Networking & System Architecture

(MECH3023)

Contents

Networking & System Architecture

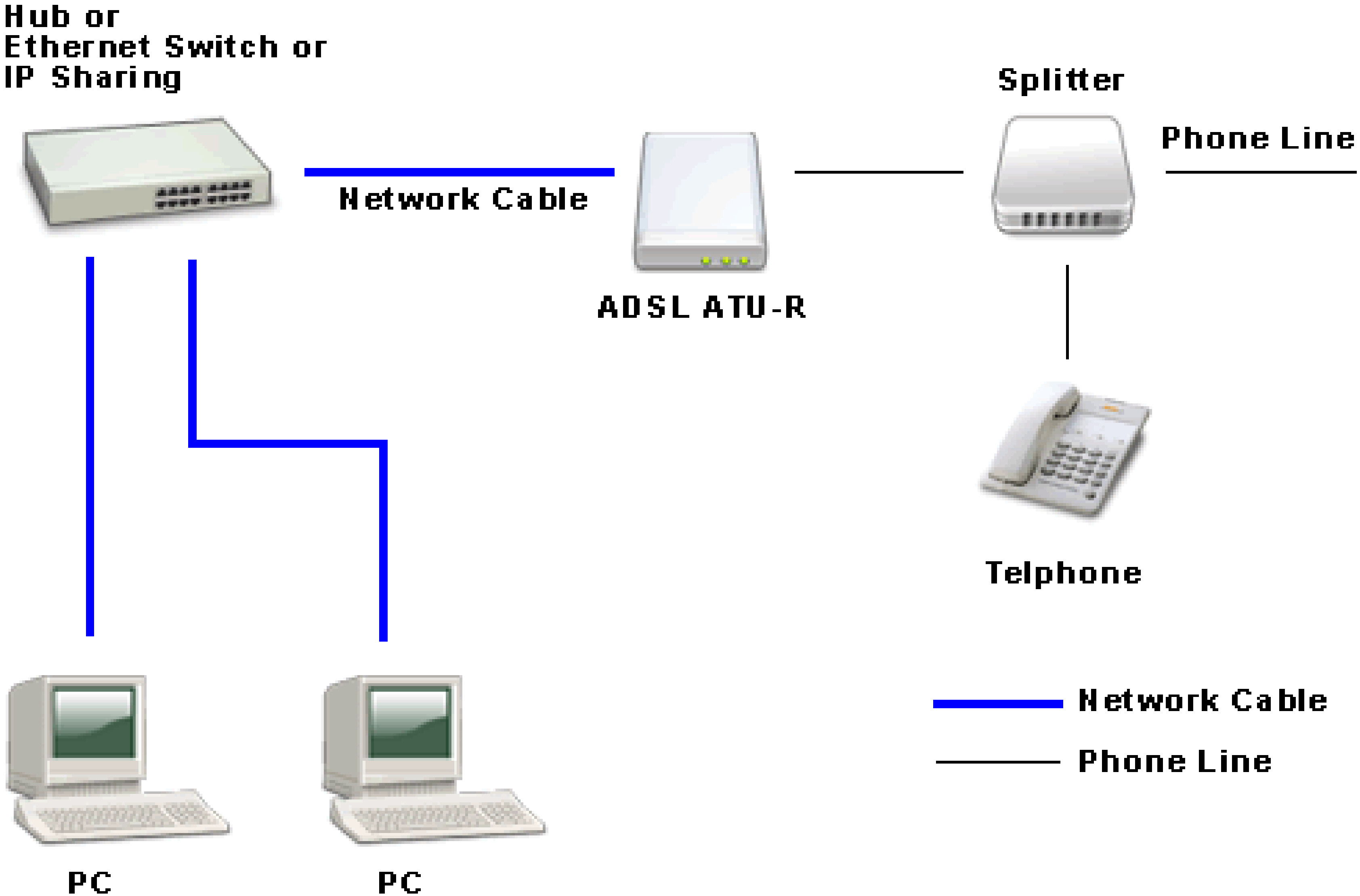
- Local Area Network (LAN)

Introduction

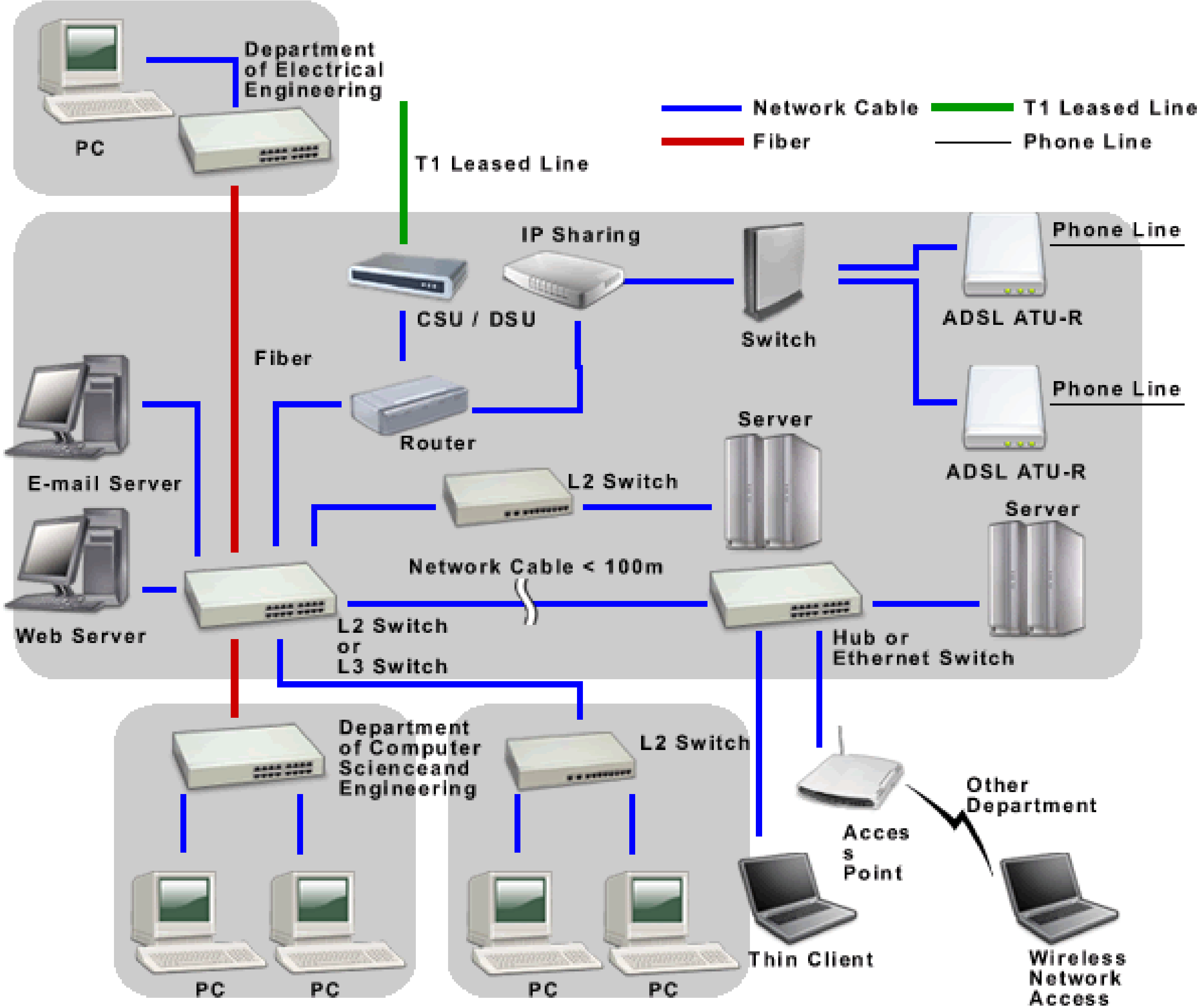
- What is a network?
  - A collection of computers, digital stations and other devices connected in a way that allows them to send out and receive data
  - The size of the network is commonly given various names of
    - Local Area Network (LAN)
    - Wide Area Network (WAN)
    - Metropolitan Area Network (MAN)
    - …

Local Area Network

- Local area network (LAN)
  - A computer network that spans a relatively small area, e.g. within a building or a company
  - Usually privately owned
  - With high-speed switched connections to 1Gbps
- Wide area network (WAN)
  - A system of LANs connected over any distance via telephone lines and radio waves
  - Usually leased from telecommunication service providers
    - Common ISPs (like internet service for residentials)
    - Dedicated lease lines of a certain bandwidth (e.g. 256kbps, 1Mbps)

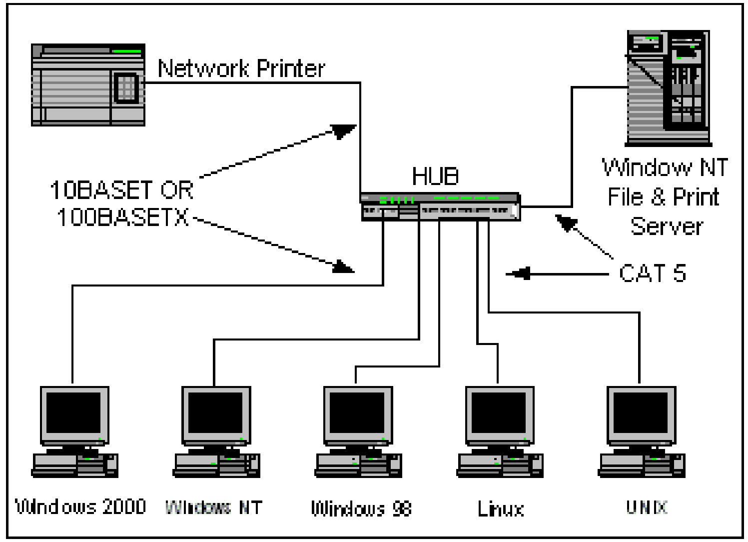


Home computer network



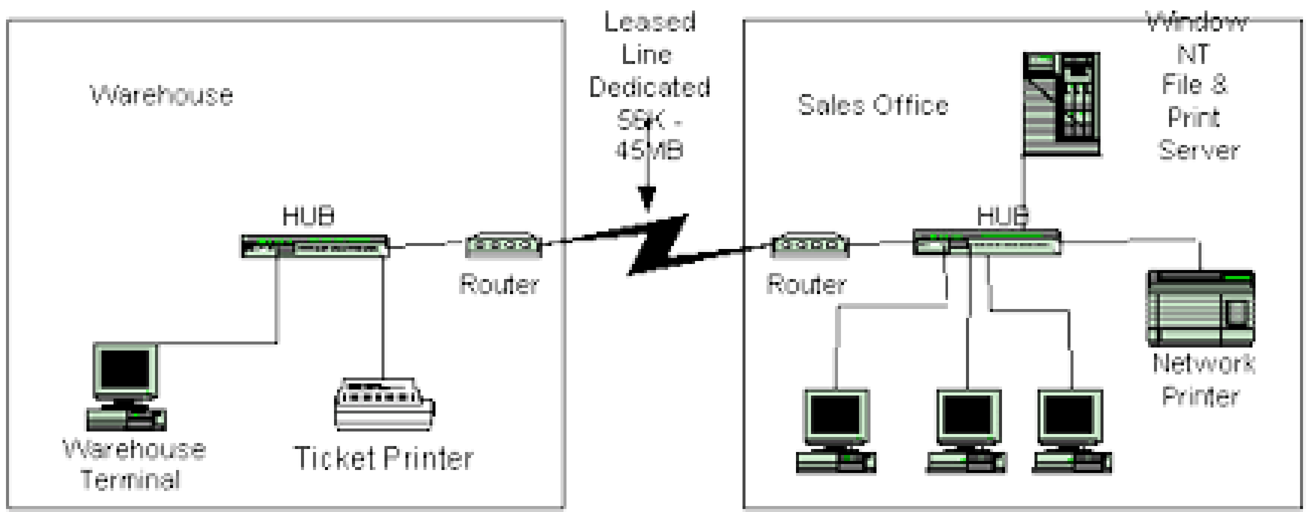
Office / Enterprise computer network

Local Area Network (LAN)

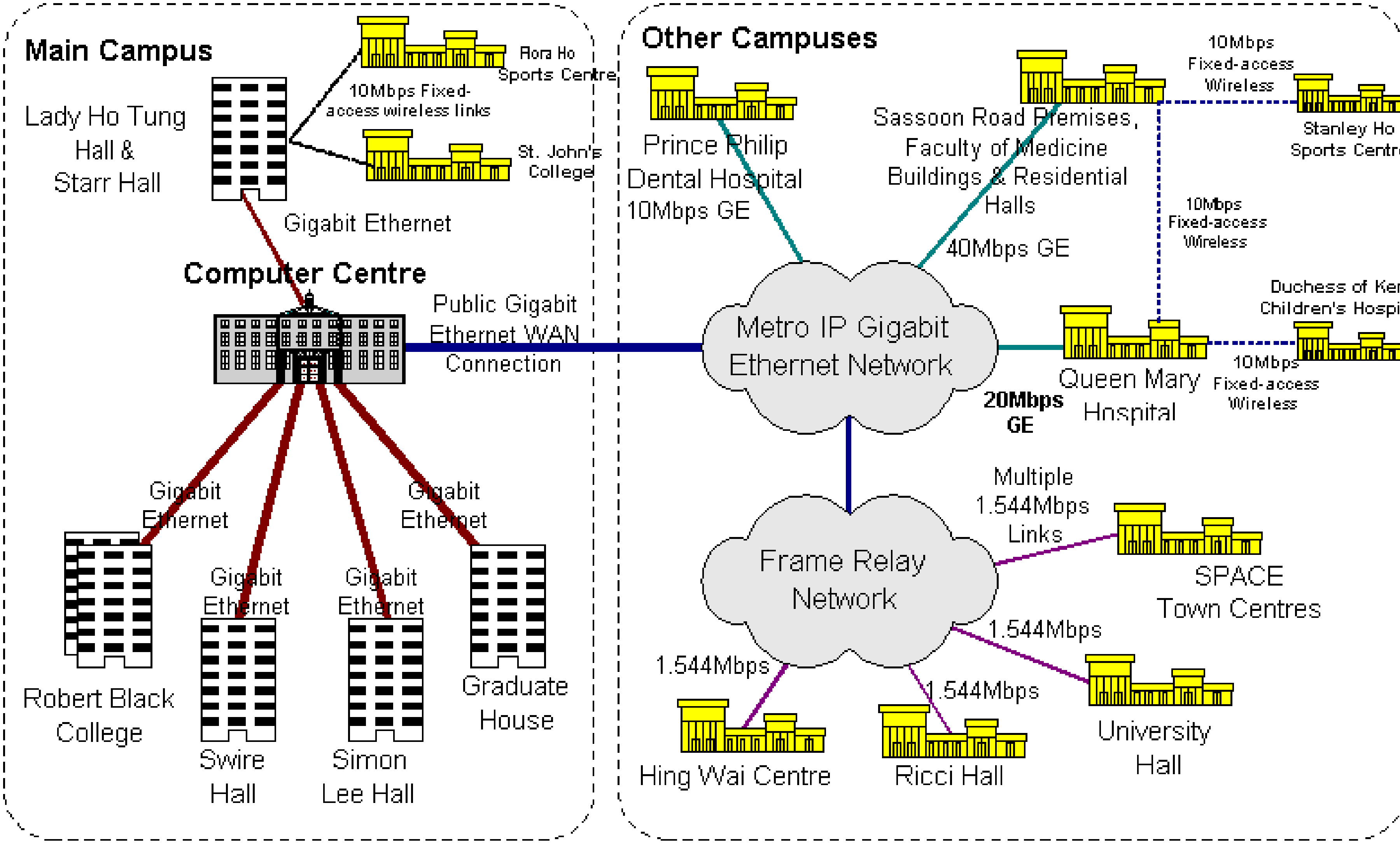


Local Area Network

Wide/Metropolitan Area Network (WAN/MAN)



