CSIE52400/CSIEM0140 Distributed Systems

Lecture 04 Networking & Internetworking

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Communication Subsystem

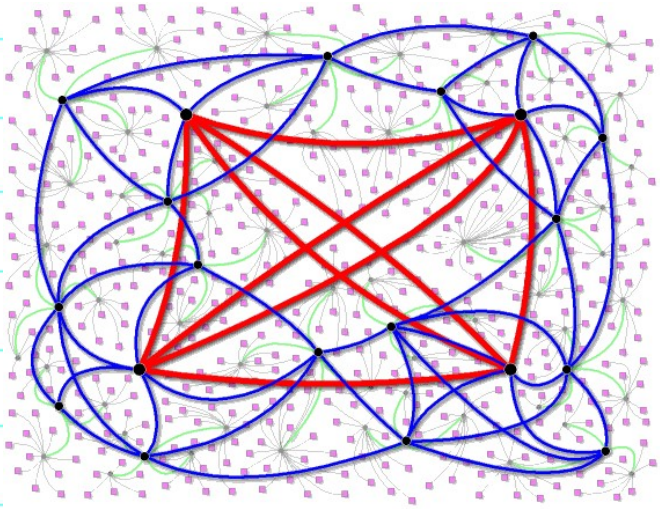
- Collection of hardware and software components that facilitates connection(communication) between hosts in a distributed system
- ***Question:*** What are the communication requirements of a distributed system?

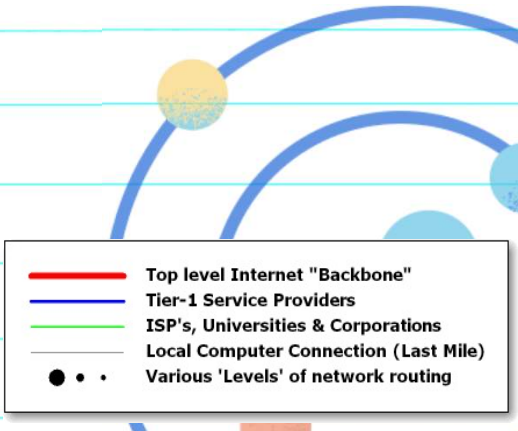
Issues and Requirements

- Performance
  - latency
  - data transfer rate
  - bandwidth
- Scalability
- Reliability
- Security
- Mobility
- Quality of Service
- Multicasting (one-to-many comm)

message transmission time = latency + length/data trans. rate

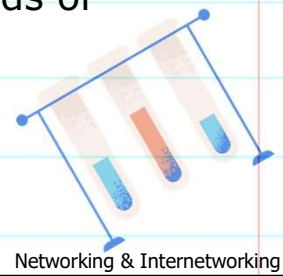
Simplified View of Internet





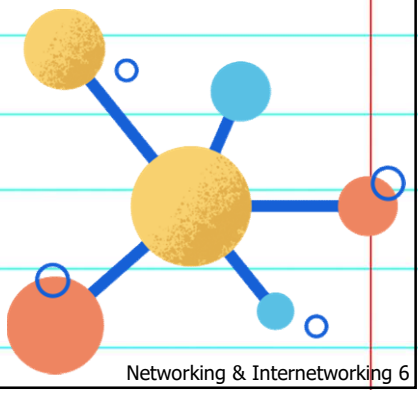
Network

- A **network** is a collection of computers and other devices that can send and receive data between each other.
- Each machine on a network is called a **node**.
- Nodes that are fully functional computers are also called **hosts**.
- Every network node has an **address** which is a series of bytes that uniquely identify it.
- Addresses are assigned differently on different kinds of networks.



Network Types

- Wired vs wireless networks
- Types of networks based on size
  - PAN - Personal area network
  - HAN – House area network
  - LAN - Local area network
  - CAN – Campus area network
  - MAN - Metropolitan area network
  - WAN - Wide area network
  - GAN – Global area network



Network Types

- Types of networks based on purposes
  - SAN - Storage area network
  - EPN - Enterprise private network
  - VPN - Virtual private network

Wireless Networks

- WPANS – Wireless Personal Area Networks
- WLANS – Wireless Local Area Networks
- WMANS – Wireless Metropolitan Area Networks
- WWANS – Wireless Wide Area Nerworks

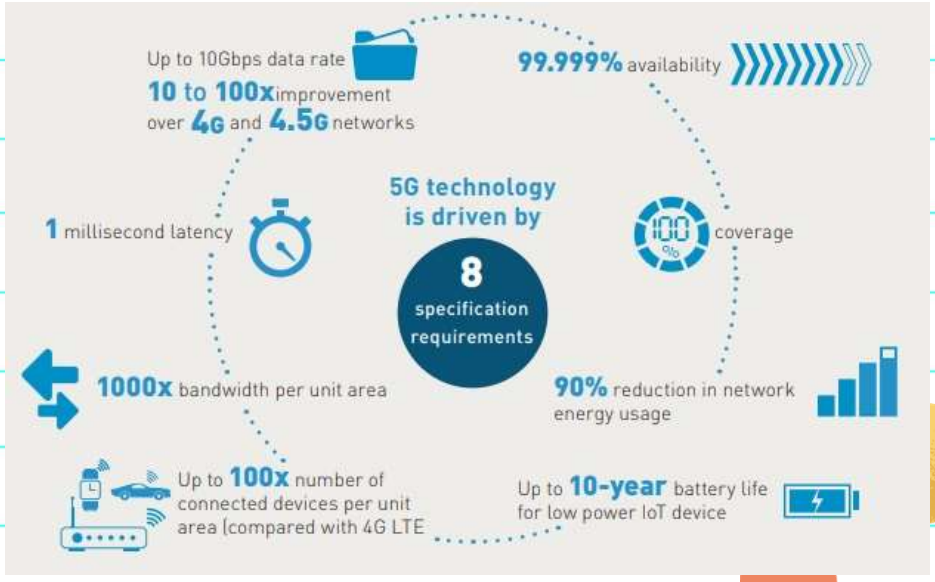
Types of Wireless Networks

Type	Coverage	Performance	Standards	Applications
Wireless PAN	Within reach of a person	Moderate	Wireless PAN Within reach of a person Moderate Bluetooth, IEEE 802.15, and IrDa Cable replacement for peripherals	Cable replacement for peripherals
Wireless LAN	Within a building or campus	High	IEEE 802.11, Wi-Fi, and HiperLAN	Mobile extension of wired networks
Wireless MAN	Within a city	High	Proprietary, IEEE 802.16, and WIMAX	Fixed wireless between homes and businesses and the Internet
Wireless WAN	Worldwide	Low	CDPD and Cellular 2G, 2.5G, and 3G 4G LTE, 5G	Mobile access to the Internet from outdoor areas

Generations of Mobile Phone Networks

Generation→ Features↓	1G	2G	3G	4G	5G
Deployment	1970 – 1980	1990 - 2001	2001-2010	2011	2015-20 onwards
Data Rates	2kbps	14.4-64kbps	2Mbps	200 Mbps to 1 Gbps	1Gbps and higher
Technology	Analog Cellular Technology	Digital Cellular Technology: Digital narrow band circuit data Packet data	Digital Broadband Packet data: CDMA 2000 EVDO UMTS EDGE	Digital Broadband Packet data: WiMax LTE Wi-Fi	wwww Unified IP seamless combination of broadband LAN PAN MAN WLAN
Service	Analog voice service No data service	Digital voice with higher clarity SMS, MMS Higher capacity packetized data	Enhanced audio video streaming video conferencing support Web browsing at higher speeds IPTV support	Enhanced audio, video streaming IP telephony HD mobile TV	Dynamic Information access, Wearable devices with AI Capabilities
Multiplexing Switching	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet
Standards	MTS AMTS IMTS	2G:GSM 2.5:GPRS 2.75:EDGE	IMT-2000 3.5G-HSDPA 3.75G:HSUPA	Single unified standard LTE, WiMAX	Single unified standard
WEB Standard		www	www(IPv4)	www (IPv4)	wwww (IPv6)
Handoff	Horizontal only	Horizontal only	Horizontal & Vertical	Horizontal & Vertical	Horizontal & Vertical
Shortfalls	Low capacity, Unreliable handoff, Poor voice links, Less secure	Digital signals were reliant on location & proximity, required strong digital signals to help mobile phones	Need to accommodate higher network capacity	Being deployed	Yet to be implemented

What 5G can do?



What about 6G?

- Connecting Intelligence
- Programable
- Determinism
- Integrated Sensing
- Sustainability
- Trustworthiness
- Affordable and Scalable

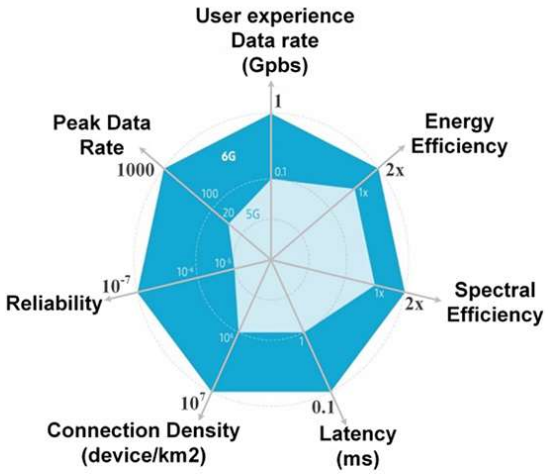


Fig. 1 Key enhancements of 6G technology.

6G vs 4G and 5G

Table 2 Comparison of 6G with 4G and 5G mobile communication systems.

