CS321: Computer Networks

Multicast Routing

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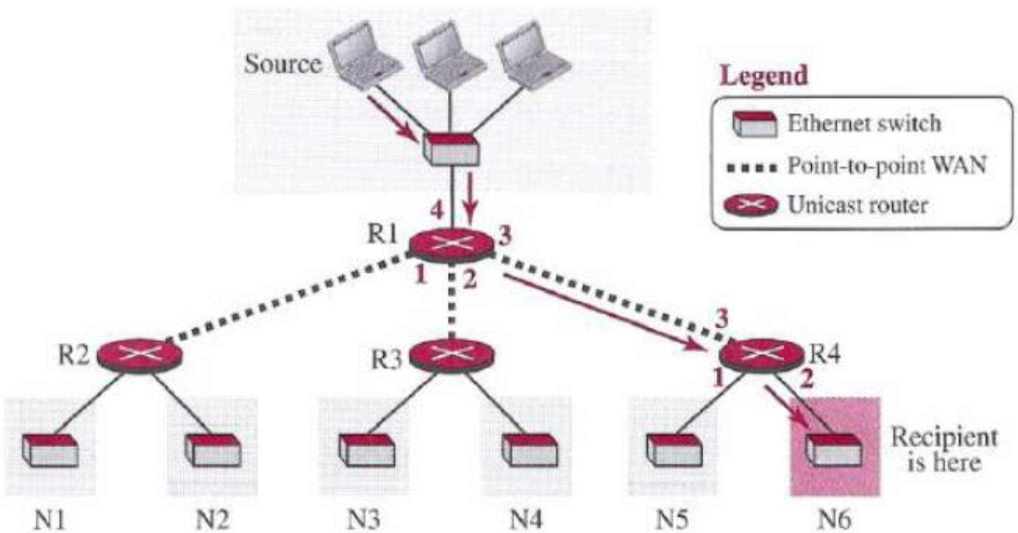
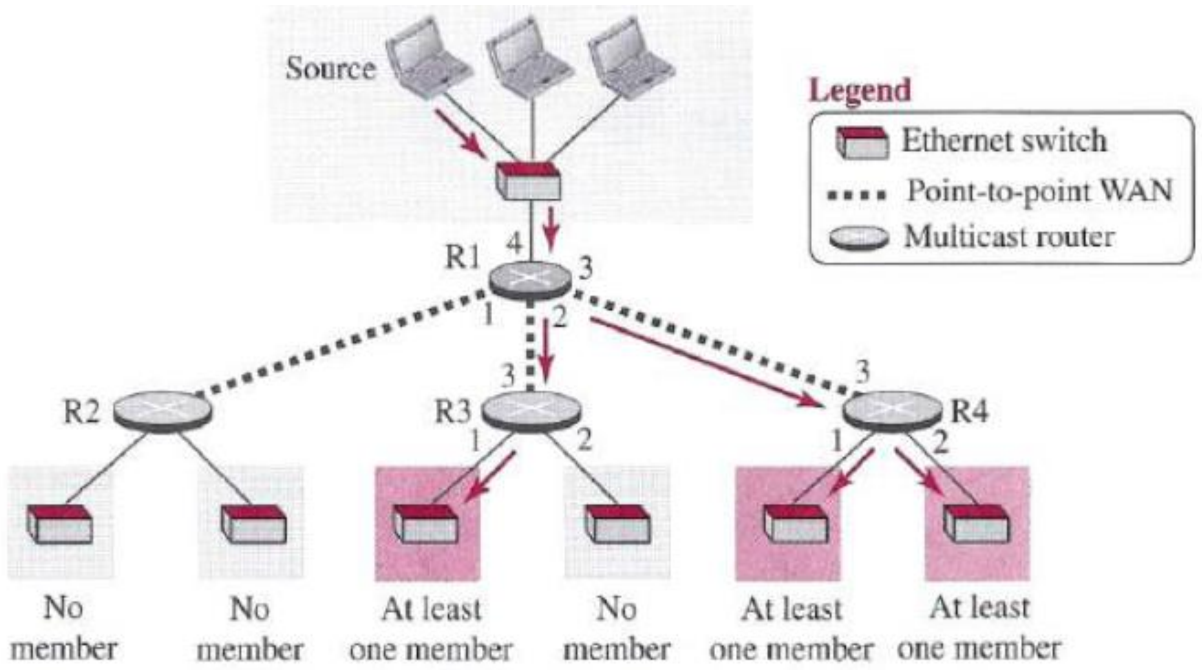
Unicasting

- 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.



