CS 3640: Introduction to Networks and Their Applications

Fall 2023, Lecture 4: Packet switching

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You should…

- Be ready to submit assignment 1 tonight.

Today's class

1. Recap
2. Packet switching
3. Performance metrics

Recap: Internet design principles

- What are the three Internet design principles? How do they impact the Internet?

Recap: Circuit switching

- What does switching aim to accomplish? What are the two primary approaches it may use?

- What is circuit switching? What types of traffic does it handle well? What makes it unsuitable for the Internet?

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Today's class

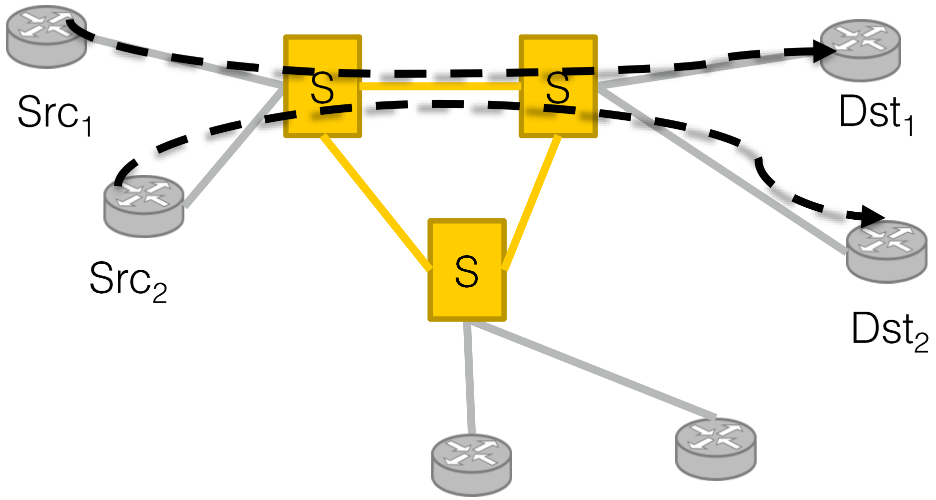
1. Recap

2. Packet switching

3. Performance metrics

Switching and link sharing

- Switching basically allows multiple devices (routers at the core) to share a single link.
  - New problem: How should they share the link?



Method 1: Make a reservation

- Reserve the maximum bandwidth you will need ahead of time.
- Reservation-based sharing.

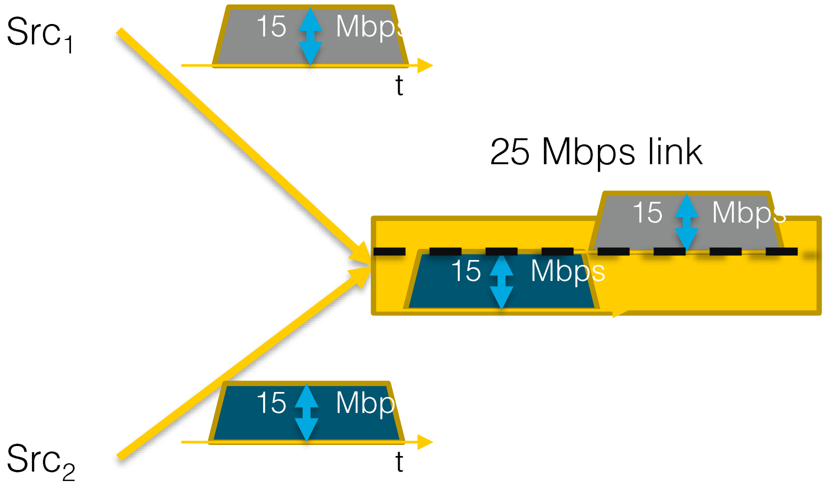
Method 2: Just hope for the best

- Just send packets when you must.
- On-demand sharing.

Switching and link sharing

Scenario:

- Bandwidth of link: 25 Mbps.
- Src_1 needs 15 Mbps at peak and Src_2 needs 15 Mbps at peak. They peak at different times.



Method 1: Make a reservation

- If we allow peak rate reservation, we turn away Src_1.
- If we allow equal reservation, we underserve both sources (12.5Mbps capacity/15Mbps source). Results in lag (reliable transport) or high packet loss (unreliable transport).

