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Section 1.1

R3 Why are standards important for protocols?

A: 确立统一的标准之后，才能在协议上创造可以相互调用、交流的产品和网络系统。

Section 1.2

R4. List four access technologies. Classify each one as home access, enterprise access, or wide-area wireless access.

A: access technologies：

- (For home) FTTH, DSL, WIFI;
- (For home or enterprise) Ethernet;
- (wide-area wireless access) 4G/5G

Section 1.3

R12. What advantage does a circuit-switched network have over a packet-switched network? What advantages does TDM have over FDM in a circuit-switched network?

A: 1. circuit-switch 建立连接后，端到端的通信资源被通话的两个用户独占，因此的传输速率是稳定可控的；而package-switch 中package在路由器存储转发时需要排队，会造成一定的延迟，无法保证速率。

2. FDM建立连接后，即使途中没有数据传输，该连接所占用的频段带宽也不能被其他连接使用；TDM建立连接后，当某个连接暂时没有数据传输时可以少分时间片或不分，让出相应的传输时间给其他连接，高效的使用网络。

   当发生拥塞等问题时，TDM数据丢失更少。

   TDM设备比FDM简单，因为TDM信号的复用和分路都是采用数字电路实现的，而且由于不需要过滤频段，所以所有的滤波器都是相同的；而FDM中为了区分频段要用到不同的带通滤波器，设备相对复杂。

   FDM中信道的非线性性可能会引起话间串扰，因此多路信号通信时FDM对线性性的要求比单路通信时要严格的多；TDM中多路信号在时间上是分开的，对线性的要求与单路通信时一样。

P8. Suppose users share a 10 Mbps link. Also suppose each user requires 200 kbps when transmitting, but each user transmits only 10 percent of the time. (See the discussion of packet switching versus circuit switching in Section 1.3.)

a. When circuit switching is used, how many users can be supported?

A: $\frac{10Mbps}{200kbps} = 50$

b. For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.

A: 0.1

c. Suppose there are 120 users. Find the probability that at any given time, exactly *n* users are transmitting simultaneously. (*Hint*: Use the binomial distribution.)

A: $C_{120}^{n} * 0.1^{n} * 0.9^{120-n}$

d. Find the probability that there are 51 or more users transmitting simultaneously.

A: 根据泊松定理：$P(X \le 50) = \sum_{k=0}^{50} \frac{(120*0.1)^k * e^{-(120*0.1)}}{k!}$，查表知当X=28时$P(X \le 28) = 1$，因此$P(X \le 50) = 1$，$P(X \ge 51) = 1 - 1 = 0$

Section 1.4

R16. Consider sending a packet from a source host to a destination host over a fixed route. List the delay components in the end-to-end delay. Which of these delays are constant and which are variable?

A: end-to-end delay:

- 传输延迟d_{trans}：将数据发送到链路上所需的时间
- 传播时延d_{prop}：数据在链路上传播所需的时间
- 处理时延d_{proc}：节点对数据进行路由、校对所需的时间，与交换机的数量有关
- 排队时延d_{queu}：当交换机有分组尚未发送完毕，新到达的分组在缓冲区排队等待造成的时延

  排队时延是不确定的，传输、传播、和处理时延是固定的。

P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate *R* bps. Suppose that the two hosts are separated by *m* meters, and suppose the propagation speed along the link is *s* meters/sec. Host A is to send a packet of size *L* bits to Host B.

a. Express the propagation delay, d_{prop}, in terms of *m* and *s*.

A: $d_{prop} = \frac{m}{s}$

b. Determine the transmission time of the packet, d_{trans}, in terms of *L* and *R*.

A: $d_{trans} = \frac{L}{R}$

c. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

A: $d = \frac{m}{s} + \frac{L}{R}$

d. Suppose Host A begins to transmit the packet at time *t* = 0. At time *t* = d_{trans}, where is the last bit of the packet?

A: last bit在刚离开Host A的链路上

e. Suppose d_{prop} is greater than d_{trans}. At time *t* =d_{trans}, where is the first bit of the packet?

A: first bit在Host A和Host B之间的链路上，还未到达Host B

f. Suppose d_{prop} is less than .d_{trans} At time *t* = d_{trans}, where is the first bit of the packet?

A: first bit已经到达Host B

g. Suppose *s* = $2.5 * 10^8$, *L* = 1500 bytes, and *R* = 10 Mbps. Find the distance *m* so that d_{prop} equals d_{trans}.

A: $d_{prop} = d_{trans}$时，$m = \frac{L}{R*s} = \frac{1500bytes}{10Mbps*2.5*10^8} = 300km$

P10. Consider a packet of length *L* that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let di, s_i, and R_i denote the length, propagation speed, and the transmission rate of link *i*, for *i* = 1, 2, 3. The packet switch delays each packet by d_{proc}. Assuming no queuing delays, in terms of d_i , s_i and R_i(*i* = 1, 2, 3), and L , what is the total end-to-end delay for the packet?

A: $d_{prop} = \sum_{i=1}^{3} \frac{d_i}{s_i}$, $d_{trans} = \sum_{i=1}^{3} \frac{L}{R_i}$

$d_{end-to-end} = d_{prop} + d_{trans} + 2 * d_{proc} = \sum_{i=1}^{3} (\frac{d_i}{s_i} + \frac{L}{R_i}) + 2 * d_{proc}$

Suppose now the packet is 1,500 bytes, the propagation speed on all three links is $2.5 * 10^8$ m/s, the transmission rates of all three links are 2.5 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

$d_{end-to-end} = 60.4ms$

P18. Perform a Traceroute between source and destination on the same continent at three different hours of the day.

