

which would allow cellular network protocols to operate in the unlicensed spectrum alongside 802.11.

Enabling multiple computers to talk to each other requires a large amount of standardization, both in the hardware and software. Organizations such as ITU-T, ISO, IEEE, and IAB manage different parts of the standardization process.

Problems

1. You set up a communication channel between two medieval castles by letting a trained raven repeatedly carry a scroll from the sending castle to the receiving castle, 160 kilometers away. The raven flies at an average speed of 40 km/h, and carries one scroll at a time. Each scroll contains 1.8 terabytes of data. Calculate the data rate of this channel when sending (i) 1.8 terabytes of data; (ii) 3.6 terabytes of data; (iii) an infinite stream of data.
2. As part of the Internet of Things, everyday devices are increasingly connected to computer networks. IoT makes it easier for people to, among other things, monitor their belongings and utility usage. But any technology can be used for both good and bad. Discuss some disadvantages of this technology.
3. Wireless networks have surpassed wired networks in popularity, even though they typically provide less bandwidth. Give two reasons why this happened.

4. Instead of buying their own hardware, small companies offer host their applications in data centers. Discuss advantages and disadvantages of this approach, from both the perspective of the company and its users.
5. An alternative to a LAN is simply a big timesharing system with terminals for all users. Give two advantages of a client-server system using a LAN.
6. The performance of a client-server system is strongly influenced by two major network characteristics: the bandwidth of the network (i.e., how many bits/sec it can transport) and the latency (i.e., how many seconds it takes for the first bit to get from the client to the server). Give an example of a network that exhibits high bandwidth but also high latency. Then give an example of one that has both low bandwidth and low latency.
7. A factor in the delay of a store-and-forward packet-switching system is how long it takes to store and forward a packet through a switch. If switching time is $20\ \mu\text{sec}$, is this likely to be a major factor in the response of a client-server system where the client is in New York and the server is in California? Assume the propagation speed in copper and fiber to be $\frac{2}{3}$ the speed of light in vacuum.
8. A server sends packets to a client via satellite. The packets must traverse one or multiple satellites before they reach their destination. The satellites use store-and-forward packet switching, with a switching time of $100\ \mu\text{sec}$. If the packets travel a total distance of 29,700 km, how many satellites do the packets have to pass if 1% of the delay is caused by packet switching?

9. A client-server system uses a satellite network, with the satellite at a height of 40,000 km. What is the best-case delay in response to a request?
10. A signal travels with $\frac{2}{3}$ the speed of light and takes 100 milliseconds to arrive at its destination. How far did the signal travel?
11. Now that almost everyone has a home computer or mobile device connected to a computer network, instant public referendums on important pending legislation will become possible. Ultimately, existing legislatures could be eliminated, to let the will of the people be expressed directly. The positive aspects of such a direct democracy are fairly obvious; discuss some of the negative aspects.
12. Five routers are to be connected in a point-to-point subnet. Between each pair of routers, the designers may put a high-speed line, a medium-speed line, a low-speed line, or no line. If it takes 50 ms of computer time to generate and inspect each topology, how long will it take to inspect all of them?
13. A group of $2n - 1$ routers are interconnected in a centralized binary tree, with a router at each tree node. Router i communicates with router j by sending a message to the root of the tree. The root then sends the message back down to j . Derive an approximate expression for the mean number of hops per message for large n , assuming that all router pairs are equally likely.
14. A disadvantage of a broadcast subnet is the capacity wasted when multiple hosts attempt to access the channel at the same time. As a simplistic example, suppose that time is divided into

discrete slots, with each of the n hosts attempting to use the channel with probability p during each slot. What fraction of the slots will be wasted due to collisions?

15. In computer networks and other complex systems, the large number of interactions between their components often make it impossible to predict with high confidence if and when bad things will happen. How do the design goals of computer networks take this into account?
16. Explain why the link layer, network layer, and transport layer each have to add source and destination information to the payload.
17. Match the layers—Link, Network, and Transport—with the guarantees that each layer could provide to higher layers.

Guarantee	Layer
Best effort delivery	Network
Reliable Delivery	Transport
In-order Delivery	Transport
Byte-stream abstraction	Transport
Point-to-point link abstraction	Data link


18. Every network layer interacts with the layer below it by using its interface. For each of the functions below, indicate to which interface it belongs.


Function	Interface
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send_bits_over_ink(bits)	
send_bytes_to_process(dst, src, bytes)	
send_bytes_over_link(dst, src, bytes)	
send_bytes_to_machine(dst, src, bytes)	


19. Suppose that two network endpoints have a round-trip time of 100 milliseconds, and that the sender transmits five packets every round trip. What will be the sender's transmission rate for this round-trip time, assuming 1500-byte packets? Give your answer in bytes per second
20. The president of the Specialty Paint Corp. gets the idea to work with a local beer brewer to produce an invisible beer can (as an anti-litter measure). The president tells her legal department to look into it, and they in turn ask engineering for help. As a result, the chief engineer calls his counterpart at the brewery to discuss the technical aspects of the project. The engineers then report back to their respective legal departments, which then confer by telephone to arrange the legal aspects. Finally, the two corporate presidents discuss the financial side of the deal. What principle of a multilayer protocol in the sense of the OSI model does this communication mechanism violate?
21. Two networks each provide reliable connection-oriented service. One of them offers a reliable byte stream and the other offers a reliable message stream. Are these identical? If so,

why is the distinction made? If not, give an example of how they differ.

