CS321: Computer Networks

Multicast Routing

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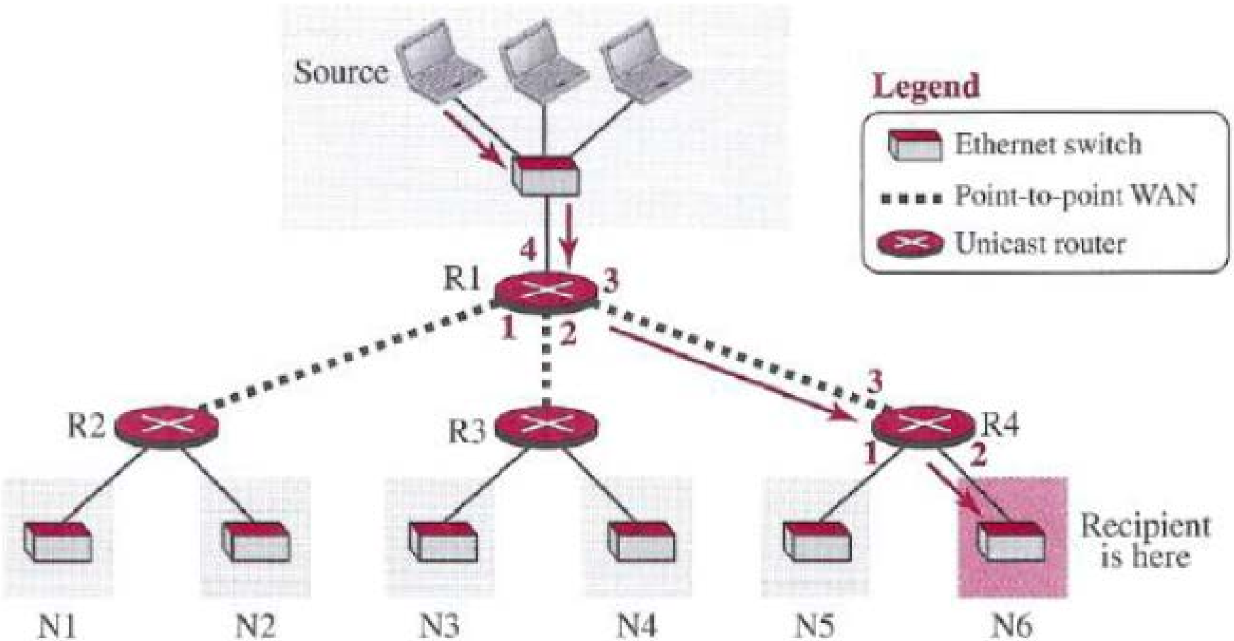
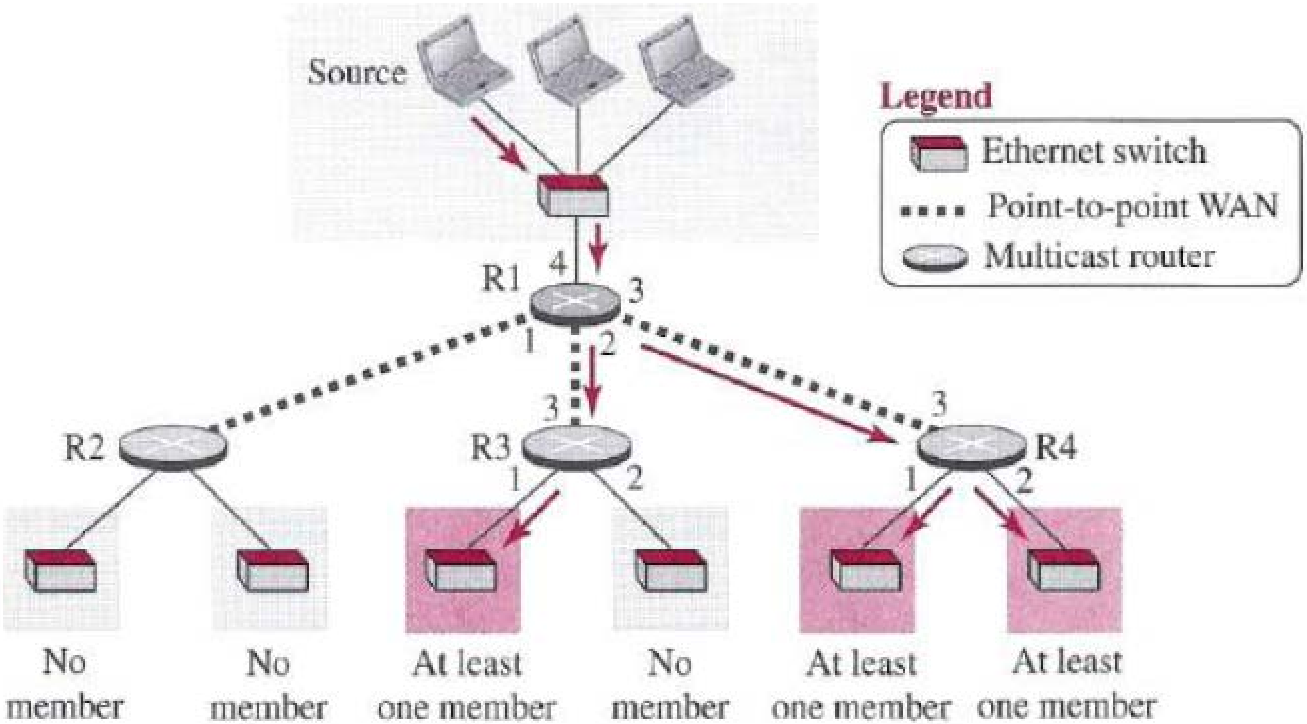
Unicasting

- There is one source and one destination network.
- The relationship between the source and the destination network is one to one.
- Each router in the path tries to forward the packet to one and only one of its interfaces.