Wide/Metropolitan Area Network



Computer Network of HKU Remote Campuses and Residential Halls

Local Area Network

- Ideal LAN should be
  - As easy to use as an electrical distribution system
    - One-time installation (plugged in)
    - Widespread access (any device/component)
    - Application independence
    - Excess capacity, easy maintenance & administration
  - Current obstacles in BAS
    - No single standard in BAS (not all are adopting to our familiar Ethernet)
    - Diverse requirements
    - Cost $$ of transmission media
    - Sophisticated functional requirements

Networking for BAS

- Why network in BAS?
  - Integration
    - System integration – digital stations or devices
    - Function integration – control and management functions
  - Flexibility – management, maintenance, expansion
  - Economic – choice of less expensive equipment

- Why networking is important for BAS?
  - Looking from the development trend from centralized systems to distributed networks
    - Centralized systems (older architecture)
      - One expensive large central computer + remote terminals
      - Networking speed relatively slow and incapable of delivering sufficient data throughput
    - Distributed processing (newer architecture)
      - Multiple smaller computers, separated and connected
      - More higher level management functions, e.g. demand analysis, optimization, etc. create the need for huge data flow among the various components
    - This evolution makes networking an important and essential component in the whole system

Centralized vs Decentralized Networks

- Relates to the operation of a network rather than the physical arrangement of the nodes and transmission links
- Centralised Network
  - Network controller (master) that controls the data transfers between all nodes (slaves) in the network
  - All transfers must pass through the central node
  - Simpler network protocol
  - Less reliable – central node fails, the whole system fails

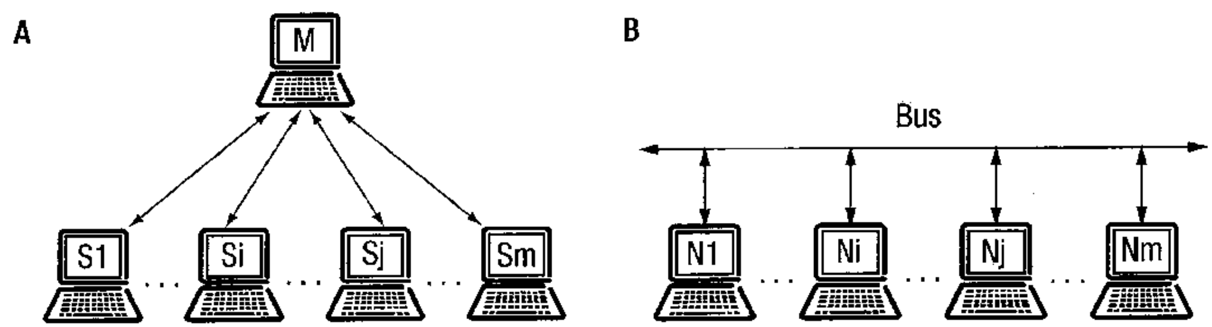


Figure 4.2 A. Centralized network; B. Decentralized network.

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

- Decentralised Network
  - All nodes have the same right to use and control over the network links
  - All nodes governed by the same rules
  - No distinct network master required
  - Failure of any one node will not affect the others
  - Network protocol is more complicated than a centralised one

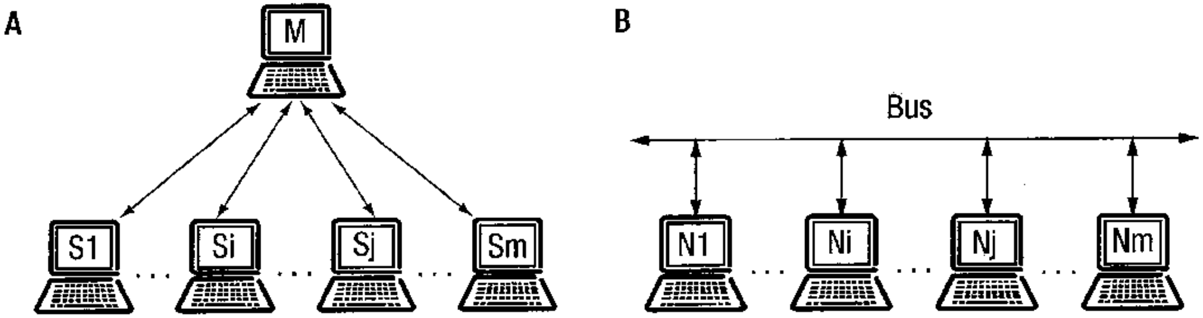


Figure 4.2 A. Centralized network; B. Decentralized network.

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

LAN Topologies

- The topology of a network is how each node (computer, device) is connected to its partners both physically and logically
- 3 most popular topologies
  - Star topology
  - Bus topology
  - Ring topology

Star Topology

- Computers/ devices are connected to a hub through which all traffic flows (similar to a home network in which the computers, network storage and network printers) are connected to a single router / hub
- Hub fails → all stations lose connectivity
- Pros → simple, not difficult to expand (by adding more hubs)
- Cons → reliability depends on the hub
- * Like home network, physically is a star topology, but logically is a bus topology

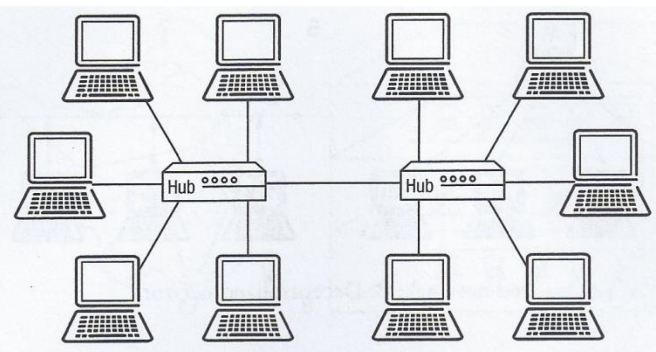


Figure 4.3 Star topology LAN.

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

Bus Topology

- Most commonly found in Ethernet environments
- Implemented using coaxial cable like a public antenna system
  - Coaxial cable has high bandwidth
- Pros → Simple and inexpensive to install or expand
- Cons → expansion beyond design limits, any disconnection results in breakdown of the system

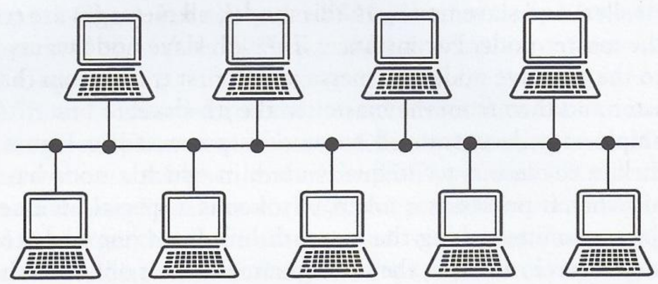


Figure 4.4 Bus topology LAN.

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

Ring Topology

- Normally associated with Token Ring and FDDI networks
  - FDDI = Fiber Distributed Data Interface
- Operation → a station will wait for a 'token' before transmitting a packet of data, once received the token, the station transmits a message and the neighbouring stations will examine if any one needs to take up the message
  - More than one station can receive the message
  - The transmitting station will know if the message has been received
- Adopts a complex access protocol using an ordered method of node access
  - Performance can be easily predicted since each node will take turns to use the resources of the network → the larger number of nodes, the smaller the shared resources (but predictable compared with others)
- Pros → robust, self-healing by use of dual, counter rotating rings
- Cons → expensive to implement

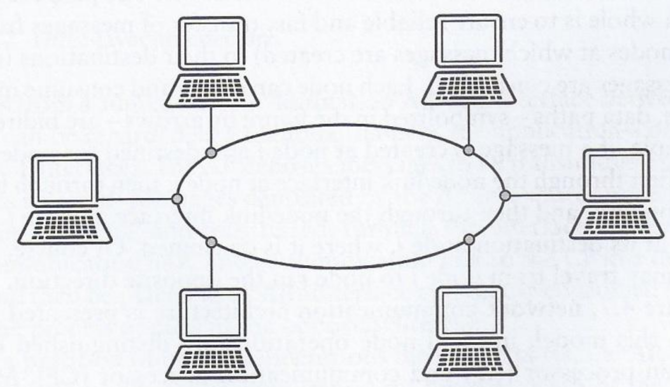


Figure 4.5 Ring topology LAN.

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

LAN Standards

- Developed under IEEE 802.x
- Includes the Data Link and Physical Layers of the OSI Seven Layer Model
- Top layer is the Logical Link Control (LLC)
- Below LLC is the Medium Access Control (MAC) and standardized as
  - 802.3 CSMA/CD Networks
  - 802.4 Token Bus Networks
  - 802.5 Token ring Networks
  - 802.6 Metropolitan Area Networks
  - 802.7 Broadband Technical Advisory Group
  - 802.8 Fiber Optic Technical Advisory Group
  - 802.9 Integrated Voice and Data LAN Interface
  - 802.10 Standard for Interoperable LAN Security
  - 802.11 Wireless LAN (a,b,g,n…)
- However, LLC layer is seldom used to improve efficiency, e.g. use of IP address (Network Layer) to directly access the MAC layer

Table 4.1 LAN standards of IEEE 802 series

Data Link Layer		
Logical Link Control	*Media Access Control*	*Physical Layer*
802.2 LLC Logical Link Control	CSMA/CD 802.3	Baseband coaxial 10/100 Mbps
		Twisted pair 1, 10, 100 Mbps
		Broadband coaxial 10 Mbps
		Optical fibre 100/1000 Mbps
	Token Bus 802.4	Broadband coaxial 1, 5, 10 Mbps
		Carrier band 1, 5, 10 Mbps
		Optical fibre 5, 10, 20 Mbps
	Token Ring 802.5	Twisted pair 4, 16 Mbps
		Unshielded twisted pair 4 Mbps
	FDDI (Token Ring)	Optical fibre 100 Mbps

Relationship between LLC, MAC and physical layer

LAN Standards – examples

- Ethernet
  - Peer-to-peer connection: Carrier Sense Multiple Access w/ Collision Detection (CSMA/CD)
  - Speed: 10Mbps (10Base-T Ethernet), 100Mbps (Fast Ethernet) & 1Gbps (Gigabit Ethernet)
  - Most popular in BAS and in computer networks
  - Advantages
    - Easy to understand, implement, manage and maintain
    - Allows low cost network implementations
    - Provides extensive topological flexibility for network installation
    - Guarantees successful interconnection and operation of standards-compliant products

Table 4.2 Ethernet technical specifications

Specification	*Characteristics*
Network standard	ISO 8802–3/IEEE 802.3 serial
Protocol	Standard for layer 1 and 2
Architecture	Bus or star topology
Transmission speed	10 Mbps – 100 Mbps, 1 Gbps
Network node capacity	48 bits addressing (normally, 254 nodes per subnet)
Network length	100 m (10Base-T) to 10 km (fibre)
Physical path cabling	Twisted pair, coaxial, optical fibre
Media Access Control (MAC) method	CSMA/CD

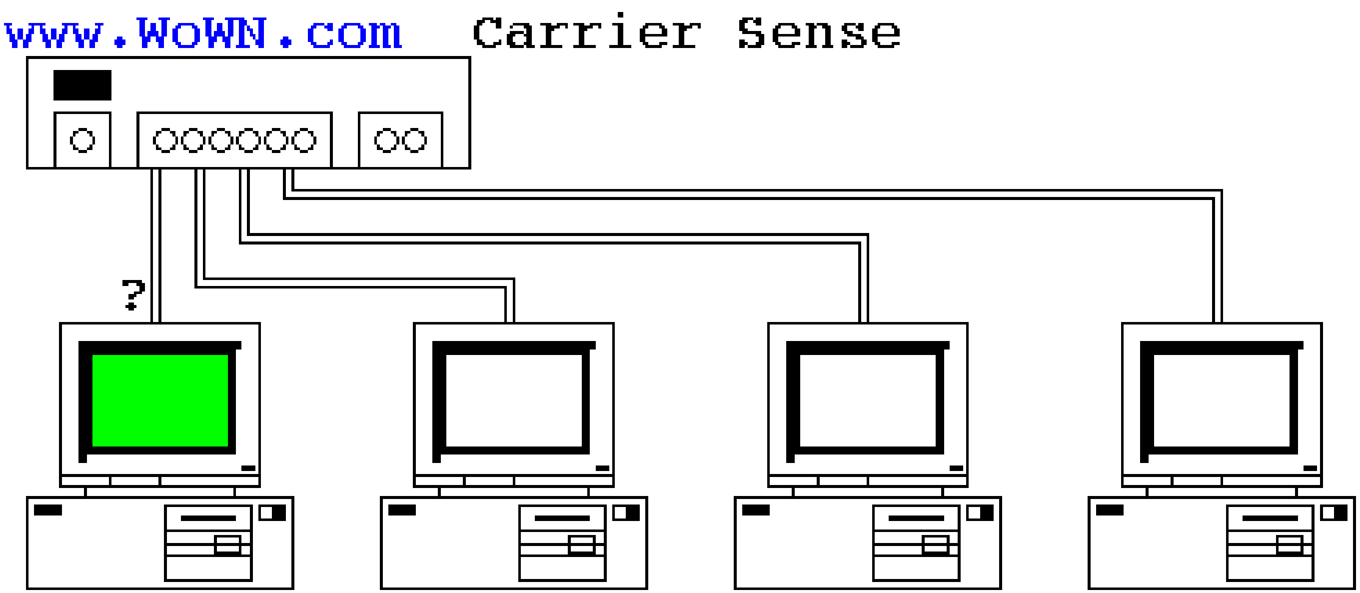
Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

Carrier Sense (CS):

Before a system can start transmitting on a Network, it 'listens' on the cable for a carrier signal (very much the same as when you pick up the phone and listen to the dial-tone). Only when the cable is not busy with another data-transfer, it will start the transmission.

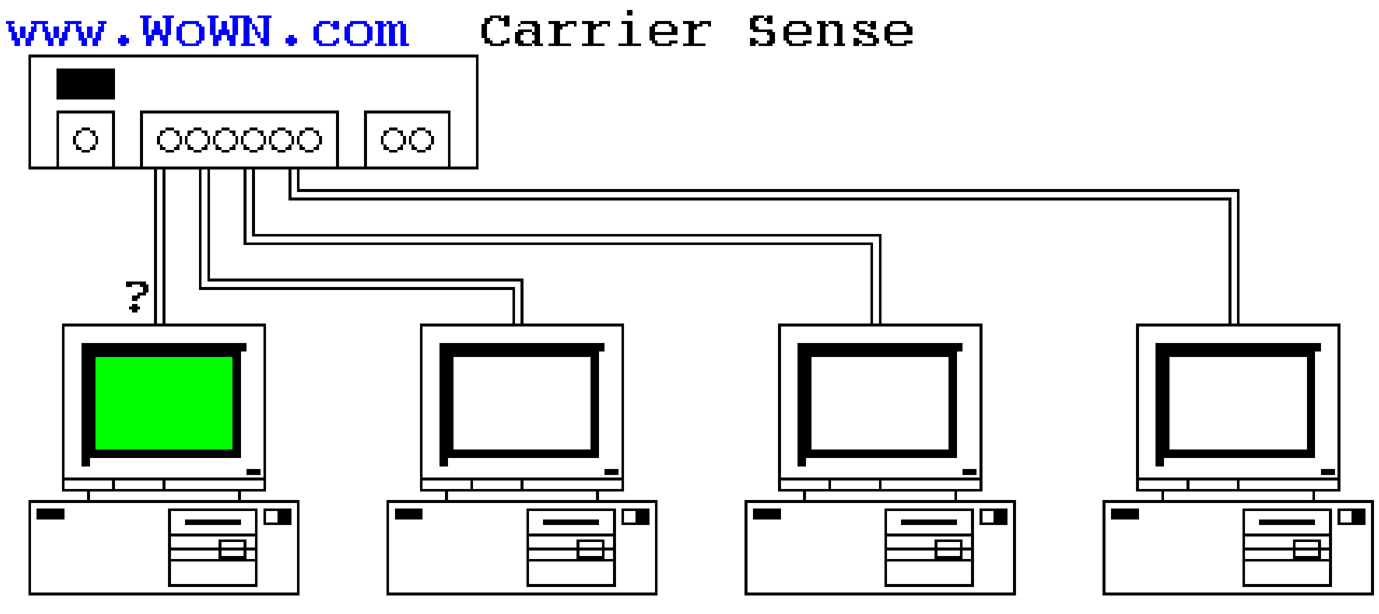
Multiple Access (MA):

As long there is no 'busy-signal' on the cable, any connected station can start transmitting immediately.