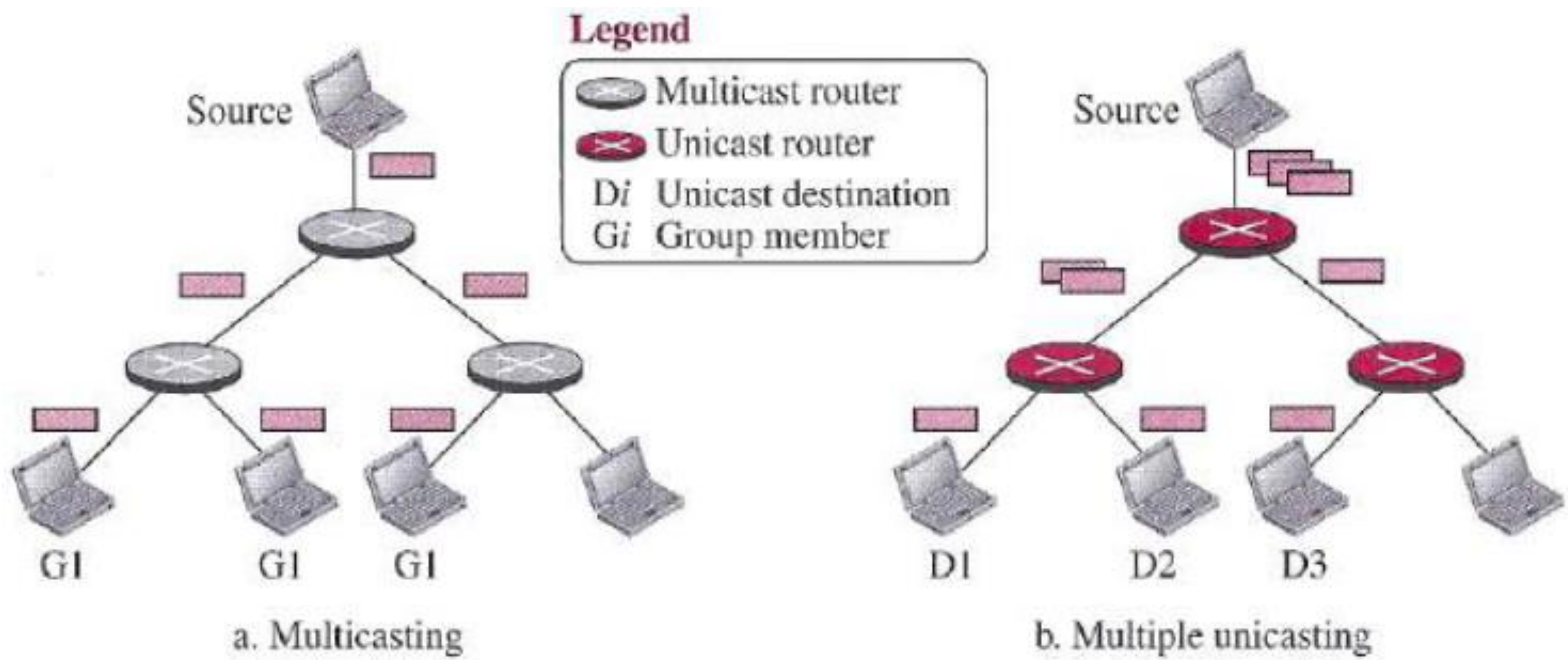
Multicast vs Multiple Unicast

- **Multicasting**
  - starts with a single packet from 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.
  - IP Multicast uses UDP for communication, therefore it is unreliable.

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

Cont…

- Example:
  - Group Email: 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.

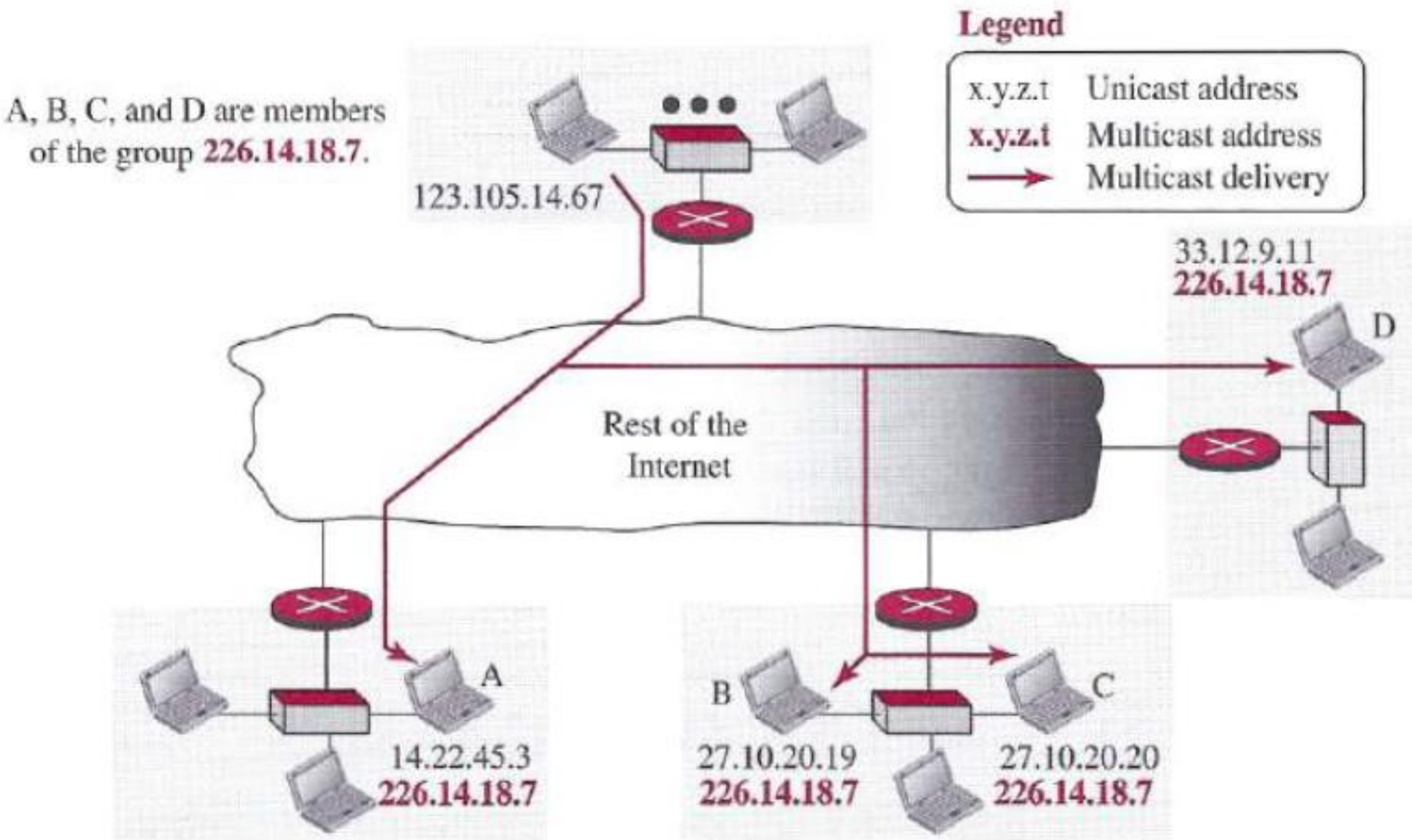
- a multicast address is an identifier for a group.

