15-441 Computer Networking

Lecture 6 – Switching,
Internet design

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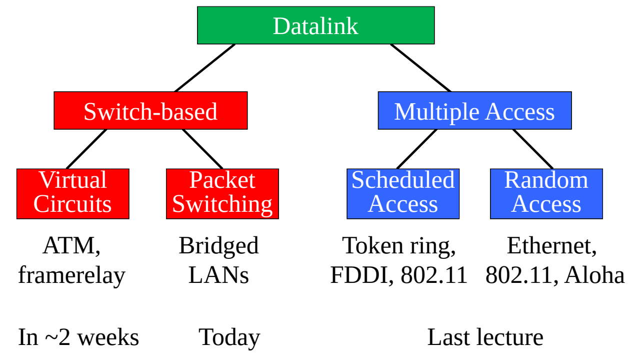
www.cs.cmu.edu/~prs/15-441-F14

Datalink Classification



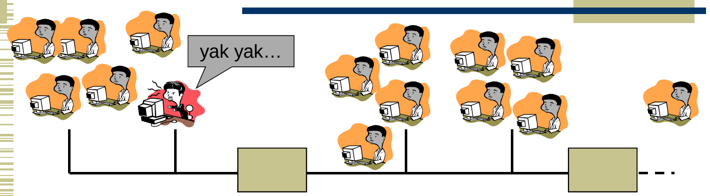
Outline

- Bridging and switching
  - Scaling the network
  - Spanning tree protocol
  - Why Ethernet?
- Something different

Scale

- What breaks when we keep adding people to the same wire?

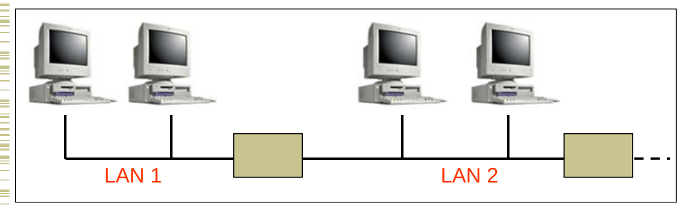
Scale



- What breaks when we keep adding people to the same wire?
- Only solution: split up the people onto multiple wires
  - But how can they talk to each other?

Building Larger LANs: Bridges

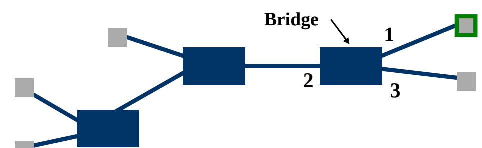
- Extend reach of a single shared medium
- Connect two or more “segments” by copying data frames between them
  - Only copy data when needed → key difference from repeaters/hubs
  - Reduce collision domain compared with single LAN
  - Separate segments can send at once → much greater bandwidth
- Challenge: learning which packets to copy across links



Transparent Bridges

- Design goals:
  - Self-configuring without hardware or software changes
  - Bridge do not impact the operation of the individual LANs
- Three parts to making bridges transparent:
  1) Forwarding frames
  2) Learning addresses/host locations
  3) Spanning tree algorithm

Frame Forwarding

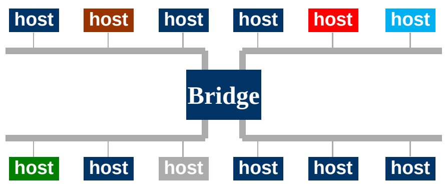


MAC Address	Port	Age
A21032C9A591	1	36
99A323C90842	2	01
8711C98900AA	2	15
301B2369011C	2	16
695519001190	3	11

- A machine with MAC Address lies in the direction of number port of the bridge
- For every packet, the bridge “looks up” the entry for the packets destination MAC address and forwards the packet on that port.
  - Other packets are broadcast – why?
- Timer is used to flush old entries

Learning Bridges

- Manually filling in bridge tables?
  - Time consuming, error-prone
- Keep track of source address of packets arriving on every link, showing what segment hosts are on
  - Fill in the forwarding table based on this information