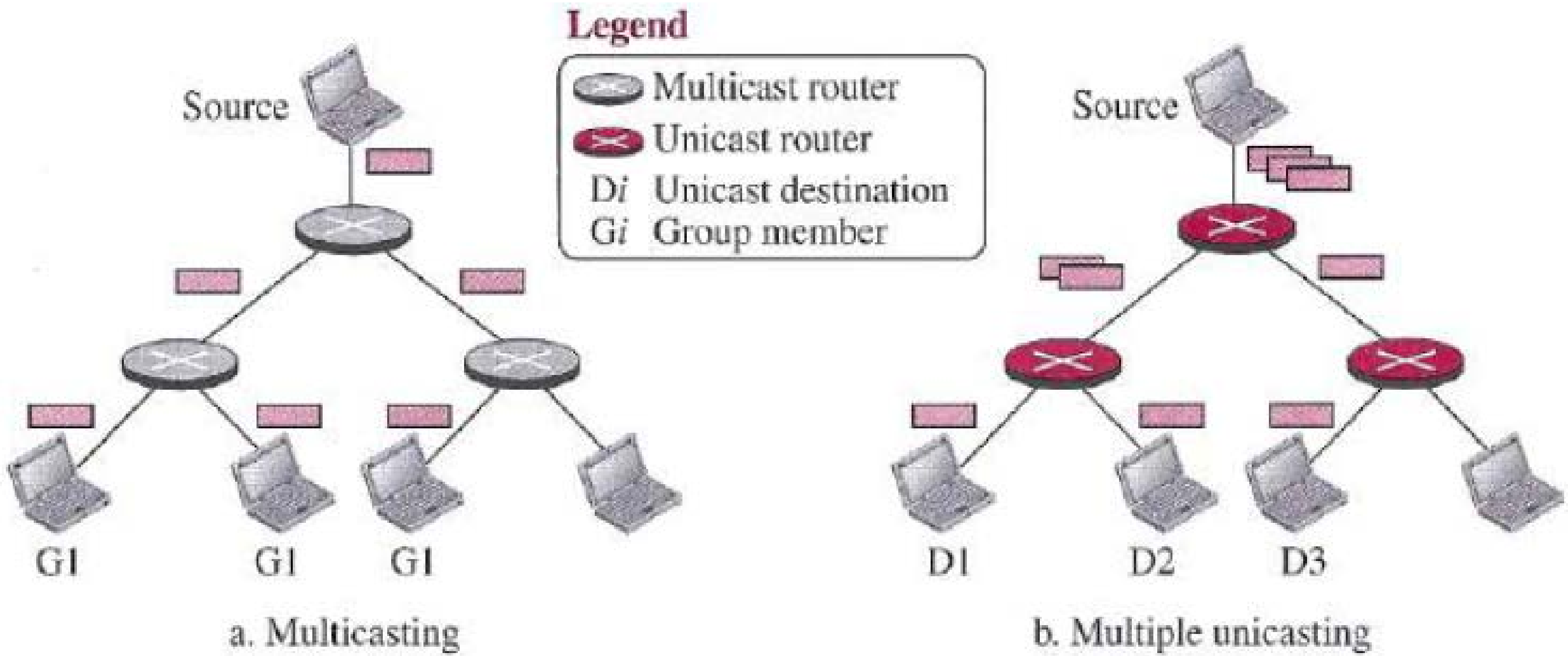
Multicasting

- There is one source and a group of destinations.
- The relationship is one to many.
- The source address is a unicast address, but the destination address is a group address, in which there is at least one member of the group that is interested in receiving the multicast datagram.



Multicast vs Multiple Unicast

- Multicasting starts with a single packet from the source that is duplicated by the routers.
- The destination address in each packet is the same for all duplicates.
- Only a single copy of the packet travels between any two routers.



Cont…

- In multiple unicasting, several packets start from the source.
- If there are three destinations, for example, the source sends three packets, each with a different unicast destination address.
- Note that there may be multiple copies traveling between two routers.

- Example:
  - When a person sends an e-mail message to a group of people, this is multiple unicasting.
  - Teleconferencing: A group of workstations form a multicast group such that a transmission from any member is received by all other group members.

Why multicasting?

- Two main reasons:
  - Multicasting requires less bandwidth than multiple unicasting.
  - In multiple unicasting, the packets are created by the source with a relative delay between packets. In multicasting, there is no delay because only one packet is created by the source.
- Why group e-mail is multiple unicast?
  - Multicast involves a subscription from the receiver's side.
  - But, multiple unicast is a decision from the sender's side.
  - Usually, sender manage the group of multiple unicast, but a receiver is associated with a multicast group.

Multicast Applications

- Teleconferencing
- Distance Learning
- Information Dissemination
- Access to Distributed Databases
- etc.

Broadcasting:

- one-to-all communication: a host sends a packet to all hosts in an internet.

Multicast Address

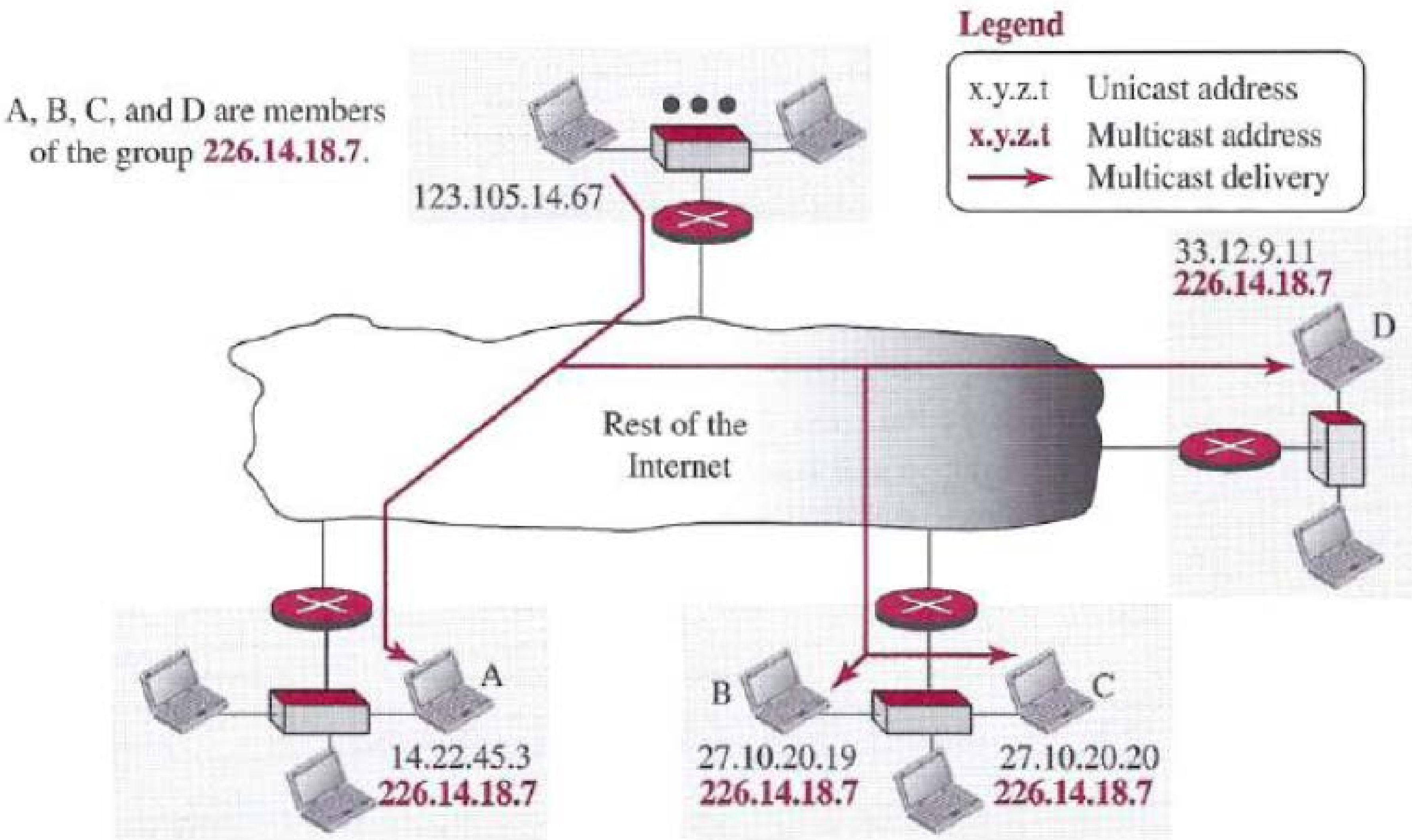
- In IP datagram, we can only write one destination address. So, we need multicast address for sending the datagram to many destinations.
- a multicast address is an identifier for a group.
- If a new group is formed with some active members, an authority can assign an unused multicast address to this group to uniquely define it

