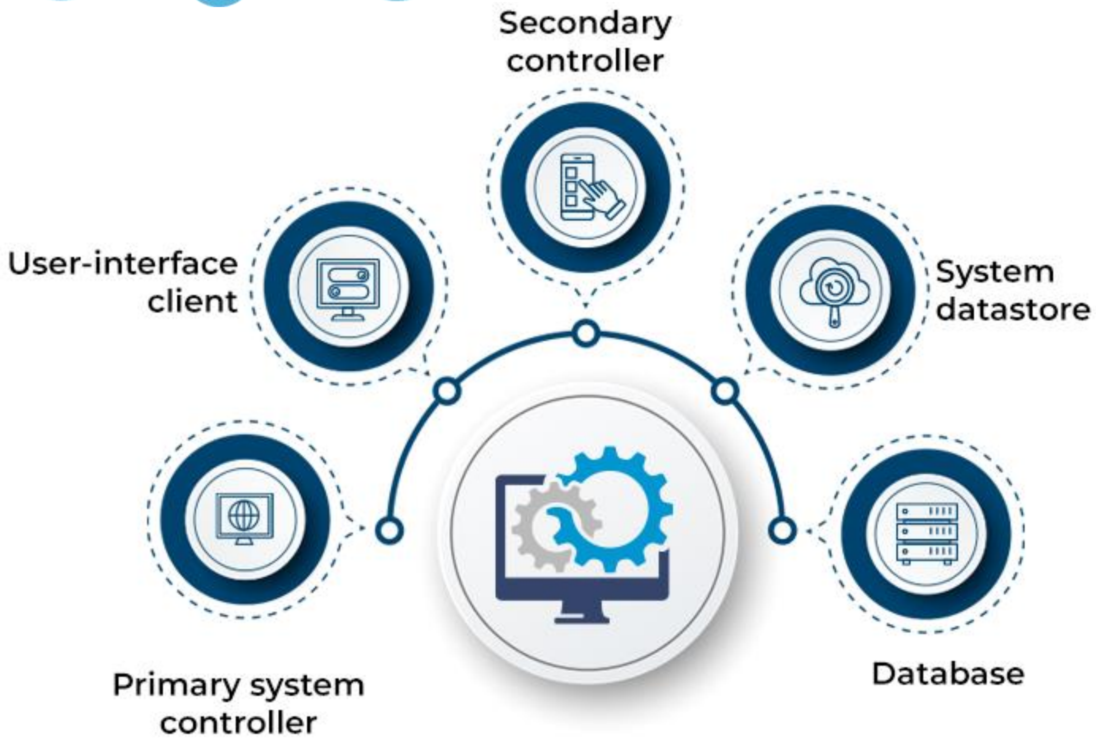


Sistem Terdistribusi

IF2222

02: Review Networking

2022-23 Ganjil

Teknik Informatika
Universitas Trunojoyo Madura

Sistem Terdistribusi 2022

1. Mengenal Sistem Terdistribusi
2. **Review Jaringan Komputer (layer 2, 3, dan 4)**
3. Arsitektur Sistem Terdistribusi
4. *Remote Procedure Calls* (RPC)
5. Layanan Penamaan
6. Sinkronisasi Data (2 pekan)
7. *Message Passing Interface* (MPI)
8. Contoh Arsitektur: Hadoop, Pregel, Blockchain
9. Teknik *Caching*
10. Teknik Replikasi Data (2 pekan)
11. Basis Data Terdistribusi
12. Toleransi Kegagalan

Capaian Pembelajaran

Kuliah ini bertujuan memberikan pemahaman mendalam dan pengalaman langsung tentang:

- Prinsip yang menjadi basis dari sistem terdistribusi
- Prinsip untuk optimalisasi sistem terdistribusi
- Model pemrograman sistem terdistribusi dan mesin analitika
- Bagaimana sistem terdistribusi modern memenuhi tuntutan aplikasi terdistribusi kontemporer

Today…

- Last Session:
  - Mengenal Sistem Terdistribusi
- Today's Session:
  - Network Types
  - Networking Principles: Layering, Encapsulation, Routing and Congestion Control
- Announcements:

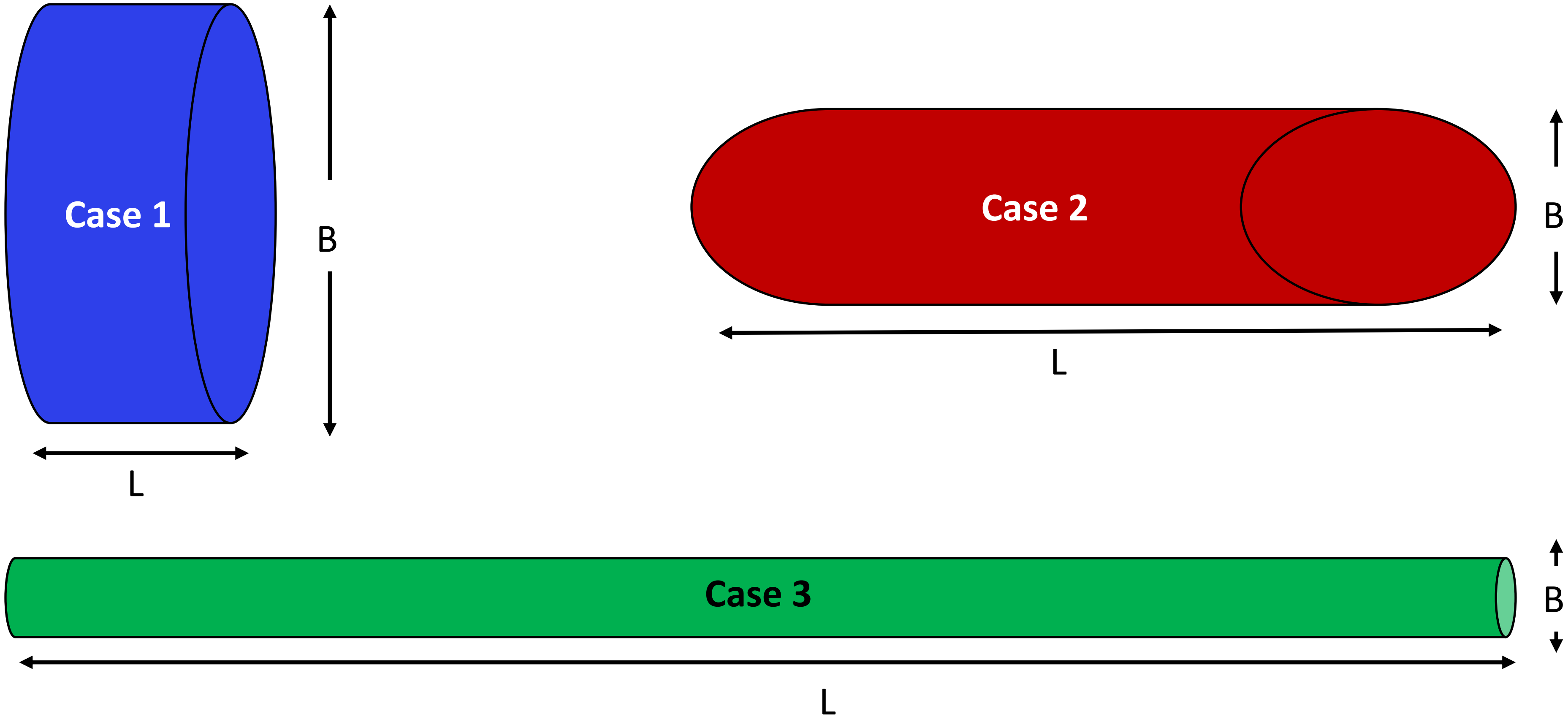
Learning Outcomes

- After two lectures on networks, you will be able to:
  - Identify different types of networks
  - Describe various networking principles such as layering, encapsulation, and packet-switching, among others
  - Examine how packets are routed
  - Realize how congestion is controlled
  - Analyze the performance, scalability, and reliability of networks

Networks in Distributed Systems

- A distributed system is a collection of components that communicate to solve a problem
- Why should designers of distributed systems know about networks?
  - Networking issues severely affect performance, fault-tolerance, and security of distributed systems
  - E.g., Gmail outage on Sep 1, 2010 – Google Spokesman said "*we had slightly underestimated the load which some recent changes placed on the request routers. … . few of the request routers became overloaded… causing a few more of them to also become overloaded, and within minutes nearly all of the request routers were overloaded.*"

A Primer: Latency and Bandwidth



- B = Bandwidth (or *Capacity*) and L = Latency (or *Delay*)
- B × L gives approximately the number of bits in flight
- As B × L increases, *uncertainty* increases (more bits might get lost)
- High value of B × L leads to *"Buffer Bloat"*

Networks in Distributed Systems

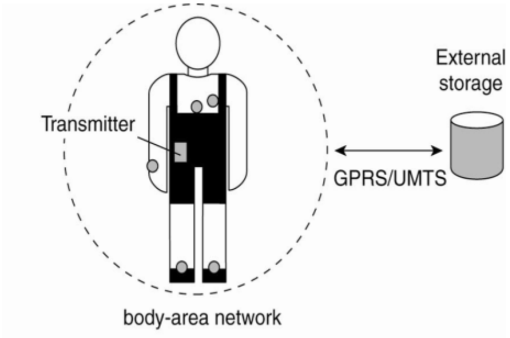
Networking Issue	Comments on a Distributed System Design
Performance	Affects choices of whether to optimize for network or other resources
Scalability	Size of Internet is increasing; expect greater traffic and latency in future
Reliability	Detect communication errors and perform error-checks at the application layer (*end-to-end argument!*)
Security	Install firewalls at gateways; deploy end-to-end authentication; employ encryption, etc.,
Mobility	Expect intermittent connection for mobile devices
Quality-of-service	Internet is best-effort. It is hard to ensure strict QoS guarantees for, say, multimedia data

Network Classification

- Important ways to classify networks
  1. Based on size
     - Body Area Networks (BAN)
     - Personal Area Networks (PAN)
     - Local Area Networks (LAN)
     - Wide Area Networks (WAN)
  2. Based on technology
     - Ethernet Networks
     - Wireless Networks
     - Cellular Networks

Network Classification – BANs and PANs

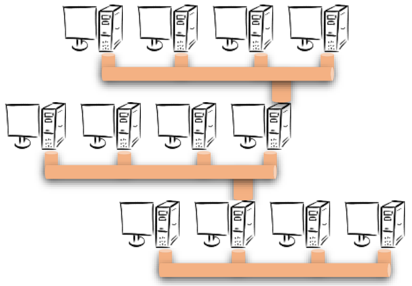
- Body Area Networks (BAN):
  - Devices form wearable computing units
  - Several Body Sensor Units (BSUs) communicate with Body Central Unit (BCU)
  - Typically, low-cost and low-energy networking



- Personal Area Networks (PAN):
  - PAN connects various digital devices carried by a user (mobile phones, tablets, cameras)
  - Low-cost and low-energy networking
  - e.g., Bluetooth

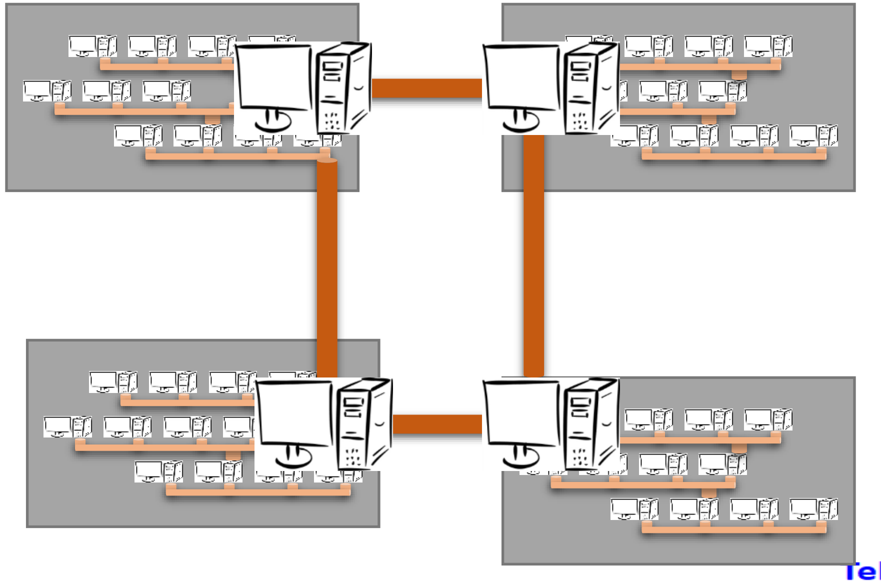
Network Classification – LAN

- Computers connected by single communication medium
  - e.g., Twisted copper wire, optical fiber
- High data-transfer-rate and low latency
- LAN consists of
  - Segment
    - Usually within a department/floor of a building
    - Shared bandwidth, no routing necessary
  - Local Networks
    - Serves campus/office building
    - Many segments connected by a switch/hub
    - Typically, represents a network within an organization