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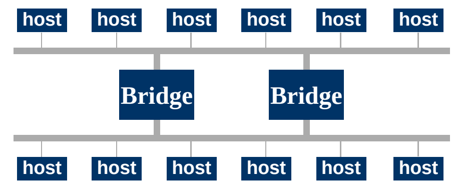
Spanning Tree Bridges

- More complex topologies can provide redundancy.
  - But can also create loops.
- What is the problem with loops?
- Solution: spanning tree



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Spanning Tree Protocol Overview

Embed a tree that provides a single unique path to each destination:

1) Elect a single bridge as a root bridge
2) Each bridge calculates the distance of the shortest path to the root bridge
3) Each LAN identifies a *designated bridge*, the bridge closest to the root. It will forward packets to the root.
4) Each bridge determines a *root port*, which will be used to send packets to the root
5) Identify the ports that form the spanning tree

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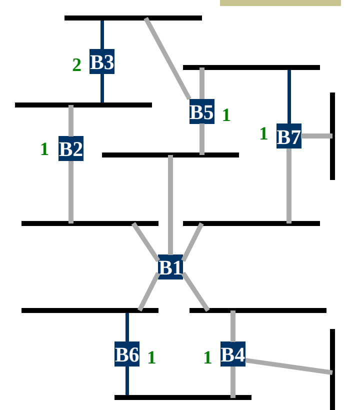
Spanning Tree Algorithm Steps

- Root of the spanning tree is the bridge with the lowest identifier.
  - All ports are part of tree
- Each bridge finds shortest path to the root.
  - Remembers port that is on the shortest path
  - Used to forward packets
- Select for each LAN the designated bridge that has the shortest path to the root.
  - Identifier as tie-breaker
  - Responsible for that LAN



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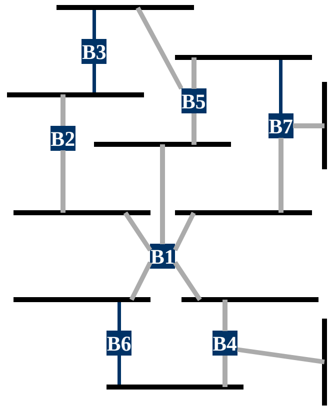
Spanning Tree Algorithm

- Each node sends configuration message to all neighbors.
  - Identifier of the sender
  - Id of the presumed root
  - Distance to the presumed root
  - E.g. B5 sends (B5, B5, 0)
- When B receive a message, it decide whether the solution is better than their local solution.
  - A root with a lower identifier?
  - Same root but lower distance?
  - Same root, distance but sender has lower identifier?
- After convergence, each bridge knows the root, distance to root, root port, and designated bridge for each LAN.



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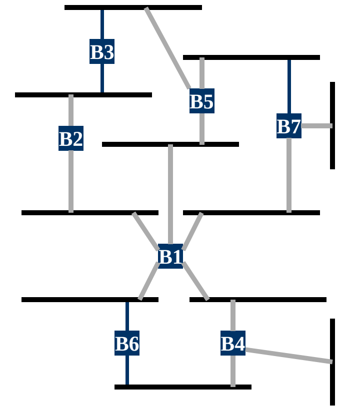
Spanning Tree Algorithm (part 2)

- Each bridge B can now select which of its ports make up the spanning tree:
  - B's root port
  - All ports for which B is the designated bridge on the LAN
- Bridges can not configure their ports.
  - *Forwarding state* or *blocked state*, depending on whether the port is part of the spanning tree
- Root periodically sends configuration messages and bridges forward them over LANs they are responsible for.