- 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

- A router / 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;
- In classless addressing it is referred to as the block 224.0.0.0/4 (i.e., 224.0.0.0 - 239.255.255.255).

Example



A, B, C, and D are members of the group 226.14.18.7.
Legend
x.y.z.t Unicast address
x.y.z.t Multicast address
Multicast delivery
123.105.14.67
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 = $2^{(32-4)}$
- The blocks are divided into multiple sub-blocks
    - Local Network Control Blocks: 224.0.0.0/24
        - Multicast routing is used inside a network
        - Datagram cannot be forwarded by the router to outside
    - Internetwork Control Block: 224.0.1.0/24
        - Routing protocol can use whole Internet
    - Source-specific Multicast Block: 232.0.0.0/8
        - IGMP protocol use this
    - GLOP Block: 233.0.0.0/8
        - To restrict inside an AS (autonomous system)
    - Administratively Scoped Block: 239.0.0.0/8
        - 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:
  - Network with Multicast Support
  - Network with No Multicast Support

Cont…

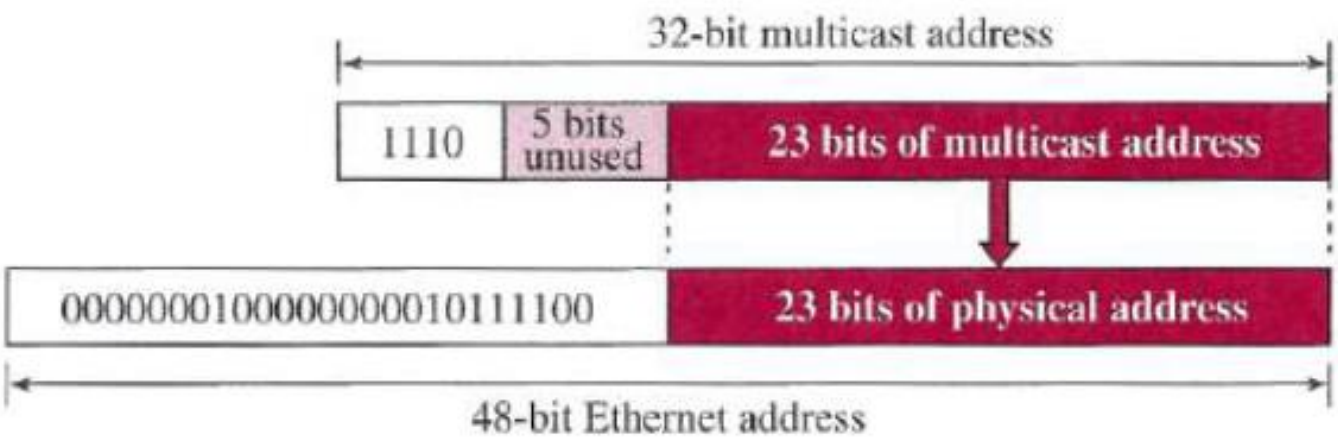
Case 1: Network with Multicast Support

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

If the first 25 bits in an Ethernet address are

0000 0001 0000 0000 0101 1110 0

this identifies a physical multicast address for the TCP/IP protocol.



- 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.

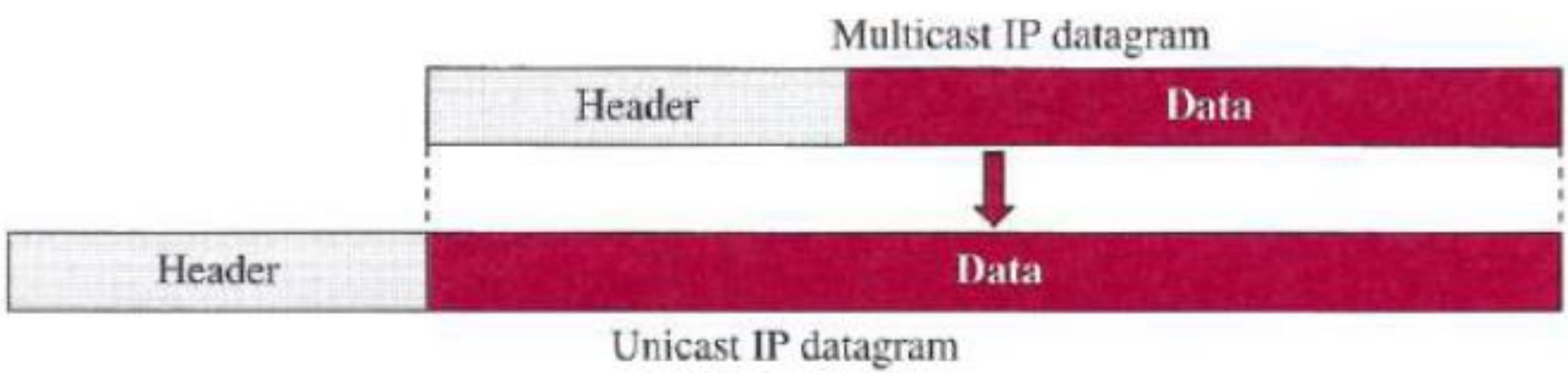
- We can do this in two steps:
  - We write the rightmost 23 bits of the IP address in hexadecimal.
  - Then subtracting 8 from the leftmost digit if it is greater than or equal to 8.
  - In our example, the result is 2B:OE:07

