

CSE 123b Communications Software

Spring 2002

Lecture 6: Routing: Overview and Distance Vector Algorithms

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Some slides courtesy David Wetherall

Last class

- Goals of congestion control
 - Use allocated bandwidth efficiently
 - Avoid sending so quickly that the network has to drop packets
 - Avoid sending so slowly that the network is underutilized
- Approach taken by TCP
 - Congestion window limits outstanding packets
 - Adjust congestion window in response to packet losses (AIMD)
 - Slow start
 - Fast retransmit/ fast recovery

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This class

- New topic: routing



How do I get
there from here?

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Overview

- Intro & Design choices
- Intra-domain routing
 - Distance vector
 - Link state
- Inter-domain routing
 - Policy

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Intra-domain routing

- Routing **within** a network/organization
- A **single** administrative domain
- Overall goals
 - Provide intra-network connectivity
 - Adapt quickly to failures or topology changes
 - **Optimize** use of network resources
- Problem statement
 - Network is a directed graph $G=(V,E)$
 - Routers are vertices, links are edges labeled with some metric
 - » For simplicity ignore hosts, they are part of each V
 - For each V , find the shortest path to every other V

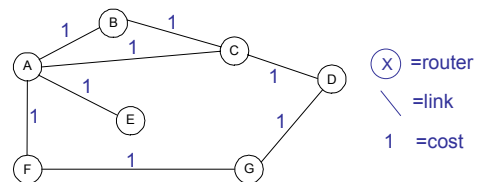
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Network as a Graph

- Routing is essentially a problem in graph theory
- Find "best" path between every pair of vertices



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Routing Questions

- How to choose best path?
 - Defining "best" can be slippery
- How to scale to millions of users?
 - Minimize control messages and routing table size
- How to adapt to failures or changes?
 - Node and link failures, plus message loss

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What does a router do?

- **Forwarding**
 - Move packet from input link to the appropriate output link
 - Purely local computation
 - Must go be very fast (executed for ever packet)
- **Routing**
 - Doing work so you're sure that the "next hop" actually leads to the destination
 - Global decisions; distributed computation and communication
 - Can go slower (only important when topology changes)

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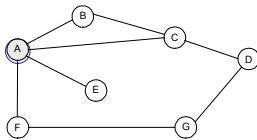
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What's in a Routing Table?

- The routing table at A, for example, lists at a minimum the next hops for the different destinations

Dest	Next Hop
B	B
C	C
D	C
E	E
F	F
G	F



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Kinds of routing/forwarding

- Source routing
 - Complete path in packet
- Virtual circuits
 - Set up path out-of-band and store path identifier in routers
 - Local path identifier in packet
- **Destination-based routing**
 - Router looks up address in forwarding table
 - Forwarding table contains (address, next-hop) tuples

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Source routing

- Routing
 - Host computes path
 - Must know global topology and detect failures
 - Packet contains complete ordered path information
 - » I.e. node A then D then X then J...
 - Requires variable length path header
- Forwarding
 - Router looks up next hop in packet header, strips it off and forwards remaining packet
 - Very quick forwarding, no lookup required
 - Very flexible
- In practice
 - ad hoc networks (DSR), SANs (Myrinet), and for debugging on the Internet (LSR,SSR)

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Virtual circuits

- Routing
 - Hosts sets up path out-of-band, requires connection setup
 - Write (input id, output id, next hop) into each router on path
 - Flexible (one path per flow)
- Forwarding
 - Send packet with path id
 - Router looks up input, swaps for output, forwards on next hop
 - Repeat until reach destination
 - Table lookup for forwarding (why faster than IP lookup?)
- In practice
 - ATM: fixed VC identifiers and separate signaling code
 - MPLS: ATM meets the IP world (why? *traffic engineering*)

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Destination-based routing

- Routing
 - All addresses are globally known
 - » No connection setup
 - Host sends packet with destination address in header
 - » No path state; only routers need to worry about failure
 - Distributed routing protocol used to routing tables
- Forwarding
 - Router looks up destination in table
 - » Must keep state proportional to destinations rather than connections
 - (Address, next-hop) tuple
 - Lookup address, send packet to next-hop link
 - » All packets follow same path to destination
- In Practice: IP routing

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Three approaches to routing

- **Static**
 - Type in the right answers and hope they are always true
- **Distance vector**
 - Tell your neighbors when you know about everyone
- **Link state**
 - Tell everyone what you know about your neighbors

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Distance Vector routing

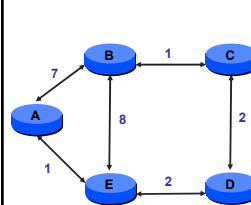
- Assume
 - Each router knows own address & cost to reach neighbors
- Goal
 - Calculate routing table containing next-hop information for every destination at each router
- **Distributed Bellman-Ford algorithm**
 - Each router maintains a vector of costs to all destinations
 - » Initialize neighbors with known cost, others with infinity
 - Periodically send copy of distance vector to neighbors
 - On reception of a vector
 - » If neighbor's path to a destination is shorter, switch to it

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Initial conditions



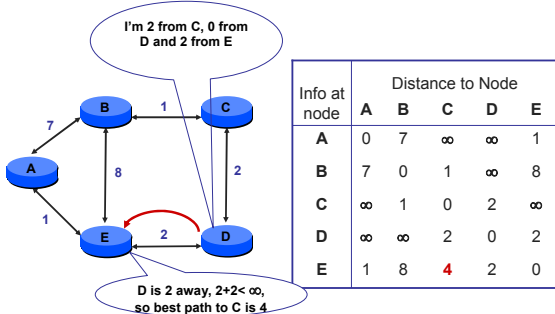
Info at node	Distance to Node				
	A	B	C	D	E
A	0	7	∞	∞	1
B	7	0	1	∞	8
C	∞	1	0	2	∞
D	∞	∞	2	0	2
E	1	8	∞	2	0