Collision Detection (CD):

It can happen, that 2 or more stations start transmitting at the same time, which causes then a collision of the signal, which is then detected causing the transmitting systems to abort, wait a little (length is randomly determined) before the systems try to access the network cable again.



LAN Standards – examples

- ARCNET
  - ARCNET = Attached Resource Computer NETwork
  - peer-to-peer token-passing
  - Speed: 2.5 Mbps
  - A token is passed from node to node
  - Widely used in industrial control and BAS
  - Very robust, with deterministic performance and can span long distances

Table 4.3 ARCnet technical specifications

Specification	*Characteristics*
Network standard	ANSI 878.1 (close to IEEE 802.4)
Protocol	Standard for layers 1 and 2
Architecture	Bus or star topology
Transmission speed	2.5 Mbps
Network node capacity	254 nodes
Network length	122 m (twisted pair) 305 m (coaxial)
Physical path cabling	Twisted pair or coaxial
Medium Access Control (MAC) method	Token passing

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

LAN Standards – examples

- LonTalk
  - A protocol which is closely associated with communication hardware (Neuron chips) under Echelon Corporation
  - Works under LonWorks protocol in controlling building automation products using the proprietary communication processor chip ‘Neuron’

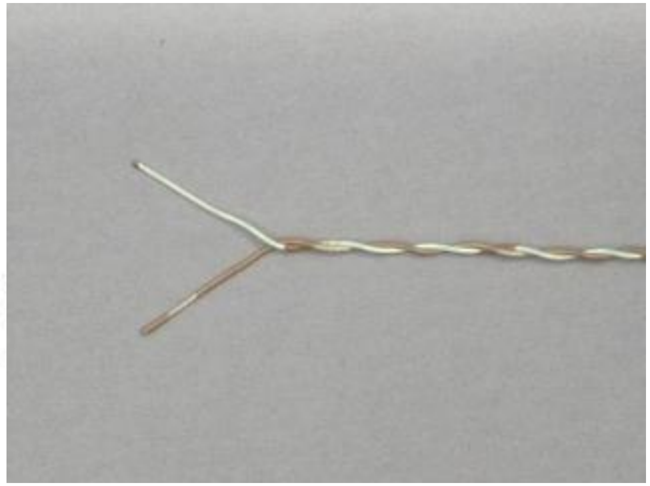
Table 4.4 LonTalk networks specifications

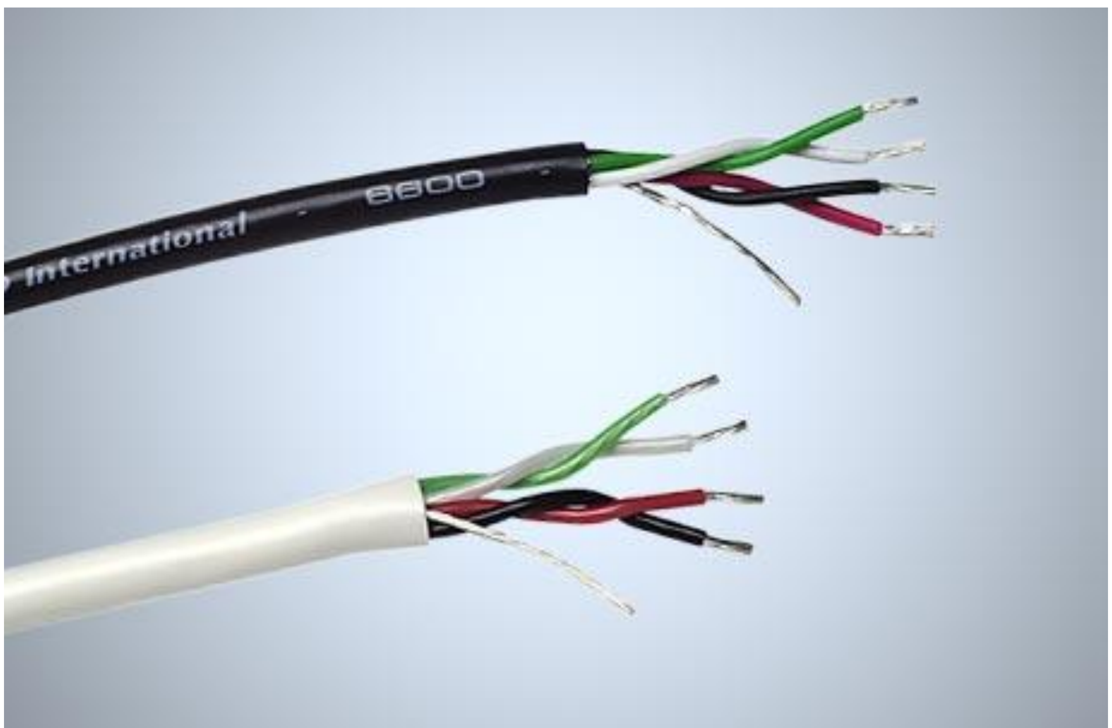
Specification	*Characteristics*
Network standard	ANSI/EIA 709.1
Protocol	Standard for layers 1 and 2
Architecture	Bus, star and free topology
Transmission speed	300 bps – 1.25 Mbps
Network node capacity	Nodes per subnet: 127
Network length	130 m (TPT/XF, 1.25 Mbps, 64 nodes) 2700 m (FTT-10, 78 Kbps, bus, 64 nodes) 2200 m (LPT-10, 78 Kbps, bus, 128 nodes)
Physical path cabling	Twisted pair, power line, EIA-485, infrared, optical fibre, coaxial cable, radio-frequency
Media access control (MAC) method	Predictive P-Persistent CSMA

Source: WANG S., Intelligent Buildings and Building Automation, 2010, Spon Press

Transmission Hardware

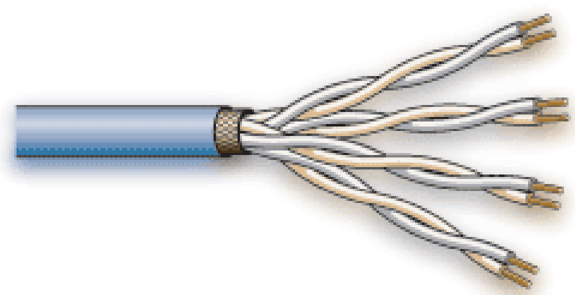
- Twisted pairs (TP)
  - Two insulated conductors twisted together to minimize interference by unwanted signals
    - Line bandwidth (300–3000 Hz)
    - Signal-to-noise ratio
    - Conditioning (of the line)
  - Conditioned line has speed up to 9600 bps
  - In most cases, 1200 bps is maximum
  - Unshielded twisted pairs (UTP)

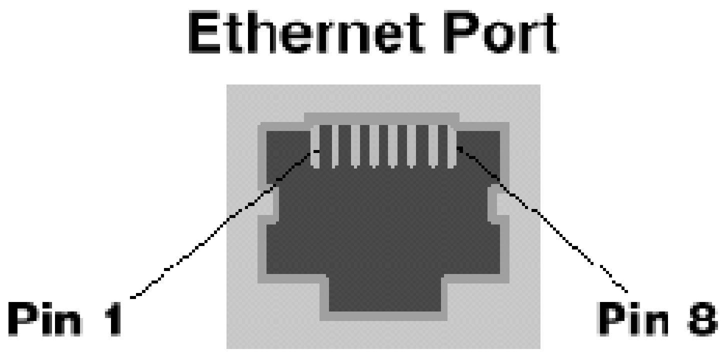


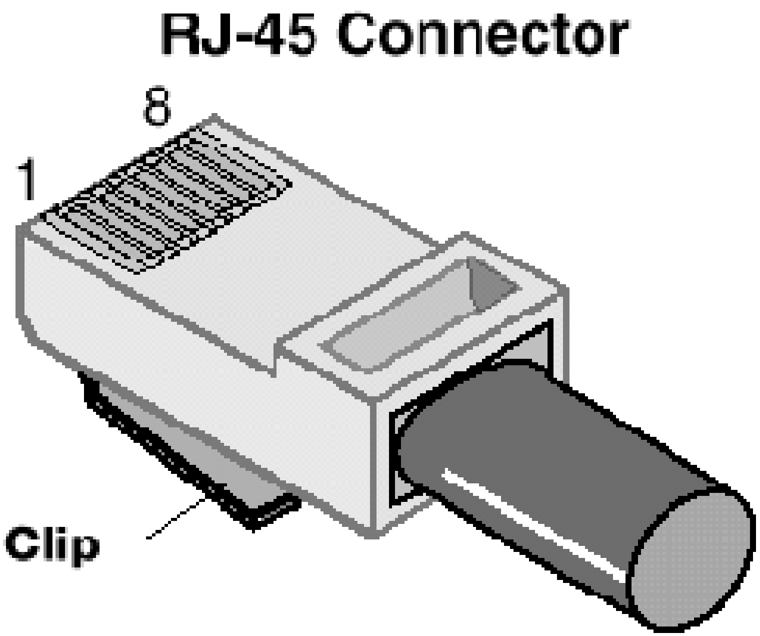


Unshielded twisted-pair

Foiled twisted-pair

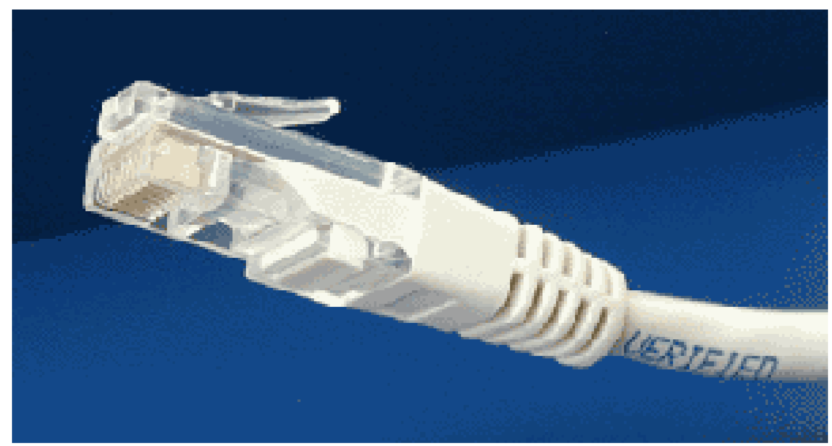






“100 Base T” means:

- 100 Mbps
- Baseband signal
- 4 pairs Twisted Pairs

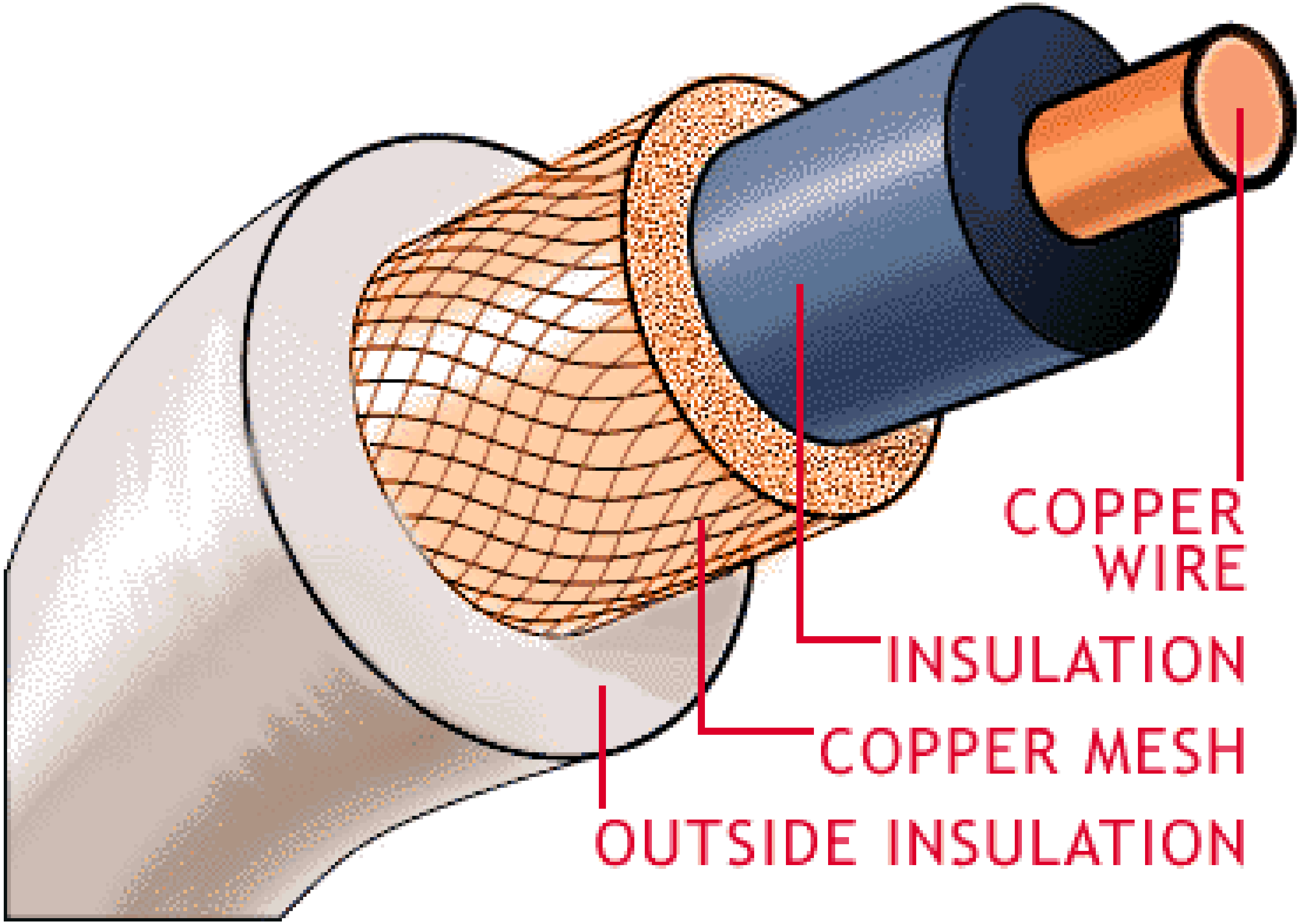


RJ-45 = Registered Jack-45 (8-wire)