  - 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…

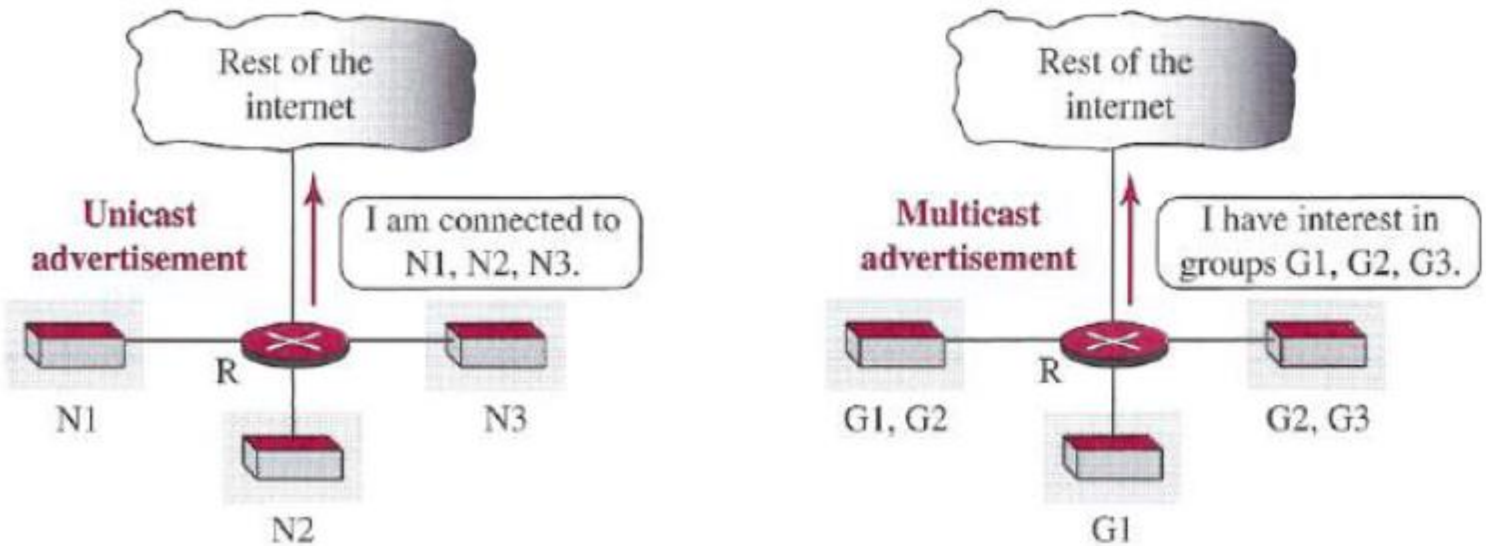
Case 2. Network with No Multicast Support

- Most WANs do not support physical multicast addressing
- To send a multicast packet through these networks, a *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…

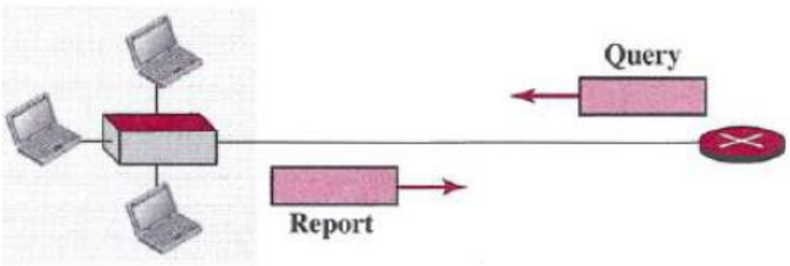
- In unicast routing, the collection of the information in the first step is automatic;
- Each router knows to which network it is connected, and the prefix of the network (in CIDR) is what a router needs.

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

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 the information to the router located in a higher level of the tree.



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

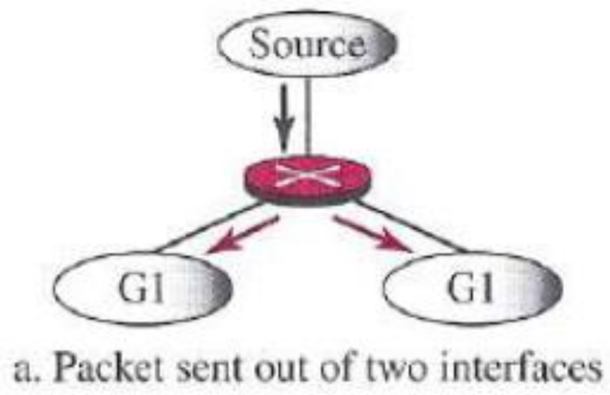
- In unicast communication, the destination address of the packet defines one single destination.
- So, forwarded through one interface.

- 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.



