Introduction to Networks
Hari Balakrishnan (hari@mit.edu)
6.02 Fall 2009, Lecture #16
November 2, 2009

• Sharing, a fundamental problem
• Switches: circuit and packet switching
• Packet bursts, queues, and Little’s law

Note: Lecture notes on course web site

From Links to Networks
So far, we’ve learned about tools to help us communicate over a point-to-point link

Your Network Here!

Key Idea: Sharing

• Fundamental to all communication networks

• Occurs at multiple levels
  • Link sharing to alleviate $O(N^2)$ scaling problem
  • Channel sharing to allow many nodes to share common medium (often wireless)

How to Build a Network

• Idea: Compose many independent point-to-point links over radio or wires

• $O(N^2)$ links for N-node network
• Too inefficient and expensive
• Doesn’t scale well to large regions

Switches Orchestrate Link Sharing

• A switch is a computing device that allows many concurrent communications to share the network

This structure is called a network topology

MIT Campus Network
Topologies Overview
Examples of Switches

- Alcatel 7670 RSP
- Avici TSR
- Cisco GSR 12416
- Lucent 5ESS telephone switch
- 802.11 access point

Two Very Different Ideas for Designing Switched Networks

- **Circuit switching**
  - Used by classic telephone networks

- **Packet switching**
  - Used by the Internet infrastructure
  - (Phone networks also now moving to this model)

Circuit Switching

- First establish a circuit between end points
  - E.g., done when you dial a phone number
  - Message propagates from caller toward callee, establishing some state in each switch
- Then, ends send data ("talk") to each other
- After call, tear down (close) circuit
  - Remove state

TDM Shares Link Equally, But Has Limitations

- Suppose link capacity is \( C \) bits/sec
  - Each communication requires \( R \) bits/sec
- \#frames in one “epoch” (one frame per communication) = \( C/R \)
  - Maximum number of concurrent communications is \( C/R \)
  - What happens if we have more than \( C/R \) communications?
  - What happens if the communication sends less/more than \( R \) bits/sec?

  \( \rightarrow \) Design is unsuitable when traffic arrives in bursts

Example: Time Division Multiplexing

- Divide time into \( N \) frame times, each frame belonging to a different conversation (color)
  - At most \( N \) concurrent conversations share link
  - Setup: Allocate time-slot to conversation
    - Add entry to table mapping (inlink, time-slot) to (outlink, time_slot)
    - Forwarding step at switch: consult table
    - When does this approach (not) work?

A Different Approach: Packet Switching

- Data is sent in packets
  - Each packet contains control information in a header
    - Destination address
    - Source address
    - Other stuff
  - Switch forwards each packet by looking up dest addr in a forwarding table
    - Receive, lookup, store in queue (if link busy), forward
    - No reservation of time slot: different communications can get different rates
Why Packet Switching Works:
Statistical Multiplexing (“Statmux”)

Aggregating multiple conversations smooths usage

Queues are Essential

Queues absorb packet bursts
They are a “necessary evil”
Needed to absorb bursts
But they add delay by making packets wait until link is available
So they shouldn’t be too big

Little’s Law

\[ n(t) = \# \text{ pkts at time } t \text{ in queue} \]

\[ A = \text{area under the } n(t) \text{ curve from 0 to } T \]

\[ \text{Then, rate } = \frac{P}{T} \text{ and mean number of pkts in queue, } E[n] = \frac{A}{T} \]

\[ \text{How to calculate mean delay per packet?} \]
\[ A \text{ is aggregate delay weighted by each packet’s time in queue (why?)} \]
\[ \text{So, mean delay per packet sent } = \frac{A}{P} \]
\[ \text{Therefore, } E[n] = \text{rate } \times \text{ mean delay} \]
\[ \text{For a given link rate, increasing queue size increases delay} \]

Traffic in 34-101 wireless LAN on Sept 14 2009

Queues absorb packet bursts
They are a “necessary evil”
Needed to absorb bursts
But they add delay by making packets wait until link is available
So they shouldn’t be too big