Switching and link sharing

Scenario:

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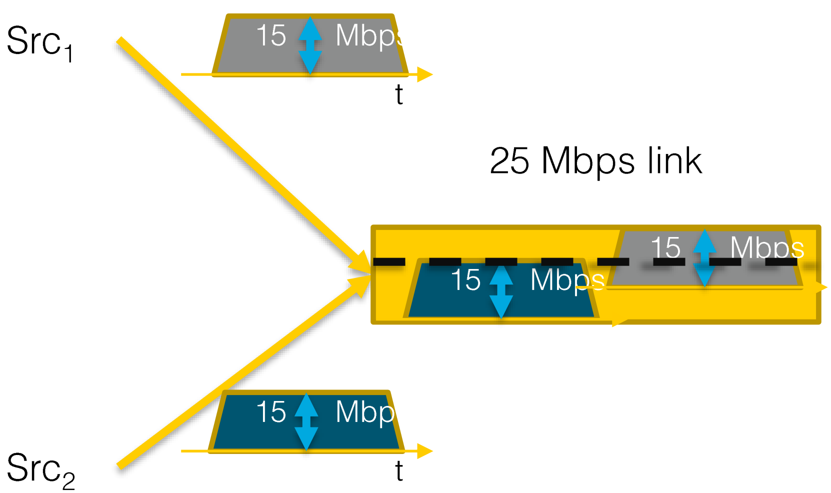


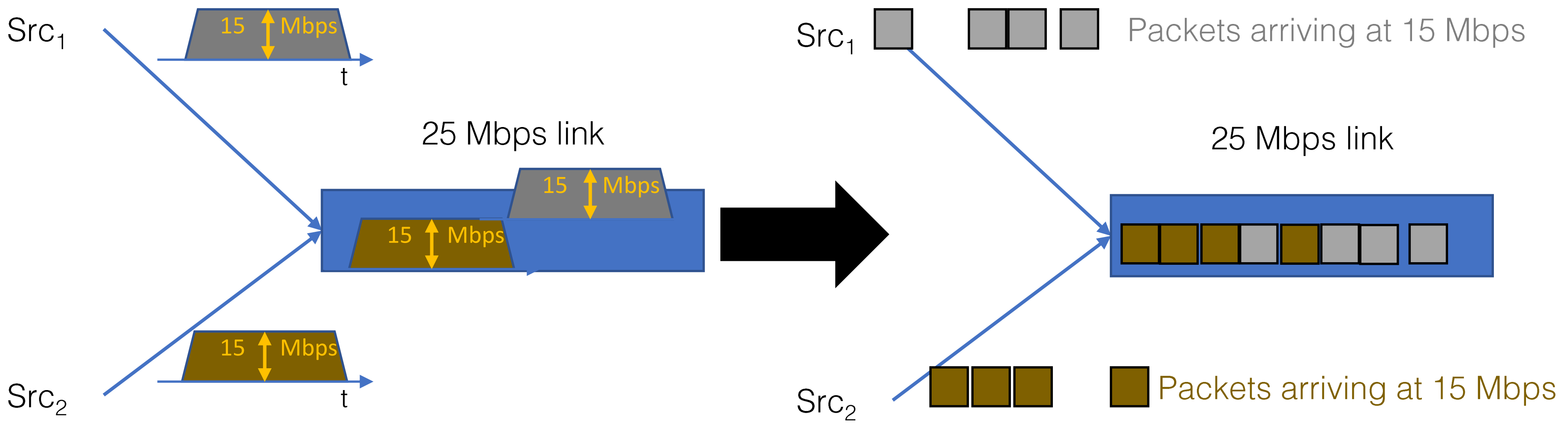
Method 2: On-demand link sharing. (aka “hope for the best”)

- Everything works out just fine!

How is on-demand link sharing implemented?

Packet switching

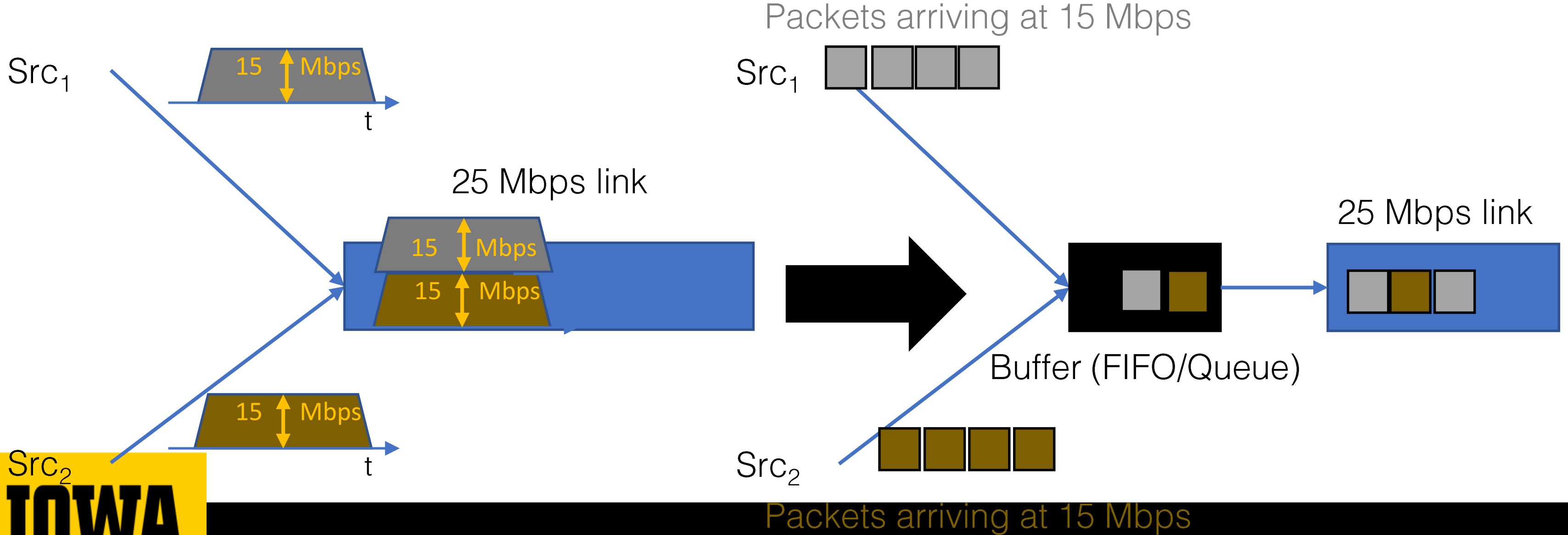
- Key idea: Data is broken down into smaller units (packets). Each packet is treated independently of the others.
- Contrast: All data was treated as a single “unit” in circuit switching.



