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MULTICAST

Introduction to Group Communications in TCP/IP Networks

Reference:

- Jon Hardwick, *"IP Multicast Explained"*, Report - Data Connection Limited

Multicast - Intro

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Applications and Services in the Internet usually target...

- single users or a group of users...
- this may require any from of point-to-point, point-to-multipoint or multipoint-to-multipoint communication model to sustain multimedia or data delivery.
- the use of *multiple unicast* communication approaches leads to inefficient resources consumption (both processing and transmission).
- solution: consider using a multicast delivery model
  - here instantiated at network level, but concepts apply, for instance, to the application layer as well.

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Motivation...

- IP packets are commonly sent from a single source to a single recipient...
- some scenarios need individual IP packets to be delivered to *multiple destinations*
- why not sending multiple unicast packets?
  - source to hold a complete list of recipients
  - send multiple identical copies of the same data
  - ... costly solution in terms of resources
- ... use *multicast, instead of multiple unicast*

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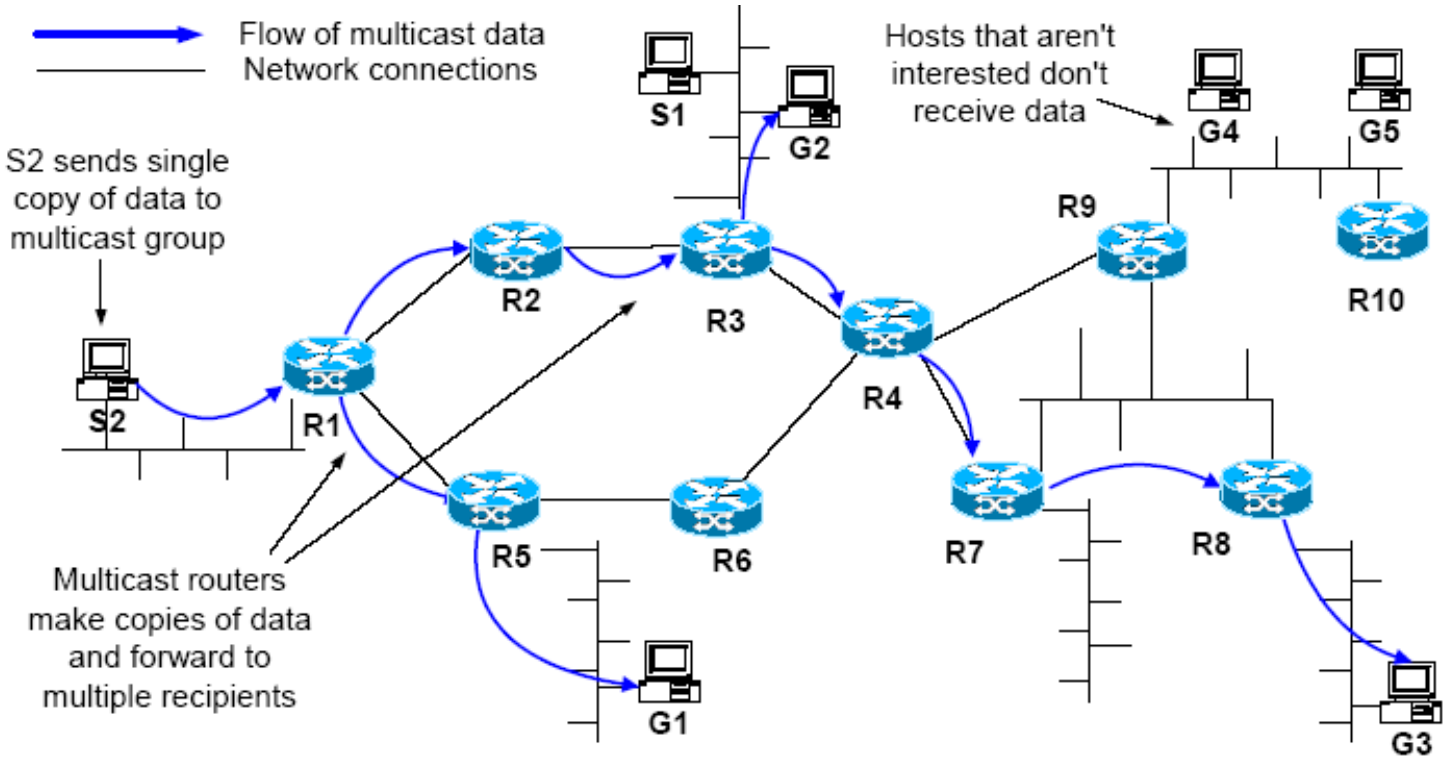
- goal: send a single copy of data to a group of recipients, identified by a *multicast address* (brings a level of abstraction!)
- routers should forward the packets and, when necessary, duplicate data packets