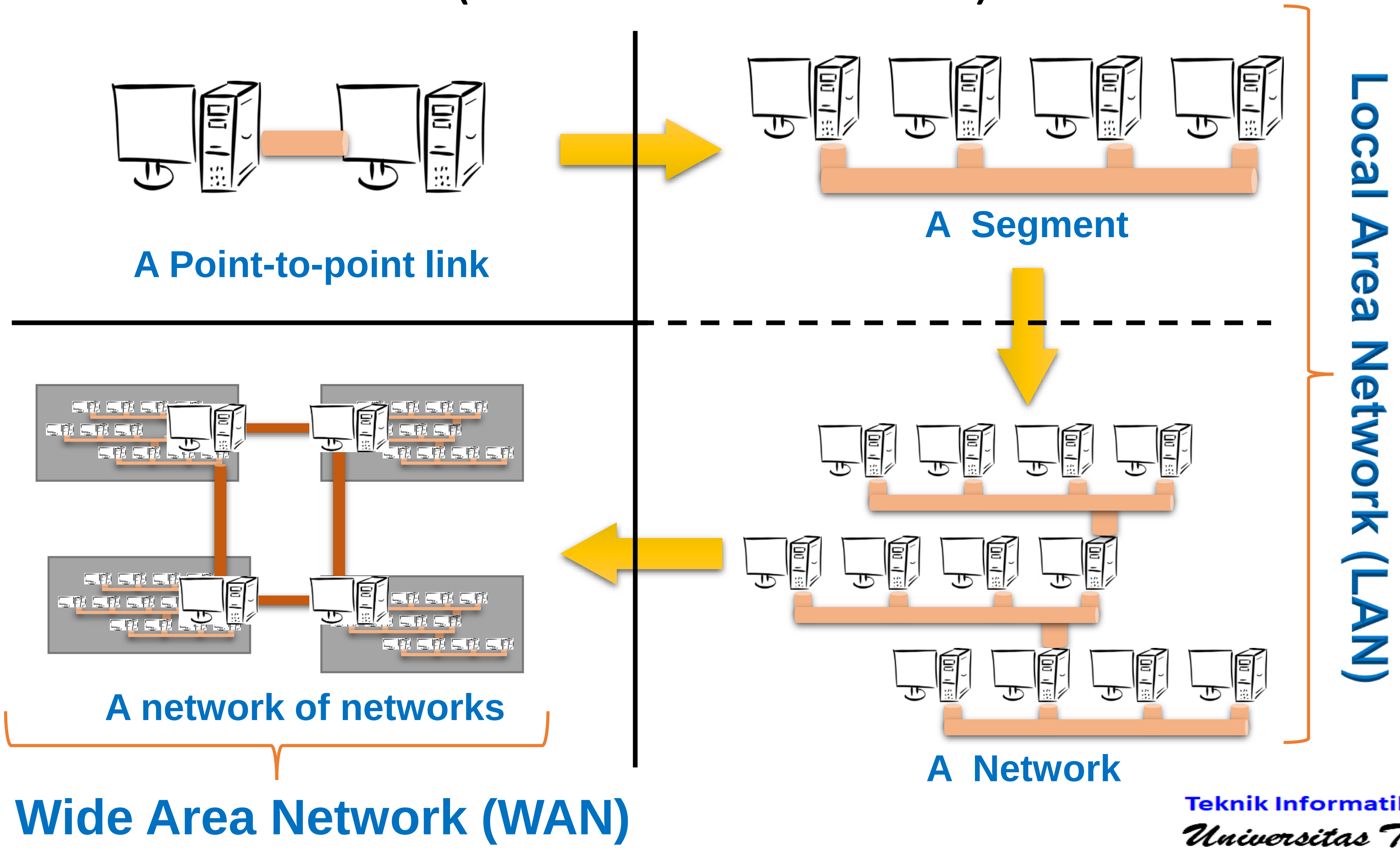


Network Classification – WAN

- Generally, covers a wider area (cities, countries,...)
- Consists of networks of different organizations
- Traffic is routed from one organization to another
  - Routers
- Bandwidth and latency
  - Vary
  - Worse than a LAN
- Largest WAN = Internet

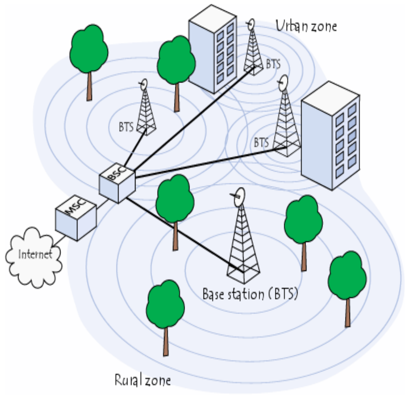


Brief Summary of Important Networks (Based on Size)