How is on-demand link sharing implemented?

Packet switching

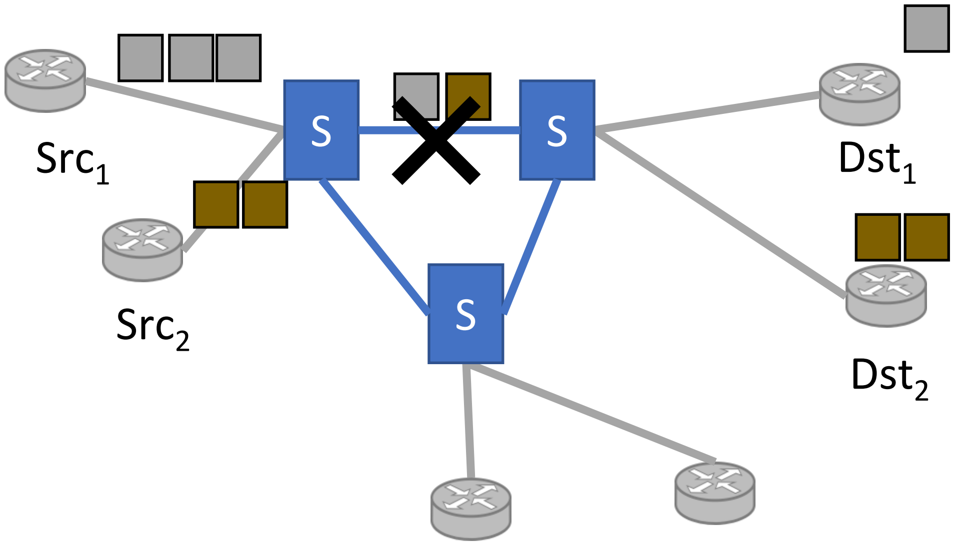
- You don't need to establish a circuit to get a packet to its destination. Just do the best you can hop-by-hop.
  - You just need to put the packet on the right wire (forward it based on specific rules written in the switch).
- **Discuss: How do you deal with bursty traffic arriving too quickly?**
  - Use a buffer.
  - Size of the buffer determines how much burstiness you can handle.
  - Full buffer = dropped packets.



Packet switching and failures

Scenario: Link failure during transmission.

Discuss: What happens when a link or switch fails?



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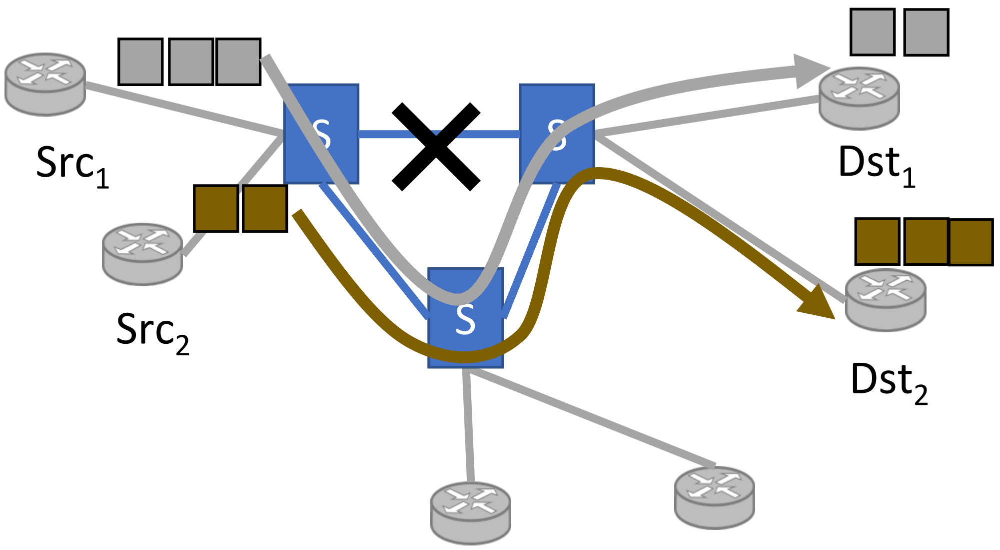
Packet switching and failures

