IP Multicasting

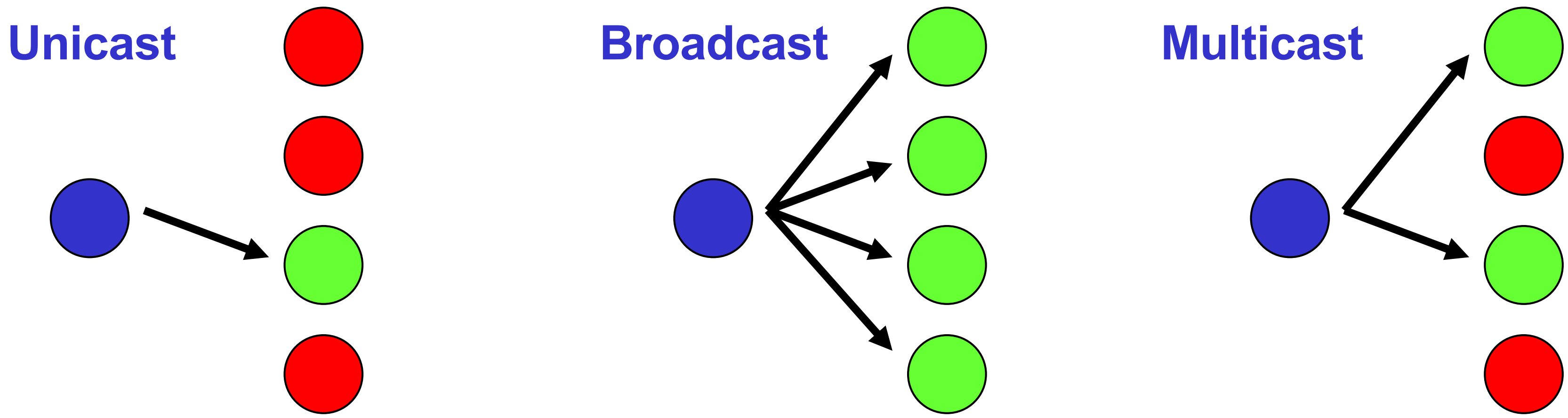
Applications with multiple receivers

- 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

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

Multicast is driven by receivers: Receivers indicate interest in receiving data

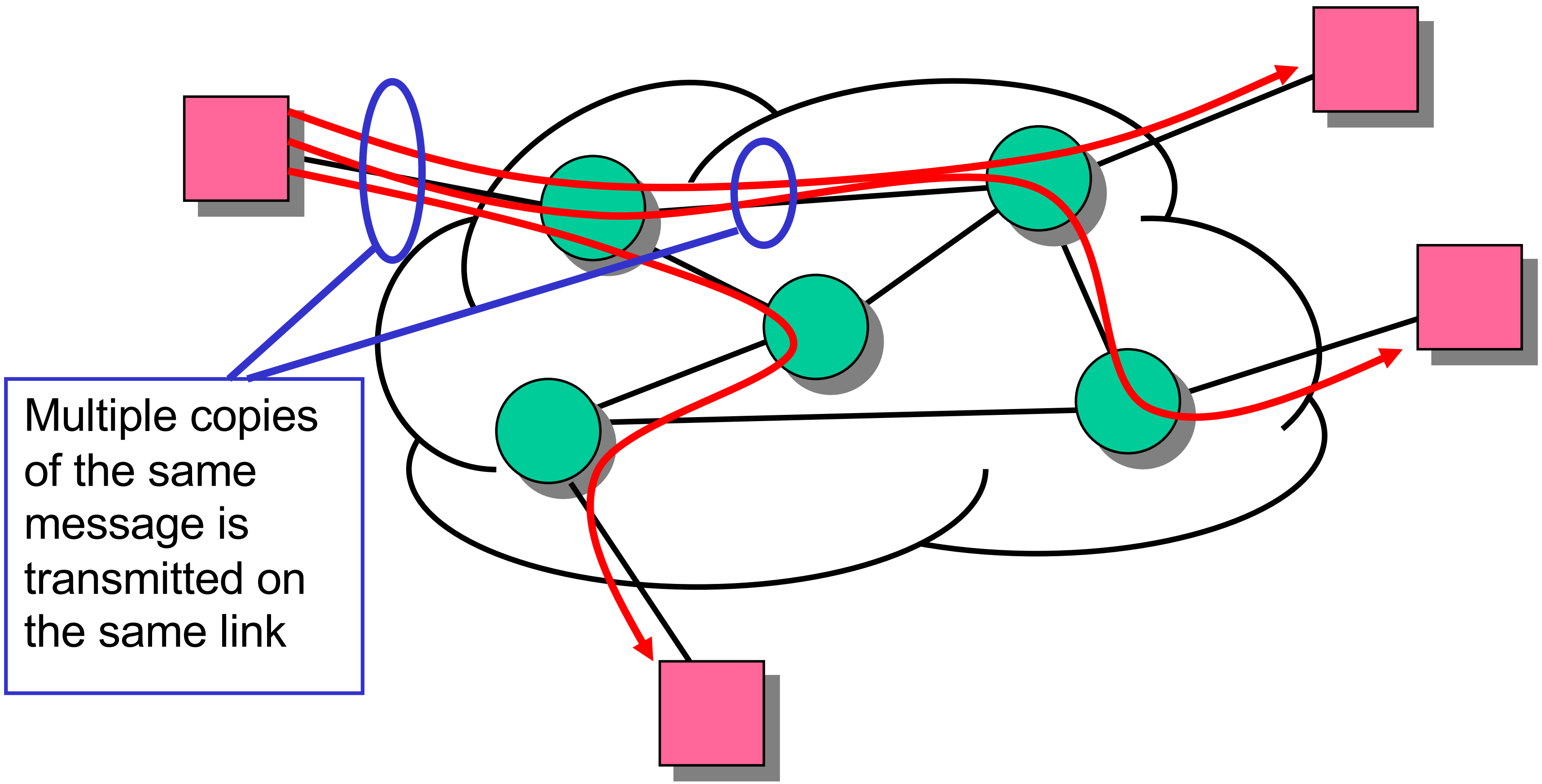
Multicast Groups

- The set of receivers for a multicast transmission is called a **multicast group**
  - A multicast group is identified by a **multicast address**
  - A user that wants to receive multicast transmissions **joins** the corresponding multicast group, and becomes a **member** of that group

- After a user joins, the network builds the necessary routing paths so that the user receives the data sent to the multicast group

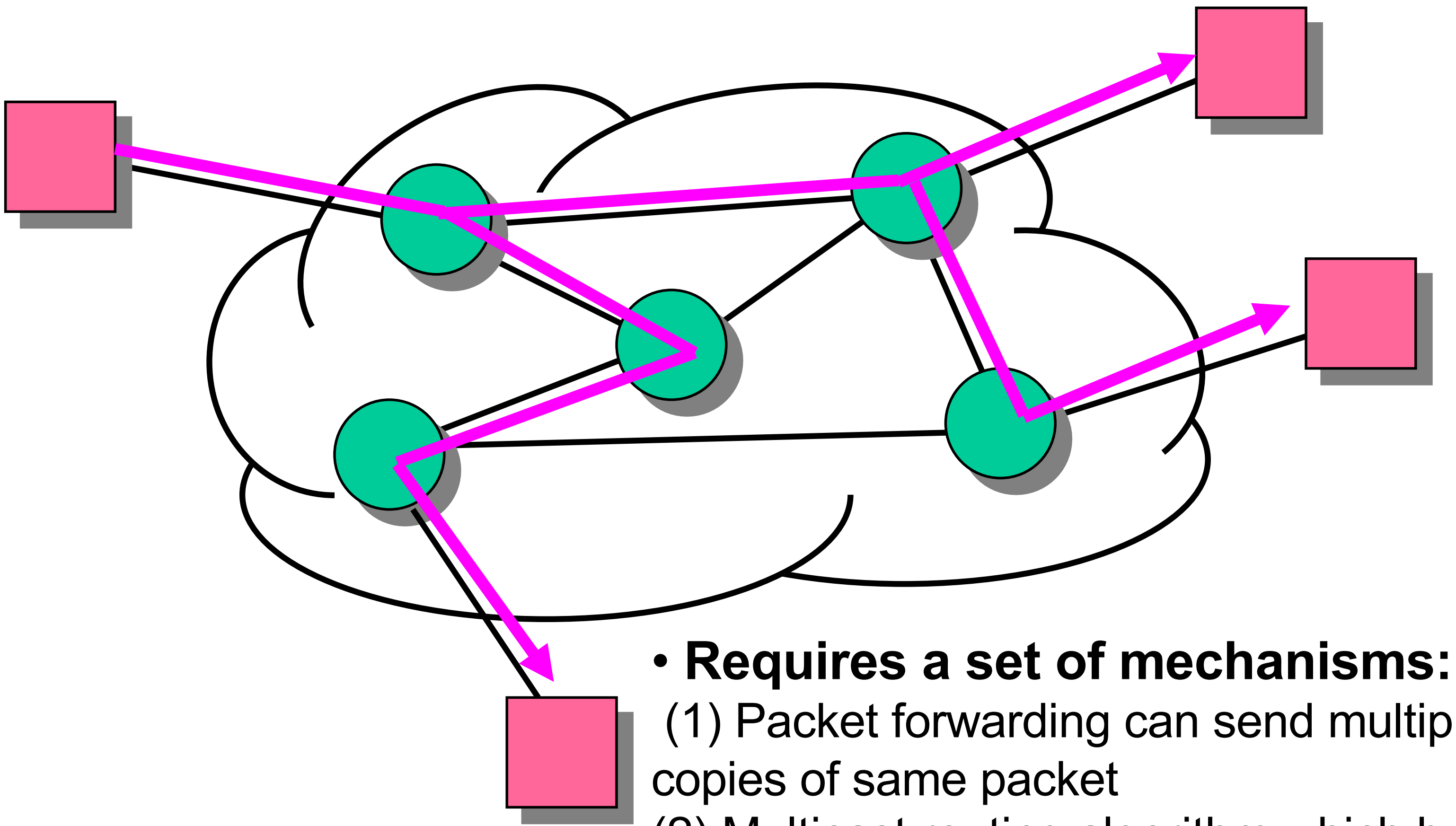
Multicasting over a Packet Network

- Without support for multicast at the network layer:



Multicasting over a Packet Network

- With support for multicast at the network layer:



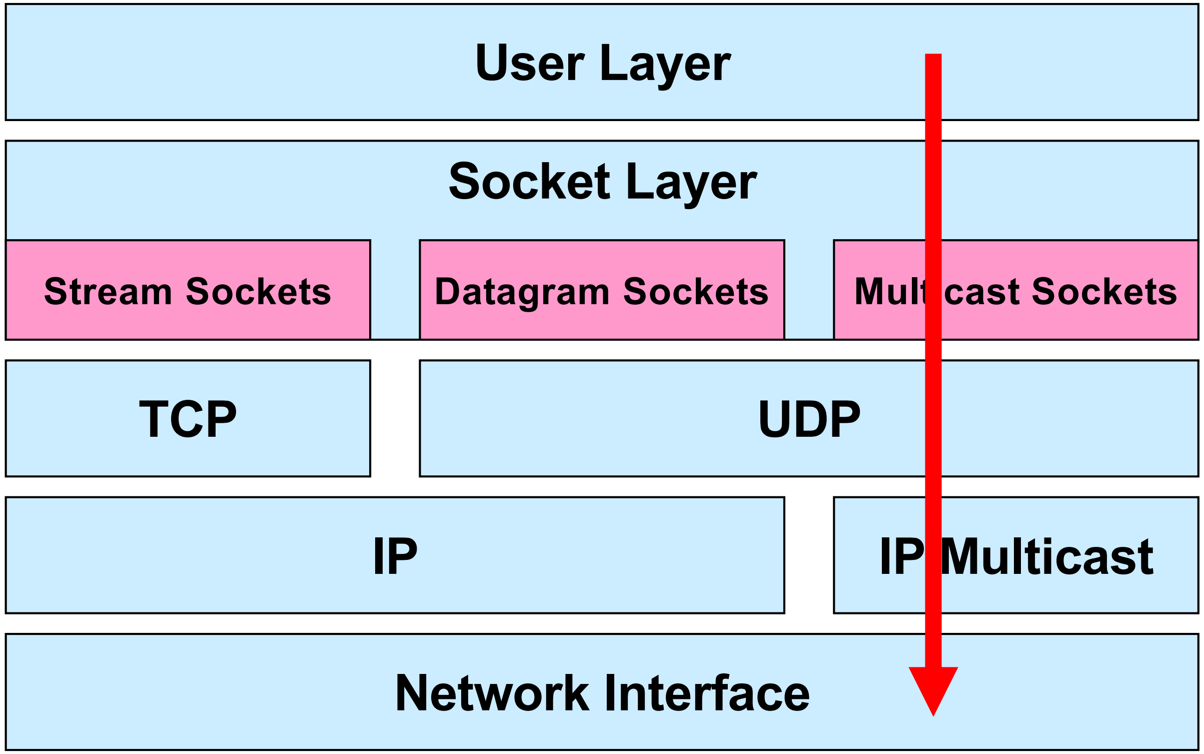
- **Requires a set of mechanisms:**
  (1) Packet forwarding can send multiple copies of same packet
  (2) Multicast routing algorithm which builds a spanning tree (dynamically)

