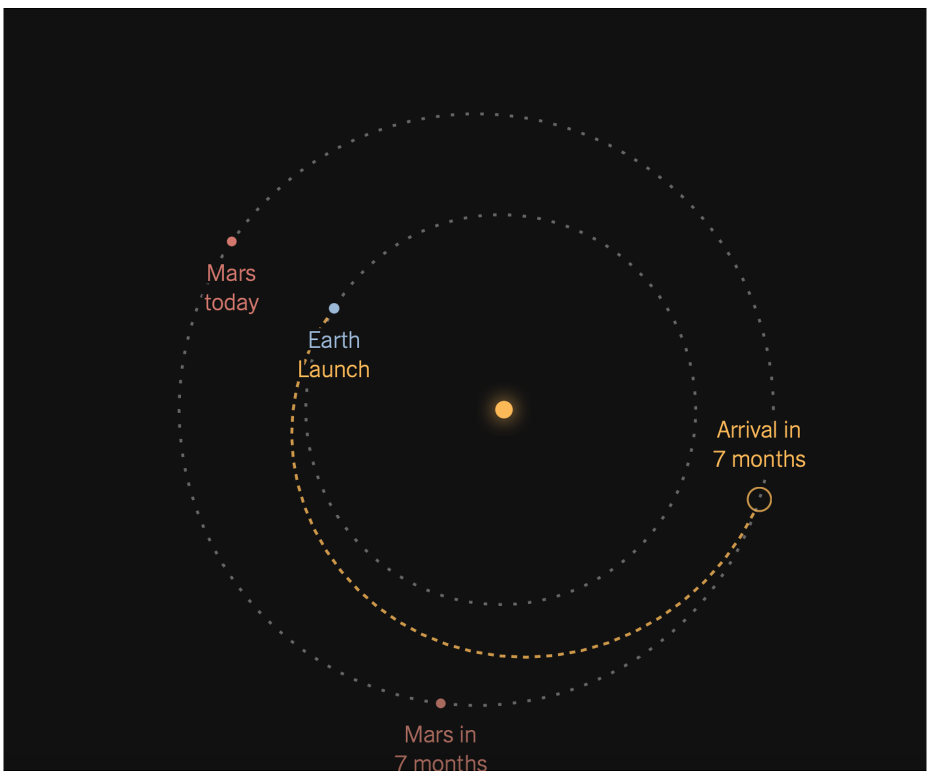
Class Notes

Textbook reading: Please start reading the textbook. In two weeks, we need to finish chapter 1.

Book author also has recorded videos if you wish to see them.