What happens when a link or switch fails?

Packets just get sent around the failed link or switch with no additional circuit construction overhead.



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Summary: Packet switching

- Packet switching is how on-demand link sharing is implemented.
  - Treat packets independently.
  - Packets can take many different routes to get to their destination.

- What does it handle well?
  - Failures and bursty traffic. This makes it great for the Internet!

- What are its limitations?
  - Needs to buffer packets if there more coming in than can be put on the link. Small buffers can result in lost packets.

Circuit switching vs. packet switching

	Circuit switching	Packet switching
Fundamental principle	Reservation-based sharing	On-demand sharing
- At what granularity does it view data?	Data flow based: Like moving bricks through pipes.	Packet based: Like moving drops of water through pipes.
- What kind of guarantees can you get?	Reserves end-to-end resources. Performance is predictable in the absence of failures.	Provides best-effort service: Just promises to put the packet on the right wire. Performance is not predictable even without failures.
- How does it impact routes taken by packets?	All data takes the same route to their destination	Packets can take many different routes to their destination
What does it handle well?	Smooth & predictable traffic	Bursty traffic
How does it handle failures?	Repeat circuit construction if link or switch failures occur	Moves around link or switch failures
What are the implementation challenges?	Complicated circuit establishment	Complicated buffer management
What is it primarily used for?	Used for old telephone system	Used for the Internet

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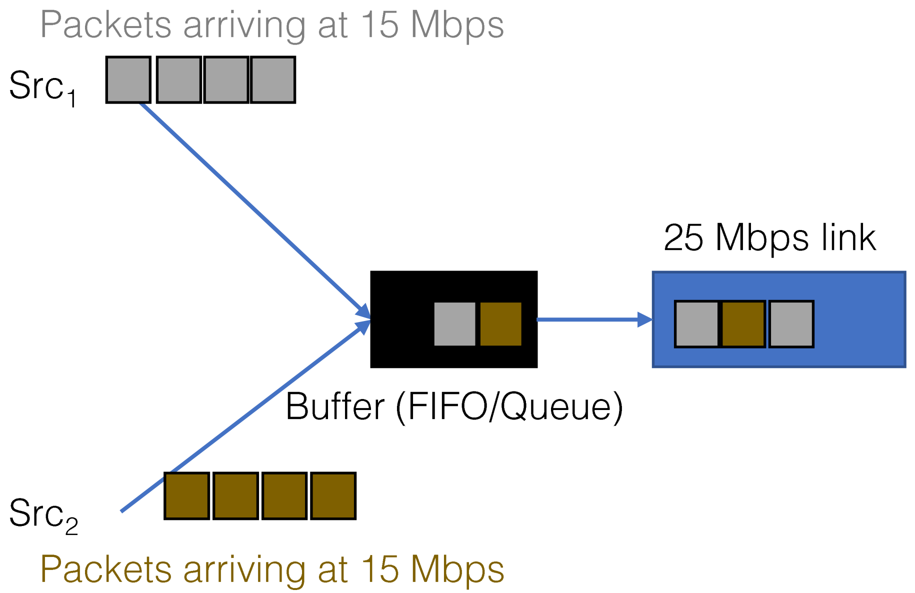
Performance of packet switched networks

- **Discuss: How do we measure the performance of a packet-switched network? What factors impact these metrics?**
  - Delay (time to reach the destination), loss (how many packets are dropped), and throughput (how fast is the destination getting data).