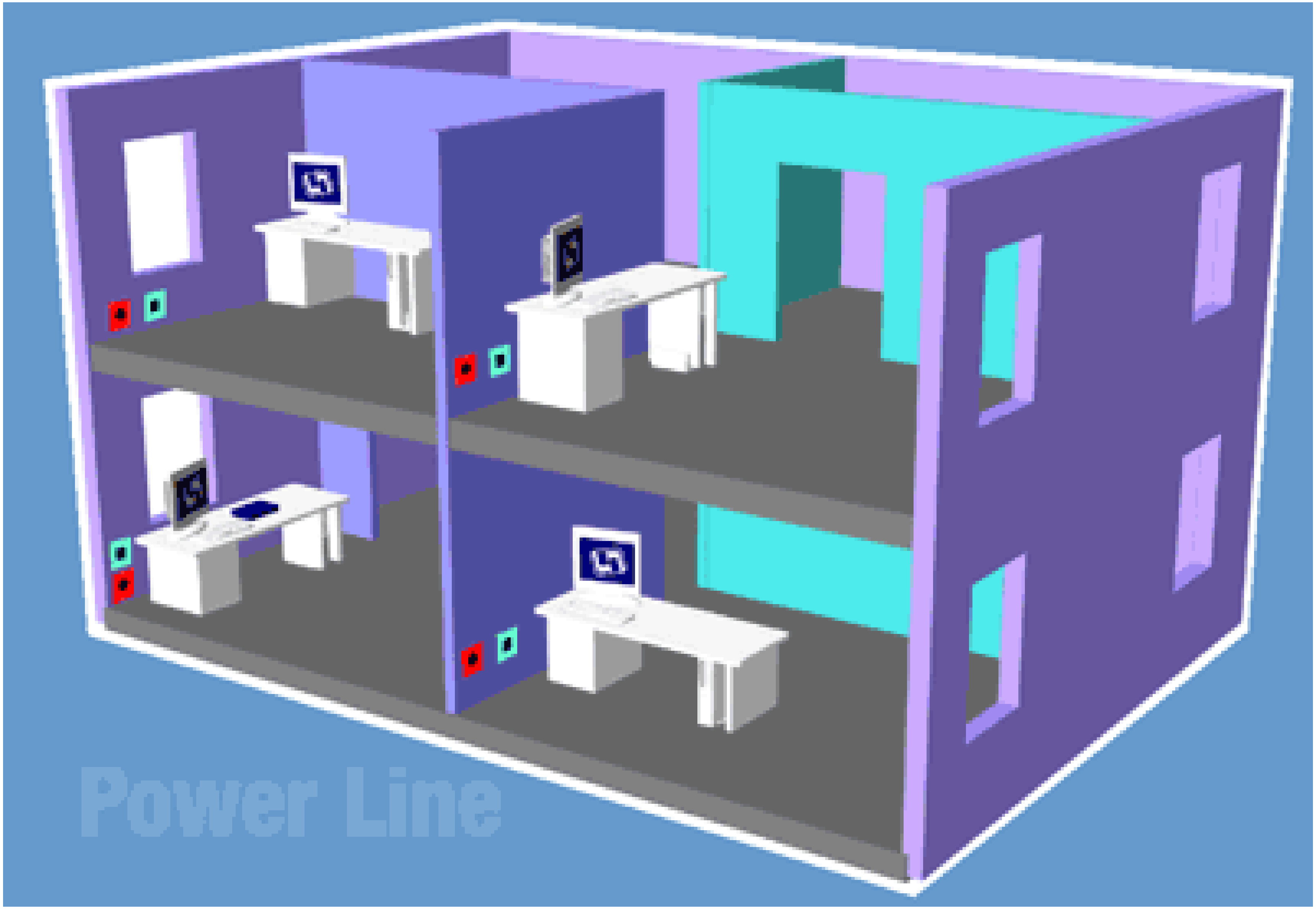
(RJ-11: for telephone, 4- or 6-wire)

Transmission Hardware

- Voice grade lines
  - Type 3002 in in the Bell Telephone Company's standard BSP41004
- Coaxial cable
  - Centre conductor surrounded by a shield
    - Electromagnetic interference
- Power lines
  - Using carrier current transmission that superimposes a low RF signal (100 kHz) onto the 50/60 Hz power distribution system



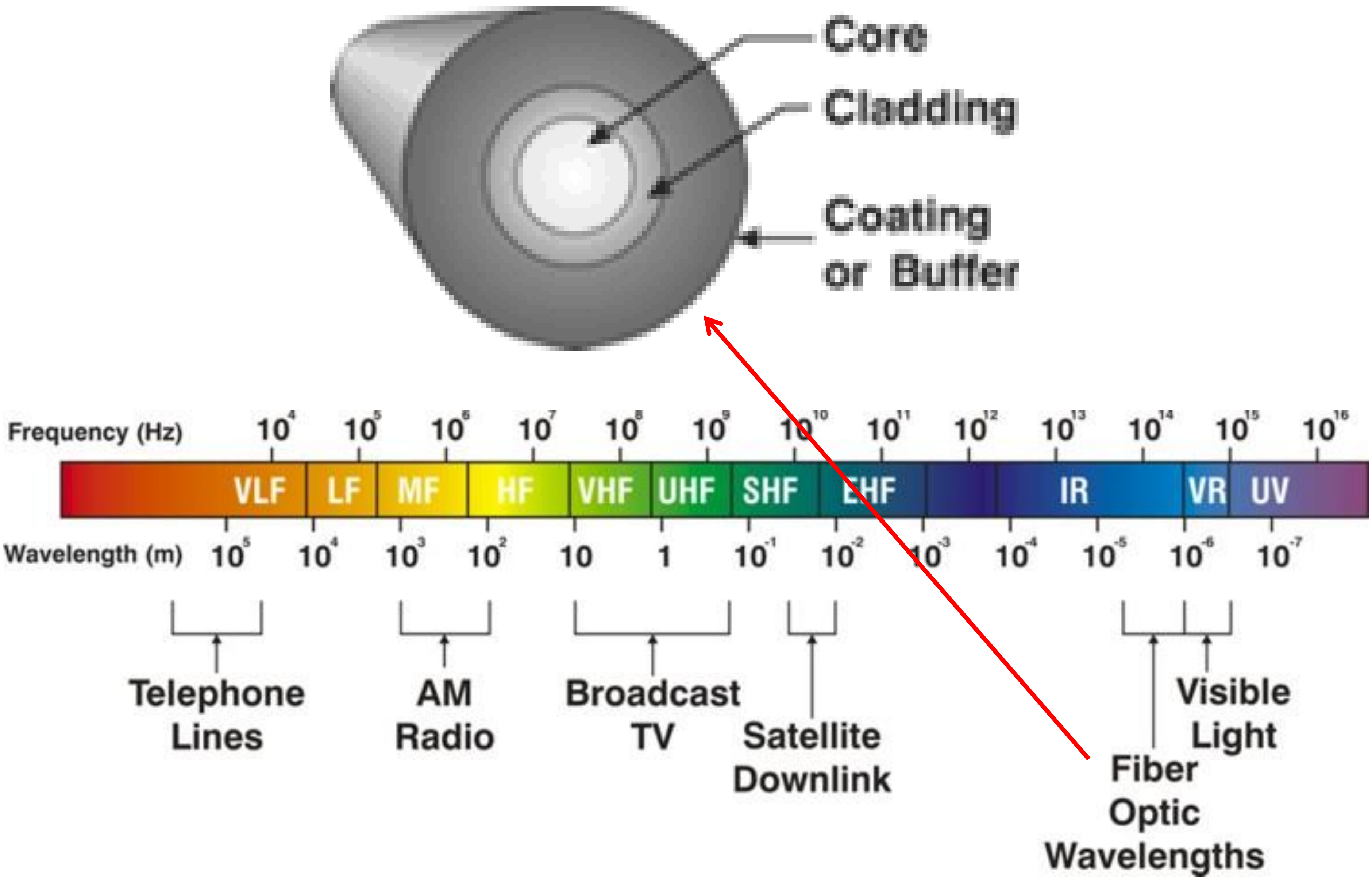
Coaxial cable



(Source: www.linksys.com)

Transmission Hardware

- [Radio frequency (RF)]
  - Modulated RF, with radio receivers and transmitters
  - Common household uses: 2.4GHz, 5GHz computer equipment
- [Microwave]
  - Used by TV stations, very high cost
- [Fiber optics]
  - Infrared light travelling through transparent fibers
  - Best suited for point-to-point high speed transmission
  - Bandwidth virtually unlimited


Core
Cladding
Coating or Buffer
Frequency (Hz)
10^4 10^5 10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
IR
VR
UV
Wavelength (m)
10^5 10^4 10^3 10^2 10 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7
Telephone Lines
AM Radio
Broadcast TV
Satellite Downlink
Visible Light
Fiber Optic Wavelengths

Comparison of transmission methods

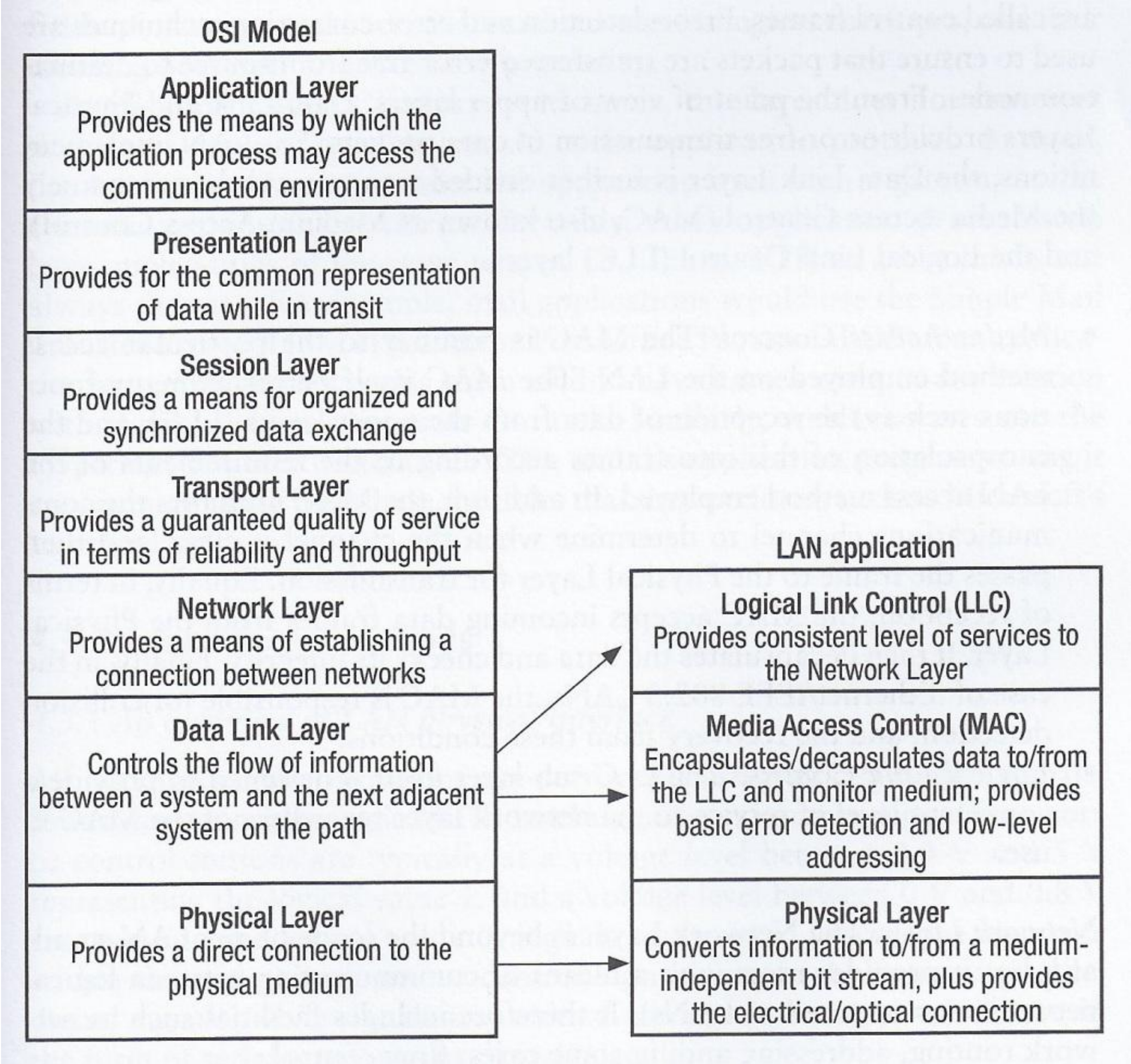
Method	**First cost**	**Scan rates**	**Reliability**	**Maint. Effort**	**Expand-ability**	**Compati-bility**
Coaxial	High	Fast	Excellent	Min.	Unlimited	Unlimited
Twisted pair	High	Medium	Very good	Min.	Unlimited	Limited
Radio frequency	Medium	Fast but limited	Low	High	Very limited	Very limited
Microwave	Very high	Very fast	Excellent	High	Unlimited	Unlimited
Telephone	Very low	Slow	Low to high	Min.	Limited	Limited
Fibre optics	High	Very fast	Excellent	Min.	Unlimited	Unlimited

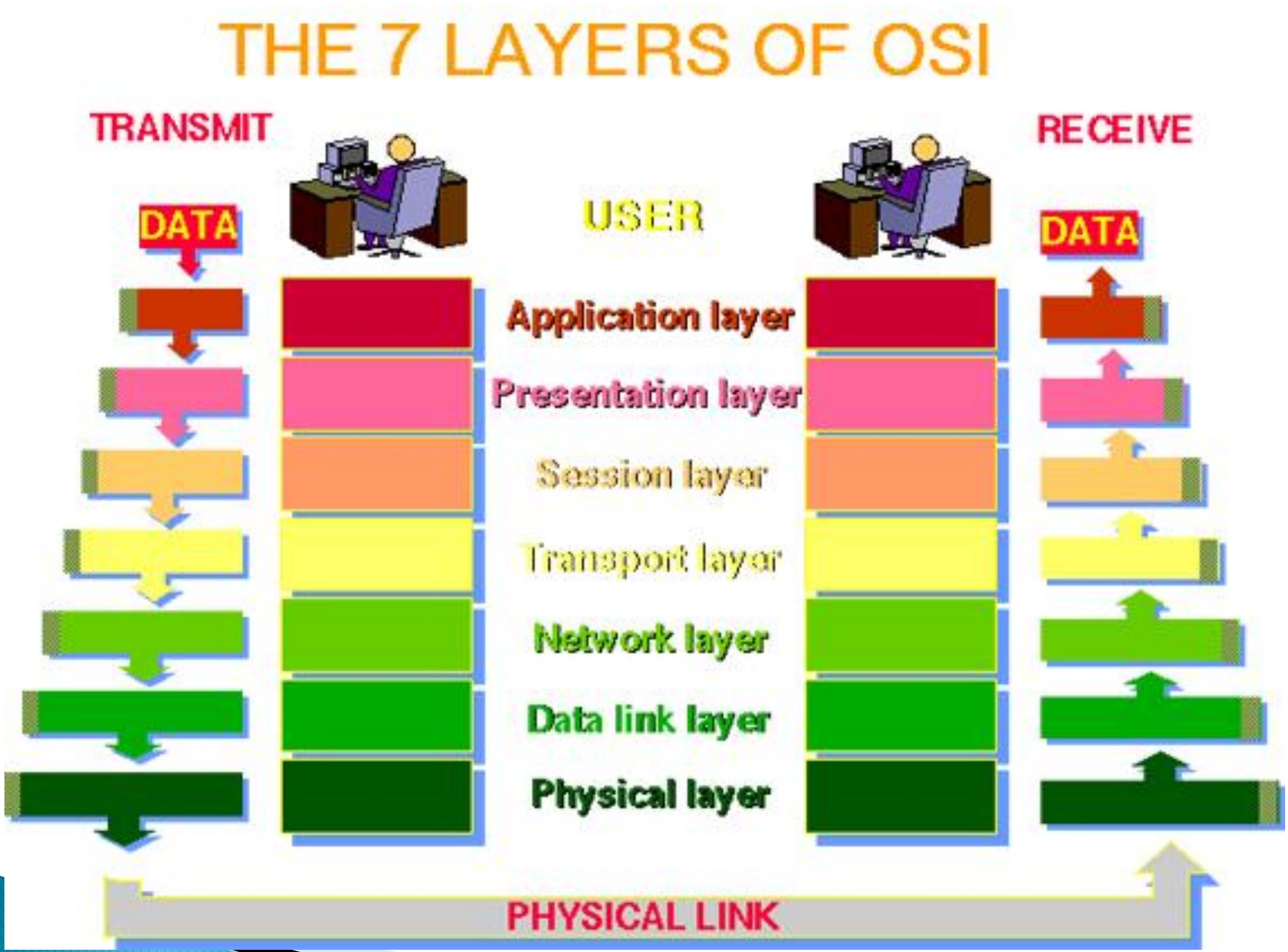
Networking & System Architecture

- OSI Seven Layer Model

- BAS system products are complicated and tend to be incompatible among different manufacturers
- Need to develop a standard to communicate on the network
- ISO proposed a network architecture model
  - Open Systems Interconnection (OSI) Model
  - Provide a framework for networking standards

OSI Seven-layer Model





(Source: www.webopedia.com)

OSI Seven-layer Model

- Level 1 – Physical Layer
  - Specifies the electrical signaling, and the mechanical or physical connections applicable to the medium
  - Defines the characteristics of these signals, such as voltage or current levels, frequency and timing
  - Also specifies the mechanical properties of network cables and connectors
  - Ensures the data are prepared properly at the interface between this Physical Layer and the upper Data Link Layer.