KPIs	4G	5G	6G
Peak data rate /device	1 Gbps	10 Gbps	1 Tbps
latency	100 ms	1 ms	0.1 ms
Max. spectral efficiency	15 bps/Hz	30 bps/Hz	100 bps/Hz
Energy efficiency	< 1000x relative to 5G	1000x relative to 4G	>10x relative to 5G
Connection density	2000 devices / km^2	1millon devices /km^2	>10millon devices/km^2
Coverage percent	< 70 %	80 %	>99 %
Positioning precision	Meters precision (50 m)	Meters precision (20 m)	Centimeter precision
End-to-end reliability	99.9 %	99.999 %	99.9999 %
Receiver sensitivity	Around −100dBm	Around −120dBm	< −130dBm
Mobility support	350 km/h	500 km/h	≥1000 km/h
Satellite integration	No	No	Fully
AI	No	Partial	Fully
Autonomous vehicle	No	Partial	Fully
Extended Reality	No	Partial	Fully
Haptic Communication	No	Partial	Fully
THz communication	No	limited	Widely
Service level	Video	VR, AR	Tactile
Architecture	MIMO	Massive MIMO	Intelligent surface
Max. frequency	6 GHz	90 GHz	10 THz

6G Architecture

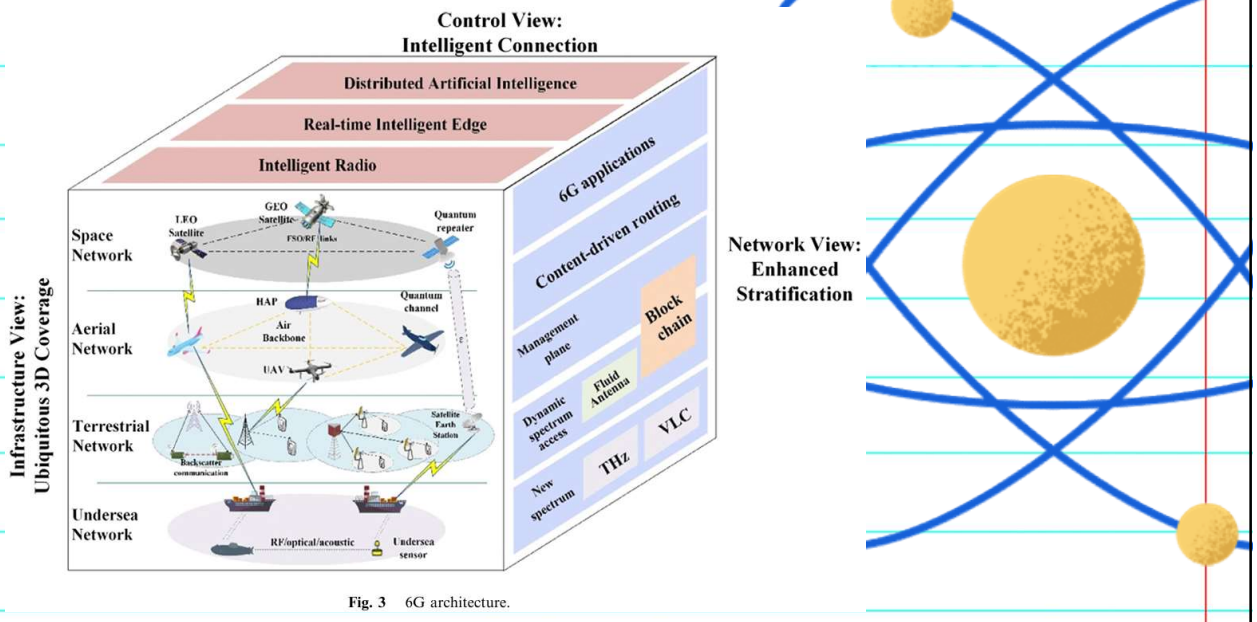
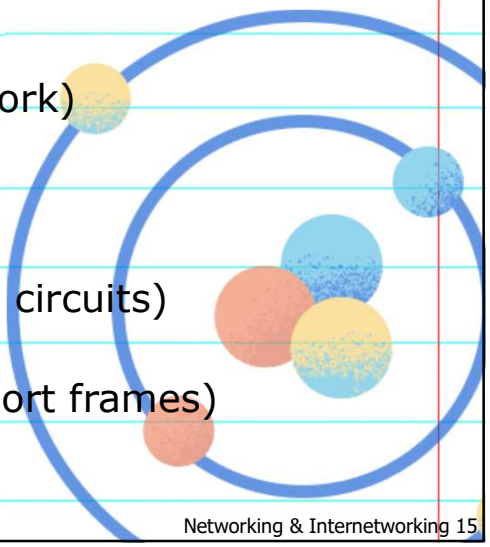


Fig. 3 6G architecture.

Switching Schemes

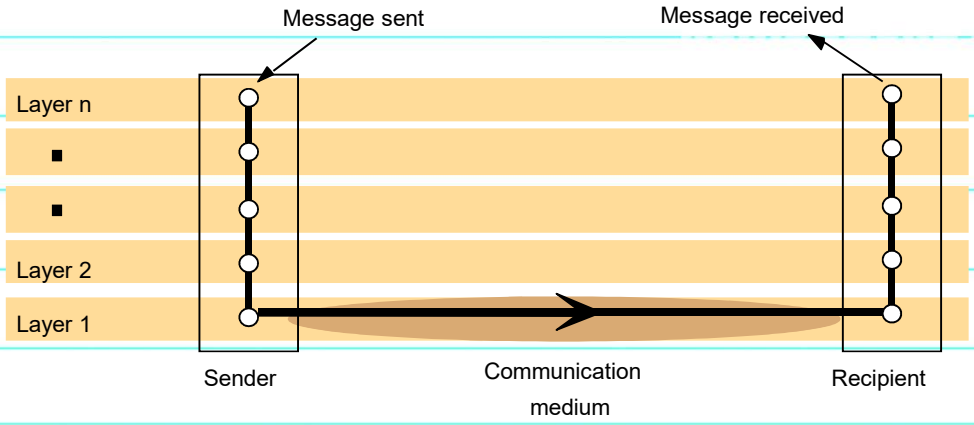
- **Broadcast**
  - Ethernet, token ring, FDDI
- **Circuit switching**
  - PSTN (Public Switched Telephone Network)
- **Packet switching**
  - IP (store-and-forward network)
- **Frame relay**
  - SONET (passing frames through virtual circuits)
- **Cell switching**
  - ATM/BISDN(Broadband ISDN) (uses short frames)



Network Communication

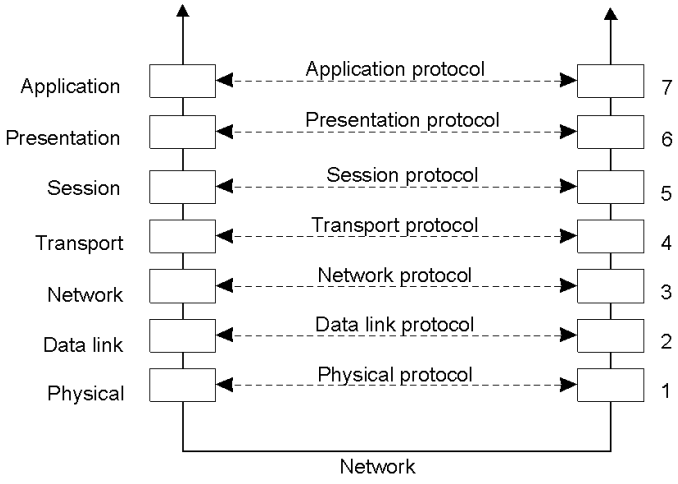
- Nodes may also have **names**. Names are not locked to addresses.
- All modern networks are **packet-switched** networks.
- A **protocol** is a precise set of rules and data format defining how computers communicate.
- Network communication is **layered**.
- Each layer represents a different level of **abstraction** between the physical hardware and the information being transmitted.

Conceptual Layering of Protocol



OSI Protocol Layers

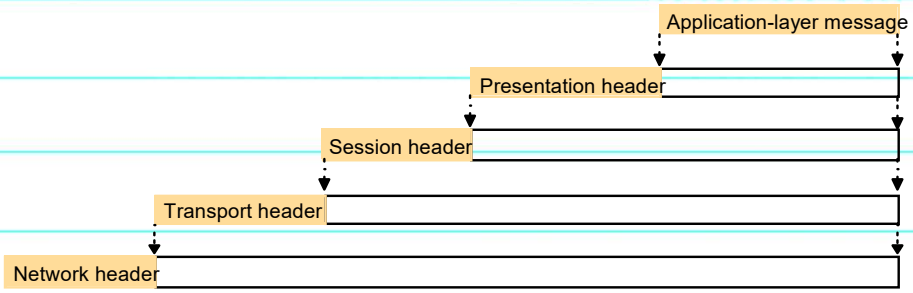
- Layers, interfaces, and protocols in the OSI model.



OSI Protocol Summary

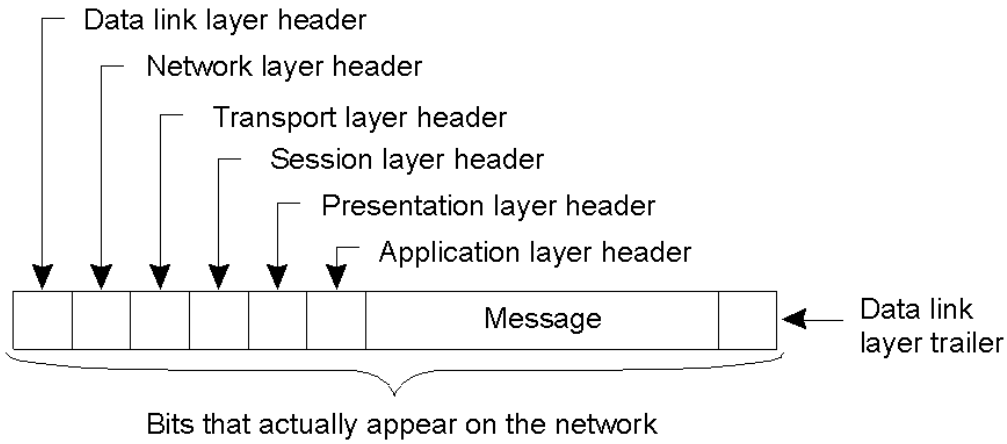
Layer	*Description*	*Examples*
Application	Protocols that are designed to meet the communication requirements of specific **applications**, often defining the interface to a service.	HTTP, FTP, SMTP, CORBA IIOP
Presentation	Protocols at this level transmit data in a **network representation** that is **independent** of the representations used in **individual computers**, which may differ. **Encryption** is also performed in this layer, if required.	Secure Sockets (SSL),CORBA Data Rep.
Session	At this level **reliability** and **adaptation** are performed, such as detection of failures and automatic recovery.	
Transport	This is the lowest level at which **messages** (rather than packets) are handled. Messages are **addressed** to communication ports attached to processes, Protocols in this layer may be connection-oriented or connectionless.	TCP, UDP
Network	Transfers data **packets** between computers in a specific network. In a WAN or an internetwork this involves the generation of a **route** passing through routers. In a single LAN no routing is required.	IP, ATM virtual circuits
Data link	Responsible for transmission of packets between nodes that are **directly connected** by a physical link. In a WAN transmission is between pairs of routers or between routers and hosts. In a LAN it is between any pair of hosts.	Ethernet MAC, ATM cell transfer, PPP
Physical	The **circuits and hardware** that drive the network. It transmits sequences of binary data by analogue signalling, using amplitude or frequency modulation of electrical signals (on cable circuits), light signals (on fibre optic circuits) or other electromagnetic signals (on radio and microwave circuits).	Ethernet base- band signalling, ISDN

Encapsulation in Layered Protocols



Encapsulation in Layered Protocols

- A typical message as it appears on the network.



