Network Layer

Abusayeed Saifullah

CS 5600 Computer Networks

These slides are adapted from Kurose and Ross
**count to infinity problem in DVR**

*bad news: A down again.*

- why does bad news propagate slowly?
  - **Answer:** no router ever has a value more than 1 higher than the minimum of all neighbors

- how will you solve count-to-infinity problem when hop-count=cost?
  - **Answer:** set any distance > n as invalid

- How will you solve the problem if link delay is the cost?
Comparison of LS and DV algorithms

message complexity
- **LS**: with n nodes $O(n^3)$ msgs sent
- **DV**: exchange between neighbors only
  - convergence time varies

speed of convergence
- **LS**: $O(n^2)$ algorithm requires $O(n^3)$ msgs
  - may have oscillations
- **DV**: convergence time varies
  - may be routing loops
  - count-to-infinity problem
1. introduction
2. virtual circuit and datagram networks
3. routing algorithms
   - naive protocol: flooding, random
   - link state routing
   - distance vector routing
   - hierarchical routing
   - broadcast routing
   - multicast routing
   - routing in mobile hosts
   - routing in ad hoc networks
4. IP: Internet Protocol
   - datagram format
   - IPv4 addressing
   - ICMP
   - IPv6
5. routing in the Internet
   - RIP
   - OSPF
   - BGP
Hierarchical routing

our routing study thus far - idealization
- all routers identical
- network “flat”
... not true in practice

**scale:** with 600 million destinations:
- can’t store all dest’s in routing tables!
- routing table exchange would swamp links!

**administrative autonomy**
- internet = network of networks
- each network admin may want to control routing in its own network
Hierarchical routing

- aggregate routers into regions, “autonomous systems” (AS)
- routers in same AS run same routing protocol
  - “intra-AS” routing protocol
  - routers in different AS can run different intra-AS routing protocol
- **gateway router:**
  - at “edge” of its own AS
  - has link to router in another AS
**Interconnected AS**

- forwarding table configured by both intra- and inter-AS routing algorithm
  - intra-AS sets entries for internal dests
  - inter-AS & intra-AS sets entries for external dests
**Inter-AS tasks**

- Suppose router in AS1 receives datagram destined outside of AS1:
  - Router should forward packet to gateway router, but which one?

**AS1 must:**

1. Learn which dests are reachable through AS2, which through AS3
2. Propagate this reachability info to all routers in AS1

*job of inter-AS routing!*
Example: setting forwarding table in router 1d

- Suppose AS1 learns (via inter-AS protocol) that subnet x reachable via AS3 (gateway 1c), but not via AS2
  - Inter-AS protocol propagates reachability info to all internal routers

- Router 1d determines from intra-AS routing info that its interface I is on the least cost path to 1c
  - Installs forwarding table entry \((x, I)\)
Example: choosing among multiple ASes

- now suppose AS1 learns from inter-AS protocol that subnet $x$ is reachable from AS3 and from AS2.
- to configure forwarding table, router 1d must determine which gateway it should forward packets towards for dest $x$
  - this is also job of inter-AS routing protocol!
Example: choosing among multiple ASes

- now suppose AS1 learns from inter-AS protocol that subnet $x$ is reachable from AS3 \textit{and} from AS2.
- to configure forwarding table, router 1d must determine towards which gateway it should forward packets for dest $x$
  - this is also job of inter-AS routing protocol!
- \textit{hot potato routing: send} packet towards closest of two routers.

<table>
<thead>
<tr>
<th>learn from inter-AS protocol that subnet $x$ is reachable via multiple gateways</th>
<th>use routing info from intra-AS protocol to determine costs of least-cost paths to each of the gateways</th>
<th>hot potato routing: choose the gateway that has the smallest least cost</th>
<th>determine from forwarding table the interface $I$ that leads to least-cost gateway. Enter $(x,I)$ in forwarding table</th>
</tr>
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Broadcast routing

- deliver packets from source to all other nodes
- source duplication → **N-way unicast** → inefficient:

- source duplication: how does source determine recipient addresses?
Broadcast Techniques

- *flooding*: when node receives broadcast packet, sends copy to all neighbors
  - problems: cycles & broadcast storm
- *controlled flooding*: node only broadcasts pkt if it hasn’t broadcast same packet before
  - node keeps track of packet ids already broadcasted
  - or reverse path forwarding (RPF): only forward packet if it arrived on shortest path between node and source

*Can we broadcast where no redundant packets are received by any node?*
Broadcast Techniques

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- **spanning tree**:
  - no redundant packets received by any node. Why?
Spanning tree

- first construct a spanning tree
- nodes then forward/make copies only along spanning tree

(a) broadcast initiated at A
(b) broadcast initiated at D
Spanning tree construction

- How will we construct a spanning tree?
Spanning tree construction

- How will we construct a spanning tree?
  - Depth-first search (DFS)
  - Center-based approach (CBA)
Spanning tree construction: CBA

- center node
- each node sends unicast join message to center node
  - message forwarded until it arrives at a node already belonging to spanning tree

(a) stepwise construction of spanning tree (center: E)

(b) constructed spanning tree
Spanning tree construction

- Now consider each link has an associated cost.
- How will we construct a spanning tree?
Spanning tree construction

- Now consider each link has an associated cost.
- How will we construct a spanning tree?

- Construct a minimum spanning tree. How?