IP Multicasting

Relates to Lab 10.

It covers IP multicasting, including multicast addressing, IGMP, and multicast routing.

Applications with multiple receivers

- Many applications transmit the same data at one time to multiple receivers
    - Broadcasts of Radio or Video
    - Videoconferencing
    - Shared Applications

- A network must have mechanisms to support such applications in an efficient manner

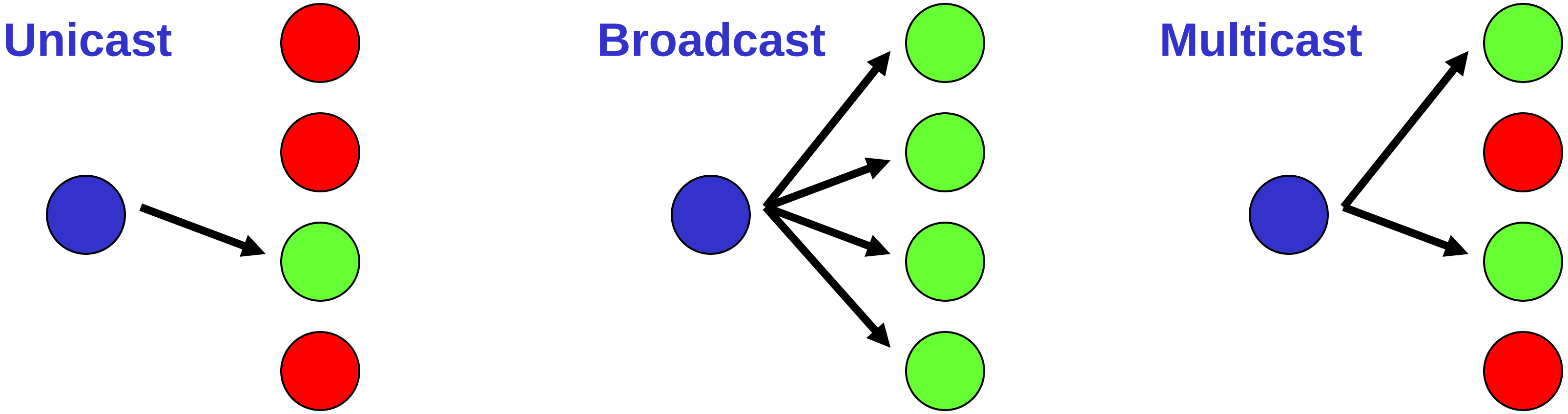
Motivation

"Together, Internet broadcasting and multicasting are the next chapters in the evolution of the Internet as a revolutionary catalyst for the information age."

Vint Cerf,Senior vice president of MCI/Worldcom,April 1999.

Multicasting

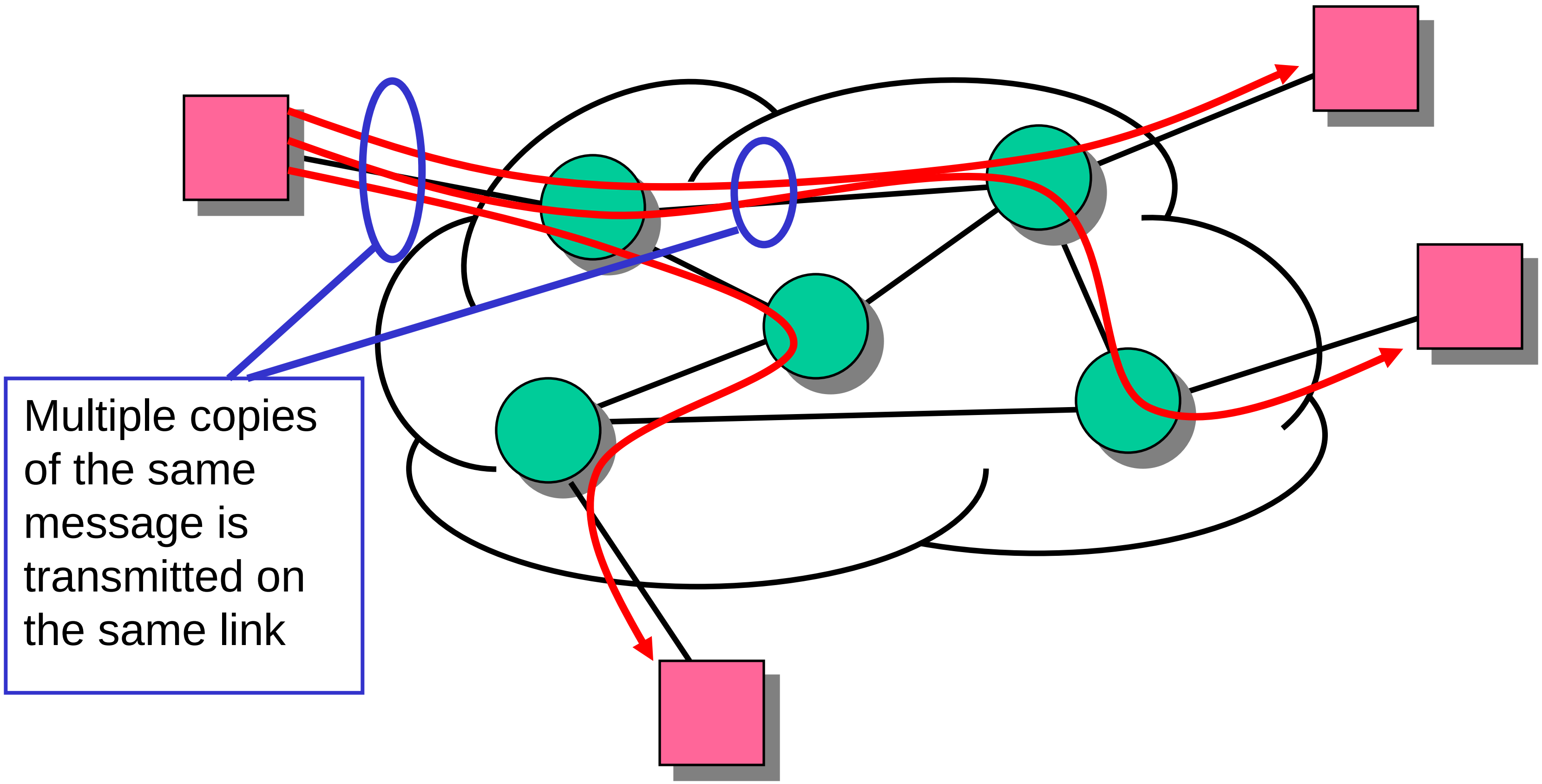
- Multicast communications refers to one-to-many or many-to-many communications.



IP Multicasting refers to the implementation of multicast communication in the Internet

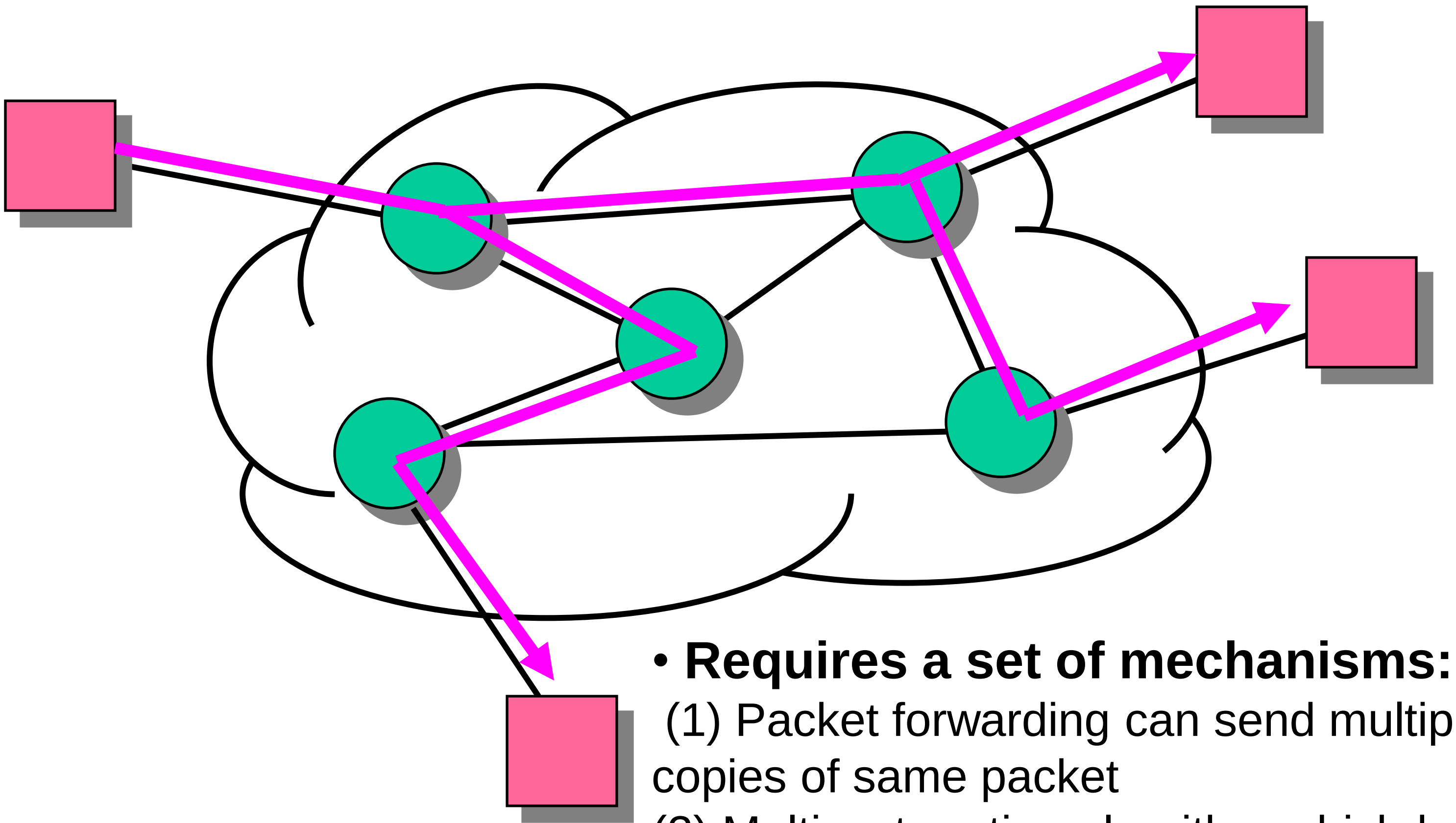
Multicasting over a Packet Network

- Without support for multicast at the network layer:



Multicasting over a Packet Network

- With support for multicast at the network layer:



- **Requires a set of mechanisms:**
 (1) Packet forwarding can send multiple copies of same packet
(2) Multicast routing algorithm which builds a spanning tree (dynamically)

Semantics of IP Multicast

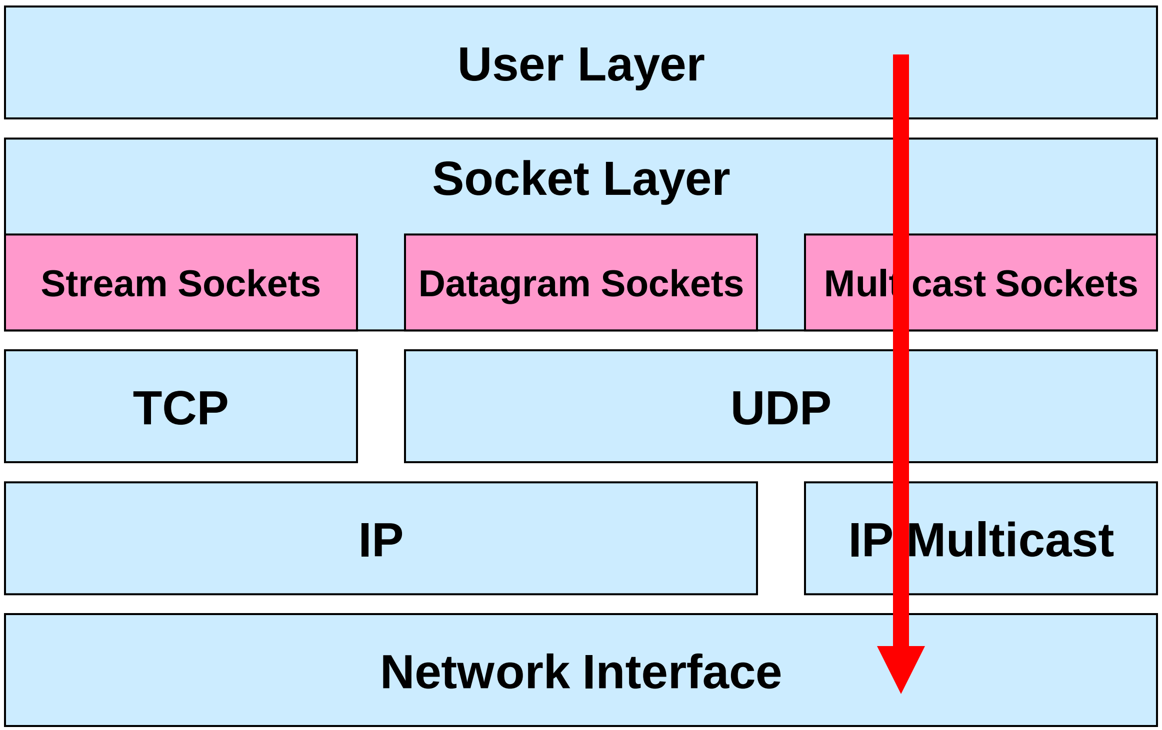
IP multicast works as follows:

- Multicast groups are identified by IP addresses in the range 224.0.0.0 - 239.255.255.255 (class D address)
- Every host (*more precisely:* interface) can join and leave a multicast group dynamically
  - » no access control
- Every IP datagram send to a multicast group is transmitted to all members of the group
  - » no security, no “floor control”

- The IP Multicast service is unreliable

The IP Protocol Stack

- IP Multicasting only supports UDP as higher layer
- There is no multicast TCP !



