# IT4371: Distributed Systems

## Spring 2016

## Networking

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## Today…

- Last Session:
  - Architectural Models of Distributed Systems
- Today's Session:
  - Network Types
  - Networking Principles: Layering, Encapsulation, Routing and Congestion Control
  - Scalability, Reliability and Fault-tolerance in the Internet

## Introduction to Networking – Learning Objectives

- You will identify how computers over Internet communicate
- Specifically, after today's class 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 Internet

## Networks in Distributed Systems

Distributed System is simply a collection of components that communicate to solve a problem

Why should distributed systems programmers 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.*"

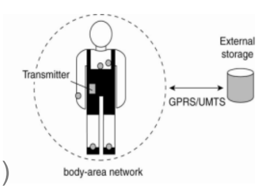
## Network Classification

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

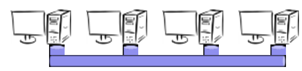



- Body Area Networks (BAN):
  - Devices form wearable computing units
  - Several Body Sensor Units (BSUs) communicate with Body Central Unit (BCU)
  - Typically, low-cost and low-energy networking

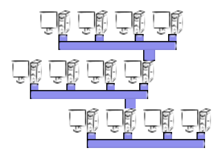
- Personal Area Networks (PAN):
  - PAN connects various digital devices carried by a user (mobile phones, tablets, cameras)
  - Low-cost and low-energy networking
  - e.g., Bluetooth

# 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



  1. Segment
     - Usually within a department/floor of a building
     - Shared bandwidth, no routing necessary



  2. Local Networks
     - Serves campus/office building
     - Many segments connected by a switch/hub
     - Typically, represents a network within an organization

# Network classification – WAN

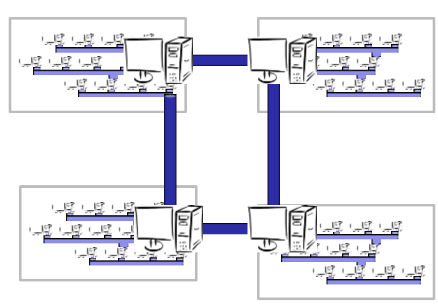
Generally covers a wider area (cities, countries,...)

Consists of networks of different organizations

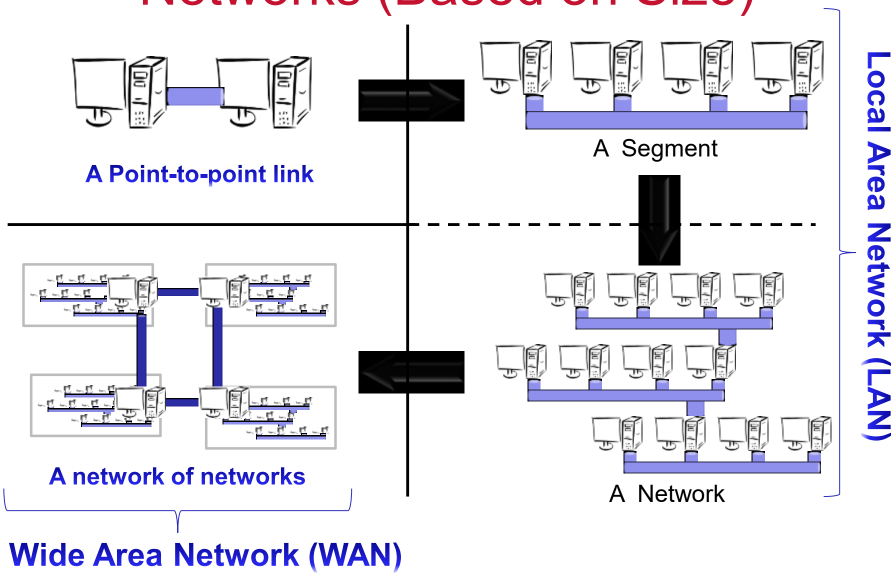
Traffic is routed from one organization to another
- Routers

Bandwidth and delay
- Varies
- Worse than a LAN

Largest WAN = Internet



# Brief Summary of Important Networks (Based on Size)




## Types of Networks – Based on Technology

### Ethernet Networks

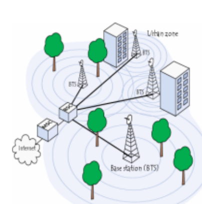
- Predominantly used in the wired Internet

### Wireless LANs

- Primarily designed to provide wireless access to the Internet
- Low-range, High-bandwidth

### Cellular networks (2G/3G)

- 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 |
| Modern Cellular | 3G | 1 – 5 km | 348 – 14.4 | 100 – 500 |

# Networking Principles

Network Protocols

Packet transmission

Network Layers

- Physical layer
- Data-link layer
- Network layer and routing
- Transport layer and congestion control

## Network Protocols

If two entities want to communicate on a network, pre-defined agreements are necessary

- How many bits should be used to signal a 0-bit or a 1-bit?
- How does the receiver know the last bit in the message?
- How can a receiver detect if the message is damaged?