OSI Seven-layer Model

- Level 2 – Data Link Layer
  - Defines rules for sharing the use of the Physical Layer among network nodes in the LAN
  - Information (in Physical Layer) is transferred in addressed data frames, one at a time
  - Define the format of these frames and the method by which a node decides when to transmit or send a frame (the method is sometimes referred to as control frames, e.g. CSMA/CD)
  - Data Link and Physical Layers provide error-free transmission of data.

OSI Seven-layer Model

- Level 3 – Network Layer
  - Provides users with a means of communicating between logical networks, including network routing, addressing and flow control
  - Each data packet is enclosed by an address to identify the node that submit the data.
  - E.g. The use of IP (Internet Protocol) address to enclose the packet.

OSI Seven-layer Model

- Level 4 – Transport Layer
  - Provides a basic interface between the Session Layer (upper layer) and the underlying network-dependent protocols
  - Provide for connection-oriented sessions which demand the exchange of data in an orderly and reliable manner
  - Typically implemented as a sequence number / acknowledge system to ensure all data are received, and in orderly manner

OSI Seven-layer Model

- Level 5 – Session Layer
  - Provides a method by which two systems may organize and synchronize their dialogue, thus manage the exchange of data between the systems
  - Most complex of all layers

OSI Seven-layer Model

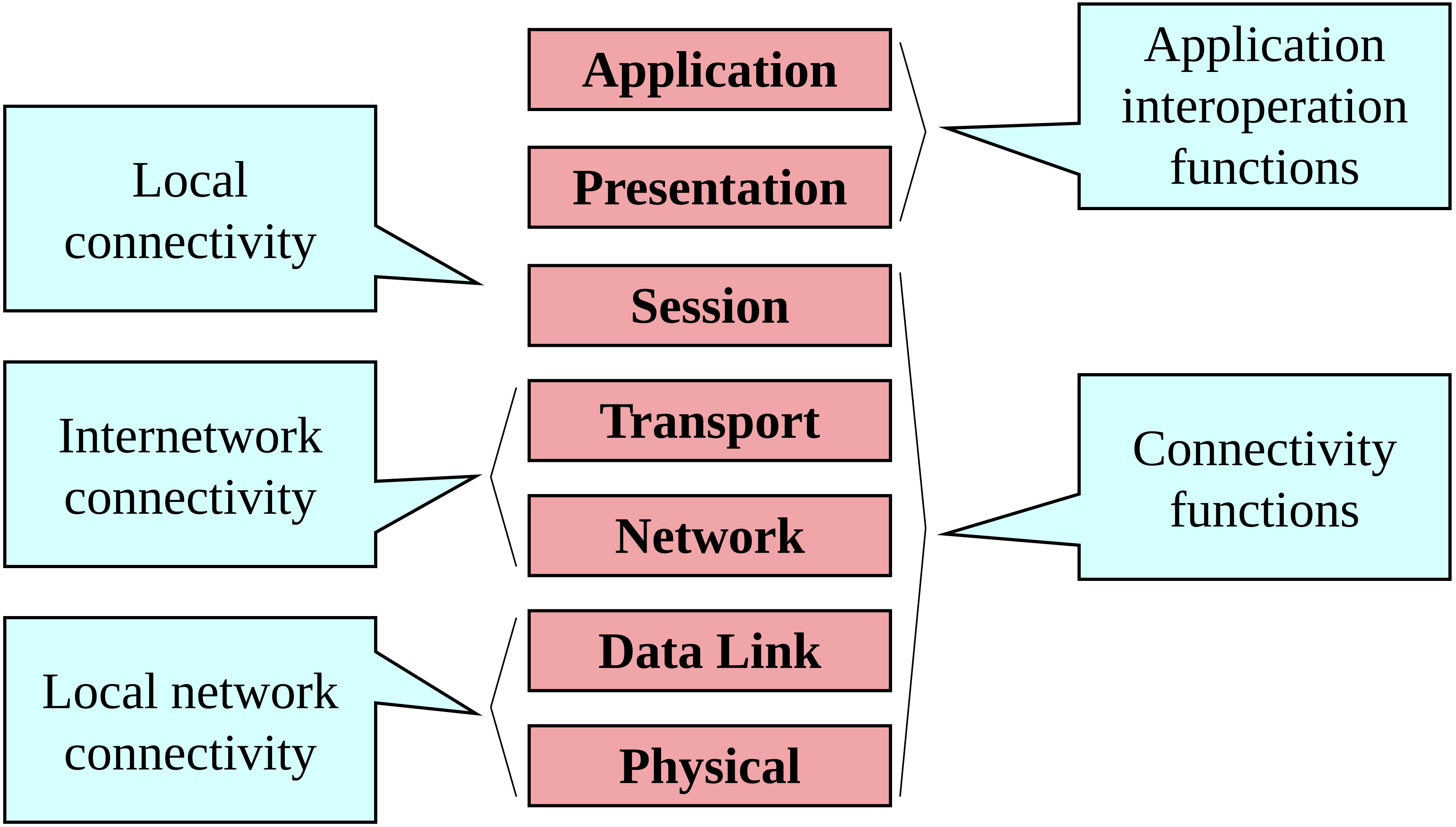
- Level 6 – Presentation Layer
  - Concerns about the presentation of data while in transit
  - Conversion of user messages from the form used by the Application Layer to that used by all lower layers
  - Message 'conversion' achieves data compression and security (encryption)
    - Upper interface of presentation layer – meaningful explicit form
    - Lower interface – meaningless packets

OSI Seven-layer Model

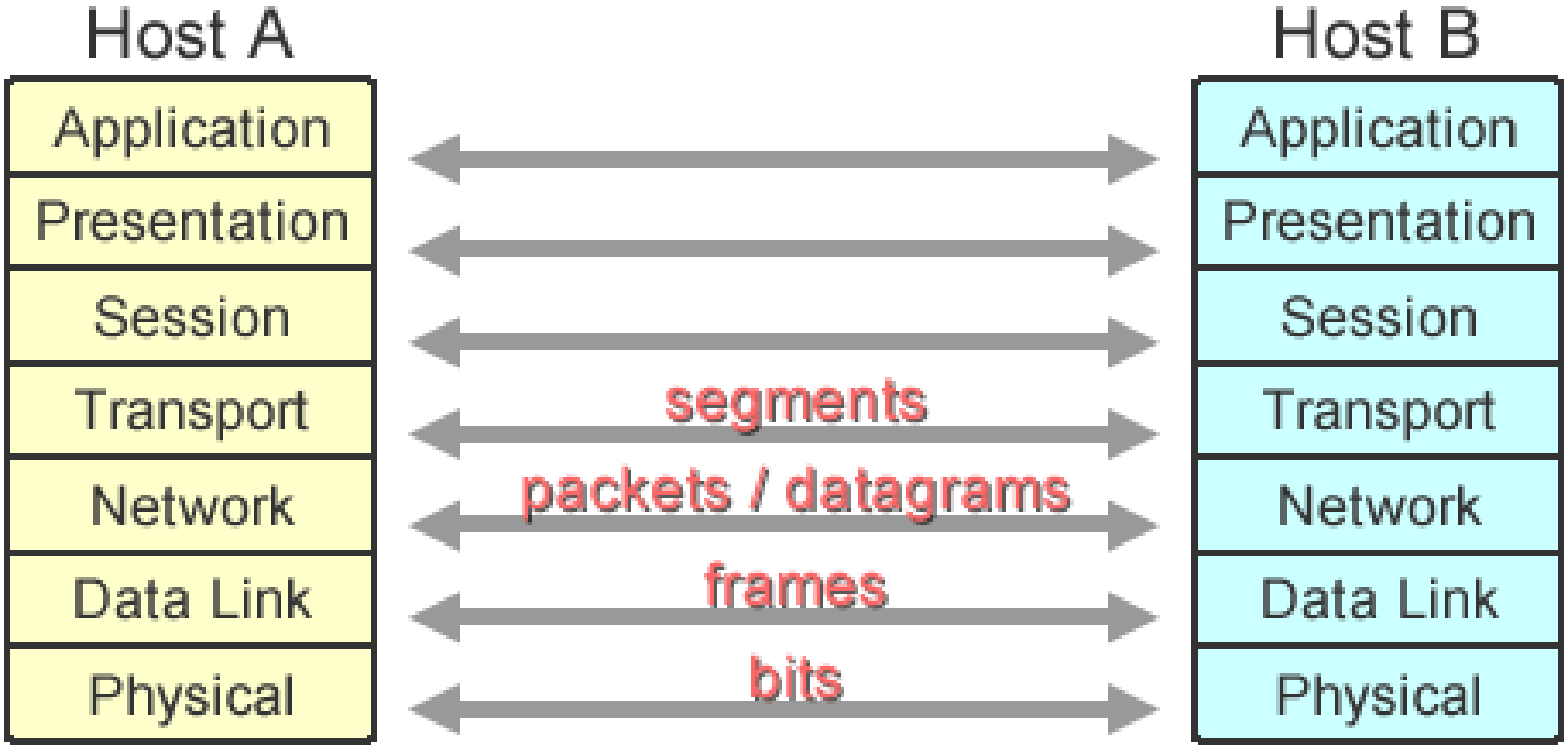
- Level 7 – Application Layer
  - An application protocol (not the actual application)
  - Act as gateway for the applications to obtain and deliver data
  - E.g. File Transfer Protocol (FTP), Simple Mail Transfer Protocol (SMTP), Post Office Protocol (POP), Hypertext Transfer Protocol (HTTP)
  - Using different protocols will decode the message accordingly

Brief summary of the OSI 7-layer model

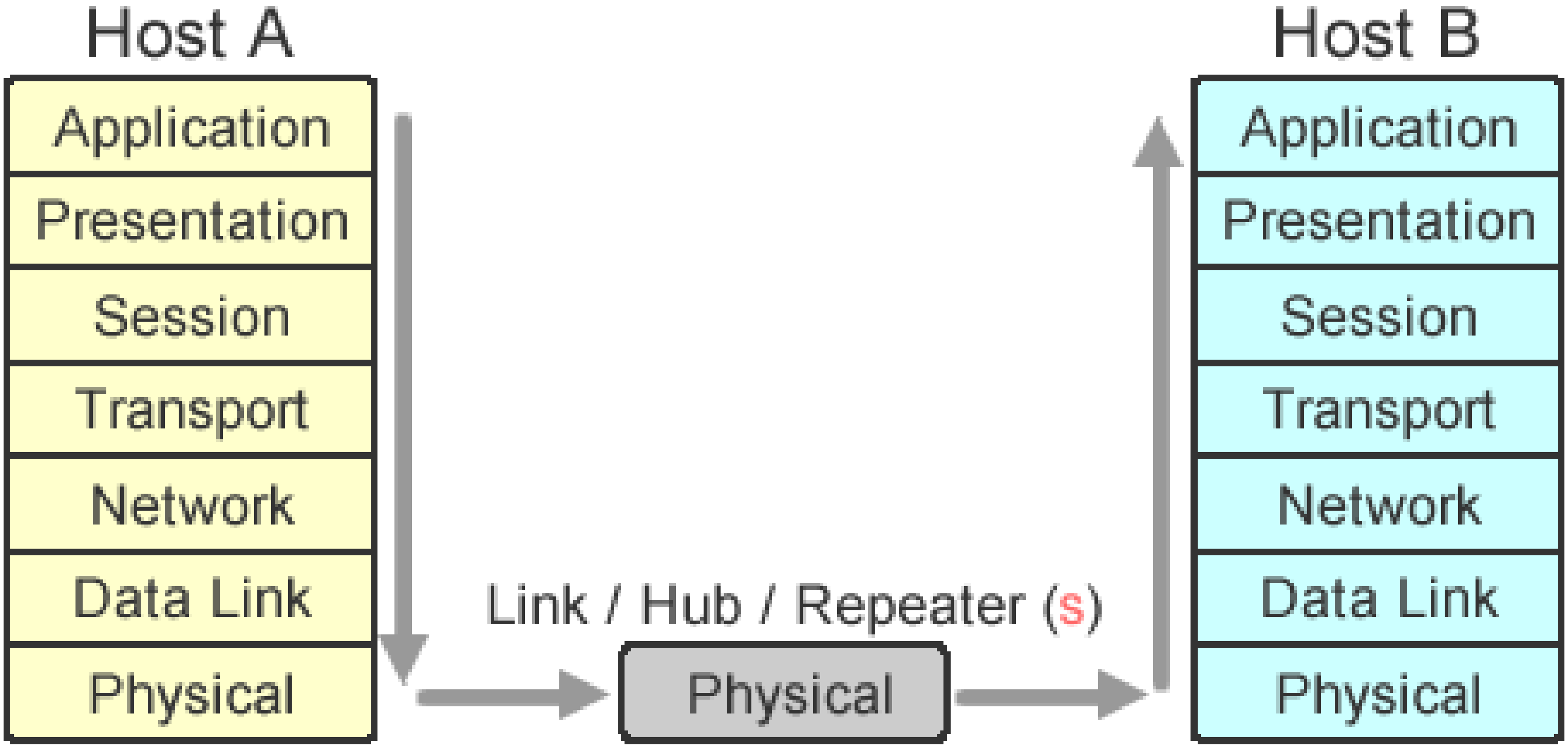
	Data	Layer
Host Layer	Data	**Application** Network Process to Application
Host Layer	Data	**Presentation** Data Representation and Encryption
Host Layer	Data	**Session** Interhost Communication
Host Layer	Segments	**Transport** End-to-End Connections and Reliability
Media Layer	Packets	**Network** Path Determination and IP (Logical Addressing)
Media Layer	Frames	**Data Link** MAC and LLC (Physical addressing)
Media Layer	Bits	**Physical** Media, Signal and Binary Transmission