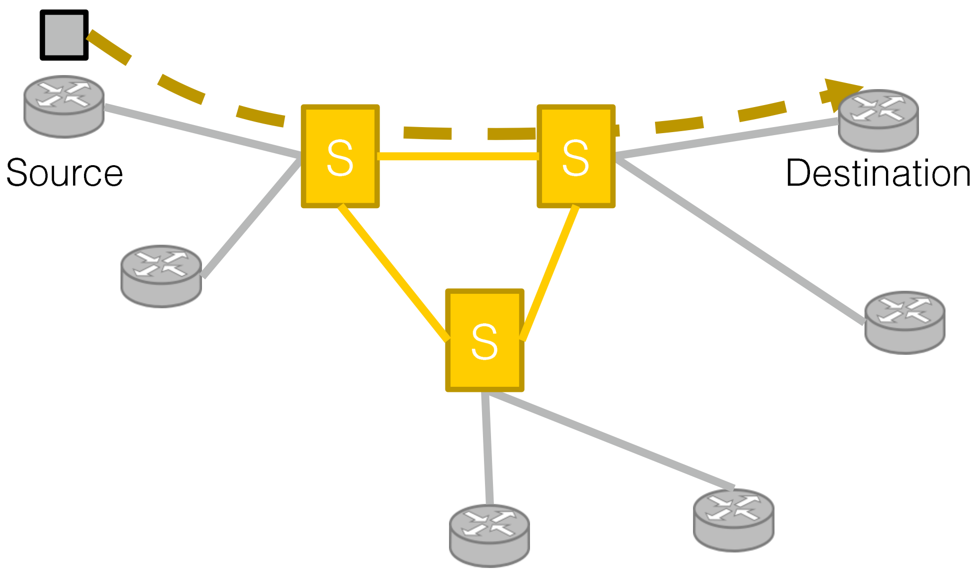


Assessing performance in packet-switched networks

- Three commonly used metrics:
  - Delay: How long does a packet take to get to its destination?
  - Loss: What fraction of packets get dropped?
  - Throughput: At what rate is data received at the destination?

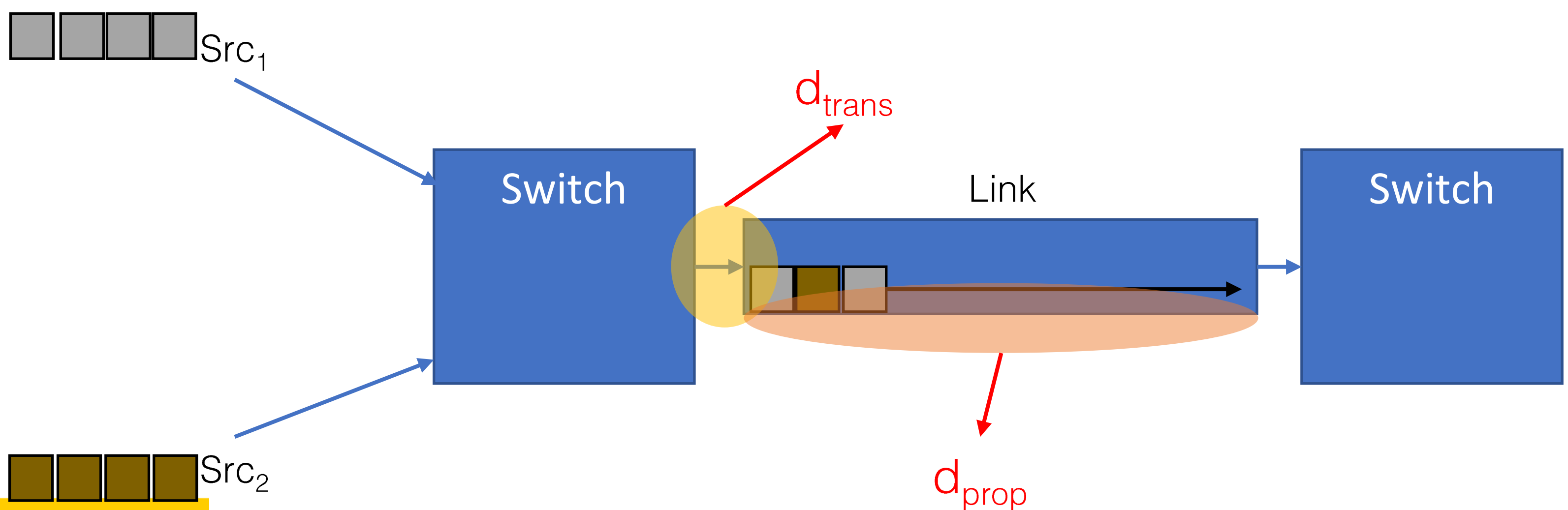
Delays in packet-switched networks

- Delay: How long does it take a packet to reach its destination?
- **Discuss: What entities might have an impact on delay?**



Impact of links on delays in packet-switched networks

- Links: What do they do?
  - They convert packets to link signals & then physically move bits from one end to the other.
    - Transmission delay: How many bits can be put on the link per second? [$\mathbf{d_{trans}}$]
    - Propagation delay: How long do bits take to reach the other end of the link? [$\mathbf{d_{prop}}$]
  - **Discuss: How would you compute these delays? What are they dependent on?**