Multicast Address in IPv4

- A router or a destination host needs to distinguish between a unicast and a multicast datagram.
- IPv4 assigns a block of addresses for this purpose

- In classful addressing, all of class D was composed of these addresses;
- classless addressing used the same block, but it was referred to as the block 224.0.0.0/4 (from 224.0.0.0 to 239.255.255.255).

Example



A, B, C, and D are members of the group 226.14.18.7.
123.105.14.67
Legend
x.y.z.t Unicast address
x.y.z.t Multicast address
Multicast delivery
33.12.9.11
226.14.18.7
D
Rest of the Internet
A
B
C
14.22.45.3
226.14.18.7
27.10.20.19
226.14.18.7
27.10.20.20
226.14.18.7

Multicast Sub-blocks

- Total number of multicast address blocks = 2^{28}
- The blocks are divided into multiple sub-blocks
  - o Local Network Control Blocks: 224.0.0.0/24
    - o Multicast routing is used inside a network
    - o Datagram cannot be forwarded by the router to outside
  - o Internetwork Control Block: 224.0.1.0/24
    - o Routing protocol can used whole Internet
  - o Source-specific Multicast Block: 232.0.0.0/8
    - o IGMP protocol use this
  - o GLOP Block: 233.0.0.0/8
    - o To restrict inside an AS (autonomous system)
  - o Administratively Scoped Block: 239.0.0.0/8
    - o To restrict inside an organization or an area

Delivery at DLL

- In multicasting, the delivery at the Internet level is done using multicast IP addresses
- But, data-link layer multicast addresses are also needed to deliver a multicast packet encapsulated in a frame.
- ARP protocol cannot help in finding multicast MAC address

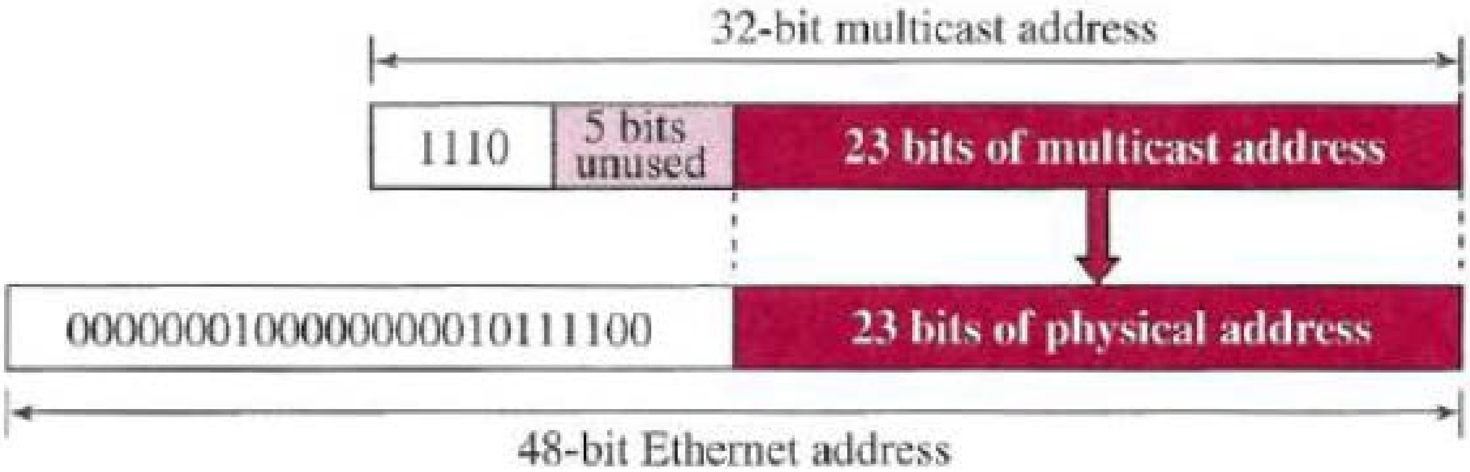
- Solution for two scenario:

  1. Network with Multicast Support

  Most LANs (e.g. Ethernet) support physical multicast addressing.

  If the first 25 bits in an Ethernet address are 00000001 00000000 01011110 0, this identifies a physical multicast address for the TCP/IP protocol.

Cont…



- An Ethernet multicast physical address is in the range

  01:00:5E:00:00:00 - 01:00:5E:7F:FF:FF

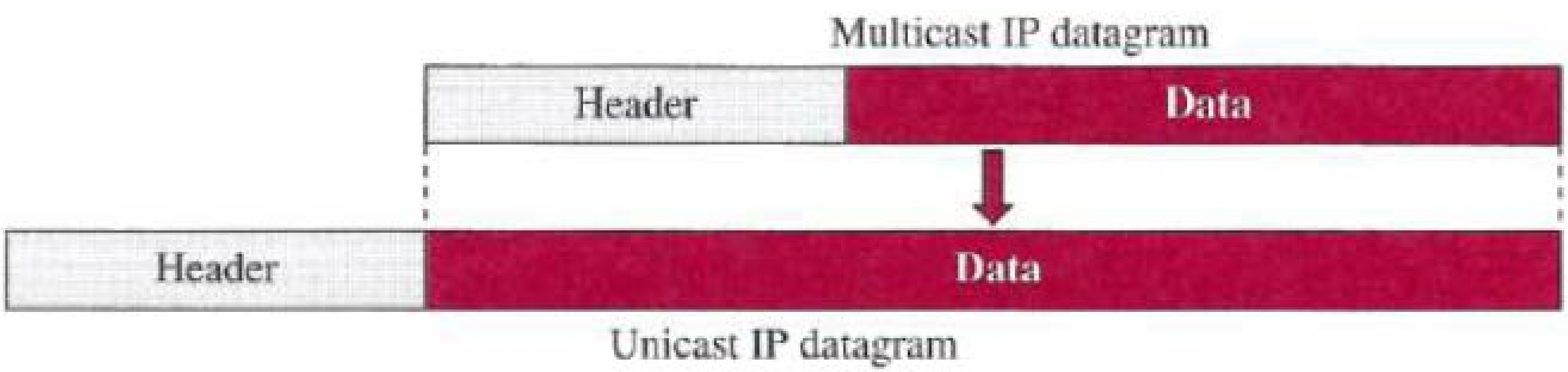
Cont…

- *Example*: Change the multicast IP address 232.43.14.7 to an Ethernet multicast physical address.