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)

Multicast Distance Vector - 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:

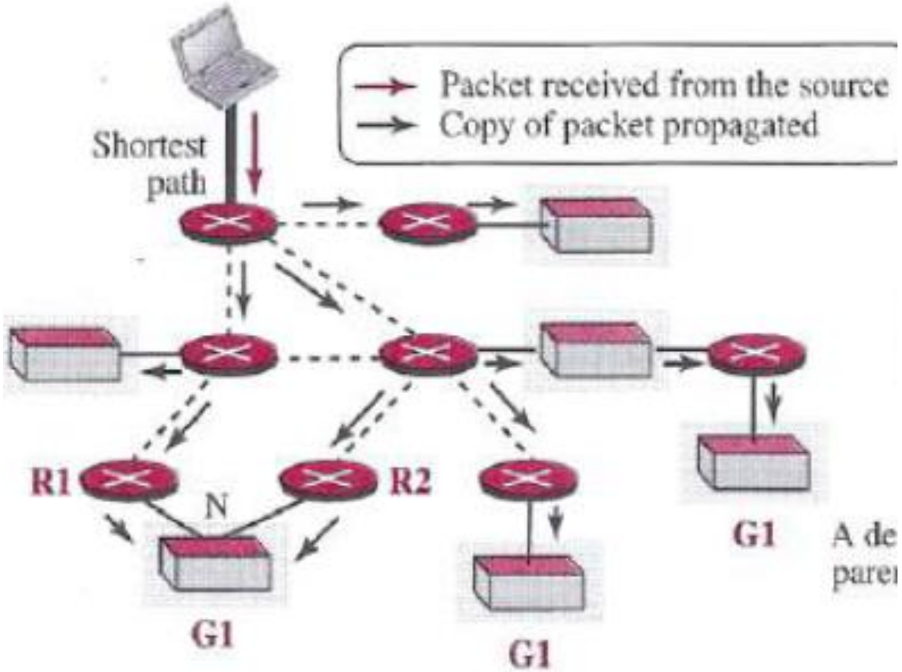
  – Router uses reverse path forwarding (RPF)
    - to create optimal source-based tree between source and itself

  – 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)

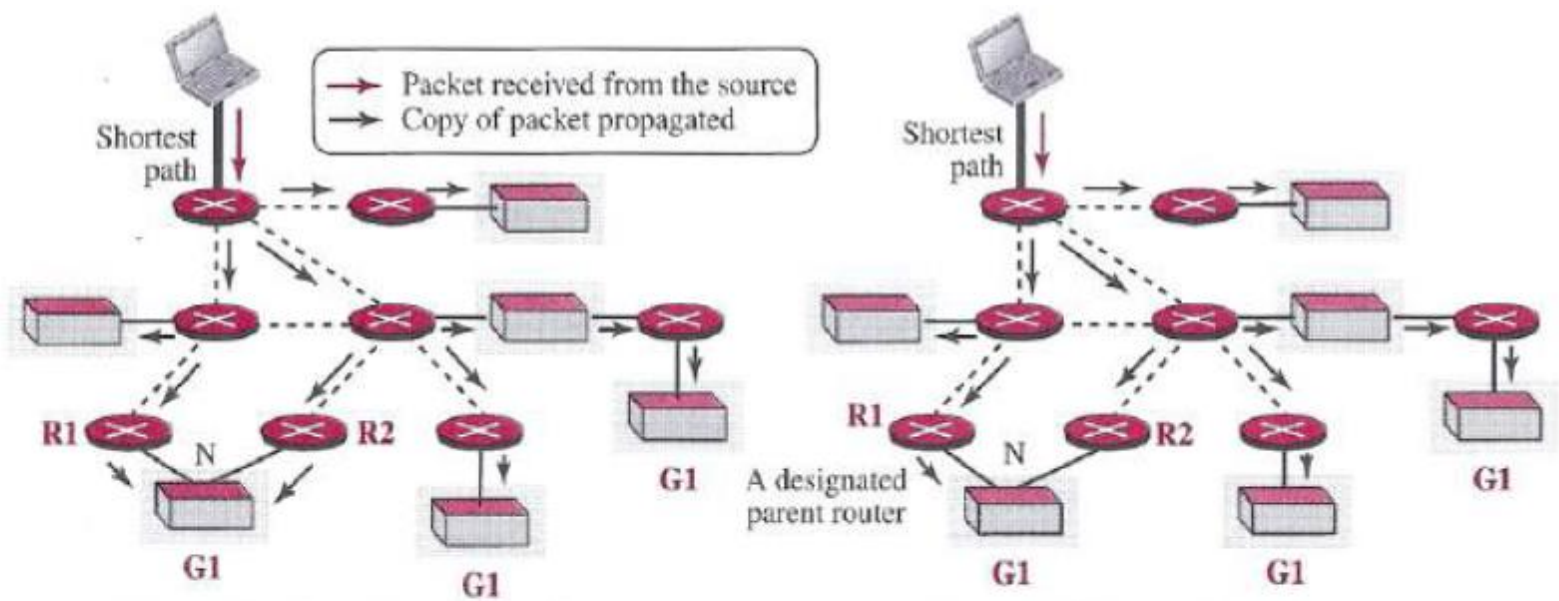
- Router forwards a multicast packet which has come through the interface associated with shortest path from source to the router
- Router does not know shortest path from source to itself; so, consults with reverse path
- It prevents from receiving duplicate packet by a router
- So, a router forwards only one copy received from a source, and drops the rest



a. Using RPF, N receives two copies.

Reverse Path Broadcasting (RPB)

- But, how to prevent looping & duplicate packet w.r.t. a network?
- We need to allow only one of the routers attached to a network to pass the packet to the network
- Designate only one router as the *parent* of a network related to a specific source.
  - Parent router forwards, others simply drop



a. Using RPF, N receives two copies.