IP Multicasting

- There are three essential components of the IP Multicast service:

IP Multicast Addressing
IP Group Management
Multicast Routing

Multicast Addressing

- All Class D addresses are multicast addresses:

Class D	1	1	1	0	multicast group id
					28 bits

Class	From	To
D	224.0.0.0	239.255.255.255

- Multicast addresses are dynamically assigned.
- An IP datagram sent to a multicast address is forwarded to everyone who has joined the multicast group
- If an application is terminated, the multicast address is (implicitly) released.

Types of Multicast addresses

- The range of addresses between 224.0.0.0 and 224.0.0.255, inclusive, is reserved for the use of routing protocols and other low-level topology discovery or maintenance protocols
- Multicast routers should not forward any multicast datagram with destination addresses in this range.

- Examples of special and reserved Class D addresses, e.g,

224.0.0.1	All systems on this subnet
224.0.0.2	All routers on this subnet
224.0.1.1	NTP (Network Time Protocol)
224.0.0.9	RIP-2 (a routing protocol)

Multicast Address Translation

- In Ethernet MAC addresses, a multicast address is identified by setting the lowest bit of the “most left byte”

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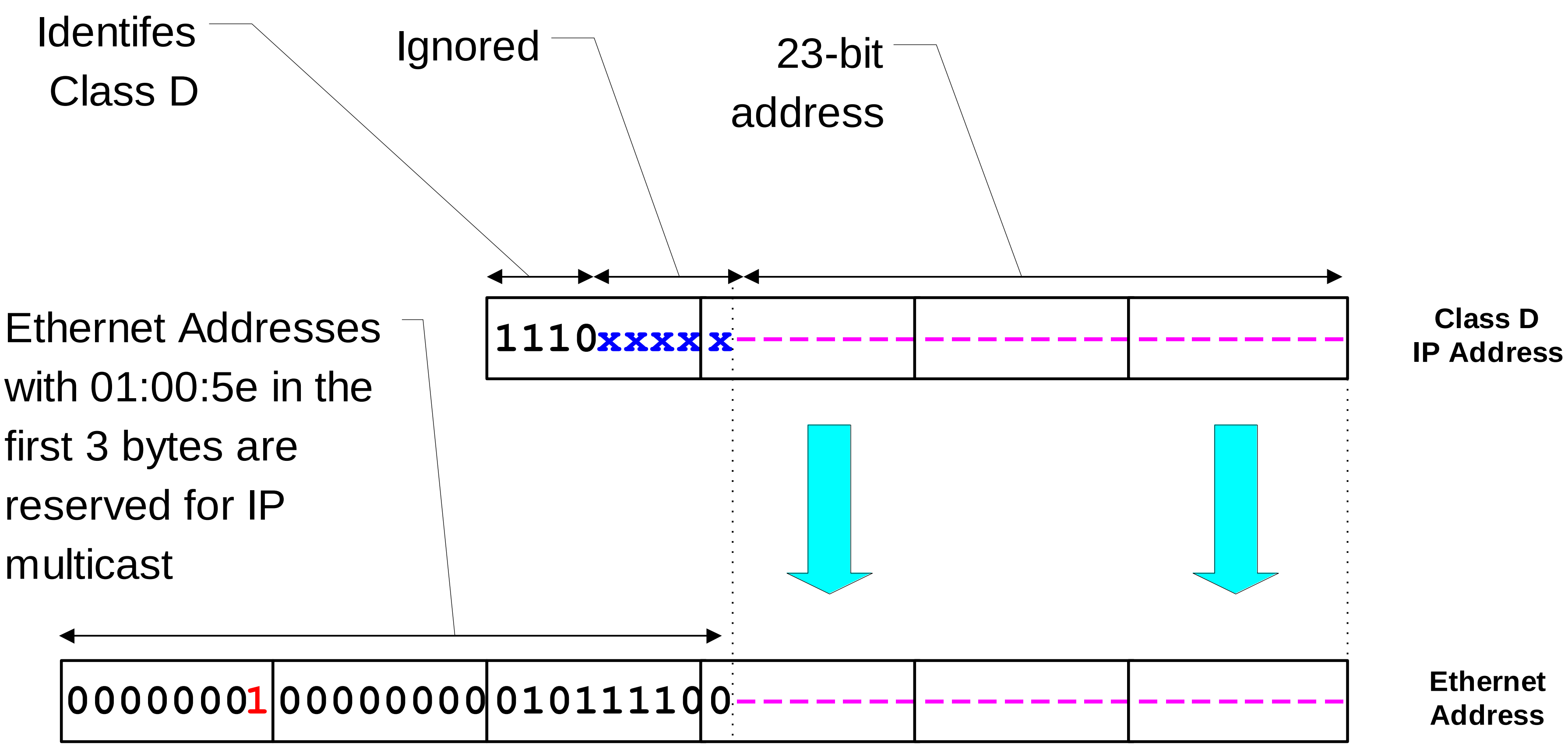
Not all Ethernet cards can filter multicast addresses in hardware

- Then: Filtering is done in software by device driver.

Multicast Address Mapping



IGMP

- The **Internet Group Management Protocol (IGMP)** is a simple protocol for the support of IP multicast.
- IGMP is defined in RFC 1112.
- IGMP operates on a physical network (e.g., single Ethernet Segment.
- IGMP is used by multicast routers to keep track of membership in a multicast group.
- Support for:
  - Joining a multicast group
  - Query membership
  - Send membership reports

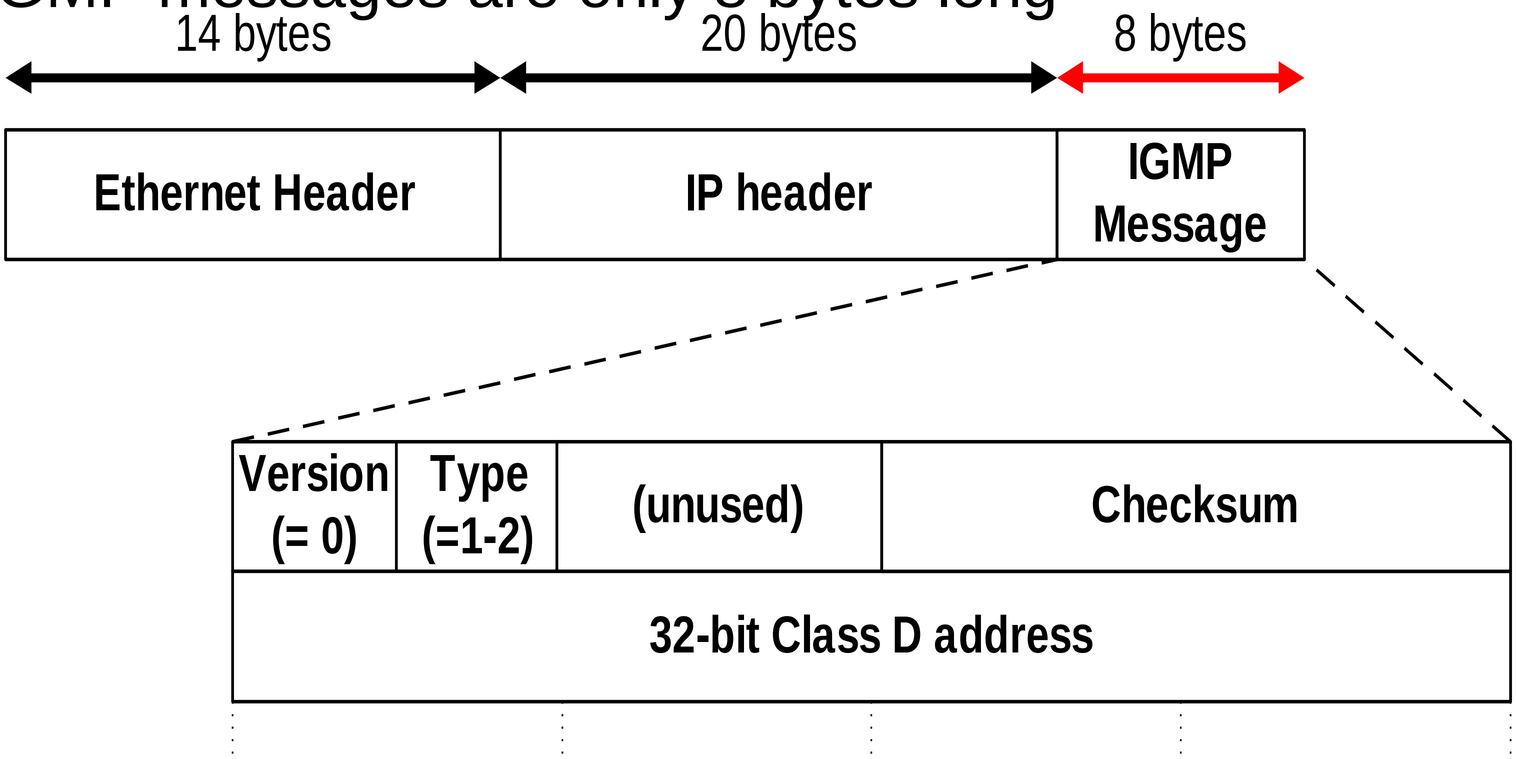
IGMP Protocol

- A host sends an IGMP report when it joins a multicast group (Note: multiple processes on a host can join. A report is sent only for the first process).
- No report is sent when a process leaves a group
- A multicast router regularly multicasts an IGMP query to all hosts (group address is set to zero).
- A host responds to an IGMP query with an IGMP report.

- Multicast router keeps a table on the multicast groups that have joined hosts. The router only forwards a packet, if there is a host still joined.
- Note: Router does not keep track which host is joined.