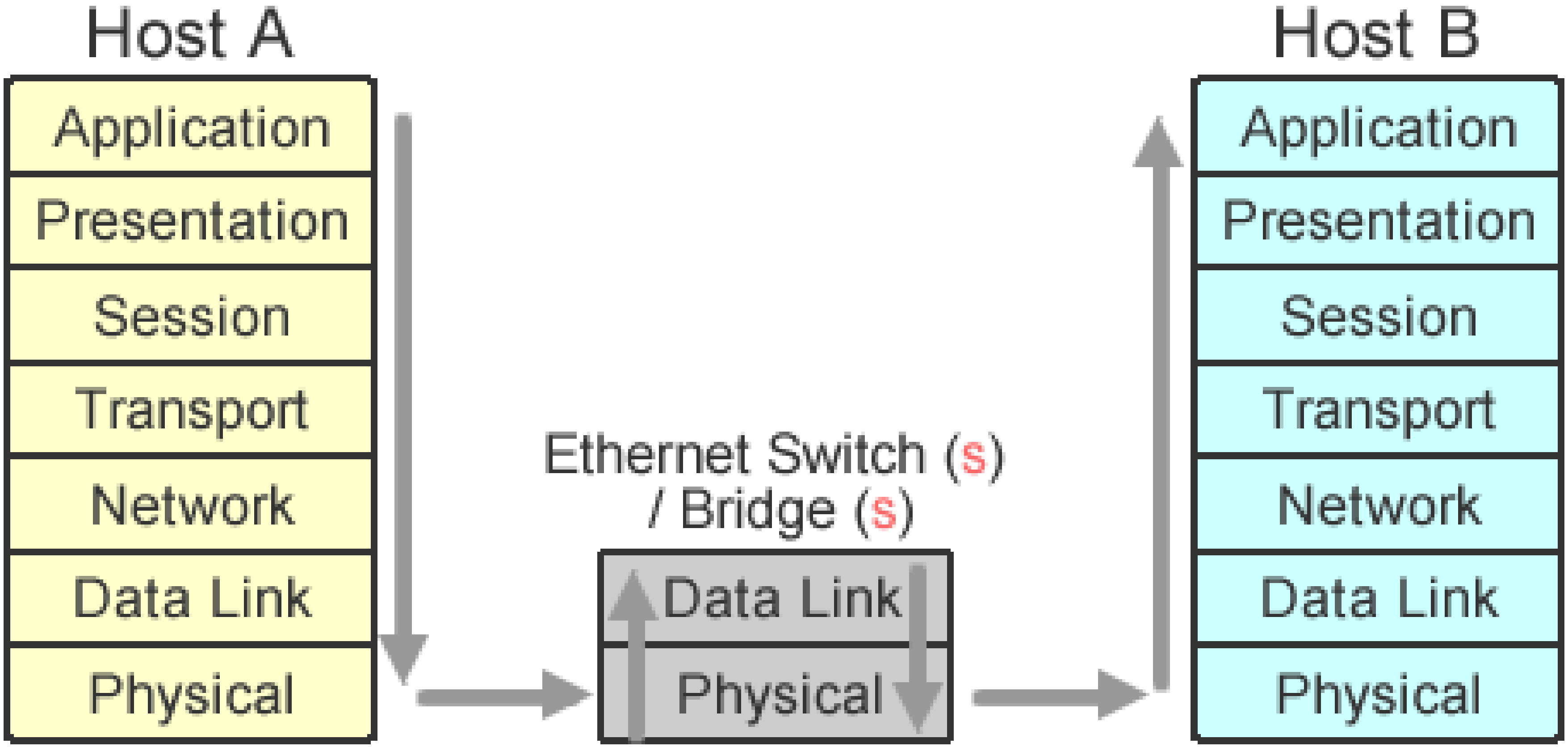
Functions of OSI 7-layer model



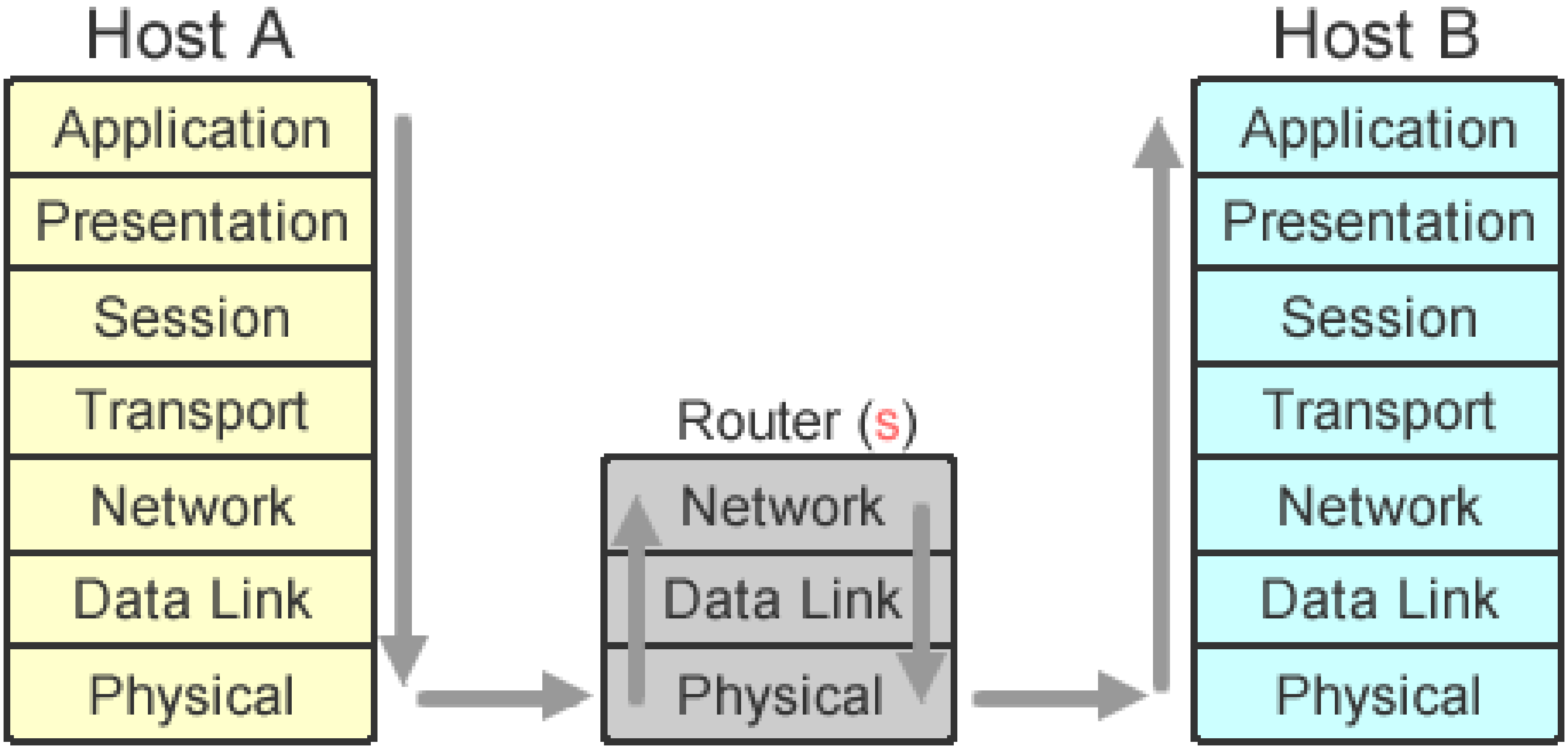
Communication of OSI 7-layer model



Connection at Layer 1 (Physical)



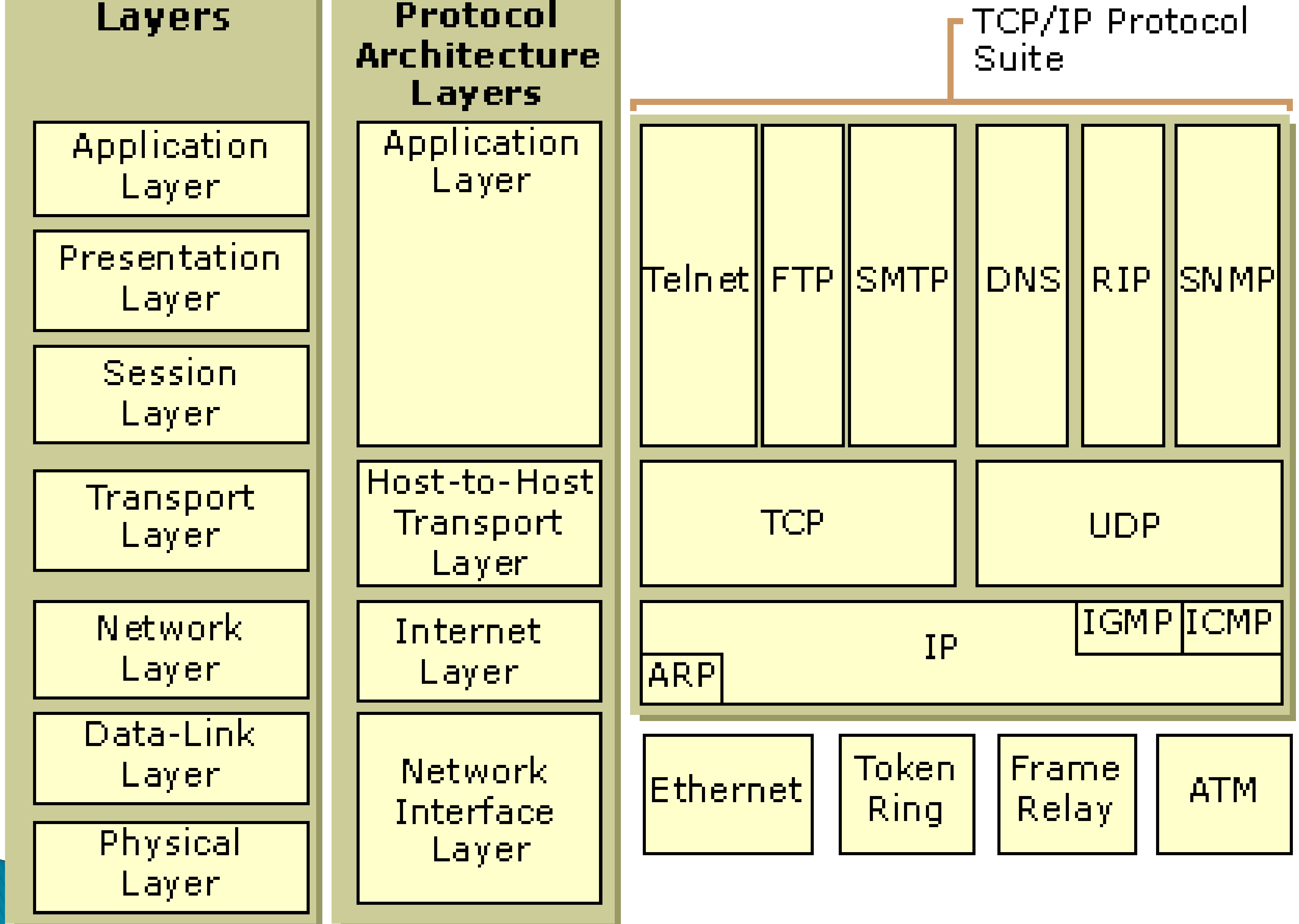
Connection at Layer 2 (Data Link)



Connection at Layer 3 (Network)

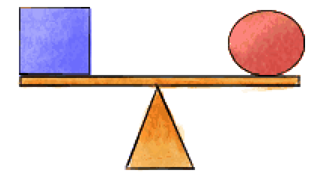
TCP = Transmission Control Protocol

IP = Internet Protocol

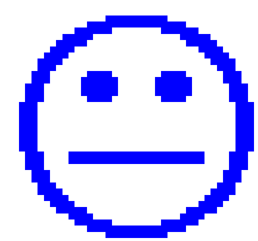


Comparison of OSI model and TCP/IP layers

OSI Seven-layer Model



- How to remember the 7 layers of OSI model?
  - All People Seem To Need Data Processing
  - Please Do Not Throw Sausage Pizza Away



Interoperability

- Definitions
  - The ability of software and hardware on different machines from different vendors to share data
  - The ability of two or more systems or components to exchange information and to use the information that has been exchanged
  - The ability of equipment to work together & communicate mutually
    - Between different manufacturers' control equipment
    - Different versions of control equipment
    - Equipment for different purposes (HVAC, fire, lights)

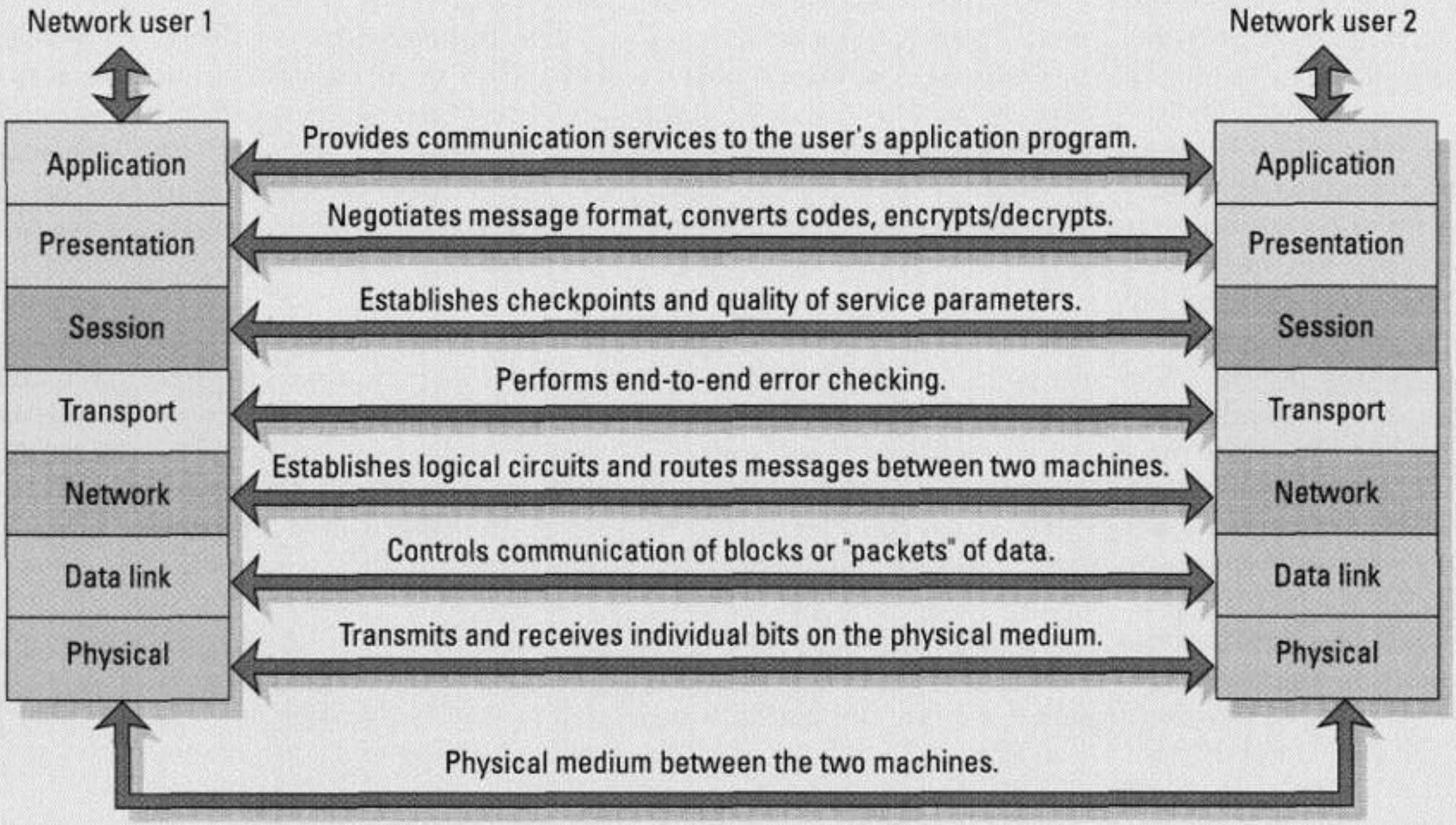
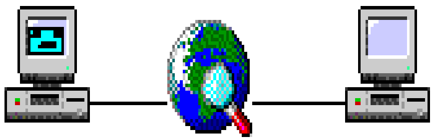