Types of Networks – Based on Technology

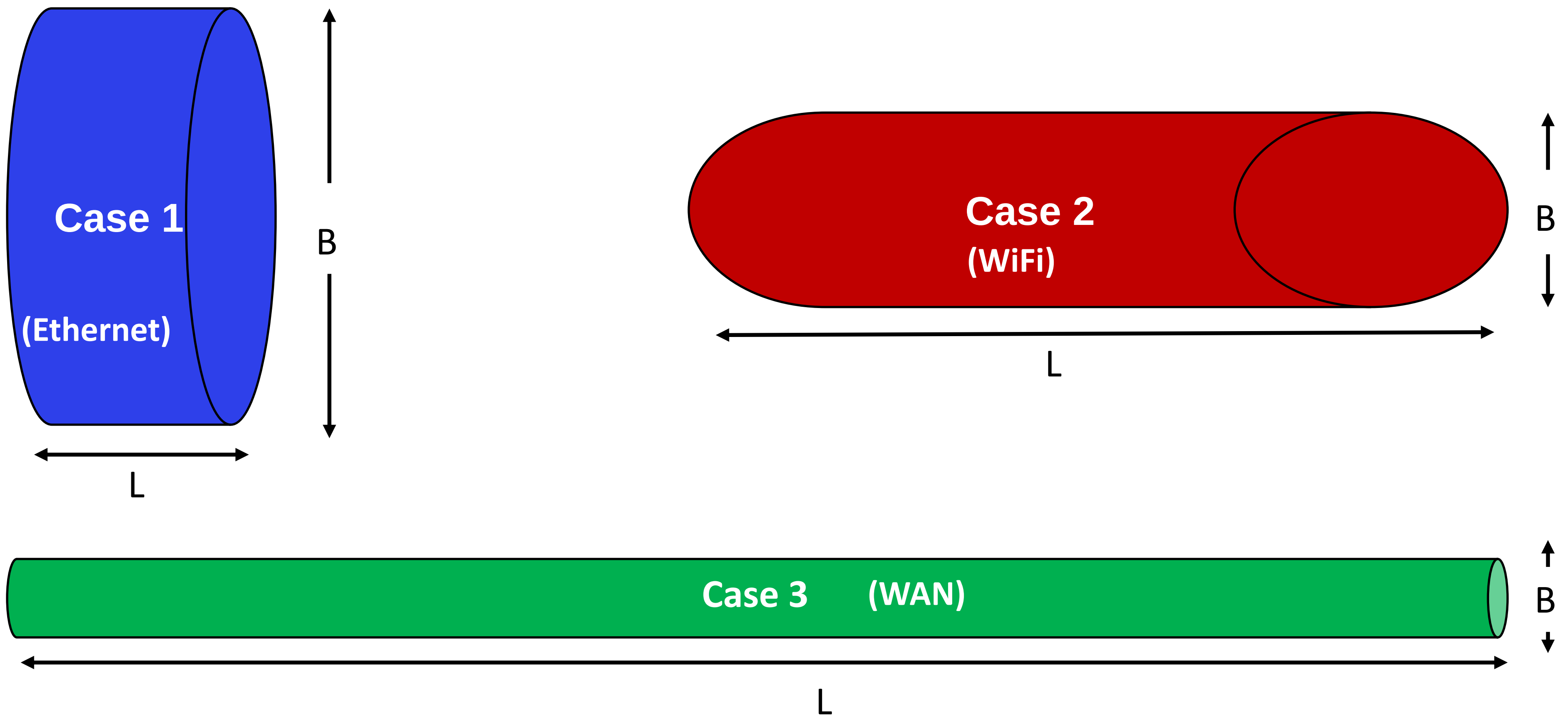
- Ethernet Networks
  - Predominantly used in the wired Internet
- Wireless LANs
  - Primarily designed to provide wireless access to the Internet
  - Low-range (100s of m), high-bandwidth
- Cellular networks (2G/3G/4G/5G)
  - Initially, designed to carry voice
  - Large range (few kms)
  - Low-bandwidth



Typical Performance for Different Types of Networks

Network	Example	Range	Bandwidth (Mbps)	Latency (ms)
Wired LAN	Ethernet	1-2 km	10 – 10,000	1 – 10
Wired WAN	Internet	Worldwide	0.5 – 600	100 – 500
Wireless PAN	Bluetooth	10 – 30 m	0.5 – 2	5 – 20
Wireless LAN	WiFi	0.15 – 1.5 km	11 – 108	5 – 20
Cellular	2G – GSM	100m – 20 km	0.270 – 1.5	5
Cellular	3G	1 – 5 km	348 – 14.4	100 – 500
Cellular	4G	16 km	10- 100	36-48
Modern Cellular	5G	2 km	50- 1000	10-30

Latency and Bandwidth



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Networking Principles

- Network Protocols
- Packet Transmission
- Network Layers
  - Physical layer
  - Data-link layer
  - Network layer and routing
  - Transport layer and congestion control

Networking Protocols

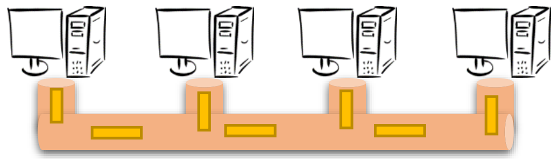
- If two entities want to communicate on a network, pre-defined agreements are necessary
  - How a message will be formatted?
  - How does the receiver know the last bit in the message?
  - How can a receiver detect if the message is damaged?

- "Protocol" is a well-known set of rules and formats to be used for communication between the entities

- Standardizing a well-known set of protocols supports communication among *heterogeneous* entities

Packet Transmission

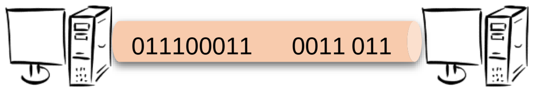
- Messages are broken up into packets
  - A packet is the unit of data that is transmitted between an origin and a destination
  - Packets can be of arbitrary lengths

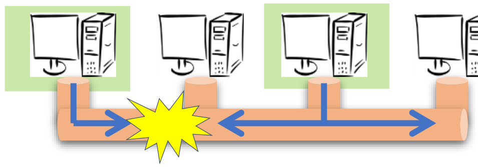


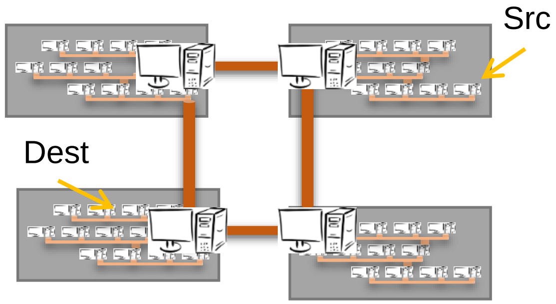
- Maximum size of the packet is known as Maximum Transmission Unit (MTU)
  - MTU prevents one host from sending a very long message
- Each packet has two main fields
  - Header: Contains meta-information about the packet
    - e.g., Length of the packet, receiver ID
  - Data

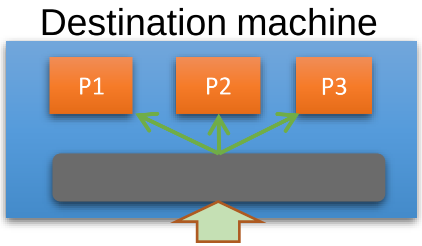
Network Layers

- Network software is arranged into a hierarchy of layers
  - Protocols in one layer perform one specific functionality
  - Layering is a scalable & modular design for complex software
- Typical functionalities in a network software:









Functionality	Layer
Transmits bits over a transmission medium	Physical
Coordinates transmissions from multiple hosts that are directly connected over a common medium	Data link
Routes the packets through intermediate networks	Network
Handles messages – rather than packets – between sender and receiver processes	Transport
Satisfies communication requirements for specific applications	Application