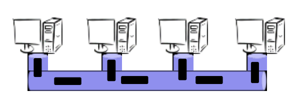
Protocol is a well-known set of rules and formats to be used for communication between the entities

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

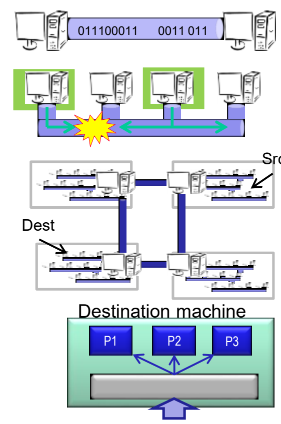
- Header: Contains meta-information about the packet
  - e.g., Length of the packet, receiver ID
- Data

# Network Layers

Network software is arranged into a hierarchy of layers
- Protocols in one layer perform one specific functionality
- Layering is a scalable and modular design for a complex software

Typical functionalities in a network software:

| Functionality | Layer |
|---|---|
| Transmit bits over a transmission medium | Physical |
| Coordinate transmissions from multiple hosts that are directly connected over a common medium | Data link |
| Route the packet through intermediate networks | Network |
| Handle messages – rather than packets – between sender and receiver processes | Transport |
| Satisfy communication requirements for specific applications | Application |



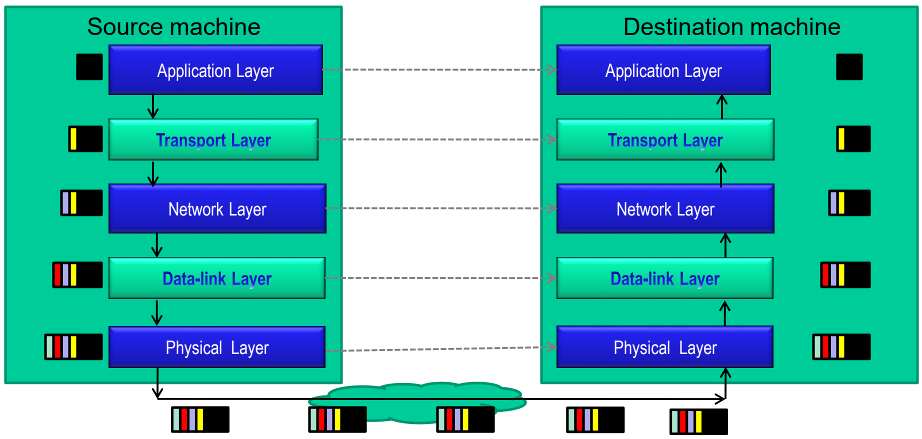

# OSI Reference Model

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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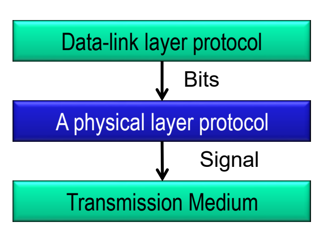
## Physical Layer

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 |



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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:

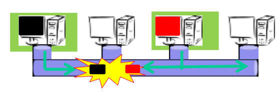
- How to coordinate between the transmitters such that packets are successfully received?
  - Coordination
- How to identify another host on the local network?
  - Addressing over local networks

## 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



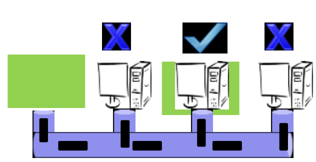
## Addressing over Local Networks

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



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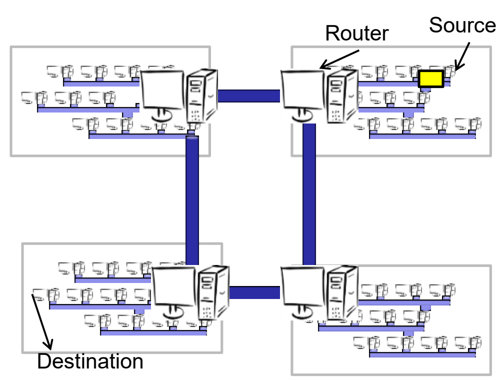
# Network Layer

Network layer protocols perform the role of routing

- Network layer protocols ensure that the 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



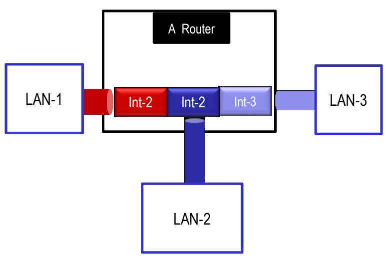
# Router

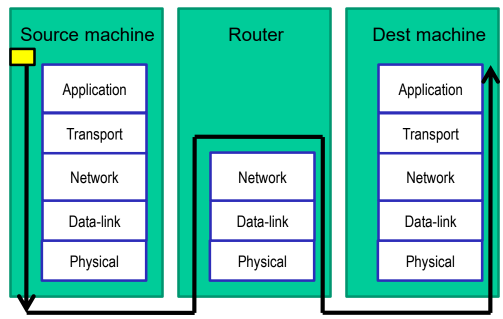
A router is a device that forwards the packets between multiple networks

