Computer Networks: Chapter 1 Summary

Author: Shun (@shun4midx)

Basic Definitions

Overview

The internet is a "network of networks" **(Interconnected ISPs, i.e. Internet Service Providers)**, where a **network** is a collection of devices, routers, and links *managed by an organization*

- **Hosts** = End systems
- **Packet Switches** = Forward packets (chunks of data), e.g. *routers, switches*
- **Communication Links**: E.g. *fiber, copper, radio, satellite*; **transmission rate** = *bandwidth* in bps
- **Internet Services**: **Infrastructure** to provide services to apps (e.g. web, email, streaming, etc), **programming interface** such as *hooks* to "connect" and *service*

Protocol

Protocols define the **format, order** of **messages sent and received** among network entities, and **actions taken** on message transmission, receipt.

Network Edge

Access Networks

Access networks are how end systems connect to **edge routers**.

- **HFC** (Hybrid Fiber Coax): A network of *fiber* (to the **neighborhood node**) and *shared coax* (to homes) attaches homes to the ISP router at the **cable headend**; Higher downstream transmission compared to upstream
  - Uses **cable-based access** via **FDM** (frequency division multiplexing), i.e. different channels are transmitted in different frequency bands
- **DSL** (Digital Subscriber Line): Uses existing *telephone line* to central office **DSLAM** (Data connects to internet, voice connects to telephone net); Higher downstream transmission compared to upstream

There are two main kinds of **wireless access networks** that connect end systems to router:

- **WLANs** (Wireless Local Area Networks): Typically within or around building, e.g. *Wi-Fi*. Can have low or high transmission rates.
- **Wide-Area Cellular Access Networks**: Provided by *mobile, cellular network operator*, typically medium transmission rate (around **tens of Mbps**), e.g. *4G/5G cellular networks*

Examples of Access Networks

- **Home Access:** DSL, HFC/Cable
- **Wide-area Wireless:** 4G LTE, 5G NR.

Local Networks (LANs, Inside Premises)

- **Home LAN:** Wi-Fi + Ethernet switch + NAT/firewall (often one gateway).
- **Enterprise LAN:** Switched Ethernet access + Managed Wi-Fi.

Physical Media Links

Physical Media Links

A **physical link** is what lies between transmitter and receiver

- **Guided**: Signals propagate in **solid media**, e.g. *twisted pair/TP* (two insulated copper wires), *coaxial cable* (bidirectional, two concentric copper conductors), *fiber optic cable* (high speed operation, low error).
- **Unguided**: Signals propagate **freely**, e.g. **radio**, such as *Wi-Fi, wide-area, bluetooth, terrestrial microwave, satellite*

Network Core

Packet Switching and Circuit Switching

There are two key network-core functions:

- **Forwarding** (i.e. *switching*): *Local*, moves packets from router's input link to output link
- **Routing**: *Global* action, determines best paths taken by packets

Packet vs. Circuit Switching

Packet switching: Messages $\rightarrow$ packets; each hop does *store-and-forward*. It **queues** your desired packets into a buffer whenever **arrival rate $>$ transmission rate**.

- **Pros**: Efficient sharing, good for bursty traffic, no call setup.
- **Cons**: Queueing delay, possible loss under congestion.

Circuit switching: End-to-end resources reserved for **call between source and destination**, i.e. you posses the entire line at a time.

- **Pros**: Predictable performance.
- **Cons**: Idle when unused, setup overhead.

Example Calculation

Problem: Say we have a 1 Gb/s output link, and each user uses 100 Mb/s when active. Each user is active around 10% of the time. How many users can use this network under circuit-switching and packet-switching?

Circuit-Switching: Each user possesses the *entire line at a time*, so $\frac{1\text{Gb/s}}{100\text{Mb/s}} = \boxed{10 \text{ users}}$

Packet-Switching: Say there are 35 users, then by binomial distribution, the probability that **more than 10** (maximum amount which we can share) are active at the same time is less than 0.0004. This means, we can hold 35 users with only 0.0004 of the data not being able to be sent.

Internet Structure

Intuitively, the reasoning is we require all hosts to be able to interconnect with each other, with as few connections as possible. As we cannot have one big global ISP (**Internet Service Provider**) in practice, we end up creating **several ISPs**, including *regional ISPs* and other **"tier-1" commercial ISPs**, e.g. *AT&T, NTT*, which regional ISPs connect to. Then, we interconnect them with **IXPs (Internet Exchange Points)**. Otherwise, a **content provider network** (e.g. Google), which is a private network, connects its data center to the Internet, often **bypassing most ISPs**. Hence why we say the internet is a *"network of networks"*.