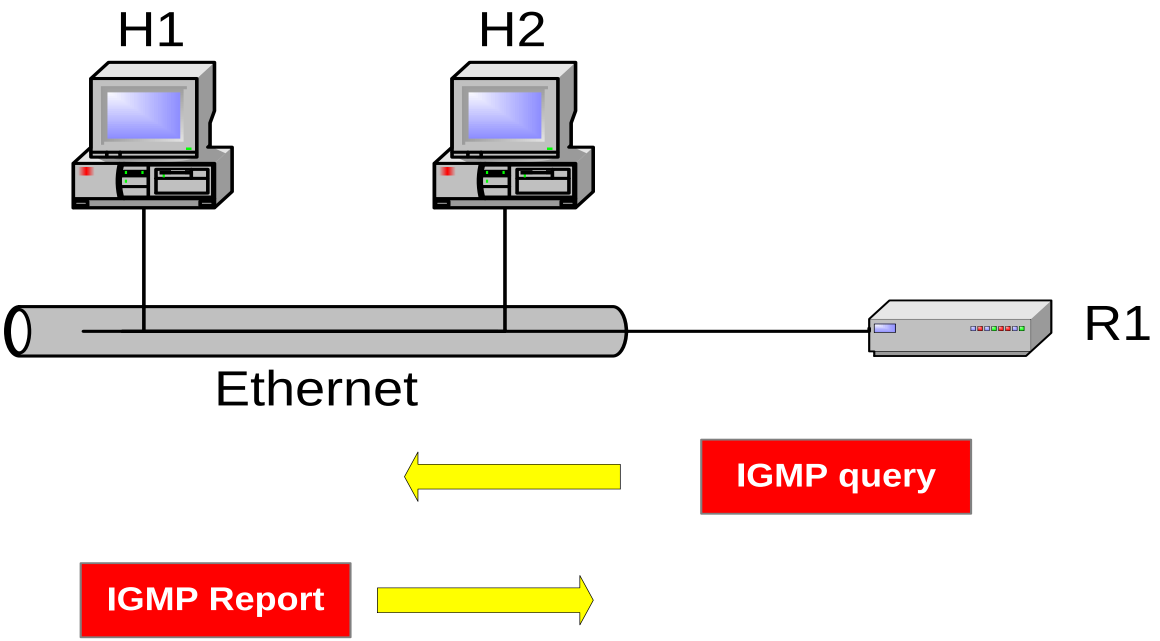
IGMP Packet Format

- IGMP messages are only 8 bytes long

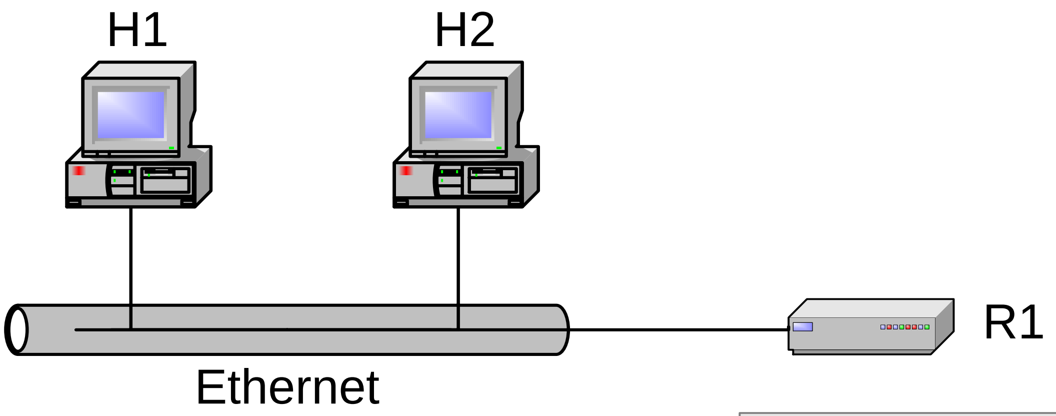


•Type: 1 = sent by router, 2 = sent by host

IGMP Protocol



IGMP Protocol



IGMP general query
IGMP group address = 0
Destination IP address = 224.0.0.1
Source IP address = router's IP address

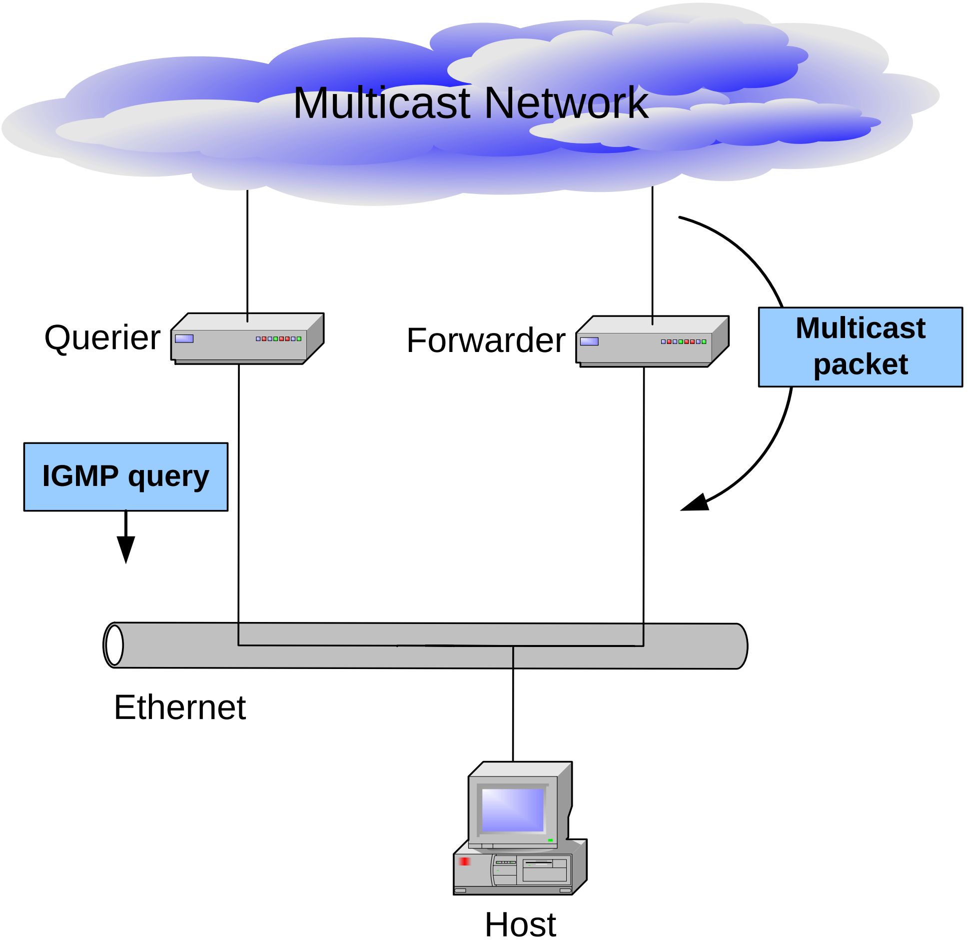
IGMP group-specific query
IGMP group address = group address
Destination IP address = group address
Source IP address = router's IP address

IGMP membership report
IGMP group address = group address
Destination IP address= group address
Source IP address = host's IP address

Networks with multiple multicast routers

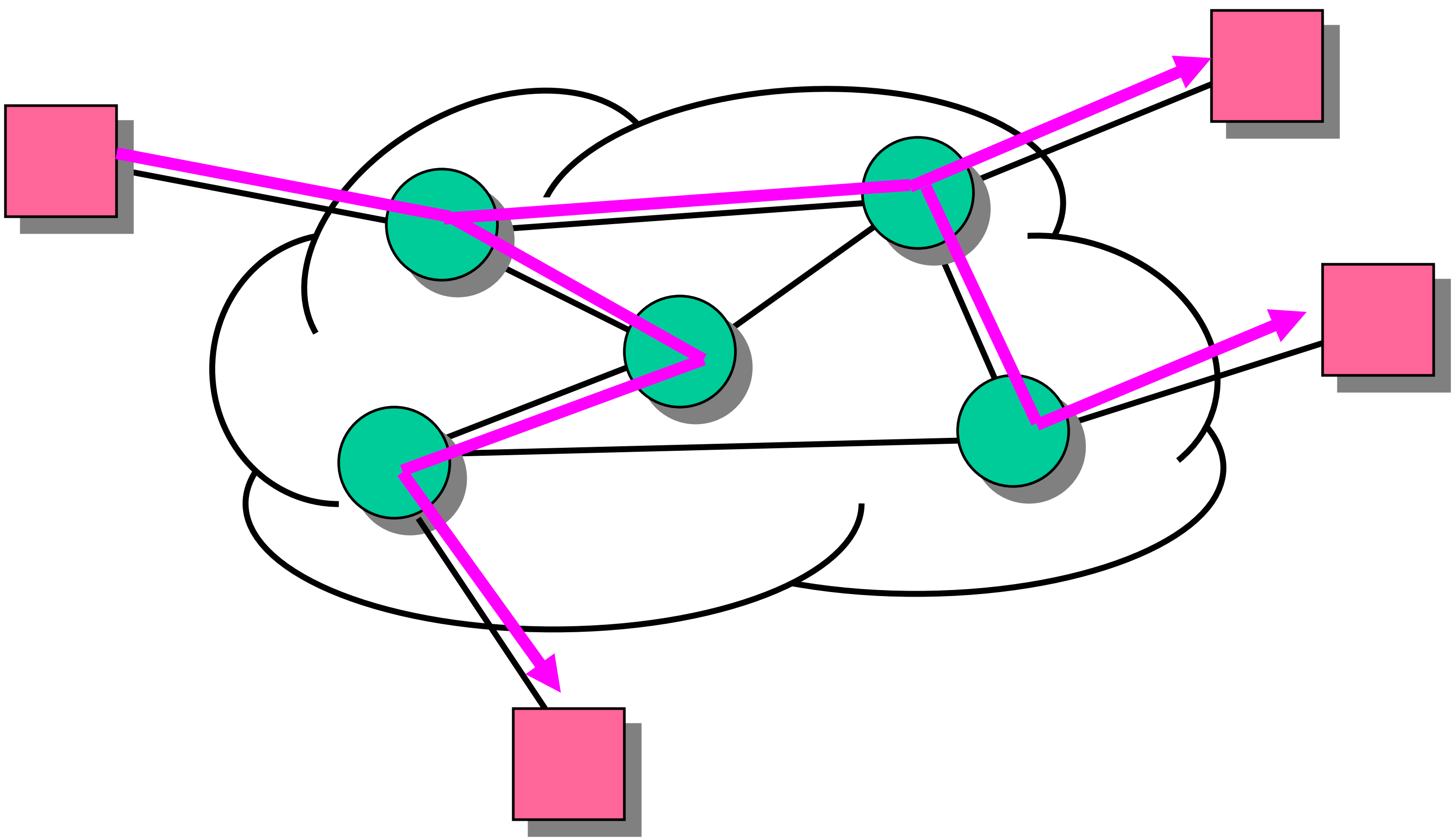
- Only one router responds to IGMP queries (***Querier***)
  - Router with smallest IP address becomes the querier on a network.

- One router forwards multicast packets to the network (***Forwarder***).



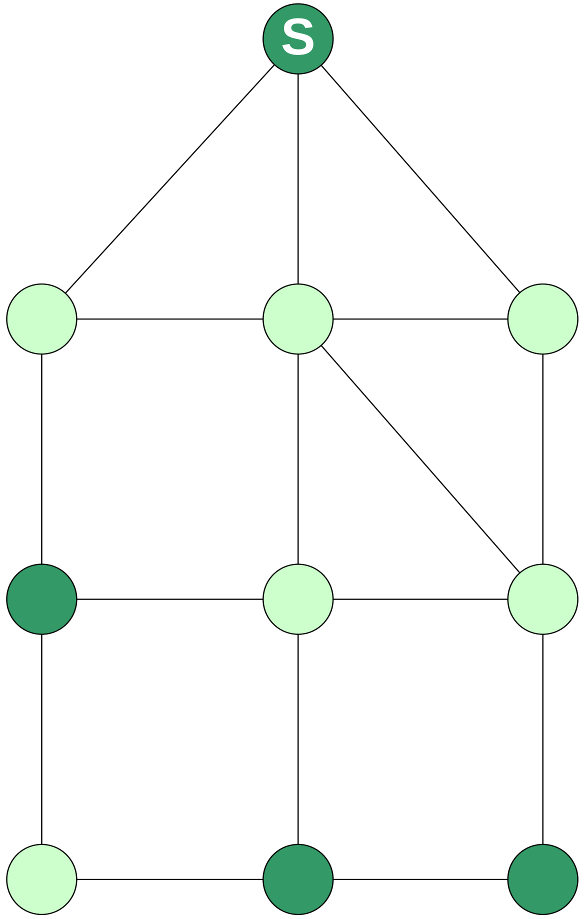
Multicast Routing Protocols

- **Goal:** Build a spanning tree between all members of a multicast group



Multicast routing as a graph problem

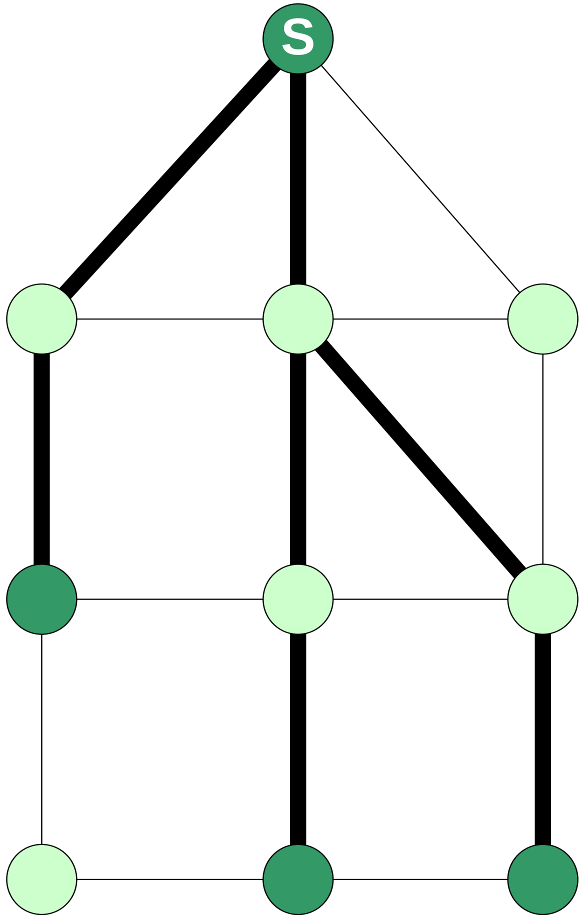
- **Problem**: Embed a tree such that all multicast group members are connected by the tree