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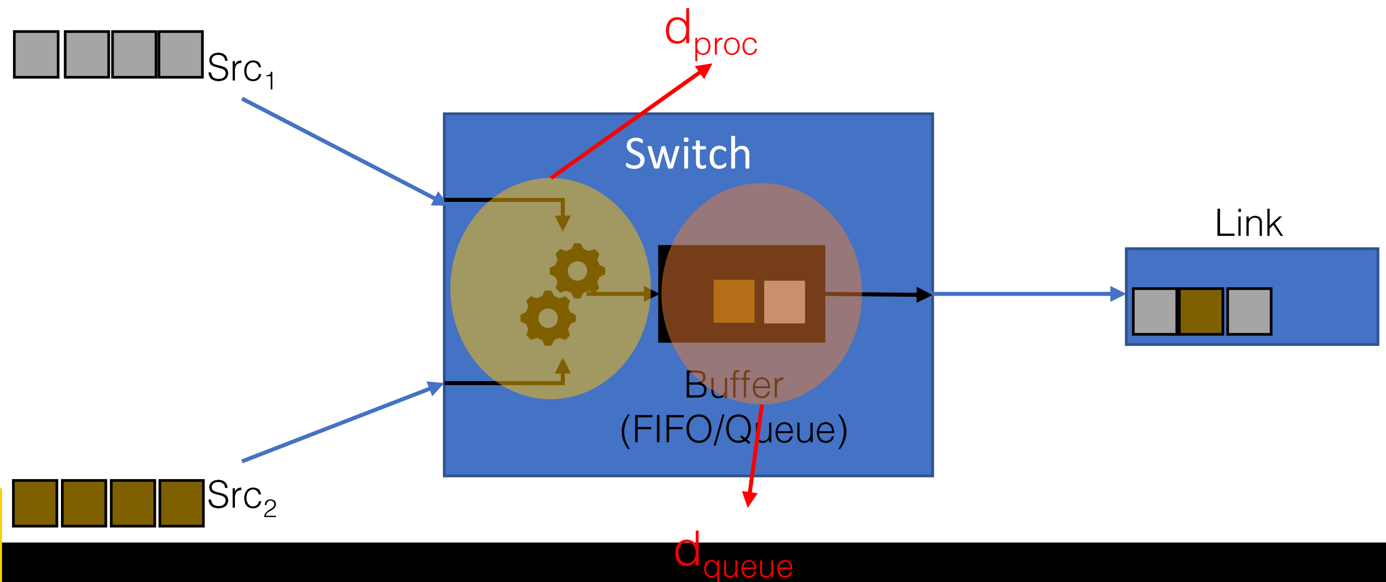
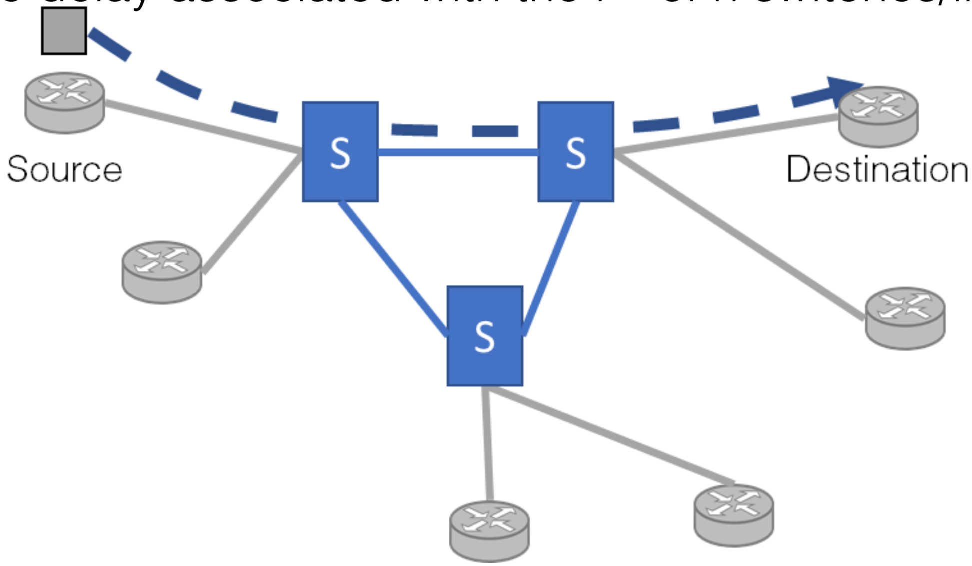
Impact of switches on delays in packet-switched networks

- Switches: What do they do?
  - They get packets and do some work (error checking, etc.) & then figure out which link the packet should go on.
    - Processing delay: At what rate can a switch figure out the right link? [“$\mathbf{d_{proc}}$”]
  - They convert packets into bits and write these bits to the link.
    - Queuing delay: How long does a packet wait in the buffer before it gets processed? [“$\mathbf{d_{queue}}$”]
    - We say that the network is “congested” when the queueing delays are high.
  - **Discuss: How would you compute these delays? What are they dependent on?**



End-to-end delay of a packet-switched network

- End-to-end delay is the sum of all the delays added by each switch/link between the source & destination.
  - $d_{e2e} = (total_{switch\ delays} + total_{link\ delays}) = \sum_{i=1}^{n} (d^{i}{}_{trans} + d^{i}{}_{prop} + d^{i}{}_{proc} + d^{i}{}_{queue})$
  - Here, $d^{\,i}$ is the delay associated with the $i^{\,th}$ of n switches/links.

