MULTICAST

Introduction to Group Communications
in TCP/IP Networks

Reference:

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

Multicast - Intro

Applications and Services on 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!)

- network nodes (e.g. routers, if at network level) should forward the packets and, when necessary, duplicate data packets
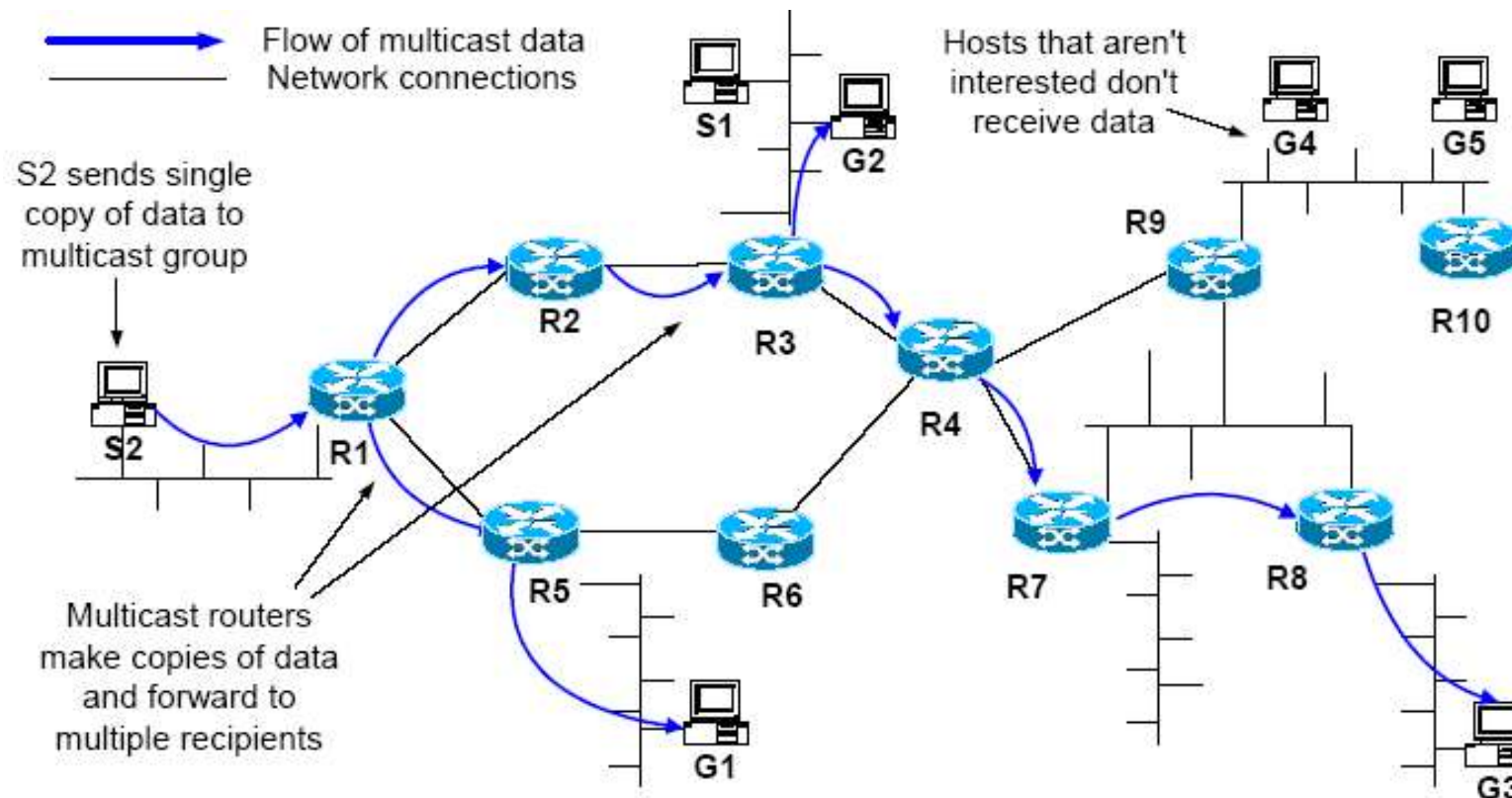
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- Which elements of the network are interested in a particular multicast group?

