Computer Networks Lecture 01: Introduction

Course Outline

- **Textbook:** Computer Networking: A Top-Down Approach, 8th ed., Kurose & Ross
- **Grading:**
    - Attendance & participation: 5-7%
    - Assignments & quizzes: 40%
    - Midterm: 15%
    - Final: 40%
- **Join with code:** 142tcab
- **Course materials and discussions will be on MS Teams.**
- **TA:** Eng. Mohamed Essam

Chapter 1: Computer Networks and the Internet

Outline

- What Is the Internet?
- The Network Edge
- The Network Core
- Delay, Loss, and Throughput in Packet-Switched Networks
- Protocol Layers and Their Service Models

What Is the Internet?

- The Internet is a **network of networks**, with interconnected **billions of computing devices** throughout the world.
- These devices are called **hosts** or **end systems**.
- By some estimates, there were about 18 billion devices connected to the Internet in 2017, and the number will reach **28.5 billion by 2022**.
- End systems are connected by a network of **communication links** and **packet switches**.
- A **packet switch** takes a packet arriving on one of its incoming communication links and forwards that packet on one of its outgoing communication links.
- The **transmission rate** of a link is measured in **bits/second (bps)**.
- The two most prominent types of packet switches in today's Internet are **routers** and **link-layer switches**.
- The sequence of communication links and packet switches traversed by a packet from the sending end system to the receiving end system is known as a **route** or **path** through the network.
- End systems access the Internet through **Internet Service Providers (ISPs)**.
- Each ISP is in itself a **network** of packet switches and communication links.
- End systems, packet switches, and other pieces of the Internet run **protocols**.
- **Transmission Control Protocol (TCP)** and **Internet Protocol (IP)** are two of the most important protocols in the Internet.
- The Internet's principal protocols are collectively known as **TCP/IP**.
- **Internet standards** are developed by the **Internet Engineering Task Force (IETF)**.
- IETF standards documents are called **requests for comments (RFCs)**.
    - There are currently nearly 9000 RFCs.
    - Other bodies also specify standards for network components, e.g., the IEEE 802 LAN Standards Committee.

The Network Edge

- The Internet's **end systems** include desktop computers (e.g., desktop PCs, Macs, and Linux boxes), servers (e.g., Web and e-mail servers), and mobile devices (e.g., laptops, smartphones, and tablets). Furthermore, an increasing number of non-traditional "things" are being attached to the Internet as end systems.
- End systems are also referred to as **hosts** because they host (that is, run) application programs.
- Hosts are sometimes further divided into two categories: **clients** and **servers**.
- Most of the servers reside in large **data centers**.
    - For example, as of 2020, Google has 19 data centers on four continents, collectively containing several million servers.

Access Networks

- **Home Access:** DSL, Cable, FTTH, and 5G Fixed Wireless
- **Access in the Enterprise (and the Home):** Ethernet and WiFi
- **Wide-Area Wireless Access:** 3G and LTE 4G and 5G

Home Access: DSL

- When **digital subscriber line (DSL)** is used, a customer's telco is also its ISP.
- A DSL modem uses the existing telephone line to exchange data with a **digital subscriber line access multiplexer (DSLAM)** located in the telco's local central office (CO).
- The residential telephone line carries both data and traditional telephone signals simultaneously, which are encoded at different **frequencies**:
    - A high-speed downstream channel, in the 50 kHz to 1 MHz band
    - A medium-speed upstream channel, in the 4 kHz to 50 kHz band
    - An ordinary two-way telephone channel, in the 0 to 4 kHz band
- On the customer side, a **splitter** separates the data and telephone signals arriving to the home and forwards the data signal to the DSL modem.
- On the telco side, in the CO, the **DSLAM** separates the data and phone signals and sends the data into the Internet.
    - Hundreds or even thousands of households connect to a single DSLAM.
    - Downstream transmission rates of **24 Mbps** and **52 Mbps**
    - Upstream rates of **3.5 Mbps** and **16 Mbps**
    - The newest standard provides for aggregate upstream plus downstream rates of **1 Gbps**.
- DSL is designed for short distances between the home and the CO.
    - Located within **5 to 10 miles** of the CO. (1 mile=1.6 km)

Other Home Access

- **Cable Internet access** makes use of the cable television company's existing cable television infrastructure.
    - It is often referred to as hybrid fiber coax (HFC) and is a shared broadcast medium.
    - Downstream bitrates of **40 Mbps** and **1.2 Gbps**, and upstream rates of **30 Mbps** and **100 Mbps**.

- **Fiber to the home (FTTH)** provides even higher speeds is that can potentially provide Internet access rates in the gigabits per second range.
- **5G fixed wireless** promises high-speed residential access, without installing costly and failure-prone cabling from the telco's CO to the home.