网站：www.tju.edu.cn

第一次trace：

第二次trace：

第三次trace：

a. Find the average and standard deviation of the round-trip delays at each of the three hours.

A: 第一小时：均值10.33ms，标准差5.1316ms

第二小时：均值18ms，标准差4ms

第三小时：均值：12.6667ms，标准差7.3711ms

b. Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?

A: 在这三个小时中，都是途径3个路由器。path没有变过。

c. Try to identify the number of ISP networks that the Traceroute packets pass through from source to destination. Routers with similar names and/or similar IP addresses should be considered as part of the same ISP. In your experiments, do the largest delays occur at the peering interfaces between adjacent ISPs?

Traceroute packets 从源到目的地通过1个ISP 网络。 下一问中尝试追踪多个ISP网络。

d. Repeat the above for a source and destination on different continents. Compare the intra-continent and inter-continent results.

网站：www.web.mit.edu

第一次trace：

第二次trace：

第三次trace：

A: 可以看出延时明显比同一大陆内长。第一小时平均延时53.3333ms，第二小时平均延时47.6667ms，第三小时平均延时44.3333ms。这次实验中Traceroute packets 从源到目的地通过了4个ISP 网络，最长延时确实出现在相邻ISP之间的对等接口处。

P23. Consider Figure 1.19(a). Assume that we know the bottleneck link along the path from the server to the client is the first link with rate R_s bits/sec. Suppose we send a pair of packets back to back from the server to the client, and there is no other traffic on this path. Assume each packet of size *L* bits, and both links have the same propagation delay d_{prop}.

a. What is the packet inter-arrival time at the destination? That is, how much time elapses from when the last bit of the first packet arrives until the last bit of the second packet arrives?

A: $\frac{L}{R_s}$

b. Now assume that the second link is the bottleneck link (i.e.$R_c < R_s$). Is it possible that the second packet queues at the input queue of the second link? Explain. Now suppose that the server sends the second packet *T* seconds after sending the first packet. How large must *T* be to ensure no queuing before the second link? Explain.

A: 第二个packet会排队，想要避免排队则需要时间间隔$T = \frac{L}{R_c} - \frac{L}{R_s}$

排队原因：第一个packet在$t_1 = \frac{L}{R_s} + d_{prop}$时到达第二个router，在$t_2 = \frac{L}{R_s} + \frac{L}{R_c} + d_{prop}$时离开。第二个packet在$t_3 = 2 * \frac{L}{R_s} + d_{prop}$时到达第二个router。因为$R_c < R_s$，所以$t_1 < t_3 < t_2$，第二个packet到达第二个router时第一个packet还没有发送完毕。

避免排队就需要第二个packet延迟发送，延迟时间为$t_2 - t_3 = \frac{L}{R_c} - \frac{L}{R_s}$

P25. Suppose two hosts, A and B, are separated by 20,000 kilometers and are connected by a direct link of *R* = 5 Mbps. Suppose the propagation speed over the link is $2.5 * 10^8$ meters/sec.

a. Calculate the bandwidth-delay product, $R * d_{prop}$.

A: $R * d_{prop} = 5Mbps * (20000km/2.5 * 10^8 m/s) = 400kb$

b. Consider sending a file of 800,000 bits from Host A to Host B. Suppose the file is sent continuously as one large message. What is the maximum number of bits that will be in the link at any given time?

A: 400kb

c. Provide an interpretation of the bandwidth-delay product.

A: 带宽延迟积是一条链路可以容纳的最大bit数量

d. What is the width (in meters) of a bit in the link? Is it longer than a football field?

A: 一个bit的宽度为$\frac{\text{链路长度}}{\text{时延}*\text{带宽}} = 50m$，小于一个标准足球场的长度

e. Derive a general expression for the width of a bit in terms of the

propagation speed *s*, the transmission rate *R*, and the length of the

link *m*.

A: 设w为比特长度，$w = \frac{s}{R}$

Section 1.5

R23. What are the five layers in the Internet protocol stack? What are the principal responsibilities of each of these layers?

A: 因特网协议栈的五层分别是应用层，传输层，网络层，链路层，物理层

应用层：面向用户提供端到端的网络服务

传输层：为应用层提供端到端的数据传输服务

网络层：为数据包找到一条从源到目的地址的路径

链路层：为共享同一条链路的多个用户分配链路资源，以便把数据包传输到网络层指定的相邻结点处

物理层：将数字信号转换成模拟信号，在物理介质中传播

R24. What is an application-layer message? A transport-layer segment? A network-layer datagram? A link-layer frame?

A: application-layer message（应用层报文）是应用程序希望发送并传递到传输层的信息。

transport-layer segment（运输层报文段）是用运输层协议头部封装应用层报文之后形成的数据

network-layer datagram（网络层数据报）是用网络层协议头部封装传输层数据后形成的数据

link-layer frame（链路层帧）是用链路层协议头部封装网络层数据后形成的数据

R25. Which layers in the Internet protocol stack does a router process? Which layers does a link-layer switch process? Which layers does a host process?

A: 大多数路由器处理：网络层、链路层、物理层
链路层交换机处理：链路层、物理层
主机处理：全部五层