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- Which elements of the network are interested in a particular multicast group?
  - apps/hosts use *Multicast Group Membership Discovery Protocols* (e.g. IGMP for IPv4) to inform the network about willingness to receive data (by sending a message to a multicast router)
  - multicast routers communicate among themselves using *Multicast Routing Protocols*
    - routing protocols need to construct a *multicast distribution tree*
    - traffic reaches all recipients that joined the group
    - number of identical copies is minimized

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Multicast Group Membership Discovery Protocols

- used by apps/hosts to inform the routers in the LAN of the address of the multicast group to join, e.g.
  - *Internet Group Management Protocol* (IGMP), IPv4
  - *Multicast Listener Discovery*, IPv6
- IGMP Basic Operation
  - host wishes to join a new multicast group -> sends an unsolicited IGMP Report message for that group
  - a local router picks up the IGMP Report message -> use a multicast routing protocol to join the multicast group
  - periodically, a querier router broadcasts IGMP Query messages to check which groups the local hosts are subscribed to

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- IGMP Basic Operation (cont.)
  - hosts respond to the Query messages -> send an IGMP Report messages indicating their group membership
  - if a router does not receive a Report message for a particular group for a period of time, the router assumes there are no more members of the group in the LAN, and removes itself from the multicast group
- Sending Queries
  - IGMPv1 depends on the multicast routing protocol to decide which router is the querier
  - IGMPv2 introduces a querier election process

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- Responding to Queries
  - to avoid several simultaneous responses -> each host starts a randomized timer for each group that it is member of -> when the timer finish -> send an IGMP report -> if meanwhile another message is received for the same group -> cancel
- Improving Group Membership Latency
  - IGMPv2 introduces a Leave Group Message
- Source Address Filtering
  - IGMPv3 -> introduces a report message allowing to include or exclude a list of sources for multicast groups that it is member of. (routers merge requirements of different hosts)

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Design alternatives

- Hosts joining to a multicast group may...
  - receive data sent to the group from any source (specify only the multicast group) - Any Source Multicast (ASM)
  - only receive data from a specific source (multicast group + source) - Source-specific multicast (SSM)

- *Multicast Routing Protocols*
  - a router knows the group memberships of its directly connect hosts -> exchange information with other routers -> join or leave trees of a multicast group

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Design alternatives

How

- *How to build a group multicast distribution tree to multiple recipients?*
  - opt-in protocols – multicast network nodes (e.g routers) indicate the groups of interest, i.e., those they want to receive
  - opt-out protocols (broadcast / prune protocols) assume that multicast network nodes (routers) want to receive data... after that, prune themselves from the tree
- Type of tree?
  - source-based trees - separate tree for each source sending data to a group; the tree is rooted at the node/router adjacent to the source
  - shared trees - single tree for all sources sending data to the group - rooted at some selected point (Rendezvous Point) (needs mechanism to transport data from sources->RP)

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Examples of Routing Protocols for Sparse and Dense Environments

- Multicast Routing Protocols
  - *Protocol Independent Multicast Sparse Mode (PIM-SM)*
  - *Protocol Independent Multicast Dense Mode (PIM-DM)*
  - *Distance Vector Multicast Routing Protocol (DVMRP)*
  - *Multicast OSPF (MOSPF)*
  - ...