Protocol Encapsulation

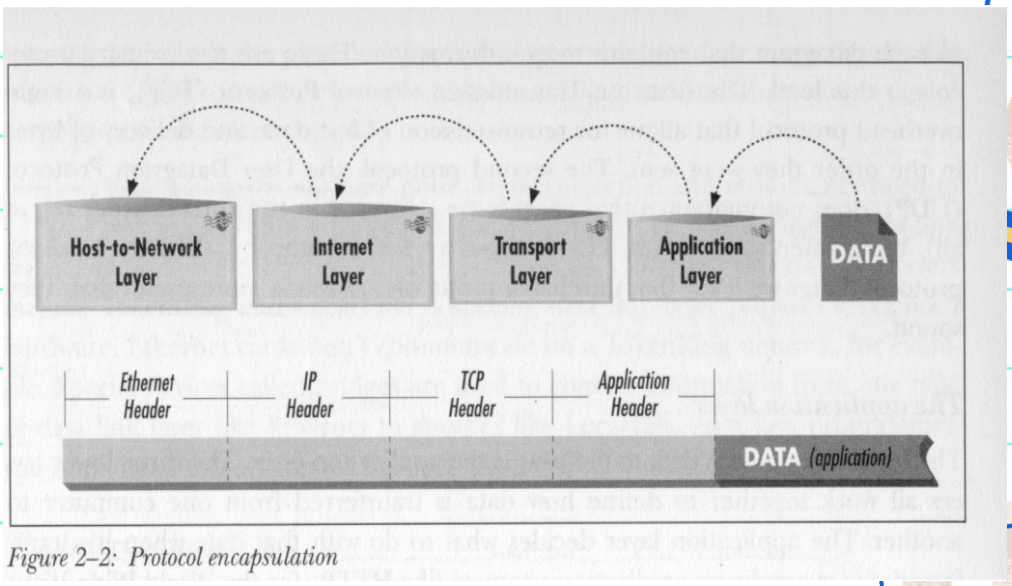
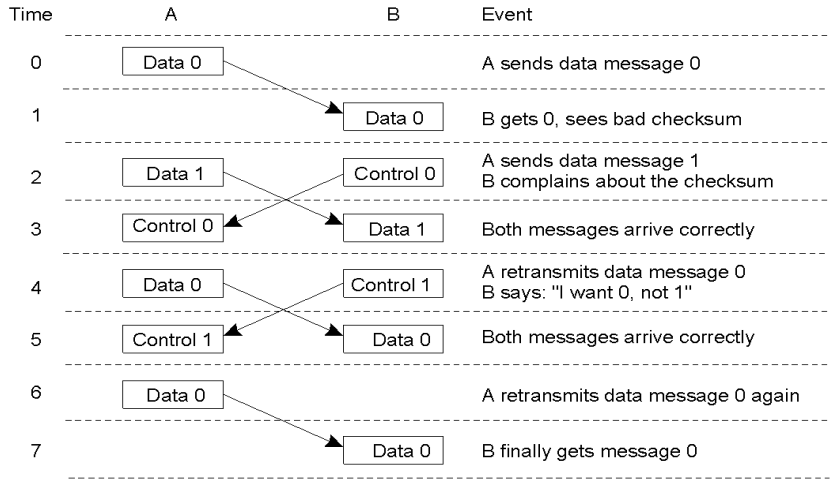


Figure 2–2: Protocol encapsulation

Data Link Layer

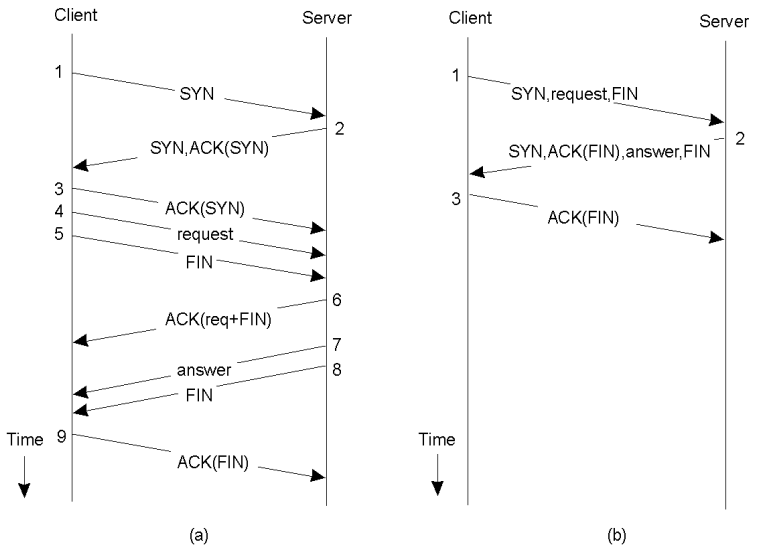
- Discussion between a receiver and a sender in the data link layer.



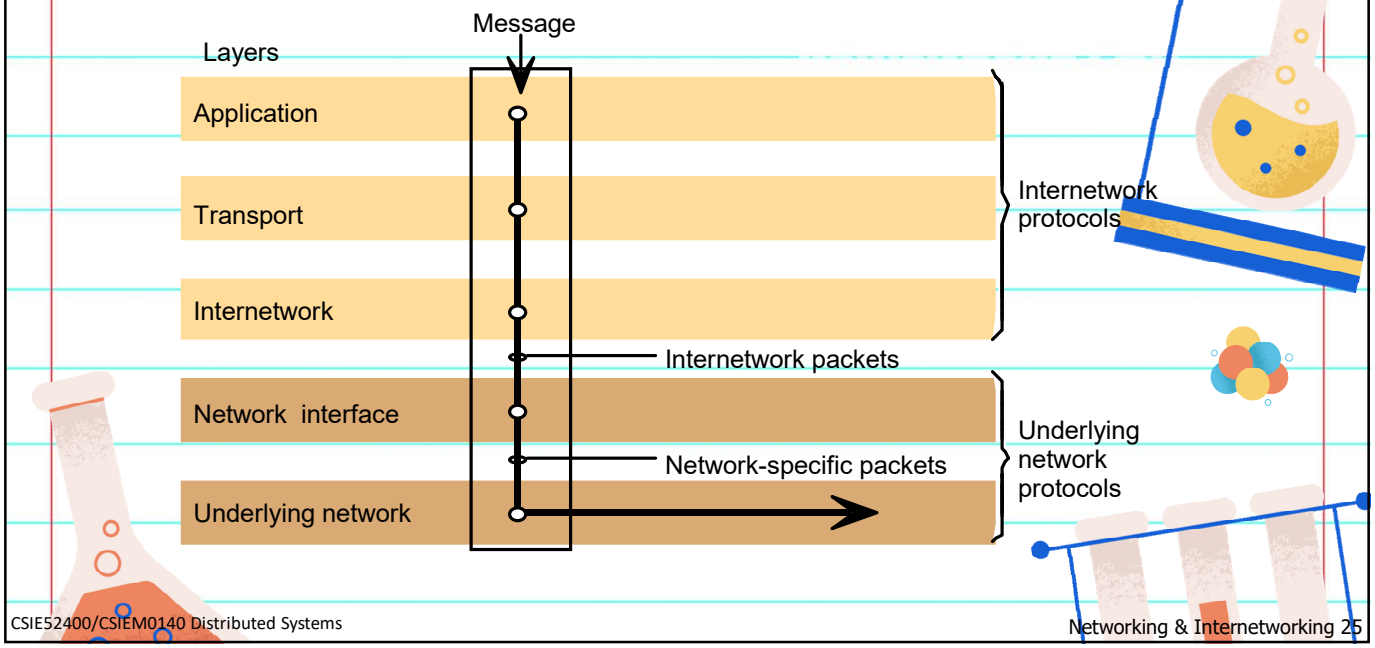
Client-Server TCP

a) Normal operation of TCP.

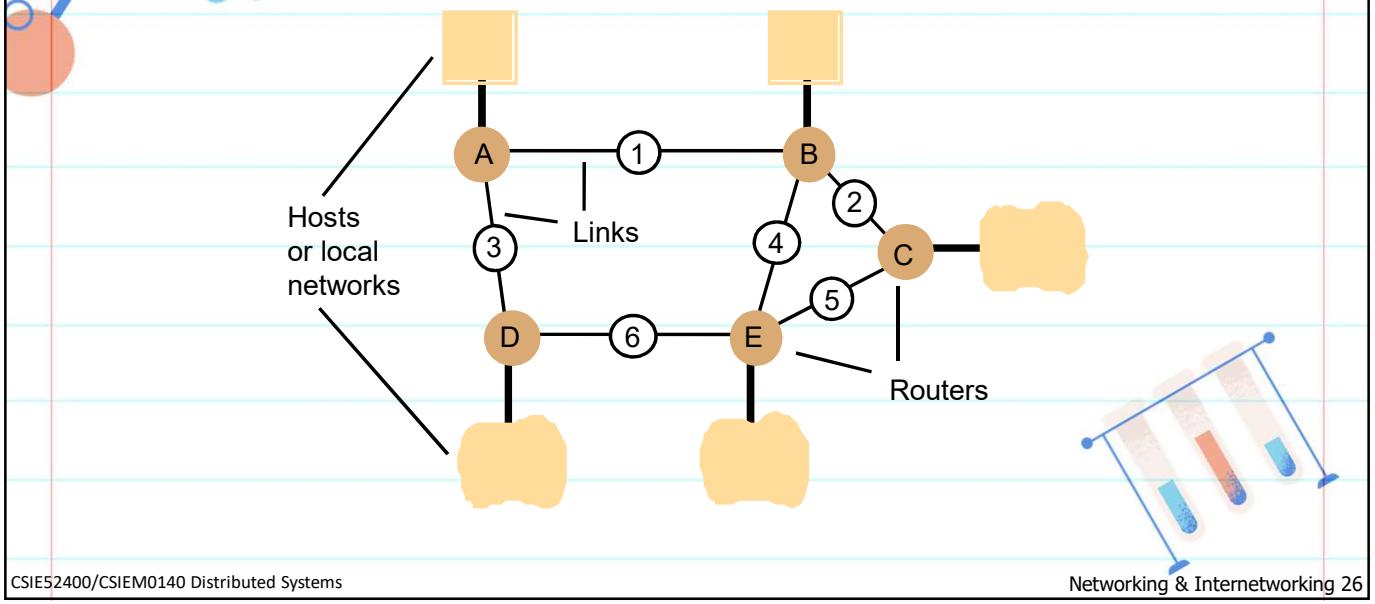
b) Transactional TCP.