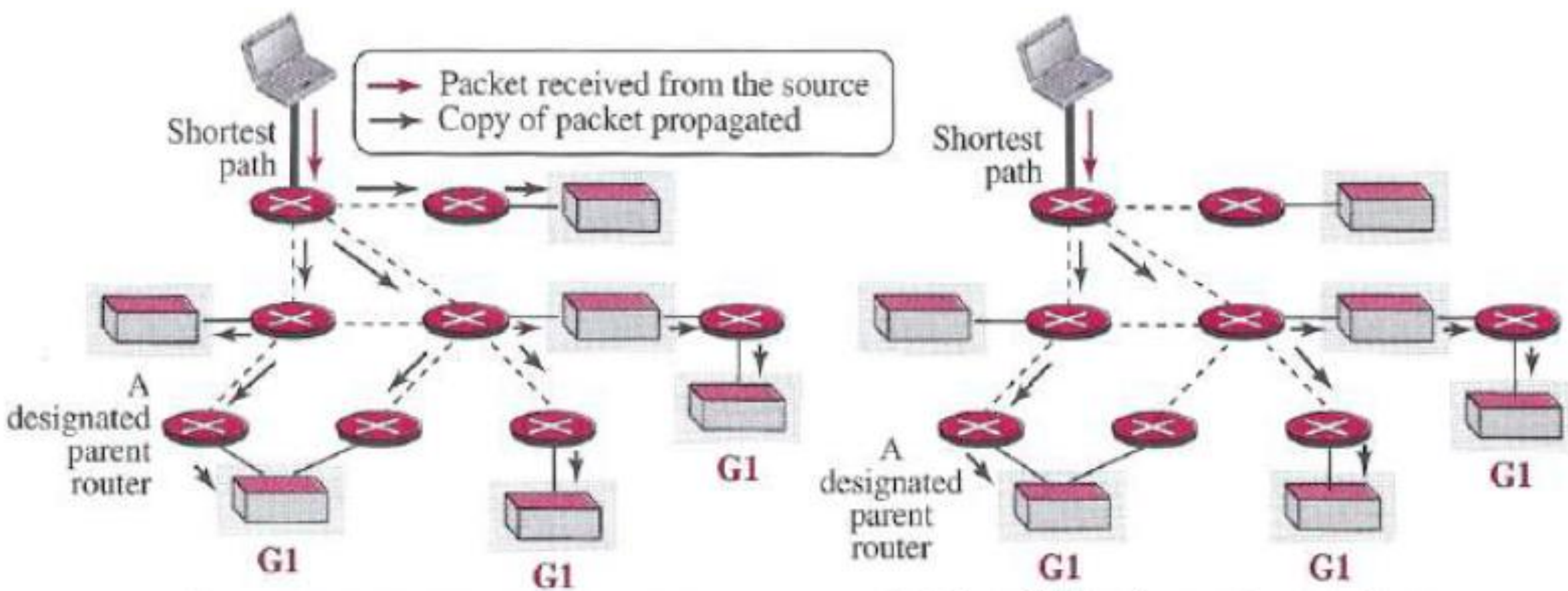
b. Using RPB, N receives only one copy.

Cont…

- 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
- **Solution**:
  - Change the broadcast shortest-path tree to a multicast shortest-path tree



a. Using RPB, all networks receive a copy.

b. Using RPM, only members receive a copy.

Cont…

- 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 (i.e. table)
  – to show which interface has active member in a particular group

Cont…

- Let a router has received a packet from source S and to be sent to group G

1. 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.

2. the router creates a shortest-path subtree with itself as the root of the subtree from the above tree.

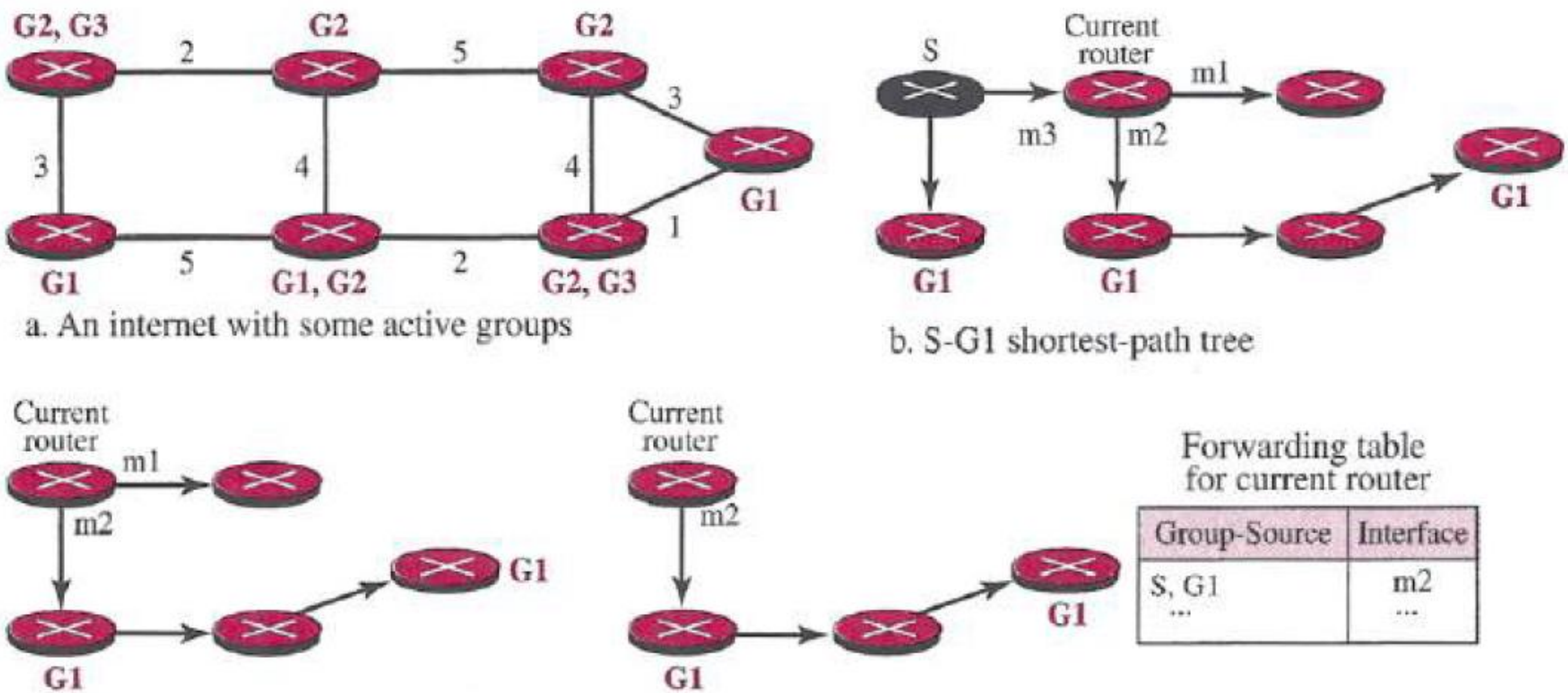
3. The router prunes the shortest-path (broadcast) subtree to change it to a multicast tree.