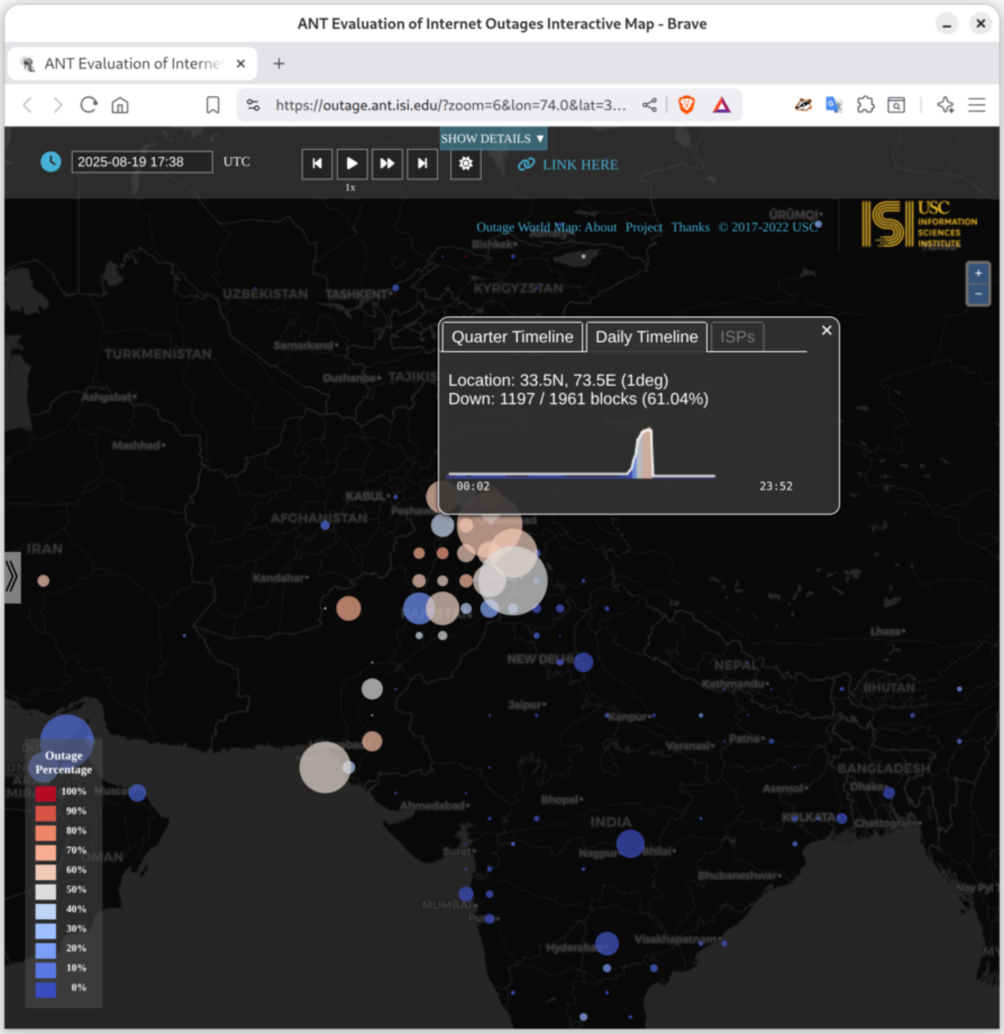
When done reading section 1.1 of book, see video: https://youtu.be/74sEFYBBRAY
When done reading section 1.2 of book, see video: https://youtu.be/k8NmM-hImBU
When done reading section 1.3 of book, see video: https://youtu.be/f1nUcCdQJ8Y
When done reading section 1.4 of book, see video: https://youtu.be/hm1y4LsphQQ
When done reading section 1.5 of book, see video: https://youtu.be/IZ_PnVXtMeY
When done reading section 1.6 of book, see video: https://youtu.be/yukwBqSwAkg
When done reading section 1.7 of book, see video: https://youtu.be/l4q8iuqbuiQ
When done reading section 1.8 of book, see video: https://youtu.be/-YaGGf8C1A4

Understand grave implications of distance between communicating entities:
Read the following cool article by New York Times
(https://www.nytimes.com/interactive/2025/01/30/science/mars-landing-trump.html)