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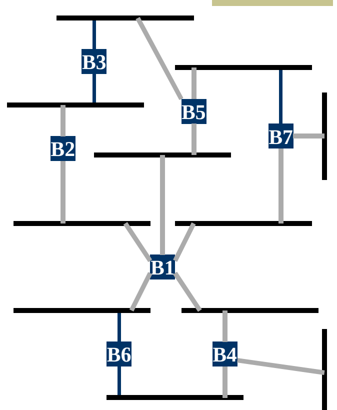
Spanning Tree Algorithm Example

- Node B2:
  - Sends (B2, B2, 0)
  - Receives (B1, B1, 0) from B1
  - Sends (B2, B1, 1) "up"
  - Continues the forwarding forever
- Node B1:
  - Will send notifications forever
- Node B7:
  - Sends (B7, B7, 0)
  - Receives (B1, B1, 0) from B1
  - Sends (B7, B1, 1) "up" and "right"
  - Receives (B5, B5, 0) - ignored
  - Receives (B5, B1, 1) - better
  - Continues forwarding the B1 messages forever to the "right"



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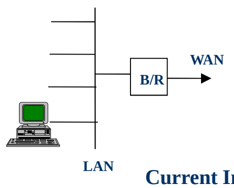
Ethernet Switches

- Bridges make it possible to increase LAN capacity.
  - Packets are no longer broadcasted - they are only forwarded on selected links
  - Adds a switching flavor to the broadcast LAN
- Ethernet switch is a special case of a bridge: each bridge port is connected to single host.
  - Can make the link full duplex (really simple protocol!)
  - Simplifies the protocol and hardware used (only two stations on the link) – no longer full CSMA/CD
  - Can have different port speeds on the same switch
    - Unlike in a hub, packets can be stored
    - An alternative is to use cut through switching

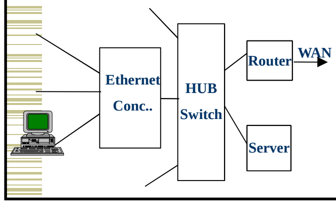
Ethernet Evolution

Early Implementations



- ·A Local Area Network
- ·MAC addressing, non-routable
- ·BUS or Logical Bus topology
- ·Collision Domain, CSMA/CD
- ·Bridges and Repeaters for distance/capacity extension
- ·1-10Mbps: coax, twisted pair (10BaseT)

Current Implementations

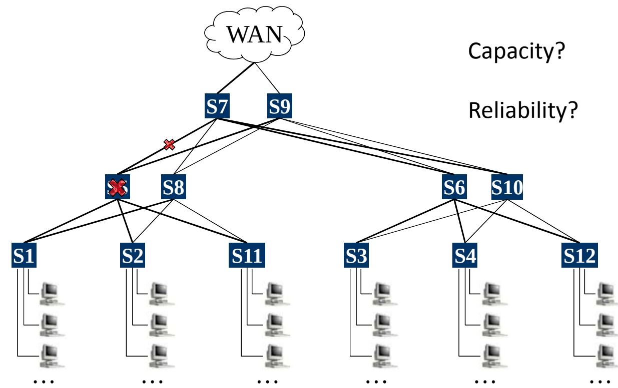


- ·Switched solution
- ·Little use for collision domains
- ·80% of traffic leaves the LAN
- ·Servers, routers 10 x station speed
- ·10/100/1000 Mbps, 10gig coming: Copper, Fiber
- ·95% of new LANs are Ethernet

CSMA Carrier Sense Multiple Access

CD - Collision Detection

Typical Campus Topology



Capacity?

Reliability?

"Traditional" Topology

- Hierarchical single tree
- Redundancy for reliability
- Spanning tree (or variant) for loop-free-ness

Outline

- Bridging and switching
- Something different
  - Data center networks
  - Software defined networks

Cloud Computing

- Elastic resources
  - Expand and contract resources
  - Pay-per-use
  - Infrastructure on demand
- Multi-tenancy
  - Multiple independent users
  - Security and resource isolation
  - Amortize the cost of the (shared) infrastructure
- Flexibility service management
  - Resiliency: isolate failure of servers and storage
  - Workload movement: move work to other locations

