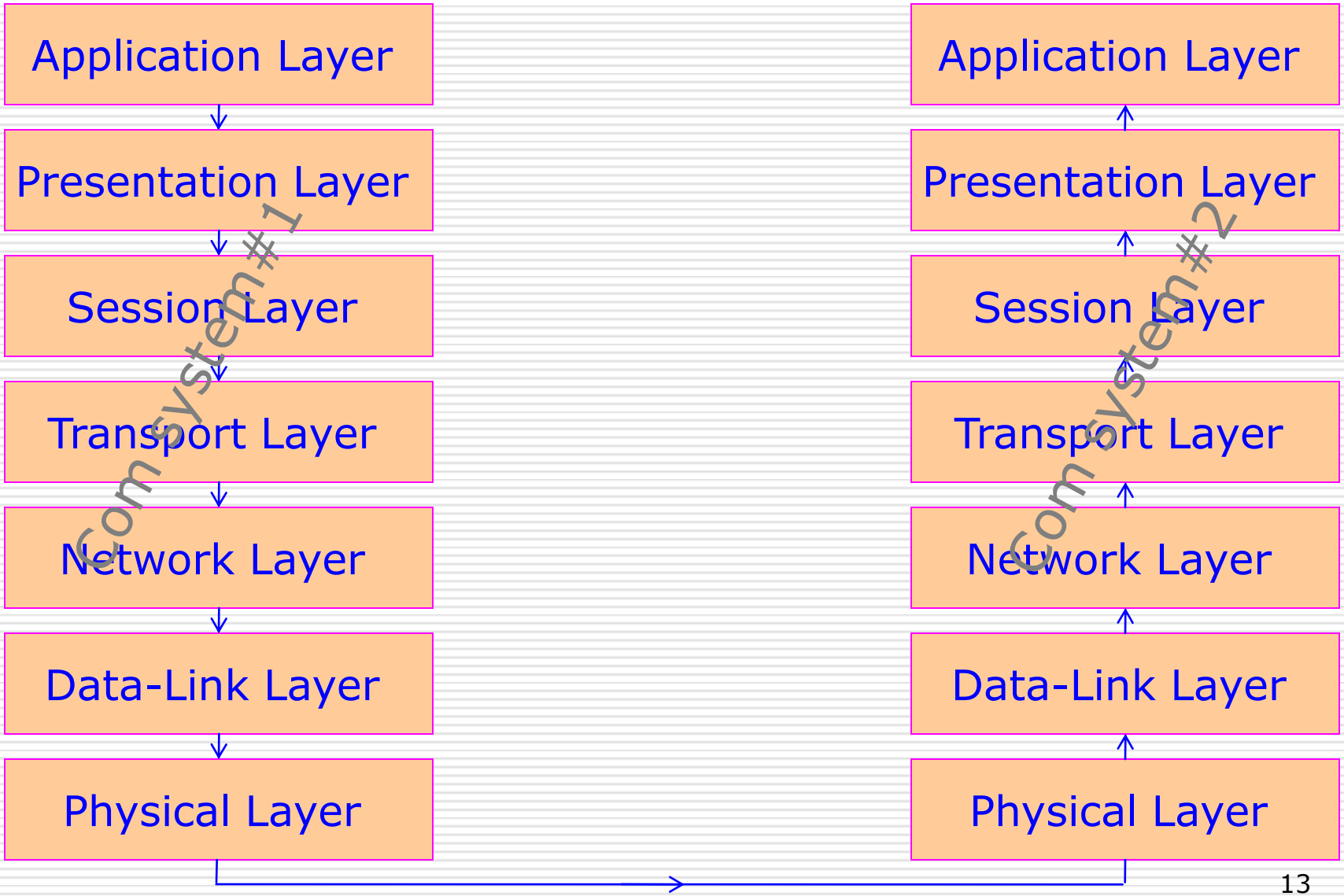
7-Layer OSI Model of Communication Systems

- OSI: Open System Interconnection
- Reference model of communication systems
- Defines 7 layers of functions in a communication system
- For use as reference "to identify and classify the different functions of a given communication system"
- Not a standard or set of prescriptions for a communication system to adhere to
- A communication system may not have all the 7 layers
- Depending on the application, some layers may be absent
- A communication protocol or standard may not define all the 7 layers

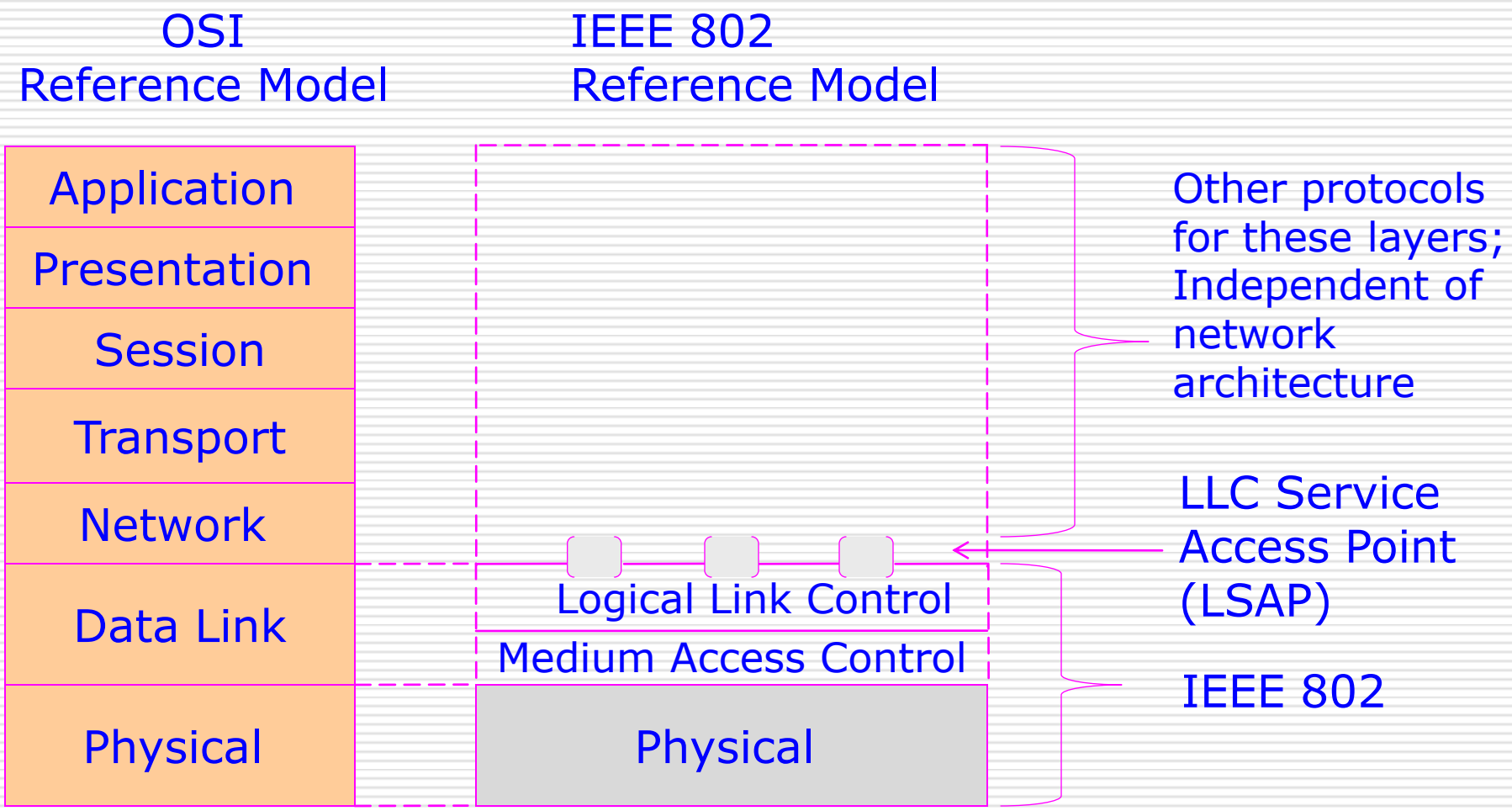
The Seven Functional Layers



Data Transfer Between Systems



IEEE-802 Reference Model



Physical Layer of IEEE-802 Ref. Model

Specifies :

1. Topology
2. Transmission Medium
3. Encoding/decoding of signals
4. Preamble generation/removal (for synchronization)
5. Bit transmission/reception

Data Link Layer of IEEE-802 Ref. Model

- DLL Functions:
  1) Assembles data into frame before transmission
  2) Disassembles the received assembled data
  3) Governs access to the LAN transmission medium

- Specifies following transmission functions:
  (a) assemble data into a frame
  (b) insert address field
  (c) add error check field

- Specifies following reception functions:
  (a) disassemble frame
  (b) perform address recognition
  (c) perform error detection

LLC Layer of IEEE-802 Ref. Model

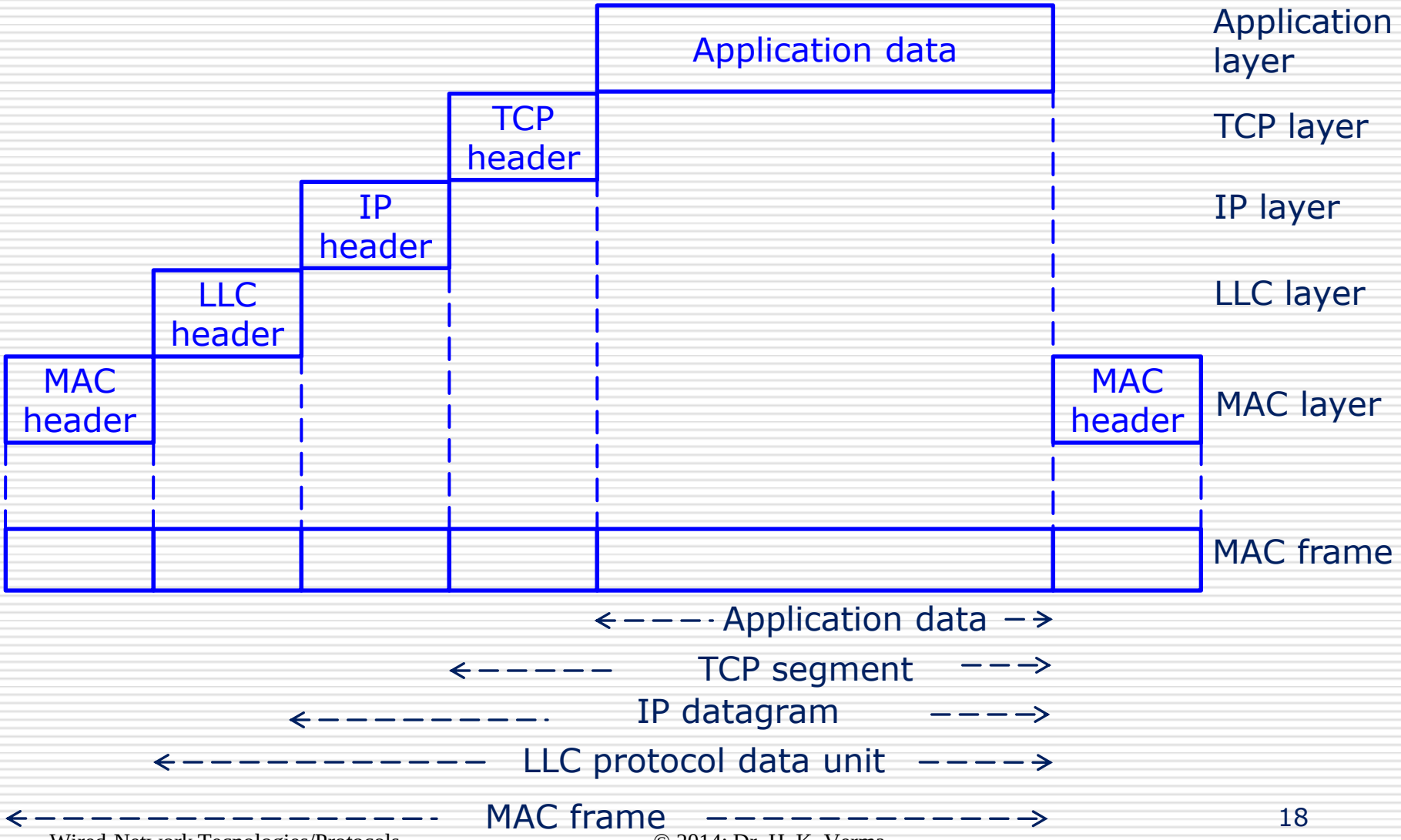
Functions:

1. Provides interface to higher layers

2. Performs flow control

3. Performs error control

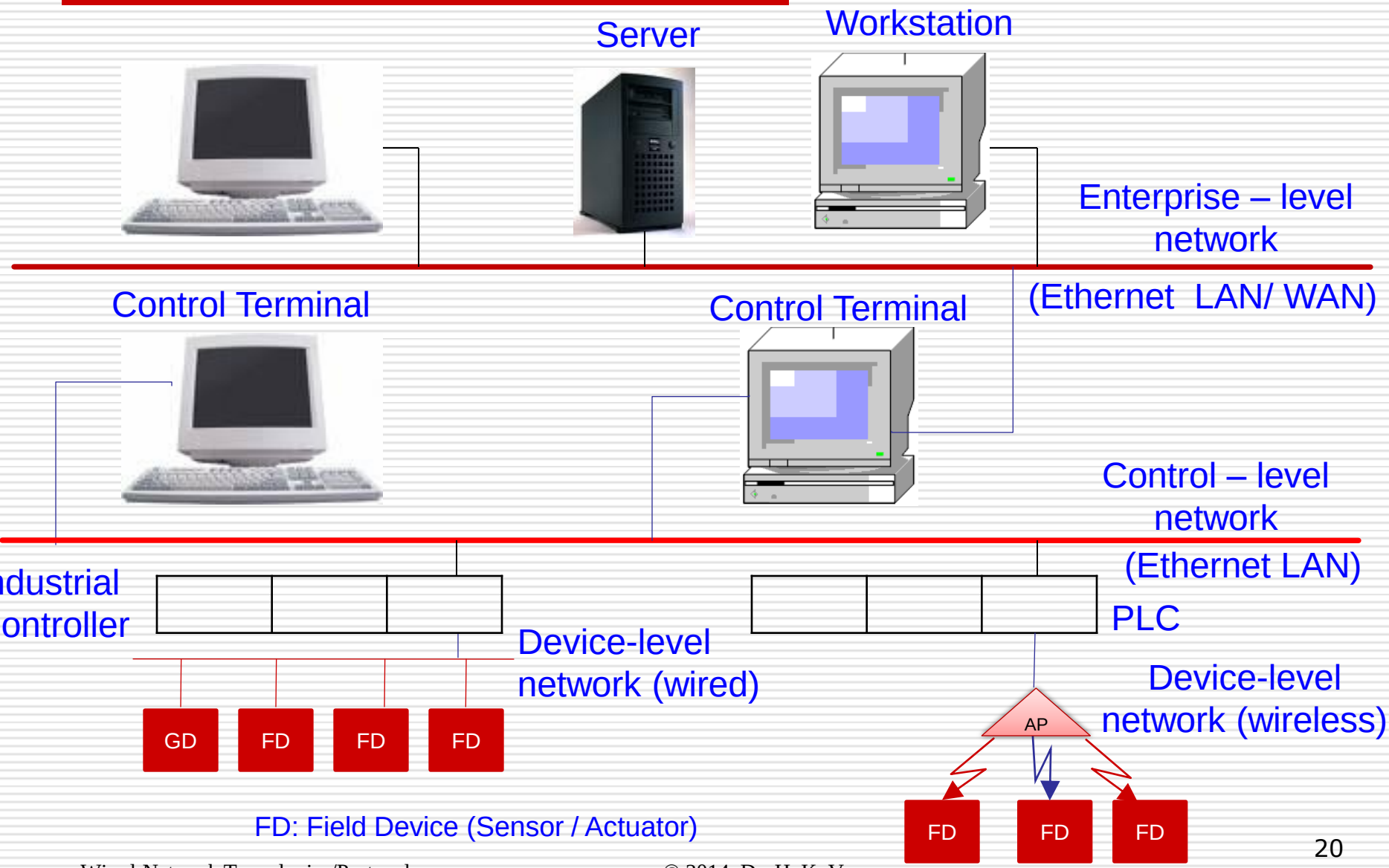
MAC Frame in IEEE-802 Standards



Ethernet/IEEE802.3

- Ethernet technology for high speed LANs
- Originally developed by Xerox Corporation
- Improved upon by DEC and Intel
- Ethernet Standard: IEEE802.3
- Most widely used technology in business LANs
- Now also used in industrial (enterprise-level and control-level) LANs

Ethernet in Industrial LANs



FD: Field Device (Sensor / Actuator)

Ethernet/IEEE802.3 General Specs

1. OSI Layers Defined: Physical, Data Link
2. Physical Layer: Coding, transmission mode, data rate, media
3. Data Link Layer: MAC, frame format
4. Coding: Manchester
5. Transmission Method Specified: Baseband
6. Transmission Modes Specified: Half duplex, full duplex
7. Data Rates Specified: 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps
8. MAC Protocol: CSMA/CD

Ethernet/IEEE802.3 (10 Mbps) Specs

- Data Rate Specified: 10 Mbps
- Cables Specified: Coaxial, UTP, MMF
- Transmission Mode Specified: Half duplex
- 4 Alternatives: 10 BASE-5
  10 BASE-2
  10 BASE-T
  10 BASE-F

Ethernet Alternatives with Coaxial Cable

10 BASE-5

Cable: Standard or thick coaxial (50 ohms)

Max. segment length: 500m

Extendable upto: 2500m (with 4 repeaters)

Topology supported: Bus

10 BASE-2

Cable: Thin coaxial

Max. segment length: 185m

Topology supported: Bus

Other Ethernet Alternatives

10 BASE-T

Cable: UTP of voice grade (cat-3)

Max. segment length: 100m

Topology supported: Star

10 BASE-F

Cable: MMF

Topology supported: Star

Max. segment length:

Star topology: 1 km

Point-to-point topology: 2 km

Fast Ethernet/IEEE802.3 (100 Mbps) Specs

- Data Rate : 100 Mbps
- Cables : UTP, STP, MMF, SMF
- Transmission Modes: Half duplex, Full duplex
- 3 Alternatives: 100 BASE- TX
  100 BASE- T4
  100 BASE- FX
- Supports mixed 10 Mbps/100 Mbps
- 10/100 Mbps switching hubs available

Fast Ethernet Alternatives with Copper Cable

100 BASE-TX

- Cable: Both STP and cat-5 UTP specified
- Max. segment length: 100m
- One pair for half duplex operation
- Two pairs for full duplex operation

100 BASE-T4

- Designed to support 100 Mbps on existing networks working with cat-3 UTP cables
- 4 pairs of cat-3 UTP cable for full duplex operation
- Data stream in each direction split into 3 separate streams and sent on 3 pairs
- So 2 pairs are configured for bidirectional communication

Fast Ethernet Alternatives with OFC

100 BASE-FX

- Cable: MMF
- Single fibre for half-duplex operation
- Two fibres for full-duplex operation
- Intensity modulation is specified

  Binary 1: Represented by high intensity light pulse

  Binary 0: Represented by very-low intensity light pulse or by absence of light pulse

1 Gbps-Ethernet/IEEE802.3(1 Gbps) Specs

- Data Rate : 1000 Mbps (1 Gbps)
- Cables : UTP, STP, MMF, SMF
- Transmission Mode: Full duplex
- Application: Backbone Networks
- Alternatives: 1000 BASE- T
  1000 BASE- CX
  1000 BASE- SX
  1000 BASE- LX
- Compatible with 10 Mbps and 100 Mbps Ethernets to ensure smooth transition from one system to other

1 Gbps-Ethernet Alternatives with Copper Cable

1000 BASE-T

- Specifies 4 pairs of cat-5 UTP cable for full duplex operation
- Max. segment length: 100 m

1000 BASE-CX

- Specifies 2 pairs of STP cable for full duplex operation
- Max. segment length: 25 m
- Supports copper links among devices within a room and copper jumpers within an equipment rack

1 Gbps-Ethernet Alternatives with OFC

1000 Base-SX		
OFC	Wavelength	Max. Length
62.5 µm MMF	Short (770-860 nm)	275 m
50 µm MMF	Short (770-860 nm)	550 m

1000 Base-LX		
OFC	Wavelength	Max. Length
62.5 µm MMF	Long (1270-1355 nm)	550 m
50 µm MMF	Long (1270-1355 nm)	550 m
10 µm SMF	Long (1270-1355 nm)	5 km

10 Gbps-Ethernet/IEEE802.3(10 Gbps) Specs

- Aimed at taking care of increase in intranet and internet traffics
- Data rate: 10 Gbps
- Cables: MMF, SMF
- Transmission Mode: Full duplex
- Alternatives: 10G BASE-S
  10G BASE-L
  10G BASE-E
  10G BASE-Lx4
- High data rate enables high-speed backbone connections
- Long lengths enable all-Ethernet MANs and WANs

10 Gbps-Ethernet Alternatives

Alternative	OFC	Wavelength	Max. Length
10G Base-S	62.5 μm MMF 50 μm MMF	850 nm 850 nm	30 m 300 m
10G Base-L	10 μm SMF	1310 nm	10 km
10G Base-E	10 μm SMF	1550 nm	40 km
10G Base-LX4	Uses WDM with 4 light waves		
	62.5 μm MMF	1310 nm	300 m
	50 μm MMF	1310 nm	300 m
	10 μm SMF	1310 nm	10 km

Media Access Control (MAC)

- Common for all speed versions of Ethernet
- IEEE 802.3 specifies CSMA/CD protocol
- Allows peer-to-peer networking
- Protocol consists in "listen before send"
- One node sends (transmits),
  all other nodes listen to carrier (receive)
- If two (or more) nodes attempt to send at the same time, collision is detected, both nodes stop sending, wait for small but random amount of time, and then resend.
- High traffic on network can result into multiple collisions