- 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
- Three steps (Fig. b,c,d)



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)

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

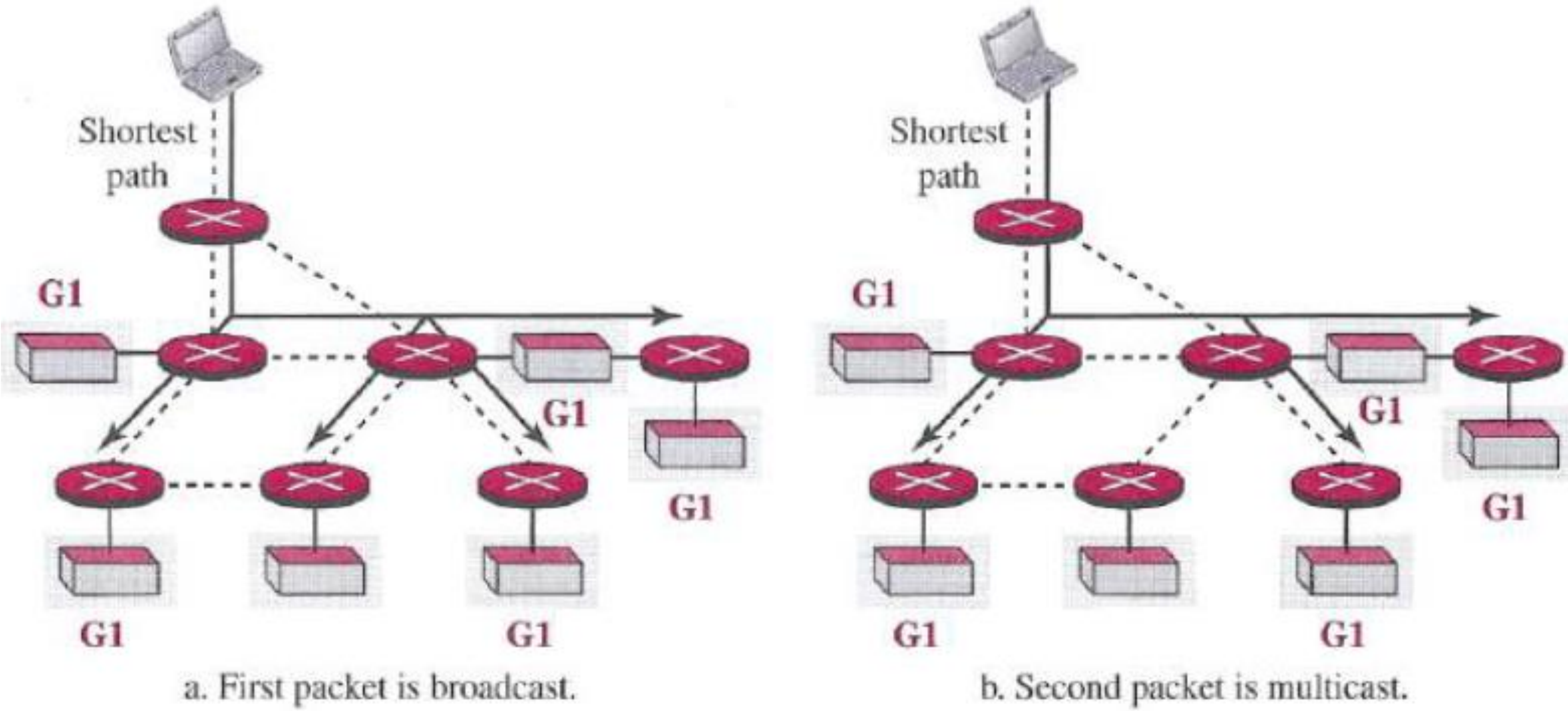
- PIM works in two modes:
  - PIM-DM for dense mode; uses source-based tree
  - PIM-SM for sparse mode; uses group-shared tree

- 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. Actually, RPB is merged with RPM)



Cont…

- RPF is used to avoid receiving a duplicate packet by a router
- 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
- 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 (e.g, resource capacity)