- We can do this in two steps:
  - We write the rightmost 23 bits of the IP address in hexadecimal. Then subtracting 8 from the leftmost digit if it is greater than or equal to 8. In our example, the result is 2B:OE:07
  - We add the result of part a to the starting Ethernet multicast address, which is 01:00:5E:00:00:00.The result is 01:00:5E:2B:OE:07

Cont…

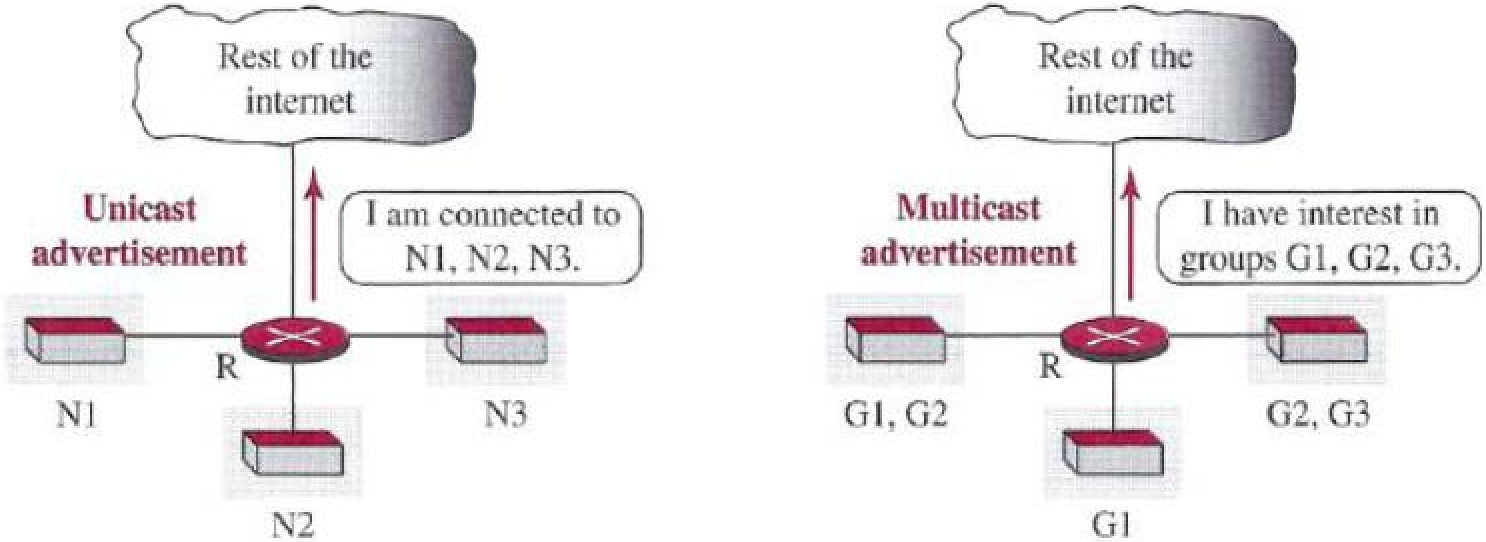
2. Network with No Multicast Support
   - Most WANs do not support physical multicast addressing
   - To send a multicast packet through these networks, a process called *tunneling* is used
   - In tunneling, the multicast packet is encapsulated in a unicast packet and sent



Collecting Information about Groups

- Creation of forwarding tables in both unicast and multicast routing involves two steps:
  - A router needs to know to which destinations it is connected.
  - Each router needs to propagate information obtained in the first step to all other routers so that each router knows to which destination each other router is connected

Cont…



- In unicast routing, the collection of the information in the first step is automatic;
- Each router knows to which network it is connected, and the prefix of the network (in CIDR) is what a router needs.

- In multicast routing, the collection of information in the first step is not automatic.

Cont…

- Because,
  - a router does not know which host in the attached network is a member of a particular group; membership in the group does not have any relation to the prefix associated with the network.
  - the membership is not a fixed attribute of a host; a host may join some new groups and leave some others even in a short period of time.

- For unicasting, the router needs no help to collect;
- but for multicasting, it needs the help of another protocol namely Internet Group Management Protocol (IGMP)

Multicast Forwarding

- a router needs to make a decision to forward a multicast packet

a. Destination in unicasting is one

b. Destination in mulicasting is more than one

- In unicast communication, the destination address of the packet defines one single destination. So, forwarded through one interface.

- In multicast communication, the destination of the packet defines one group, but that group may have more than one member in the internet. So, forwarded through many interfaces.

Cont…

- Forwarding decisions in unicast communication depend only on the destination address of the packet.
- Forwarding decisions in multicast communication depend on both the destination and the source address of the packet.

a. Packet sent out of two interfaces

b. Packet sent out of one interface

Multicasting Approaches

- we need to create routing trees to optimally route the packets from their source to their destination.
  - Source-Based Tree Approach
    - each router needs to create a separate tree for each source-group combination.
    - In each tree, the corresponding source is the root, the members of the group are the leaves, and the router itself is somewhere on the tree.
  - Group-Shared Tree Approach
    - we designate a router to act as the dummy source for each group.
    - The designated router, which is called the *core* router, acts as the representative for the group.
    - Any source that has a packet to send to a member of that group sends it to the core router (unicast communication) and the core router is responsible for multicasting.