RS422 Serial Interface Protocol

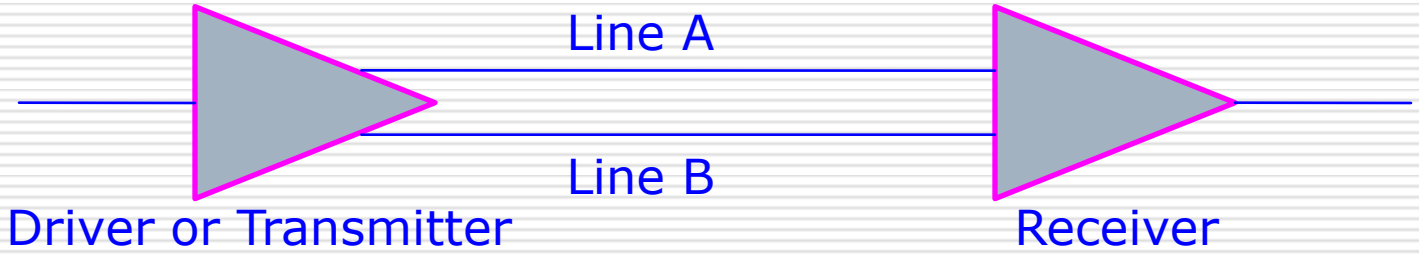
- Recommended Standard for "Electrical Characteristics of Balanced-Voltage Digital-Interface Circuits"
- Published by TIA & EIA, it is an industry standard
- Specifies balanced mode of transmission (differential signals)
- Connectors not specified
- Differential signals help nullifying
  - Effects of ground shifts
  - Effects of induced common-mode noise signals on wires
- Consequence is superior performance, viz.
  - Long distances
  - High data rates

Main Specifications

- Cable: 2 Unshielded twisted pairs (UTPs)
- Maximum data rate: 10 Mbps @ cable length upto 12m
- Maximum cable length: 1200m @ 100 kbps
- Specified for multi-drop (party-line) applications
- One driver transmits on a bus of upto 10 receivers
- Does not support a truly multi-point network (consisting of multiple drivers and multiple receivers on a single bus)
- Supports full-duplex communication only
- Supports "Master-Slave" mode of communication only

Balanced Mode Transmission

- Signal in either direction is transmitted over a separate pair
- Driver (transmitter) converts SE signal to differential signal
- Receiver translates differential signal back to SE signal
- CM noise induced in two lines is rejected by receiver



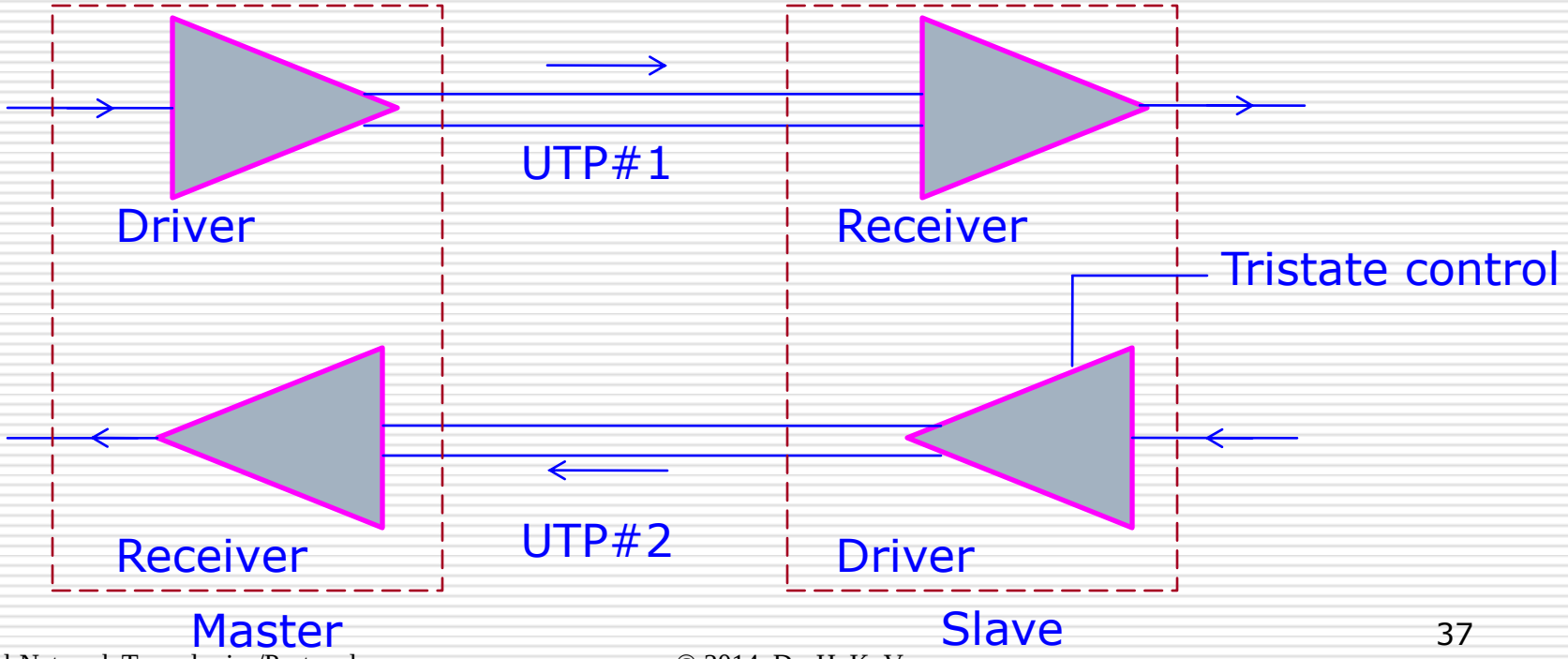
- Signal Levels:

  Logic 0 : Line B more positive than Line A
  Logic 1 : Line A more positive than Line B
  Differential voltage = 0.4 V to 12 V

- Max CM voltage permitted: ±7V
- Twisted pair provides transposition of lines A & B

Full Duplex Transmission

- Two UTPs or 4 wires used
- Master always initiates dialogue on one UTP
- The addressed (polled) slave responds on the other UTP
- Driver of master is always enabled, hence needs no tri-state capability
- Drivers of slaves should have tri-state capability



RS485 Field Network Protocol

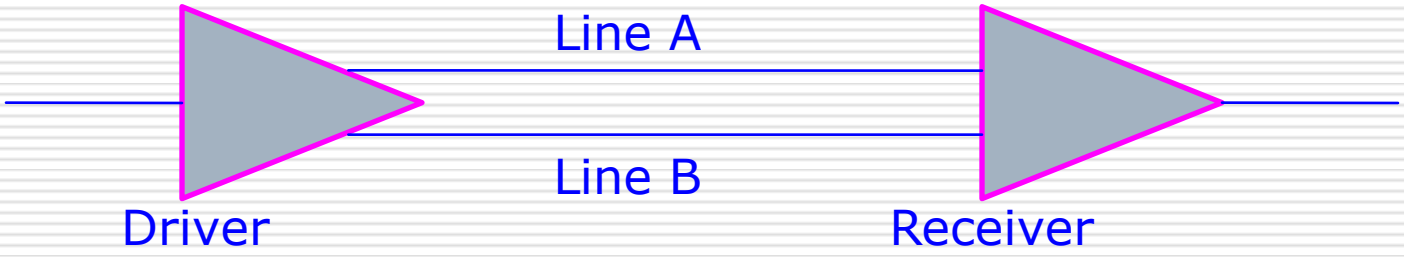
- "Standard for Electrical Characteristics of Generators and Receivers for use in Balanced Digital Multipoint Systems"
- Recommended by EIA, it is an industry standard
- Specifies balanced differential signals
- Supports multi-point networks
- Very common in distributed data acquisition and other field networks/device-level networks

Main Specifications

- Specifies Physical Layer and MAC protocol
- MAC Protocol: Master-Slave
- Physical Layer specifies:
  a) Signal Transmission Medium: UTP cable
  b) Data-to-signal relationship: Next slide
- Maximum data rate: 10 Mbps @ cable length upto 12m
- Maximum cable length: 1200m @ 100 kbps
- Supports half-duplex as well as full-duplex communication
- Allows upto 32 drivers and 32 receivers

Balanced Mode Transmission

- Driver (transmitter) converts SE signal to differential signal
- Receiver translates diff. signal back to SE signal
- CM noise induced in two lines is rejected by receiver

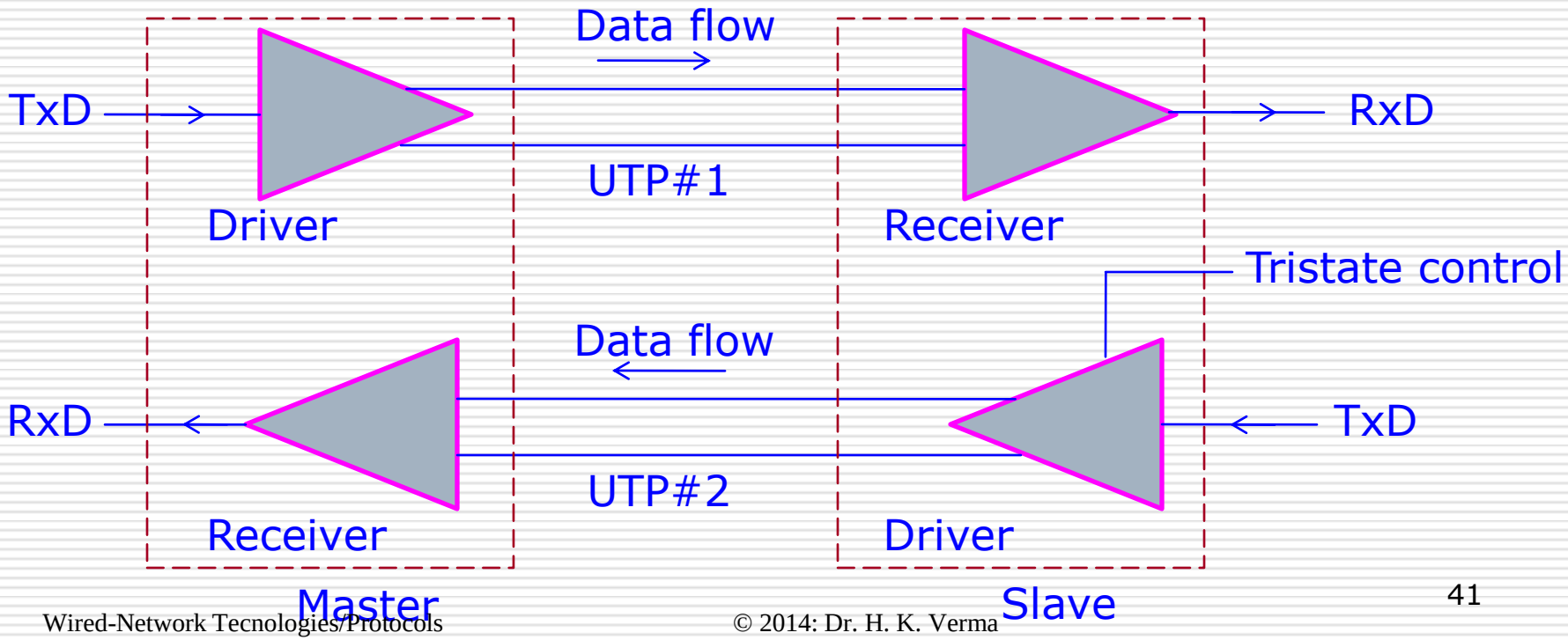


- Data-to-Signal relationship specified:

  Logic 0 : Line B more positive than Line A
  Logic 1 : Line A more positive than Line B
  Difference : 0.4 V to 12 V
- Max CM voltage permitted: ±7V
- Twisted pair provides transposition of lines A & B

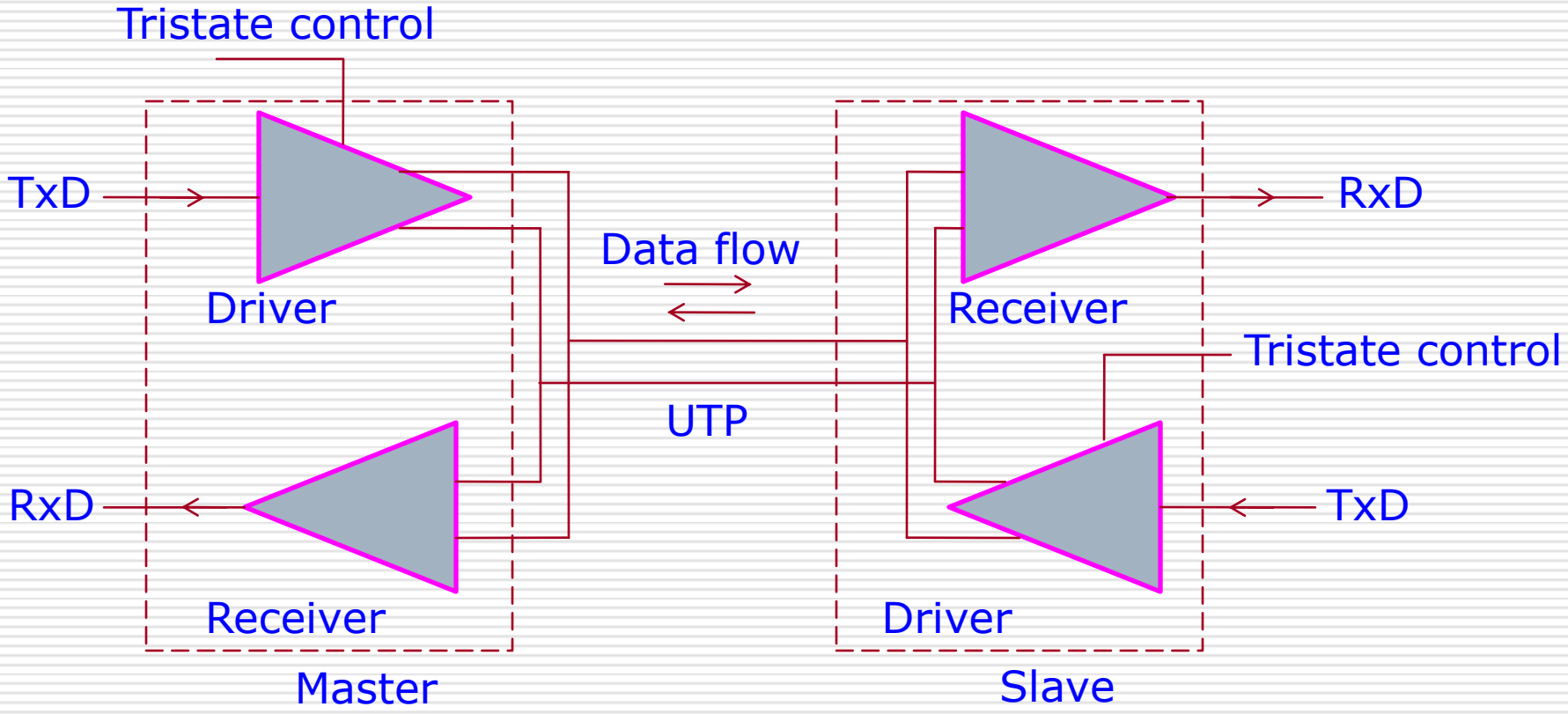
Transmission in Full-Duplex Mode

- Two UTPs or 4 wires used
- Master always initiates dialogue on one UTP
- The addressed (polled) slave responds on the other UTP
- Driver of aster is always enabled, hence needs no tri-state capability
- Drivers of slaves should have tri-state capability



Transmission in Half-Duplex Mode

- One UTP or 2 wires used
- All drivers, including master, must have tri-state capability



MODBUS

1. Open, serial communication protocol
2. Suitable for field-device networks
3. Developed and introduced in 1980 by AEG Modicon for use with PLCs
4. Now an industry standard
5. Only Application Layer is specified in Modbus
6. So Modbus is implemented in conjunction with another protocol to take care of Physical Layer and MAC
7. Accordingly, various Modbus implementations are:
   - Modbus over serial line
   - Modbus over TCP/IP
   - Modbus over high speed token passing network (Modbus Plus)

Modbus Over Serial Line

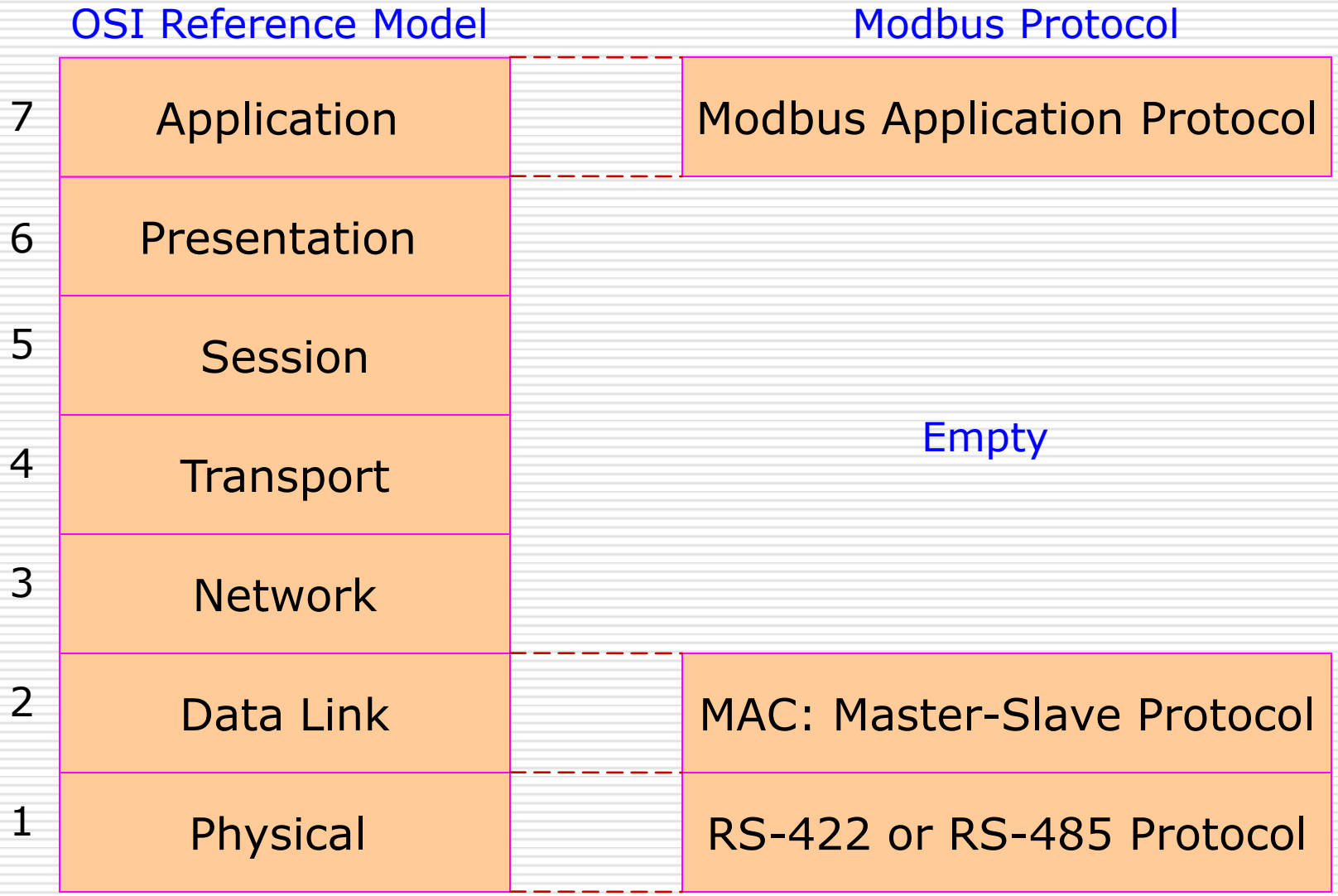
1. Application layer is completely specified by Modbus protocol

2. Serial line options:
   a) RS-422
   b) RS-485

3. MAC protocol: Master-slave

4. Transmission modes:
   a) RTU
   b) ASCII

Modbus Protocol Stack



Master-Slave Protocol

1. Communication always initiated by master
2. A slave transmits data (replies) only on master's request
3. Slaves never communicate with each other
4. Master node initiates only one transaction at a time
5. Master's request to slaves are either in "Unicast" mode or in "Broadcast" mode

Request/Response Modes

Unicast Mode

- Master addresses an individual slave
- Only the addressed slave replies to master

Broadcast Mode

- Master addresses all slaves on the bus
- All slaves accept the "broadcast message" for "writing function"
- No reply is sent to master

Modbus Address Space

- Address Size: 8 bits
- Total Address Space: 256 addresses

Address	Purpose
0	Broadcast address
1-247	Individual addresses of slaves
248-255	Reserved

Coding & Bit Sequence in RTU Mode

Coding System:

- Uses 8-bit binary data bytes
- Hexadecimal characters 0-9 and A-F are used
- Two hexadecimal characters per byte

Bit Sequence for Transmission if Parity is Used:
11 bits per data byte

Start bit	8 data bits (LSB ….. MSB)	Parity bit	Stop bit

Bit Sequence for transmission if Parity is not t Used:
11 bits per data byte

Start bit	8 data bits (LSB ….. MSB)	Stop bit	Stop bit

Modbus Message Frame in RTU Mode

Field	Master-to-Slave Message (Request)	Slave-to-Master Message (Response)
1. Address	Slave address	Slave address
2. Function Code	Indicates to slave the kind of action to perform	Indicates the kind of response
3. Data	Request parameters	Response parameters & values
4. Error Check Code	CRC	CRC

Bytes	1	1	0-252	2
	Address	Function Code	Data	Error Check Code

Coding & Bit Sequence in ASCII Mode

Coding System:

- Uses 7-bit ASCII characters

Bit Sequence for Transmission if Parity is Used:
10 bits per ASCII character

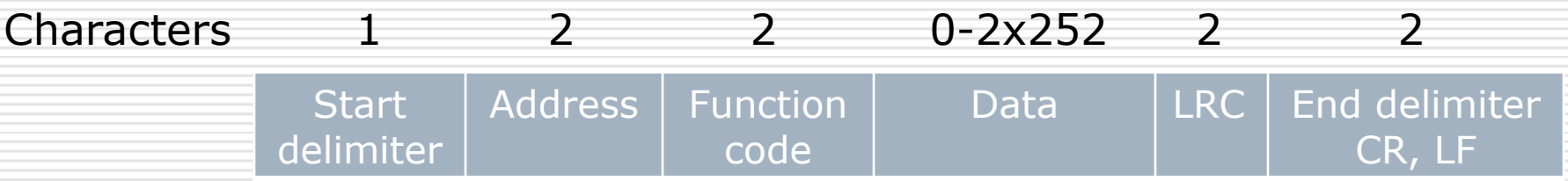
Start bit	7 data bits (LSB …MSB)	Parity bit	Stop bit