Internetwork Layers



Routing in WAN



Routing Tables

Routings from A

To	*Link*	*Cost*
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

Routings from B

To	*Link*	*Cost*
A	1	1
B	local	0
C	2	1
D	1	2
E	4	1

Routings from C

To	*Link*	*Cost*
A	2	2
B	2	1
C	local	0
D	5	2
E	5	1

Routings from D

To	*Link*	*Cost*
A	3	1
B	3	2
C	6	2
D	local	0
E	6	1

Routings from E

To	*Link*	*Cost*
A	4	2
B	4	1
C	5	1
D	6	1
E	local	0

RIP(Routing Information Protocol)

Send: Each *t* seconds or when *Tl* (routing table) changes, send *Tl* (RIP packet) on each non-faulty outgoing link.

Receive: Whenever a routing table *Tr* is received on link *n*:

```
for all rows Rr in Tr {
    if (Rr.link ≠ n) {
        Rr.cost = Rr.cost + 1;
        Rr.link = n;
        if (Rr.destination is not in Tl) add Rr to Tl;
         // add new destination to Tl
        else for all rows Rl in Tl {
            if (Rr.destination = Rl.destination and
                    (Rr.cost < Rl.cost or Rl.link = n)) Rl = Rr;
            // Rr.cost < Rl.cost : remote node has better route
            // Rl.link = n : remote node is more authoritative
        }
    }
}
```

Newer protocols exist, such as OSPF(Open Shortest Path First), IGRP(Interior Gateway Routing Protocol) and EIGRP(Enhanced IGRP).

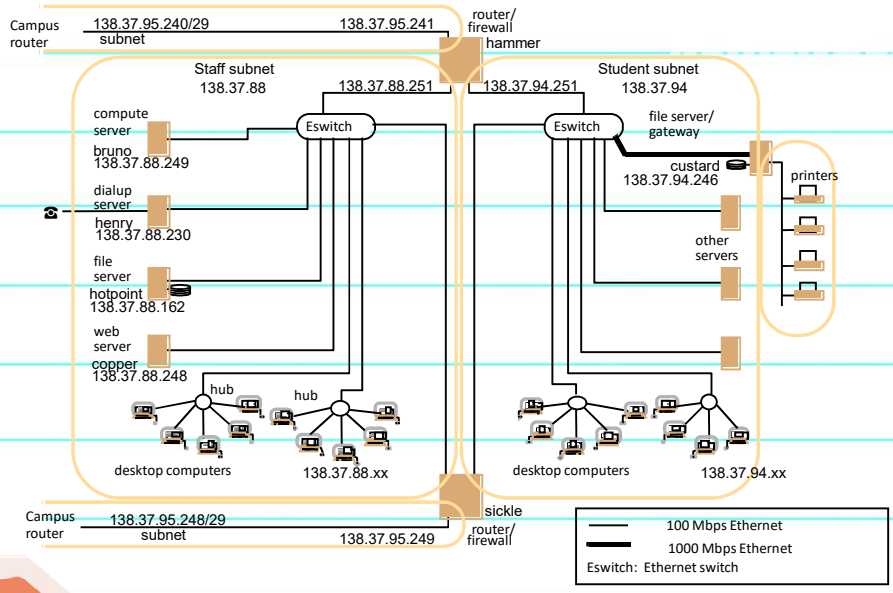
Congestion Control

- Network capacity is limited by its links and nodes.
- When limit is reached, dropped packets and retransmission may lower the throughput significantly.
- Congestion control is to regulate the network traffic to avoid the arrivals of packets to over-congested nodes.
- This will results in increased delays but will not significantly degrade the overall throughput.

Internetworking

- To build an integrated network (internetwork) on top of many different networks, we need
  1. A unified internetwork addressing scheme
  2. Internetworking protocols
  3. Internetworking components for addressing, routing and transmission
- For Internet, the corresponding components are
  1. IP address
  2. IP protocol
  3. Internet routers

A Univ Campus Network

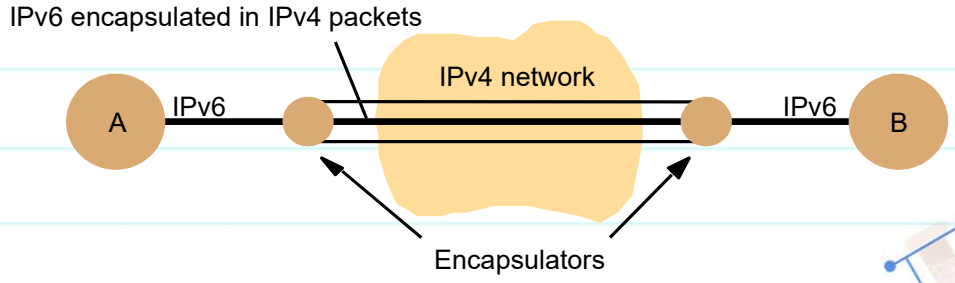


Network Components

- NIC – Network Interface Card
- Routers – Routing packets
- Bridges – Linking networks of different types
- Hubs – Connecting and extending network
- Switches – Fast routing on local networks
- Cables and connectors – transmit signals
- Modem – Connecting through phone line
- Tunnelling – A pair of nodes on different networks of the same type can communicate using protocol tunnel. (next slide)

Tunnelling Example

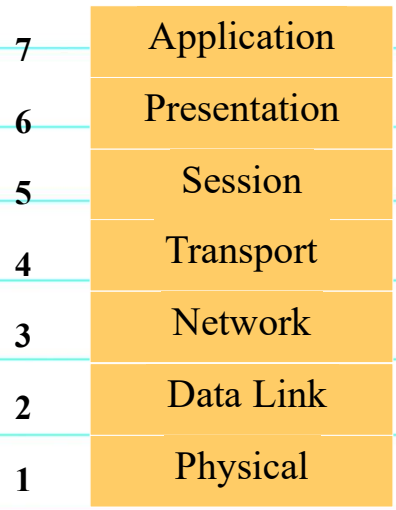
- 'Islands' of IPv6 networking can communicate with each other by protocol tunnelling.



TCP/IP

- In simple terms is a language that enables communication between computers
- A suite of protocols named after the two most important protocols TCP and IP but includes other protocols such as UDP, RTP, etc
- Each protocol is a set of rules that defines how two computers address each other and send/receive data to/from each other

OSI Model Revisited



APPLICATION
- Upper Layers
- Application oriented
- Independent of layers below

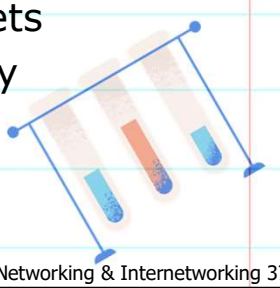
TRANSPORT
- Lower Layers
- Transmission of data
- No differentiation of upper layers

Layers 7, 6, 5

- 7: Application layer
  - Provides different services to the applications
  - Uses the underlying layers to carry out work
    - e.g. SMTP (mail), HTTP (web), Telnet, FTP, DNS
- 6: Presentation layer
  - Converts data from applications into network common format and vice versa
- 5: Session layer
  - organizes and synchronizes the exchange of data between application processes

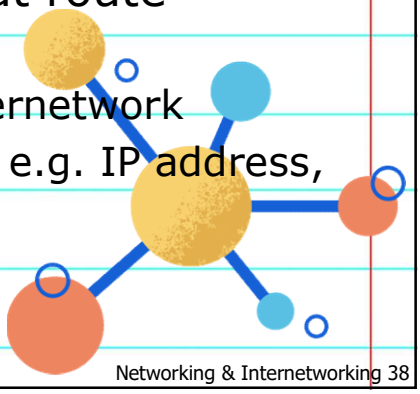
Layers 4

- 4: Transport layer
  - Provides end to end transportation of segments
  - TCP:
    - encapsulates TCP segments in network layer packets
    - adds reliability by detecting and retransmitting lost packets
    - uses acknowledgements and sequence numbers to keep track of successful, out-of-order, and lost packets
    - timers help differentiate between loss and delay
  - UDP is much simpler: no reliability features



Layer 3

- 3: Network layer
  - Routes the information in the network
  - E.g. IP is a network layer implementation which defines addresses in such a way that route selection can be determined.
    - Single address space for the entire internetwork
    - adds an additional layer of addressing, e.g. IP address, which is different from MAC address.