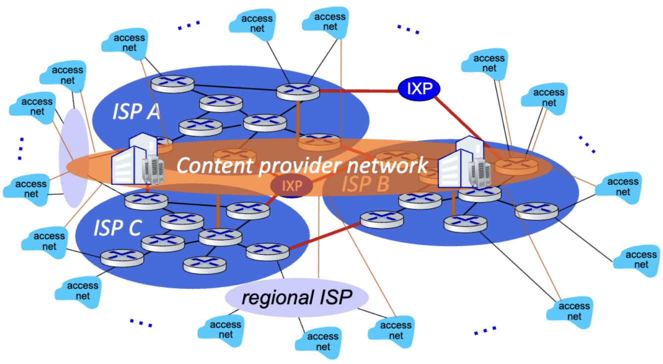


Figure 1: A visual for internet structure.

Performance Loss: Delay and Throughput

Packet Delay

There are four main types of packet delay, as better shown in the figure below.

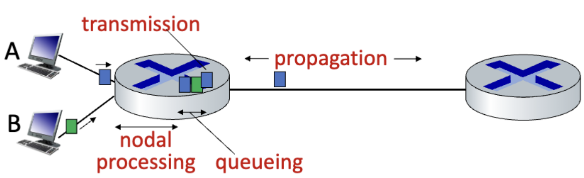


Figure 2: Depiction of the four main sources of packet delay

Packet Delay Formula

In general, we have:

$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- **Nodal Processing *(Const)*:** When checking bit errors and determining *output link*; typically within *microsecs*
- **Queueing Delay:** Time waiting at output link for transmission, depends on the congestion level of the router
- **Transmission Delay:** $d_{\text{trans}} = \frac{L}{R}$, L = *packet length (bits)*, R = link *transmission rate (b/s)*
- **Propagation Delay *(Const)*:** $d_{\text{prop}} = \frac{d}{s}$, d = *length of physical link*, s = *propagation speed* ($\approx 2 \times 10^8$ m/s)

Traffic Intensity (Packet Queueing Delay)

Define a as the average packet *arrival rate*, L as the packet length in bits, and R as the link bandwidth (bit transmission rate). We define the **traffic intensity** as follows:

$$\frac{L \cdot a}{R} = \frac{\text{arrival rate of bits}}{\text{service rate of bits}}$$

Usually, traffic intensity could tell us certain info as follows:

- $\frac{La}{R} \approx 0$: average *queueing delay is small*
- $\frac{La}{R} \to 1$: average *queueing delay is large*
- $\frac{La}{R} > 1$: work arriving $>$ servicable work $\Rightarrow$ infinite delay!

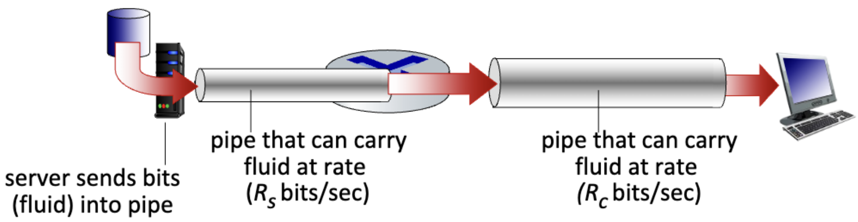
In real life, we can use `traceroute <website>` in the terminal to measure internet delay. It will output the time elapsed for each (publically accessible) step required, to reach said website.

Throughput

Throughput Definition

Throughput is defined as the **rate** (bits/time) at which bits are being **sent** from sender to receiver.

In practice, R_c or R_s, as demonstrated below, is the bottleneck. In extreme cases, R/(number of shared connections) may be the bottleneck. **The bottleneck is the minimum rate R**.



Network Security

The main takeaway is the Internet was designed **without considering adverseries**, so it's **prone to attacks**.

Types of Attacks

- **Denial of Service (DoS):** Overwhelm resources to block service
- **Packet Sniffing:** Reads all packets (including passwords) in a network
- **Spoofing:** Injection of packet with false sourcce address

Countermeasures

- **Cryptography:** Encryption, authentication
- **Integrity Checks:** Signatures to prevent and detect tampering
- **Firewalls** to avoid DoS attacks and filter incoming packets

Protocol Layers and Reference Models

Layering Principle: Modular design; each layer offers services to the layer above and relies on services from the layer below. Then, change in layer service implementation is isolated from other layers.

Internet (TCP/IP) model: 5 layers

1. **Application:** Supports network applications (e.g. *HTTP, IMAP, SMTP, DNS*)
2. **Transport:** Process-to-process data transfering (e.g. *TCP, UDP*)
3. **Network:** Routes datagrams from source to destination (e.g. *IP, routing protocols*)
4. **Link:** Transfers data between neighboring network elements (e.g. *Ethernet, Wi-Fi, PPP*)
5. **Physical:** bits "on the wire"

Encapsulation

As data travels down the stack, each layer **adds a header**. As data travels up, each layer **removes its header**. This crates a **link-layer frame** via what we call **encapsulation**.