Semantics of IP Multicast

- 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”
    - Sender does not need to be a member of the group
- 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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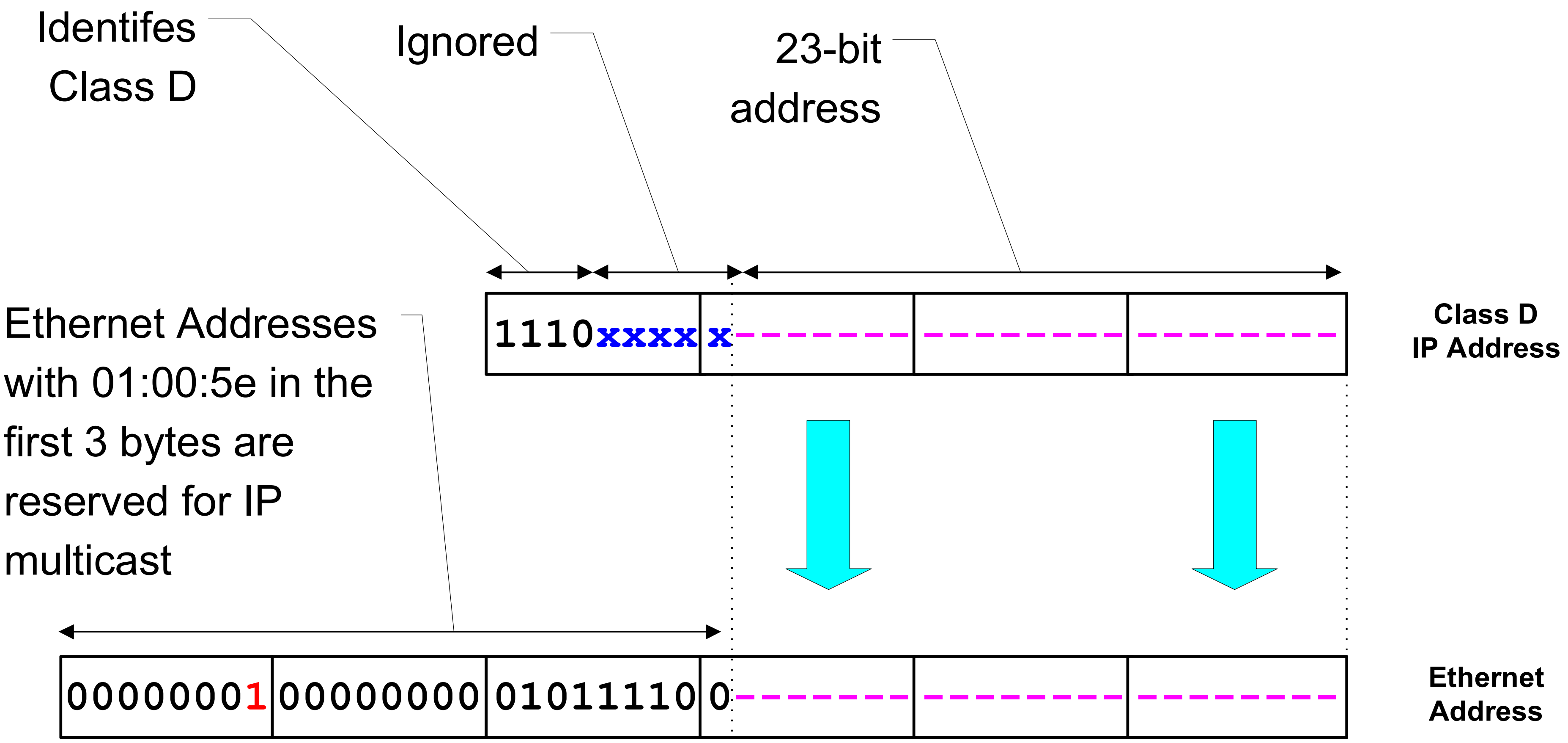
Not all Ethernet cards can filter multicast addresses in hardware

- 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

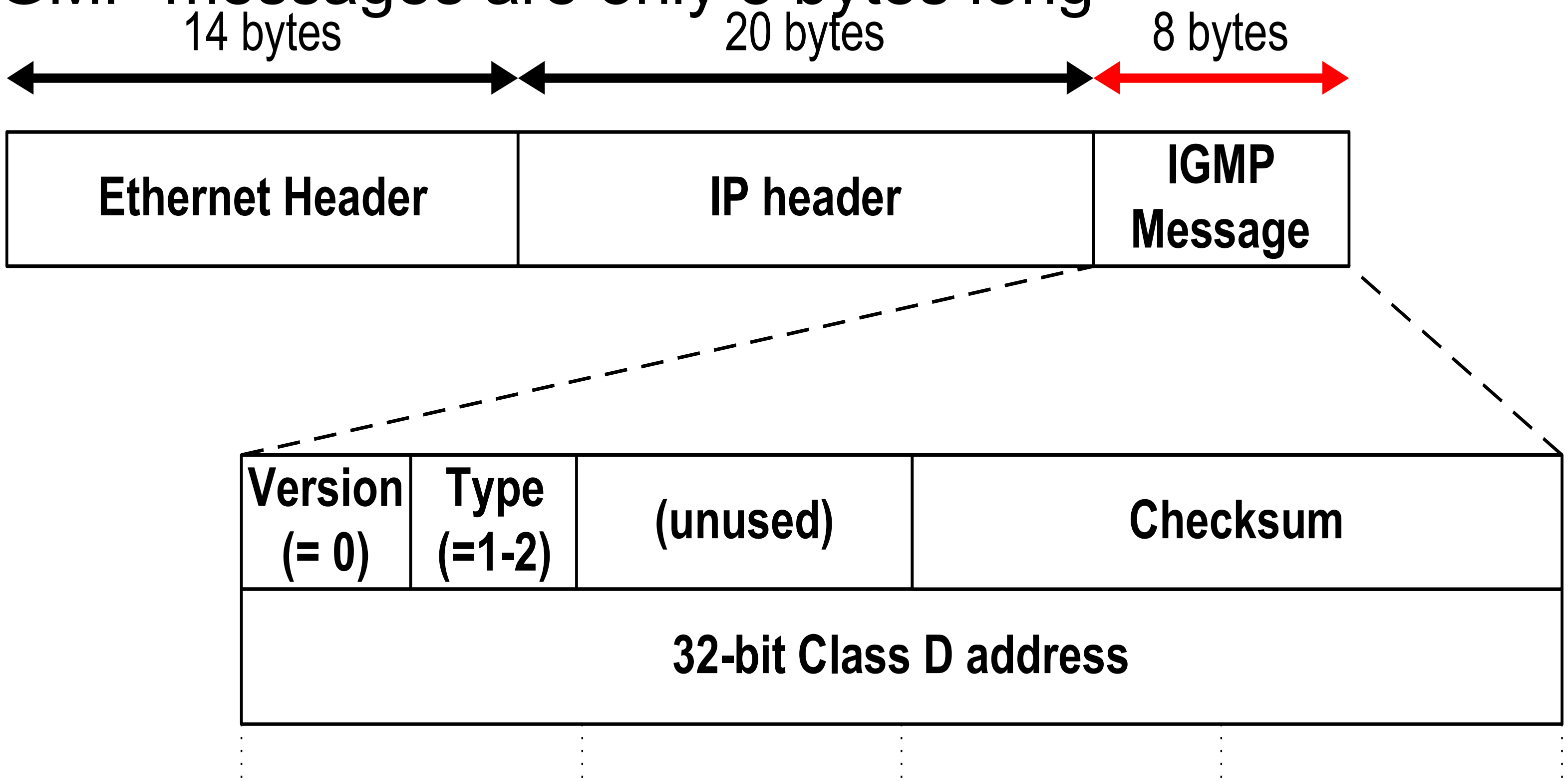
IGMP Protocol

- 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.