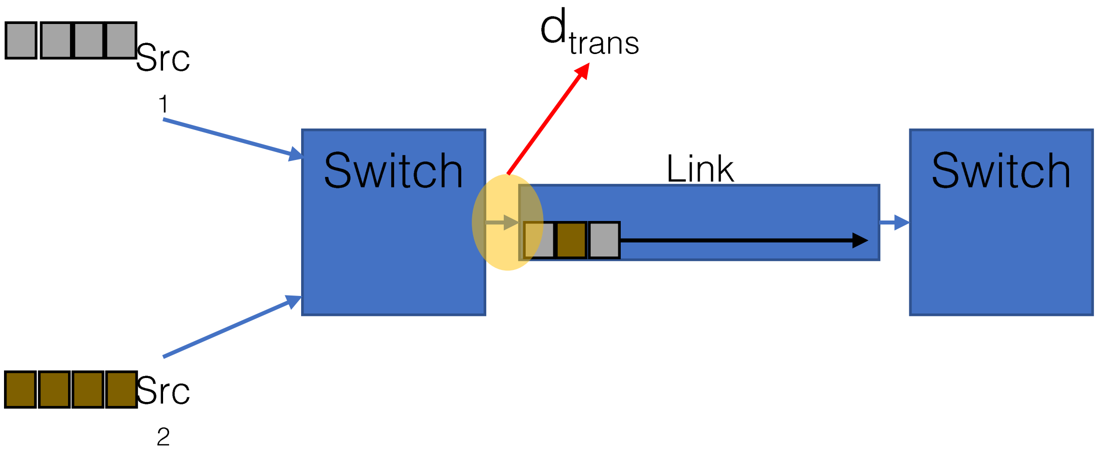


$$\boldsymbol{d^i}_{\boldsymbol{trans}} + d^i{}_{prop} + d^i{}_{proc} + d^i{}_{queue}$$

- Transmission delay of a link
  - Q: How many bits can you write to the link in one second?
    A: How much $$$ can you spend?

$$d^i_{trans} + d^i_{prop} + d^i_{proc} + d^i_{queue}$$

- **Discuss: Need to send a 1000KB packet over a 1, 10, and 100 Gbps link adapter. What is the transmission delay over each one?**



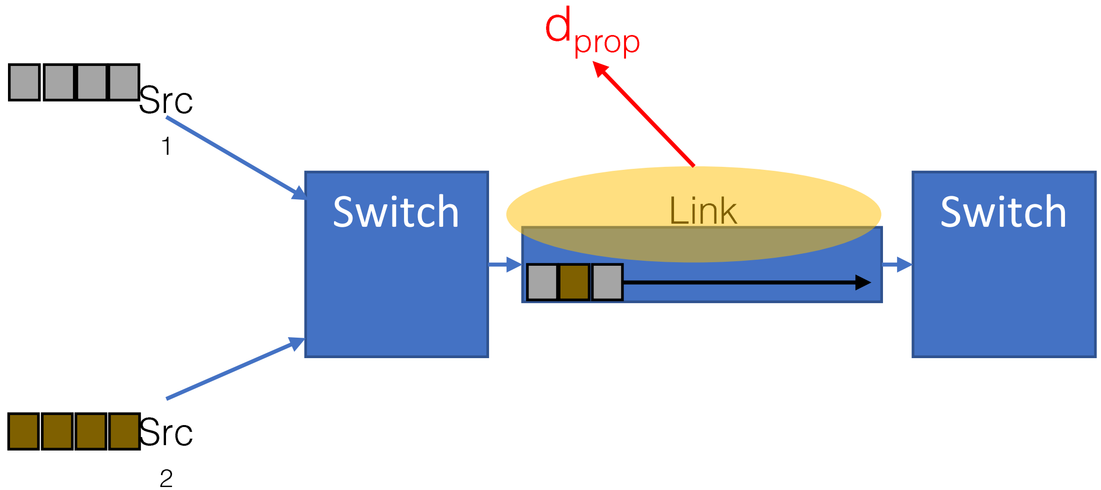
8000 Kbits = 8 x 10^6 bits
100 Gbps = 100 x 10^9 bits/sec
10 Gbps = 10 x 10^9 bits/sec
1 Gbps = 10^9 bits/sec