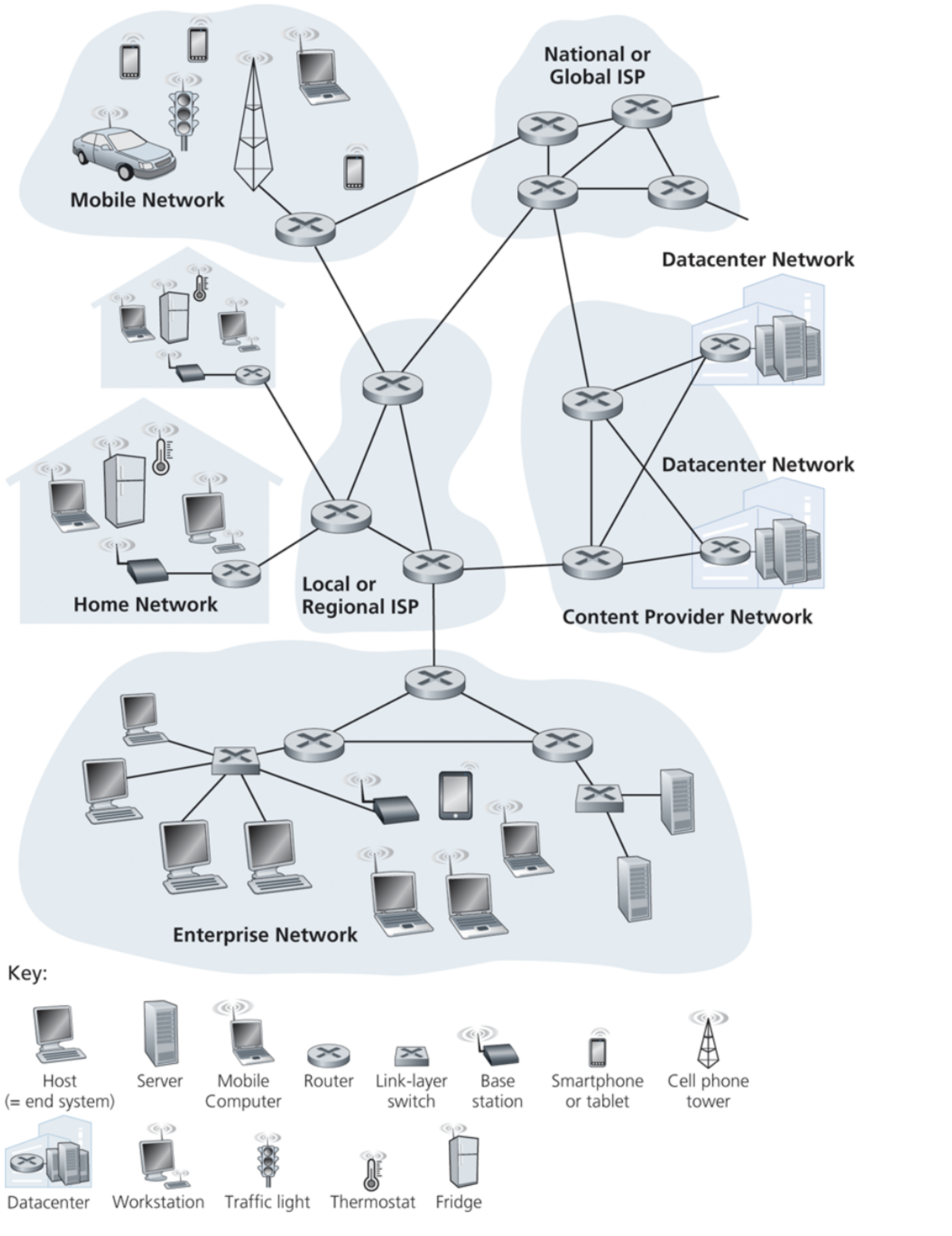
Also note: Good pictures and animations make it easy to get your point through. I expect students to try their best in their presentations instead of coming with slides full of text and reading it out!

Pakistan's Internet outage this week was observed worldwide. Here is a blog entry.
https://ant.isi.edu/blog/?p=2256



Internet is one of the largest human artifacts. It is amazing to watch and observer such a huge system in operation for interesting events and insights. Above work is by Prof. John Heidemann and his Ph.D. students using a tool called Trinocular.

Layer-2 Switch VS Layer-3 Switch (Direct delivery VS Delivery via the IP):



Source: Figure 1.1 from the textbook

FAST is networked using L2 switches (probably Ethernet Switches) internally. Only traffic going outside FAST goes though a router at the edge of FAST campus.

So two computers should not need to use network layer routing (L3).

Simple experiment: Login to two machines in a lab. See what are their IPs. From one machine traceroute to the other. What do you see? (Before conducting the experiment, carefully think what is your expected result. Only then conduct the experiment. Does the actual result match what you though should happen? Why or why not?)

An aside: The traceroute program sends IP packets with remaining hop-count from 1,2, and so on. So when an IP packet reaches first router with hop-count 1, that router decrements it (and that hop count becomes 0). Now because that hop-count became 0, router does not forward the backet. Rather drops the packet and instead sends the source back a special ICMP packet telling about such happening. In next round, trace route program sends in packet with hop count = 2. Not it can make up to the second router and so on.

See Request For Comments (**RFC**) no 1393 for more details if you are interested. https://www.rfc-editor.org/rfc/rfc1393.html
(RFCs are official documents of Internet Engineering Task Force (**IETF**) whose task is to standardize many of the Internet's protocols, and other mandate such as Internet evolvability in an operable manner)

STOP: Don't read the text in the following box until you do the above experiment yourself.

