Computer Networking

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0 Front Matter

Notes on computer networking.

0.1 Schedule

Week of	Monday	Wednesday	Readings	Assignments
01/02/23	**No Class**	[Introduction and Overview]	1.1, 1.3, 1.4	A1 Out
01/09/23	[Protocol Layering]	[HTTP and the Web]	1.5	
01/16/23	**No Class**	[DNS and CDN]	2.2, 2.4	
01/23/23	[Video Streaming and Cloud Systems]	[Transport Layer]	2.6, 3.1, 3.2, 3.3, 3.4	A1 Due, A2 Out
01/30/23	[TCP Basics]	[Flow and Congestion Control]	3.5, 3.6	
02/06/23	[More Congestion Control]	[Network Layer and IP]	3.7, 4.1, 4.3.1, 4.3.2, 4.3.5	
02/13/23	[IP Routers]	[*Midterm Review*]	4.2	

Week of	Monday	Wednesday	Readings	Assignments
02/20/23	**No Class**	**MIDTERM**		A2 Due
02/27/23	**No Class**	**No Class**		A3 Out
03/06/23	[Routing Fundamentals]	[Intra-AS Routing]	5.1, 5.2, 5.3	
03/13/23	[IP Addressing and Inter-AS Routing]	[BGP]	4.3.3, 5.4	
03/20/23	[Software-Defined Networking]	[Link Layer]	4.4, 5.5, 6.1, 6.3	A3 Due, A4 Out
03/27/23	[Switched LAN]	**No Class**	6.4	
04/03/23	[Wireless Networking]	[Datacenter Networking]	6.6, 7.1, 7.2, 7.3	
04/10/23	[*Final Review*]	**No Class**		
04/17/23	**No Class**			A4 Due
04/21/23	**FINAL**			