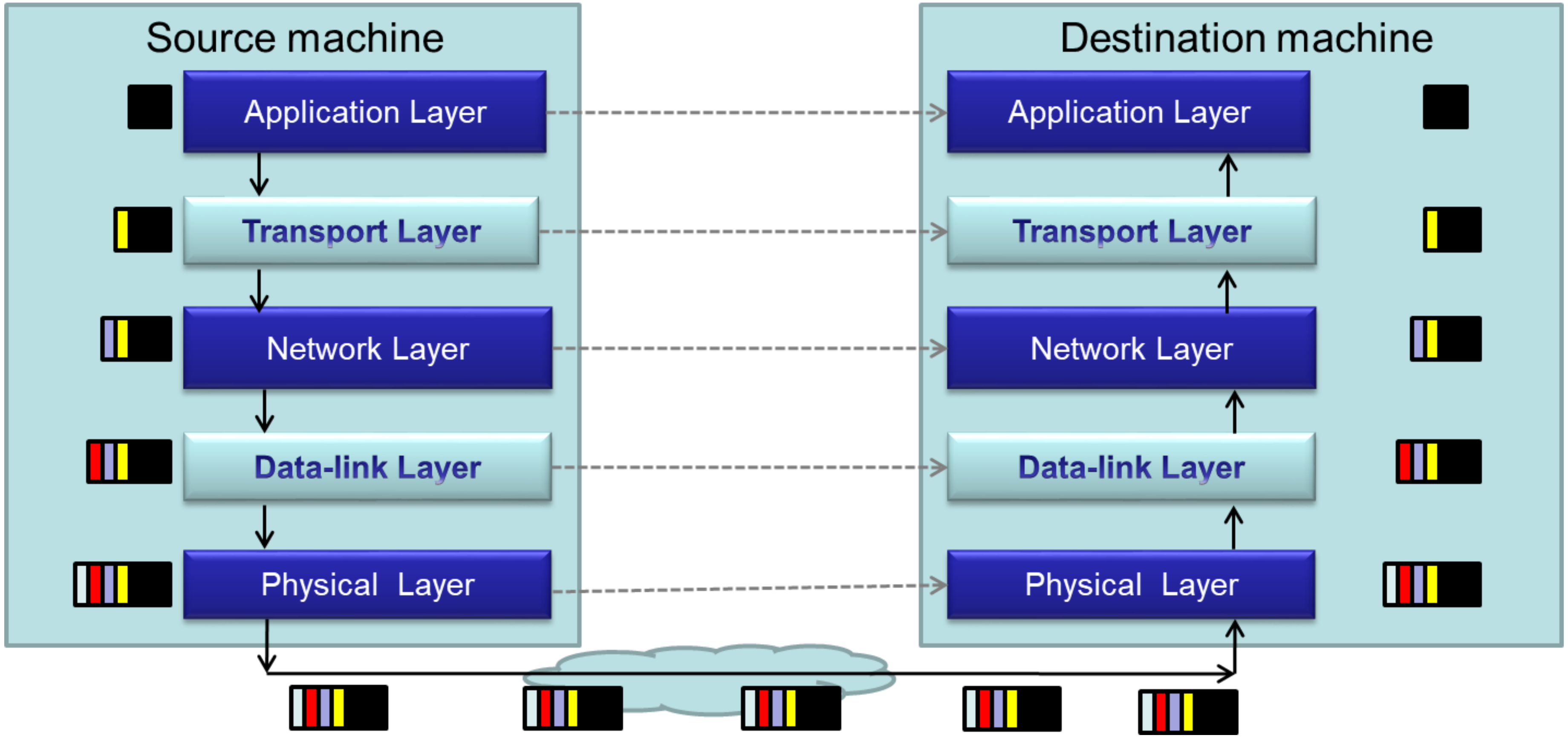
OSI Reference Model

- Open Systems Interconnection (OSI) Reference Model
  - A layered networking model standardized by ISO
  - The model identifies various layers and their functionalities

Functionality	Layer	Example Protocols
Satisfy communication requirements for specific applications	Application	HTTP, FTP
Transmit data in network representation that is independent of representation in individual computers	Presentation	CORBA data representation
Support reliability and adaptation, such as failure detection and automatic recovery	Session	SIP
Handle messages – rather than packets – between sender and receiver processes	Transport	TCP, UDP
Route the packet through intermediate networks	Network	IP, ATM
Coordinate transmissions from multiple hosts that are directly connected over a common medium	Data-link	Ethernet MAC
Transmit bits over a transmission medium	Physical	Ethernet

Packet Encapsulation

- Encapsulation is a technique to pack and unpack data packets in a layered architecture



Layers that We Will Study Today

1. Physical layer
2. Data-link layer
3. Network layer
4. Transport layer

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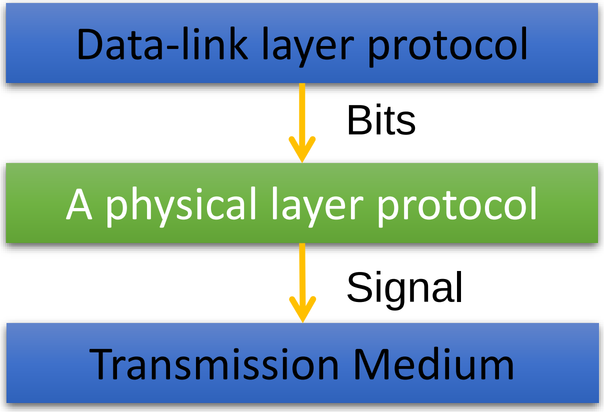
Physical Layer

- Physical layer protocols transmit a sequence of bits over a transmission medium
  - Modulate the bits into signals that can be transmitted over the medium

Transmission Medium	Type of signal transmitted
Twisted-pair (Ethernet cable)	Electrical signal
Fiber Optic Circuits	Light signal
Wireless channel	Electro-magnetic signal



Layers that We Will Study Today

1. Physical layer
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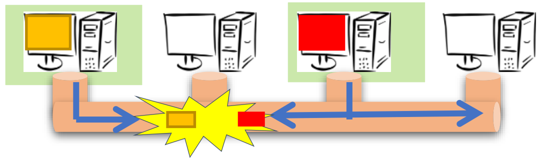
Data-link Layer

- Protocols in data-link layer ensure that the packets are delivered from one host to another within a local network
- Data-link layer protocols provide two main functionalities:
  - How to coordinate between the transmitters such that packets are successfully received?
    - Coordination
  - How to identify another host on the local network?
    - Addressing over local networks

Coordination at Data-link Layer

- A packet is not received successfully at the receiver if a sender transmits the data when another sender's transmission is active
  - The packet is said to have experienced collision if it is not successfully received at the receiver

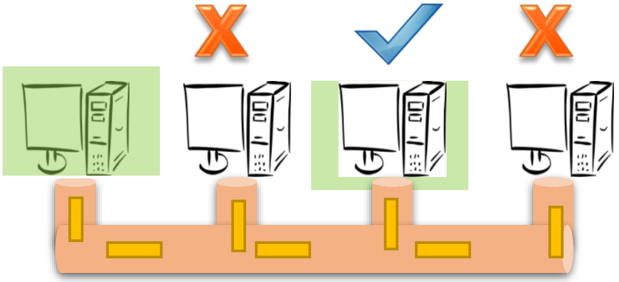
- Collision is avoided by sensing the medium before transmission