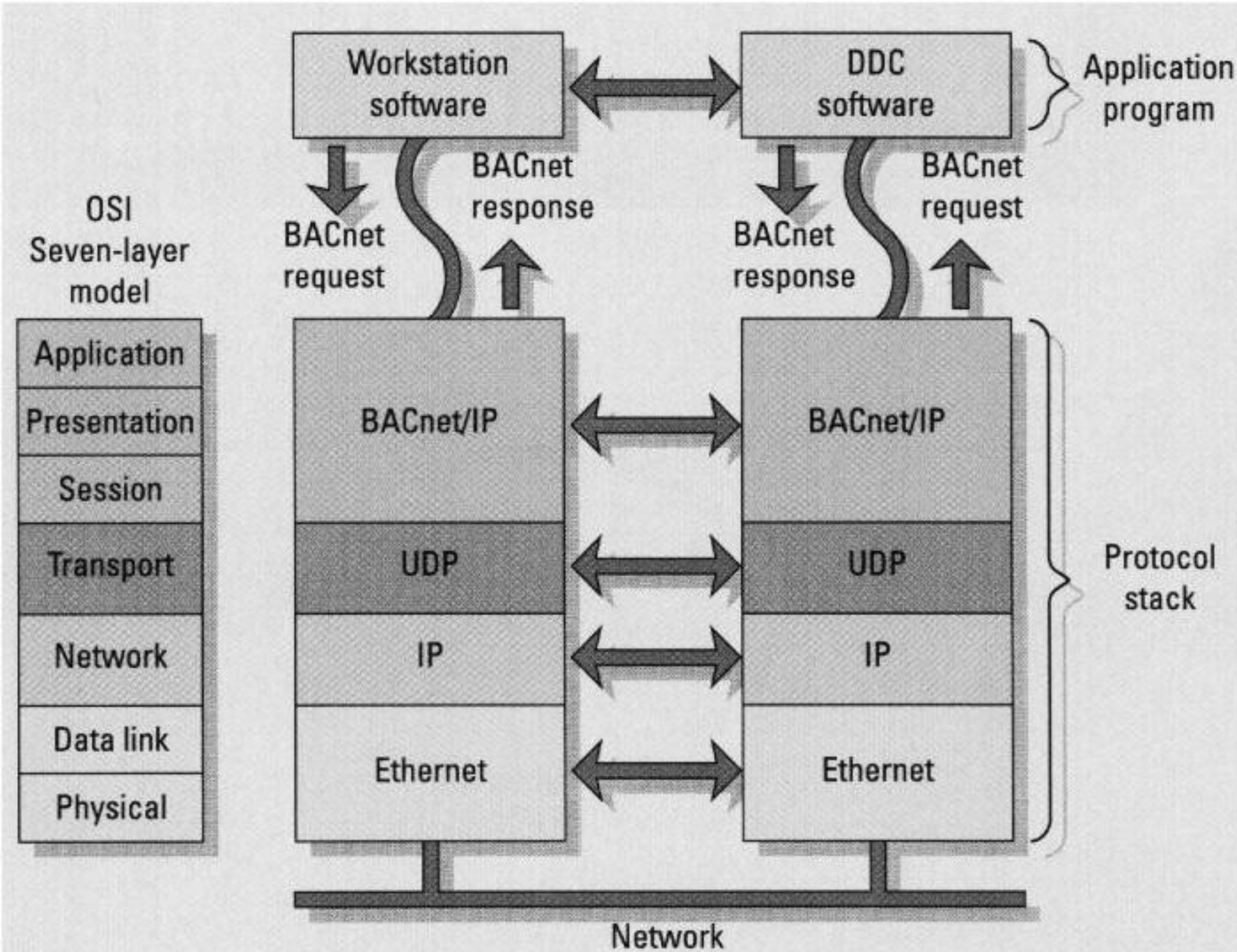
FIGURE 2. The ISO/OSI Seven-Layer Model arranges communication functions into seven groups or "layers." Each layer provides services locally to the layer above while communicating with its peer layer in the remote device. Protocols that implement the model need only select the functions needed for the application at hand.

(Source: Newman, H. M., 2001. Control networks and interoperability, *Network Controls*, May 2001, pp. 17-27.)

Interoperability

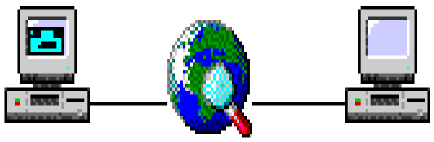


- Example: Building Automation System
  - Protocol ‘stack’:
    - BACnet/IP
    - UDP (User Datagram Protocol)
    - IP (Internet Protocol)
    - Ethernet
  - Data communication
    - Horizontal bi-directional (conceptual)
    - Vertical procedure: BACnet request & response
      - User UDP software
      - Protocol control information (PCI) is added

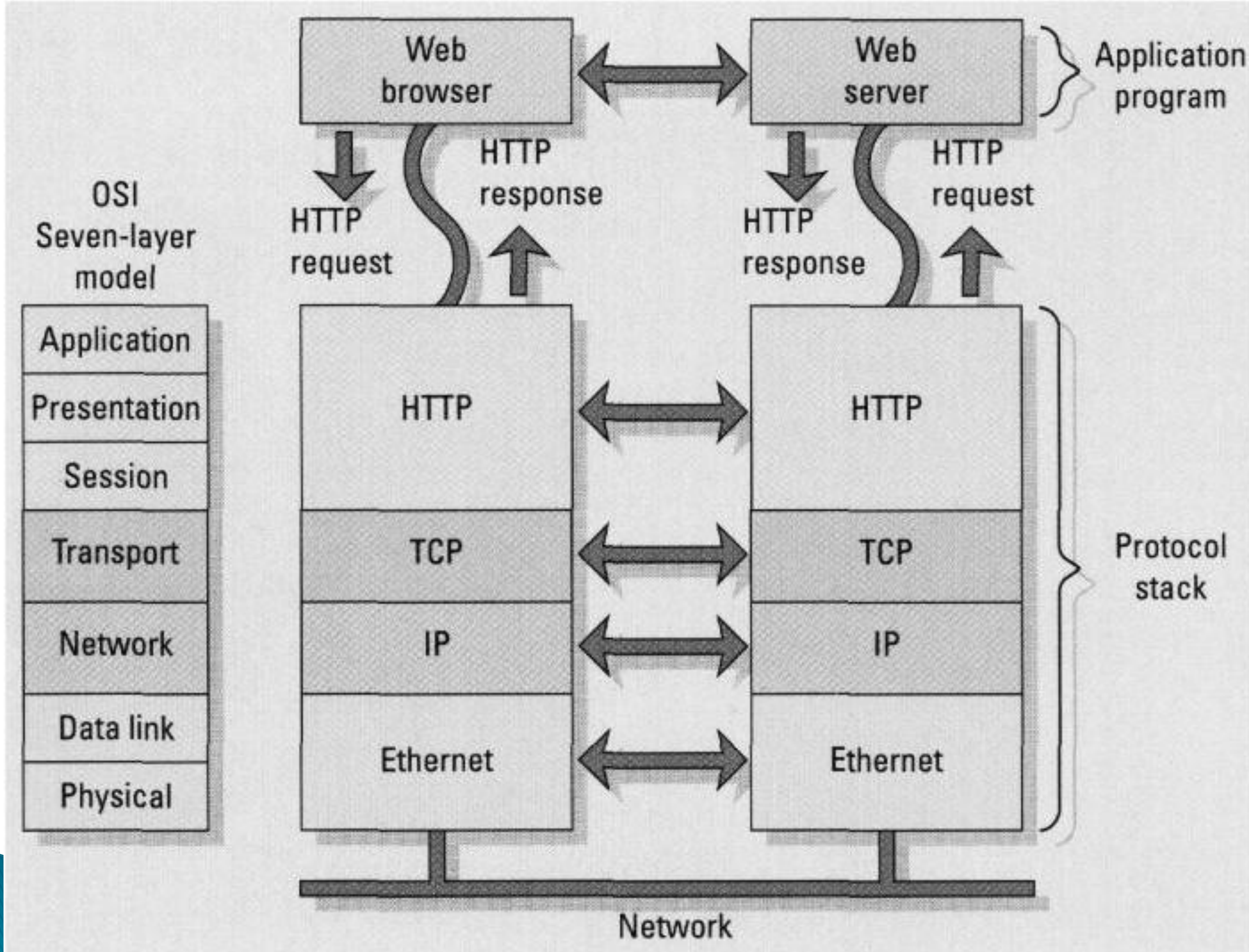


(Source: Newman, H. M., 2001. Control ne[illegible] and interoperability, *Network Controls*, May 2001, pp. 17-27.)

Interoperability

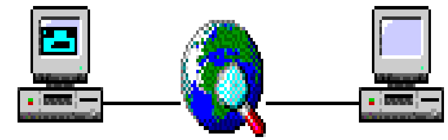


- Example: Web browsing
  - Protocol 'stack':
    - HTTP (Hypertext Transfer Protocol)
    - TCP (Transmission Control Protocol)
    - IP (Internet Protocol)
    - Ethernet
  - Data communication
    - Horizontal (Web browser & Web server)
    - Vertical procedure: HTTP request & response



(Source: Newman, H. M., 2001. Control networks and interoperability, *Network Controls*, May 2001, pp. 17-27.)

Interoperability



- Using the same OSI Seven Layer Model, it is possible for data to be collected from different hardware and applications, to be interpreted properly for monitoring or even control
- Web browser as control system workstation
  - Any PC with a Web browser can be used
  - Web server/control system gateway
    - Web server -> Workstation software (proprietary)
    - Data in HTML format for display at Web browser

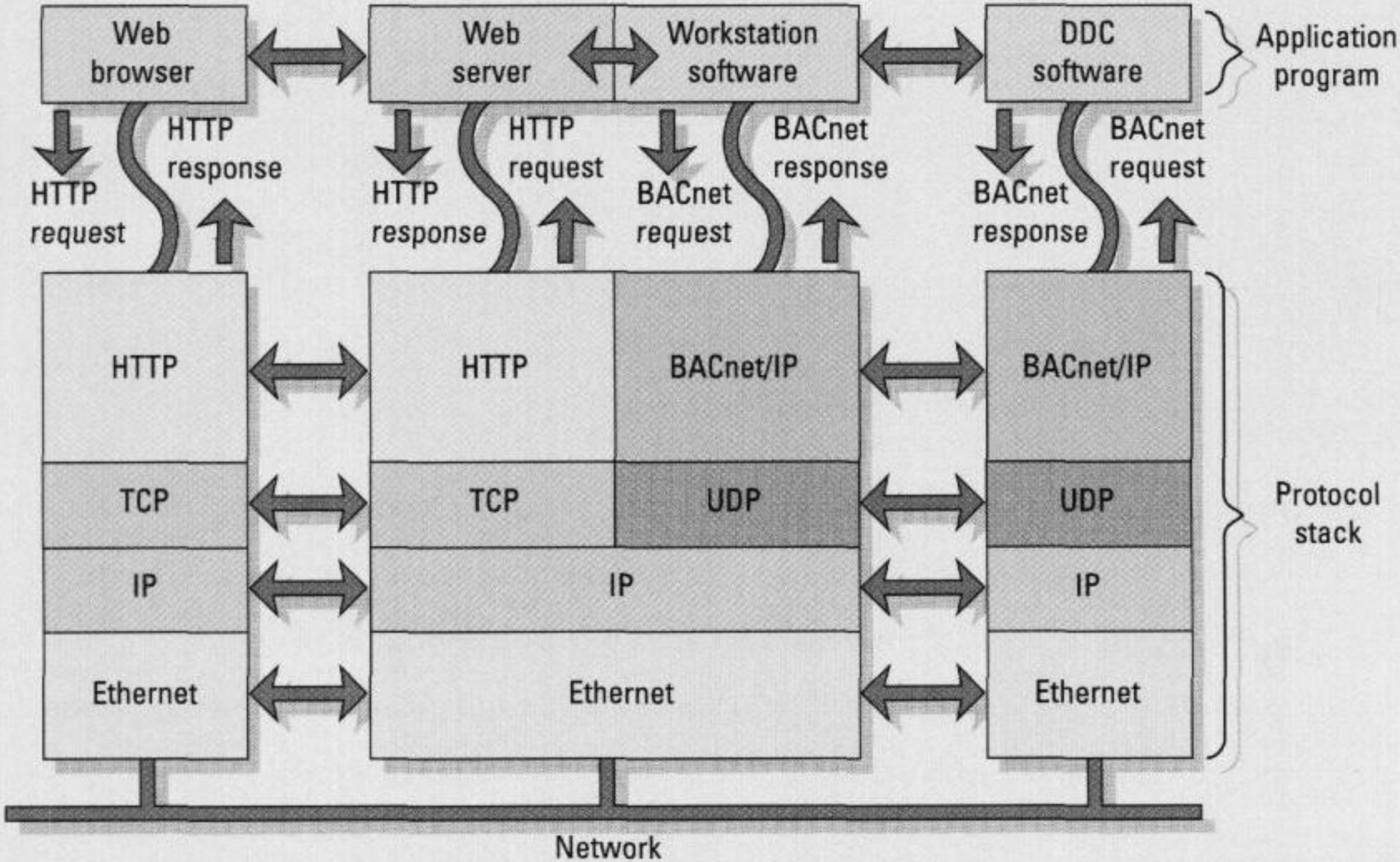
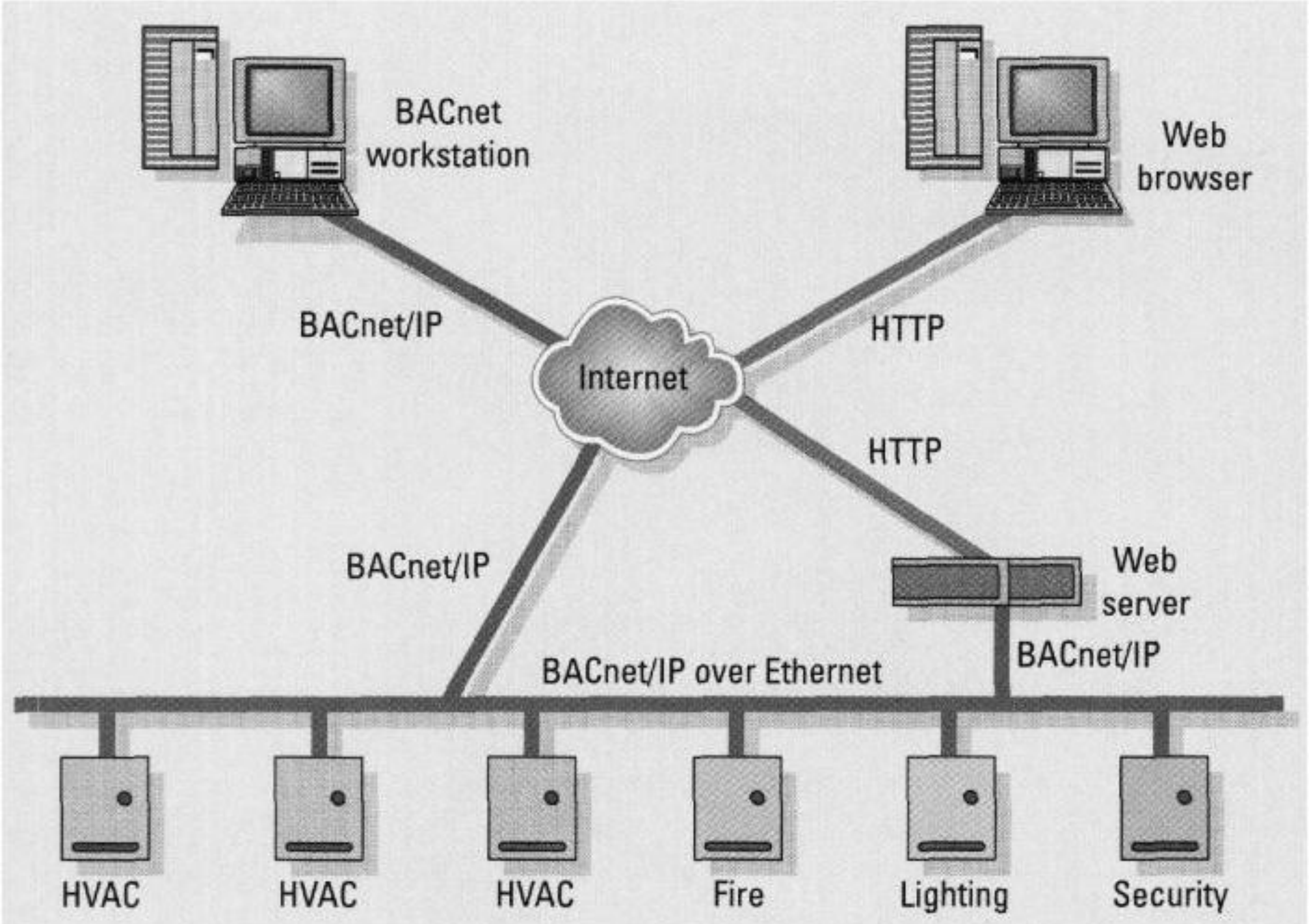


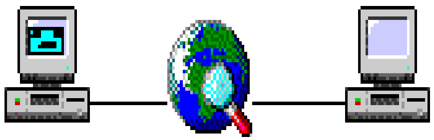
FIGURE 6. A Web browser that accesses an appropriately programmed Web server can perform the same kind of functions as the dedicated workstation in Figure 3.