Layer 3

- 3: Network layer (e.g. IP)
  - Unreliable (best effort)
    - if packet gets lost, network layer doesn't care for higher layers can resend lost packets
  - Forwards packets hop by hop
    - encapsulates network layer packet inside data link layer frame
    - different framing on different underlying network types
    - receive from one link, forward to another link
    - There can be many hops from source to destination

Layer 3

- 3: Network layer (e.g. IP)
  - Makes routing decisions
    - how can the packet be sent closer to its destination?
    - forwarding and routing tables embody "knowledge" of network topology
    - routers can talk to each other to exchange information about network topology

Layer 2

- 2: Data Link layer
  - Provides reliable transit of data across a physical network link
  - bundles bits into frames and moves frames between hosts on the same link
  - a frame has a definite start, end, size
  - often also a definite source and destination link-layer address (e.g. Ethernet MAC address)
  - some link layers detect corrupted frames while other layers re-send corrupted frames

Layer 1

- 1: Physical layer
  - moves bits using voltage, light, radio, etc.
  - no concept of bytes or frames
  - bits are defined by voltage levels, or similar physical properties

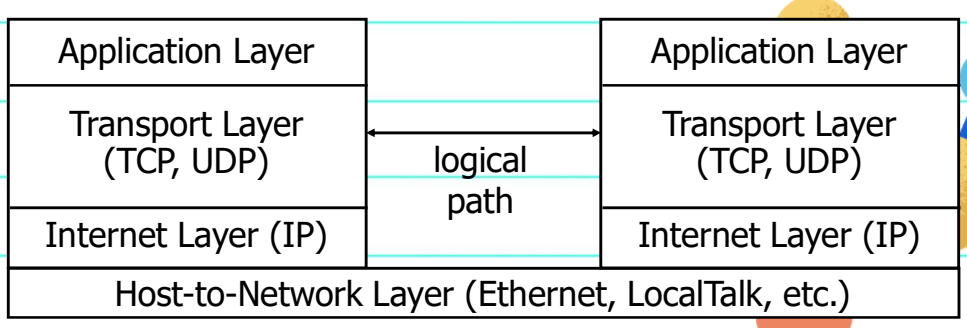
1101001000

OSI vs TCP/IP

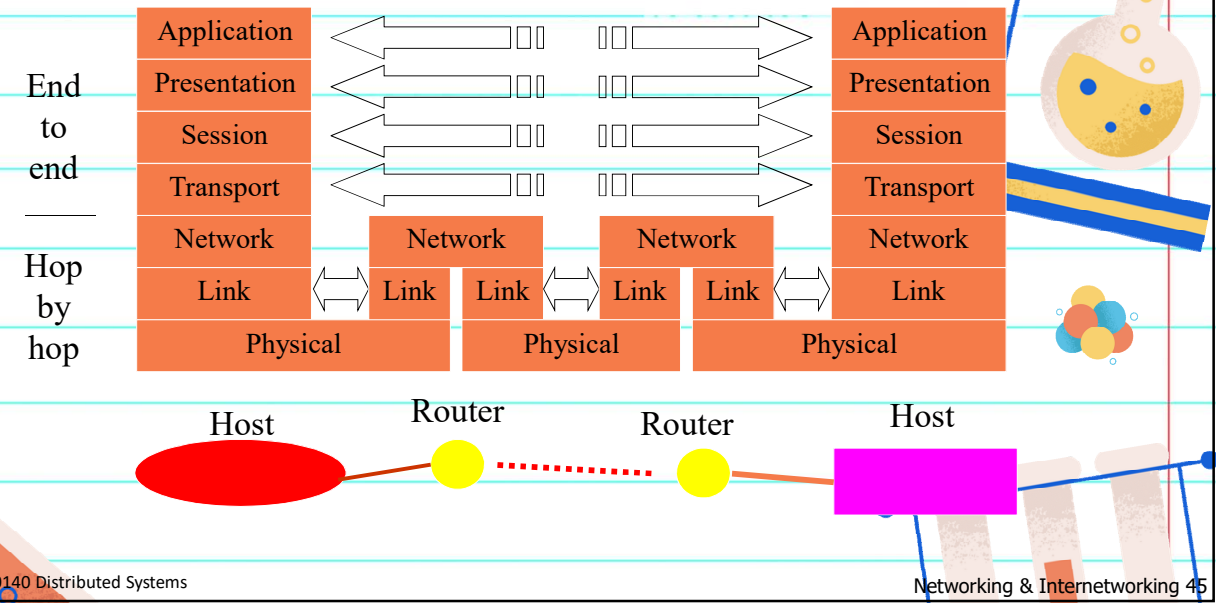
	OSI	TCP/IP	
7	Application	Application	*Mail, Web, etc.*
6	Presentation		
5	Session		
4	Transport	Transport	*TCP/UDP – end to end reliability*
3	Network	Network	*IP - Forwarding (best-effort)*
2	Data Link	Data Link &	*Framing, delivery*
1	Physical	Physical	*Raw signal*

Internet Protocol Layers

- The Internet connection can be simplified into a four-layer model. Each layer only talks to the layers immediately above and below it.
- Layers model reduces complexity and increase modularity.

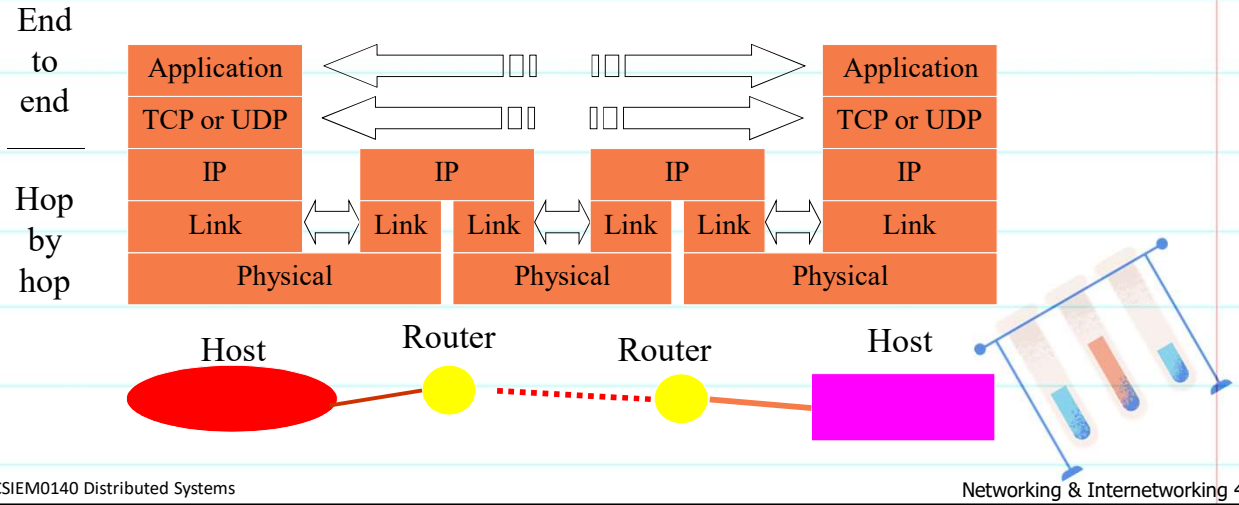


Layer Interaction: OSI

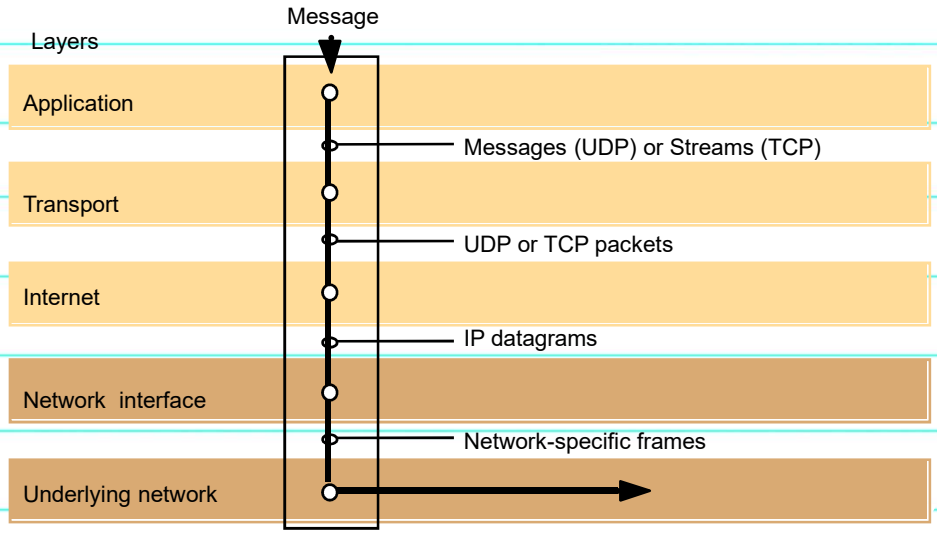


Layer Interaction: TCP/IP

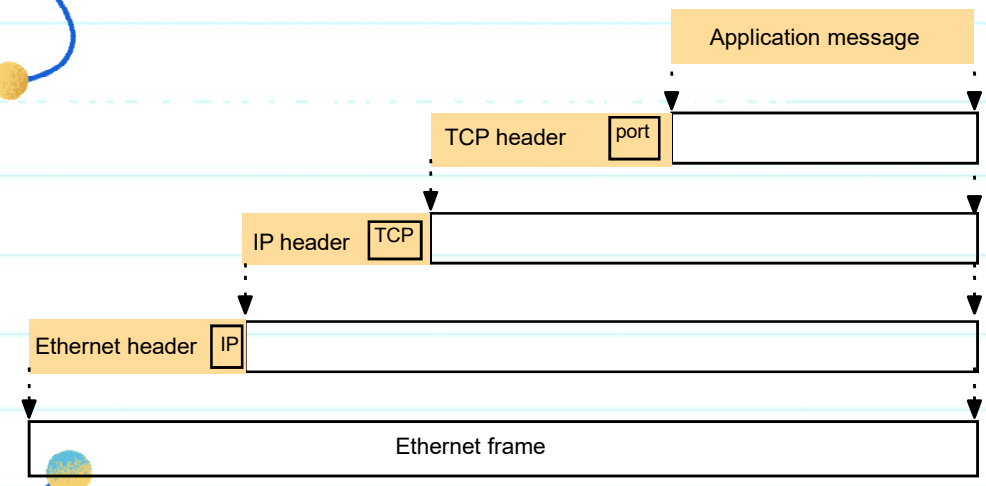
No session or presentation layers in TCP/IP model



TCP/IP Layers



Encapsulation in TCP/IP



Host-to-Network Layer

- = **physical layer** + **data link layer**
- The actual wires used to connect different computers make up the **physical layer**.
  - How packets of electricity map into bits and bytes.
  - Digital-to-analog conversion (sending end)
  - Analog-to-digital conversion (receiving end)
- **Error correction** and **redundancy** are done in the **data link layer**. (Ethernet)
- A specific data link layer requires specialized hardware. **Bridges**: convert information from one type to another.
- For distributed programming, we usually don't need to worry about either of the two layers.