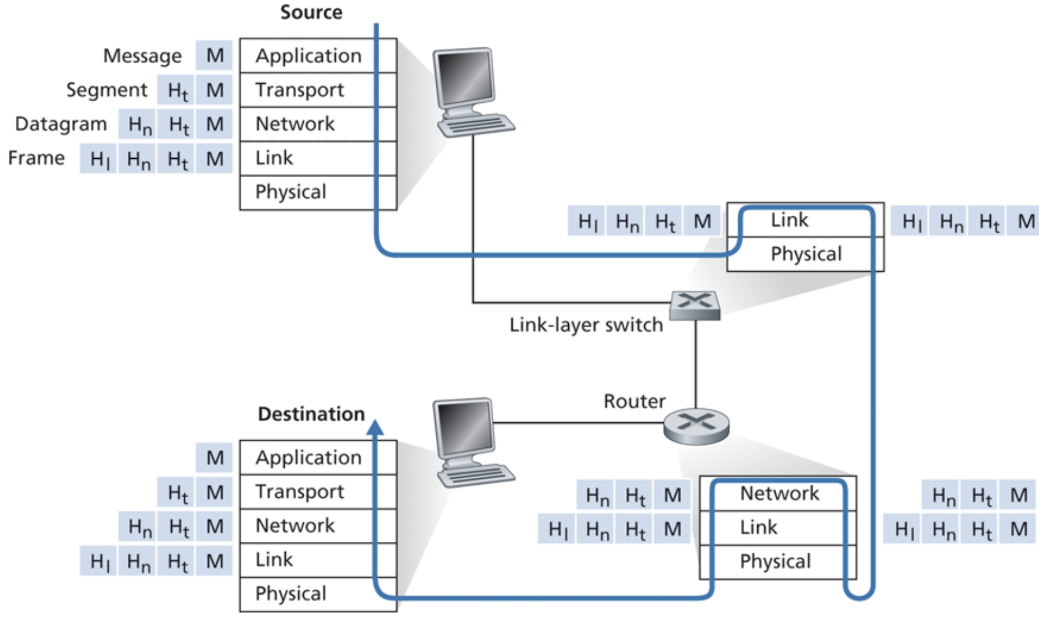
I ran a quick experiment in my office, from my laptop to the desktop computer in my room. Both were connected to the same network. I tracerouted desktop from the laptop, and the results were as follows:

```
C:\Users\abdul>tracert 2401:ba80:a181:dc09:d47a:248a:3bb7:3ed

Tracing route to 2401:ba80:a181:dc09:d47a:248a:3bb7:3ed over a maximum of 30 hops

  1    33 ms     3 ms     2 ms  2401:ba80:a181:dc09:d47a:248a:3bb7:3ed

Trace complete.
```

So trace route is telling me that my destination is just one hop away from my laptop. That means, there was no L3 switch (called a router) involved. Packets of traceroute were able to go through using just the L2 direct delivery!

Encapsulation and its overhead:

Service model: To provide service to layer (n+1), layer n does some work, and uses the services provided by the layer (n-1).



Source: Figure 1.24 from the textbook

See a **demo** in the Wireshark and calculate the overhead of encapsulation.

Read section 1.5 of the book and see the video: https://www.youtube.com/watch?v=IZ_PnVXtMeY

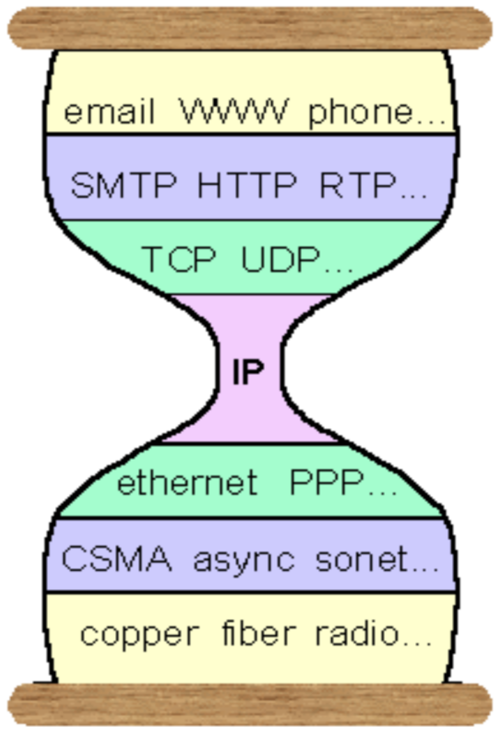
There are cool animations of above picture in the slides (I already uploaded in GCR) and in the above video.

The narrow waist of the Internet:

The IP layer (network layer) is special in the TCP/IP stack, and it is one of the major reasons for the Internet's success.

- If you have a brilliant app idea, you don't have to get anyone's permission. You can just build your app (client/server etc.) and try it out. Internet will route your app's data. No change needed in the network core!