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E receives D's vector

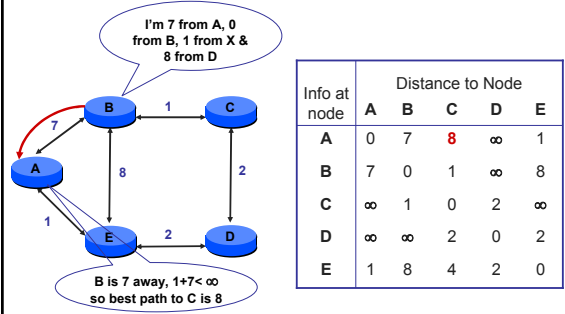


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A receives B's vector

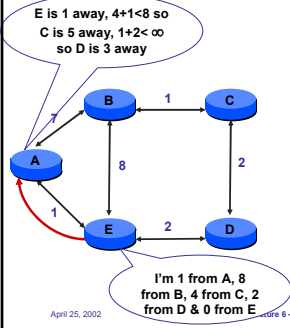


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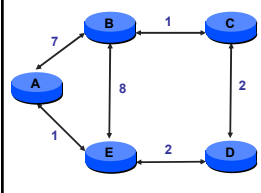
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A receives E's vector



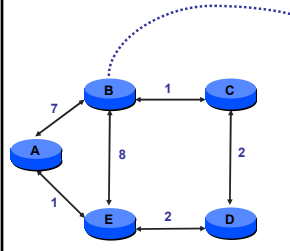
Info at node	Distance to Node				
	A	B	C	D	E
A	0	7	5	3	1
B	7	0	1	∞	8
C	∞	1	0	2	∞
D	∞	∞	2	0	2
E	1	8	4	2	0

Final state



Info at node	Distance to Node				
	A	B	C	D	E
A	0	6	5	3	1
B	6	0	1	3	5
C	5	1	0	2	4
D	3	3	2	0	2
E	1	5	4	2	0

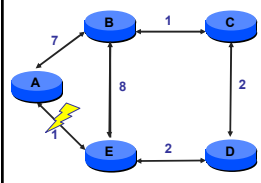
View from a node (B)



Dest	Next hop		
	A	E	C
A	7	9	6
C	12	12	1
D	10	10	3
E	8	8	5

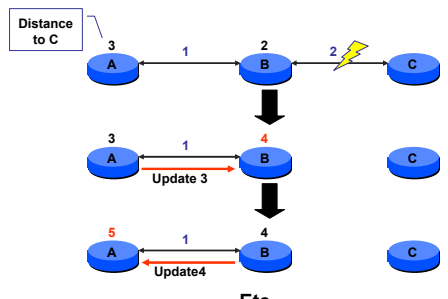
Link failure

- A marks distance to E as ∞, and tells B
- E marks distance to A as ∞, and tells B and D
- B and D recompute routes and tell C, E and E
- etc... until converge



Info at node	Distance to Node				
	A	B	C	D	E
A	0	7	8	10	12
B	7	0	1	3	5
C	8	1	0	2	4
D	3	3	2	0	2
E	12	5	4	10	0

Problems: Count to Infinity



Etc...

Why?

- Updates don't contain enough information
- Can't totally order bad news above good news
- B's accepts A's path to C that is *implicitly* through B!
- Aside: this also causes delays in convergence

Solutions

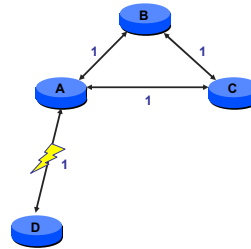
- **Hold downs**
 - As metric increases, delay propagating information
 - Limitation: Delays convergence
- **Split horizon**
 - Never advertise a destination through its next hop
 - » A doesn't advertise C to B
 - Poison reverse: Send negative information when advertising a destination through its next hop
 - » A advertises C to B with a metric of ∞
 - Limitation: Only works for "loop"s of size 2
- **Loop avoidance**
 - Full path information in route advertisement
 - Explicit queries for loops (e.g. DUAL)

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How split horizon/pv fails



- A tells B & C that D is unreachable
- B tells C that D is unreachable
- B tells A that D is reachable with cost=3 (since route is through C, split horizon doesn't apply)
- A tells C that D is reachable through A (cost=4)
- Etc...

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Other issues

- When to send route updates?
- **Periodically**
 - Limits granularity of failure recovery
 - Global synchronization can cause packet loss
- **Jittered**
 - Random offset from periodic deals with synchronization problem
- **Triggered**
 - Send updates immediately when metric changes
 - Converges more quickly, but causes flood of packets

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Routing Information Protocol (RIP)

- DV protocol with hop count as metric
 - Infinity value is 16 hops; limits network size
 - Includes split horizon with poison reverse
- Routers send vectors every 30 seconds
 - With triggered updates for link failures
 - Time-out in 180 seconds to detect failures
- RIPv1 specified in RFC1058
 - www.ietf.org/rfc/rfc1058.txt
- RIPv2 (adds authentication etc.) in RFC1388
 - www.ietf.org/rfc/rfc1388.txt

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Key Concepts

- Routing is a global process, forwarding is local one
- The Distance Vector algorithm and RIP
 - Simple and distributed exchange of shortest paths.
 - Weak at adapting to changes (loops, count to infinity)

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For next time...

- No new reading... although review the section about link state routing
- Finally, projects ☺

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