Internet Layer

- A protocol defines how bits and bytes are organized into **packets**, and the **addressing scheme** by which different machines find each other.
- The **Internet Protocol (IP)** is the most popular protocol in the world.
- Others: IPX(Netware), AppleTalk(Macintoshes)
- Internet layer protocols are **hardware-independent**.
- Data is sent in packets called **datagrams**.
- Each IP datagram contains a **header** (20 ~ 60 bytes) and a **payload** (up to 65515 bytes).
- The header contains the protocol version no. and the **addresses** of the sending and receiving hosts.

Transport Layer

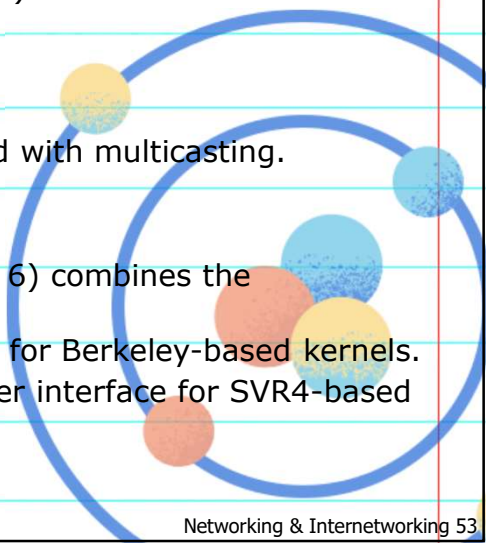
- Datagrams may not be delivered or arrived orderly.
- Responsible for ensuring that packets are **received in the order sent** and that **no data is lost**.
- Lost packets must be retransmitted.
- Two primary protocols: **TCP** and **UDP**.
- The **Transmission Control Protocol (TCP)** is a **reliable** protocol that guarantees the order of packets and no data lost, but with higher overhead.
- The **User Datagram Protocol (UDP)** is an **unreliable** protocol that does not guarantee correct delivery of packets, but is often much faster.

Application Layer

- Deliver data to and from the application processes.
- Lower layers define **how** data is transferred.
- The application layer decides **what** to do with that data and **when** it's transferred.
- **Example**: HTTP makes sure that your browser knows to display an image as a picture, not a long stream of numbers.
- **Examples**: SMTP and POP for email, FTP for file transfer, NNTP for news, …
- The way these four layers work together is called **encapsulation**.

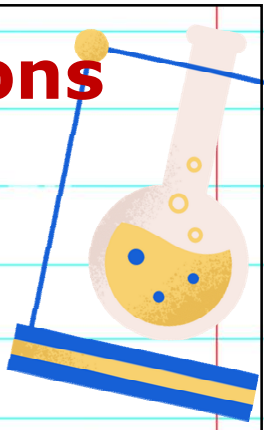
Common Internet Protocols

- IPv4 (Internet Protocol, version 4, 32-bit addresses)
- IPv6 (Internet Protocol, version 6, 128-bit addresses)
- TCP (Transmission Control Protocol)
- UDP (User Datagram Protocol)
- ICMP (Internet Control Message Protocol)
- IGMP (Internet Group Management Protocol) is used with multicasting.
- ARP (Address Resolution Protocol)
- RARP (Reverse Address Resolution Protocol)
- ICMPv6 (Internet Control Message Protocol, version 6) combines the functionality of ICMPv4, IGMP, and ARP.
- BPF (BSD Packet Filter) is a data link layer interface for Berkeley-based kernels.
- DLPI (Data Link Provider Interface) is a datalink layer interface for SVR4-based kernels.

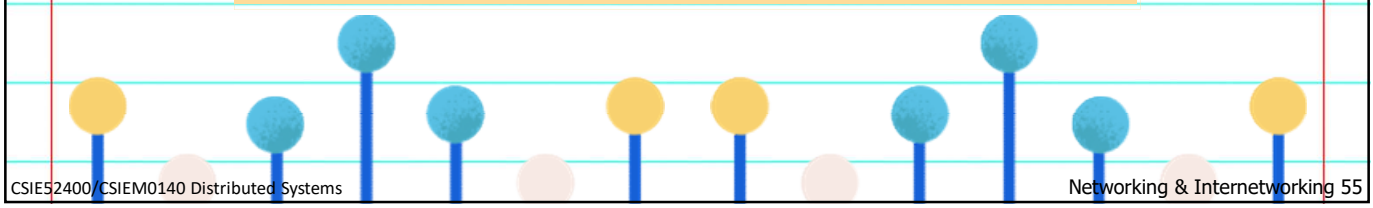


Some Internet Applications

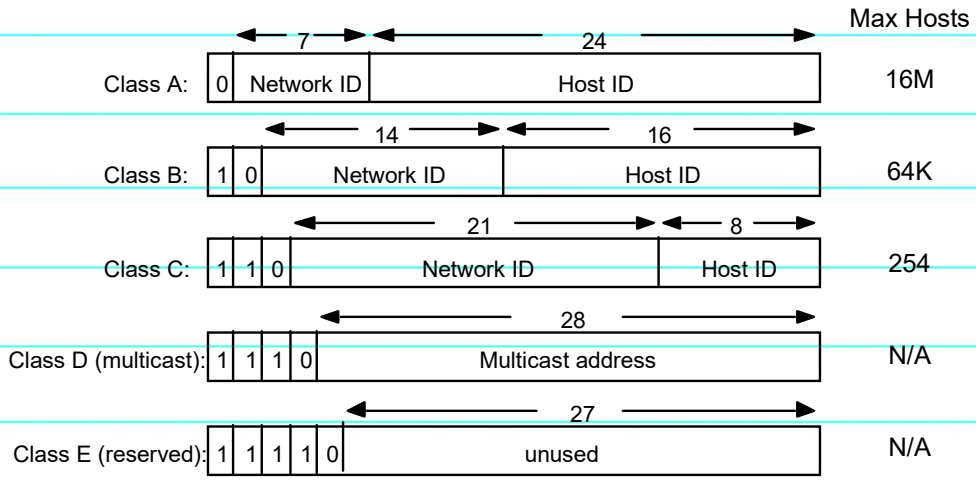
- OSPF (routing) - Open Shortest Path First
- RIP (routing) - Routing Information Protocol
- BGP (routing) – Border Gateway Protocol
- SMTP (email) – Simple Mail Transfer Protocol
- POP (email) – Post Office Protocol
- Telnet (remote login)
- SSH (remote login) – Secure Shell
- FTP (file transfer) – File Transfer Protocl
- HTTP (web) – HyperText Transfer Protocol
- NNTP (netnews) - Network News Transfer Protocol
- NTP (time) – Network Time Protocol
- DNS (name service) – Domain Name Service
- NFS (distributed file system) – Network File System
- Sun RPC (remote procedure call)
- DCE RPC (remote procedure call)



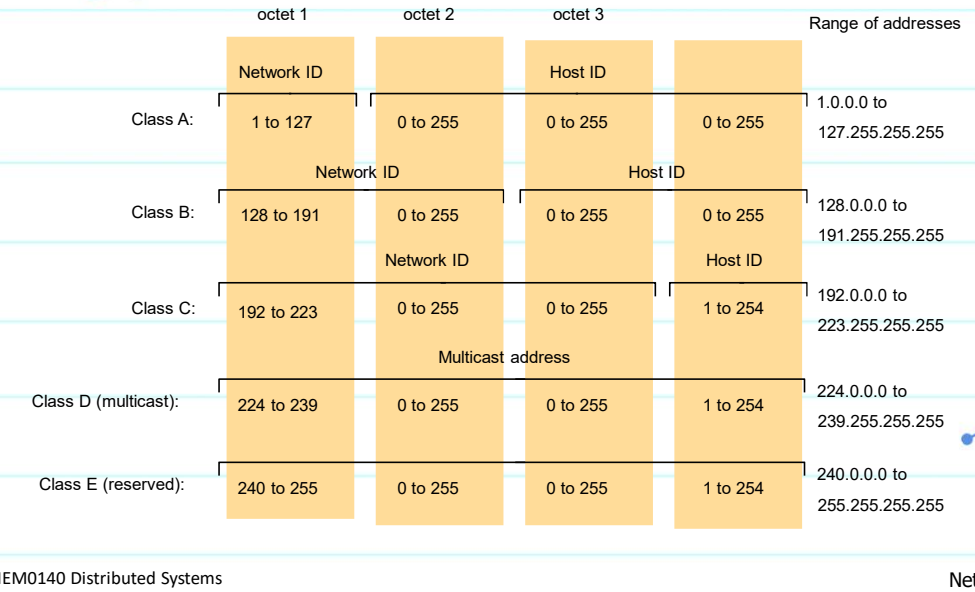
Programmer's View of TCP/IP Internet



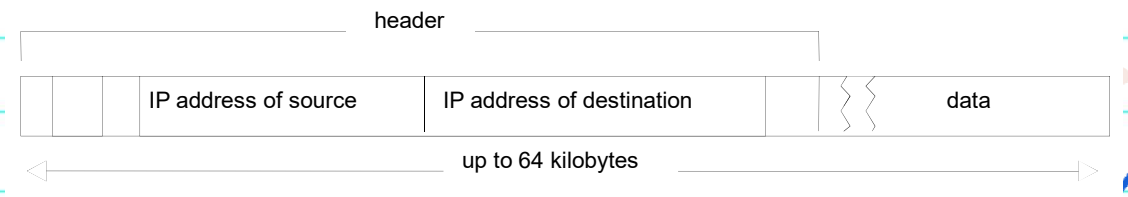
Address Classes (IPv4)



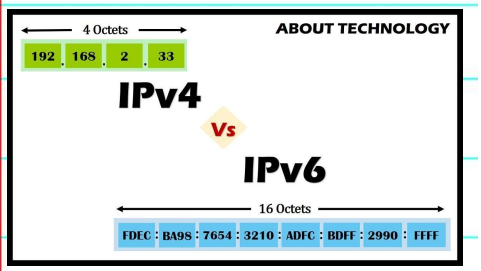
Internet Address in Decimal



IP Packet Layout



IPv6



Example of the IPV6 address format

FDEC : BA98 : 7654 : 3210 : ADBF : BBFF : 2922 : FFFF

Global Prefix Subnet Interface ID

Here each block is denoted in hexadecimal digits and each block is separated by a colon.