Addressing over Local Networks

- Each device that is connected to a network has a unique address called Medium Access Control (MAC) address
  - MAC addresses are six bytes long
    - e.g., 2A:D4:AB:FD:EF:8D

- Approach:
  - Data-link layer *broadcasts* the packet over the medium
  - Receiver reads the packet header and checks if the packet is addressed to it



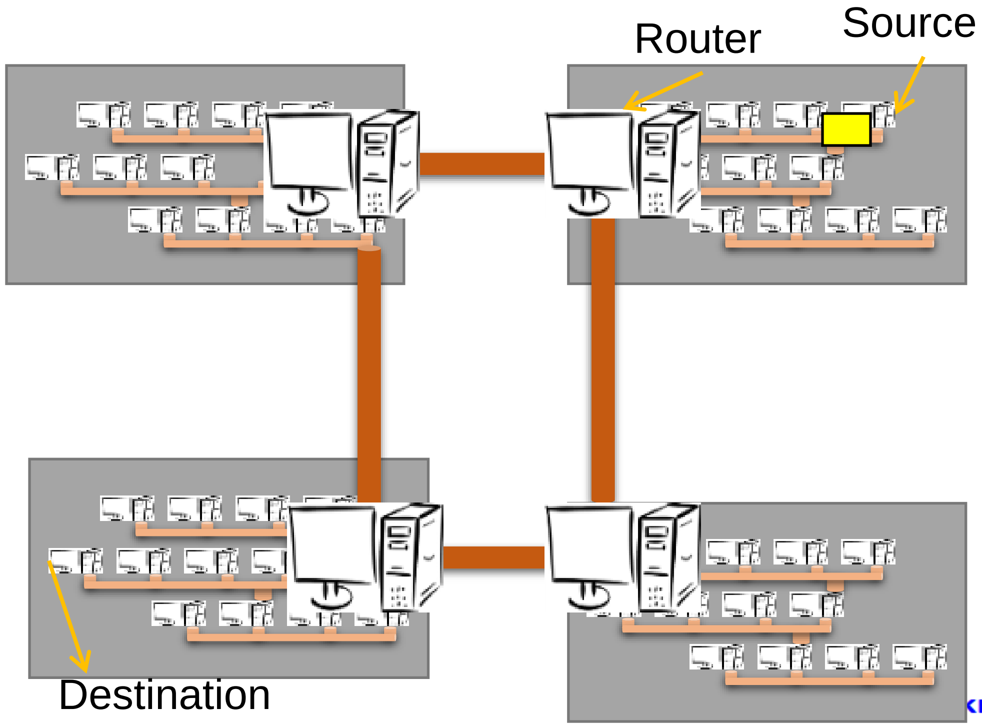
The Four Layers We Are Studying

1. Physical layer
2. Data-link layer
3. Network layer
4. Transport layer

Network Layer

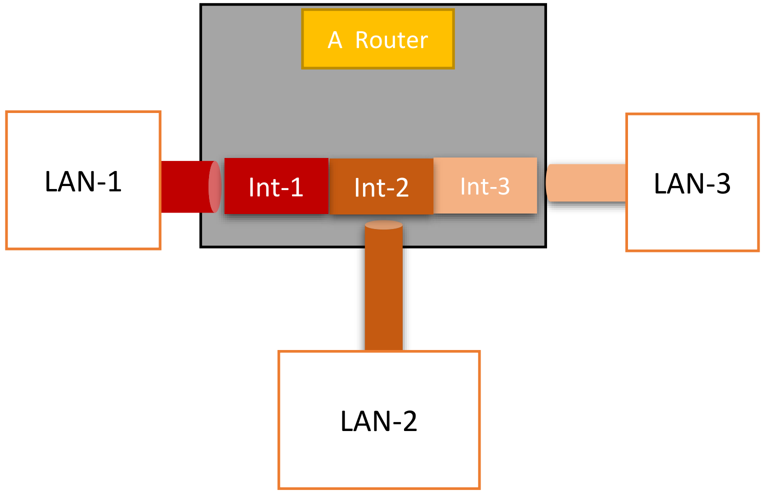
- Network layer protocols perform the role of routing
  - They ensure that a packet is routed from the source machine to the destination machine
  - Packets may traverse different LANs to reach the destination

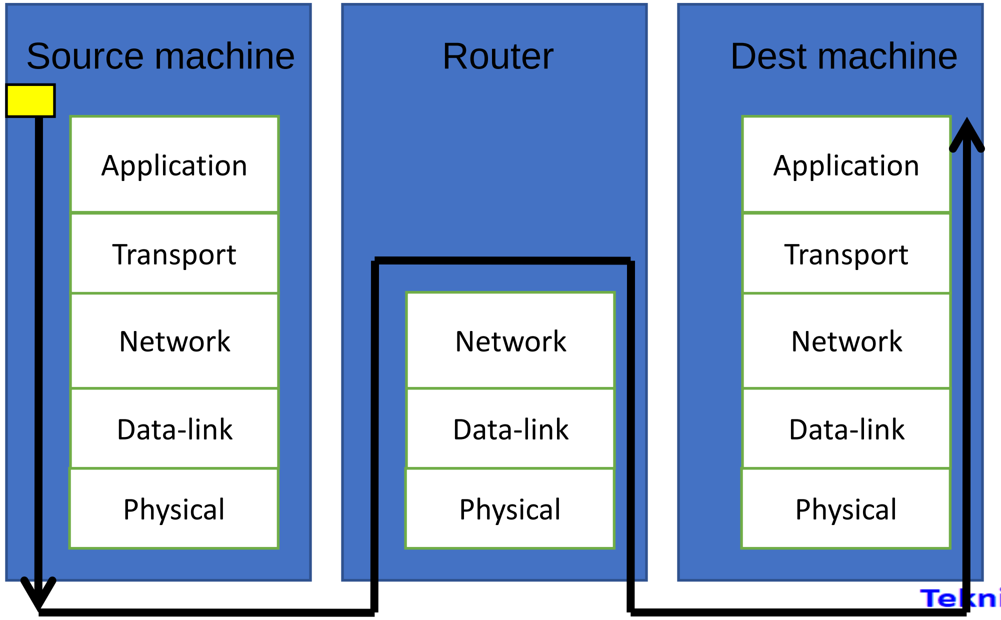
- Internet Protocol (IP) is a widely-used network layer protocol
  - IP addresses are typically used to identify machines