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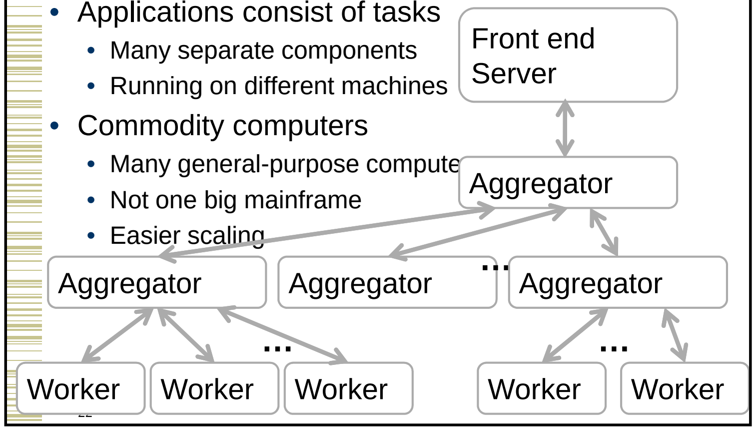
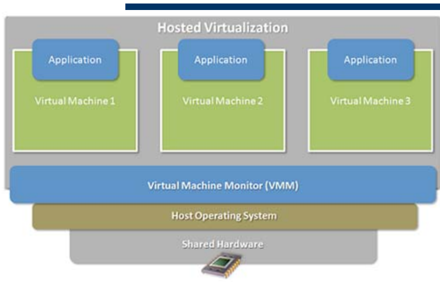
Multi-Tier Applications

- Applications consist of tasks
  - Many separate components
  - Running on different machines
- Commodity computers
  - Many general-purpose computers
  - Not one big mainframe
  - Easier scaling



Enabling Technology: Virtualization



- Multiple virtual machines on one physical machine
- Applications run unmodified as on real machine
- VM can migrate from one computer to another

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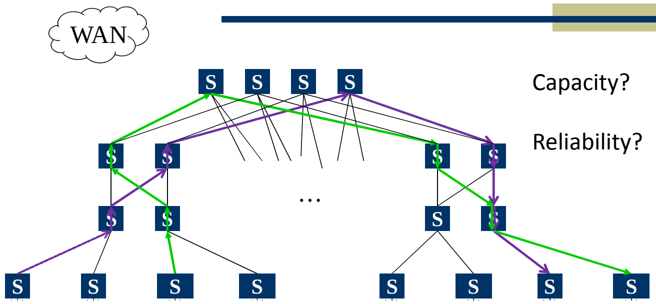
Some Differences Between Commodity DC Networking and Internet/WAN

Characteristic	Internet/WAN	Commodity Datacenter
Latencies	Milliseconds to Seconds	Microseconds
Bandwidths	Kilobits to Megabits/s	Gigabits to 10's of Gbits/s
Causes of loss	Congestion, link errors, …	Congestion
Administration	Distributed	Central, single domain
Statistical Multiplexing	Significant	Minimal, a few flows can dominate links
Incast: many "fat" flows to same destination	Rare	Frequent, due to synchronized responses

- Historically, DC networks used custom network technologies
  - Low latency, high bandwidth, minimal protocol stack
  - E.g., Myrinet
- Today: leverage commodity ethernet technology - Why?

"Fat Tree" Topology



Capacity?

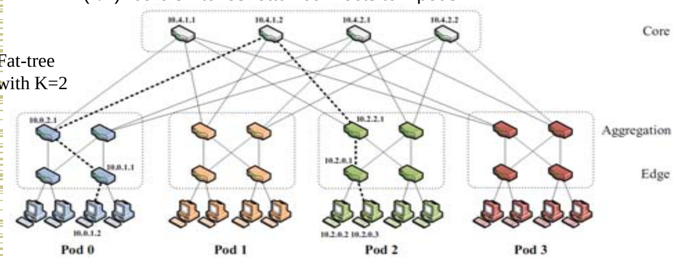
Reliability?