Intra-domain Multicast Protocol

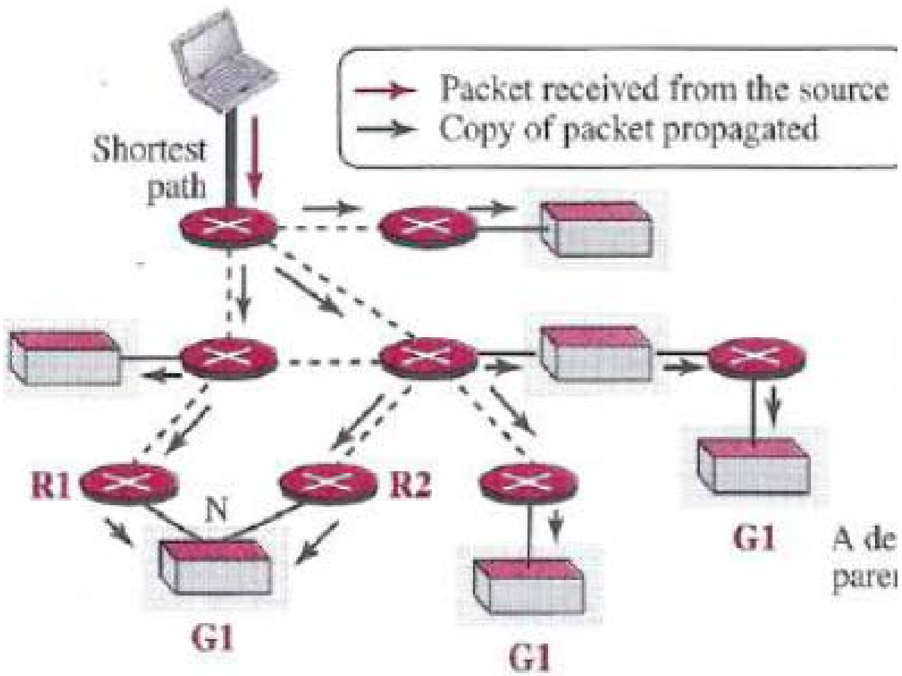
- Using distance-vector + source-based tree approach
  - Distance Vector Multicast Routing Protocol (DVMRP)
    - Extension of RIP and OSPF
- Using link-state + source-based tree approach
  - Multicast Open Shortest Path First (MOSPF)
- Using distance-vector / link-state + source-based tree / group-shared tree approach
  - Protocol Independent Multicast (PIM)

DVMRP

- Distance Vector Multicast Routing Protocol (DVMRP) is an extension of RIP for multicasting
- Router creates a multicast tree to forward multicast packet using the 3 steps:
  – Router uses reverse path forwarding (RPF)
    - to create optimal source-based tree between source and itself
  – Router uses reverse path broadcasting (RPB)
    - to create a broadcast (spanning) tree whose root is router itself and whose leaves are all networks in the Internet
  – Router uses reverse path multicasting (RPM)
    - to create multicast tree by cutting some branches of the tree that end in network with no member in the group.

Reverse Path Forwarding (RPF)

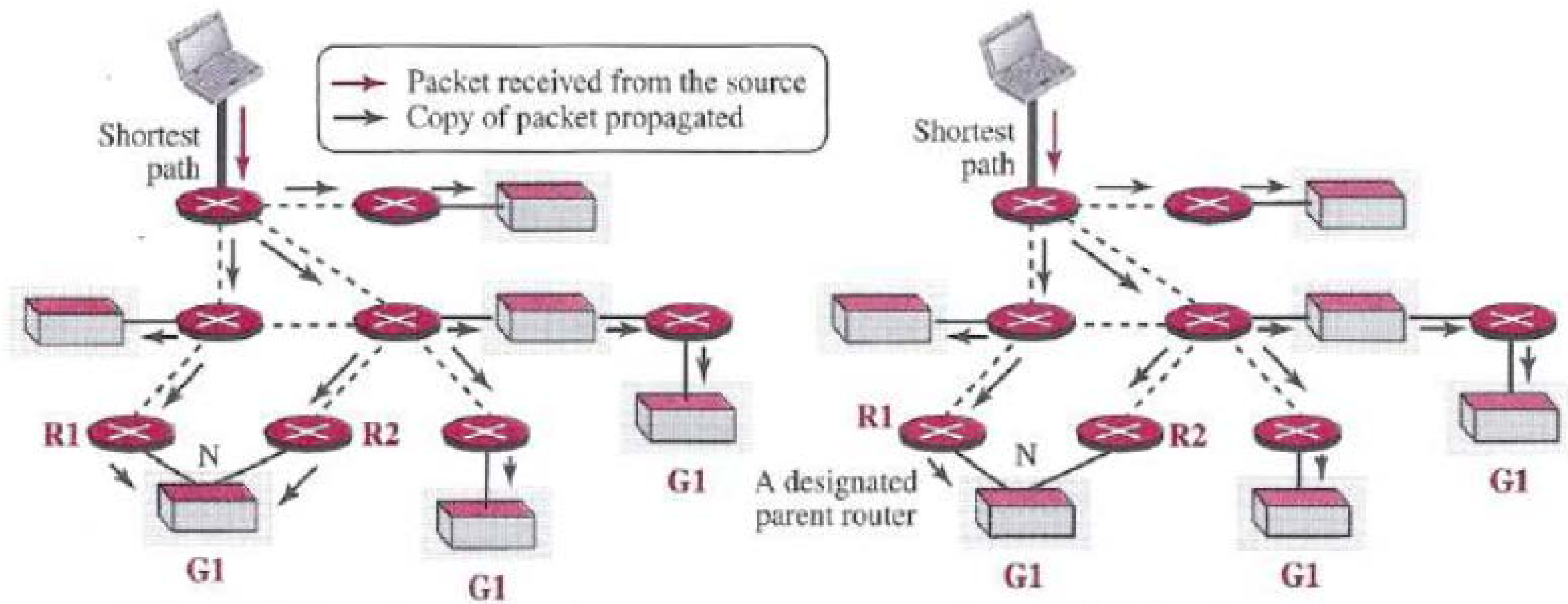
- Router forwards a multicast packet which has come through the interface associated with shortest path from source to the router
- Router does not know shortest path from source to itself; so, consults with reverse path
- prevents looping & duplicate packet receive



a. Using RPF, N receives two copies.

Reverse Path Broadcasting (RPB)

- helps a router to forward only one copy received from a source and drop the rest
- we need to allow only one of the routers attached to a network to pass the packet to the network



a. Using RPF, N receives two copies.

b. Using RPB, N receives only one copy.