particularly widespread

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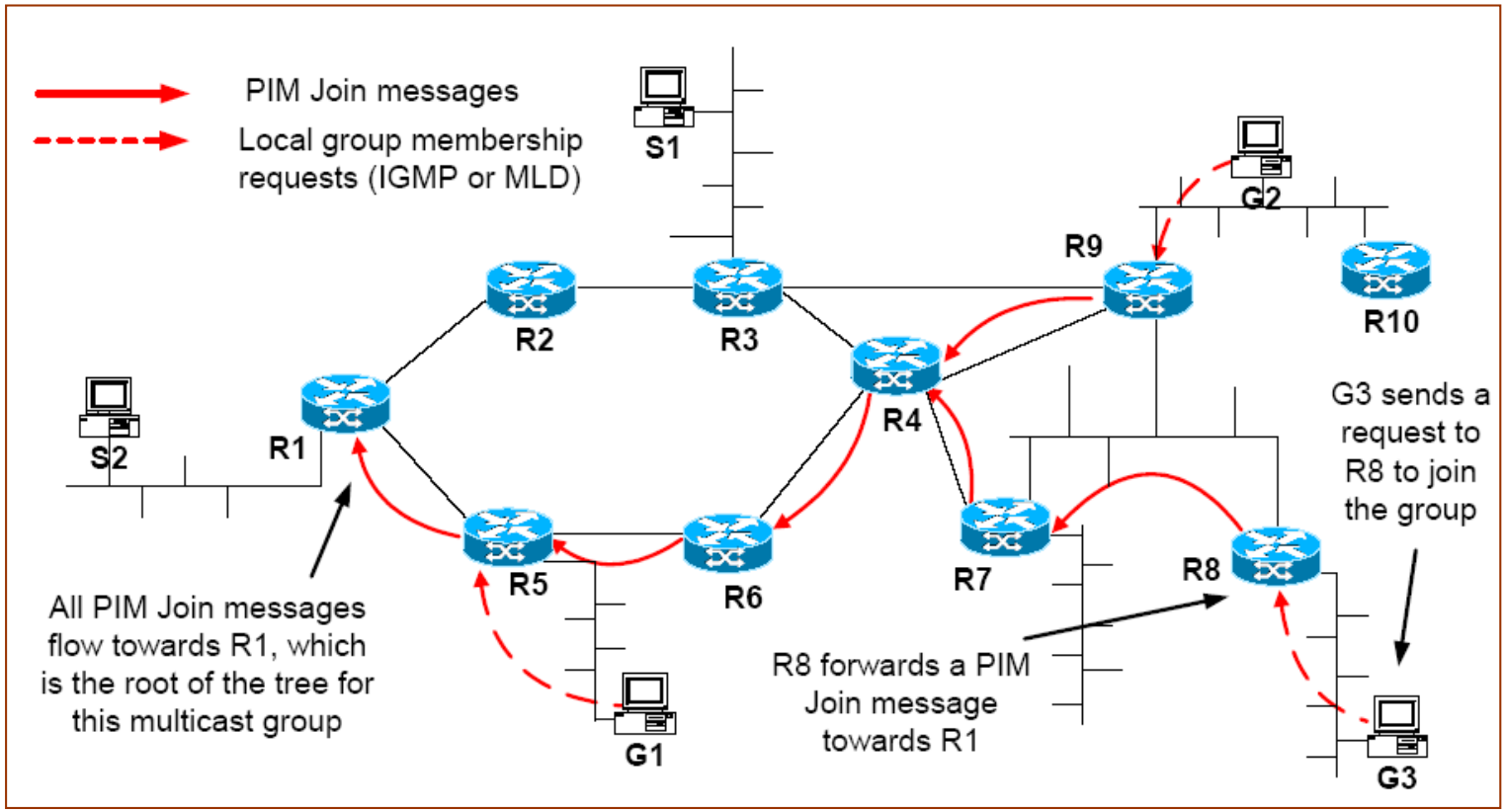
Opt-in example (PIM SM)