Fat-Tree Based DC Architecture

- Inter-connect racks (of servers) using a fat-tree topology
- Fat-Tree: a special type of Clos Networks (after C. Clos)

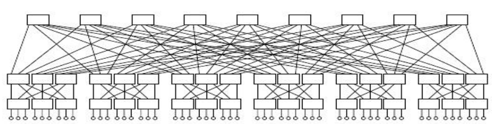
  K-ary fat tree: three-layer topology (edge, aggregation and core)
  - each pod consists of $(k/2)^2$ servers & 2 layers of k/2 k-port switches
  - each edge switch connects to k/2 servers & k/2 aggr. switches
  - each aggr. switch connects to k/2 edge & k/2 core switches
  - $(k/2)^2$ core switches: each connects to k pods

Fat-tree with K=2



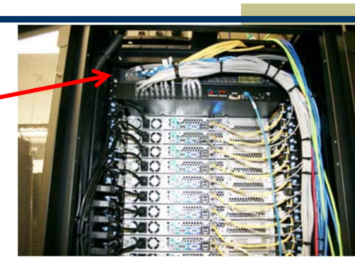
Fat-Tree Based Topology …

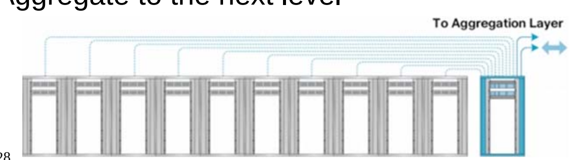
- Why Fat-Tree?
  - Fat tree has identical bandwidth at any bisections
  - Each layer has the same aggregated bandwidth
- Can be built using cheap devices with uniform capacity
  - Each port supports same speed as end host
  - All devices can transmit at line speed if packets are distributed uniform along available paths



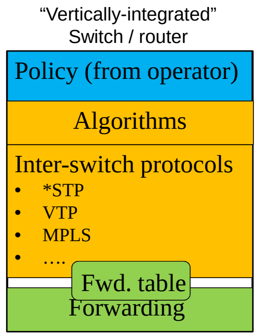
Top-of-Rack Architecture

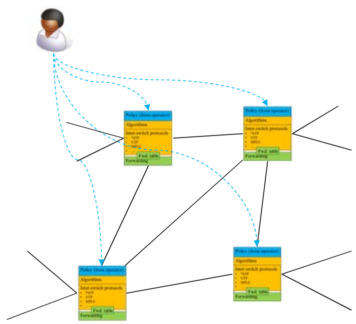
- Rack of servers
  - Commodity servers
  - And top-of-rack switch
- Modular design
  - Preconfigured racks
  - Power, network, and storage cabling
- Aggregate to the next level



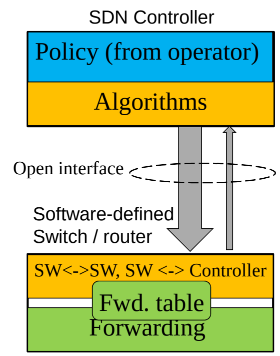


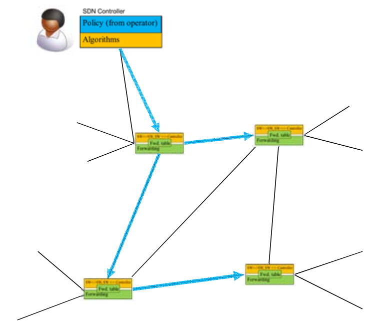
Traditional Management: Distributed





New Approach - SDN Software-Defined Networking





SDN Discussion

- Centralized "controller" runs control and management "applications"
  - Separates control and data topology
  - Can be logically centralized
- Motivation: easier to manage and centralized algorithms can be "smarter" than distributed ones
  - Customization of decisions per flow, server, …
- Why now?
  - Need for more sophisticated policies (perf., security, ..)
  - Much better technology, e.g., speed, reliability, ..
  - Currently mostly limited to DC networks

Things to Remember

- Trends from CSMA networks to switched networks
  - Need for more capacity
  - Low cost and higher line rate
- Emphasis on low configuration and management complexity and cost
  - Fully distributed path selection
  - Trend towards centralization, e.g., SDN in DC (and in wireless – later in course)
    - Richer policies – easier to manage centrally