Multicast routing as a graph problem

- **Problem**: Embed a tree such that all multicast group members are connected by the tree

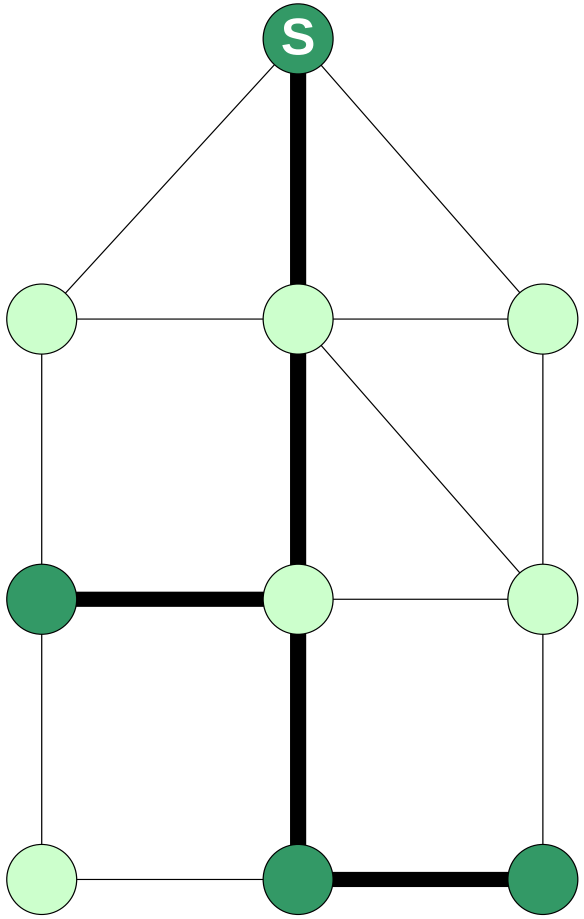
- **Solution 1:** **Shortest Path Tree or source-based tree**
  Build a tree that minimizes the path cost from the source to each receiver
  - *Good tree if there is a single sender*
  - *If there are multiple senders, need one tree per sender*
  - *Easy to compute*



Multicast routing as a graph problem

- **Problem**: Embed a tree such that all multicast group members are connected by the tree

- **Solution 2: Minimum-Cost Tree** Build a tree that minimizes the total cost of the edges
  - *Good solution if there are multiple senders*
  - *Very expensive to compute (not practical for more than 30 nodes)*



Multicast routing in practice

- Routing Protocols implement one of two approaches:

1. **Source Based Tree:**
   - Essentially implements Solution 1.
   - Builds one shortest path tree for each sender
   - Tree is built from receiver to the sender → reverse shortest path / reverse path forwarding

2. **Core-based Tree:**
   - Build a single distribution tree that is shared by all senders
   - Does not use Solution 2 (because it is too expensive)
   - Selects one router as a "core" (also called "rendezvous point")
   - All receivers build a shortest path to the core → reverse shortest path / reverse path forwarding

Reverse Path Forwarding (RPF)

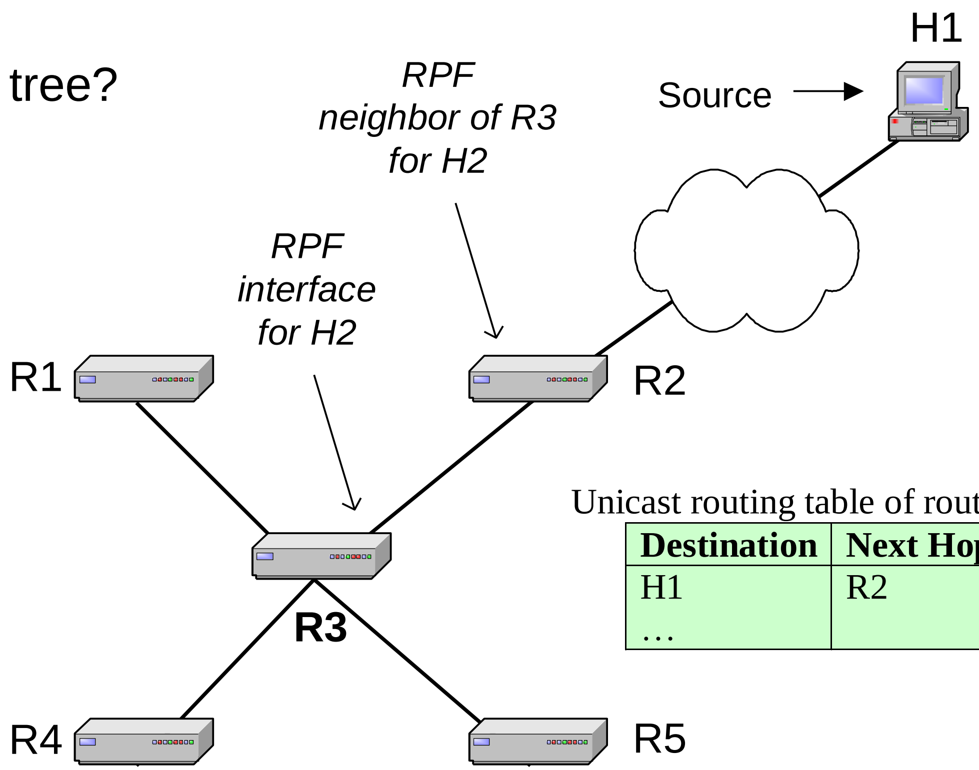
- RPF builds a shortest path tree in a distributed fashion by taking advantage of the unicast routing tables.
- **Main idea:** Given the address of the root of the tree, a router selects as its upstream neighbor in the tree the router which is the next-hop neighbor for forwarding unicast packets to the root.

- How can this be used to build a tree?

1. RPF Forwarding:

Forward a packet only if it is receives from an RPF neighbor

2. Set up multicast routing table in according from receiver to sender along the reverse shortest path tree



Unicast routing table of router R3:

Destination	Next Hop
H1	R2
…	

Multicast routing in practice

- Routing algorithms in practice implement one of two approaches:

1. **Source Based Tree Tree:**
   - Establish a reverse path to the source
2. **Core-based Tree:**
   - Establish a reverse path to the core router

Multicast Routing table

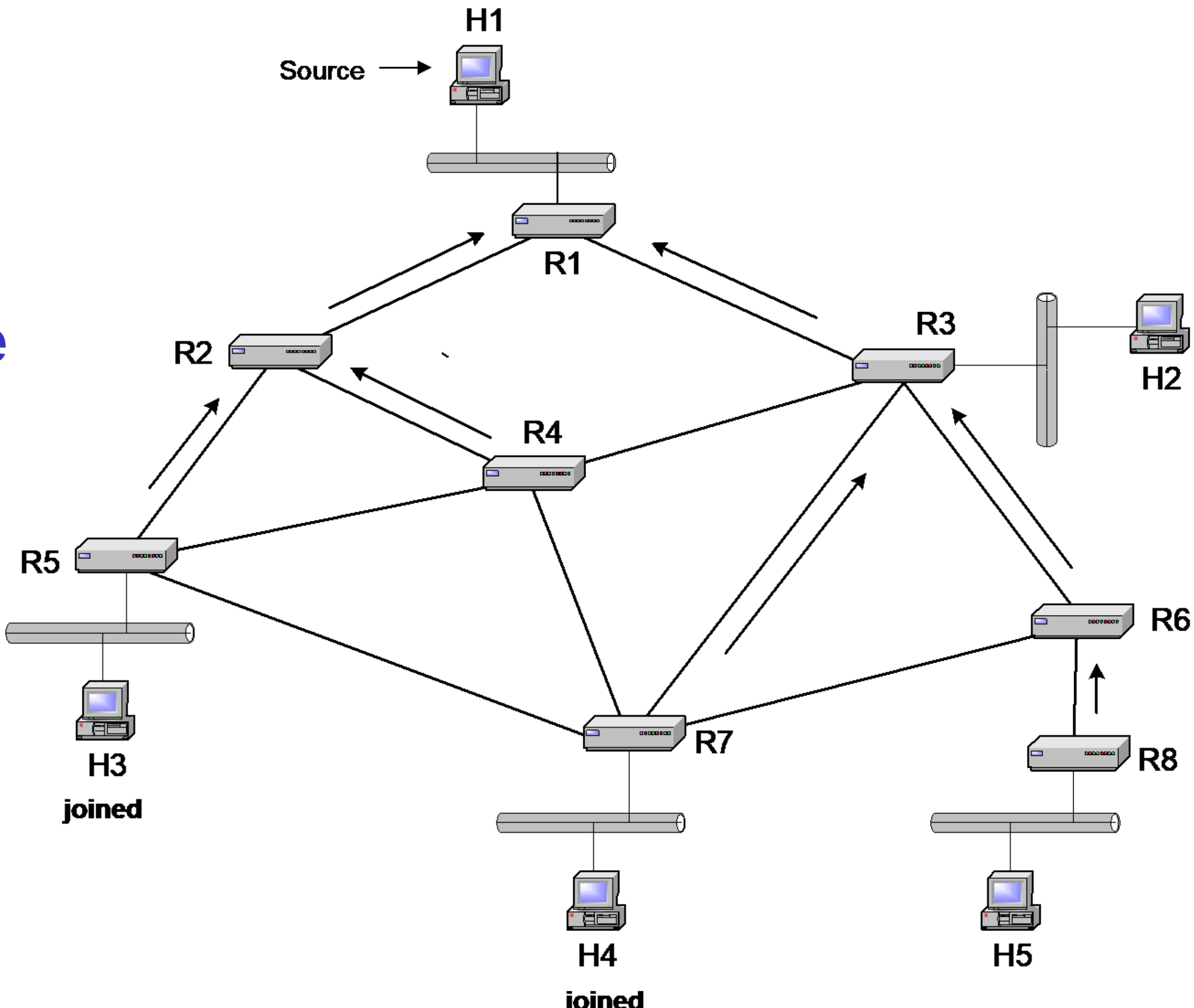
- Routing table entries for source-based trees and for core-based trees are different
  - **Source-based tree**: (Source, Group) or (S, G) entry.
  - **Core-based tree:** (*, G) entry.

Source IP address	Multicast group	Incoming interface (RPF interface)	Outgoing interface list
S1	G1	I1	I2, I3
*	G2	I2	I1, I3

