Q1 Layer Model

Find the best matching layer for the following operations/devices. You can use the standard 5-layer model (Application, Transport, Network, Link, Physical):

(a) Bit-to-bit transmission between two devices. Physical

(b) Encryption of a message. Application / presentation

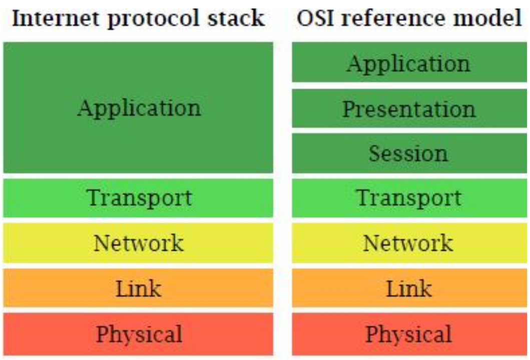
(c) A switch in a network. Link

(d) Routing path search. Network

(e) Adding a sequence number to each packet. Transport

(f) A router in a network. Network

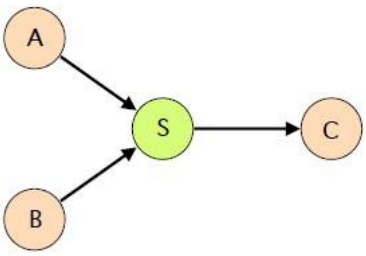
(g) A middlebox in a network performing deep packet inspection (DPI) to find malware in Web traffic. Application



Internet communication layers: Internet protocol stack and the OSI reference model.

Q2 Delay

Consider the network on the left. A and B are sending data towards C over a switch S and a shared link. All the links in the network have a bandwidth of 10 Mbps and you can assume that the propagation and switch processing time are negligible. For circuit switching, assume that circuit establishment and teardown each take 50 ms. For packet switching, you can assume that switch S already knows how to reach C.



Network with a shared link.

(a) How long does it take if node A is sending a 50 $Mbit$ file to C using packet switching? Assume A is the only sender and the link bandwidth is 10 $Mbps$.

50/10=5s

(b) How long does it take if node B is sending a 50 $Mbit$ file to C using circuit switching? Assume the link bandwidth is 10 $Mbps$ and circuit setup/teardown takes 50 ms each.

(50/10 + 0.05)=5.05s

(c) Assume A and B are simultaneously sending a 50 $Mbit$ file using packet switching. If the switch has no buffer, what will happen?

if the data rate of each one is 10Mbps then the switch will
drops packets

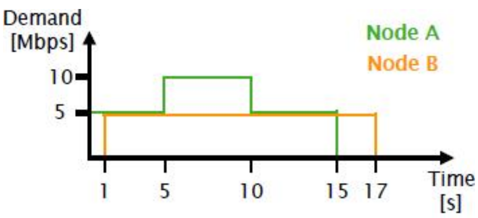
(d) How large has the buffer to be (in Mbit) such that both senders can successfully transmit their files to C when they are simultaneously sending at full speed?

Buffer size= delay * Bandwidth=50

(e) How is it possible to successfully send data over the Internet even if some packets are dropped due to full buffers?

switch can inform sender to slow down transmission

Finally, assume that A and B have to send data with a demand according to the diagram below.



Demand distributions for node A and B.

(f) How long does it take to send all data if A and B use circuit switching (reserving for the peak demand)? (Use values from the provided demand distribution chart.)

Node A delay=15   Node B delay=16   15+16=31

(g) How long does it take to send all data if A and B use packet switching (assuming an unlimited buffer size on the switch)? (Use values from the provided demand distribution chart.)

just from 5 to 10 we have 5s buffer and from 15 to 17 the channel is free and will send

2s Buffer ,   then the net delay will be =17+3 extend buffer =20 s

Q3 Layering and Encapsulation

We represent the suite of protocols that make up a network system with a protocol graph. The nodes of the graph correspond to protocols or applications. A node uses services offered by the node directly connected below it in the protocol graph and offers services to the node directly connected above it in the protocol graph.
Figure 1 shows a protocol graph for a network system consisting of various applications and protocols.