Access in the Enterprise/Home: Ethernet

- A **local area network (LAN)** is used to connect an end system to the edge router. Ethernet users use twisted-pair copper wire to connect to an **Ethernet switch**.
- With Ethernet access:
  - Users typically have **100 Mbps to tens of Gbps** access to the Ethernet switch
  - Servers may have **1 Gbps to 10 Gbps** access

Access in the Enterprise/Home: WiFi

- Wireless LAN access based on IEEE 802.11 technology (**WiFi**) is now just about everywhere.
- A wireless LAN user must typically be within **a few tens of meters** of the access point.
- 802.11 today provides a shared transmission rate of up to more than **100 Mbps**.
- **e.g. home network:**
  - a roaming laptop, multiple home appliances, as well as a wired PC
  - a base station (**WiFi access point**) that communicates with the wireless PC and other wireless devices in the home
  - a **home router** that connects the wireless access point, and any other wired home devices, to the Internet.

The Network Core

- **Packet Switching:**
  - In a network application, end systems exchange **messages** with each other.
  - The source breaks long messages into smaller chunks of data known as **packets**.
  - Each packet travels through communication links and **packet switches**.
    - **Routers** and **link-layer switches**
    - A router will typically have many incident links
  - Most packet switches use **store-and-forward transmission** at the inputs to the links. That is it must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link.
  - Each packet consisting of L bits; Transmission rate is R bits/sec.
  - Sending one packet from source to destination over a path consisting of N links (N - 1 routers) each of rate R, the delay
    - *dend-to-end = NL/R* (ignoring propagation delay)
  - For each attached link, the packet switch has an **output buffer/queue**, which stores packets that the router is about to send into that link.
  - In addition to the store-and-forward delays, packets suffer output buffer **queuing delays**
    - That depend on the level of congestion in the network
  - The amount of buffer space is finite, therefore **packet loss** will occur-either the arriving packet or one of the already-queued packets will be dropped

- **Circuit Switching:**
    - Traditional **telephone networks** are examples of circuit-switched networks.
    - In **circuit-switched networks**, the resources needed along a path (buffers, link transmission rate) are **reserved** for the duration of the communication session between the end systems.
    - When two hosts want to communicate, the network establishes a dedicated **end-to-end connection** between the two hosts.
        - The sender can transfer the data to the receiver at the **guaranteed** constant rate.
    - The Internet makes its **best effort** to deliver packets in a timely manner, but it does not make any guarantees.
- **Multiplexing in Circuit-Switched Networks:**
    - A circuit in a link is implemented with either **frequency-division multiplexing (FDM)** or **time-division multiplexing (TDM)**.
    - **e.g.:**
        - FM radio stations use FDM to share the frequency spectrum between 88 MHz and 108 MHz, with each station being allocated a specific frequency band.
        - For a TDM link, time is divided into frames of fixed duration, and each frame is divided into a fixed number of time slots.
    - Circuit switching is wasteful because the dedicated circuits are idle during silent periods.
    - Establishing end-to-end circuits is complicated and requires **complex signaling software** to coordinate the operation of the switches along the end-to-end path

Delay, Loss, and Throughput

- **Overview:**
    - The physical laws introduce **delay** and **loss** as well as constrain **throughput**.
        - **Throughput** is the amount of data per second that can be transferred between end systems
    - The packet suffers from several **types of delays** at each node along the path.
        - **Processing delay** (microseconds or less)
        - **Queuing delay** (microseconds to milliseconds) (depend on the number of earlier-arriving packets)
        - **Transmission delay** is L/R (packet length L bits; R transmission rate in bps) (amount of time required to push all of the packet's bits into the link)
        - **Propagation delay** (d/s distance between two routers divided by the propagation speed) (depends on the physical medium) (milliseconds)
            - 2 × 108 meters/sec to 3 × 108 meters/sec
- **Nodal Delay:**
    - *dnodal = dproc + dqueue + dtrans + dprop*

- The contribution of these delay components can vary significantly.
  - **e.g. LAN:** *dprop* is negligible
  - **e.g. routers interconnected by a geostationary satellite link:** *dprop* is hundreds of milliseconds (dominant)
- The processing delay, *dproc*, is often negligible
  - However, it strongly influences a router's maximum throughput

- **Queuing Delay and Packet Loss:**
  - The queuing delay can vary from packet to packet (uses **statistical measures** such as average, variance, probability).
  - Queuing delay depends on:
    - The rate at which traffic arrives (a packets/sec) (assume each is L bits),
    - The transmission rate of the link (Rbps), and
    - The nature of the arriving traffic (periodically or in bursts; or random).
  - **Traffic intensity = La/R**
    - If La/R > 1 the queue will tend to increase without bound and the queuing delay will approach infinity!
  - La/R < 1: the nature of the arriving traffic impacts the queuing delay.
    - If packets arrive periodically, then every packet will arrive at an empty queue and there will be no queuing delay.
    - If packets arrive in bursts but periodically, there can be a significant average queuing delay.
      - **e.g. N packets arrive simultaneously every (L/R)N seconds, nth packet transmitted has a queuing delay of (n - 1)L/R seconds.**
  - A small percentage increase in the intensity will result in a much larger percentage-wise increase in delay.
  - Performance at a node is often measured not only in terms of **delay**, but also in terms of the probability of **packet loss**.
- **End-to-End Delay:**
  - Assume, N - 1 routers, no queuing delay: *dend-to-end = N(dproc + dtrans + dprop)*
  - **Traceroute** is a simple program, when the user specifies a destination hostname, the program in the source host sends multiple, special packets toward that destination. (graphical interface **PingPlotter**)
    - The source sends 3 × N packets to the destination.
    - As these packets work their way toward the destination, they pass through a series of routers.
    - When a router receives one of these special packets, it sends back to the source a short message that contains the **name and address of the router**.
    - The source can reconstruct the route taken by packets flowing from source to destination, and the source can determine the **round-trip delays** to all the intervening routers.