Building a source-based tree

- Set routing tables according to RPF forwarding

- **Flood-and-Prune**

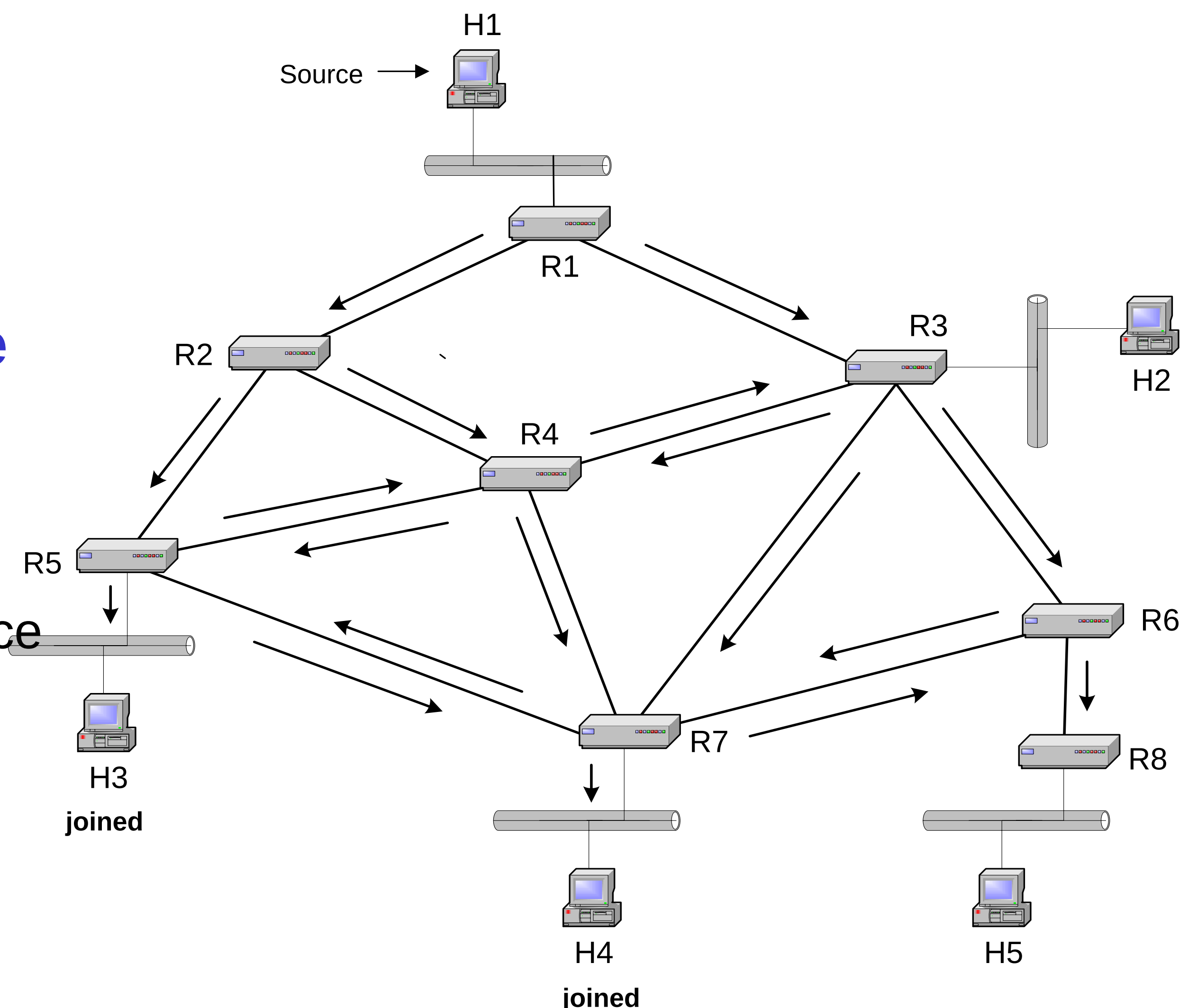


Building a source-based tree

- Set routing tables according to RPF forwarding

- **Flood-and-Prune**

Flood=
  Forward packets that arrive on RPF interface on all non-RPF interfaces



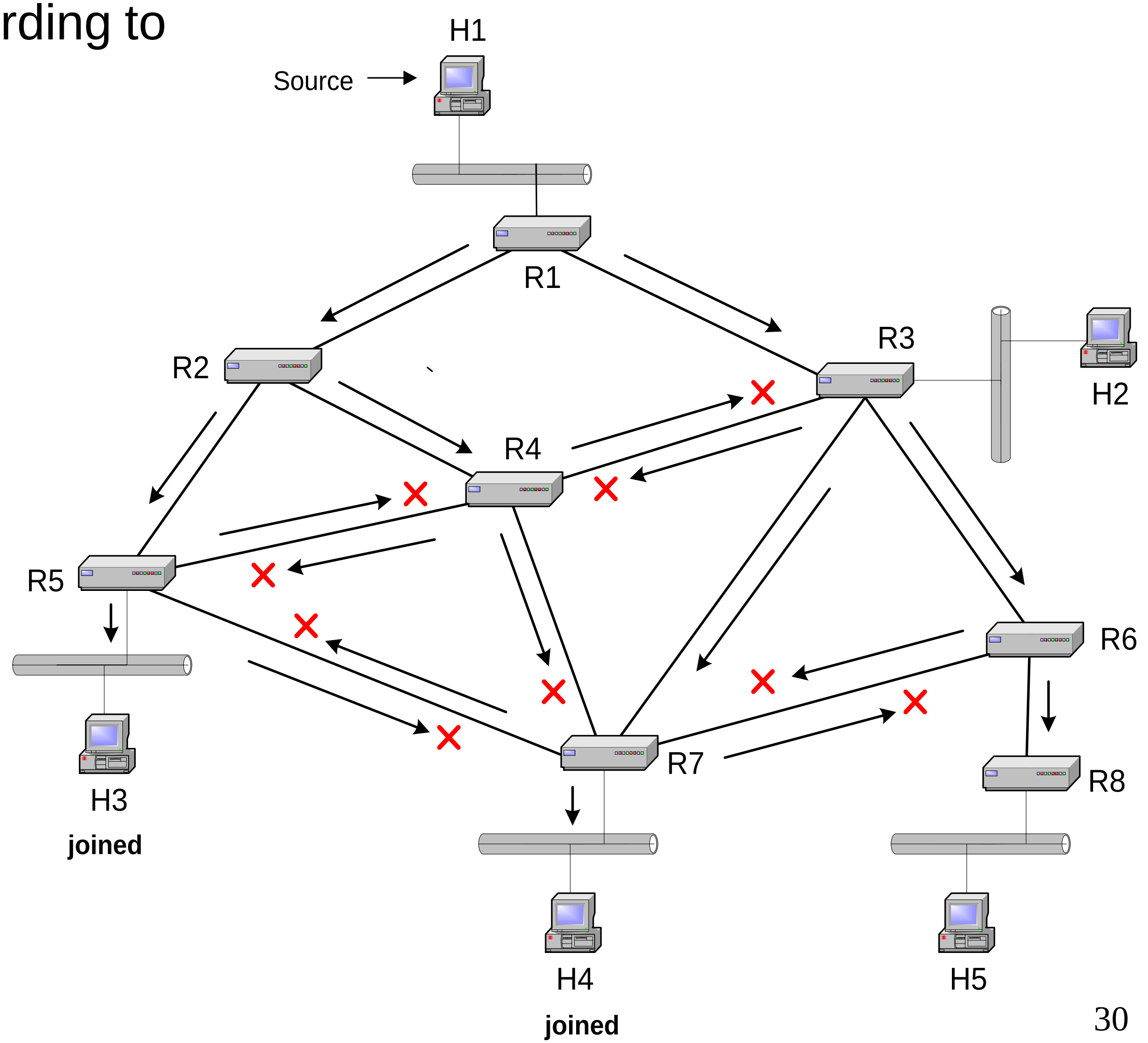
Building a source-based tree

- Set routing tables according to RPF forwarding

- **Flood-and-Prune**

Flood=
    Forward packets
    on all non-RPF interfaces

    Receiver drops packets
    not received on
    RPF interface



Building a source-based tree

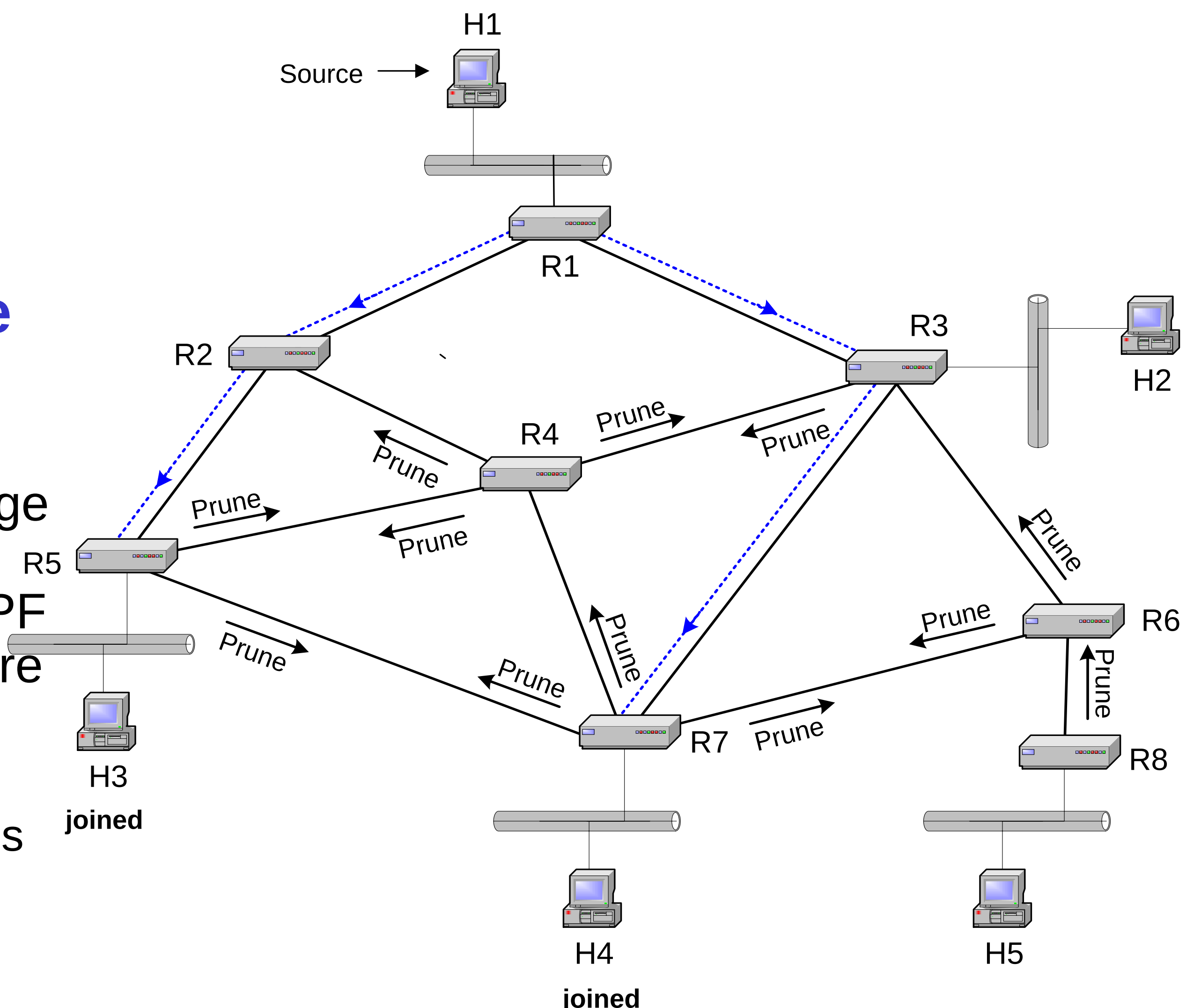
- Set routing tables according to RPF forwarding

- **Flood-and-Prune**

Prune=

Send a prune message when a packet is received on a non-RPF interface or when there are no receivers downstream

Prune message disables routing table entry



Pruning

- Prune message temporarily disables a routing table entry
  - **Effect**: Removes a link from the multicast tree
  - No multicast messages are sent on a pruned link
  - Prune message is sent in response to a multicast packet
  - *Question: Why is routing table only temporarily disabled?*

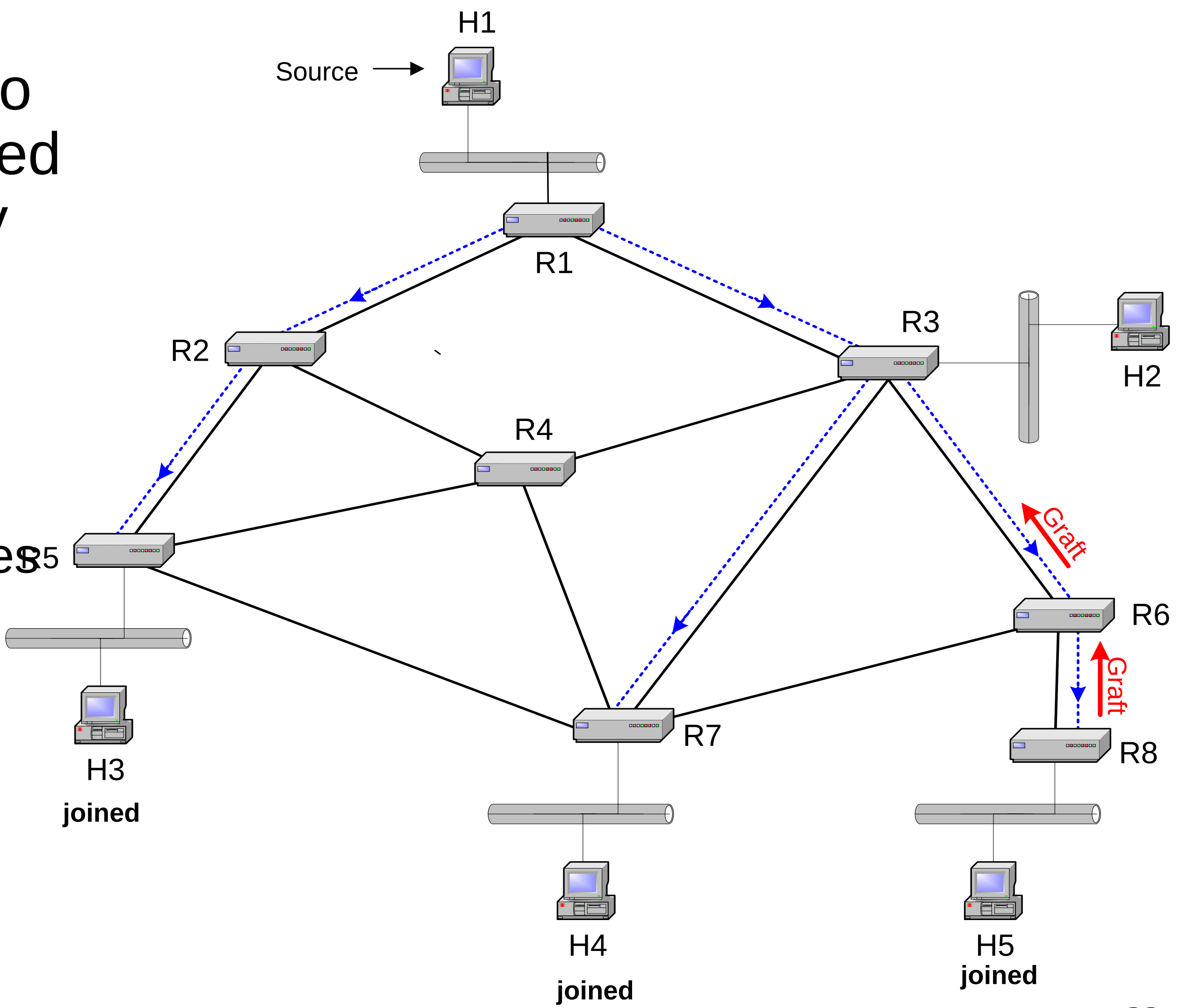
- Who sends prune messages?
  - A router with no group members in its local network and no connection to other routers
  - A router with no group members in its local network which has received a prune message on all non-RPF interfaces
  - A router with group members which has received a packet from a non-RPF neighbor