- routers announce interest
- can use either *source-based* or *shared trees*



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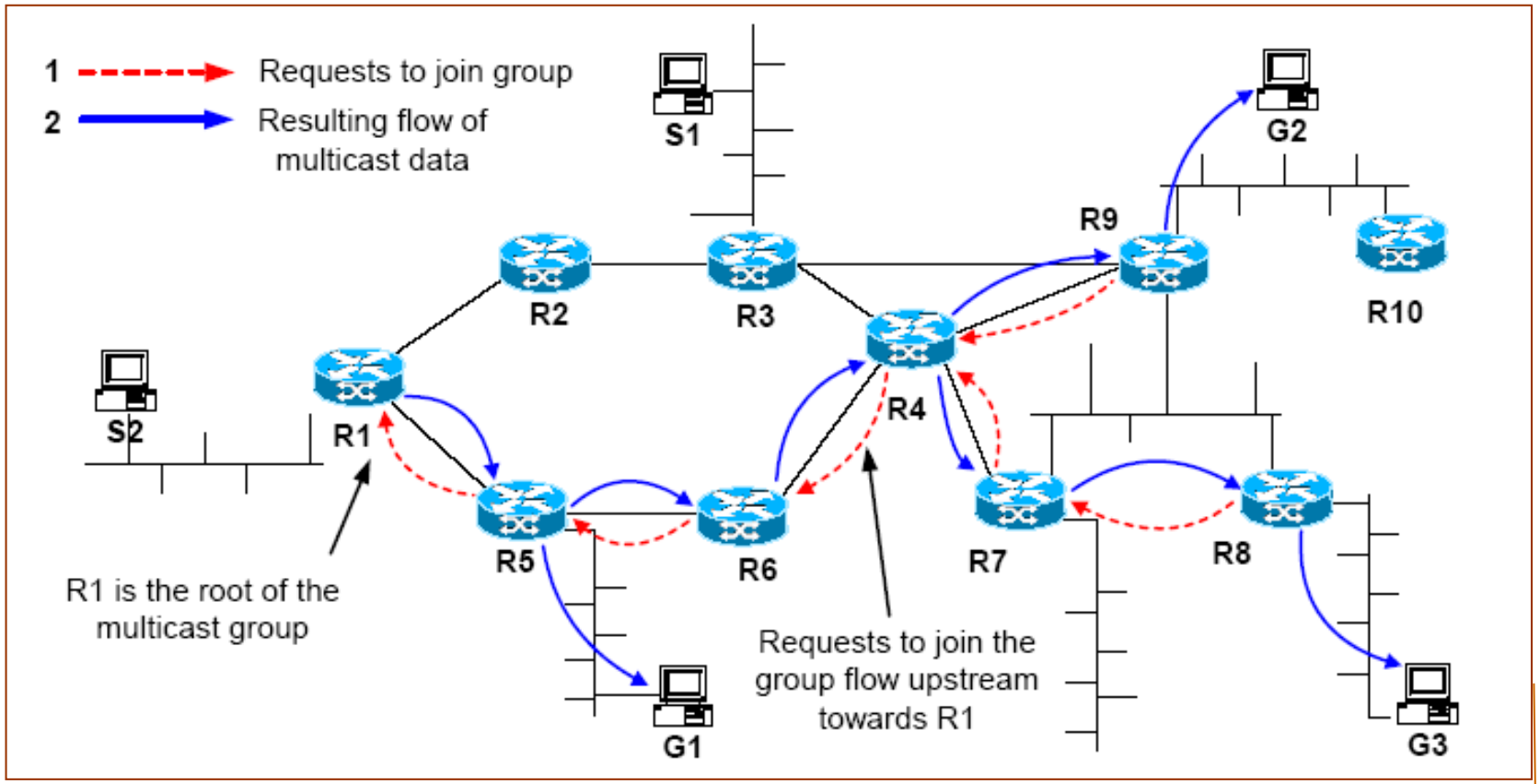
Opt-in example (PIM SM)