Bit Sequence for Transmission if Parity is not Used:
10 bits per ASCII character

Start bit	7 data bits (LSB …MSB)	Stop bit	Stop bit

Modbus Message Frame in ASCII Mode

Field	Master-to-Slave Message (Request)	Slave-to-Master Message (Response)
1. Start Delimiter	:	:
2. Address	Slave address	Slave address
3. Function Code	Indicates to slave the kind of action to perform	Indicates the kind of response
4. Data	Request parameters	Response parameters & values
5. Error Check Code	LRC	LRC
6. End Delimiter	CR, LF	CR, LF



Foundation Fieldbus

- Foundation Fieldbus is an open fieldbus protocol
- Fieldbuses are fully-digital network protocols
- Fieldbuses have been developed by industry for networking of field devices on plant/factory floor
- Application Area: Industrial Measurement and Control
- Common standard for fieldbuses: IEC-61185

IEC-61158 Standard

- International Standard for "Digital Data Communications for Measurement and Control – Fieldbus for Use in Industrial Control Systems"
- Communication speeds: 31.25 kbps, 1 Mbps, 2 Mbps
- Specifies operation over 2 wires carrying power as well as com signals
- Specifies multi-drop operation with minimum of 30 devices
- Operation in hazardous areas using intrinsic safety techniques
- Interoperability between equipments from different manufacturers.

Important Fieldbuses

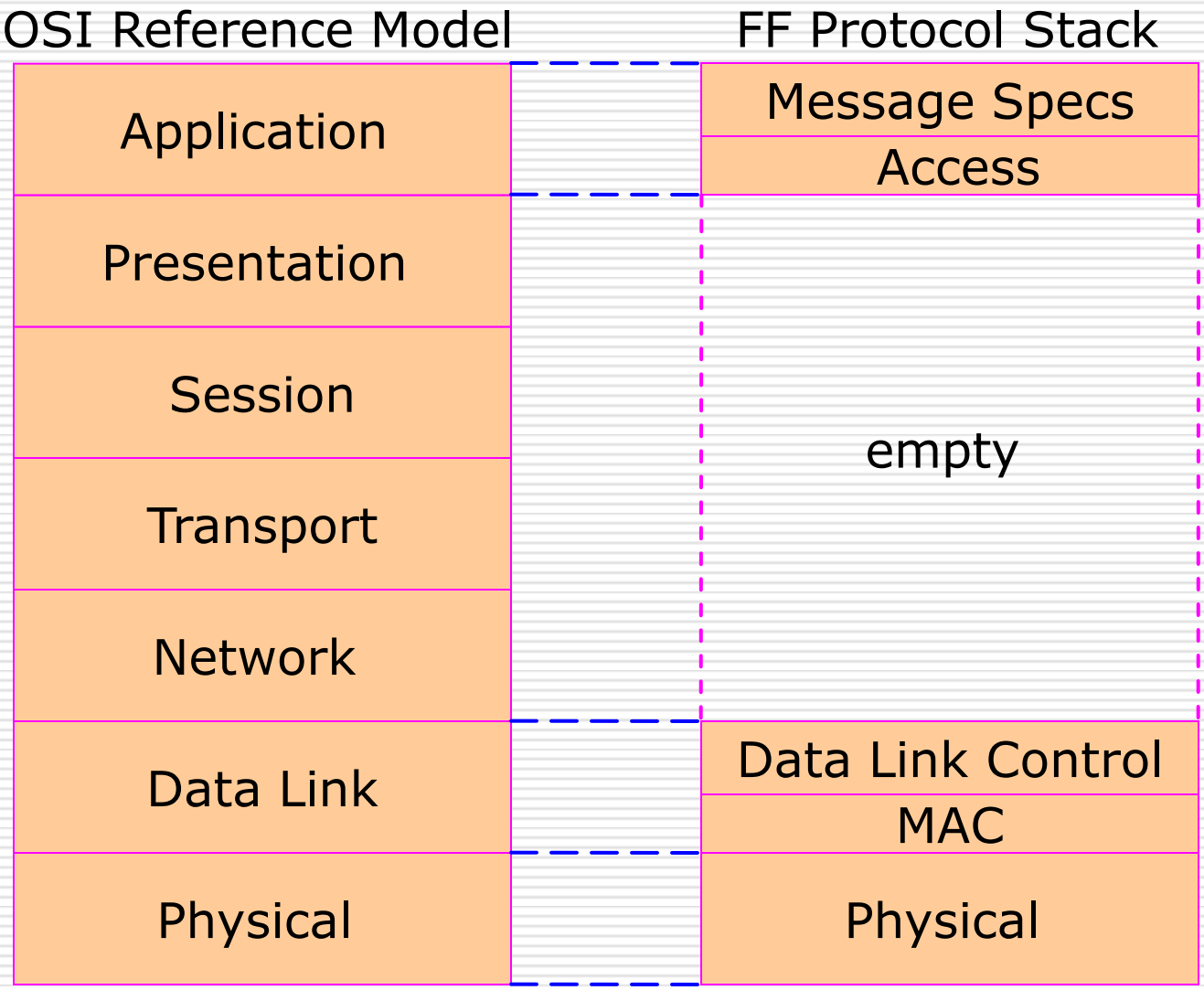
S. No.	Bus	Developer	Year	Application Area
1	Modbus	AEG Modicon	1980	Process Control
2	MAP(2)	General Electric	1980	Manufacturing plants
3	LON(3)	Echelons	1991	Building automation Energy distribution
4	Profibus(4)	Siemens	1994	Process control
5	SDS(5)	Honeywell	1994	Process control
6	CAN(6)	Bosch	1995	Automobiles
7	Foundation Fieldbus	Fieldbus Foundation	1997	Process control

(2) Manufacturing Automation Protocol, (3) Local Operation Network
(4) Process Control Fieldbus, (5) Small Distributed System
(6) Controller Area Network

Foundation Fieldbus: Key Features

- Developed in 1997 as an open field-bus protocol
- Developed by "Fieldbus Foundation": A world-wide consortium of manufacturers and industry groups
- Being adopted world over by most of manufacturers and users for industrial measurement & control (industrial automation)
- Protocol defines physical, data link and application layers

Foundation Fieldbus Protocol Stack



Foundation Fieldbus Physical Layer

Following aspects are specified:

A. Data rates

B. Network topologies

C. Signal strength and encoding

D. Types and lengths of cable

E. Physical-frame format

A – Data Communication Rates

31.25 kbps

- Specified as **intrinsically-safe option**
- Supports applications that need high security but moderate data rates
- Used for control and measurement data

1 Mbps and 2 Mbps

- Specified as non-intrinsically-safe options
- Supports applications that need high data rates
- Used for configuration data, self-test command etc.