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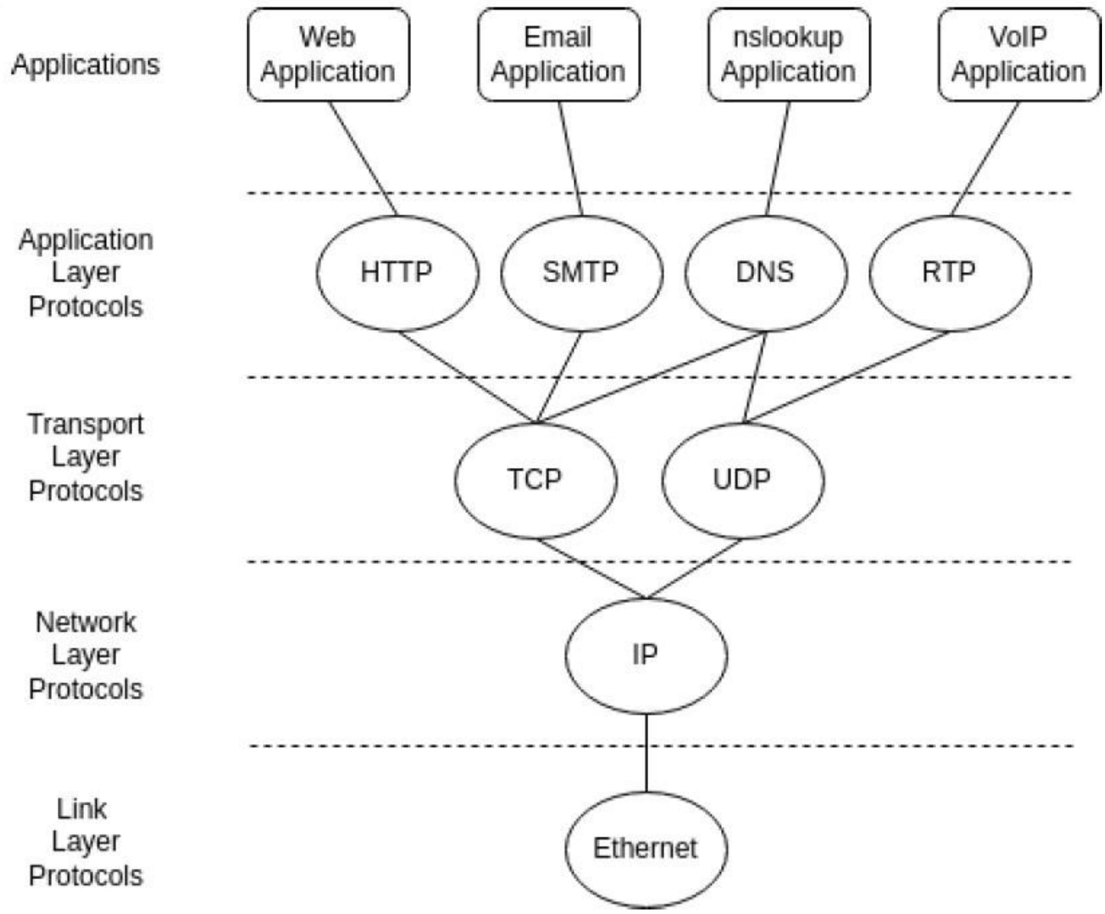


1.

Suppose that you want to send an email using your computer that is connected to the Internet over an Ethernet network. Draw a diagram of an Ethernet frame carrying your email data as it appears on the wire. In your diagram, show the location of 1) various protocol headers, 2) application-layer payload (email data), 3) start of the frame, 4) end of the frame.

Bits received over wire.
L2 header source MAC destination MAC
L3 header source and destination IP
L4 header source and destination port

(email data),

2. For the Ethernet frame you drew before, which is the first header that your computer added to your email data? Which is the last header that your computer added to your email data?

the first header is L4 header then L3 header then L2 header is the last

3.