- … and the resulting flow of multicast data



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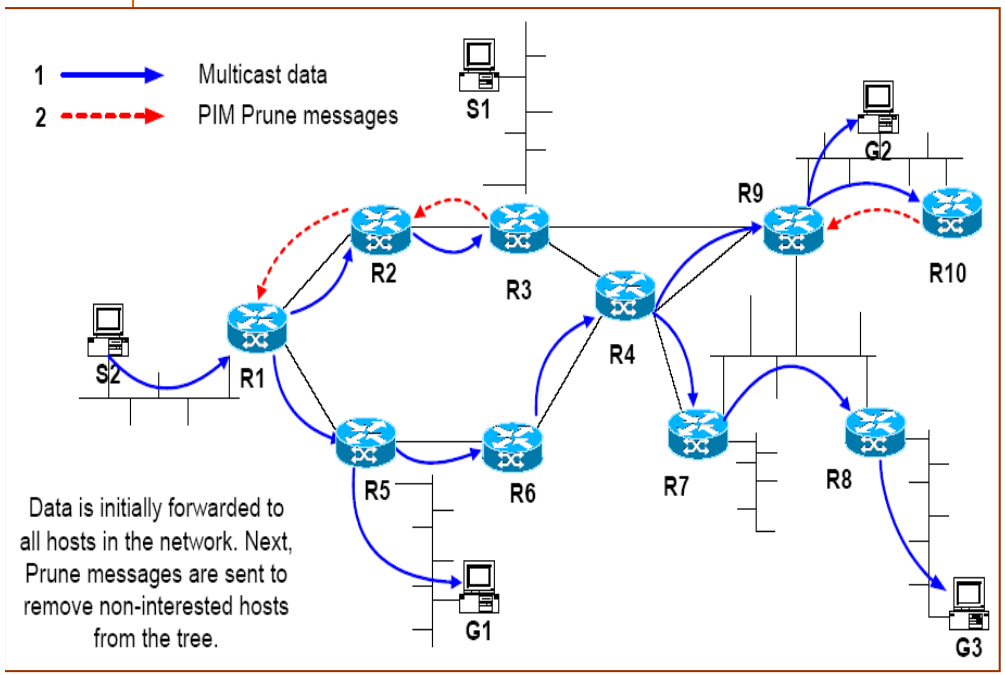
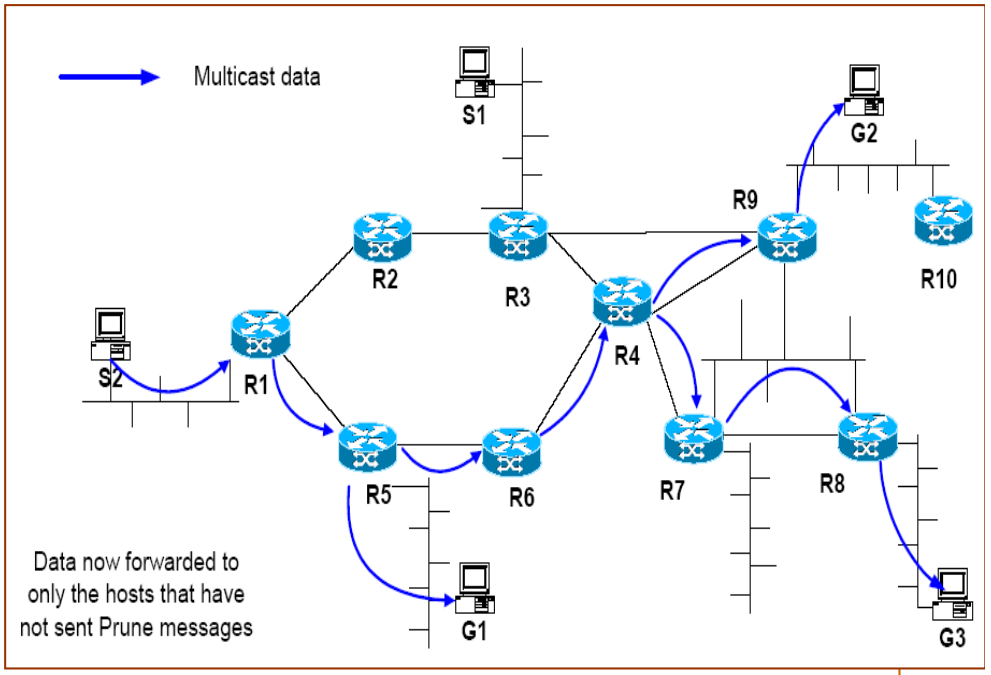
Opt-out Example (PIM DM)