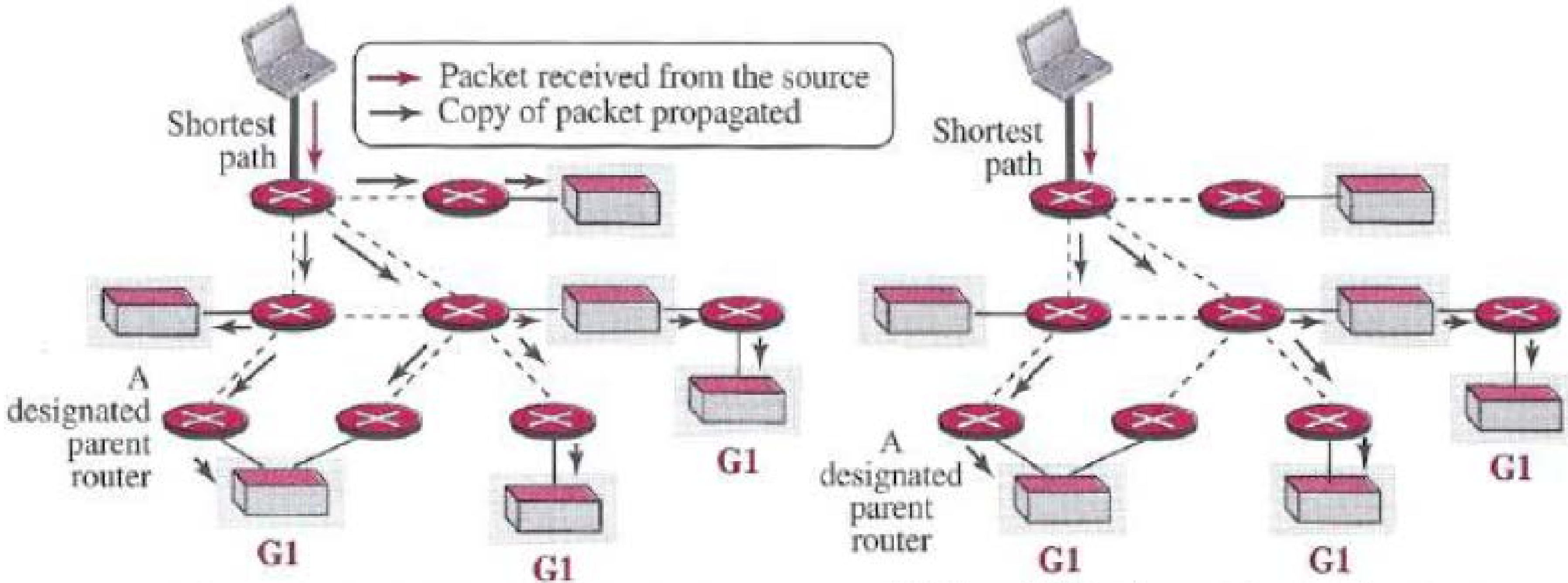
Cont…

- designate only one router as the *parent* of a network related to a specific source.
  - Parent router forwards, others simply drop

- How to select the parent?
  - select the router that has shortest path to the source
  - If there is a tie in this case, the router with the smaller IP address can be selected.
- RPB creates broadcast tree from the graph created by RPF
- RPB cuts those branches of the tree that cause cycles
- Finally, we have a shortest-path tree with the source as the root and all networks (LANs) as the leaves.

Reverse Path Multicasting (RPM)

- RPB does broadcast; so, not efficient
- To increase efficiency, we should do multicast



a. Using RPB, all networks receive a copy.

b. Using RPM, only members receive a copy.

Cont…

- change the broadcast shortest-path tree to a multicast shortest-path tree
- How?
  - each router needs to prune the interfaces that do not reach a network with active members corresponding to a particular source-group combination.
  - Follow bottom-up approach
  - At the leaf level, the routers connected to the network collect the membership information using the IGMP
  - The parent router of the network can then disseminate this information upward using the reverse shortest-path tree from the router to the source
  - disseminated periodically; so joining and leaving is updated dynamically

Multicast Link-State (MOSPF)

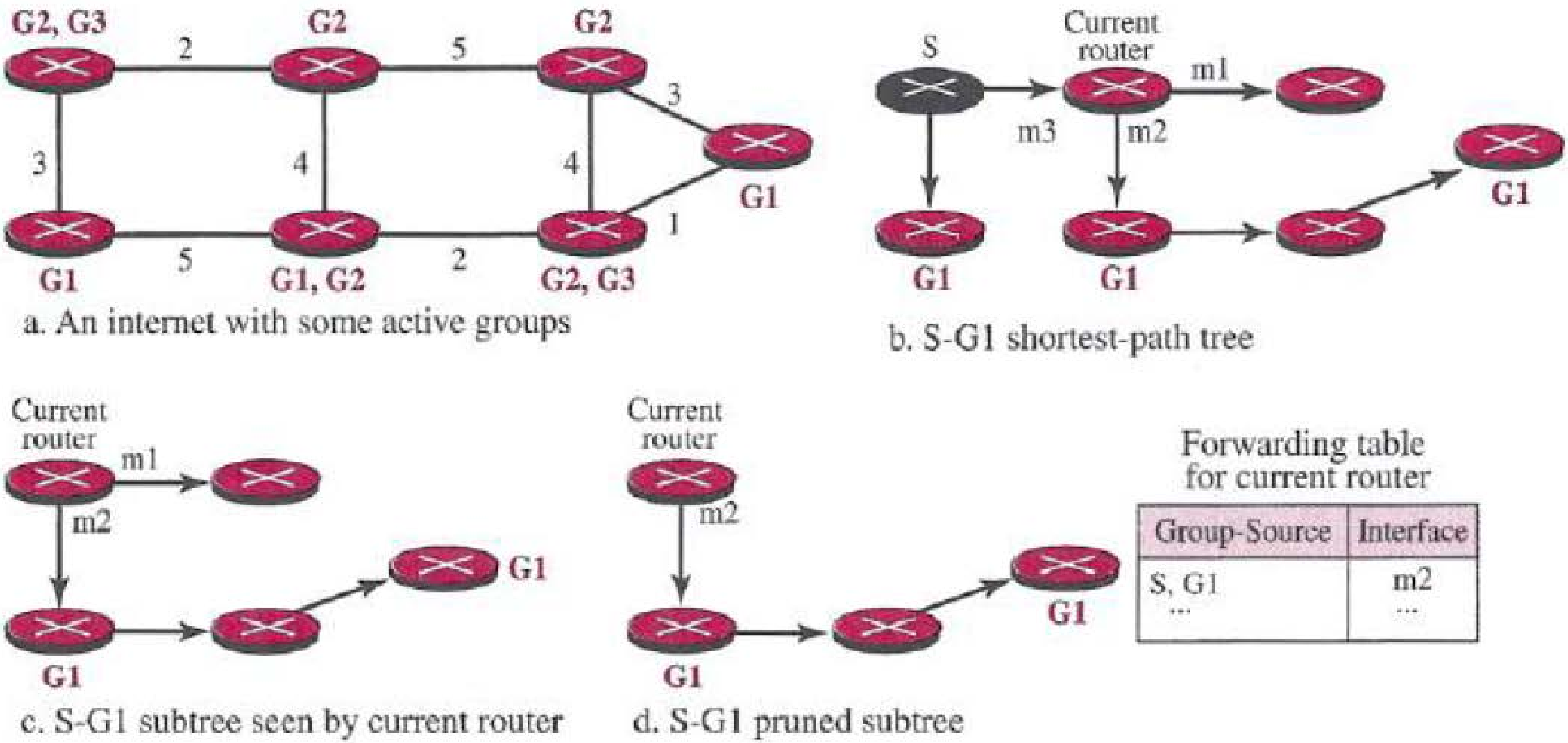
- MOSPF (Multicast Open Shortest Path First) is the extension of link-state unicast protocol OSPF
- Uses source-based tree approach
- In Link-state, router uses LSDB (link-state database) to create shortest-path tree
- For multicasting, router needs another database
  - to show which interface has active member in a particular group
- Let a router has received a packet from source S and to be sent to group G