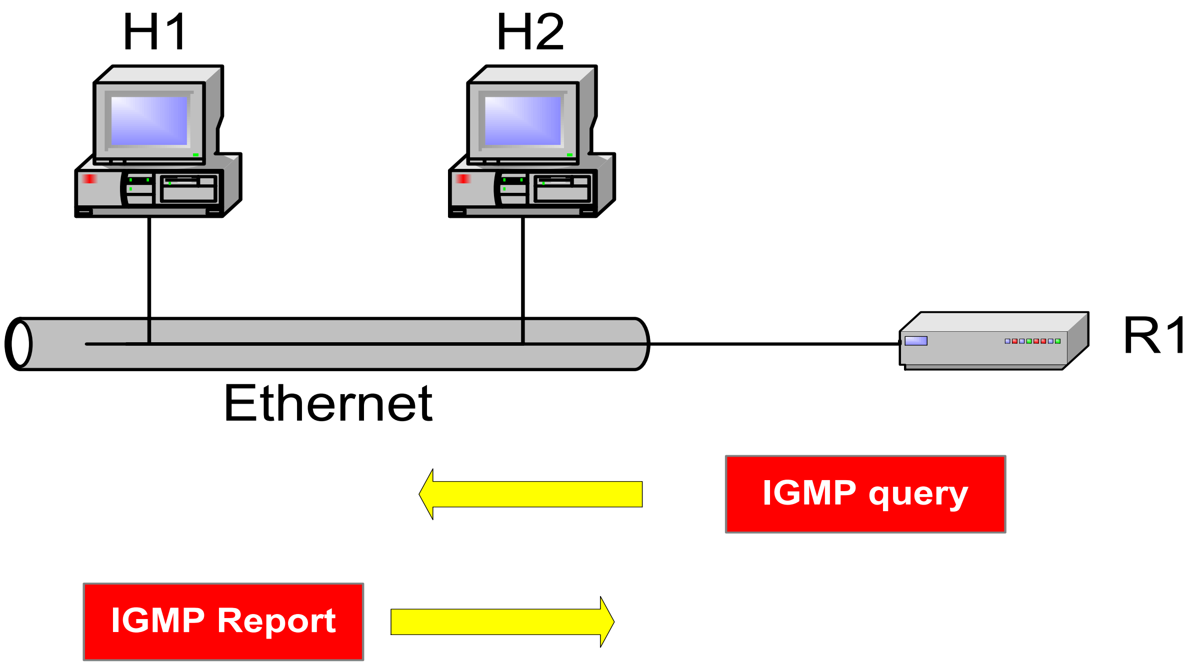
IGMP Packet Format

- IGMP messages are only 8 bytes long

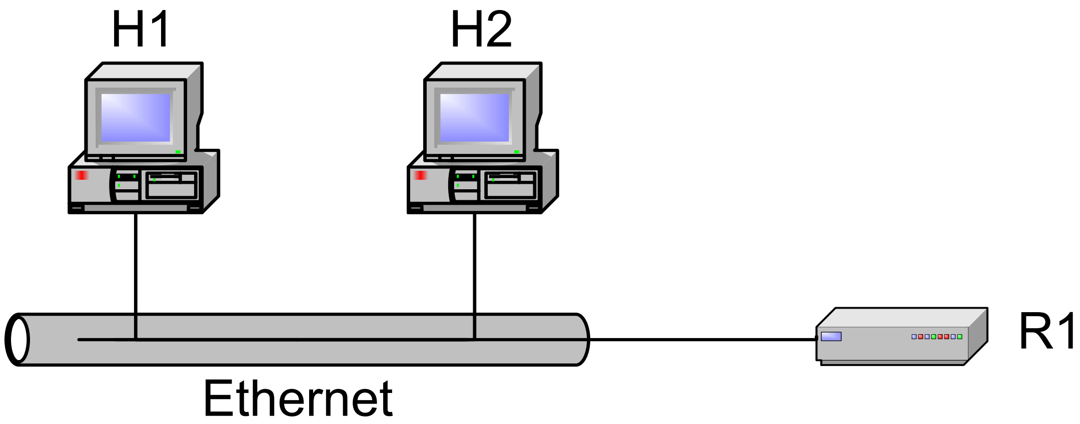


- Type: 1 = sent by router, 2 = sent by host

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

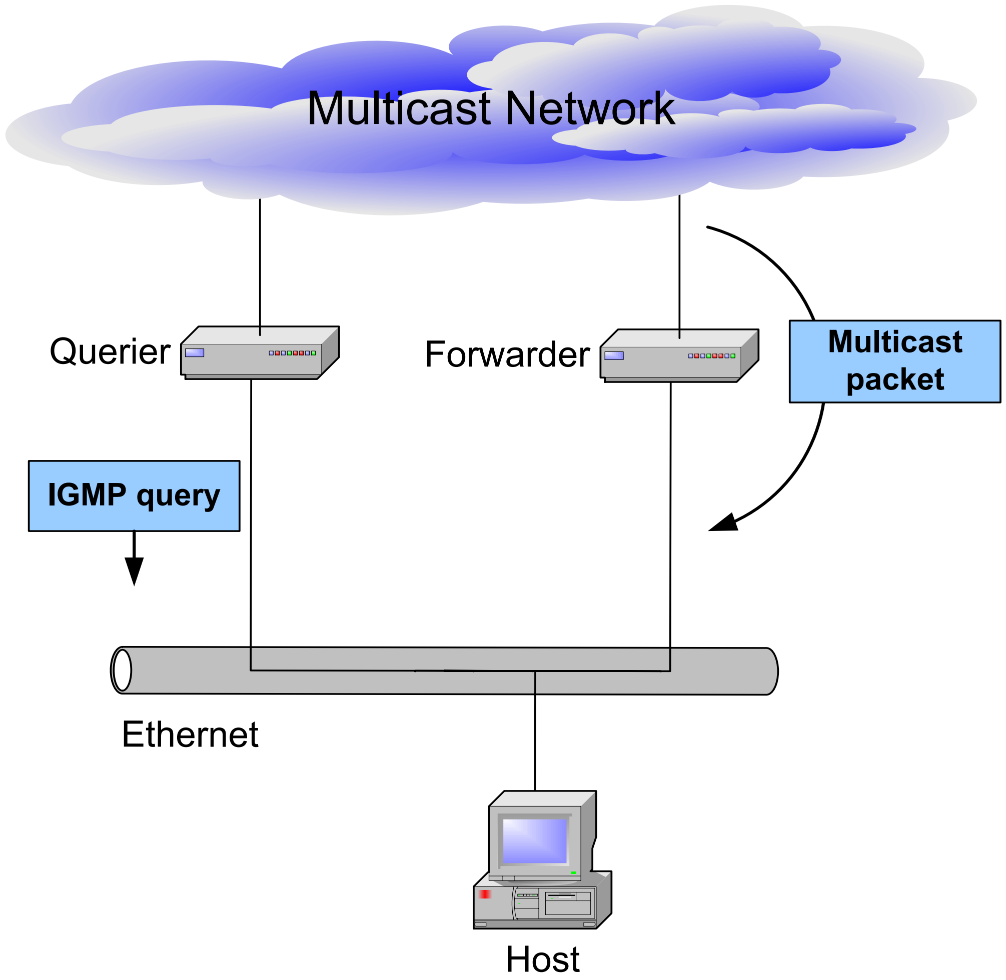
IGMP group-specific query
IGMP group address = group address
Destination IP address = group address
Source IP address = router's IP address

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

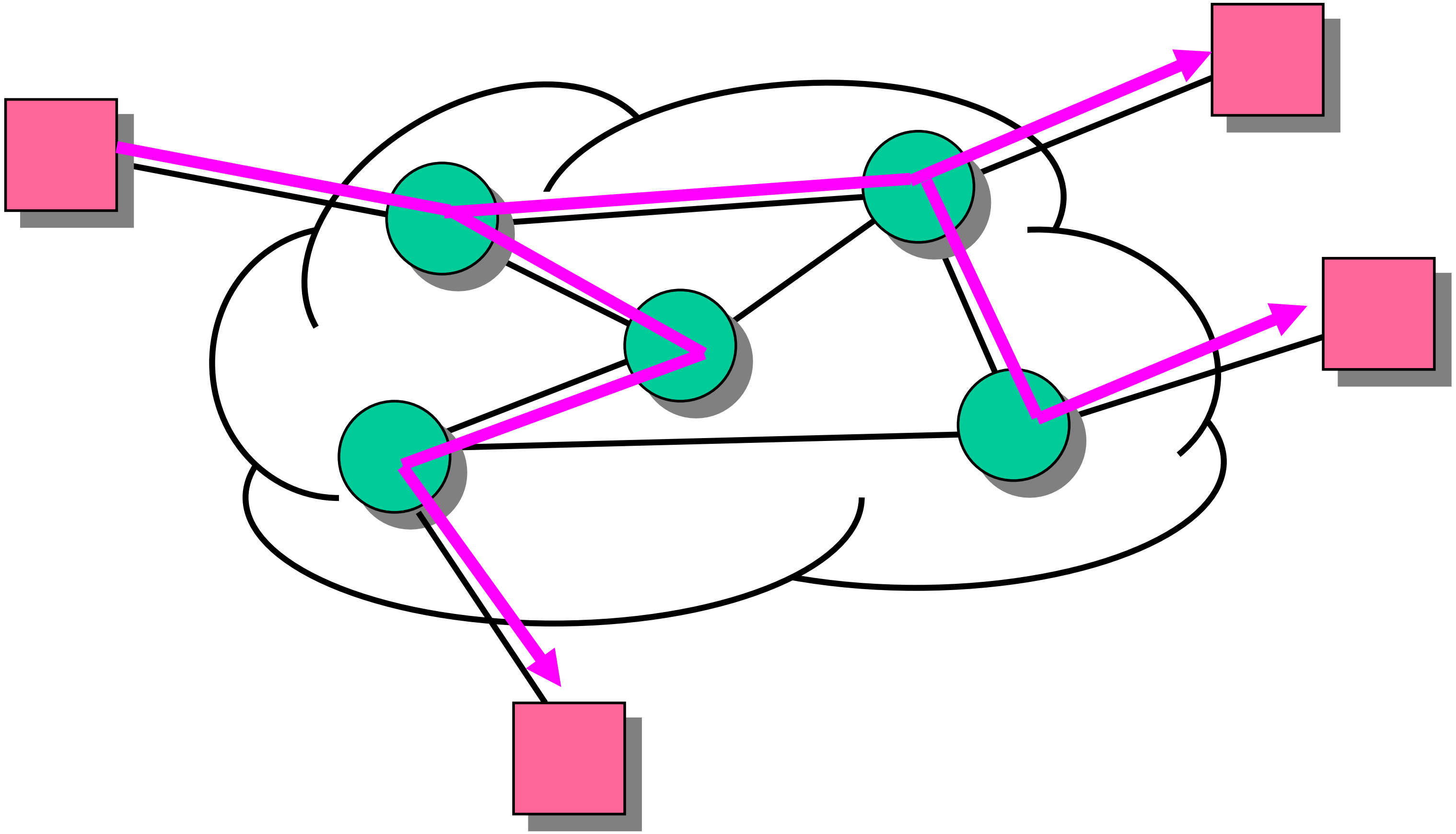
- Only one router responds to IGMP queries (***Querier***)
  - Router with smallest IP address becomes the querier on a network.

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



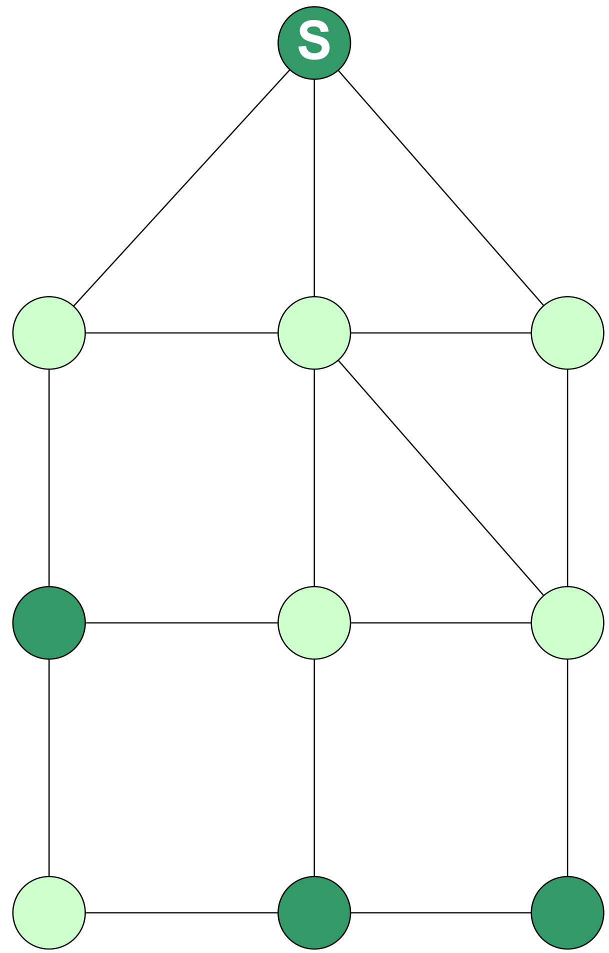
Multicast Routing Protocols

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



Multicast routing as a graph problem

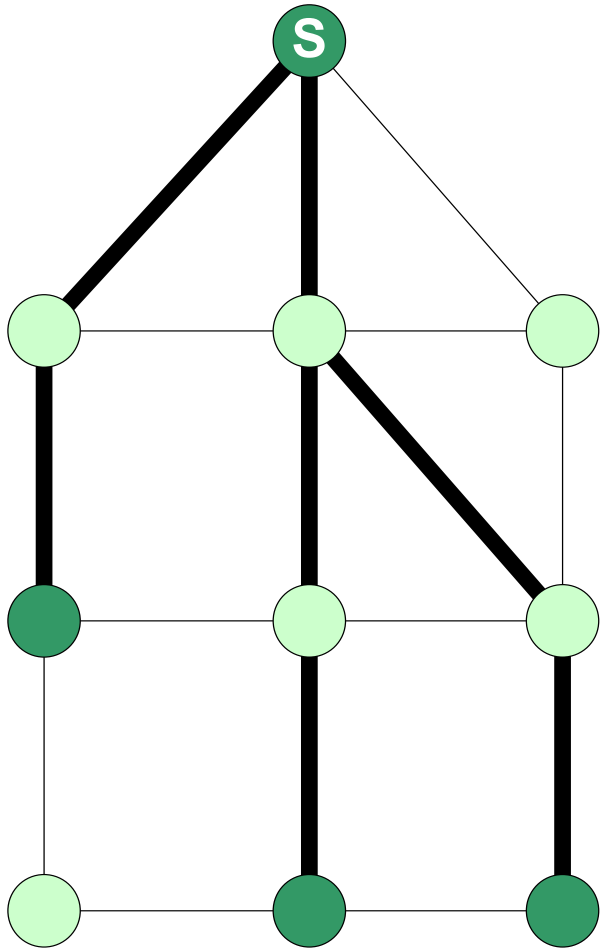
- **Problem**: Embed a tree such that all multicast group members are connected by the tree