- use *source-based trees*
- … data initially sent to all hosts in the network
- … prune messages to remove from the multicast tree





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Source-based Trees Protocols

- built a separate tree for each source that sends data
- each tree is rooted at a router adjacent to the source
- routers wishing to join the multicast group must specify both the source and the group of the multicast data they would like to receive -> send an (S,G) message to the next upstream router
- advantages:
  - multicast data paths are efficient
- disadvantages:
  - scalability problems when there are a large number of sources
- Source Specific Multicast (SSM) requires the use of source-based trees

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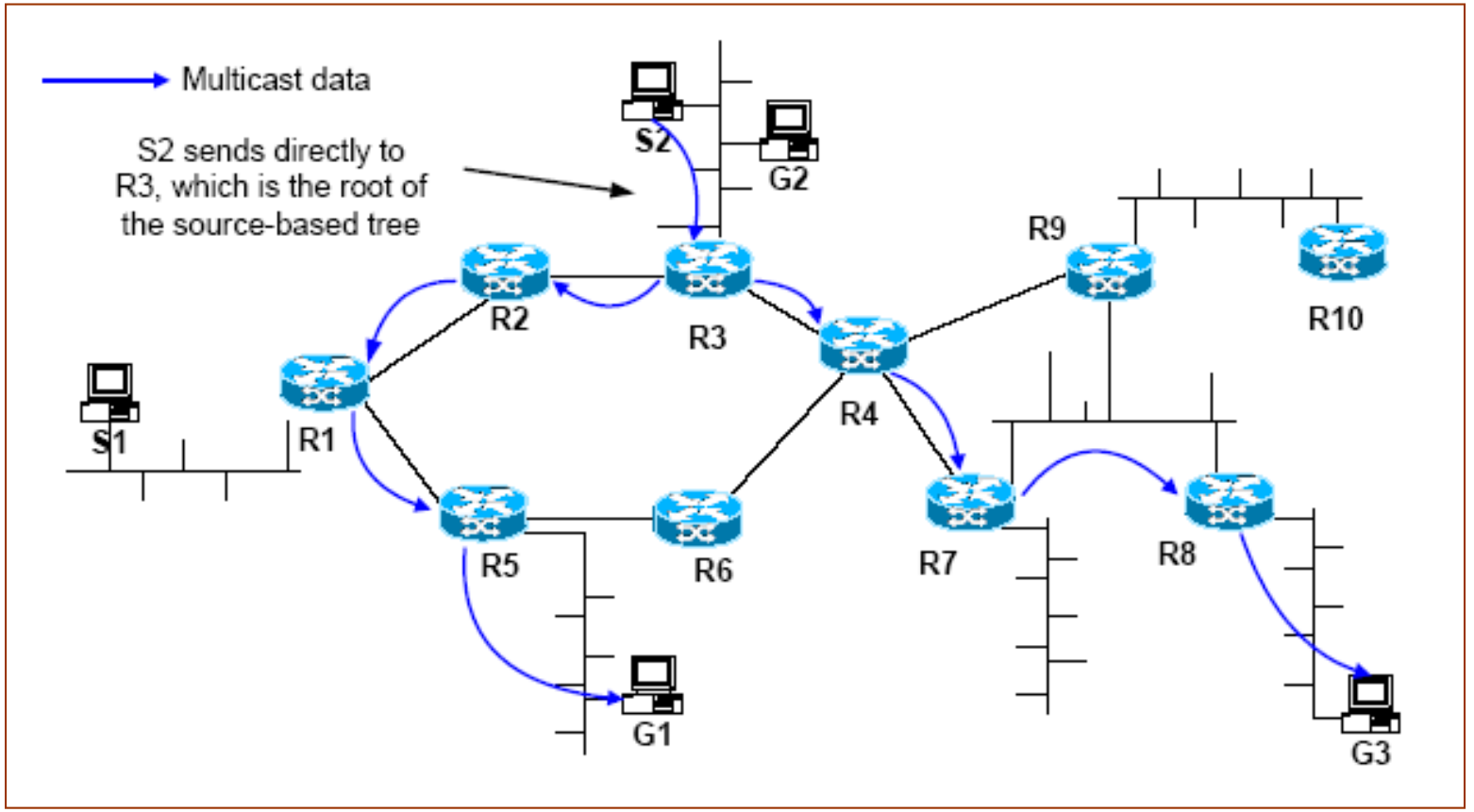
Source-based Trees Protocols - Example

- tree rooted at R3; S2 sends data directly to the root of tree
- new source at S1? -> new source-based tree rooted at R1



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Shared Trees Protocols

- a single tree is used by all sources in the multicast group
- a router wishes to join a multicast group, it does not need to specify the source -> sends a (*, G) message to the next upstream router
- rooted? -> some selected node (called RP in PIM)
  - pre-configured or...
  - election
  - …
- how to deliver traffic from sources to root of the shared tree?

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Shared Trees Protocols

- mechanism to deliver traffic from sources to root of the shared tree?
  - *unidirectional shared trees* - each data packet is encapsulated by a source router, sent to the root of the tree (using unicast delivery) and decapsulated (PIM-SM)
  - *...*
- Advantages:
  - for a large number of sources -> shared trees are better than source-based
- Disadvantages:
  - inefficient data paths; require a selection mechanism for the root of the tree (RP)