Suppose that you want to make a video call to your friend using a VoIP application installed on your computer. Your computer and your friend's computer are each connected to the Internet via an Ethernet network. Draw a diagram of an Ethernet frame carrying your video call data as it appears on the wire. In your diagram, show the location of 1) various protocol headers, 2) application-layer payload (video call data), 3) start of the frame, 4) end of the frame.

Bits received over wire.

L2 header source MAC destination MAC

L3 header source and destination IP

L4 header source and destination port

(video call data

4.

When the Ethernet frame you drew in Q6.3 reaches your friend's computer, which is the first header that your friend's computer strips? Which is the last header that your friend's computer strips?

the first header strip is L2 header and the second is L3 header then L4 header

Q8 Datagram Packet Switching

Consider datagram packet switching being used to send n packets across a single path with h hops, where n >> h. Each packet has a length of l bits. Each link has a data rate of b bits per second. Each link has a propagation delay of p seconds. Although there is processing delay and queuing delay at each node, they are both so small that you can assume they are both 0.

1. Write an equation that gives the total time, $T_{datagram}$ it takes from when the source host initiates the data transfer until the destination host has received all of the data.

Packet delay=Transmission delay+Propagation delay=1/b+p

Delay for 1 packet across h hops = h(1 / b + p)

First packet takes h(1 / b + p)

After the pipeline is filled, every new packet only adds 1/b to the finishing

So:

T datagram = h(1 / b + p) + (n - 1) * 1 / b

2. If all the conditions above are the same except virtual circuit packet switching was used instead of datagram packet switching, then would the total time, $T_{virtualcircuit}$ be greater than $T_{datagram}$, less than $T_{datagram}$, equal to $T_{datagram}$ or there is insufficient information to know. Explain your answer.

$T_{virtualcircuit}$ = **T datagram + Tcircuitesetup**

3. Explain an advantage of virtual circuit packet switching compared to datagram packet switching.

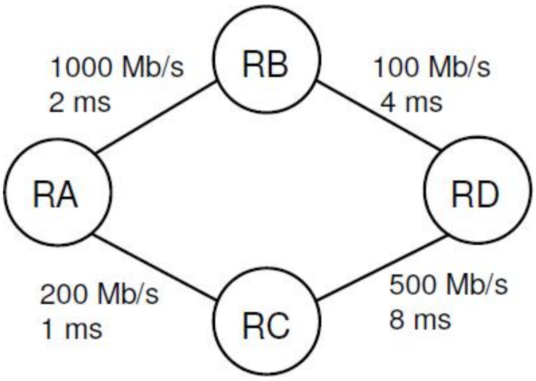
Reservation / per-flow state: once a virtual circuit is set up, routers can keep per-flow state (or resource allocations) and thereby provide more predictable behavior for that flow (useful for quality-of-service guarantees or real-time traffic). This makes performance more predictable for applications that need steady bandwidth.

Simpler forwarding on each hop: packets can be forwarded using a small virtual-circuit identifier rather than performing a full routing lookup per packet (reducing per-packet processing overhead in some designs).

In-order delivery along the same path: since all packets follow the same path, ordering is naturally preserved (good for some applications).

Q4 Routing and Headers

Consider the network topology in the Figure below. It contains four switching nodes, RA, RB, RC and RD, each connected via point-to-point WAN links. The link characteristics of data rate and delay are shown next to each link; the characteristics as the same in each direction.



1. What is the least cost path from RA to RD (and its cost)if the metric is a function of

data rate defined as data rate?

Least-cost path (metric) = cost=2000/data rate

Links (from the figure):

RA–RB: 1000 Mb/s, delay 2 ms

RB–RD: 100 Mb/s, delay 4 ms

RD–RC: 500 Mb/s, delay 8 ms

RC–RA: 200 Mb/s, delay 1 ms.