Multicast routing as a graph problem

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

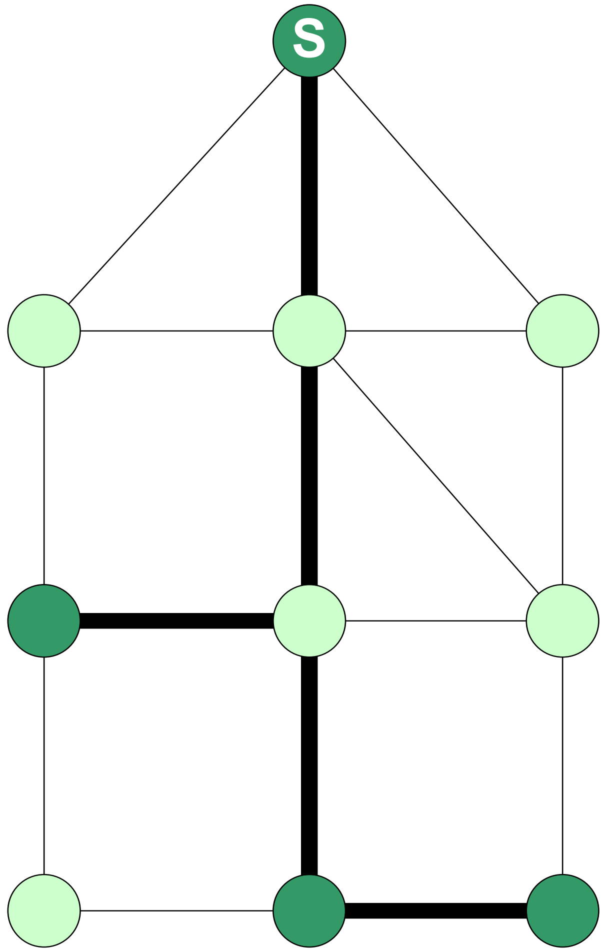
- **Solution 1: Shortest Path Tree or source-based tree**
  Build a tree that minimizes the path cost from the source to each receiver
  - *Good tree if there is a single sender*
  - *If there are multiple senders, need one tree per sender*
  - *Easy to compute*



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

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

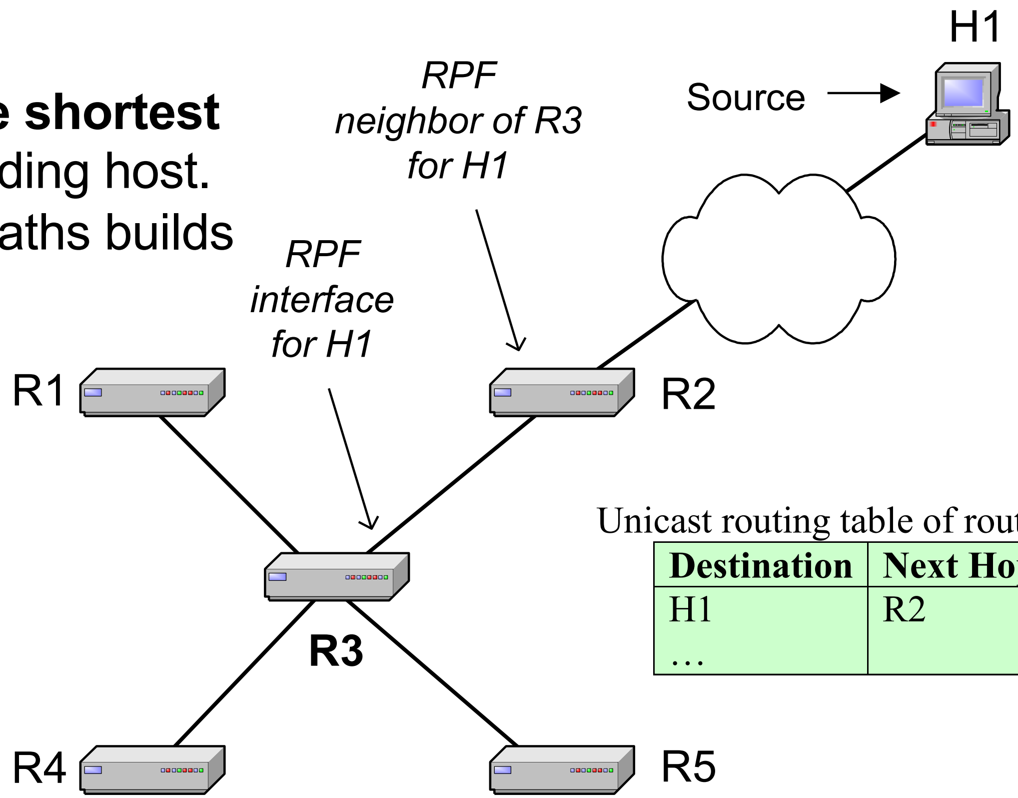
Reverse Path Forwarding (RPF)

- RPF builds a shortest path tree in a distributed fashion by taking advantage of the unicast routing tables.
- **Main concept:** Given the address of the root of the tree (e.g., the sending host), 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.

- This concept leads to a **reverse shortest path** from any router to the sending host. The union of reverse shortest paths builds a **reverse shortest path tree**.

RPF Forwarding:

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



Unicast routing table of router R3:

Destination	Next Hop
H1	R2
…	

Multicast routing in practice

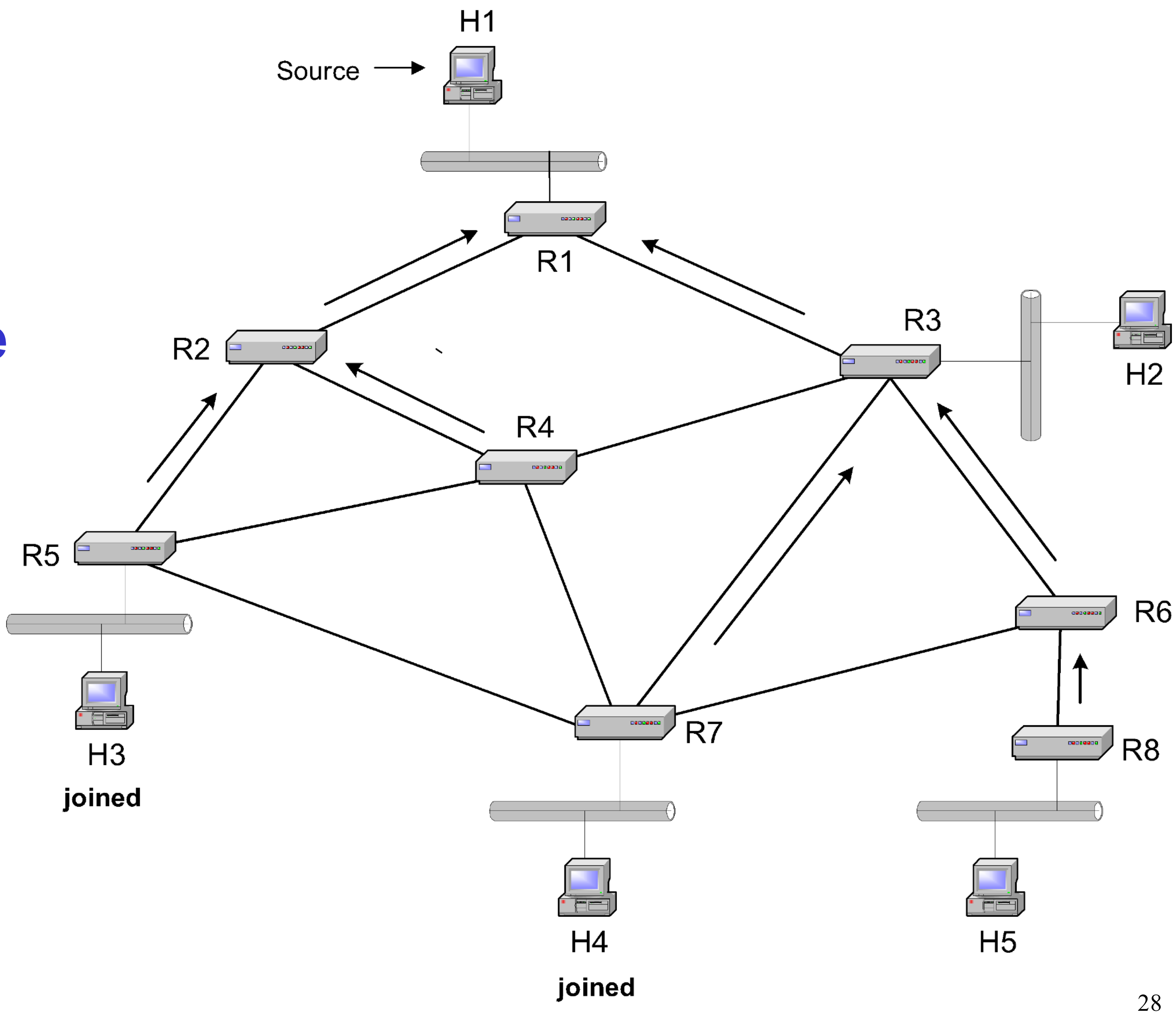
- Routing algorithms in practice implement one of two approaches:

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

Building a source-based tree

- Set routing tables according to RPF forwarding

- **Flood-and-Prune**

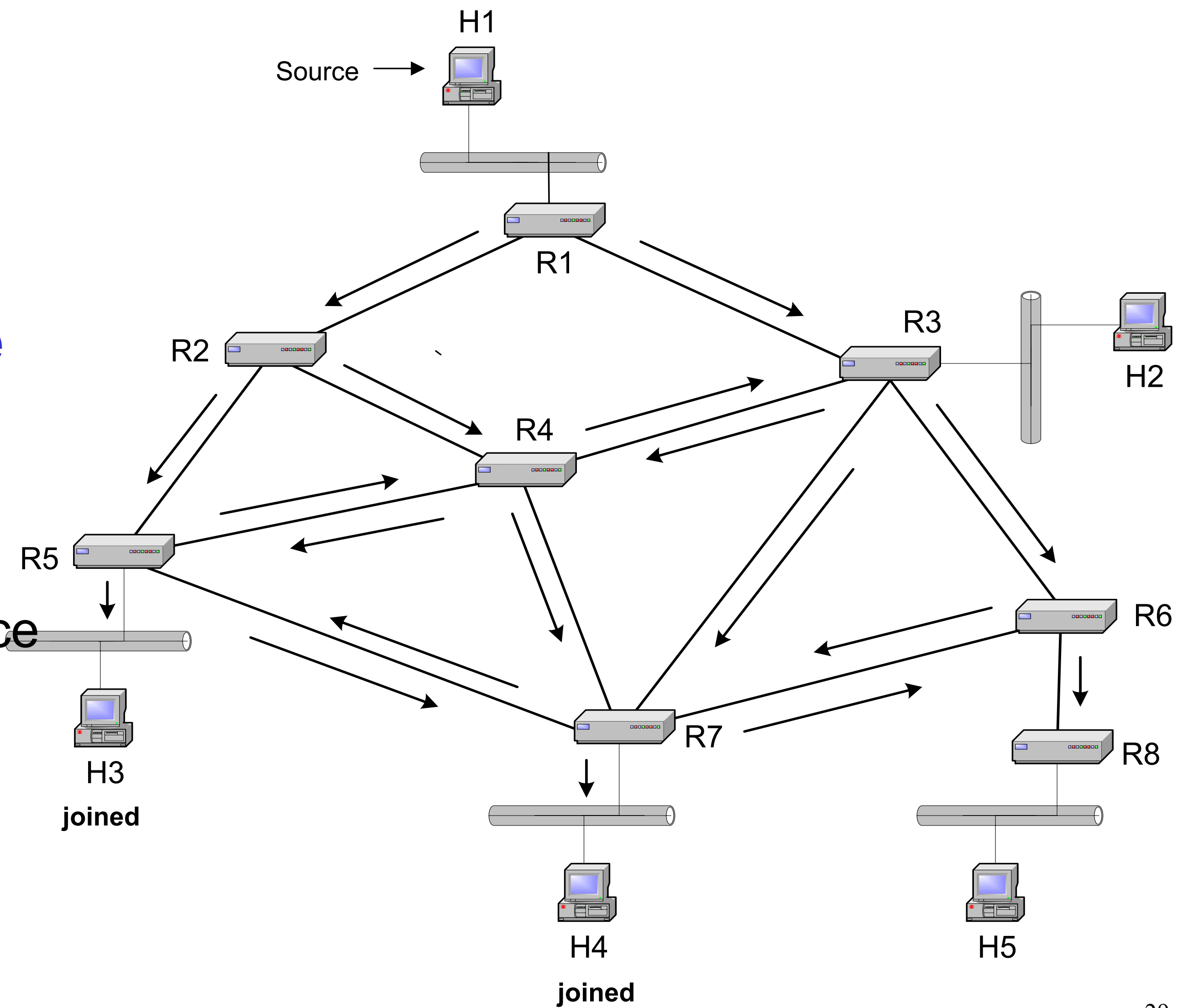


Building a source-based tree

- Set routing tables according to RPF forwarding

- **Flood-and-Prune**

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

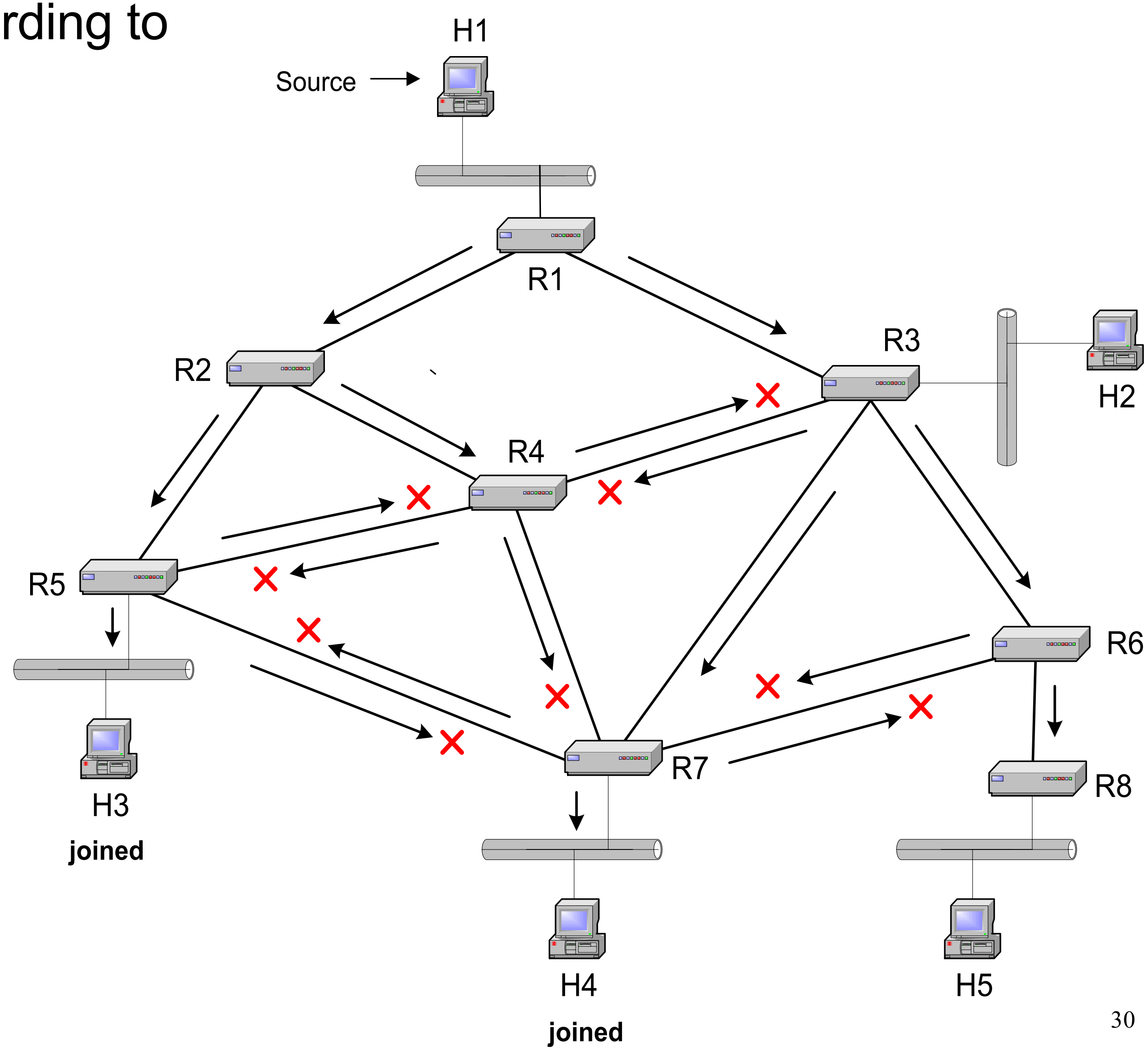


Building a source-based tree

- 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

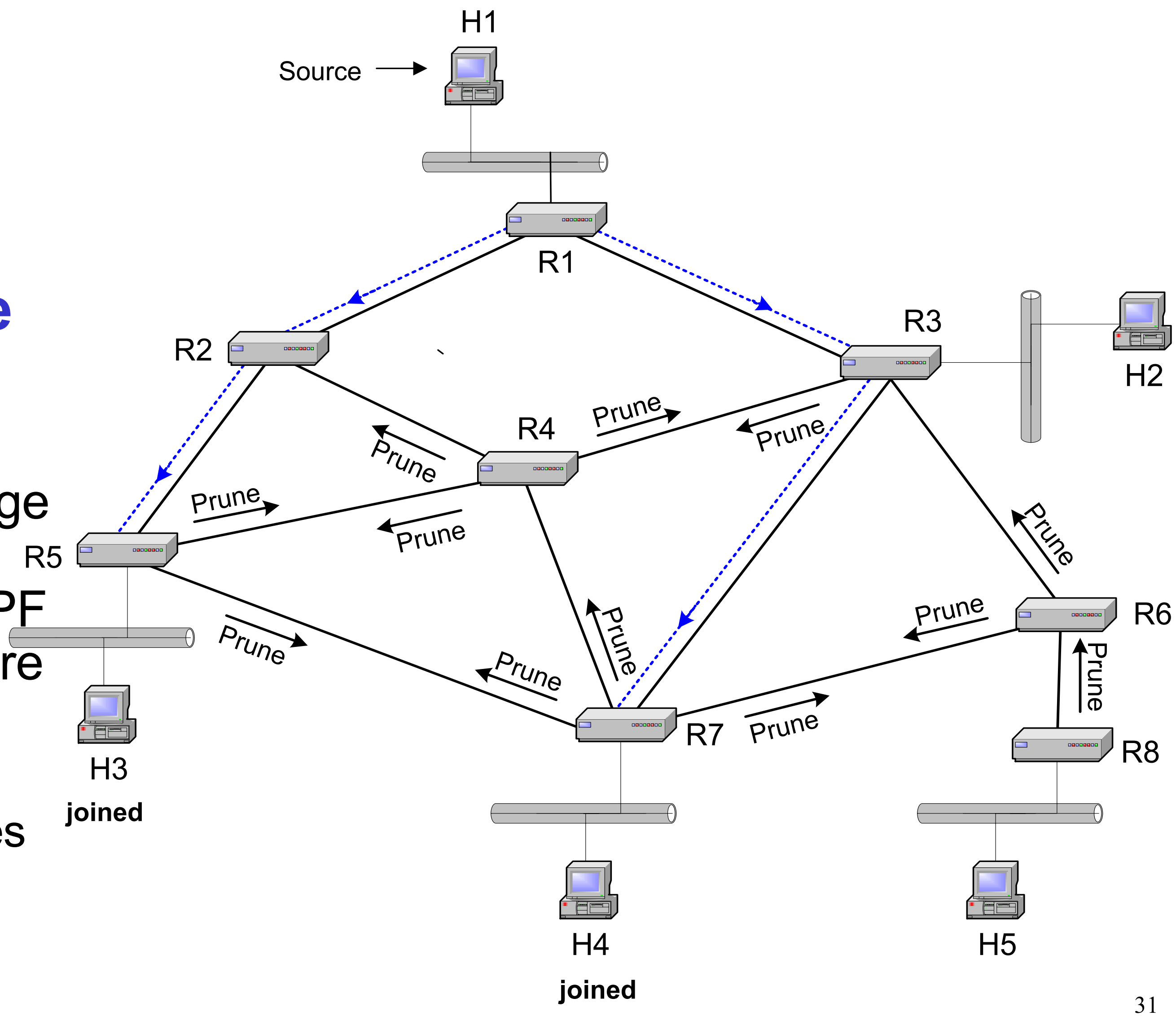
- Set routing tables according to RPF forwarding

- **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?*

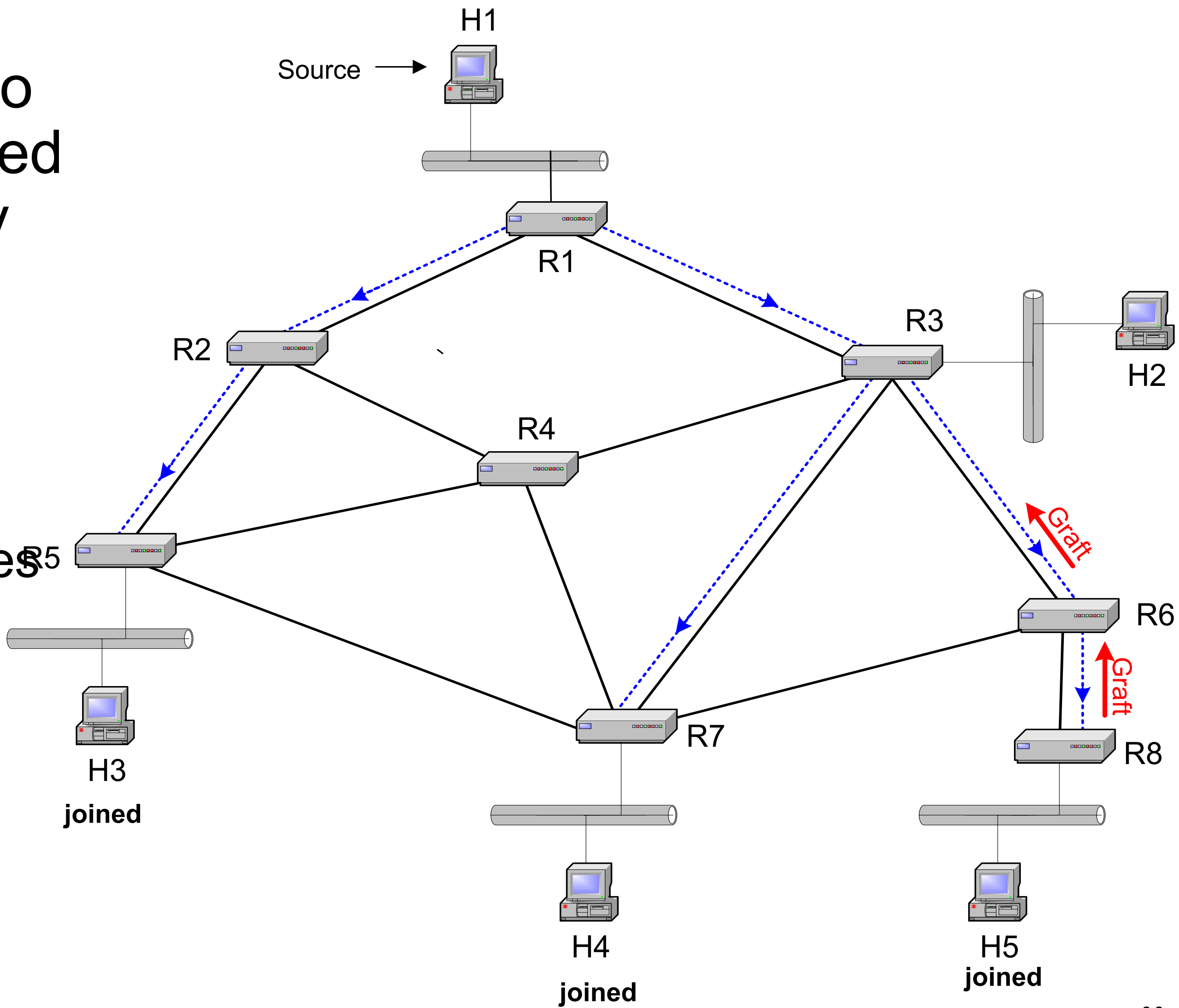
- Who sends prune messages?
  - A router with no group members in its local network and no connection to other routers (sent on RPF interface)
  - A router with no group members in its local network which has received a prune message on all non-RPF interfaces (sent on RPF interface)
  - A router with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