Cont…

- Let a router has received a packet from source S and to be sent to group G
  – Router uses Dijkstra algorithm to create a shortest-path tree with S as the root (unlike unicasting in which router itself is the root) and all destinations in the internet as the leaves.
  – the router creates a shortest-path subtree with itself as the root of the subtree from the above tree.
  – The router prunes the shortest-path (broadcast) subtree to change it to a multicast tree.
  – How to get the membership information?
    - Using IGMP at the leaf level
    - Update the link state by flooding
  – Router then forwards through appropriate interface

Cont…

- Source S is attached with the top-left router
- Destination is G1



Group-Source	Interface
S, G1	m2
...	...

a. An internet with some active groups

b. S-G1 shortest-path tree

c. S-G1 subtree seen by current router

d. S-G1 pruned subtree

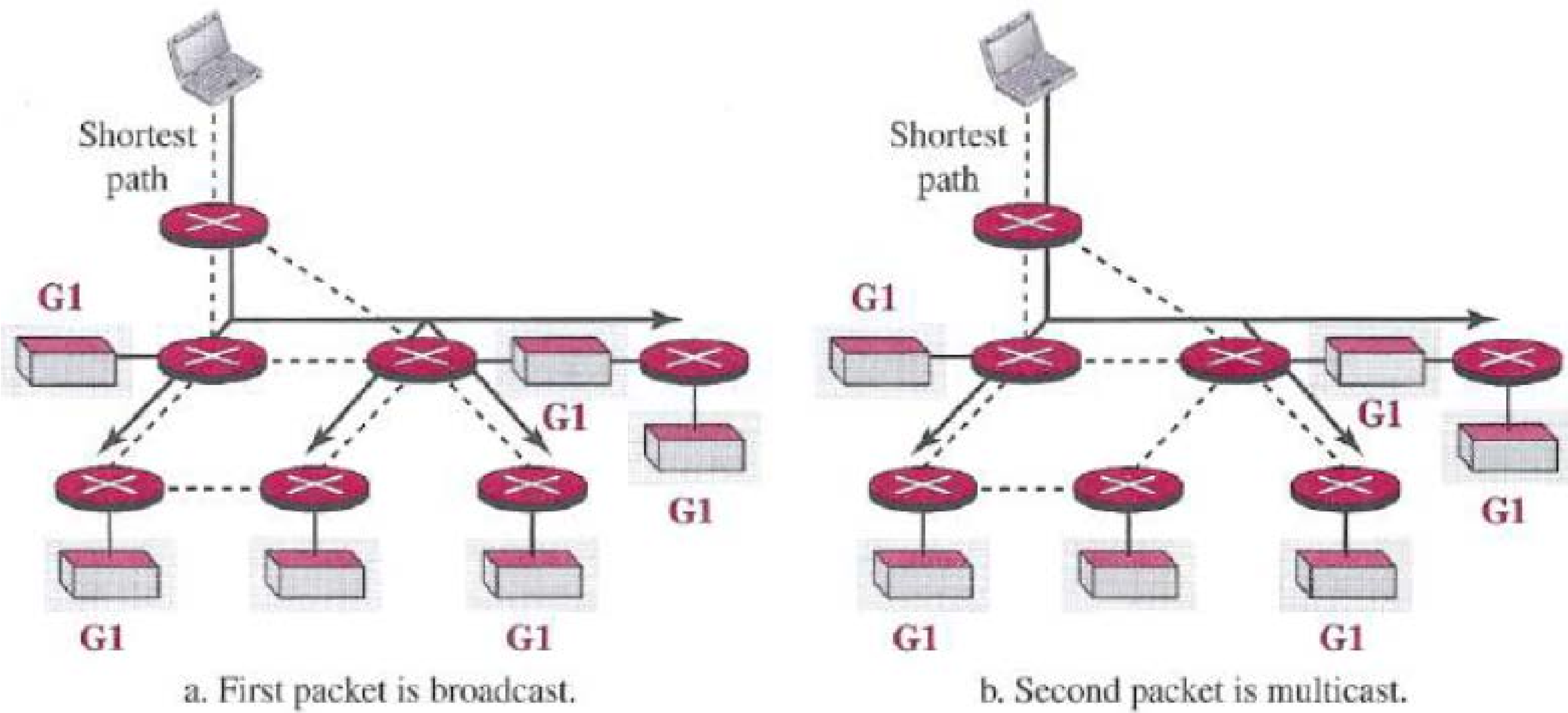
Protocol Independent Multicast

- PIM takes help of
  - Any type of unicast algo: distance vector / link state
  - Any type of multicast tree: source-based / group-shared

- PIM works in two modes:
  - PIM-DM for dense mode; uses source-based tree
  - PIM-SM for sparse mode; uses group-shared tree
- The term *dense* here means that the number of active members of a group in the internet is large
  - e.g. DM: popular teleconference that has a lot of members
  - e.g. SM: technical teleconference where a number of members are spread somewhere in the internet

PIM-DM

- PIM-DM uses only two strategies:
  - RPF & RPM.   (no need of RPB)



Cont…

- RPF is used to avoid receiving a duplicate packet
- If the packet has not arrived from the next router in the reverse direction, it drops the packet and sends a prune message in that direction to prevent receiving future packets related to pair (S, G).

- Else, router forwards the packet to all interfaces except
  - the receiving interface &
  - the interface from which it has already received a prune message related to (S, G).

- Initially, it is broadcast; but over the time it switches to multicast as pruned message arrives to the routers

PIM-SM

- In this environment, the use of a protocol that broadcasts the packets until the tree is pruned is not justified
- PIM-SM uses a group-shared tree approach to multicasting

- In PIM-SM, we designate a router to act as core router / *rendezvous point* (RP)
- Multicast communication is achieved in two steps:
  - From source to core router: Unicast
  - From core router to group members : Multicast