  - 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?*
    - <u>opt-in protocols</u> – multicast network nodes indicate the groups of interest; building the tree is triggered by client joins

    - <u>opt-out protocols</u> (flood / prune) – assume that multicast network nodes want to receive data... after that, prune themselves from the tree, if no clients are interested.

- Type of tree?
    - <u>source-based trees</u> - separate tree for each source sending data to a group; the tree is rooted at the node/router adjacent to the source

    - <u>shared trees</u> - 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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Example of Multicast Routing Protocols for <u>Sparse</u> and <u>Dense</u> Environments

- Multicast Routing Protocols

  - *Protocol Independent Multicast Sparse Mode (PIM-SM)*

    > particularly widespread

  - *Protocol Independent Multicast Dense Mode (PIM-DM)*

  - *Distance Vector Multicast Routing Protocol (DVMRP)*
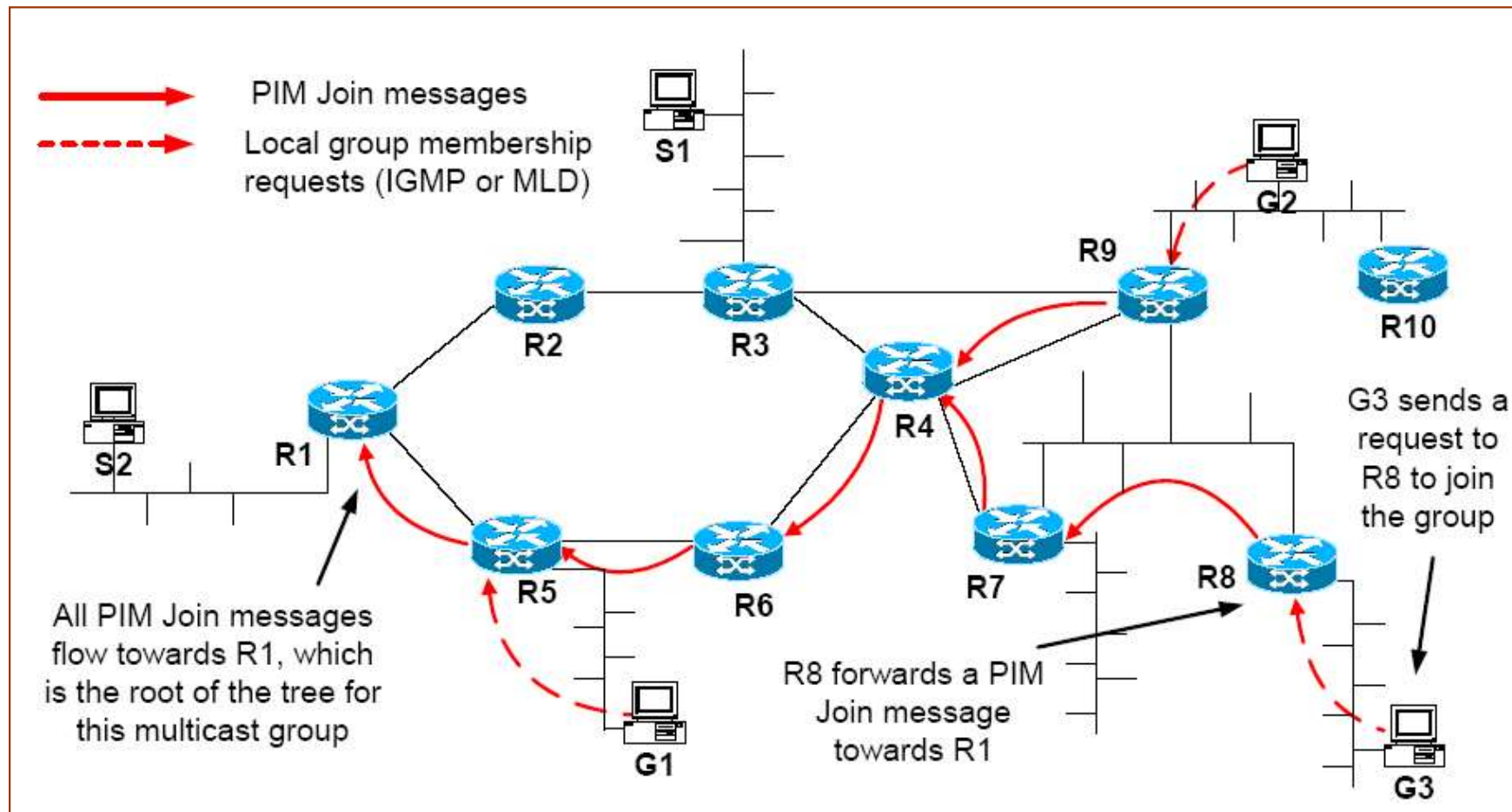
  - *Multicast OSPF (MOSPF)*