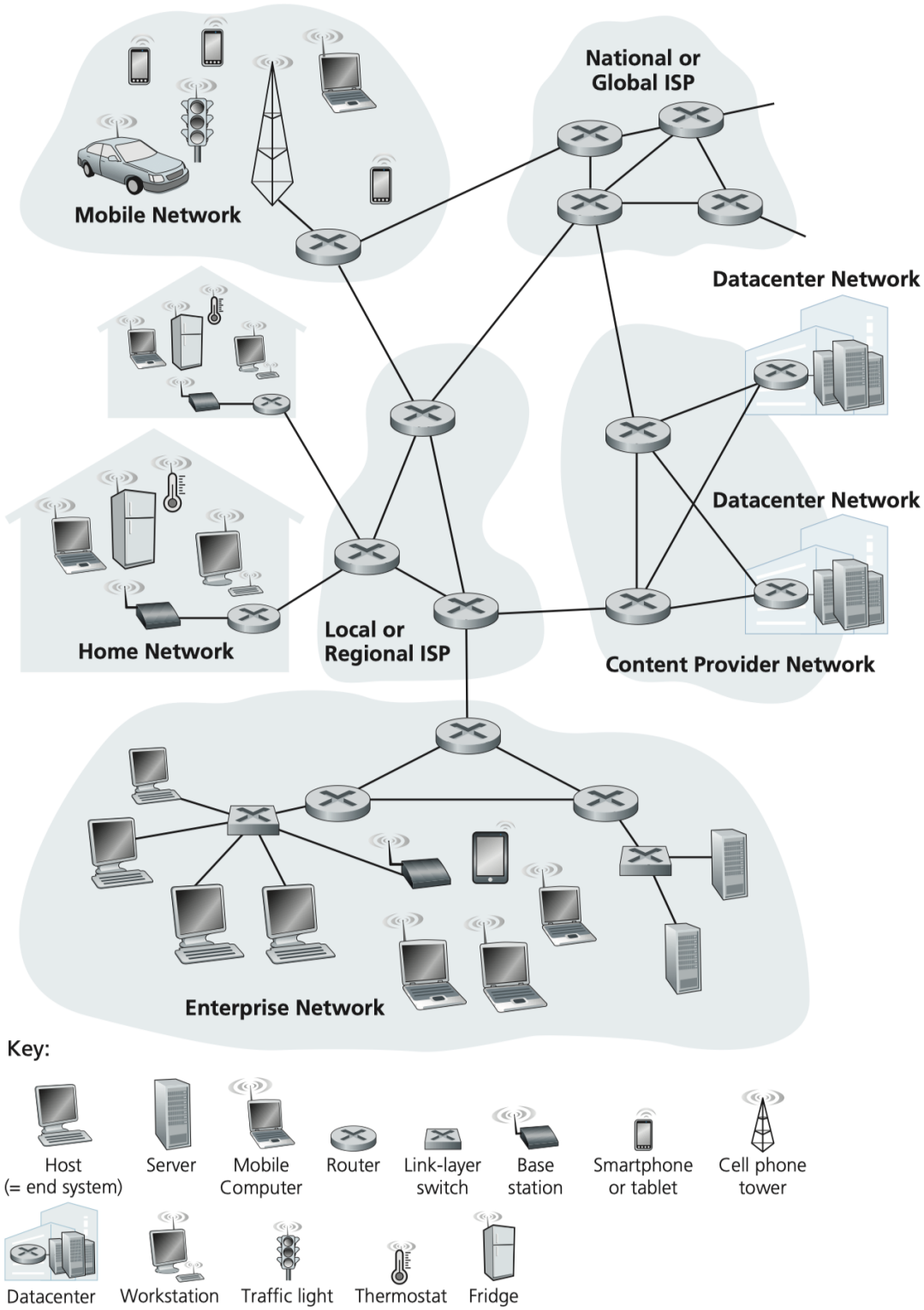
0.2 Motivating Questions

- If I get to design the internet, what would I do?
- What happens when I type an URL into a browser?
- What happens when I search on Google?
- How does p2p downloading work, and how do people get caught pirating with p2p?
- How do I mess with the website of my high school?
- How does TCP/IP work?
- To what extent can my privacy be at risk on the internet? How?
- How does VPN work?
- How does the GFW work, and how to bypass it?
- What does it take to build a social networking protocol?

0.3 References

- [KR] *Computer Networking: A Top-Down Approach, 8th Edition*, Kurose and Ross, 2020.
- [PD] *Computer Networks: A Systems Approach, 6th Edition*, Peterson and Davie, 2021.

1 Computer Networks and the internet



1.1 What is the internet?

1.1.1 Nuts n bolts definition

- a computer network that interconnects billions of computing devices (**Hosts/end systems**) throughout the world.

- End systems are connected together by a network of **communication links** and **packet switches**.
  - Communication links examples: copper wire, optical fiber, radio spectrum.
  - A packet switch takes packets from one of its communication links to another. Eg. routers (in the network core), link-layer switches(like wifi router and modem).
- **Packet**: segment of data with header sent and reassembled.
- End systems access the Internet through **Internet Service Providers (ISPs)**. Each ISP is in itself a network of packet switches and communication links.
  - Eg. local cable company, university ISPs
  - Eg. lower-tier ISPs are interconnected by upper-tier ISPs such as AT&T
- End systems, packet switches, and other pieces of the Internet run **protocols** that decides how they talk to each other
  - Eg. **TCP/IP**

1.1.2 Service definition

- an infrastructure that provides services to applications running on end systems
  - eg. supports sending email, browsing web, streaming videos

1.2 The network edge

- Access networks: networks that connect end systems to the first router
  - mobile network: 5G phone -> cell tower -> ISP router
  - Enterprise network
  - Home network: TV -> modem -> ISP router
  - Datacenter network
  - Empowered by physical media
    - eg. cables, radio channels, fiber optics
- The internet puts most of its complexity in its periphery

1.3 The Network Core

- Def. The mesh of packet switches and communication links that interconnects the access networks
- Two ways of moving data through networks: packet switching and circuit switching
  - packet switching is simpler and has more transmission capacity.

1.3.1 Packet Switching

- Packet switches uses **store-and-forward transmission**
  - packet switches must receive the entire packet and process it before it forwards its first bit to the outbound link.
- The packets are pipelined through the path because of store-and-forward
  - The delay of sending P packets of L bits each over a path of N links each of rate R is $d = (N+P-1)L/R$
- Since it takes time to put packets onto the link, routers have **output buffers** that stores packets before they are sent out.
  - When the buffer is full, the **packet loss** occurs
- Routers figures out where a packet should go via a **forwarding table**, which maps (portions of) the destination IP address to the router's outgoing link
  - The forwarding table is set automatically by **routing protocols**.