Building a source-based tree

- When a receiver joins, one needs to re-activate a pruned routing table entry

- **Grafting**

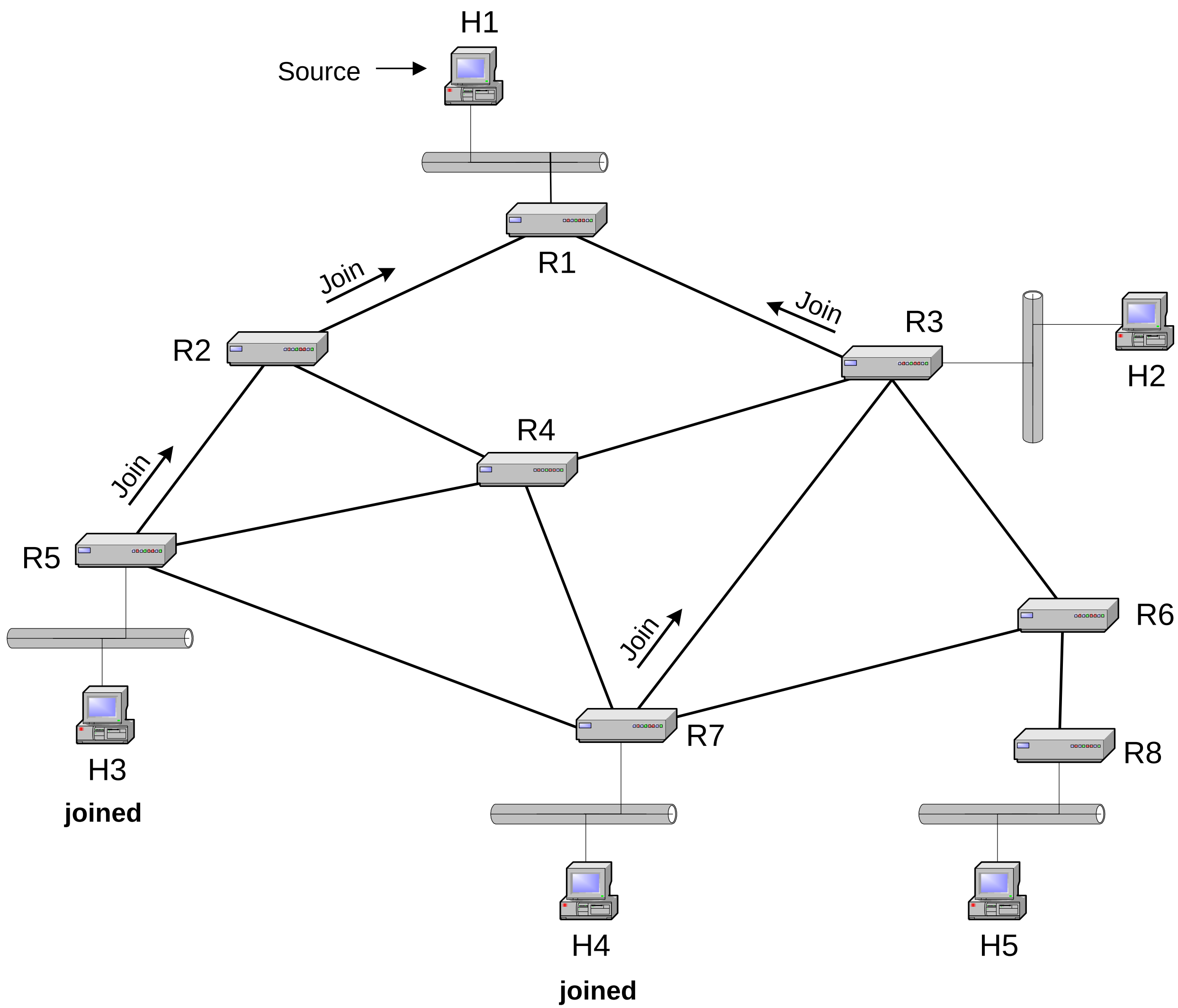
  Sending a Graft message disables prune, and re-activates routing table entry.



Alternative method for building a source-based tree

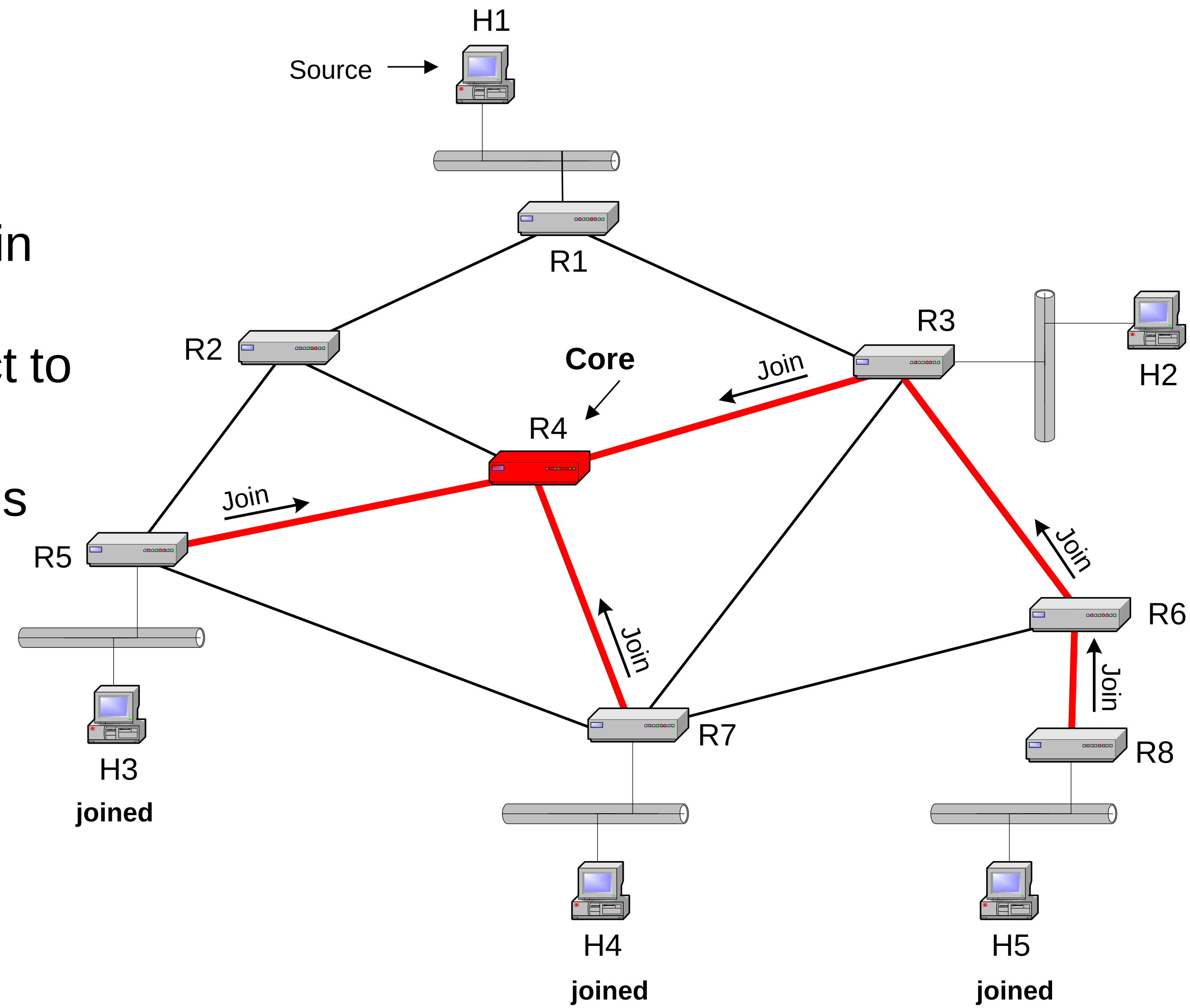
- This only works if the receiver knows the source

- **Explicit-Join**
  - Receiver sends a Join message to RPF neighbor
  - Join message creates (S,G) routing table entry
  - Join message is passed on



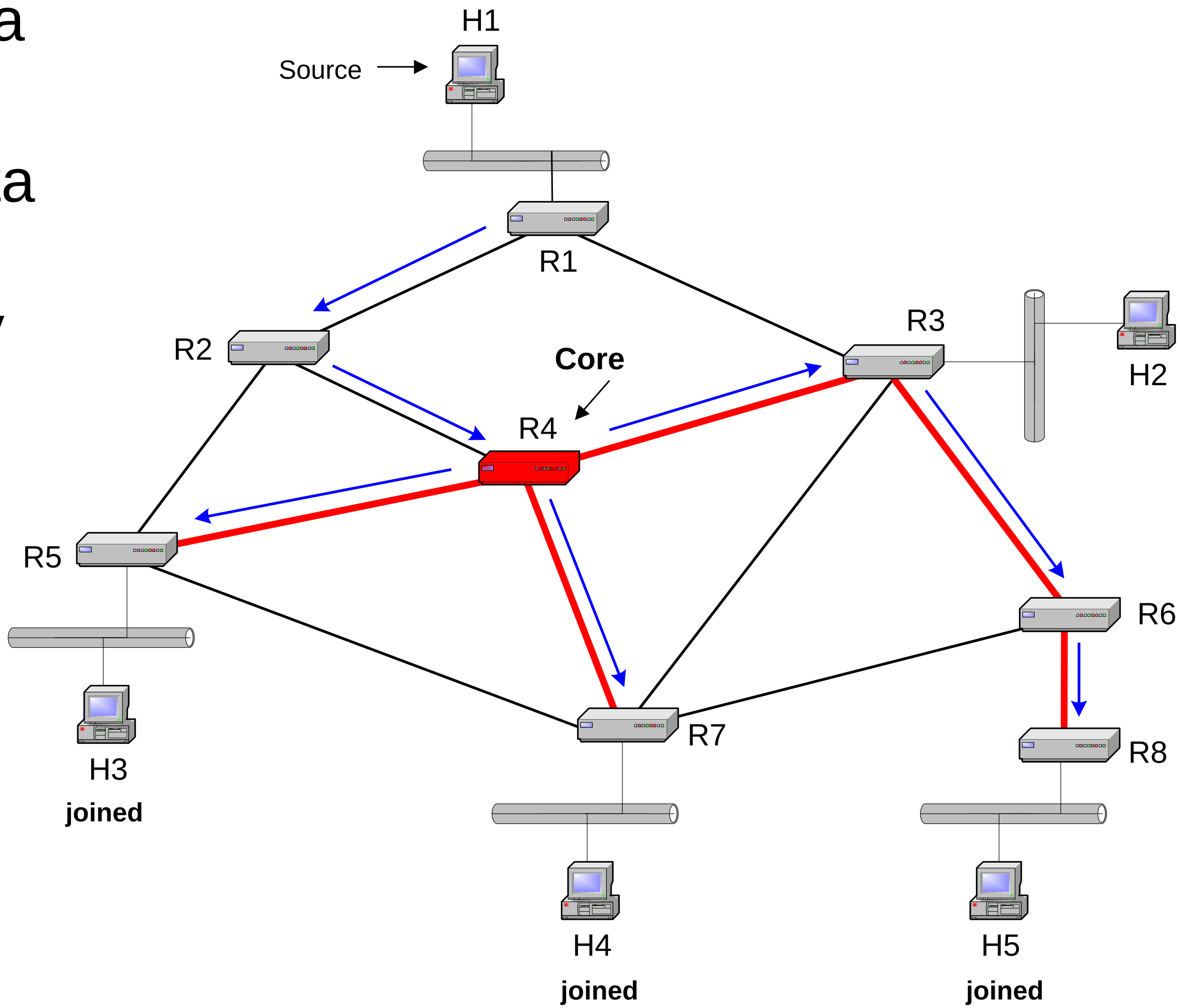
Building a core-based tree

- One route is the **core**
- Receiver sends a Join message to RPF neighbor with respect to core
- Join message creates (*, G) routing table entry