22. What does “negotiation” mean when discussing network protocols? Give an example.
23. In **Fig. 1-31** , a service is shown. Are any other services implicit in this figure? If so, where? If not, why not?
24. In some networks, the data link layer handles transmission errors by requesting that damaged frames be retransmitted. If the probability of a frame’s being damaged is p , what is the mean number of transmissions required to send a frame? Assume that acknowledgements are never lost.
25. Which of the OSI layers and TCP/IP layers handles each of the following:
 - a. Dividing the transmitted bit stream into frames.
 - b. Determining which route through the subnet to use.
26. If the unit exchanged at the data link level is called a frame and the unit exchanged at the network level is called a packet, do frames encapsulate packets or do packets encapsulate frames? Explain your answer.
27. Consider a six-layer protocol hierarchy where layer 1 is the lowest layer, and layer 6 is the highest layer. An application sends a message M by passing it to layer 6. All the even-numbered layers attach a trailer to their payload, and all the odd-numbered layers attach a header to their payload. Draw the headers, trailers, and original message M in the order they are sent over the network.

28. A system has an n -layer protocol hierarchy. Applications generate messages of length M bytes. At each of the layers, an h -byte header is added. What fraction of the network bandwidth is filled with headers?
29. Give five examples of a device connected to two networks at the same time, and explain why this is useful.
30. The subnet of **Fig. 1-12(b)**  was designed to withstand a nuclear war. How many bombs would it take to partition the nodes into two disconnected sets? Assume that any bomb wipes out a node and all of the links connected to it.
31. The Internet is roughly doubling in size every 18 months. Although no one really knows for sure, one estimate put the number of hosts on it at 1 billion in 2018. Use these data to compute the expected number of Internet hosts in the year 2027. Do you believe this? Explain why or why not.
32. When a file is transferred between two computers, two acknowledgement strategies are possible. In the first one, the file is chopped up into packets, which are individually acknowledged by the receiver, but the file transfer as a whole is not acknowledged. In the second one, the packets are not acknowledged individually, but the entire file is acknowledged when it arrives. Discuss these two approaches.
33. Mobile phone network operators need to know where their subscribers' mobile phones (hence their users) are located. Explain why this is bad for users. Now give reasons why this is good for users.
34. How long was a bit in the original 802.3 standard in meters? Use a transmission speed of 10 Mbps and assume the

propagation speed of the signal in coax is $\frac{2}{3}$ the speed of light in vacuum.

35. An image is 3840×2160 pixels with 3 bytes/pixel. Assume the image is uncompressed. How long does it take to transmit it over a 56-kbps modem channel? Over a 1-Mbps cable modem? Over a 10-Mbps Ethernet? Over 100-Mbps Ethernet? Over gigabit Ethernet?
36. Ethernet and wireless networks have some similarities and some differences. One property of Ethernet is that only one frame at a time can be transmitted on an Ethernet. Does 802.11 share this property with Ethernet? Discuss your answer.
37. Wireless networks are easy to install, which makes them inexpensive since installation costs usually far overshadow equipment costs. Nevertheless, they also have some disadvantages. Name two of them.
38. List two advantages and two disadvantages of having international standards for network protocols.
39. When a system has a permanent part and a removable part (such as a CD-ROM drive and the CD-ROM), it is important that the system be standardized, so that different companies can make both the permanent and removable parts and everything still works together. Give three examples outside the computer industry where such international standards exist. Now give three areas outside the computer industry where they do not exist.
40. **Fig. 1-34**  shows a number of different protocols in the TCP/IP network stack. Explain why it can be useful to have multiple protocols in a single layer. Give an example.

41. Suppose the algorithms used to implement the operations at layer k is changed. How does this impact operations at layers $k - 1$ and $k + 1$?
42. Suppose there is a change in the service (set of operations) provided by layer k . How does this impact services at layers $k-1$ and $k+1$?
43. Find out how to open your browser's built-in network monitor. Open it and navigate to a Webpage (e.g., <https://www.cs.vu.nl/~ast/>). How many requests does your browser (client) send to the server? What types of requests does it send? Why are these requests done separately, and not as one large request?
44. Make a list of activities that you do every day in which computer networks are used.
45. The *ping* program allows you to send a test packet to a given location and see how long it takes to get there and back. Try using *ping* to see how long it takes to get from your location to several known locations. From these data, plot the one-way transit time over the Internet as a function of distance. It is best to use universities since the location of their servers is known very accurately. For example, berkeley.edu is in Berkeley, California; mit.edu is in Cambridge, Massachusetts; vu.nl is in Amsterdam; The Netherlands; www.usyd.edu.au is in Sydney, Australia; and www.uct.ac.za is in Cape Town, South Africa.
46. Go to IETF's Web site, www.ietf.org, to see what they are doing. Pick a project you like and write a half-page report on the problem and the proposed solution.