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Chapter 4: Network Layer

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4.3 What’s inside a router
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   - Datagram format
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   - ICMP
   - IPv6
4.5 Routing algorithms
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   - Distance Vector
   - Hierarchical routing
4.6 Routing in the Internet
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   - OSPF
   - BGP
4.7 Broadcast and multicast routing
Multicast Routing: Problem Statement

- **Goal:** find a tree (or trees) connecting routers having local mcast group members
  - *tree:* not all paths between routers used
  - *source-based:* different tree from each sender to rcvrs
  - *shared-tree:* same tree used by all group members
## Why Johnny can’t multicast?

### Broadcast
- Flooding (PI)
- Spanning trees
  - Avoid duplication
  - Allow termination (PIF)
  - Reduces memory
- Optimal:
  - Needs full information
  - Minimum spanning tree
  - Prim-Dijkstra or Kruskal
- Distributed:
  - Reverse Path Forwarding
  - Center based tree

### Multicast
- Flooding = overshooting
- Spanning trees
- Optimal: Steiner Tree
  - Needs full information
  - NP Hard, approximable
- Distributed:
  - All the others + Pruning
- Not really used
  - Inter-domain routing hard
  - Congestion control hard
  - What is used instead: mesh, epidemic, p2p
**Shared-Tree: Steiner Tree**

- **Steiner Tree**: minimum cost tree connecting all routers with attached group members
- Problem is NP-complete
- Excellent heuristics exists
- Not used in practice:
  - Computational complexity
  - Information about entire network needed
  - Monolithic: rerun whenever a router needs to join/leave
Approaches for building mcast trees

Approaches:
- source-based tree: one tree per source
  - shortest path trees
  - reverse path forwarding
- group-shared tree: group uses one tree
  - minimal spanning (Steiner)
  - center-based trees

...we first look at basic approaches, then specific protocols adopting these approaches
Shortest Path Tree

- mcast forwarding tree: tree of shortest path routes from source to all receivers
  - Dijkstra’s algorithm

LEGEND

S: source

router with attached group member

router with no attached group member

link used for forwarding, i indicates order link added by algorithm
Reverse Path Forwarding

- rely on router’s knowledge of unicast shortest path from it to sender
- each router has simple forwarding behavior:

  \[
  \text{if} \ (\text{mcast datagram received on incoming link on shortest path back to center}) \\
  \quad \text{then} \text{ flood datagram onto all outgoing links} \\
  \quad \text{else} \text{ ignore datagram}
  \]
Reverse Path Forwarding: example

- result is a source-specific reverse SPT
  - may be a bad choice with asymmetric links
Reverse Path Forwarding: pruning

- forwarding tree contains subtrees with no mcast group members
  - no need to forward datagrams down subtree
  - “prune” msgs sent upstream by router with no downstream group members

**LEGEND**
- router with attached group member
- router with no attached group member
- prune message
- links with multicast forwarding
Center-based trees

- single delivery tree shared by all
- 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
Center-based trees: an example

Suppose R6 chosen as center:

LEGEND
- router with attached group member
- router with no attached group member
- path order in which join messages generated
Internet Multicasting Routing: DVMRP

- **DVMRP**: distance vector multicast routing protocol, RFC1075
- **flood and prune**: reverse path forwarding, source-based tree
  - RPF tree based on DVMRP’s own routing tables constructed by communicating DVMRP routers
  - no assumptions about underlying unicast
  - initial datagram to mcast group flooded everywhere via RPF
  - routers not wanting group: send upstream prune msgs
DVMRP: continued...

- **soft state:** DVMRP router periodically (1 min.) “forgets” branches are pruned:
  - mcast data again flows down unpruned branch
  - downstream router: reprune or else continue to receive data

- routers can quickly regraft to tree
  - following IGMP join at leaf

- odds and ends
  - commonly implemented in commercial routers
  - Mbone routing done using DVMRP
Tunneling

**Q:** How to connect “islands” of multicast routers in a “sea” of unicast routers?

- mcast datagram encapsulated inside “normal” (non-multicast-addressed) datagram
- normal IP datagram sent thru “tunnel” via regular IP unicast to receiving mcast router
- receiving mcast router unencapsulates to get mcast datagram
PIM: Protocol Independent Multicast

- not dependent on any specific underlying unicast routing algorithm (works with all)
- two different multicast distribution scenarios:
  
  **Dense:**
  - group members densely packed, in “close” proximity.
  - bandwidth more plentiful

  **Sparse:**
  - # networks with group members small wrt # interconnected networks
  - group members “widely dispersed”
  - bandwidth not plentiful
Consequences of Sparse-Dense Dichotomy:

**Dense**
- group membership by routers *assumed* until routers explicitly prune
- *data-driven* construction on mcast tree (e.g., RPF)
- bandwidth and non-group-router processing *profligate*

**Sparse**:  
- no membership until routers explicitly join
- *receiver-driven* construction of mcast tree (e.g., center-based)
- bandwidth and non-group-router processing *conservative*
PIM - Dense Mode

flood-and-prune RPF, similar to DVMRP but

- underlying unicast protocol provides RPF info for incoming datagram
- less complicated (less efficient) downstream flood than DVMRP reduces reliance on underlying routing algorithm
- has protocol mechanism for router to detect if it is a leaf-node router
PIM - Sparse Mode

- center-based approach
- router sends join msg to rendezvous point (RP)
  - intermediate routers update state and forward join
- after joining via RP, router can switch to source-specific tree
  - increased performance: less concentration, shorter paths
sender(s):
- unicast data to RP, which distributes down RP-rooted tree
- RP can extend mcast tree upstream to source
- RP can send stop msg if no attached receivers
  - “no one is listening!”
Chapter 4: summary

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