Compute per-link costs = 2000/data rate (Mb/s)

RA→RB: 2000/1000=2

RB→RD: 2000/100=20

RA→RC: 2000/200=10

RC→RD: 2000/500=4

Now path sums RA→RB→RD = 2+20=22

RA→RC→RD = 10+4=14

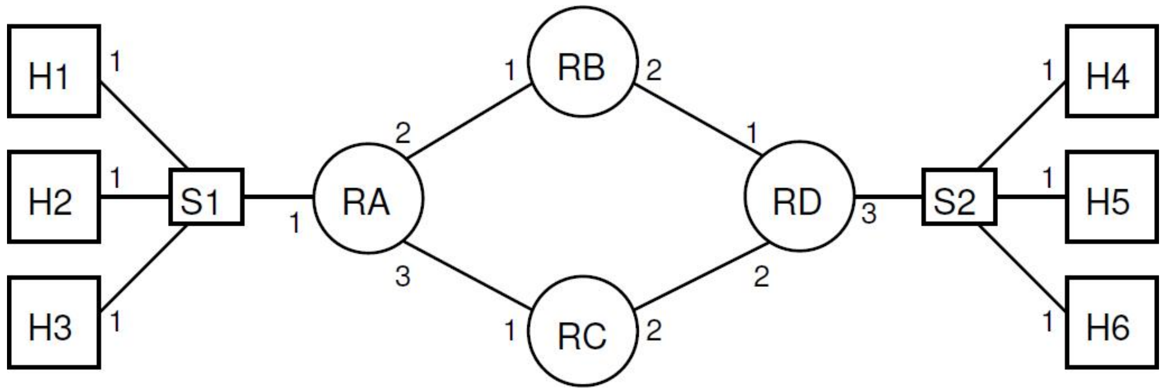
$$cost = \frac{2000}{data\ rate}?$$

Path: RA→RC→RD = Cost: 10+4=14

2. Draw the distributed routing tables for each node if the metric is delay. That is, draw

four routing tables, one for RA, another for RB and so on, where the destinations are the other nodes.

Now consider the network topology in Figure 2. The four switching nodes are IP routers. In addition there are hosts connected via switched Ethernet LANs: the subnet to the left of RA uses 1 Gb/s and the subnet to the right of RD uses 100 Mb/s. Assume the point-to-point WAN links between the routers are 10 Gb/s Ethernet.



The numbers next to each link into a device in the Figure above are interface numbers. For example, RA has three interfaces: interface 1 connects to the switch, interface 2 connects to RB, and interface 3 connects to RC. The Table below lists the MAC and IP addresses currently assigned to a selection of the interfaces.

Suppose that the following IP packet arrives at ”interface 2” of router R1. To successfully deliver the above IP packet, the router needs to send an ARP request. Which host(s) receive the ARP request?

Table 1: Interface Addresses

Device	*Interface*	*MAC*	*IP*
H1	1	11:22:33:aa:bb:cc	103.17.48.97/24
H2	1	22:33:44:bb:cc:dd	103.17.48.12/24
H3	1	33:44:55:cc:dd:ee	?
RA	1	12:34:56:78:90:ab	103.17.48.11/24
RA	2	cd:ef:12:34:56:78	24.114.6.49/16
RA	3	90:ab:cd:ef:12:34	206.100.16.1/16
RB	1	aa:bb:cc:11:22:33	24.114.120.1/16
RB	2	bb:cc:dd:22:33:44	150.12.67.5/20
RC	1	cc:dd:ee:33:44:55	206.100.16.2/16
RC	2	dd:ee:ff:44:55:66	96.27.1.1/18
RD	1	56:78:90:ab:cd:ef	150.12.67.6/20
RD	2	ef:cd:ab:90:78:56	96.27.1.2/18
RD	3	34:12:ef:cd:ab:90	97.33.180.1/21
H4	1	99:a1:b2:c3:d4:e5	97.33.177.1/21
H5	1	88:f6:a7:b8:c9:d0	97.33.179.45/21
H6	1	77:e1:f2:a3:b4:c5	97.33.181.65/21