Building a source-based tree

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

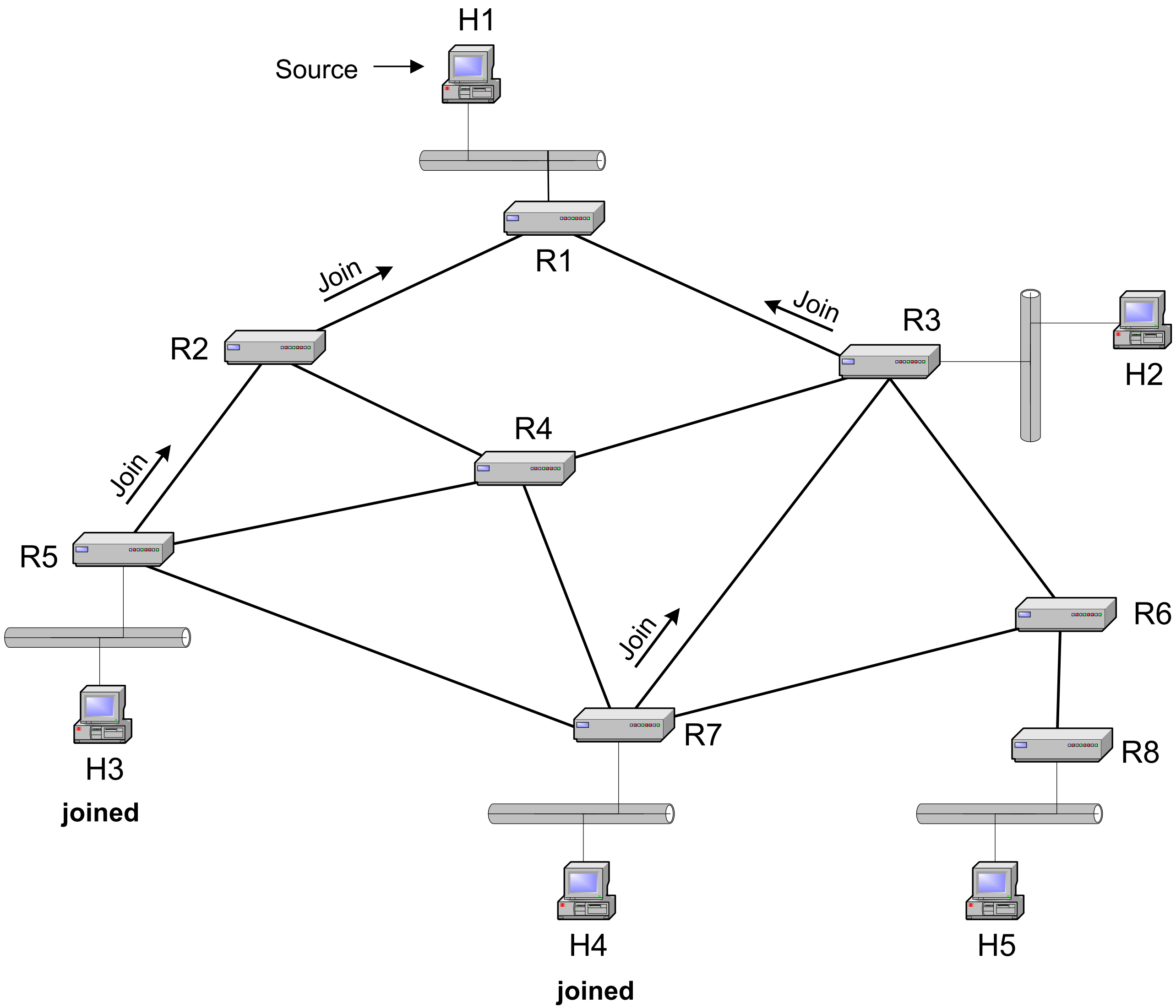
- **Grafting**

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



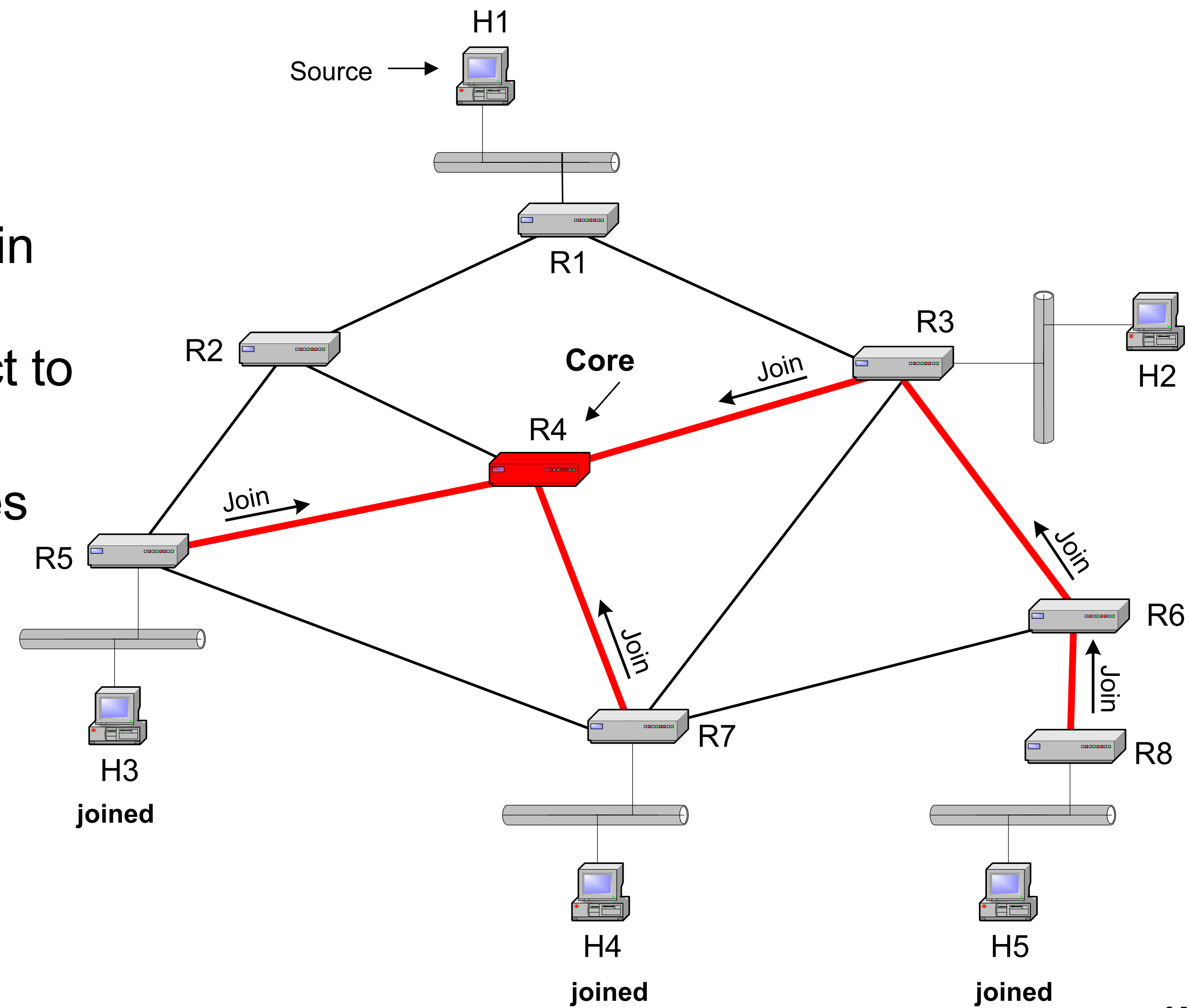
Alternative method for building a source-based tree

- 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



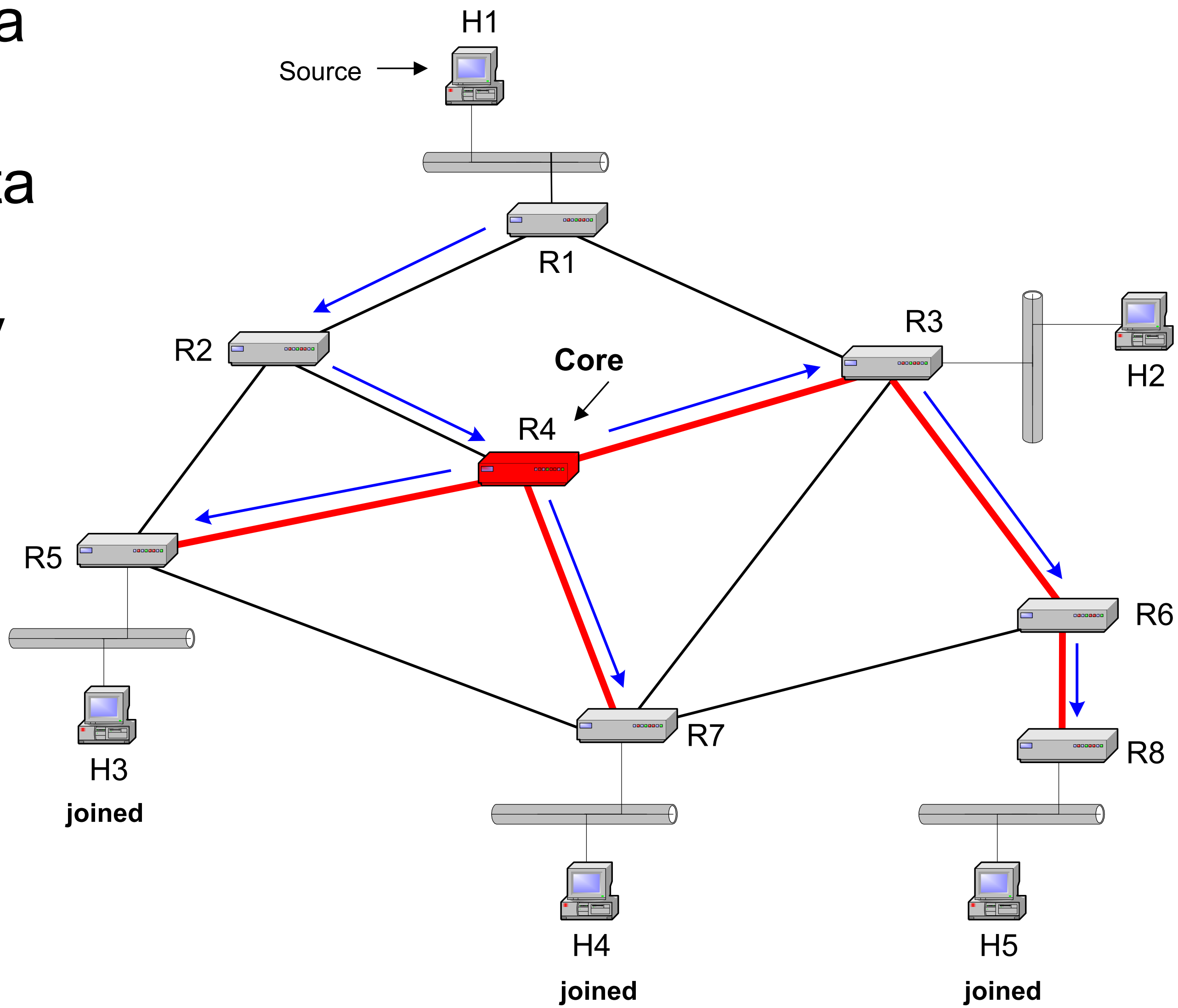
Building a core-based tree

- 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):**
  - 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.