- If you are a hardware vendor and making a new kind of network. Great you are free to do so, as long as your new network technology is able to carry through the IP packets.
- Huge innovation on both ends of the spectrum (apps, hardware) due to stability provided by the IP layer.



Source: Steve Deering Presentation: Watching the narrow waist of the Internet
https://www.ietf.org/proceedings/51/slides/plenary-1/sld002.htm

More about Delays (Latency)

Processing delays:

- Time taken by a router to decide on which egress (outgoing) port a packet should go
- Difference between routing and forwarding

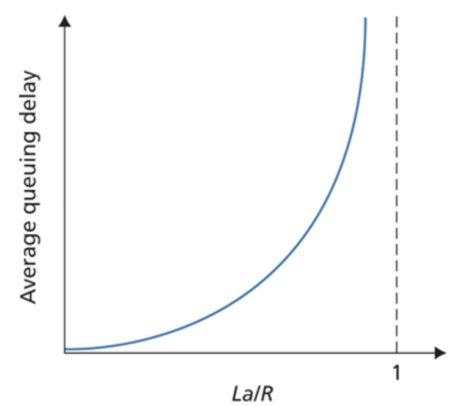
Queuing delays:

- A huge topic for research, and a body of study called queuing theory

- Applicability at a lot of places in real life (super market check outs, bank tellers, roads, networks, etc.)

- Traffic intensity:
    - Let a be the average rate of packet arrival at some router in packets per second
    - Let R be the transmission rate in bits per second
    - Let's assume (for simplicity) that all packets coming at the router are of equal size, size of each packet being L bits
    - Average rate of arrival of bits at the router = L*a bits per second
    - Ratio: L*a/R is traffic intensity
        - If traffic ration is consistently > 1 (meaning more data coming in than a router can process and transmit (push out)). A very bad situation!
        - If L*a/R <= 1, then queuing delay depends if traffic is periodic (say a packet comes in every L/R seconds) or as a burst of traffic. A burst will experience more delays.
    - In real life traffic is random and traffic intensity alone is usually not sufficient to understand or estimate delays. But still traffic intensity is a good approximation.

Figure 1.18 **Dependence of average queuing delay on traffic intensity**



Source: Textbook figure 1.18

Queueing delays shoot up rapidly as traffic intensity approaches 1

- In the above simple model we assumed buffers at the router has infinite capacity. But in reality router buffers are of finite size (again an area of research that what is an appropriate size for a router buffer). Once buffer fills up, packet loss is inevitable.

Space-time diagrams for end-to-end latency:

Problem: Compare the total delay in sending **x bits** of user data over a **k-hop path** in a circuit-switched network and a packet-switched network. Here, the total delay is defined to be the time from the data starts to be delivered to the network till all the data bits have been received at the end of the path. For the packet-switched network, it is assumed that the network is lightly loaded and the queuing delay at each switching node is ignored, and in addition, the packet header size is ignored. For both networks, there is no loss. The circuit setup time is **s second**, the **propagation delay is d second per hop**, each **packet contains p data bits**, and the **bit rate of the line on each hop is b bps**.

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1) What is the total delay, if the message is sent over the circuit-switched network?

2) What is the total delay, if the message is sent over the packet-switched network?

3) Under what condition does the packet-switched network have a lower delay?

Solution:

Some info to jog your memory about circuit and packet switching:

Circuit switching is a switching technique for communication networks. Circuit switching creates a direct physical connection/path between two devices. The transmission capacity on the path is exclusively reserved for the connection.

Packet switching is a switching technique for communication networks. In packet switching, each packet has a header providing an address to identify the destination. In the network, packets are switched in the store-and-forward manner, i.e., at each node, packets are received and stored, before being forwarded to the next hop.