Router

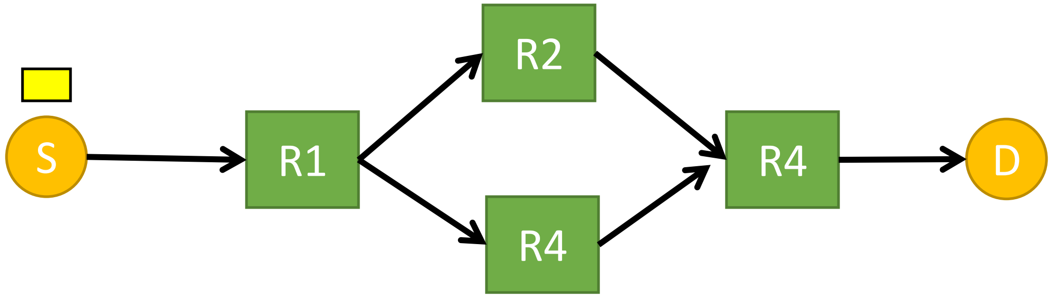
- A router is a device that forwards the packets between multiple networks
- Routers are connected to two or more networks
  - Each network *interface* is connected to a LAN or a host
- Packet travels up until the network layer on the router





Routing Algorithm

- Packets have to be transmitted in a series of hops through the routers
  - The series of hops that a packet takes is known as a route
- Routing algorithm is responsible for determining the routes for the transmission of packets
- Challenges for designing routing algorithms in the Internet:
  - Performance: The traffic across different networks vary
  - Router failures: Routers in the Internet may fail



Routing Algorithm (Cont'd)

- Routing algorithms have two activities
  1. Determine the next-hop taken by each packet
     - The algorithm should be fast and efficient
  2. Dynamically update connectivity information
     - Maintain the knowledge of the network by monitoring routers and traffic
- The above activities are *distributed* throughout the network
  - Routing decisions are made on an *hop-by-hop basis*
  - Information about possible next-hop routers is stored locally
  - Information is updated periodically
- Let us study a simple routing algorithm called "Distance Vector Algorithm"

Distance Vector Algorithm

- Distance Vector (DV) relies on graph theory to find the best route in a given network
  - It uses a well-known shortest path algorithm called ***Bellman-Ford***

- Two activities for the DV routing algorithm:
  1. Determining the best next-hop at each router
  2. Dynamically update connectivity information at all the routers

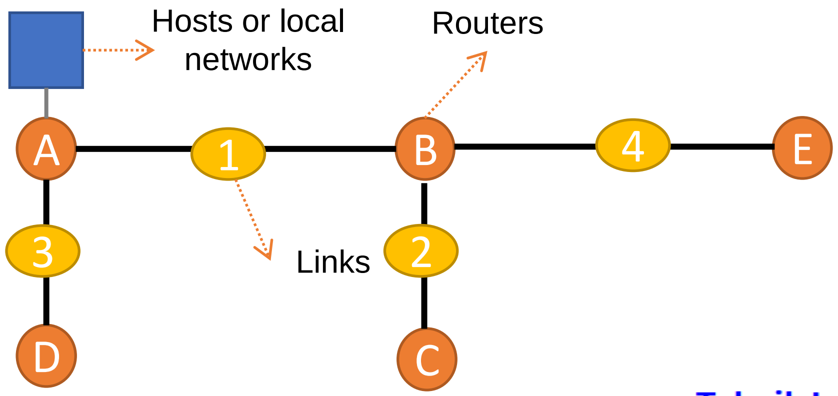
Distance Vector Algorithm – Next-hop Determination

- Each router maintains a routing table that consists of:
  - Destination: The destination IP of the packet
  - Link: The outgoing link on which the packet should be forwarded
  - Cost: The *distance* between the router and the destination
    - E.g., Cost can be estimated as the delay for the packet to reach the destination

- Router looks up the table to determine the best next-hop

Routing table at a router A

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



Routing Tables for an Example Scenario

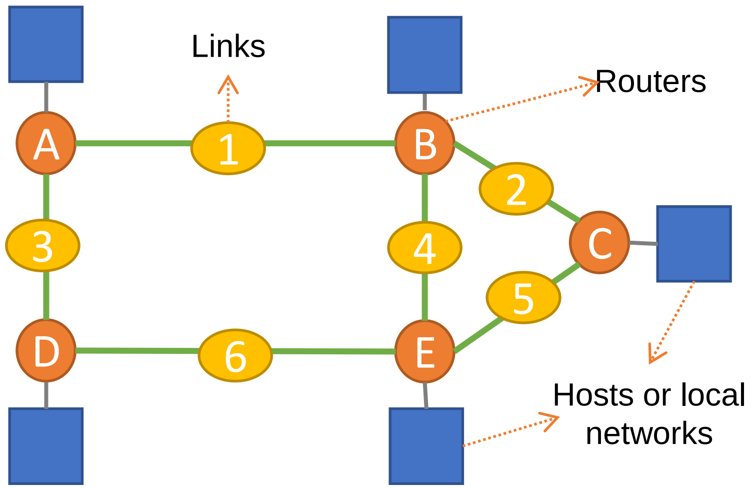
Routings from A		
To	*Link*	*Cost*
A	local	0
B	1	1
C	1	2
D	3	1
E	1	2

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



Distance Vector Algorithm – Updating the Connectivity Information

- Connectivity is updated by exchanging routing table

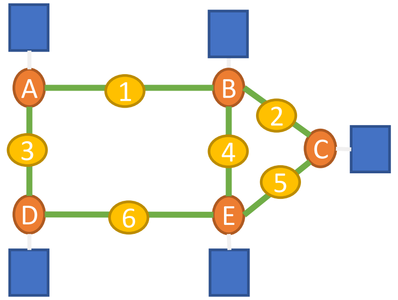
- Router Information Protocol (RIP) is used for sending update messages
  1. Send routing table to neighboring routers
     - Periodically, or when local table changes
  2. When a neighbor's routing table is received:

Case	If the received routing table …	Updates to the local routing table
1	Has a new destination that is not in the local routing table	Update the Cost and Link
2	Has a better-cost route to a destination in the local routing table	Update the Cost
3	Has a more recent information	Update the Cost and Link