PIM Messages (PIM version 2)

32 bit

Version (= 2)	Type	Reserved	Checksum
Message type specific part			

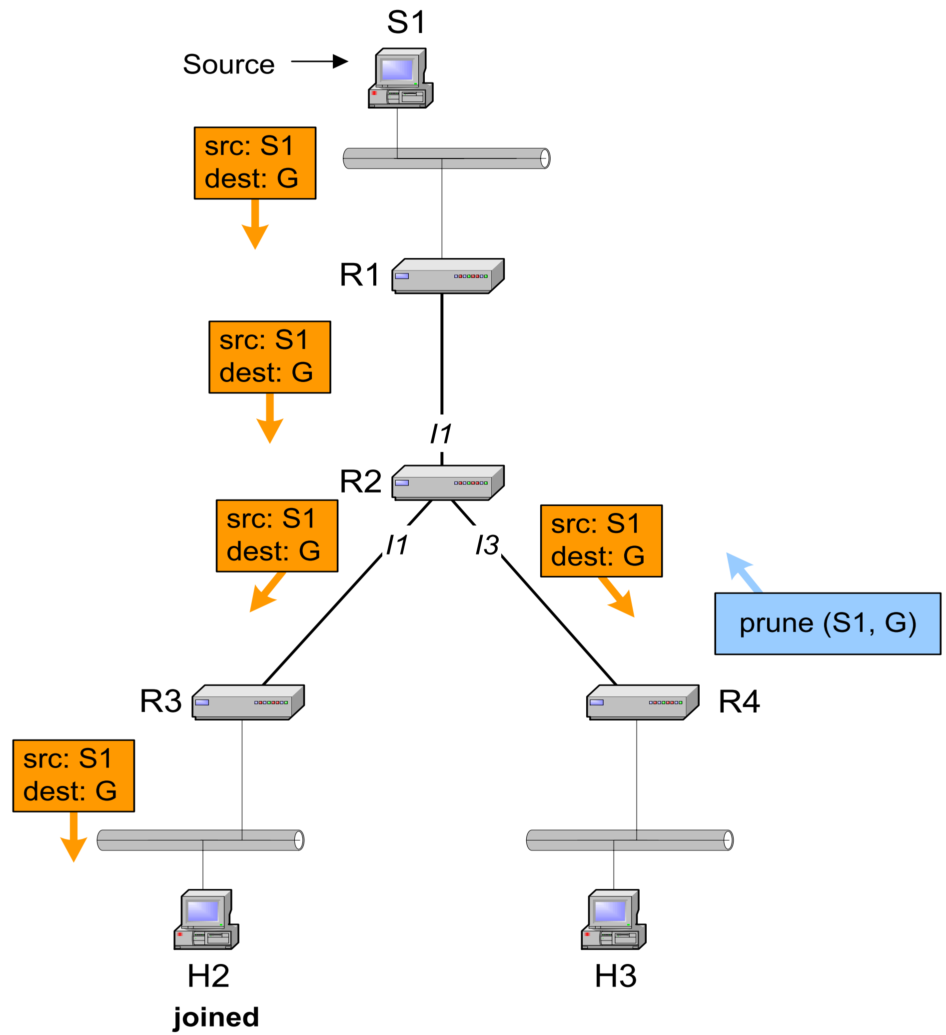
PIM-DM messages	Type	PIM-DM	PIM-SM
Hello	0	✓	✓
Register	1		✓
Register-Stop	2		✓
Join/Prune	3	✓	✓
Bootstrap	4		✓
Assert	5	✓	✓
Graft	6	✓	
Graft-Ack	7	✓	
Candidate-RP-Advertisement	8		✓

- 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

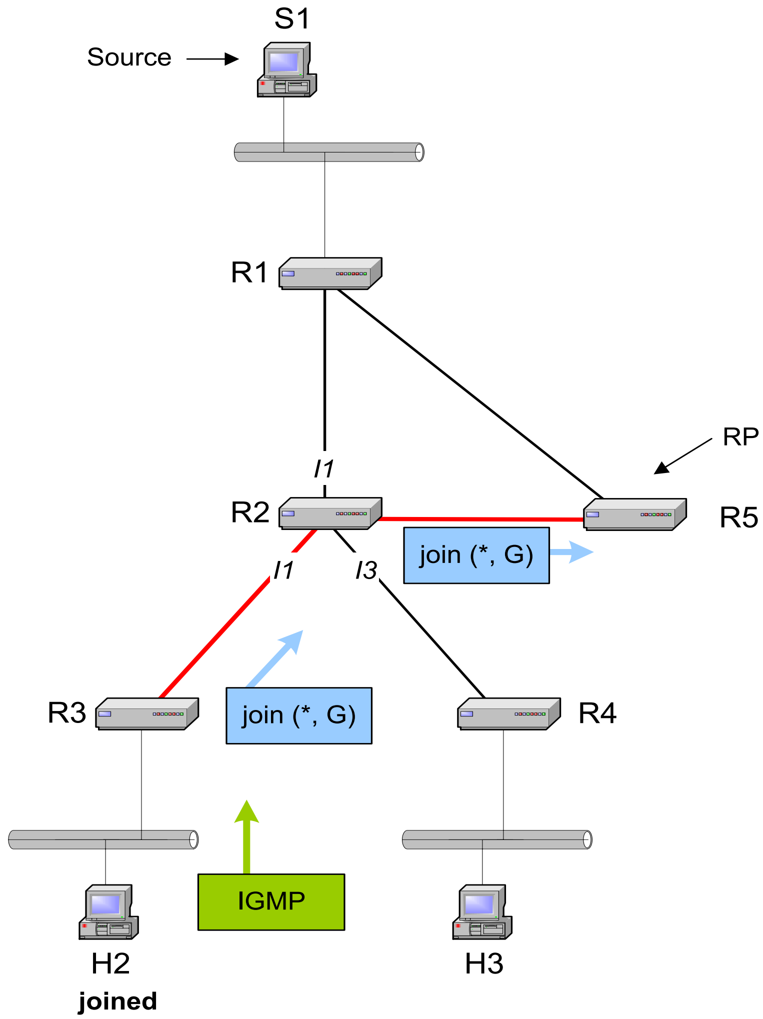
- PIM-DM implements flood-and-prune

- Orange packet:
  Multicast packet (=Data)
- Blue packet:
  PIM message



PIM-SM: PIM Sparse Mode

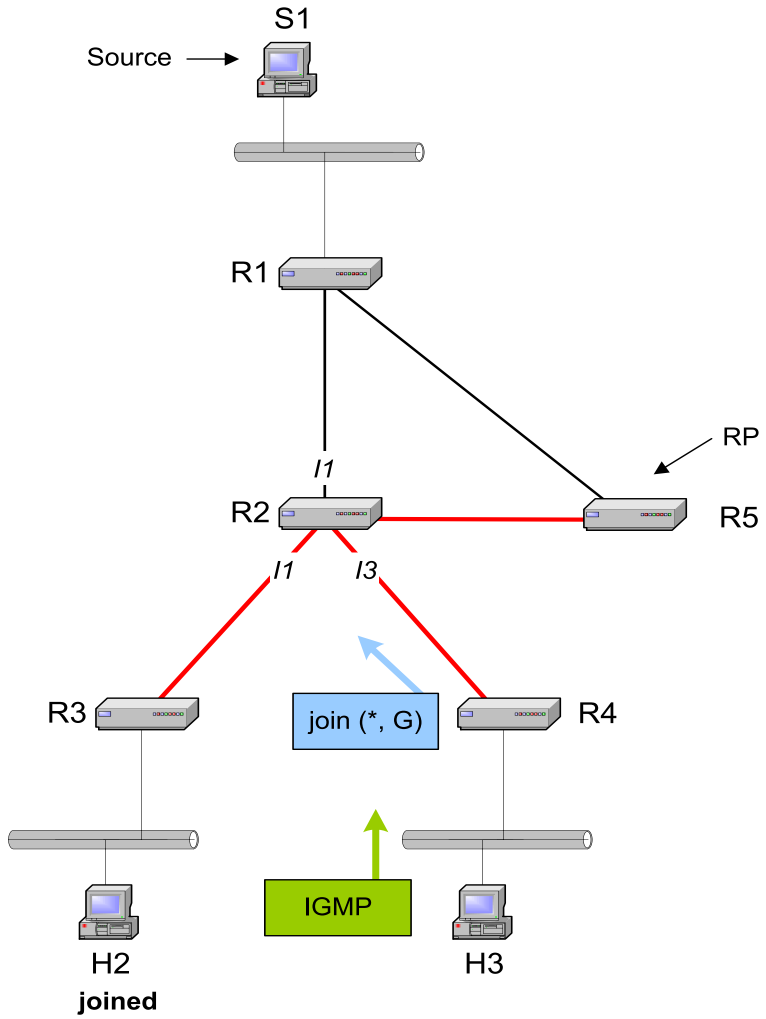
- Core is called rendezvous-point **(RP)**
- Receivers know RP (statically configured or dynamically elected)
- When receiver joins, a Join message is sent to RP on RPF.



(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.

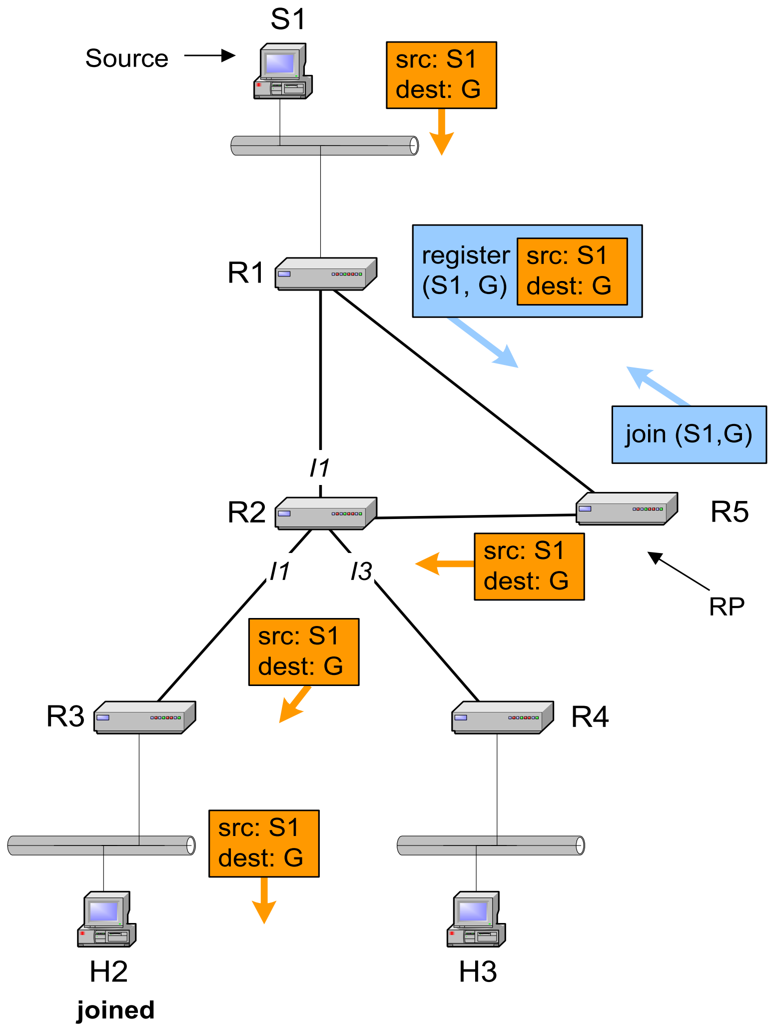


PIM-SM: Data transmission

- Source sends multicast packet to RP
- Packet is attached to an RP Register message