  - *...*

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Opt-in example (PIM SM)

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

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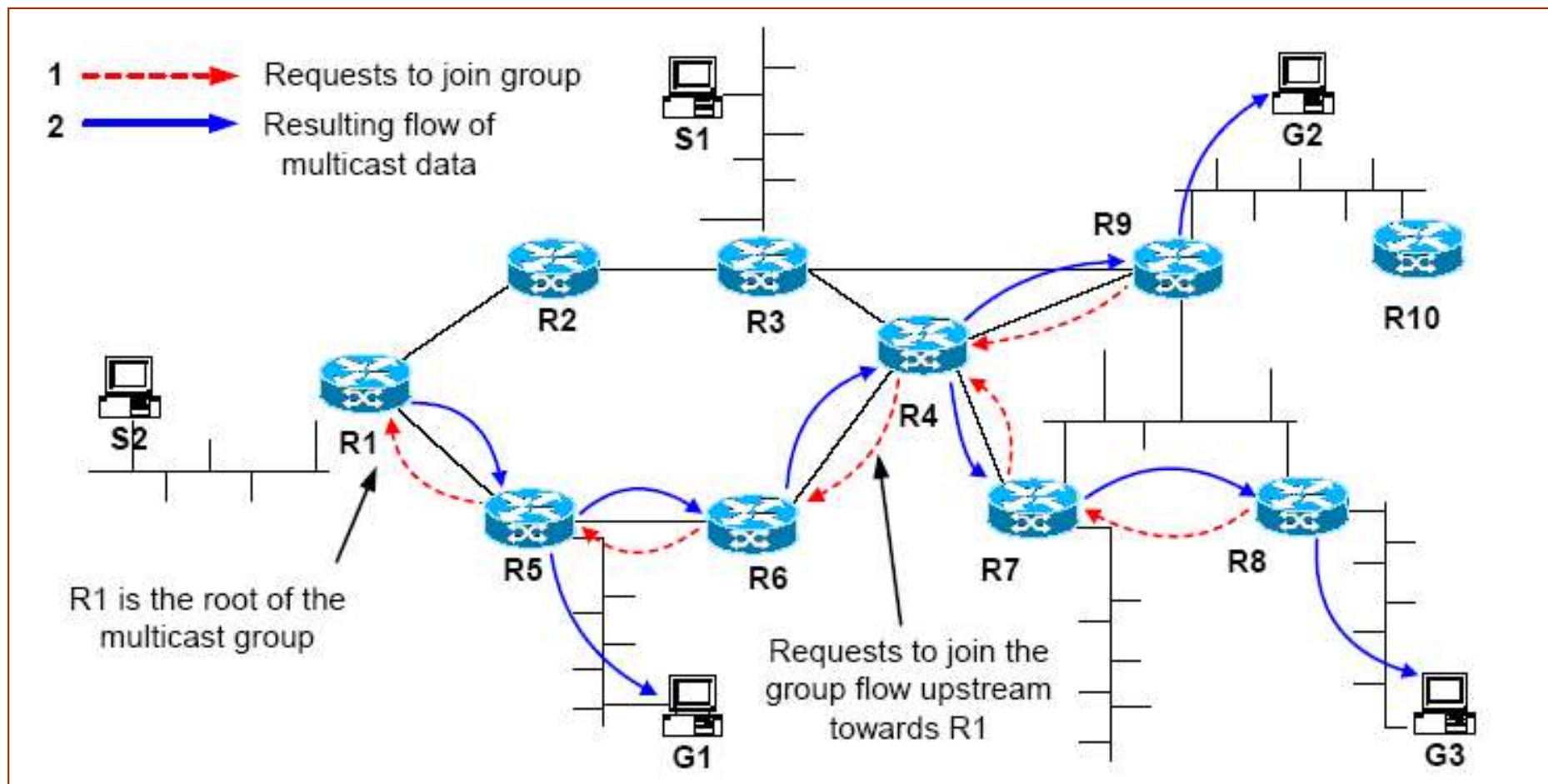## Opt-in example (PIM SM)