Building a core-based tree

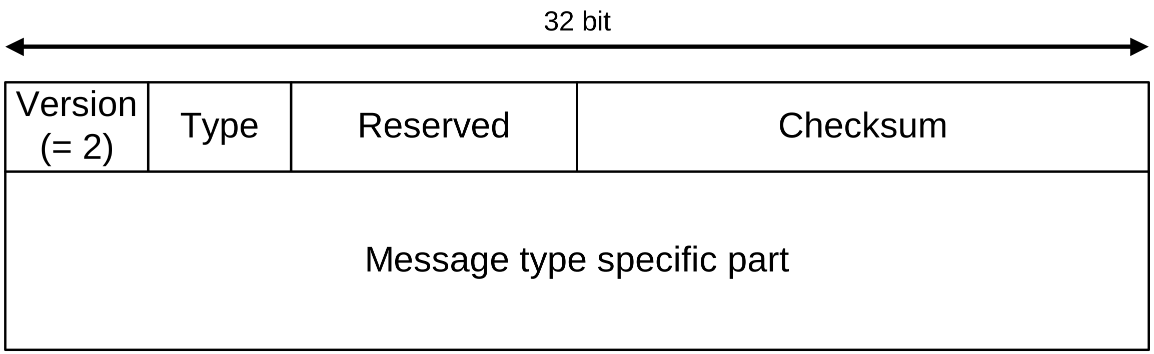
- Source sends data to the core
- Core forwards data according to routing table entry



Multicast routing protocols in the Internet

- **Distance Vector Multicast Routing Protocol (DVMRP):**
  - First multicast routing protocol
  - Implements flood-and-prune
- **Multicast Open Shortest Path First (MOSPF):**
  - Multicast extensions to OSPF. Each router calculates a shortest-path tree based on link state database
  - Not widely used
- **Core Based Tree (CBT):**
  - First core-based tree routing protocol
- **Protocol Independent Multicast (PIM):**[1]
  - Runs in two modes: PIM Dense Mode (PIM-DM) and PIM Sparse Mode (PIM-SM).
  - PIM-DM builds source-based trees using flood-and-prune
  - PIM-SM builds core-based trees as well as source-based trees with explicit joins. [1] RFC2362

PIM Messages (PIM version 2)

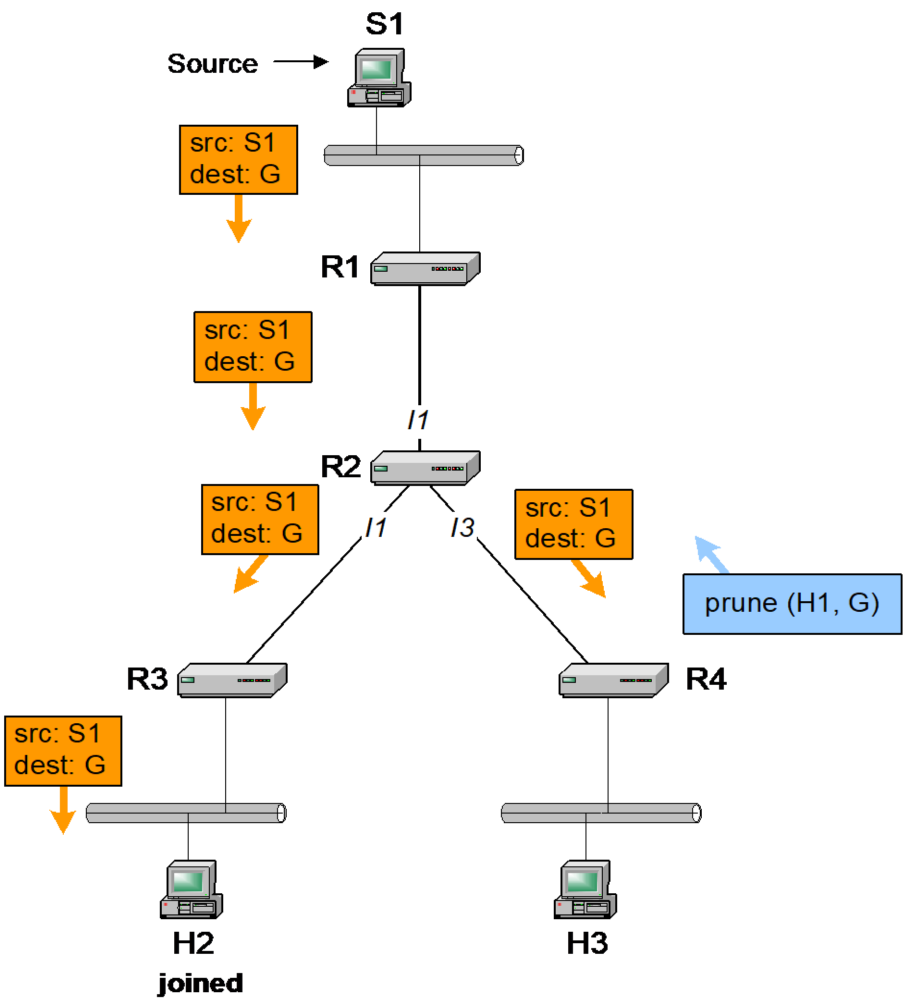


PIM-DM messages	Type	PIM-DM	PIM-SM
Hello	0	✓	✓
Register	1		✓
Register-Stop	2		✓
Join/Prune	3	✓	✓
Bootstrap	4		✓
Assert	5	✓	✓
Graft	6	✓	
Graft-Ack	7	✓	
Candidate-RP-Advertisement	8		✓

- Encapsulated in IP datagrams with protocol number 103.
- PIM messages can be sent as unicast or multicast packet
- 224.0.0.13 is reserved as the *ALL-PIM-Routers* group

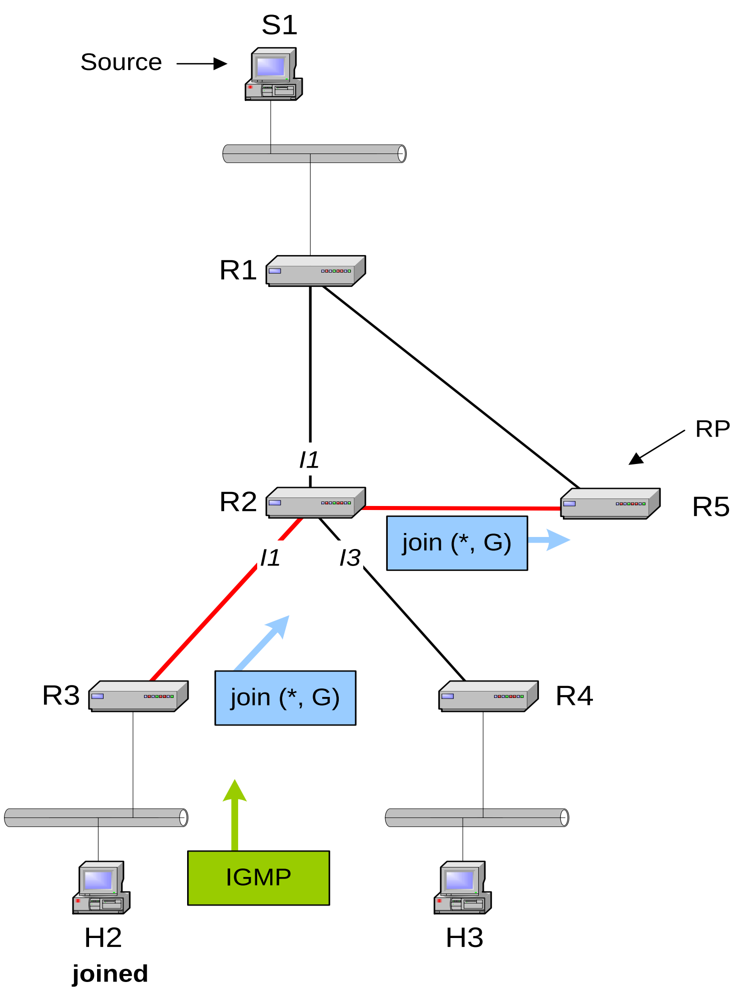
PIM-DM: PIM Dense Mode

- PIM-DM implements flood-and-prune
- Orange packet: Multicast packet (=Data)
- Blue packet: PIM message



PIM-SM: PIM Sparse Mode

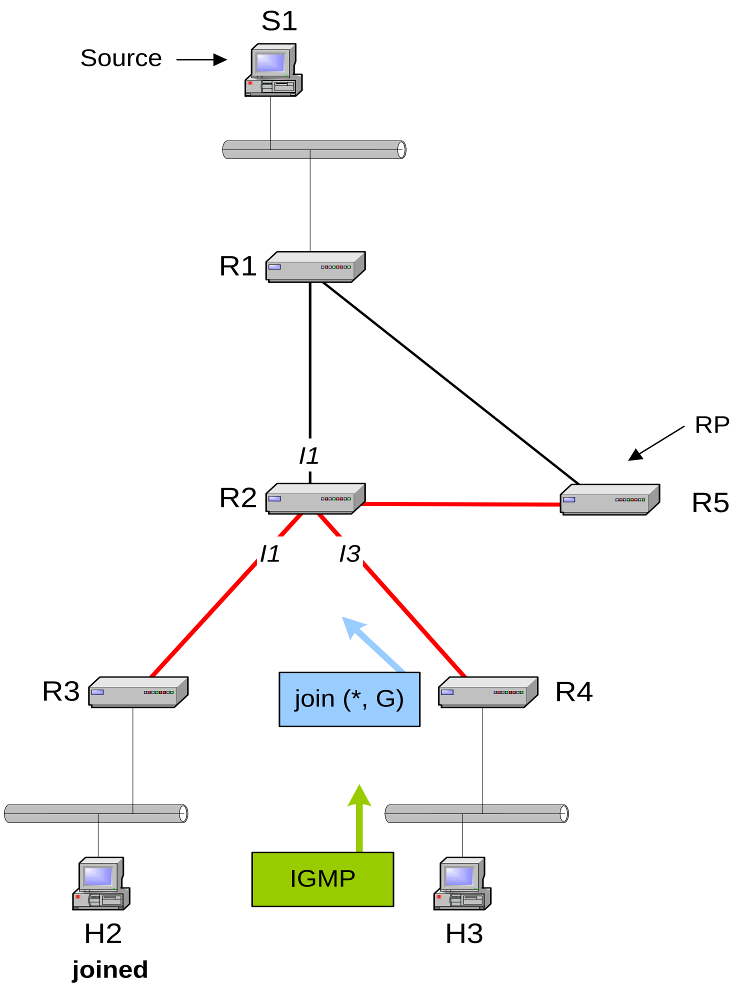
- Core is called rendezvous-point **(RP)**
- Receivers know RP (statically configured or dynamically elected)
- When receiver joins, a Join message is sent to RP on RPF.



(a) PIM-SM: H2 joins

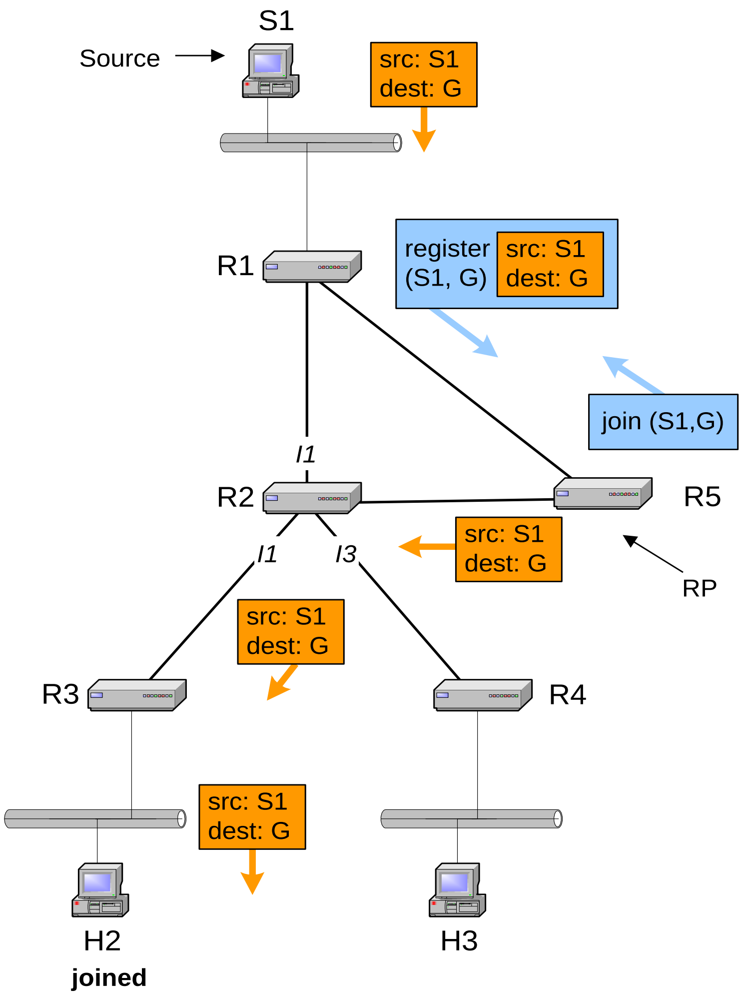
PIM-SM: PIM Sparse Mode

- Host H3 joins:
  Join message is only forwarded until the first router that is part of the core-based tree.



