Multiprotocol Label Switching and the related protocols that fed its development are described in Chandranmenon et al. [CV95], Rekhter et al. [RDR+97], and Davie et al. [DR00]. The latter reference describes many applications of MPLS such as traffic engineering, fast recovery from network failures, and virtual private networks. [RR06] provides the specification of MPLS/BGP VPNs, a form of layer 3 VPN that can be provided over MPLS networks.

Mobile IP is defined in Perkins [Per02] for IPv4 and in Johnson et al. [JPA04] for IPv6. Basagni et al. [BCGS04] provide a good background of the problems and research in mobile *ad hoc* networking, while one of the primary MANET routing protocols is described by Clausen et al. [CHCB01].

Finally, we recommend the following live references:

- http://www.isoc.org/internet/history/: A collection of links related to Internet history, including some articles written by the original researchers who built the Internet.
- http://bgp.potaroo.net/: Lots of data about the growth of the routing tables in the Internet, including IPv6 deployment.

EXERCISES

1. Consider the network shown in Figure 4.28, in which horizontal lines represent transit providers and numbered vertical lines are interprovider links.
   (a) How many routes to P could provider Q's BGP speakers receive?
   (b) Suppose Q and P adopt the policy that outbound traffic is routed to the closest link to the destination's provider, thus minimizing their own cost. What paths will traffic from host A to host B and from host B to host A take?

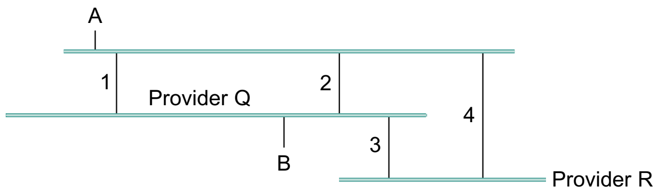


FIGURE 4.28 Network for Exercise 1.

(c) What could Q do to have the B $\longrightarrow$ A traffic use the closer link 1?

(d) What could Q do to have the B $\longrightarrow$ A traffic pass through R?

2. Give an example of an arrangement of routers grouped into autonomous systems so that the path with the fewest hops from a point A to another point B crosses the same AS twice. Explain what BGP would do with this situation.

☆ 3. Let A be the number of autonomous systems on the Internet, and let D (for diameter) be the maximum AS path length.

(a) Give a connectivity model for which D is of order $\log A$ and another for which D is of order $\sqrt{A}$.

(b) Assuming each AS number is 2 bytes and each network number is 4 bytes, give an estimate for the amount of data a BGP speaker must receive to keep track of the AS path to every network. Express your answer in terms of A, D, and the number of networks N.

4. Propose a plausible addressing plan for IPv6 that runs out of bits. Specifically, provide a diagram such as Figure 4.11, perhaps with additional ID fields, that adds up to more than 128 bits, together with plausible justifications for the size of each field. You may assume fields are divided on byte boundaries and that the InterfaceID is 64 bits. (Hint: Consider fields that would approach maximum allocation only under unusual circumstances.) Can you do this if the InterfaceID is 48 bits?

5. Suppose P, Q, and R are network service providers with respective CIDR address allocations C1.0.0.0/8, C2.0.0.0/8, and C3.0.0.0/8. Each provider's customers initially receive address allocations that are a subset of the provider's. P has the following customers:

PA, with allocation C1.A3.0.0/16

PB, with allocation C1.B0.0.0/12.

Q has the following customers:

QA, with allocation C2.0A.10.0/20

QB, with allocation C2.0B.0.0/16.

Assume there are no other providers or customers.

(a) Give routing tables for P, Q, and R assuming each provider connects to both of the others.

(b) Now assume P is connected to Q and Q is connected to R, but P and R are not directly connected. Give tables for P and R.

(c) Suppose customer PA acquires a direct link to Q, and QA acquires a direct link to P, in addition to existing links. Give tables for P and Q, ignoring R.

6. In the previous problem, assume each provider connects to both others. Suppose customer PA switches to provider Q and customer QB switches to provider R. Use the CIDR longest-match rule to give routing tables for all three providers that allow PA and QB to switch without renumbering.

7. Suppose most of the Internet used some form of geographical addressing, but that a large international organization has a single IP network address and routes its internal traffic over its own links.

   (a) Explain the routing inefficiency for the organization's inbound traffic inherent in this situation.

   (b) Explain how the organization might solve this problem for outbound traffic.

   (c) For your method above to work for inbound traffic, what would have to happen?

   (d) Suppose the large organization now changes its addressing to separate geographical addresses for each office. What will its internal routing structure have to look like if internal traffic is still to be routed internally?