Transmission delay for a 1000KB packet:
@100Gbps: 8×10^{-5} sec
@10 Gbps: 8×10^{-4} sec
@1 Gbps: 8×10^{-3} sec

Transmission delay = data size/transmission rate of link interface

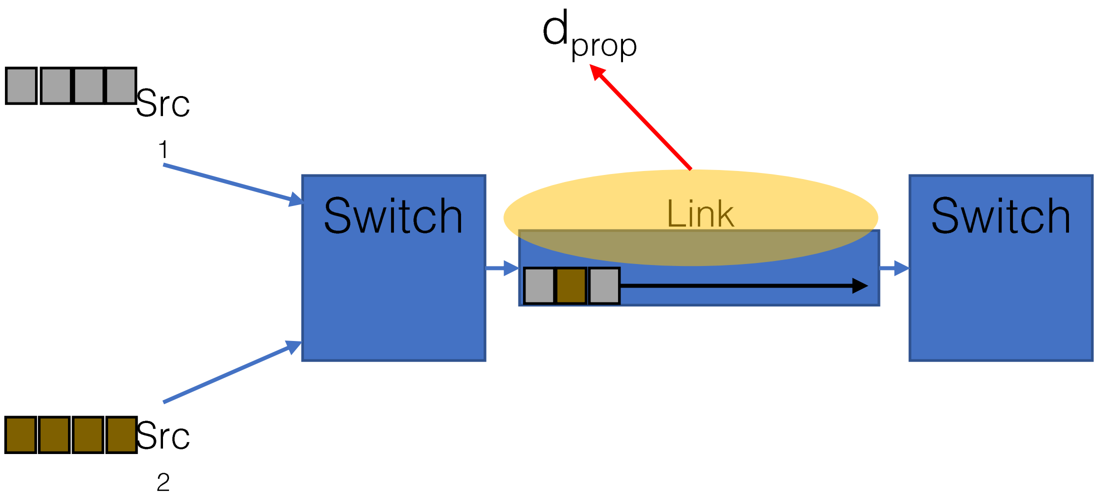
$$d^i{}_{trans} + \boldsymbol{d^i{}_{prop}} + d^i{}_{proc} + d^i{}_{queue}$$

- Propagation delay of a link
  - How long does it take to move one bit from one end of the link to the other?
    - Depends on how long the link is.
    - Depends on the material used by the link.
    - Since links are usually optic fiber, they propagate bits at $2\text{x}10^8$ mps.
      - This is the speed of light in glass.
      - If we could cost-effectively send bits in vacuum, this would be $3\text{x}10^8$ mps.



$$d^{i}{}_{trans} + \boldsymbol{d^{i}{}_{prop}} + d^{i}{}_{proc} + d^{i}{}_{queue}$$

- **Discuss: What is the propagation delay of a 100m optic fiber link? (speed of light in glass: $2x10^8$ mps)**
  - Time to travel 100 meters @ $2x10^8$ mps = $100m/2x10^8$ mps= $.5x10^{-6}$ sec



Propagation delay = length of link/propagation speed of link

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Propagation delay = length of link/propagation speed of link

Transmission delay = data size/transmission rate of link interface

$$\boldsymbol{d^i}_{\boldsymbol{trans}} + \boldsymbol{d^i}_{\boldsymbol{prop}} + d^i_{proc} + d^i_{queue}$$

- **Discuss: Assume we have no switch-induced delays.**
  - **Link propagation speed: $2x10^8$ mps. Link length: $20x10^3$ m**
  - **Two different networks. When should you invest in a faster link interface card?**
  - **Scenario 1:**
    - **Link adapter: 1 Gbps, Data: 1 GB? What is d_{trans}? What is d_{prop}?**
      - $d_{trans} = 1x8x10^9/1x10^9 = 8s$, $d_{prop} = 20x10^3/2x10^8 = 10^{-4}s$,
      - $d_{e2e} = 8+10^{-4}s$
      - d_{trans} is dominant. Investing in a faster link interface card is a good idea.
  - **Scenario 2:**
    - **Link adapter: 1 Gbps, Data: 100 B? What is d_{trans}? What is d_{prop}?**
      - $d_{trans} = 8x10^2/1x10^9 = 8x10^{-7}$ s, $d_{prop} = 20x10^3/2x10^8 = 10^{-4}$ s,
      - $d_{e2e} = (8x10^{-7}) + 10^{-4}$ s
      - d_{prop} is dominant. Investing in a faster link interface card a waste.

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Coming up next…

- Lecture:
  - Queueing delays
  - Processing delays
  - Wrapping up “Fundamentals”.

Things to remember

- Differences between circuit and packet-switched networks.

- Metrics for measuring performance in packet-switched networks.

- Sources and types of delays in packet-switched networks.