- … and the resulting flow of multicast data

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Opt-out Example (PIM DM) – use *source-based trees*

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Opt-out Example (PIM DM)

- resulting tree

Multicast data

S1

G2

R9

R2

R3

R10

R4

S2

R1

R5

R6

R7

R8

Data now forwarded to
only the hosts that have
not sent Prune messages

G1

G3
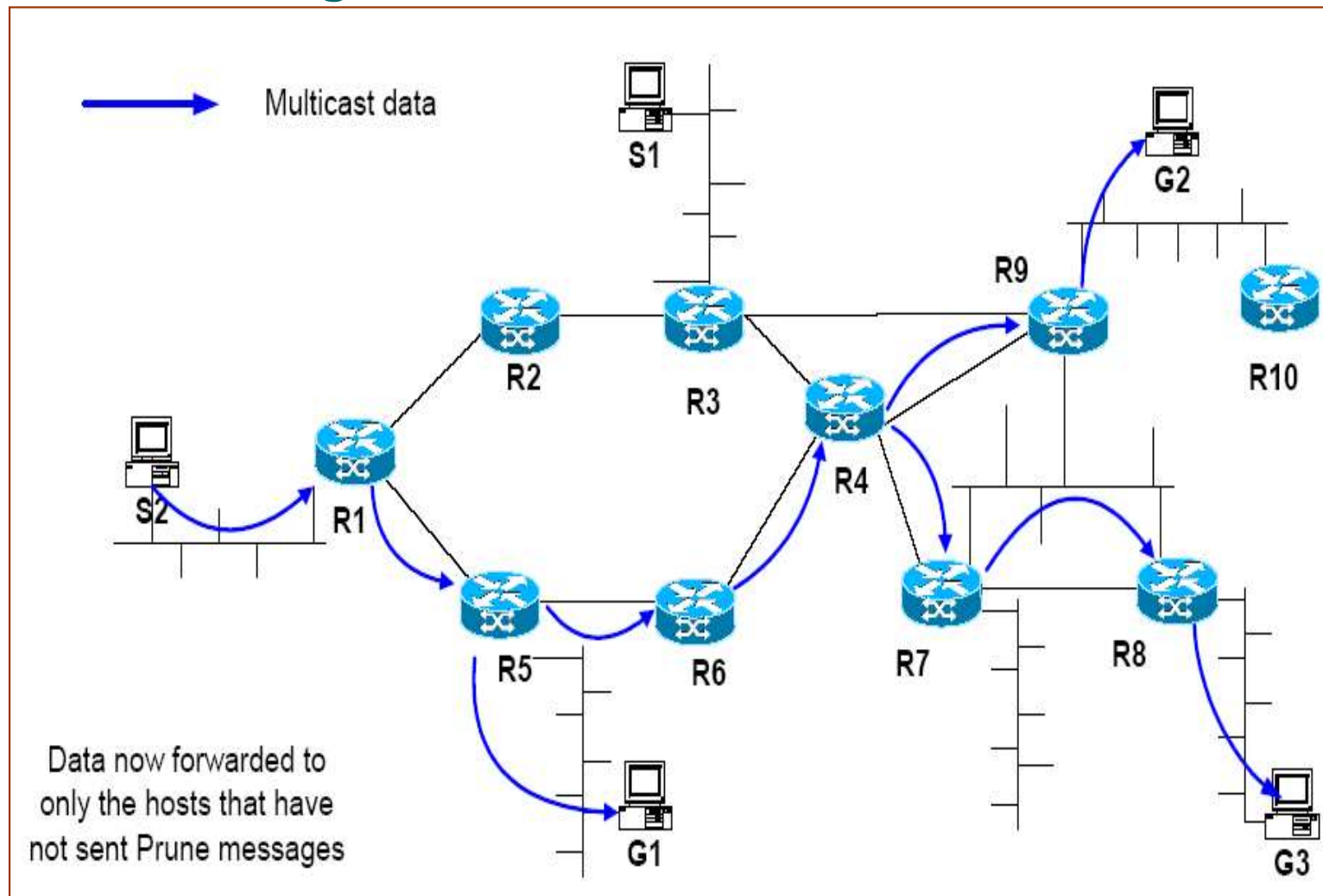
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Source-based Trees Protocols