1.3.2 A network of networks

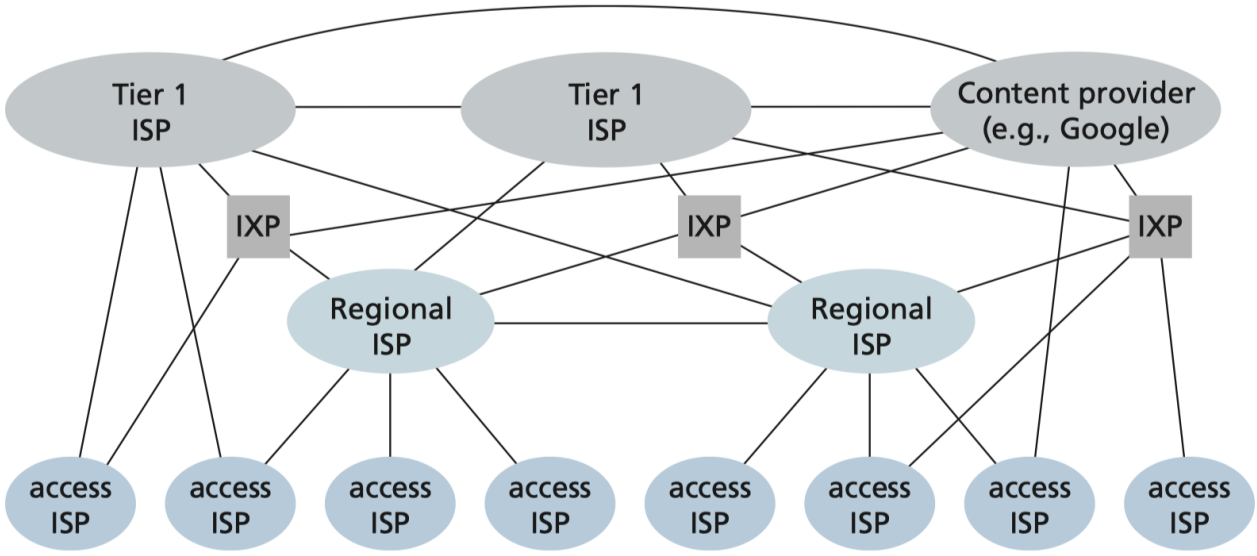


Figure 1.15 ♦ Interconnection of ISPs

1.4 Delay, Loss, and Throughput

1.4.1 Types of delay

- Processing delay: time to process the packet at the router
  - microseconds or less
- Queuing delay
  - microseconds to milliseconds
- Propagation delay: time for the packet to travel on the link
  - milliseconds in wide area networks
- Transmission delay
  - `# bits / transmission rate`
- **Total nodal delay** is the sum of the four above.
  - Its exact composition can vary significantly

1.4.2 Queueing delay

- Depends on the rate at which packets arrive at the queue, the transmission rate of the link, and the nature of the traffic.
- Estimated by **traffic intensity**.
  - Suppose that the packets arrive at the queue at a bits/sec, all packets consist of L bits, and the transmission rate of the link is R bits/sec. The traffic intensity is aL/R.
  - If $aL/R > 1$, the queue will grow without bound
- Typically, the arrivals to a queue do not follow any pattern. So, queueing delay grows exponentially with the traffic intensity.

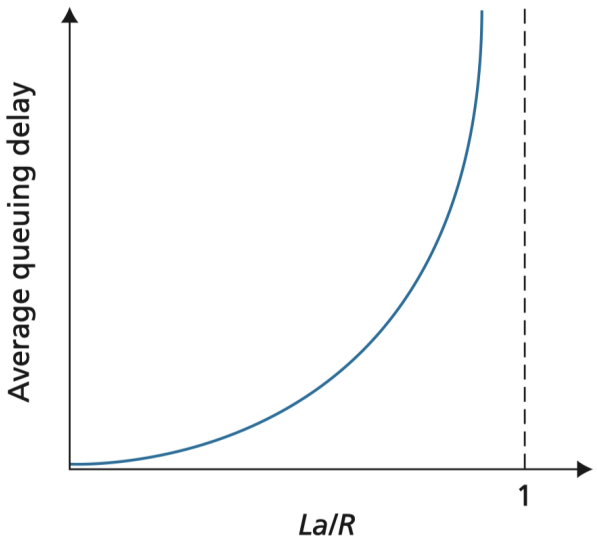


Figure 1.18 ♦ Dependence of average queuing delay on traffic intensity

1.4.3 Throughput

- 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.
- more generally the throughput depends not only on the transmission rates of the links along the path, but also on the intervening traffic.