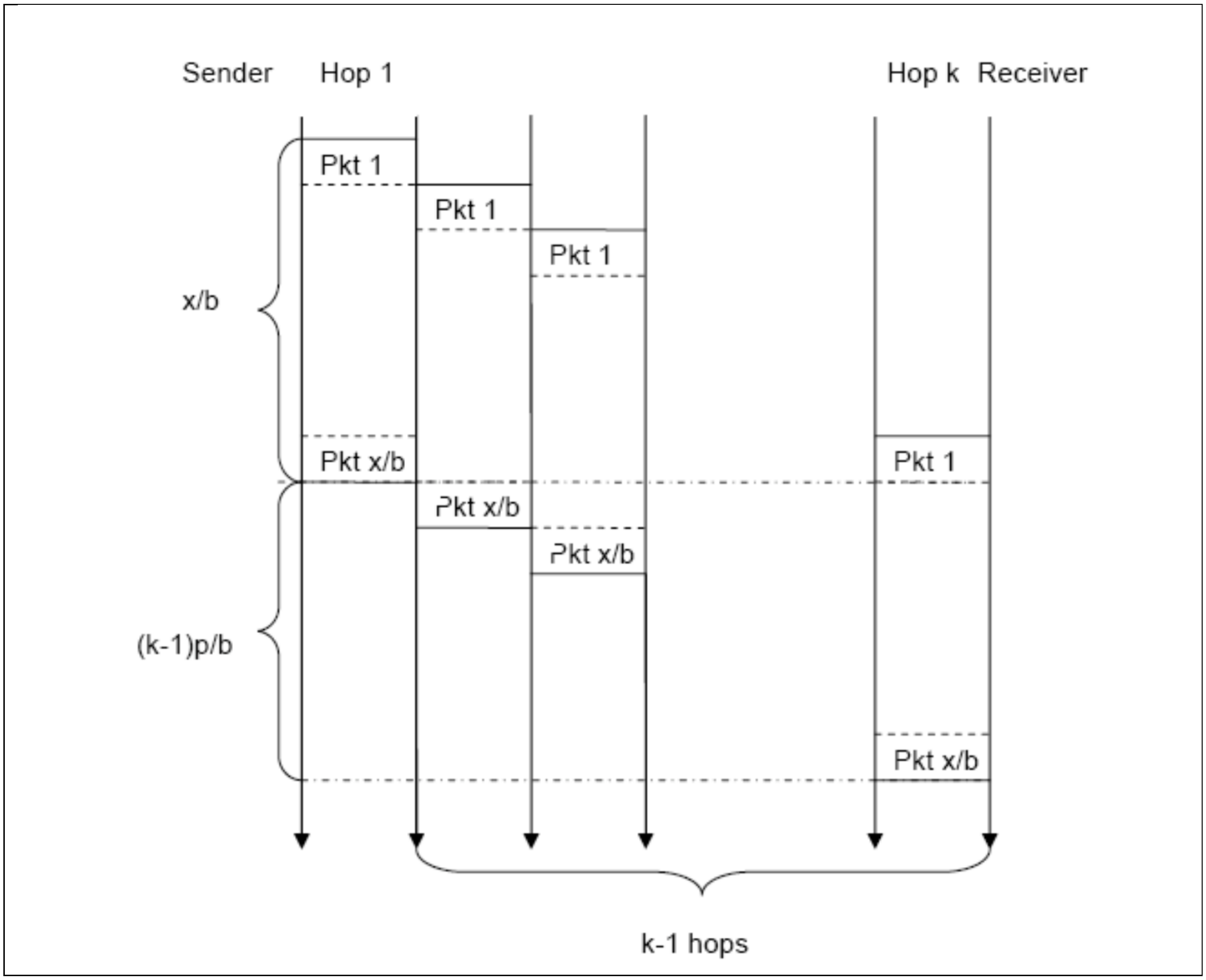
(c) Circuit switching requires a connection setup, while packet switching may not have the setup process. (ii) Packet switching uses store-and forward transmission, while with circuit switching, the bits just flow through the path continuously. (iii) Circuit switching is completely transparent to the sender and receiver, and they can use any bit format or framing method they want to. But, with packet switching, packets have special formats in assembling bits or frames. (iv) In circuit switching, the transmission capacity on a path is dedicated to the corresponding connection, while in packet switching, the transmission capacity on a link is shared by packets from different connections.

Source: University of Utah: https://my.ece.utah.edu/~ece6962-003/exams/Midterm%201/practice%20exam%201-solutions.pdf

Time for circuit switching: s + kd + x/b in seconds

Time for packet switching: kd + x/b + (k-1)*p/b [Remember: Packet switches are doing store-and-forward]

(See https://my.ece.utah.edu/~ece6962-003/exams/Midterm%201/practice%20exam%201-solutions.pdf for details)



If time permits, we will discuss statistical multiplexing.