- 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

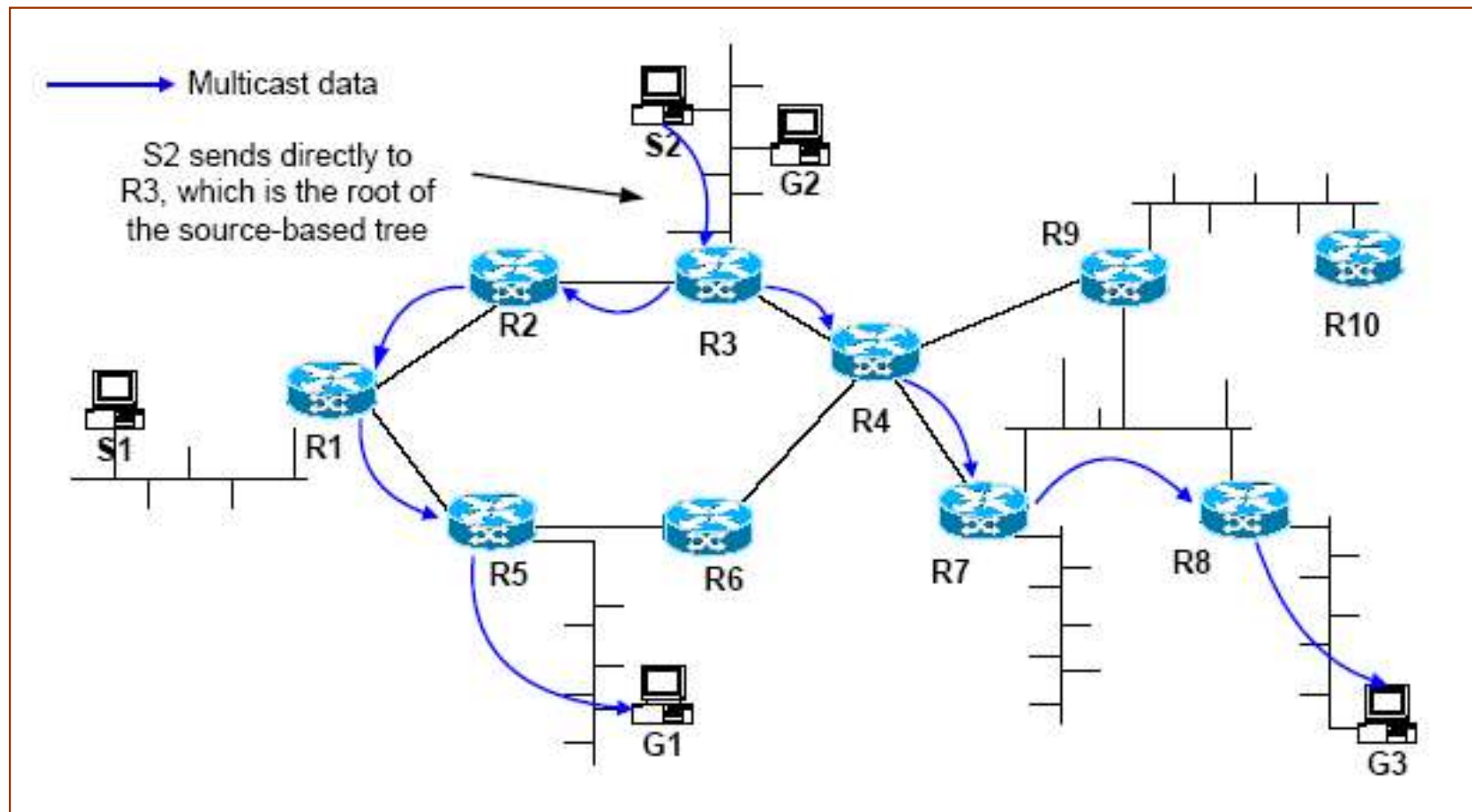- Source Specific Multicast (SSM) requires the use of source-based trees

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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

Multicast data
Unicast data

When joining this shared tree, routers do not need to specify a particular source