B - Topologies Supported

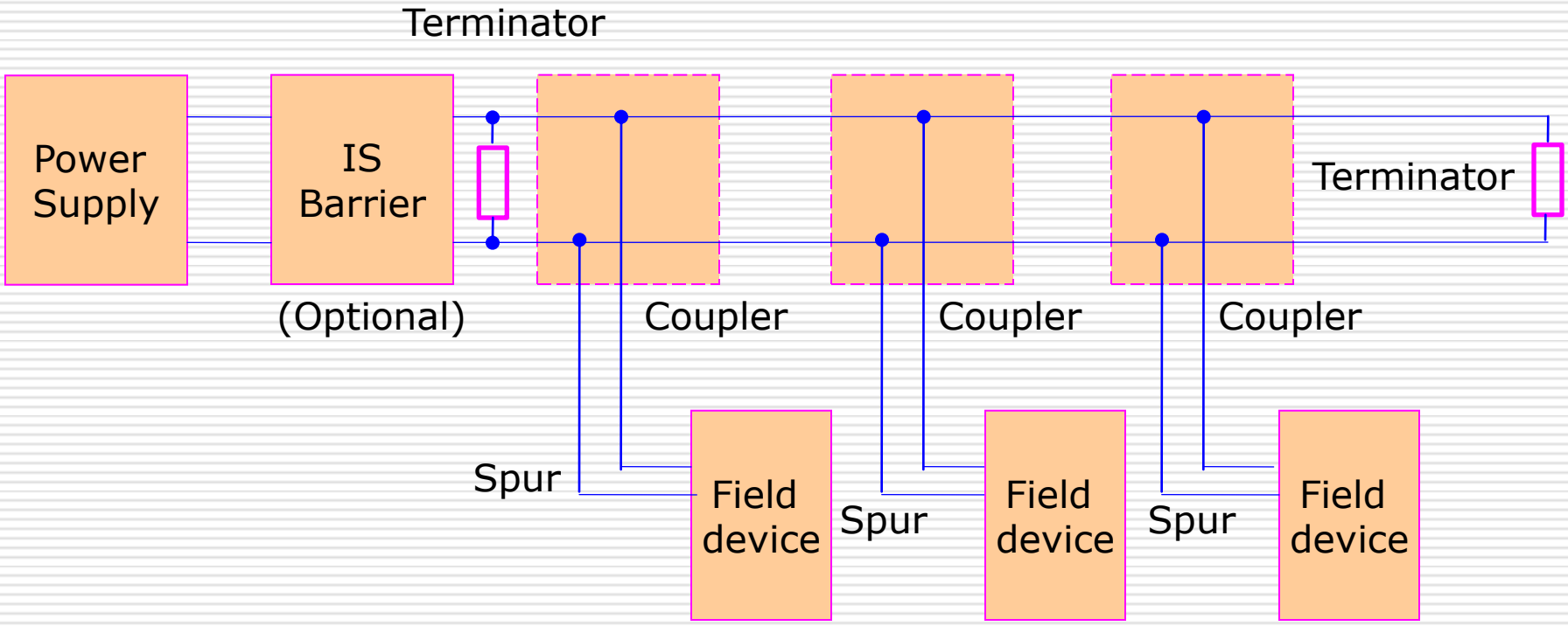
Bus Topology

- Supported at all speeds

Tree Topology

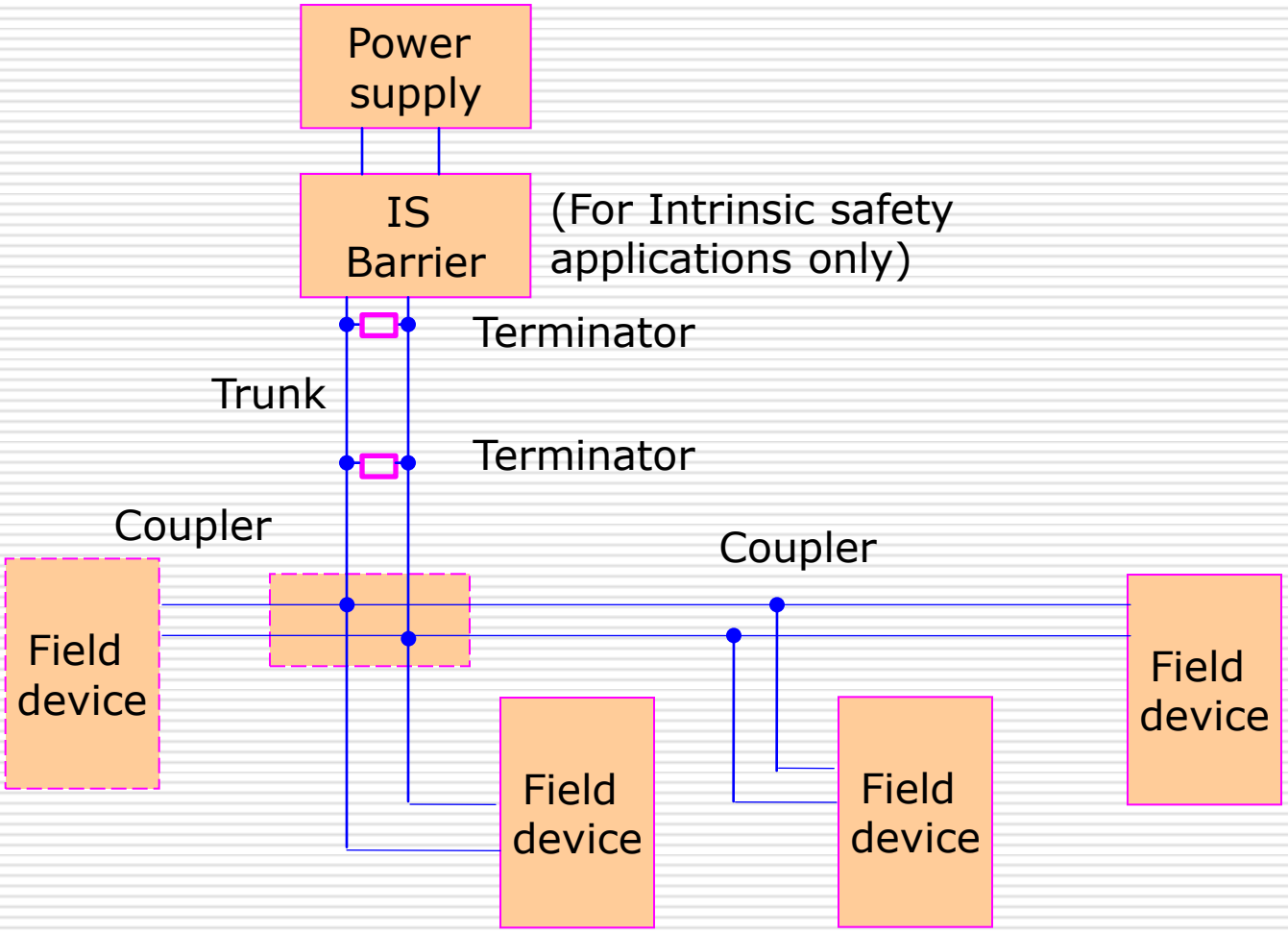
- Supported at 31.25 kbps only

Foundation Fieldbus Network of Bus Topology



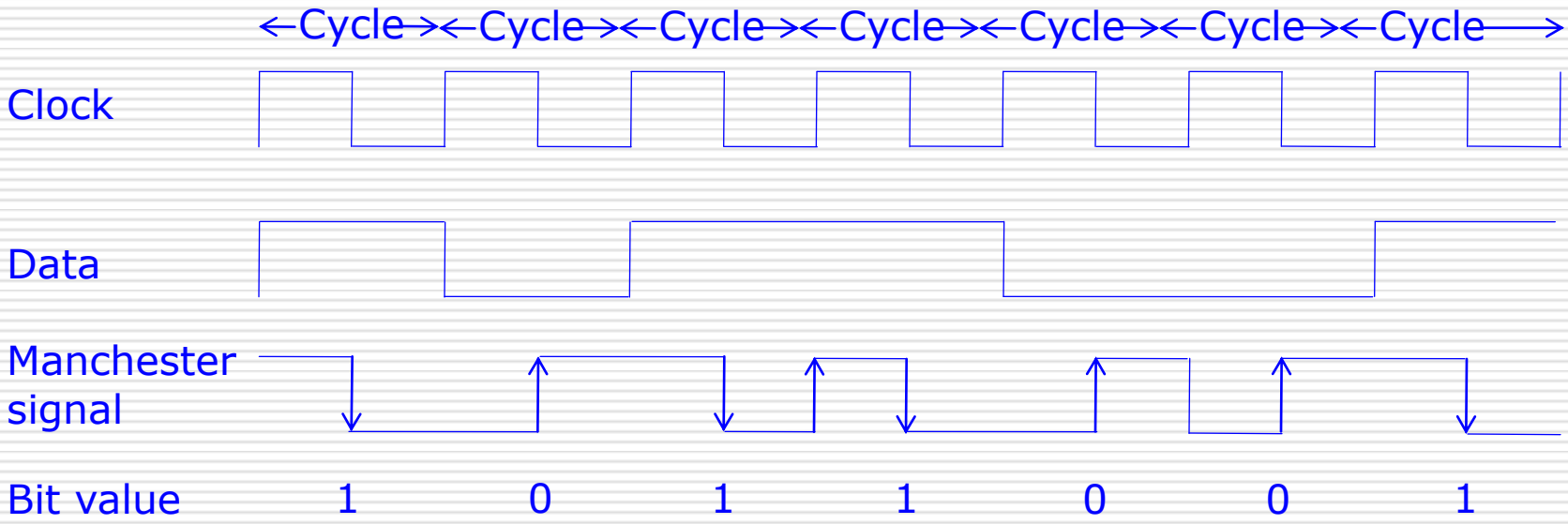
Passive coupler: To connect field devices
Active coupler: To extend spur length
IS Barrier: For intrinsic-safety applications only
Spur: Connection > 1m
Splice: Connection < 1m

Foundation Fieldbus Network of Tree Topology



C - Signal Strength and Encoding

- Signal Strength : 15-20 mA p-p
- Receiver Sensitivity: 150 mV
- Encoding Method : Manchester
  ‘0’ represented by mid-cycle rising edge
  ‘1’ represented by mid-cycle falling edge



D - Types and Lengths of Cable

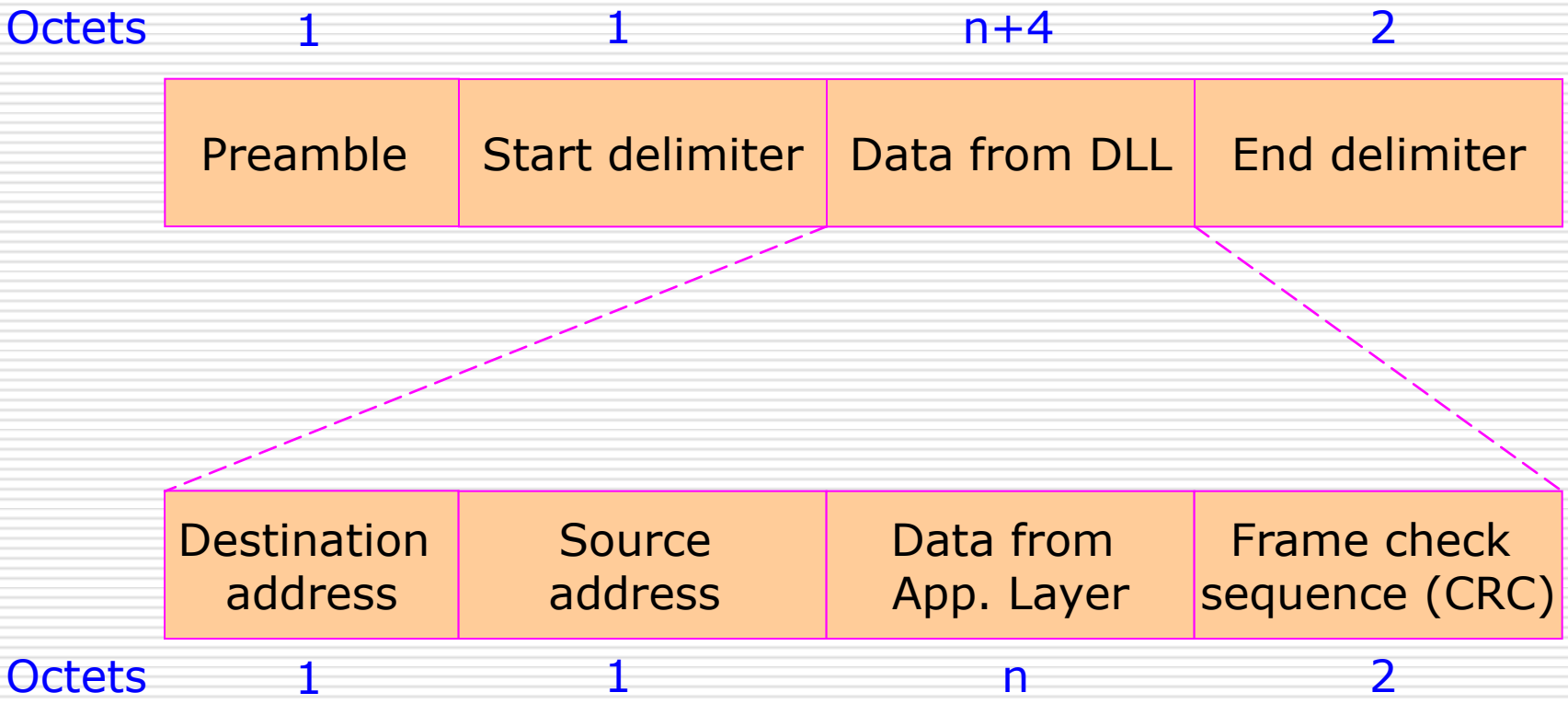
FF Type	31.25 kbps	1 MHz	2.5 MHz	Cable Type
A	1900 m	750 m	500 m	Single twisted pair with overall shield
B	1200 m	x	x	Multiple twisted pair with overall shield
C	400 m	x	x	Single or multiple twisted pair without any shield
D	200 m	x	x	Multiple conductor cable without twisted pairs

Note: Cable length = Trunk + spur lengths

Length of Spur

Devices on bus	Max. spur length at 31.25 Kbps
1-12	120 m
13-14	90 m
15-18	60 m
19-24	30 m
25-32	0 m (none)