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

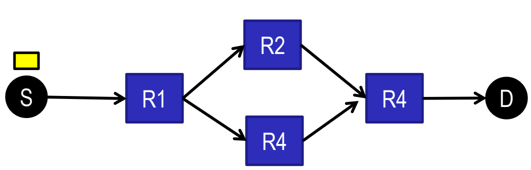
Packets have to be transmitted in a series of hops through the routers

- 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

We will study a simple routing algorithm called "Distance Vector Algorithm"

# Distance Vector Algorithm

Distance Vector (DV) uses graph theoretical algorithms to find the best route in the network

- Uses a well-known shortest path algorithm called Bellman-Ford algorithm

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

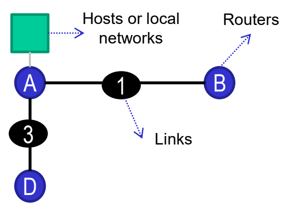
Each router maintains a routing table that consists of:

- 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 next-hop
  - e.g., cost can be the estimated as the delay for the packet to reach the next-hop

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*

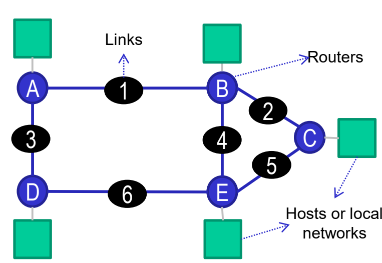
| *To* | *Link* | *Cost* |
|---|---|---|
| A | 2 | 2 |
| B | 2 | 1 |
| C | local | 0 |
| D | 5 | 2 |
| E | 5 | 1 |

*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

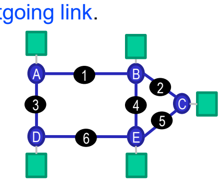
Router Information Protocol (RIP) is used for sending update messages

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 |

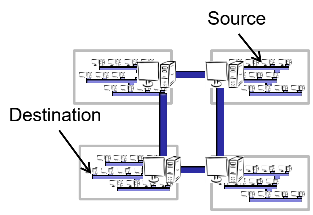
*Tr* recvd @ A from B on link n=1

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

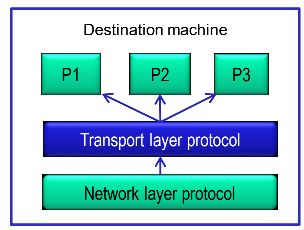
# Transport Layer

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

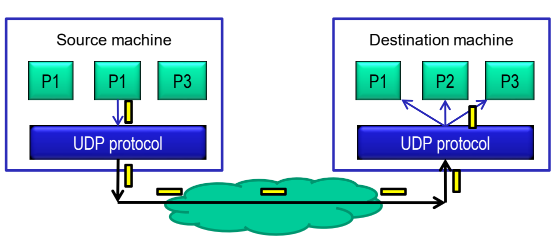



# Simple Transport Layer Protocols

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)



# Transport Control Protocol (TCP)

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

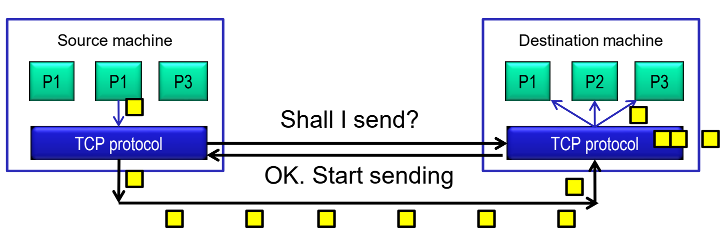
# 1. Connection-Oriented Communication

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 process

- Destination will buffer the packets until previous packets are received
- Delivers packets to the process in the order that the sender had sent



## 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?

- Packet drops at intermediate routers. No ACK received at source
- Source retransmits
- More packets build-up on router queue
- Network collapses

## 3. Congestion Control (Cont'd)

To avoid congestion, two functionalities are adopted

1. Detect congestion at routers:
   If a router expects a buffer overflow, it typically follows one of the two strategies
   - Drop packets at the router. Sources will regulate after observing packet loss
   - Send an "Explicit Congestion Notification (ECN)" packet to the sender

2. Regulate input at sources:
   If the TCP-sender concludes congestion (e.g., it receives an ECN packet), then it reduces its sending rate

## Next class

Examine Inter-process Communication in distributed systems

- Examine IPCs through Socket API and Remote Invocations
- Analyze concepts and middleware that support Message-oriented Communication

# References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