1.5 Protocol layers and their service models

- Network protocols are organized in layers.
- Each layer provides a service (**service model**) to the layer above it and uses the service of the layer below it.
- A protocol layer can be implemented in software or hardware or both.
- A layer n protocol distributed among the end systems, packet switches, and other components that make up the network.

1.5.1 Internet protocol stack

^
Application
Transport
Network
Link
Physical

- **Application layer**: where network applications and their protocols reside
  - Eg. HTTP, FTP, DNS, SMTP
  - **Message**: application layer packet
- **Transport layer** transports messages between applications
  - Eg. TCP, UDP

  - **Segment**: transport layer packet
- **Network layer** routes segments between hosts
  - Eg. IP, routing protocols
  - **Datagram**: network layer packet
- **Link layer** delivers datagrams from one node (host or router) to another
  - Eg. Ethernet, WiFi
  - **Frame**: link layer packet
- **Physical layer** moves bits within the frame from one node to another
  - Eg. copper wire, optical fiber, radio spectrum

1.5.2 Encapsulation

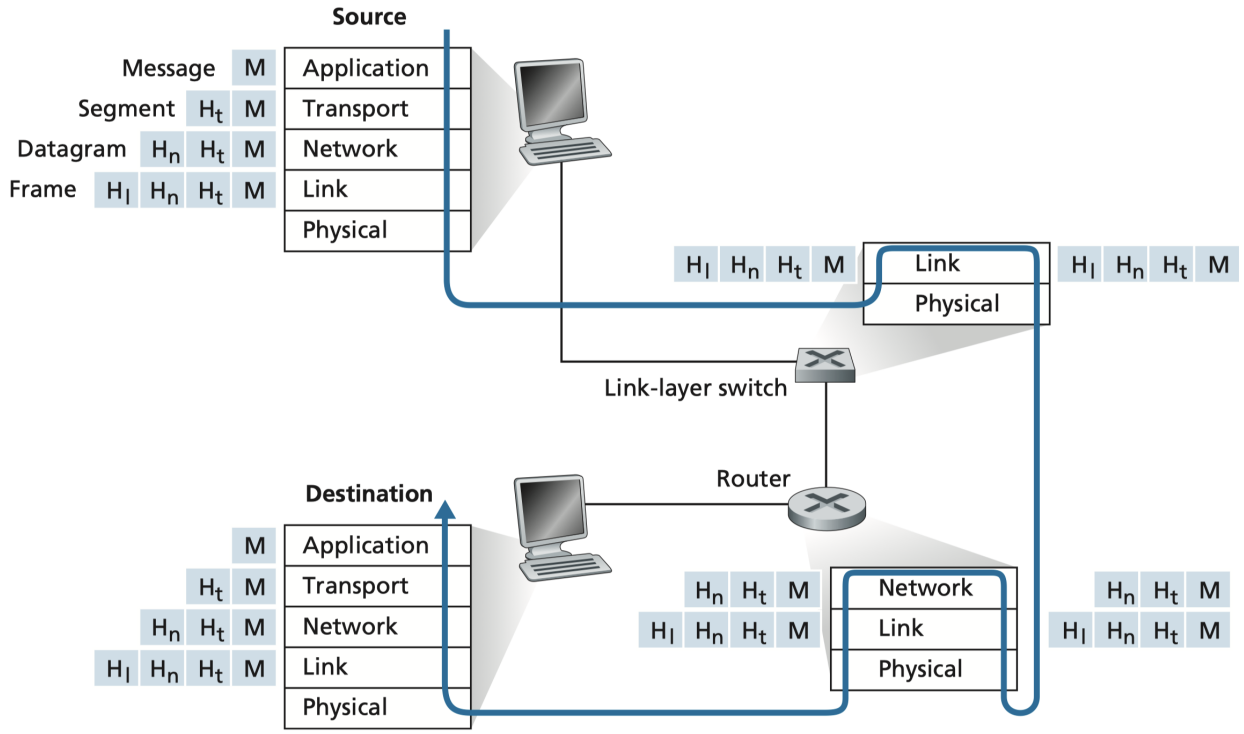


Figure 1.24 ♦ Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality

- Link-layer switches and routers
  - both only implement the bottom layers
  - Routers implement the network layer but link-layer switches do not
- At each layer, a packet has two types of fields: header fields and a **payload field**. The payload is typically a packet from the layer above.