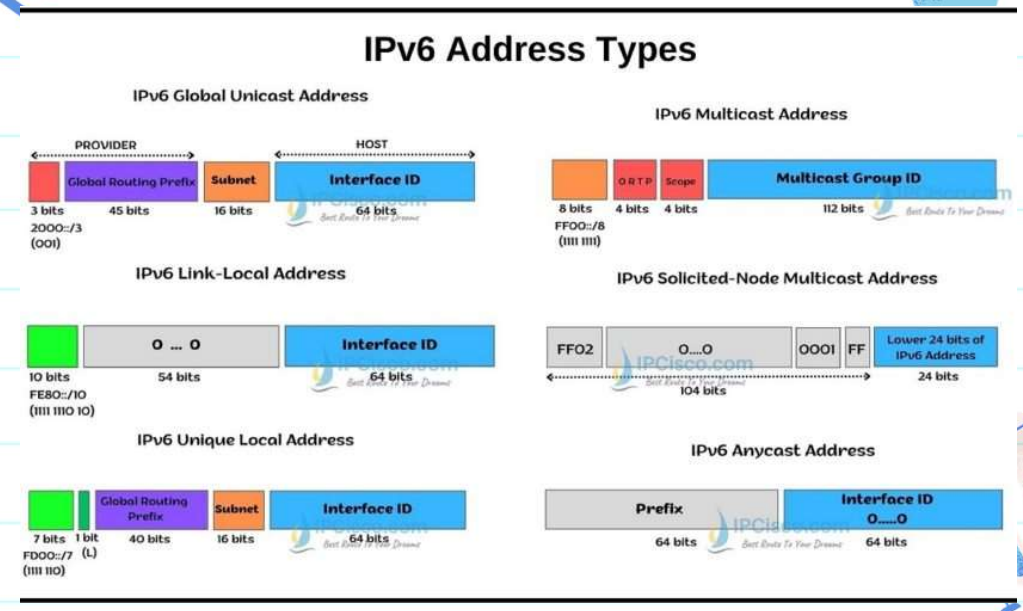
IPv6 in Short Form

- Eg.

IPV6 Address	20D1:0000:3238:DFE1:0063:0000:0000:FEFB							
BLOCK	1	2	3	4	5	6	7	8

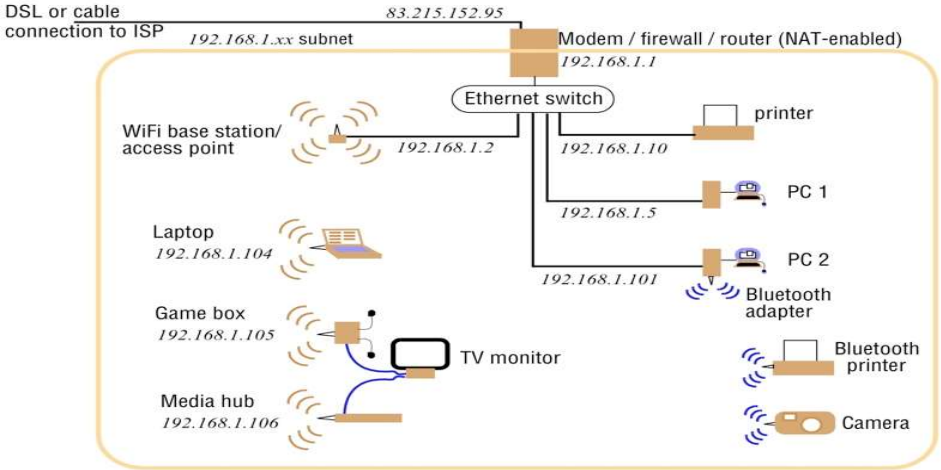
- **Rule 1**: Discard leading zero. (eg. 0063)
  - 20D1:0000:3238:DFE1:**63**:0000:0000:FEFB
- **Rule 2**: Replace two or more blocks of consecutive zeros with :: (only once)
  - 20D1:0000:3238:DFE1:63**::**FEFB
- **Rule 3**: Remaining blocks of zeros can be shrunk down to a single zero.
  - 20D1:**0**:3238:DFE1:63::FEFB

IPv6 Address Types



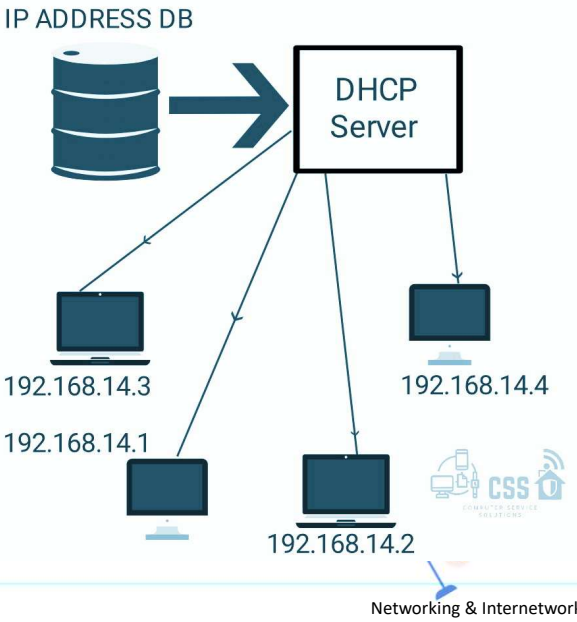
NAT-based Home Network

- NAT(Network Address Translation) allows devices to have non globally unique IP addresses.



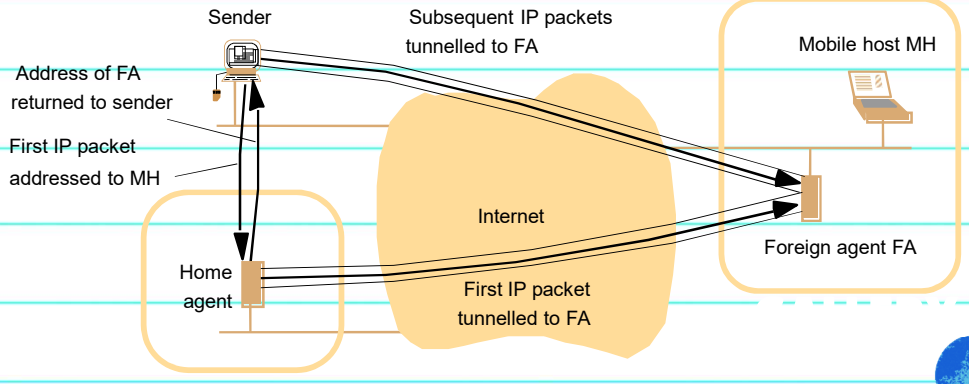
What about DHCP?

- DHCP is for dynamic and automatic address assignment.
- If the addresses assigned are public, no further translation is needed.
- If the addresses are private (such as home network), than translation is still needed.

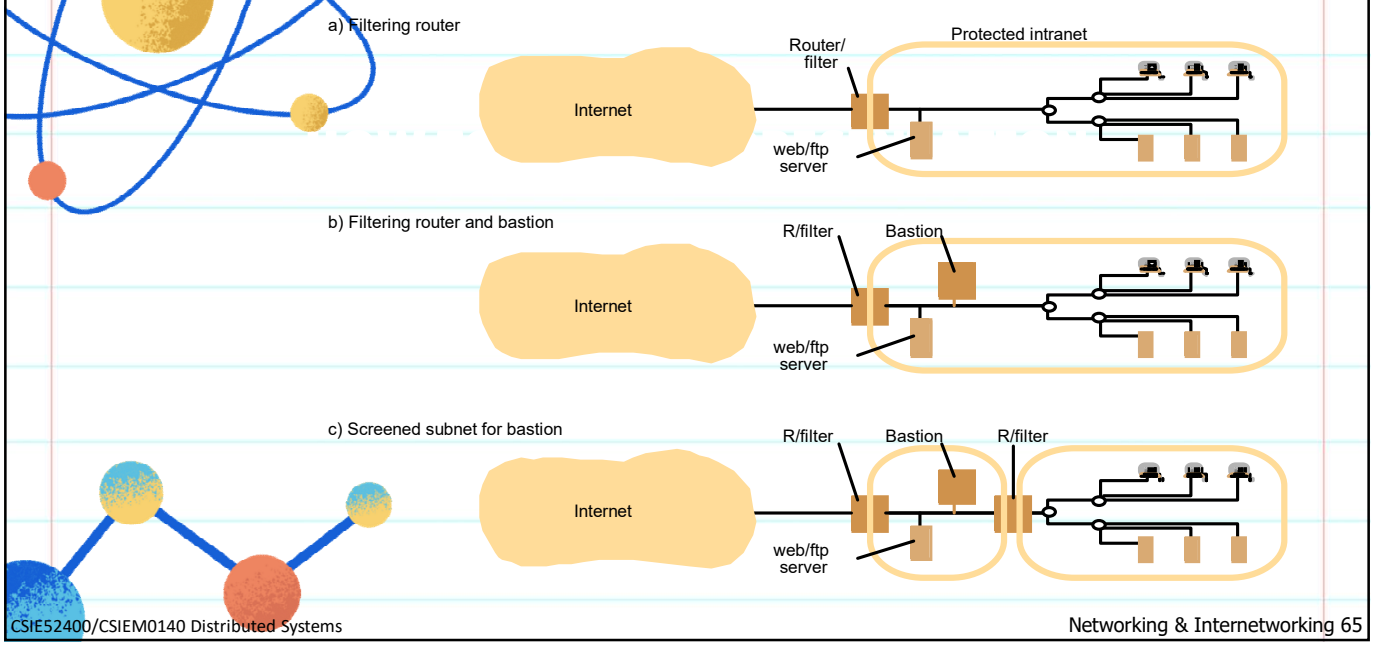


MobileIP Routing

- HA(Home Agent) is responsible for keeping up-to-date info of mobile host's current location.
- FA(Foreign Agent) allocates "care-of address" to mobile host.