Cont…

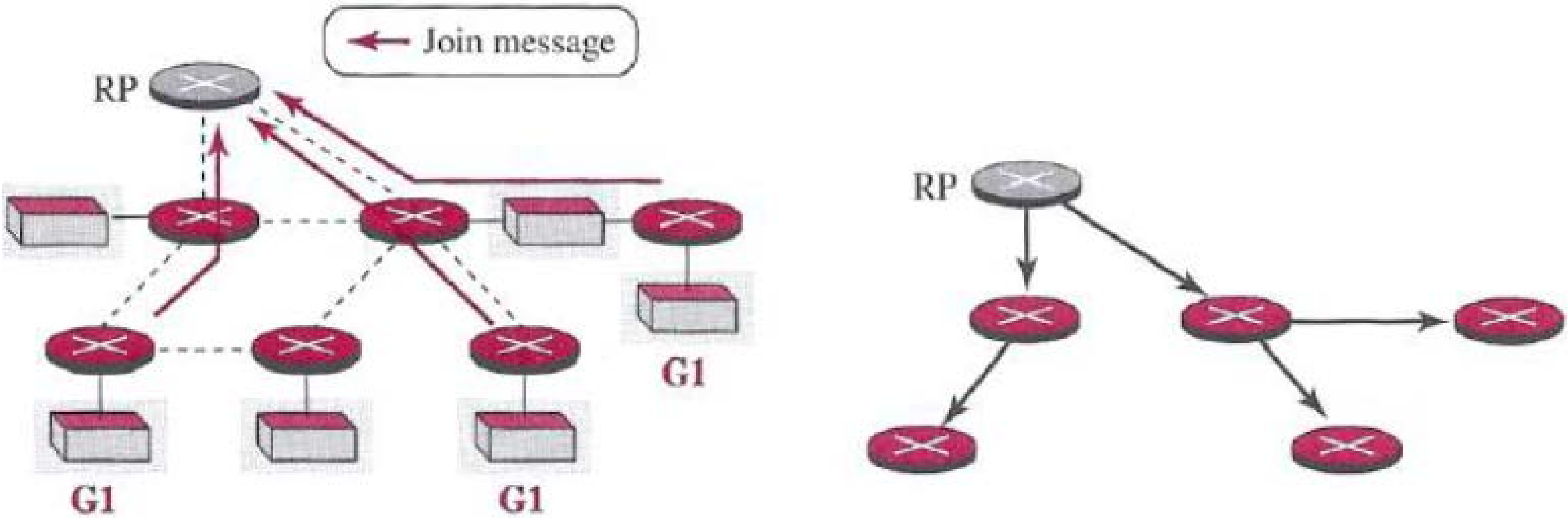
- How to select the core router for a group?
  - Following any suitable method

- PIM-SM uses a spanning multicast tree rooted at the core router with leaves pointing to designated routers connected to each network with an active member.

- How to form the multicast tree for a group?
  - The router should know the unique interface from which it should accept a multicast packet destined for a group. (likewise RPF)
  - It needs to avoid delivering more than one copy of the same packet to a network through several routers. (likewise RPB)
  - The router should know the interface or interfaces from which it should send out a multicast packet destined for a group. (like RPM)

Cont…

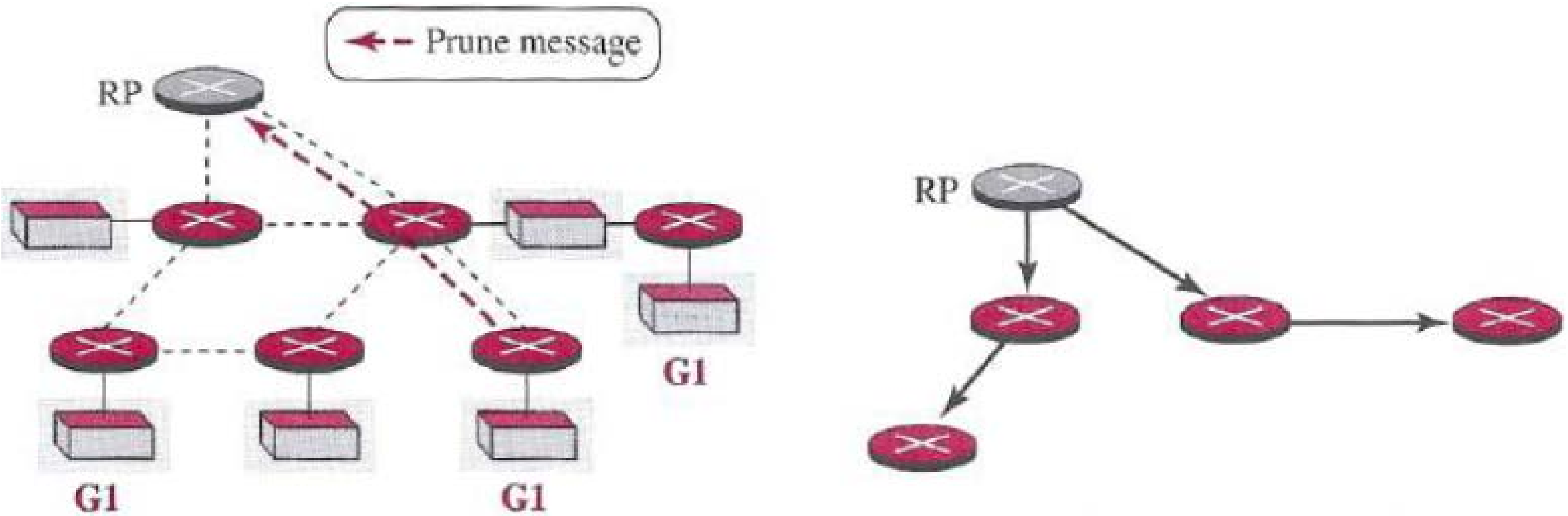
- PIM-SM uses *join* and *prune* messages to create a multicast tree rooted at the RP (core router)
- Router maintains a join counter. It increases for each interface after receiving a join message through that interface.



a. Three networks join group G1

b. Multicast tree after joins

Cont…



c. One network leaves group G1

d. Multicast tree after pruning

- When a router receives a prune message, it decrements the join count for the interface through which the message has arrived and forwards it to the next router.
- When the join count for an interface reaches zero, that interface is not part of the multicast tree anymore.

Interdomain Multicast Protocol

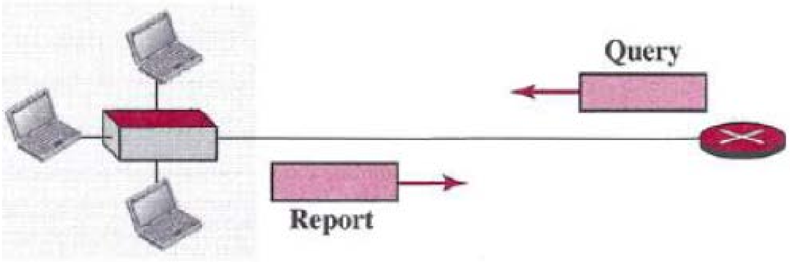
- When the members of the groups are spread among different autonomous domains (ASs), we need an interdomain multicast routing protocol.
  – Multicast BGP

- MBGP provides two paths between ASs:
  – one for unicasting
  – one for multicasting

- Information about multicasting is exchanged between border routers in different ASs.
- MBGP is a group-shared multicast routing protocol in which one router in each AS is chosen as the core router.

IGMP

- IGMP: Internet Group Management Protocol
- IGMP messages, like ICMP messages, are encapsulated in an IP datagram.
- IGMP uses two messages: Query and Report
- A query message is periodically sent by a router to all hosts attached to it to ask them to report their interests about membership in groups.
- A report message is sent by a host as a response to a query message.
- After a router has collected membership information from the hosts and other routers at its own level in the tree, it can propagate it to the router located in a higher level of the tree.



Thanks!