The following sub-questions give a scenario of one device sending data to others. For that given scenario, you need to fill in the details of the packet (Ethernet frame and/or IP datagram), that is, the packet header field values and other information about the packet. Assume the default/typical headers are used

RA’s Routing Table

Destination	Next Hop	Cost (ms)
RB	RB	2
RC	RC	1
RD	RB	6

RB's Routing Table

Destination	Next Hop	Cost (ms)
RA	RA	2
RC	RA	3
RD	RD	4

RC's Routing Table

Destination	Next Hop	Cost (ms)
RA	RA	1
RB	RA	3
RD	RD	8

RD's Routing Table

Destination	Next Hop	Cost (ms)
RB	RB	4
RC	RC	8
RA	RB	6

3.

H1 has TCP data to send to H4. The entire TCP segment (including header) is 1000 Bytes long. The path that the IP datagram takes is H1→RA→RB→RD→H4 (this path, may or may not be a least cost path identified in parts (1) or (2)). The initial time to live set by H1 is 10. Fill in the table below for the packet sent by H1.

Field	Value
Ethernet Source	11:22:33:aa:bb:cc
Ethernet Destination	12:34:56:78:90:ab
IP Source	103.17.48.97
IP Destination	97.33.177.1
IP Protocol	TCP
IP Total Length	1020

4.

The same as for part (3), but fill in the table below for the packet sent by RA.

Field	Value
Ethernet Source	cd:ef:12:34:56:78
Ethernet Destination	aa:bb:cc:11:22:33
IP Source	103.17.48.97
IP Destination	97.33.177.1
IP TTL	9

5.

H3 has just booted and currently does not have an IP address, nor does it know the network address of its current subnet or the IP address of any devices on its subnet. H3 sends an IP datagram to everyone on its subnet, with the hope that one device will respond giving H3 an IP address. Fill in the table below for the packet sent by H3.

Field	Value
IP Source	0.0.0.0
IP Destination	255.255.255.255

6.

H1 wants to send one IP datagram and have it delivered to all devices on the same subnet as H4. Fill in the table below for the packet sent by H1.

Field	Value
IP Source	103.17.48.97
IP Destination	97.33.183.255

7.

What is the network address for the subnet that H1 is attached to?

8.103.17.48.0/24

Currently there are 4 devices on the subnet that H1 is attached to. How many more new devices can be added to the subnet?

So, A /24 has 254 usable host addresses; 4 are already used → 254 - 4 = 250

Q16 Delay

1. What is the queueing delay at a network link with a link rate of 100 Mb/s, an arriving traffic rate of 9,000 packets per second an average packet length of 1250 bytes and a queue length of 500 packets?

Transmission time per packet = 10,000 bits ÷ 100,000,000 bps = 0.0001 s = 100 μs.

If 500 packets ahead in queue, queueing delay = 500 × 0.0001 s = 0.05 s.

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2. What is the delay if the arriving traffic rate increases to 15,000 packets per second?

- **Service capacity in packets/sec = link_rate /packet_bits = 100,000,000 / 10,000 = 10,000 pkt/s.**

- **Arrival rate 15,000 pkt/s > service 10,000 pkt/s → the link is overloaded (utilization > 1).**

3. Consider an audio application that sends audio data using RTP and UDP over an Ethernet network. How many overhead bytes does each packet include, assuming that the RTP header is 12 bytes? You may ignore the Ethernet preamble and flag.

Ethernet header = 14 bytes

IP header (IPv4, no options) = 20 bytes

UDP header = 8 bytes

RTP header = 12 bytes

14 + 20 + 8 + 12 = **54 bytes**.