8. The telephone system uses geographical addressing. Why do you think this wasn't adopted as a matter of course by the Internet?

9. Suppose a small ISP X pays a larger ISP A to connect him to the rest of the Internet and also pays another ISP B to provide a fall-back connection to the Internet in the event that he loses connectivity via ISP A. If ISP X learns of a path to some prefix via ISP A, should he advertise that path to ISP B? Why or why not?

10. Suppose a site A is *multihomed*, in that it has two Internet connections from two different providers, P and Q. Provider-based addressing as in Exercise 5 is used, and A takes its address assignment from P. Q has a CIDR longest-match routing entry for A.

(a) Describe what inbound traffic might flow on the A–Q connection. Consider cases where Q does and does not advertise A to the world using BGP.

(b) What is the minimum advertising of its route to A that Q must do in order for all inbound traffic to reach A via Q if the P–A link breaks?

(c) What problems must be overcome if A is to use both links for its outbound traffic?

11. Suppose a network N within a larger organization A acquires its own direct connection to an Internet Service Provider, in addition to an existing connection via A. Let R1 be the router connecting N to its own provider, and let R2 be the router connecting N to the rest of A.

(a) Assuming N remains a subnet of A, how should R1 and R2 be configured? What limitations would still exist with N's use of its separate connection? Would A be prevented from using N's connection? Specify your configuration in terms of what R1 and R2 should advertise, and with what paths. Assume a BGP-like mechanism is available.

(b) Now suppose N gets its own network number; how does this change your answer in (a)?

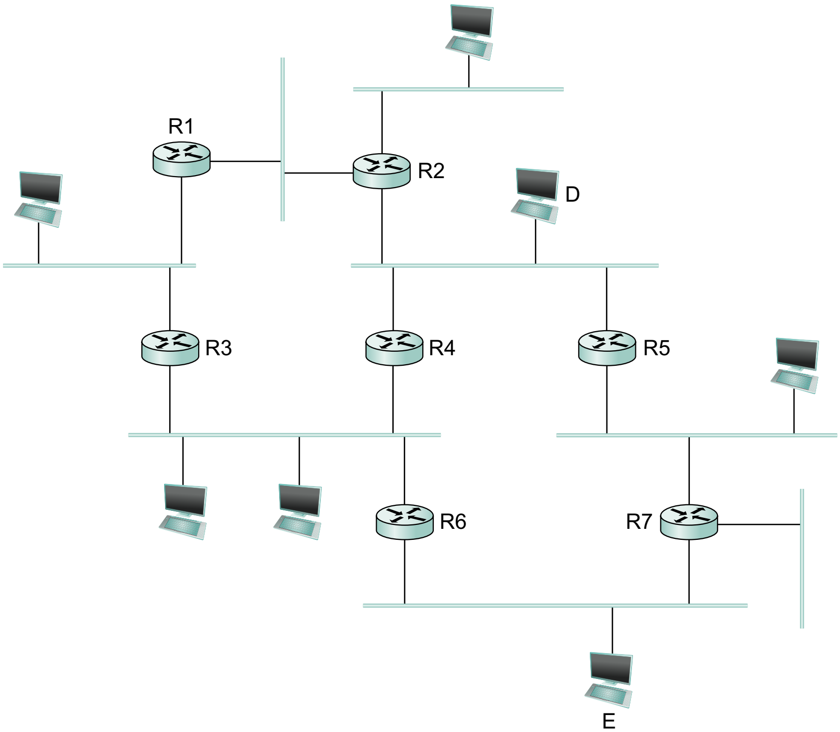
(c) Describe a router configuration that would allow A to use N's link when its own link is down.

12. How do routers determine that an incoming IP packet is to be multicast? Give answers for both IPv4 and IPv6.

13. Suppose a multicast group is intended to be private to a particular routing domain. Can an IP multicast address be assigned to the group without consulting with other domains with no risk of conflicts?

14. Under what conditions could a non-router host on an Ethernet receive a IP multicast packet for a multicast group it has not joined?

15. Consider the example internet shown in Figure 4.29, in which sources D and E send packets to multicast group G. All hosts except D and E are members of G. Show the shortest-path multicast trees for each source.



■ **FIGURE 4.29** Example internet for Exercise 15.