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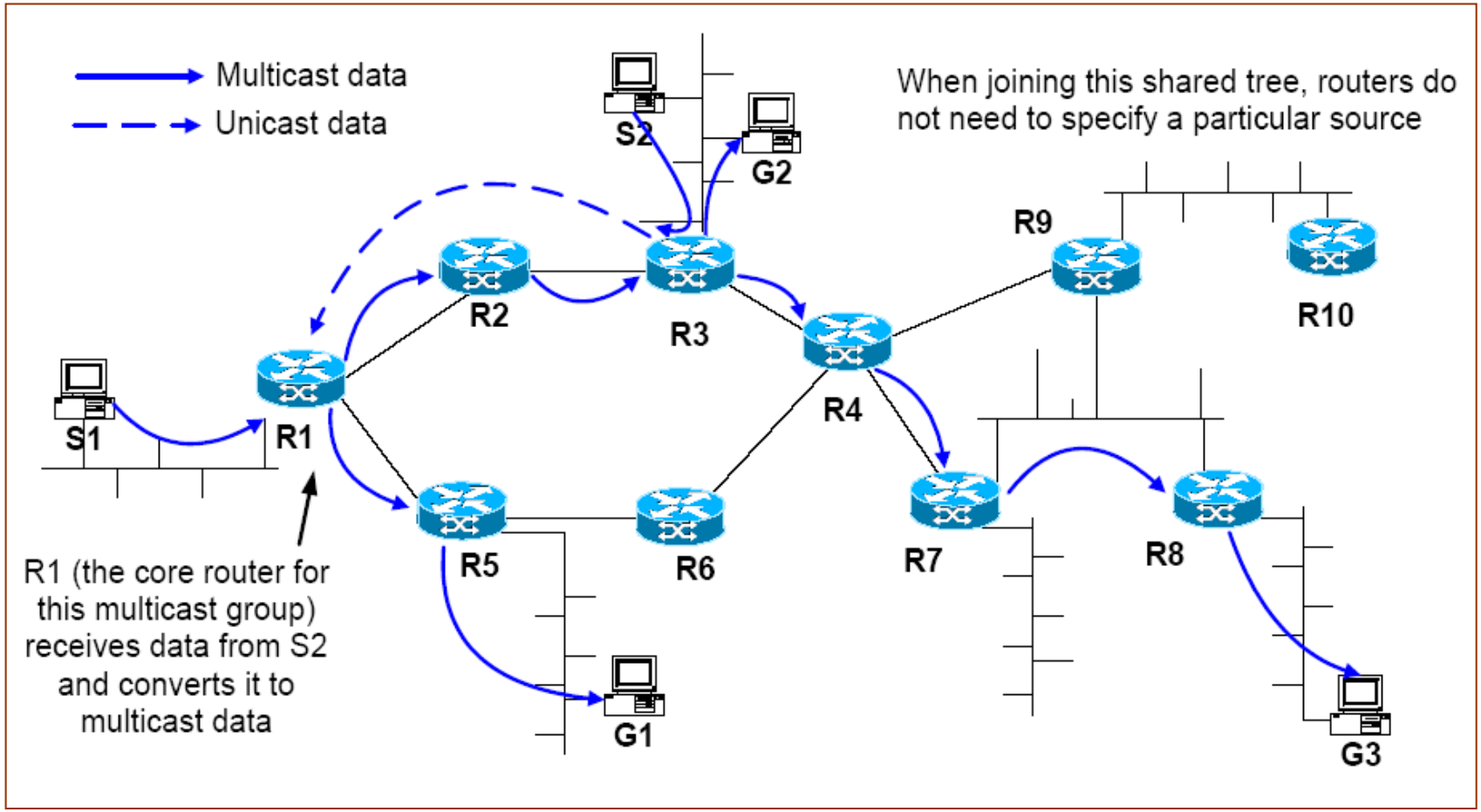
Shared Trees Protocols - Example



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Determining the Upstream Router

- routing protocols need to determine the next upstream interface for the multicast group - *Reverse Path Forwarding (RPF) algorithm*
- router uses the upstream interface...
  - as outgoing interface for control packets (e.g. join, leave, prune messages…)
  - as incoming interface for multicast data... e.g. if packets arrive from a distinct interface -> drop/ignore packets to avoid duplicated packets and loops
- e.g. PIM relies on a Multicast Routing Information Database (MRIB) to perform RPF lookups
  - MRIB - similar to a unicast forwarding table...

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Protocol Independent Multicast (PIM)

Two main PIM protocols:

- PIM Sparse Mode (PIM-SM) is an opt-in protocol that uses (mostly) shared and source-based trees
  - multicast routing protocol most widely used in sparse environments
- PIM Dense Mode (PIM-DM) is an opt-out (*broadcast /prune)* protocol that uses source-based trees only...
  - mostly used for individual small domains
  - low resource-constrained networks

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PIM Sparse Mode

- opt-in protocol, by default uses shared-trees rooted at a router (rendezvous point)
- ...also supports source-based trees
  - ... to avoid encapsulation
  - ... to optimize data path
  - ... for source-specific multicast (SSM)
- PIM-SM is a soft-state protocol
  - state times-out some time after receiving control messages
  - join messages are periodically re-transmitted to keep state