E – Physical-Frame Format



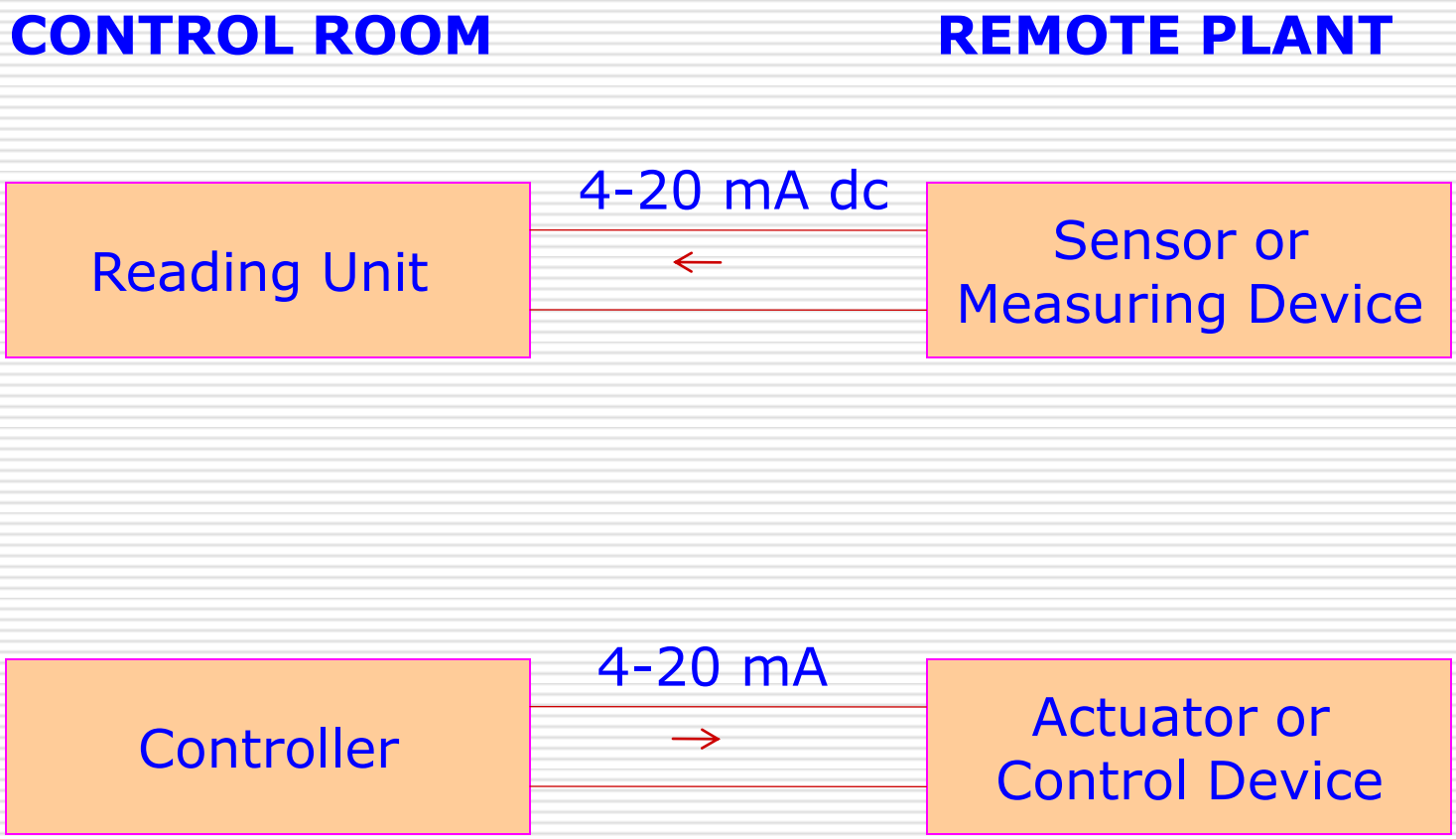
MAC Protocol

- Network can have multiple masters
- So MAC Protocol is fusion of:
  - **Token-passing principle**
    - Used by masters to initiate communication
    - Token passed to next master after communication is finished
  - **Polling principle**
    - Used by the master to poll slaves
    - The master requests, the addressed slave responds
    - So all frames contain SA and DA

HART Protocol

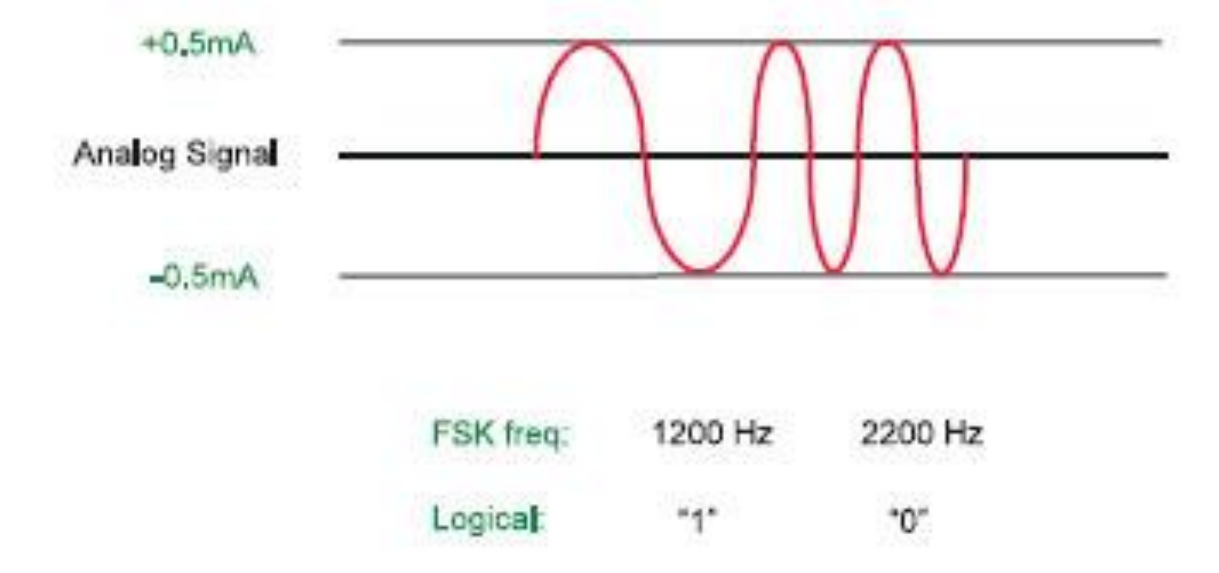
- A field communication protocol
- HART: Highway Addressable Remote Transducer
- HART protocol adds digital (data) communication to 4-20 mA field devices widely used in process automation
- Superimposes digital communication signal on analog communication signal of 4-20 mA on the same pair of wires
- Analog Communication: One-way only
- Digital Communication: Two-way (half duplex)
- Normally used for collecting data from field devices, configuring them and controlling them

4-20 mA Field Devices



Digital Communication Technique

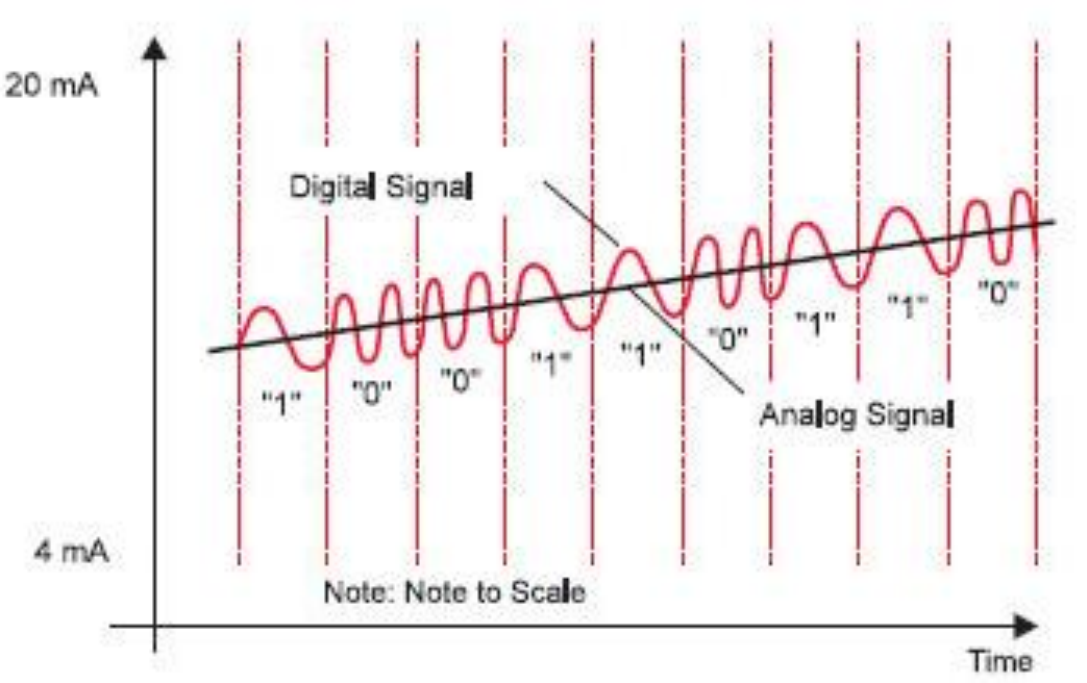
- Bell-202 FSK standard for digital communication
- Digital communication signal is low-level current carrier (0.5mA peak)
- Logic 1: 1200 Hz, Logic 0: 2200 Hz
- Maximum data rate: 1200 bps



Source: www.smar.com

Signal Superimposition

Digital (FSK) signal is superimposed on Analog (4-20 mA) signal



Source: www.smar.com

Cable Specifications

One UTP

- Maximum length of 1500 m

Alternatively, one STP

- Maximum length of 3000 m

Communication Configurations

HART protocol supports two com system configurations:

A. Point-to-Point Configuration

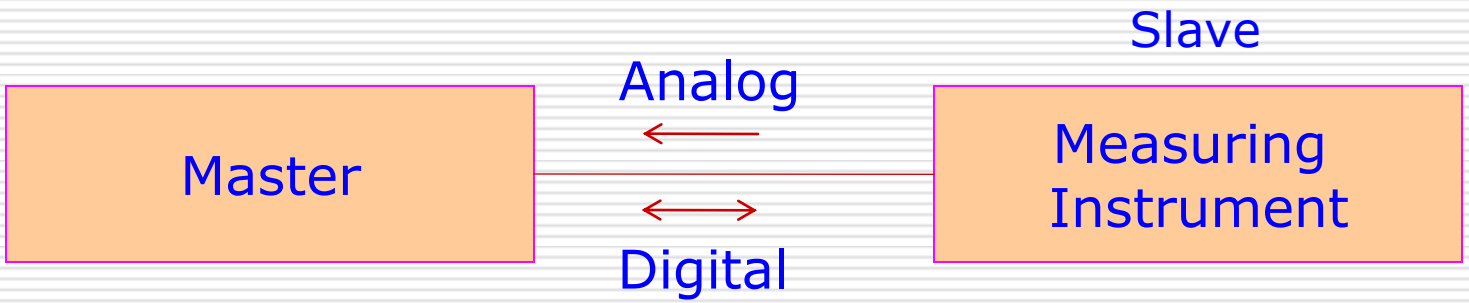
- Both analog and digital communications are supported
- One-to-one communication

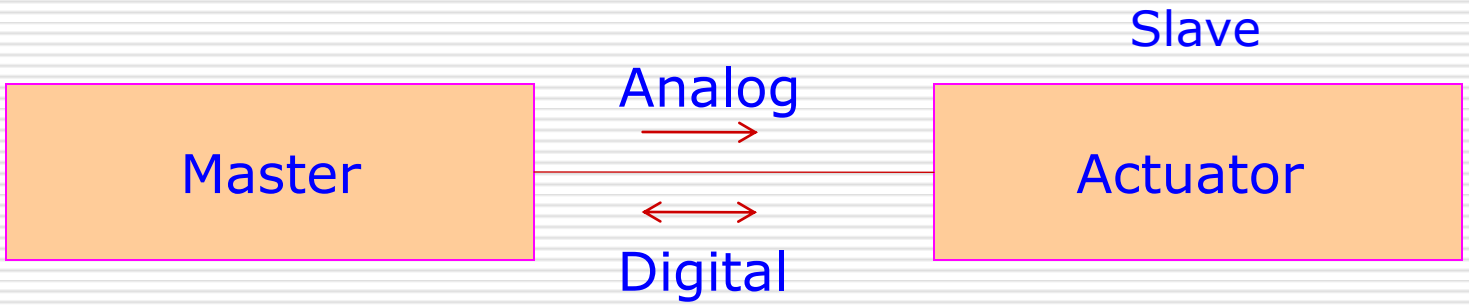
B. Multi-drop or Party-line configuration