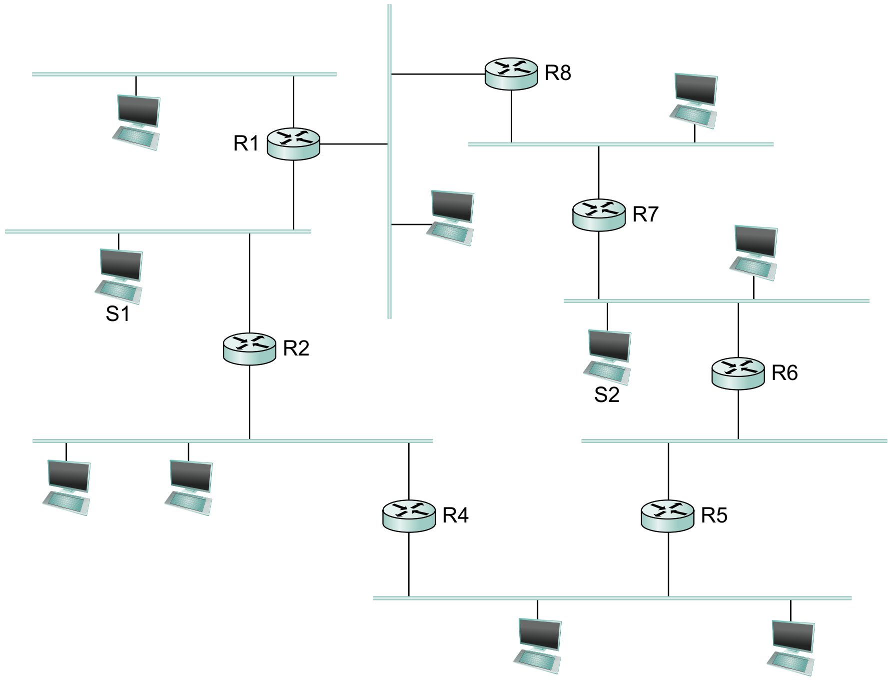
16. Consider the example internet shown in Figure 4.30 in which sources S1 and S2 send packets to multicast group G. All hosts except S1 and S2 are members of G. Show the shortest-path multicast trees for each source.

17. Suppose host A is sending to a multicast group; the recipients are leaf nodes of a tree rooted at A with depth N and with each nonleaf node having k children; there are thus k^N recipients.

(a) How many individual link transmissions are involved if A sends a multicast message to all recipients?

(b) How many individual link transmissions are involved if A sends unicast messages to each individual recipient?

(c) Suppose A sends to all recipients, but some messages are lost and retransmission is necessary. Unicast retransmissions to what fraction of the recipients is equivalent, in terms of individual link transmissions, to a multicast retransmission to all recipients?



■ **FIGURE 4.30** Example Network for Exercise 16.

18. The existing Internet depends in many respects on participants being good "network citizens"—cooperating above and beyond adherence to standard protocols.

(a) In the PIM-SM scheme, who determines when to create a source-specific tree? How might this be a problem?

(b) In the PIM-SSM scheme, who determines when to create a source-specific tree? Why is this presumably not a problem?

19. **(a)** Draw an example internetwork where the BIDIR-PIM route from a source's router to a group member's router is longer than the PIM-SM source-specific route.

(b) Draw an example where they are the same.

20. Determine whether or not the following IPv6 address notations are correct:

(a) ::0F53:6382:AB00:67DB:BB27:7332

(b) 7803:42F2:::88EC:D4BA:B75D:11CD

(c) ::4BA8:95CC::DB97:4EAB

(d) 74DC::02BA
(e) ::00FF:128.112.92.116

21. MPLS labels are usually 20 bits long. Explain why this provides enough labels when MPLS is used for destination-based forwarding.

22. MPLS has sometimes been claimed to improve router performance. Explain why this might be true, and suggest reasons why in practice this may not be the case.

23. Assume that it takes 32 bits to carry each MPLS label that is added to a packet when the “shim” header of Figure 4.20(b) is used.
    (a) How many additional bytes are needed to tunnel a packet using the MPLS techniques described in Section 4.3.3?
    (b) How many additional bytes are needed, at a minimum, to tunnel a packet using an additional IP header as described in Section 3.2.9?
    (c) Calculate the efficiency of bandwidth usage for each of the two tunneling approaches when the average packet size is 300 bytes. Repeat for 64-byte packets. Bandwidth efficiency is defined as (payload bytes carried) ÷ (total bytes carried).

24. RFC 791 describes the Internet Protocol and includes two options for source routing. Describe three disadvantages of using IP source route options compared to using MPLS for explicit routing. (Hint: The IP header including options may be at most 15 words long.)

25. DHCP allows a computer to acquire a new IP address whenever it moves to a new subnet. Why is this not always enough to address the communications needs of mobile hosts?

26. What is the main downside of requiring traffic destined to a mobile node to be sent first to its home agent?

27. Mobile IP allows a home agent to tell a correspondent node a new care-of address for a mobile node. How might such a mechanism be used to steal traffic? How could it be used to launch a flood of attack traffic at another node?