(Source: Newman, H. M., 2001. Control networks and interoperability, *Network Controls*, May 2001, pp. 17-27.)



(Source: Newman, H. M., 2001. Control ne[illegible] and interoperability, *Network Controls*, May 2001, pp. 17-27.)

Interoperability



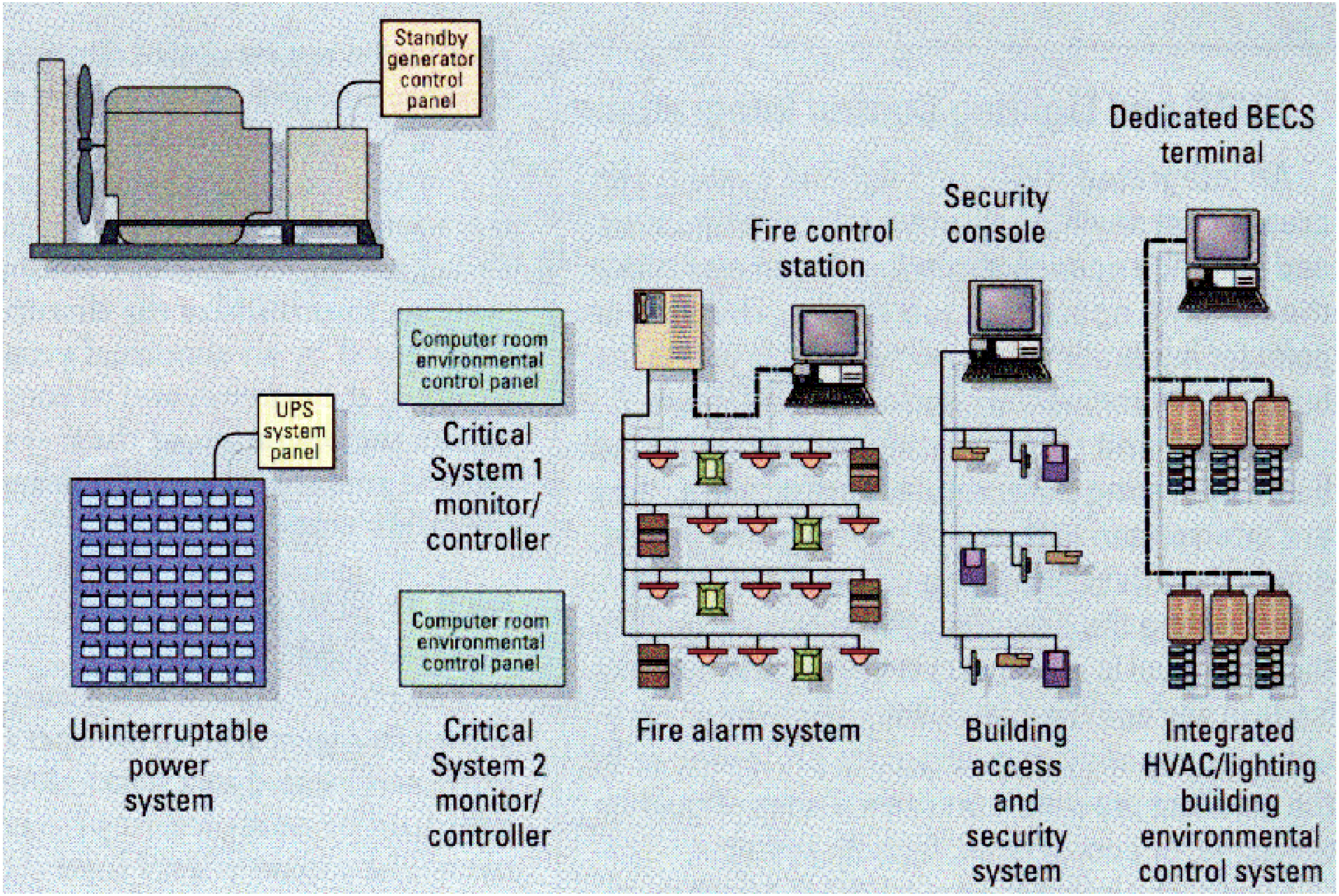
- Designing interoperable systems
  - Define the application (which system, what data)
  - Select equipment that performs the desired functions & supports a common protocol
  - For equipment that does not supports common protocol directly, add gateways or relays
  - Determine operator-machine interface (OMI): workstation, Web server gateway
  - Ensure the contractor understand the network architecture well

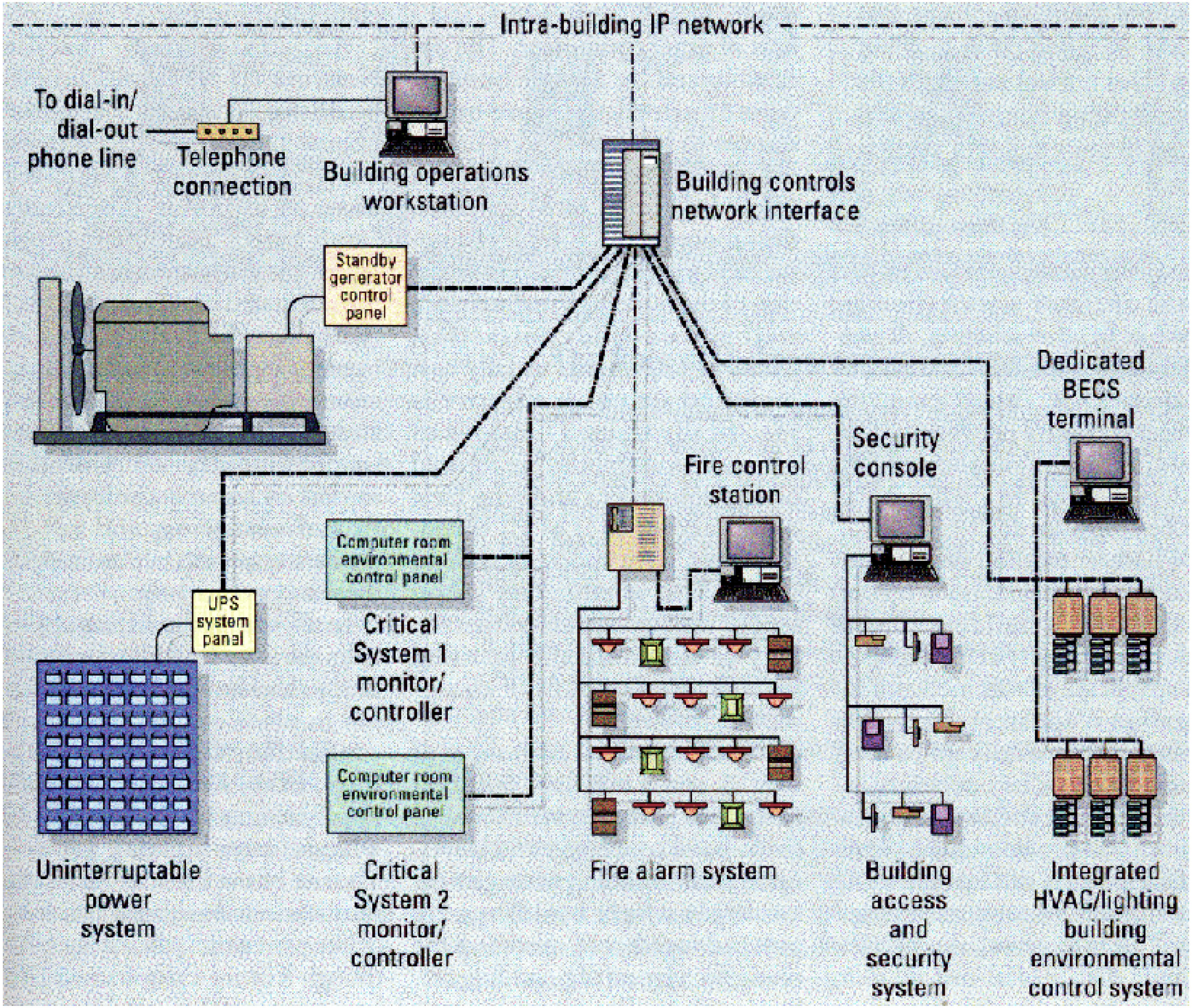
Networking & System Architecture

- Whole Building Network

Whole Building Network

- Advantages of network-based systems
  - Easier & more convenient monitoring
  - Improved energy efficiency
  - Simplified system maintenance
  - Self-balancing & self-setup
- Integrated facility networks (IFNs)
  - To streamline building O&M activities
  - To monitor & control the systems/equipment
- Can be integrated in various BS systems

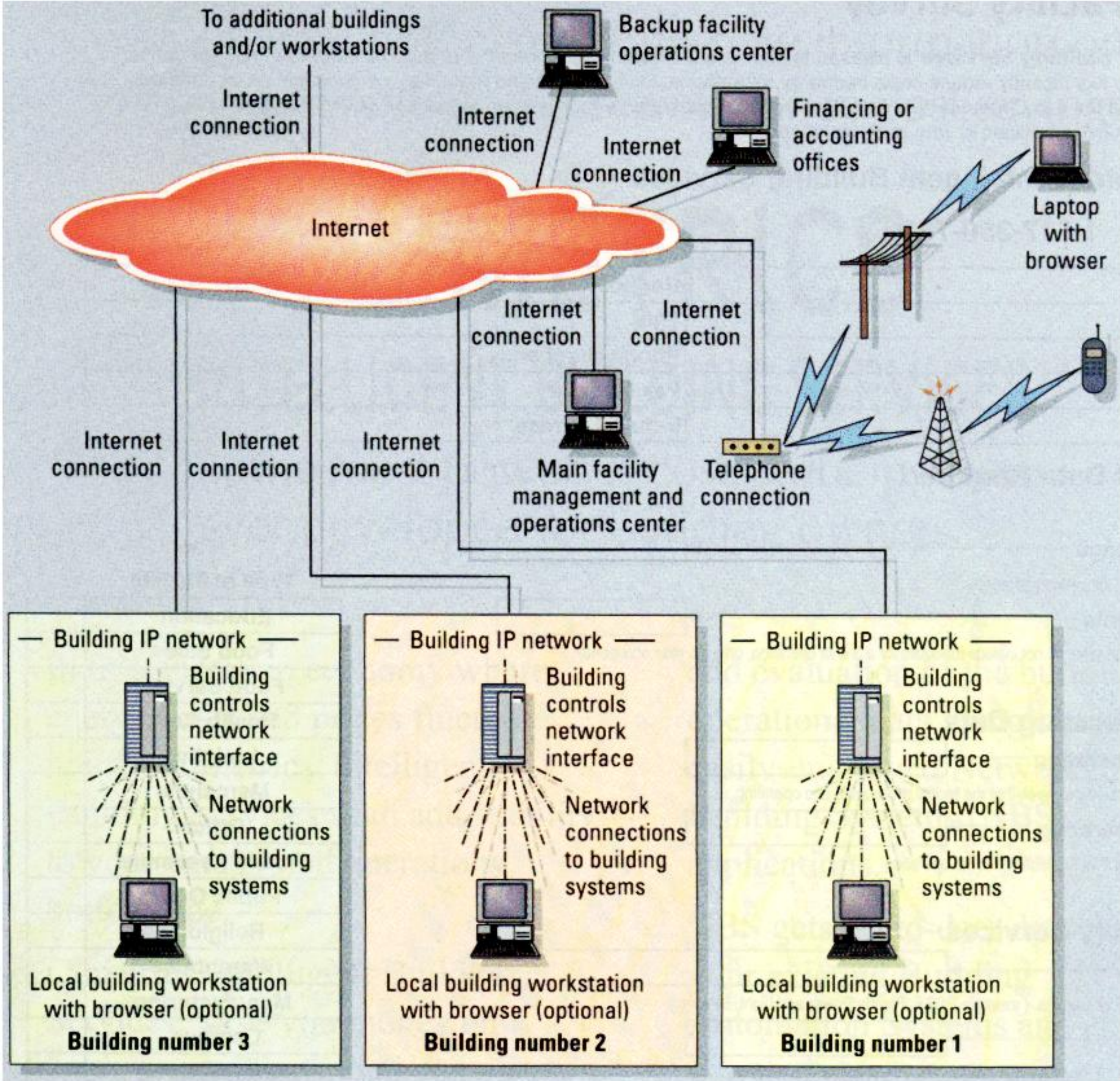

Standby generator control panel
Dedicated BECS terminal
Security console
Fire control station
Computer room environmental control panel
UPS system panel
Critical System 1 monitor/ controller
Computer room environmental control panel
Uninterruptable power system
Critical System 2 monitor/ controller
Fire alarm system
Building access and security system
Integrated HVAC/lighting building environmental control system



Intra-building IP network
To dial-in/ dial-out phone line
Telephone connection
Building operations workstation
Building controls network interface
Standby generator control panel
UPS system panel
Uninterruptable power system
Computer room environmental control panel
Critical System 1 monitor/ controller
Computer room environmental control panel
Critical System 2 monitor/ controller
Fire control station
Fire alarm system
Security console
Building access and security system
Dedicated BECS terminal
Integrated HVAC/lighting building environmental control system

Whole Building Network

- Advantages of network integration
  - Everything can be checked at one location
  - Improved reliability on critical systems
  - Benefits of interoperability (e.g. minimize disruption & operation costs)
- Multi-building management
  - Benefit: shared O&M resources & expertise
  - Can reduce maintenance costs
  - Internet:- inter-building communication backbone
    - Web browser
    - Less dependent on vendors


To additional buildings and/or workstations
Backup facility operations center
Internet connection
Internet connection
Internet connection
Financing or accounting offices
Laptop with browser
Internet
Internet connection
Internet connection
Internet connection
Internet connection
Internet connection
Main facility management and operations center
Telephone connection
Building IP network
Building controls network interface
Network connections to building systems
Local building workstation with browser (optional)
Building number 3
Building IP network
Building controls network interface
Network connections to building systems
Local building workstation with browser (optional)
Building number 2
Building IP network
Building controls network interface
Network connections to building systems
Local building workstation with browser (optional)
Building number 1

Whole Building Network

- Challenges of multi-building networks
  - Lack of uniformity w/ individual systems
    - Increases the complexity
  - Some systems need to stand alone in each building
    - Such as fire alarm, security, UPS
  - Regulatory & administration practices
    - Fire alarm is often not allowed to be monitored remote
  - Lack of communication standards