- Only digital communication is supported
- Primary Master (e.g. PC, Controller)
- Secondary Master (e.g. Hand-held communicator)
- Slaves (e.g. Field devices)

Point-to-Point Configuration

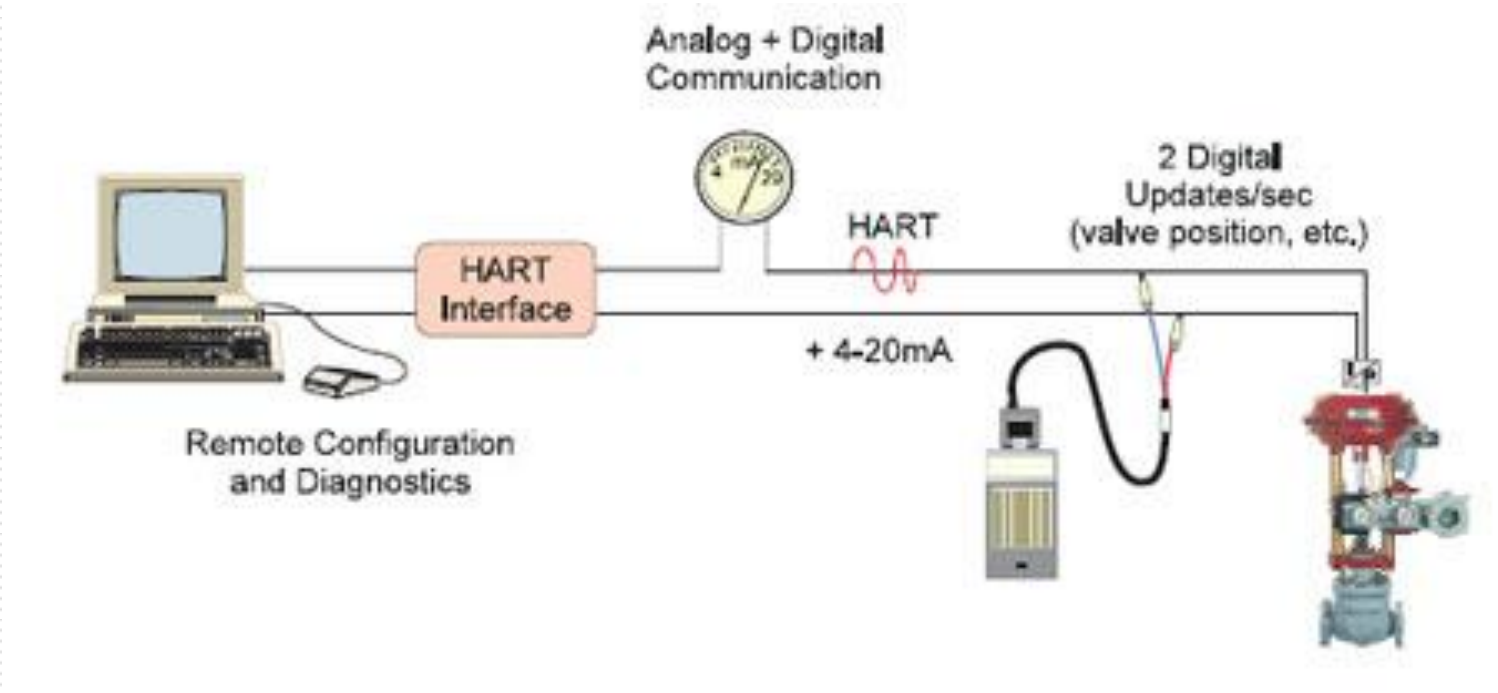
A: Master + Slave





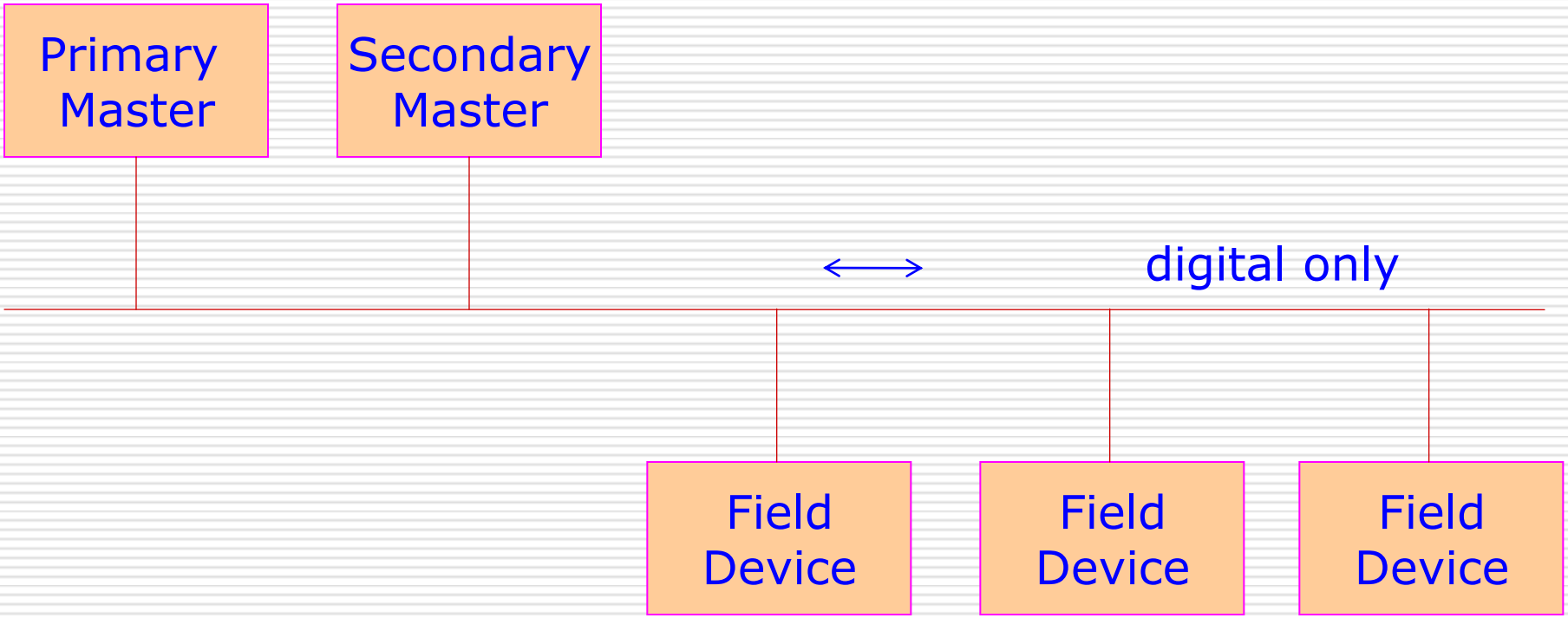
Point-to-Point Communication

B: Primary Master + Secondary Master + Slave



Source: www.smar.com

Multi-Drop or Party-Line Configuration



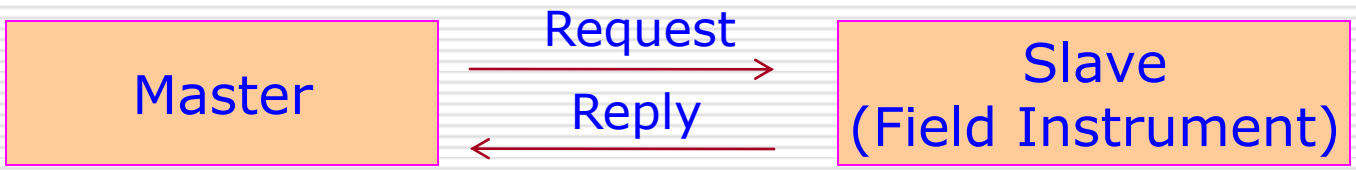
Digital Communication Modes

A. Normal Mode or
Poll-Response Mode

B. Burst Mode

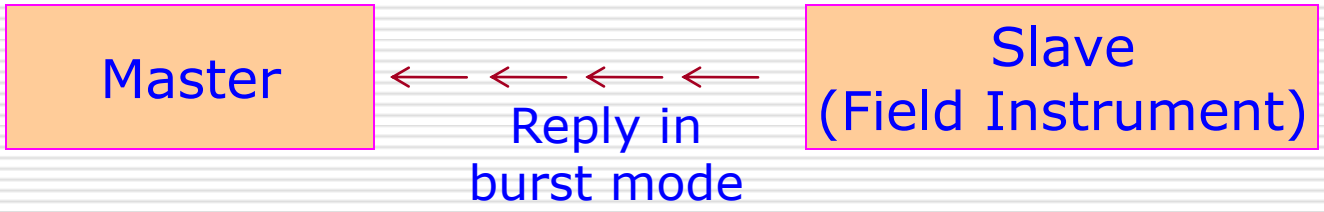
Digital Communication in Normal Mode

- Configuration: Point-to-point or Multi-point
- Master sends command (request), slave responds (replies)
- Typically, 2 responses per second (maximum)



Digital Communication in Burst Mode

- Slave transmits messages continuously (e.g. values of a measurand)
- Used for fast updation of the values of measurands



HART Command Set

HART command-set comprises three groups of commands:

A. Universal Commands

B. Common-Practice Commands

C. Device-Specific Commands

A. Universal Commands

"The commands that must be recognized and implemented by every HART compliant field device"

Examples:

- Read manufacturer's name
- Read model
- Read serial number
- Read range
- Read process variable names
- Read current output

B. Common-Practice Commands

"The commands that are recognized and implemented by most HART-compliant field devices"

Examples:

- Read (upto 4) variables
- Perform calibration check
- Perform self-test
- Write damping time constant
- Write transmitter range
- Set fixed current output

Note: A HART device can handle upto 256 process variables and can communicate upto 4 process variables in one message

C. Device-Specific Commands

"The commands that are specific to a HART-compliant field device"

Examples:

- Start, stop or clear (totalizer)
- Select ^{0}C/^{0}F (temperature sensor)
- Read alarm set point (relay)
- Write alarm set point (relay)
- Tune a control parameter (control device)
- Select proportional / PID control (control device)

Benefits of HART Protocol

- Maintains 4-20 mA compatibility while allowing simultaneous digital communication
- Relatively easy to understand & use
- Allows manufacturers to add special features to existing field instrument designs
- HART devices can be added incrementally
- "No-risk" solution as integrity of 4-20 mA signal is not disturbed
- Saving in installation cost due to multi-drop capability
- Supported by large number of device/system manufacturers

Limitations of HART Protocol

- Applicable to 4-20 mA devices only
- Only for sensors/measuring instruments and actuators
- Multiple controllers not possible
- Wireless alternative not possible