More on IP and the Network Layer

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The Internet Protocol
- Addressing, LAN grouping of addresses
- Packet format
- Hierarchical routing:
  - intra-AS (RIP, OSPF)
  - inter-AS (BGP)

IPv6
- A key motivation: address depletion
  - 128-bit addresses
- Additional motivation:
  - simplification help speed processing/forwarding
    - fixed-length 40 byte header
  - no fragmentation allowed in intermediate routers
  - header changes to facilitate QoS
  - flow label
  - new “anycast” address: route to one of a set of several servers

Transition From IPv4 To IPv6
- It is difficult to change the network layer protocol
  - The large number of routers and administrative autonomy makes simultaneous change impossible.
  - Routers speaking different protocols do not naturally work together.
- Two proposed approaches:
  - Dual Stack: some routers with dual stack (v6, v4) can “translate” between formats.
### Dual Stack Approach

Two kinds of routers:
- IPv4 only
- IPv6 capable

![Diagram of dual stack approach]

- Need v4/v6 address translation.
- Problems: lose some header info, require v4 support on all nodes.

### Tunneling Approach

- Logical view:
  - A-to-B: IPv6
  - B-to-C: IPv4
  - D-to-E: IPv4
  - E-to-F: IPv6

- Physical view:
  - A-to-B: IPv6 inside IPv4
  - D-to-E: IPv6 inside IPv4

- Think of v4 as the lower (link-layer) protocol.

### IPv6 Deployment

IPv6 deployment is slow:
- Resistance to change since you see little benefit when few others support new protocol due to lack of critical mass to produce large benefit.
- v4/v6 co-existence requires backward compatibility (means additional overhead and complexity).

Address depletion is delayed by incremental techniques like DHCP and NAT.

### Multicast

- **Multicast**: act of sending packet to multiple receivers with single "transmit" operation.
- Applications:
  - Internet radio
  - Network conferencing
  - Multiplayer games
  - …
Multicast via Multiple Unicasts

- Multicast via unicast
  - source sends N unicast packets, one addressed to each of N receivers
  - no change on routers
  - problem?

Ideal Network Multicast

- Router actively participate in multicast, making copies of packets as needed and forwarding towards multicast receivers

Local and Wide-Area Multicast Management

- **Local**: host informs local mcast router of desire to join group
  - IGMP (Internet Group Management Protocol)
- **Wide area**: local router interacts with other routers to receive mcast packet flow

Shortest Path Tree

- **Goal**: find path/paths (tree) connecting multicast routers having local mcast group members
- Tree of shortest path routes from source to all receivers
  - Dijkstra’s algorithm

$S$: source

R1

R2

R3

R4

R5

R6

R7
Reverse Path Forwarding

What if we don’t have global network information?

Goal is to forward along shortest paths. **Heuristic:**
- not to forward when packets clearly have deviated from the shortest paths;
- rely on router’s knowledge of unicast routing table.

```plaintext
if (mcast packet received on incoming link on shortest path back to source)
    then flood packet onto all outgoing links
else ignore packet
```

Reverse Path Forwarding: Example

- result is a source-specific reverse SPT
- problem: reaching routers that are not in the group

Reverse Path Forwarding: Pruning

- forwarding tree contains subtrees with no mcast group members
  - “prune” msgs sent upstream by router with no downstream group members

Wide-area Multicast Routing

**Goal:** find path/paths (tree) connecting multicast routers.

- source-based tree: one tree per source
- shortest path trees, reverse path forwarding
- group-shared tree: group uses one tree
Shared-Tree Multicast

- Assume complete global network information is available, derive minimum cost tree connecting all relevant routers
  - Steiner tree
  - problem is NP-complete

A Distributed Solution: Center-based Tree

- One router identified as “center” of tree
- To join:
  - edge router sends unicast join-msg addressed to center router
  - join-msg "processed" by intermediate routers and forwarded towards center
  - join-msg either hits existing tree branch for this center, or arrives at center
  - path taken by join-msg becomes new branch of tree for this router
- How to define a "good" center router?

Comparison

Compare reverse path forwarding with center-based tree

- Better multicast delivery along shortest paths produced by reverse path forwarding
- Too much pruning in a "sparse" system with relatively few interested routers

Internet Multicast Routing

- DVMRP
  - distance vector multicast routing protocol, based on reverse path forwarding and pruning
- PIM
  - in a sparse mode where DVMRP doesn't do well, it uses center-based trees
- IP multicast deployment?
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