4. If audio is encoded at 32 Kb/s and we want or audio packets to be large enough so that the overhead is at most 20% of the total, how many audio bytes must each packet carry?

audio payload bytes = x, overhead = 54 bytes. Require overhead fraction ≤ 0.20:

$$54 / (54 + x) \leq 0.20$$

$$54 \leq 0.20 \times (54 + x)$$

$$54 \leq 10.8 + 0.2x$$

$$54 - 10.8 \leq 0.2x \rightarrow 43.2 \leq 0.2x$$

$$x \geq 43.2 \div 0.2 = 216 \text{ audio bytes per packet}$$

5. How long does it take to acquire the audio data needed to "fill" a packet?

Audio rate = 32 Kb/s = 32,000 bits/s. Payload required = 216 bytes = 216 × 8 = 1,728 bits.

Time = 1,728 bits ÷ 32,000 bits/s = 0.054 s = 54 ms.

Q17 Delay

Suppose that a point-to-point link exists between 2 routers and the distance 320 km

1. Assuming that signals propagate at approximately 2×10^8 meters per second,

what is the propagation delay for a single bit to travel ? 2 x 10**8 m/s

(1) *Propagation delay for single bit:*

Delay = distance / speed = 320,000 m ÷ (2×10^8 m/s)

320,000 ÷ 200,000,000 = 0.0016 s = 1.6 ms.

2. Assuming that the link transmission rate *R* is 1 Gbps (1×10^9 bits per second), how many 1000-byte packets would be needed to completely fill the link in one direction ?

With R = 1 Gbps, how many 1000-byte packets to fill the link one-way?

Bandwidth-delay product (bits in pipe) = R × propagation_delay = 1×10^9 bps × 0.0016 s = 1.6×10^6 bits.

One 1000-byte packet = 1000 × 8 = 8,000 bits.

Number of packets = 1,600,000 ÷ 8,000 = 200 packets.

Q5 Delay

Calculate the latency (from first bit sent to last bit received) for the following:
(a) 100-Mbps Ethernet with a single store-and-forward switch in the path and a packet size of 12,000 bits. Assume that each link introduces a propagation delay of 10 μs and that the switch begins retransmitting immediately after it has finished receiving the packet.

Given: 100-Mbps Ethernet (R = 100×10^6 bps), packet size L = 12,000 bits, propagation per link = 10 μs (10×10^{-6} s). Transmission time T_tx = L / R.

Compute T_tx:

T_tx = 12,000 bits ÷ 100,000,000 bps = 0.00012 s = 120 μs.

(a) ***Single store-and-forward switch (path: sender → switch → destination), switch retransmits after it has finished receiving the packet.***

There are 2 links. Total latency = (transmit on link1) + (propagation link1) + (switch transmit link2) + (propagation link2)
Which equals 2×T_tx + 2×prop_delay.

$$2 \times 120\ \mu s + 2 \times 10\ \mu s = 240\ \mu s + 20\ \mu s = 260\ \mu s.$$

(b) Same as (a) but with three switches.

Three switches → 4 links (sender→S1, S1→S2, S2→S3, S3→dest). For store-and-forward each link requires full transmit + propagation, so total = 4×T_tx + 4×prop_delay.

$$4 \times 120\ \mu s + 4 \times 10\ \mu s = 480\ \mu s + 40\ \mu s = 520\ \mu s.$$

(c) Same as (a), but assume the switch implements "cutthrough" switching; it is able to begin retransmitting the packet after the first 200 bits have been received L2? Why?

- **Time for 200 bits to be sent by sender = 200 ÷ 100,000,000 = 2×10^{-6} s = 2 μs.**
- **First bit arrives at switch after propagation = 10 μs.**
- **So the switch can start transmitting onto link2 at t_start = propagation + time_for_200_bits = 10 μs + 2 μs = 12 μs.**
- **The switch will take T_tx = 120 μs to transmit the entire packet onto link2 (it streams as it receives). It finishes transmitting at t_start + 120 μs = 12 + 120 = 132 μs.**
- **Last bit arrives at destination after propagation on link2: +10 μs → total = 132 + 10 = 142 μs**

cut-through greatly reduces latency because the switch forwards before the whole frame is received.)