Pseudocode for RIP

Send: Each *t* seconds or when *Tl* changes, send *Tl* 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; // Update cost
                Rr.link = n; // Update next-hop
                if (Rr.destination is not in Tl) {
                        add Rr to Tl;  // add new destination to Tl        Case 1
                }
                else for all rows Rl in Tl {
                        if (Rr.destination = Rl.destination) {
          Case 2                // Rr.cost < Rl.cost : remote node has better route
          Case 3                // Rl.link = n : information is more recent
                                if (Rr.cost < Rl.cost OR Rl.link = n) {
                                        Rl = Rr;
                                }
                        }
                }
        }
}
```



Tl at A

Routing table at router A

To	Link	Cost
A	local	0
D	3	1
C	3	3

Tr recvd @ A from B on link n=1

Routing table of router B

To	Link	Cost
A	1	1
B	local	0
C	2	1

Summary: Routing over Internet

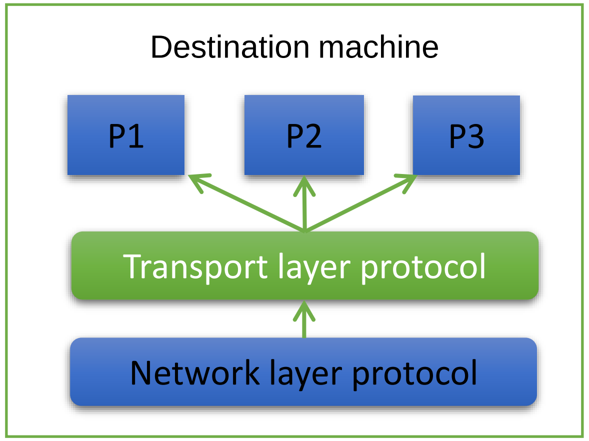
- Each machine over the Internet is identified by an IP Address
- Source machine transmits the packet over its local network
- Intermediate routers examine the packet, and forward it to the best next-hop router
- If the destination is directly attached to the local network of a router, the router forwards the packet over the respective local network
- Routers exchange information to keep an up-to-date information about the network

Layers that we will study today

1. Physical layer
2. Data-link layer
3. Network layer
4. Transport layer

Transport Layer

- Transport layer protocols provide end-to-end communication for applications
- This is the lowest layer where messages (rather than packets) are handled
- Messages are addressed to communication ports attached to the processes
  - Transport layer multiplexes each packet received to its respective port



Simple Transport Layer Protocols

- Simple transport protocols provide the following services:
  1. Multiplexing Service

  2. Connection-less Communication: The sender and receiver processes do not initiate a connection before sending the message
     - Each message is encapsulated in a packet (also called as *datagram*)
     - Messages at the receiver can be in different order than the one sent by the sender
     - E.g., User Datagram Protocol (*UDP*)

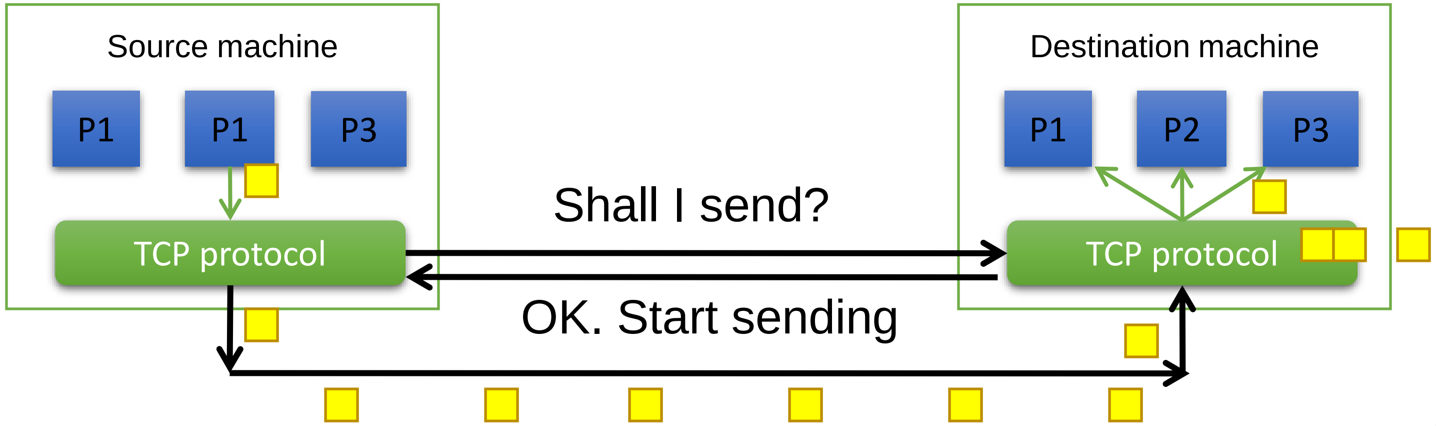
Advanced Transport Layer Protocols

- Advanced transport layer protocols typically provide more services than simple multiplexing

- Transmission Control Protocol (TCP) is a widely-used protocol that provides three additional services:
    1. Connection-oriented Communication
    2. Reliability
    3. Congestion Control

1. Connection-Oriented Communication

- Sender and receiver will handshake before sending the messages
  - Handshake helps to set-up connection parameters, and to allocate resources at destination to receive packets
- Destination provides *in-order delivery* of messages to the intended process
  - Destination will buffer the packets until previous packets are received
  - It will then deliver packets to the process in the order that the sender had used



2. Reliability

- Packets may be lost in the network due to buffer overflows at the router or transmission error(s)

- In TCP, destination sends an ACK to the sender
  - If ACK is not received at the sender, the sender will infer a packet error, and retransmit the packet

3. Congestion Control

- The capacity of a network is limited by the individual communication links and routers
  - Limited buffer space and link-bandwidth
- What happens if a source transmits packets at a rate that is greater than the capacity of the network?
  - Packets drop at intermediate routers
  - Corresponding ACKs will NOT be received at the source
  - The source retransmits
  - More packets build-up on the router queue
  - The network collapses

3. Congestion Control (Cont’d)

- To avoid congestion, *two* functionalities can be adopted
  1. Detect congestion at routers
     - If a router expects a buffer overflow, it typically follows one of two strategies:
       - It drops packets and lets sources regulate upon observing packet losses
       - It sends an “Explicit Congestion Notification (ECN)” packet to sources
  2. Regulate input at sources
     - If the TCP-sender concludes congestion (e.g., it receives an ECN packet), then it reduces its sending rate

Recap: Learning Objectives

- You will identify how computers over the Internet communicate
- Specifically, after the two lectures in networking you will be able to:
  - Identify different types of networks
  - Describe networking principles such as layering, encapsulation, and packet-switching
  - Examine how packets are routed and how congestion is controlled
  - Analyze scalability, reliability, and fault-tolerance over the Internet

Next Class

- Arsitektur Sistem Terdistribusi