PIM-SM: Data transmission

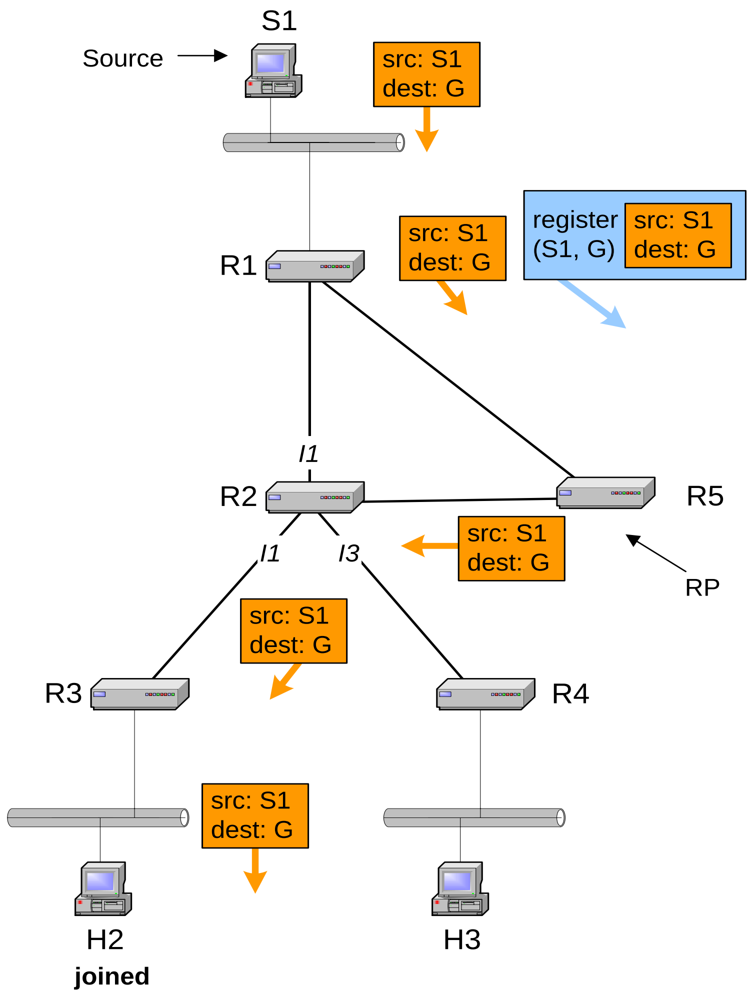
- Source sends multicast packet to RP
- Packet is attached to an RP Register message
- When packet reaches RP, it is forwarded in the tree
- Also: RP sends a Join message on reverse path to S1



(a) PIM-SM: Register message to RP

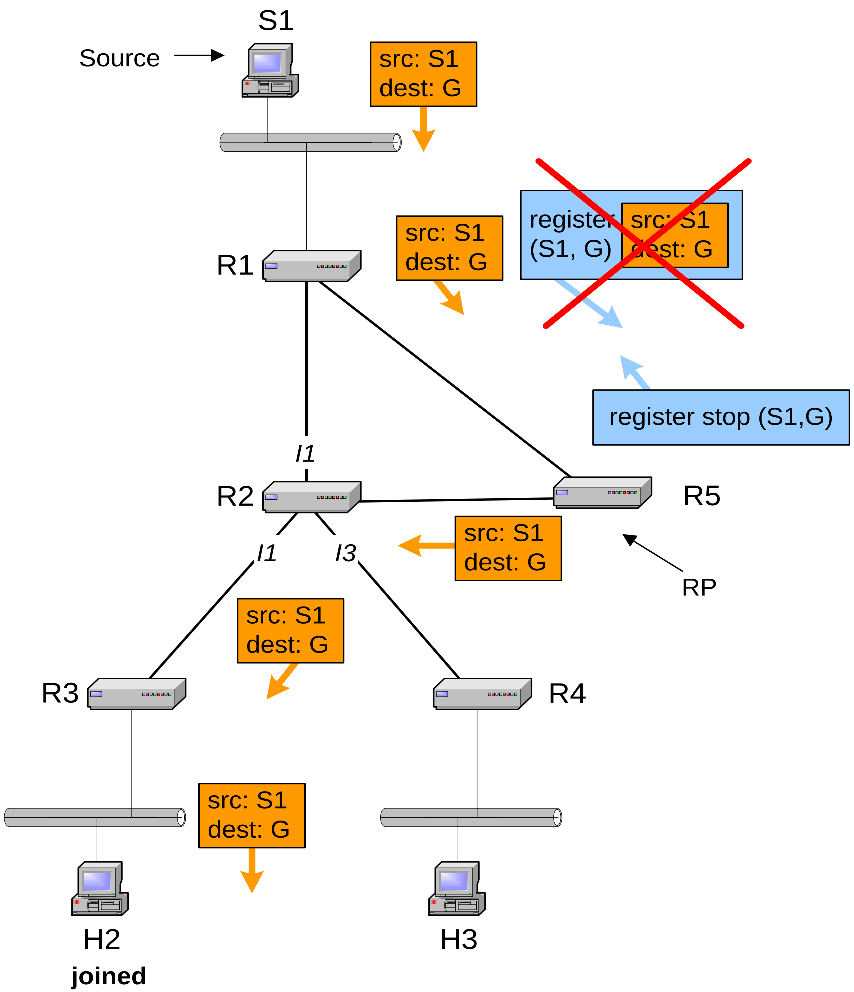
PIM-SM: Data transmission

- When Join messages reaches R1, it sends a native multicast packet to the RP (in addition to the packet attached to the register message)



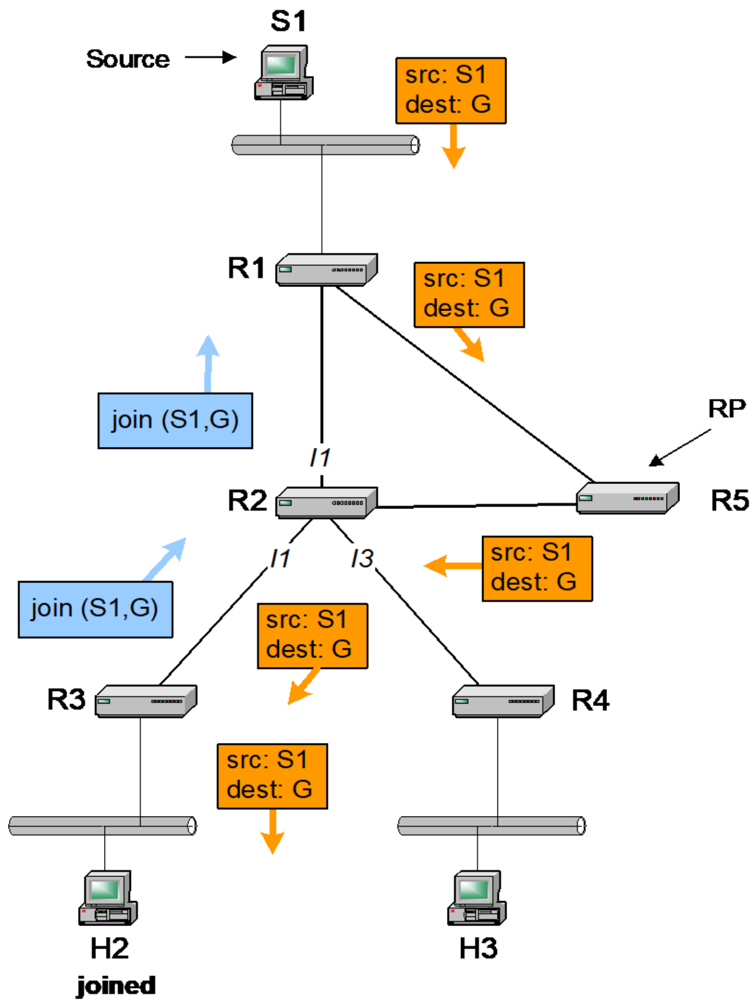
PIM-SM: Data transmission

- When RP receives native multicast packet it sends a register stop message to R1. This message stops the transmission of register messages from R1.



PIM-SM: Switching to source-based tree

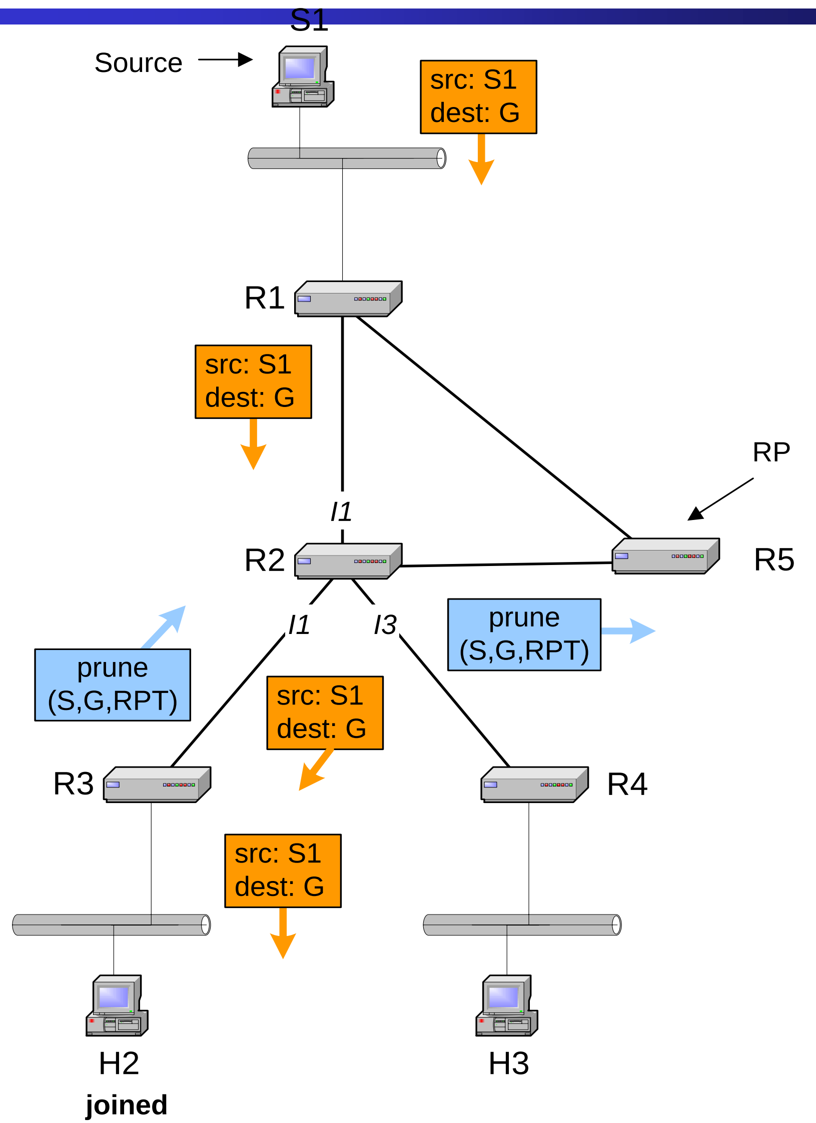
- When data to receivers exceeds a threshold, routers switch to a source-based tree
- This is done by sending an explicit join message to the source
- There may be duplicate packets being sent for some time



(a) PIM-SM: R3 switches to a SPT

PIM-SM: Switching to source-based tree

- When data arrives from source (as opposed to RP), a Prune message is sent to the RPT
- Now: data is forwarded only along the shortest-path tree



(b) PIM-SM: Data follows a SPT