S2
G2

R9
R10

R2
R3
R4
R7
R8

S1
R1

R1 (the core router for this multicast group) receives data from S2 and converts it to multicast data

R5
R6

G1
G3

MEI/MIEI

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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
    - **Sparse mode: only forward the multicast traffic after a downstream router request it**

- 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
    - **Dense mode: forward multicast traffic to all interfaces until a down-stream router request to stop it**
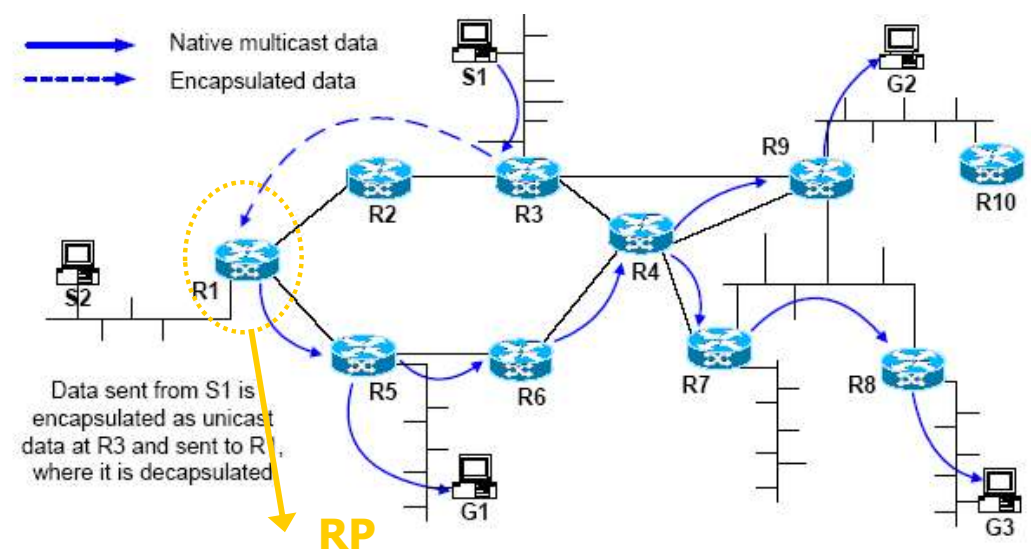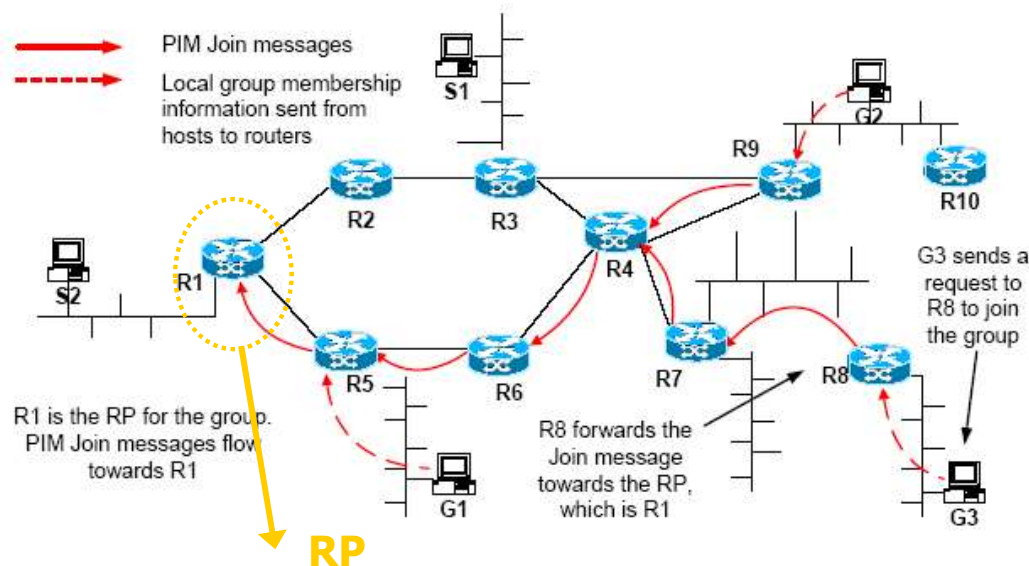
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PIM Sparse Mode

- opt-in protocol, <u>by default</u> 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