- When packet reaches RP, it is forwarded in the tree

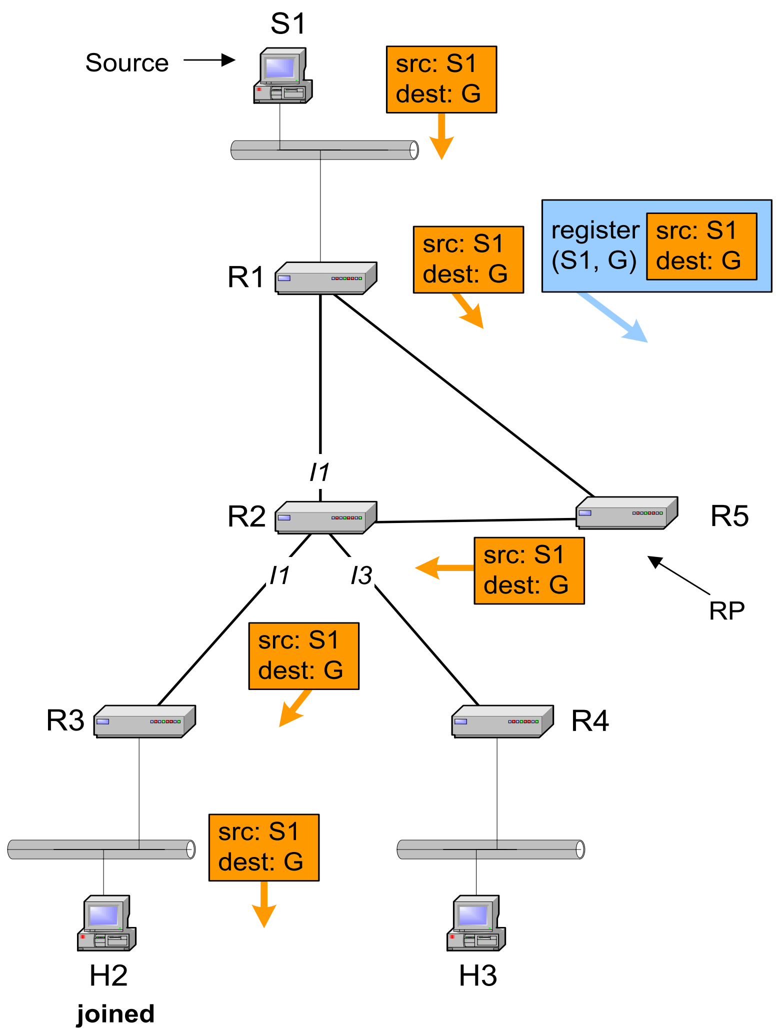
- Also: RP sends a Join message on reverse path to S1



(a) PIM-SM: Register message to RP

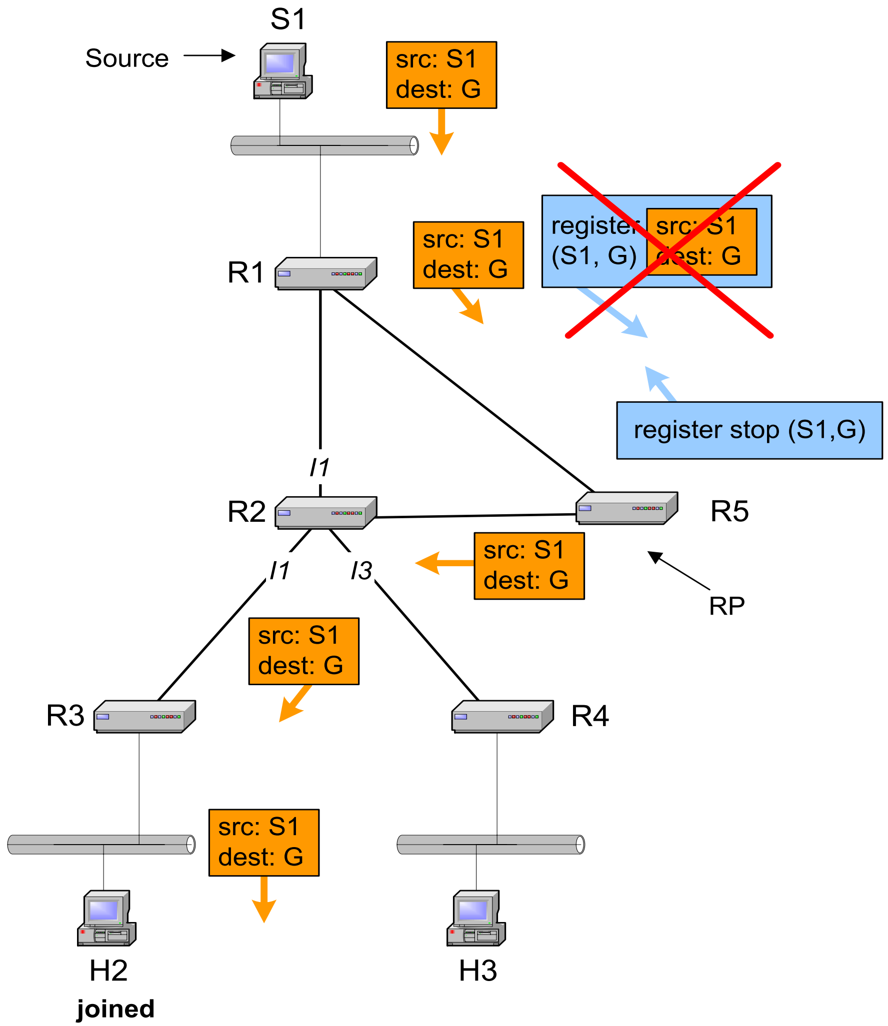
PIM-SM: Data transmission

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



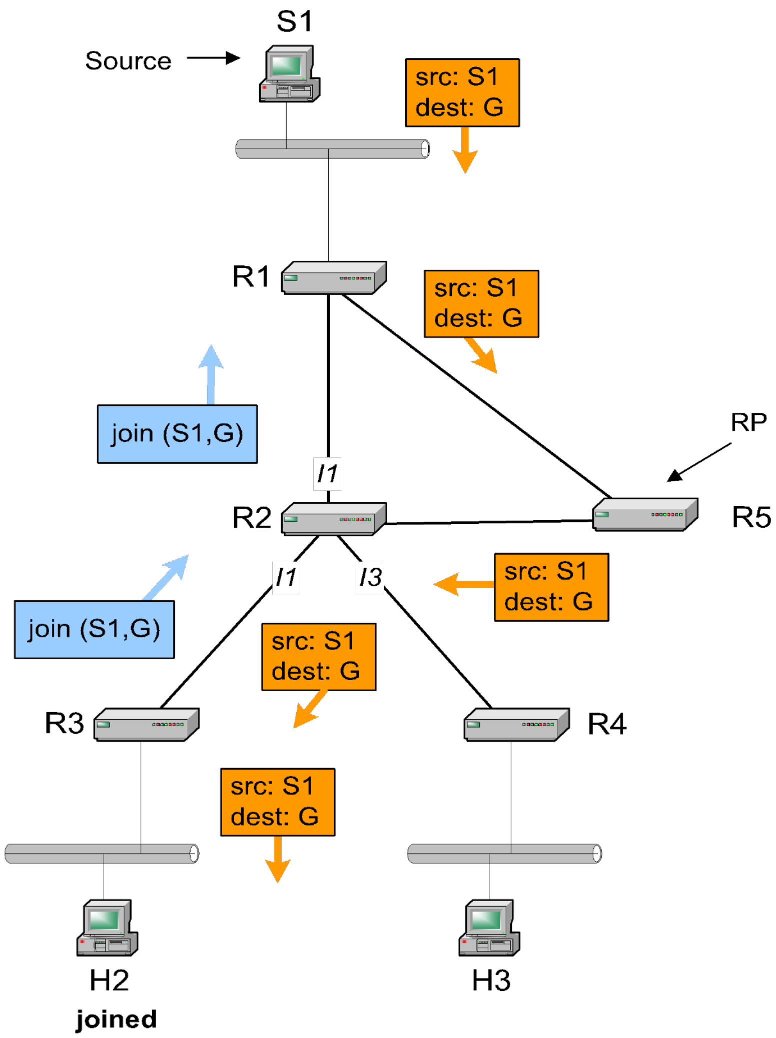
PIM-SM: Data transmission

- 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

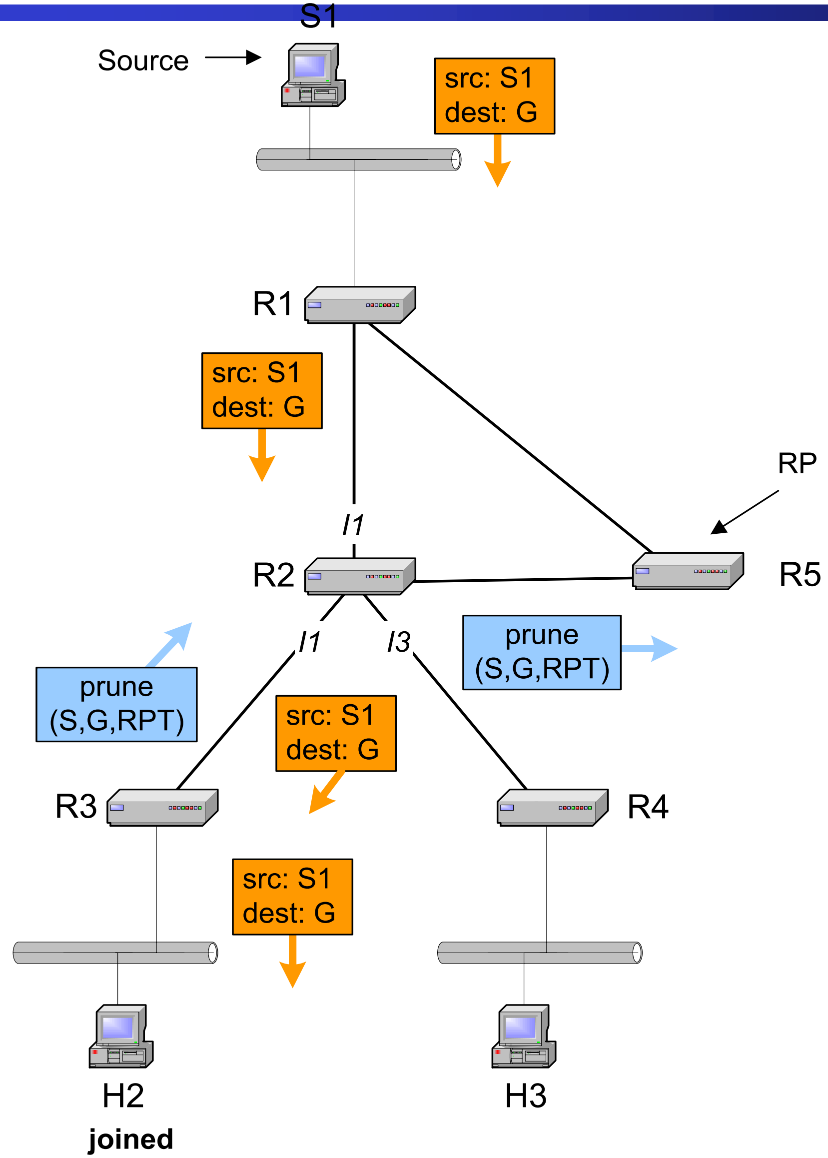
- When data to receivers exceeds a threshold, routers switch to a source-based tree
- This is done by sending an explicit join message to the source
- There may be duplicate packets being sent for some time



(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