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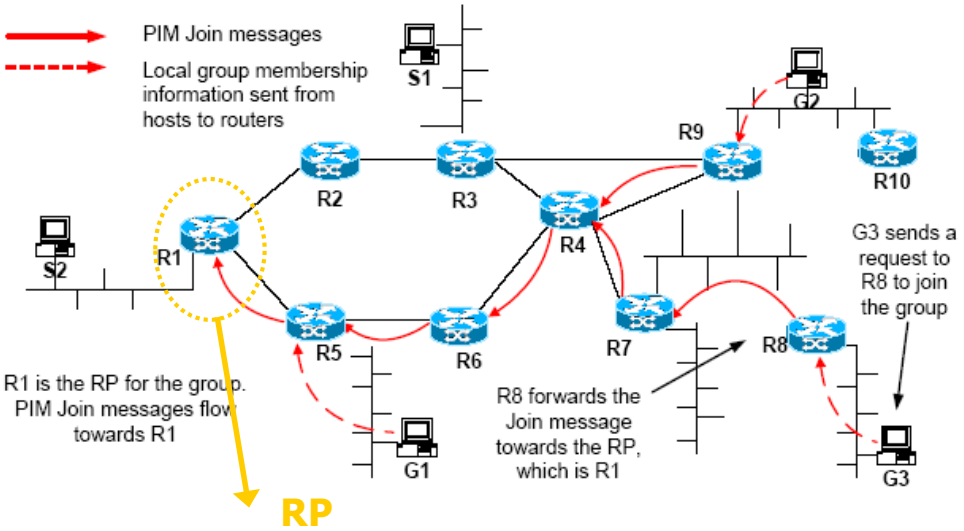
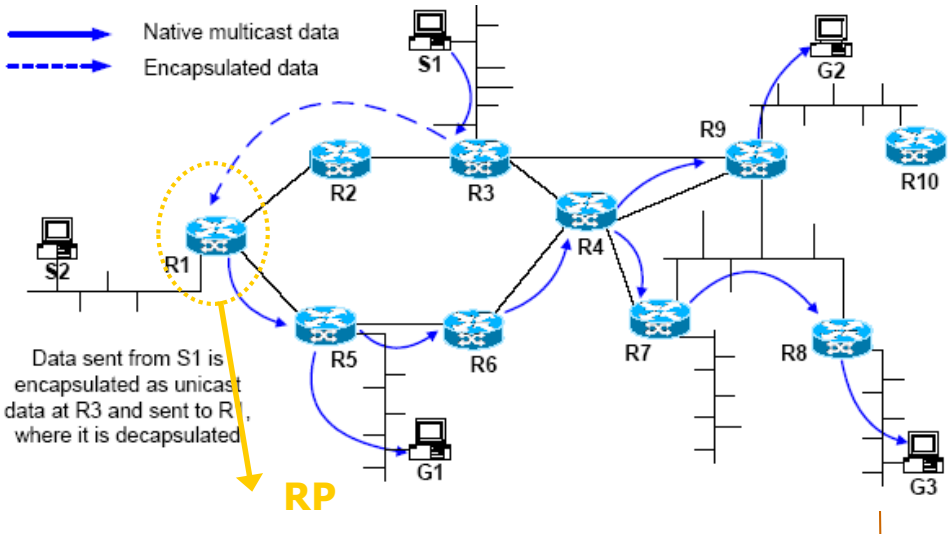
PIM Sparse Mode

- hosts indicate their interest using IGMP or MLD
- one of the routers of the LAN is elected as designated router (DR); responsible for joining the multicast group and forwarding traffic
- routers send PIM (*,G) Join Messages -> forwarding state in routers -> Rendezvous Point Tree (RPT)





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PIM Sparse Mode - Summary

- some advantages:
  - protocol independent of the unicast protocol operating in the network
  - scales well
  - supports both SSM and ASM
  - supports shared trees (no need to keep per source state) and source-based trees (more efficient data paths)
- some disadvantages:
  - shared trees
    - require encapsulation/ decapsulation between source and rendezvous point
    - source to RP mechanism is necessary

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PIM Dense Mode

- it assumes that most the networks in the domain are interested in receiving multicast data
- does not scale well for large domains, mostly used for small domains -> opt-out protocol
- opt-out protocol, source-based trees
  - *see the examples presented before*
- the data is flooded to all parts of the network (but the router checks if the packet arrives from the interface closest to the source -> otherwise packet is dropped)
- if the router has no need of the data? -> send PIM (S,G) Prune message upstream -> upstream router stops sending data

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PIM Dense Mode

- prune state at routers will time-out
  - data begin to follow to previously pruned areas -> prune or accept (graft) if interest

- new receiver in a pruned network part?
  - local router sends a PIM (S,G) Graft message upstream which means a rejoin request to the multicast tree
  - graft messages are acknowledge by an explicit acknowledgment (unique situation in PIM)

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PIM Dense Mode - Summary

- some advantages:
  - efficient if receivers are densely distributed in the network
  - avoid the complexity of RP configuration
- some disadvantages:
  - all routers need to store per-source state for every source in the domain
  - does not scale well for domains where most of receivers do not wish to receive data

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Multicast Routing Protocols (summary)

Protocol	Opt-in / Opt-out	Supports SSM	Tree Type	Upstream Router Info Via
PIM-SM	Opt-in	Yes	Shared or source-based	MRIB
PIM-DM	Opt-out	Yes	Source-based	MRIB
BIDIR-PIM	Opt-in	No	Shared	MRIB
DVMRP	Opt-out	Yes	Source-based	Distance vector mechanism
MOSPF	Opt-in	No	Source-based	Link state mechanism