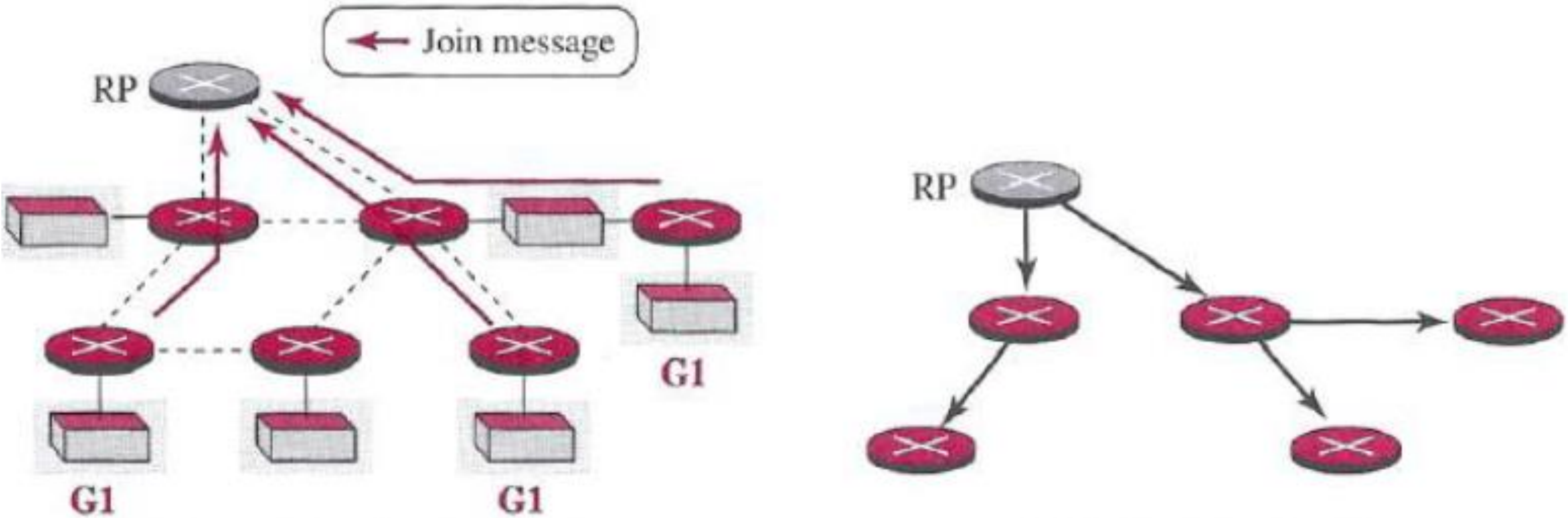
- PIM-SM uses a spanning multicast tree rooted at the core router with leaves pointing to designated routers connected to each network with an active member.

- 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. (likewise RPM)

Cont…

- PIM-SM uses *join* and *prune* messages to create a multicast tree rooted at the core router

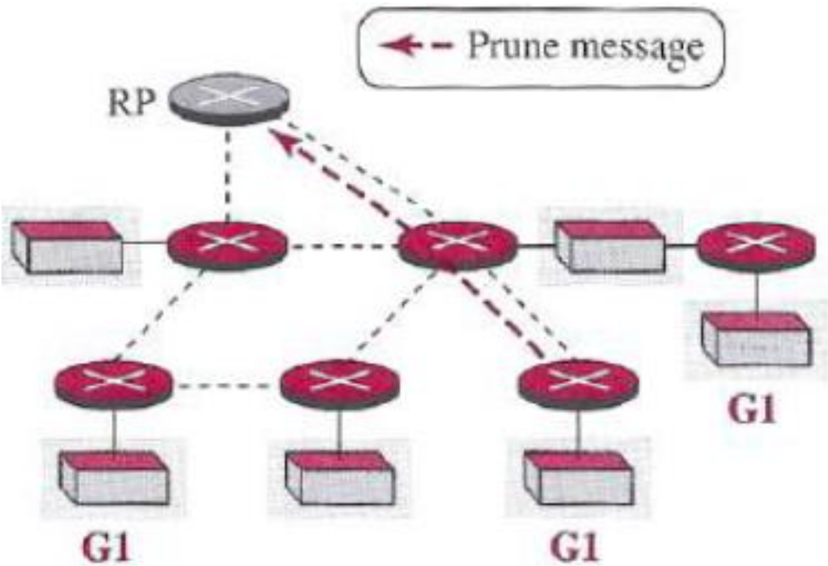
- Router maintains a join counter. It increases for each interface after receiving a join message through that interface.



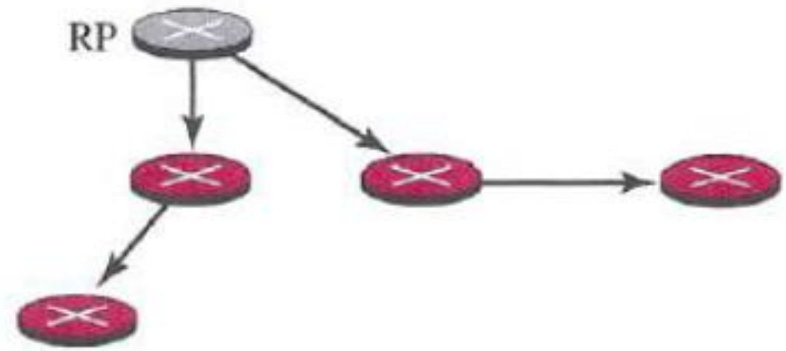
a. Three networks join group G1

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.

Inter-domain Multicast Protocol

- When the members of the groups are spread among different autonomous domains (ASs), we need an inter-domain 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.

Thanks!