Firewall Configurations



IEEE 802 Standards

Standard	Name	Topic
802.1	Internetworking	Routing,Bridging,and network-to-network Communications
802.2	Logical Link Control	Error and flow control over data frames
802.3	Ethernet LAN	All forms of Ethernet media and interfaces
802.4	Token BUS LAN	All forms of Token Bus media and interfaces
802.5	Token Ring LAN	All forms of Token Ring media and interfaces
802.6	Metropolitan Area Network	MAN technologies,Addressing, and Services
802.7	Broadband technical Advisory Group	Broadband network media,interfaces, adn other Equipments
802.8	Fiber Optic Technical Advisory Group	Fiber Optic media used in token-passing Networks like FDDI
802.9	Integrated Voice/ Data Network	Integration of voice and data traffic Over a single network medium
802.10	Netwok Security	Network access controls,encryption,Certification, and other Security topics
802.11	Wireless Networks	Standards for wireless networking for many different broadcast frquencies and usage techniques
802.12	High-Speed Networking	A variety of 100 Mbps-plus technologies,including 100 BASE-VG
802.14	Cable Broadband LANs and MANs	Standards for designing network over coaxial cable-based broadband connections.
802.15	Wireless Personal Area Networks	The coexistence of wireless personal area networks with Others wireless devices in unlicensed frequency bands.
802.16	Broadband Wireless Access	The atmospheric interface and related functions associated with Wireless Local Loop(WLL)

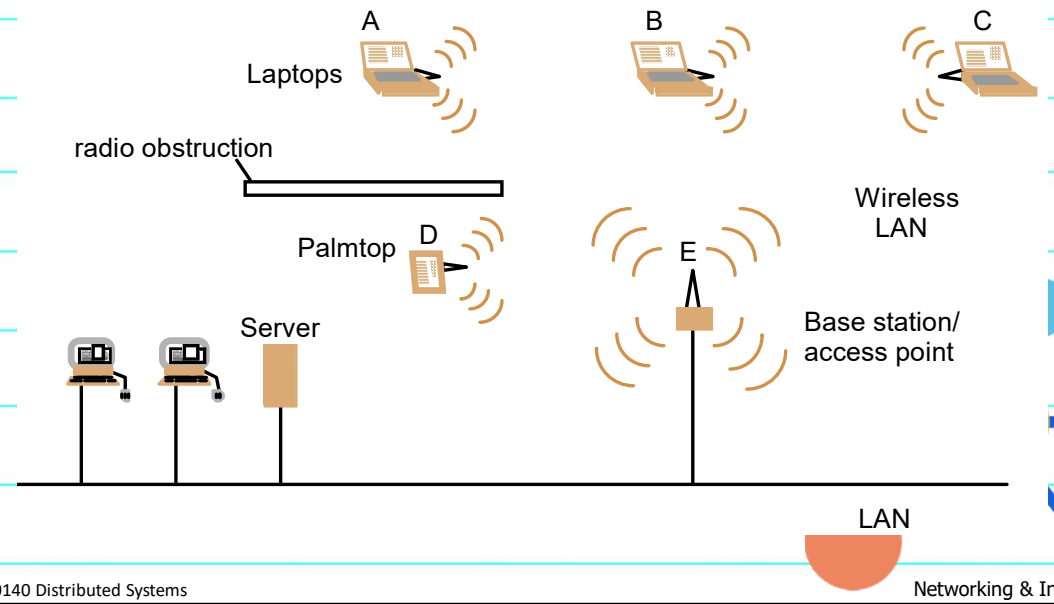
IEEE 802 Standards

IEEE No.	*Name*	*Title*	*Reference*
802.3	Ethernet	CSMA/CD Networks (Ethernet)	[IEEE 1985a]
802.4		Token Bus Networks	[IEEE 1985b]
802.5		Token Ring Networks	[IEEE 1985c]
802.6		Metropolitan Area Networks	[IEEE 1994]
802.11	WiFi	Wireless Local Area Networks	[IEEE 1999]
802.15.1	Bluetooth	Wireless Personal Area Networks	[IEEE 2002]
802.15.4	ZigBee	Wireless Sensor Networks	[IEEE 2003]
802.16	WiMAX	Wireless Metropolitan Area Networks	[IEEE 2004a]

Types of Ethernet

Speed	Common Name	Informal IEEE Standard Name	Formal IEEE Standard Name	Cable Type, Maximum Length
10 Mbps	Ethernet	10BASE-T	802.3	Copper, 100m
100 Mbps	Fast Ethernet	100BASE-T	802.3u	Copper, 100m
1000 Mbps	Gigabit Ethernet	1000BASE-LX	802.3z	Fiber, 5000 m
1000 Mbps	Gigabit Ethernet	1000BASE-T	802.3ab	Copper, 100 m
10 Gbps	10 Gig Ethernet	10GBASE-T	802.3an	Copper, 100 m

Wireless LAN Configuration

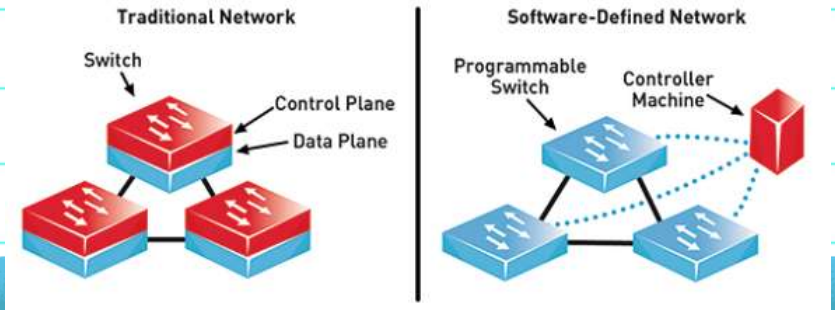


Levels of Communication

- Interprocess Communication
  - request/reply (RPC and RMI)
  - message passing (MOM)
  - transaction
  - data stream
- Network Operating System
  - transport connection
- Communication Network
  - packet switching

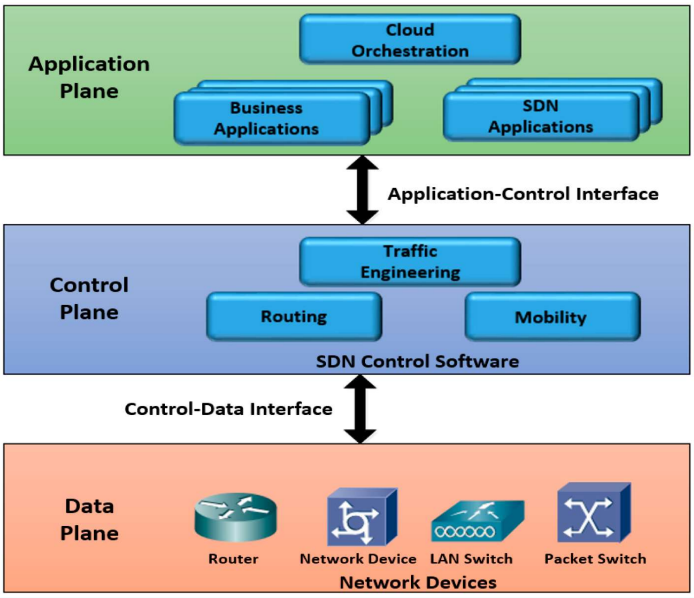
Software-Defined Network

- Software-Defined Networking (SDN) is a network architecture that enables intelligent and central control using software applications.
- Operators can manage the entire network consistently and holistically, regardless of the underlying network technology.



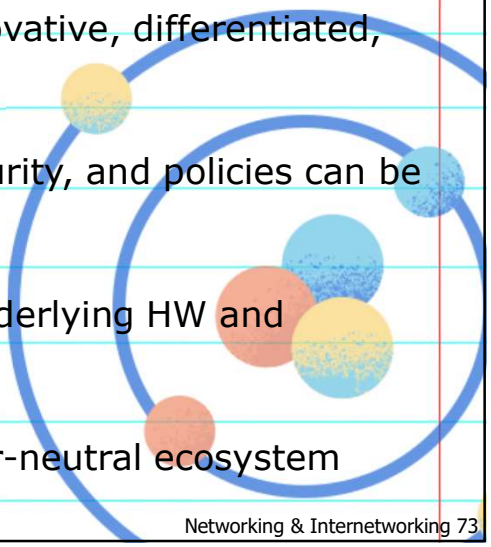
SDN Architecture

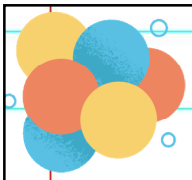
- In SDN, the network is separated into three planes: data, control, application



Benefits of SDN

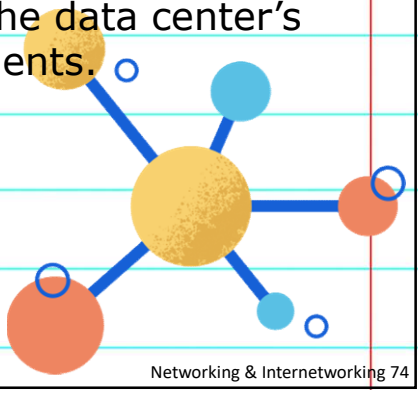
- Network programmability
  - Programmable network behavior beyond physical connectivity
  - Decoupling of HW from SW facilitates innovative, differentiated, and fast responding new services
- Logically centralize intelligence and control
  - Bandwidth management, restoration, security, and policies can be highly intelligent and optimized
- Abstraction of the network
  - Services and apps are abstracted from underlying HW and networking technologies
- Openness
  - A new era of openness, fostering a vendor-neutral ecosystem





800G and 1.6T Networking

- Ever heard of 800G or even 1.6T networking?
- These new ultra-high-speed network technologies/standards will help the world's need for increased bandwidth and higher line-rate connections.
- Will also introduce cost savings because of the data center's reduced space and power footprint requirements.
- Be ready to Rock N' Roll !!



Summary and Lab 0

- Networking and internetworking technologies
- Old and new standards
- Current and future trends

- **Lab 0**: Insatall the latest Python and practice low-level network programing using the `socket` module. (self practice lab)