- **Additional Delays:**
  - Delay of the transmission as part of its protocol for sharing the medium with other end systems as in a **WiFi**.
  - **Packetization delay** (to fill a packet), which is present in **Voice-over-IP (VoIP)** applications.
- **Throughput:**
  - Use the **speedtest** application to measure the end-to-end delay and download throughput between a host and servers.
  - If a file consists of F bits and the transfer takes T seconds for Host B to receive all F bits, then the **average throughput** of the file transfer is F/T bits/sec.
  - We may think of bits as **fluid** and communication links as **pipes**.
  - In a simple two-link network, the throughput is *min{Rc, Rs}*, that is, it is the transmission rate of the **bottleneck link**.
  - For a network with N links between the server and the client, with the transmission rates of the N links being R1, R2, ..., RN. The throughput for a file transfer from server to client is *min{R1, R2, ..., RN}*.
  - When there is **no other intervening traffic**, the throughput can simply be approximated as the minimum transmission rate along the path between source and destination.
  - Links in the **core** of the communication network have very high transmission rates.
  - The constraining factor for throughput in today's Internet is typically the **access network**.

Protocol Layers

- **Layered Architecture:**
  - There are **many pieces** to the Internet: numerous applications and protocols, various types of end systems, packet switches, and various types of link-level media.
  - Given this **enormous complexity**, is there any hope of organizing a network architecture, or at least our discussion of network architecture?
  - A **layered architecture** allows us to discuss a well-defined, specific part of a large and complex system.
    - Each layer provides its service by performing certain actions and using the services of the layer directly below it.
    - **Modularity** makes it much easier to change the **implementation** of the service provided by a layer without affecting other components.
- **Protocol Layering:**
  - Network designers organize protocols in **layers**.
  - A protocol layer can be implemented in software, in hardware, or in a combination of the two.
    - **Application-layer** protocols are almost always implemented in software and so are **transport-layer** protocols.
    - The **physical layer** and **data link layers** are responsible for handling communication over a specific link, they are typically implemented in a network interface card.
    - The **network layer** is often a mixed implementation of hardware and software.
  - Potential **drawbacks** of layering is that one layer may duplicate lower-layer

functionality and the functionality at one layer may need information that is present only in another layer.

- The **application layer** is where network applications and their application-layer protocols reside.
  - With the application in one end system using the protocol to exchange packets of information (called **messages**) with the application in another end system.
    - **e.g. HTTP, SMTP, FTP, DNS**
- The **transport layer** transports application-layer messages between application endpoints. (a transport-layer packet is refered as a **segment**)
  - The **UDP protocol** provides a connectionless service to its applications.
  - **TCP** provides a connection-oriented service to its applications: guaranteed delivery; flow control; congestion-control.
- The **network layer** (IP layer) is responsible for moving network-layer packets known as **datagrams** from one host to another.
  - IP protocol defines the fields in the datagram as well as how the end systems and routers act on these fields.
  - This layer contains **routing protocols** that determine the routes that datagrams take between sources and destinations.
- The **link layer** delivers the datagram to the next node along the route. At this next node, the link layer passes the datagram **up** to the network layer.
  - A datagram may be handled by **different** link-layer protocols at different links along its route.
  - The link-layer packets are refereed as **frames**.
    - **e.g. Ethernet, WiFi**
- The job of the **physical layer** is to move the **individual bits** within the frame from one node to the next.
  - Depends on the actual transmission medium of the link.
    - **e.g. Ethernet** has many physical-layer protocols: one for twisted-pair copper wire, another for coaxial cable, another for fiber, and so on.

- **Encapsulation:**
  - The transport layer takes the **message** and appends additional information. The **transport-layer segment encapsulates** the application-layer message.
  - The network layer adds network-layer header information such as source and destination end system addresses, creating a **network-layer datagram**.
  - The datagram is then passed to the link layer, which (of course!) will add its own link-layer header information and create a **link-layer frame**.

Summary

- What Is the Internet?

- The Network Edge
- The Network Core
- Delay, Loss, and Throughput in Packet-Switched Networks
- Protocol Layers and Their Service Models