(1) application layer: Network applications and their protocols reside. One end system uses the protocol to exchange packets of information with the app in another end system. (information at this layer: message)
(2) Presentation layer: allow communicating applications to interpret the meaning of data exchanged
(3) Session layer: provides for delimiting and synchronization of data exchange, including the means to build a checkpointing and synchronization.
(4) Transport layer: UDP and TCP can transport application-layer message.(transport-layer packet: segment)
(5) Network layer: Containing routing protocols & IP protocols (end systems & routers act in Datagram field).
Datagram (network-layer packets)
(6) Link layer: move a packet from one node to the next node in the route. (link-layer packets: frame) e.g. Ethernet ,Wi-fi…
(7) Physical layer: twisted-pair copper wire, coaxial cable
Point-to-point, reliable, in-order byte stream, pipelined, connection-oriented, flow-controlled, full duplex data, send & receive buffers, packet-switching, fairness

Problem 6 (15 Points):
Suppose there is a 10 Mbps microwave link between a geostationary satellite and its base station on Earth. Every minute the satellite takes a digital photo and send it to the base station. Assume a propagation speed of 2.4 * 10^8 meters/sec.

a. What is the propagation delay of the link?
b. What is the bandwidth-delay product, $R * d_{prop}$?
c. Let x denote the size of the photo. What is the minimum value of x for the microwave link to be continuously transmitting?

Recall geostationary satellite is 36,000 kilometers away from earth surface

a. *150 msec*
b. *1,500,000 bits*
c. *600,000,000 bits*

Consider that only a single TCP (Reno) connection uses one 15Mbps link which does not buffer any data. Suppose that this link is the only congested link between the sending and receiving hosts. Assume that the TCP sender has a huge file to send to the receiver, and the receiver's receive buffer is much larger than the congestion window. We also make the following assumptions: each TCP segment size is 1,200 bytes; the two-way propagation delay of this connection is 160 msec; and this TCP connection is always in congestion avoidance phase, that is, ignore slow start.

a. What is the maximum window size (in segment) that this TCP connection can achieve?
b. What is the average window size (in segment) and average throughput (in bps) of this TCP connection?
c. How long would it take for this TCP connection to reach its maximum window again after recovering from a packet loss?

Answer:

a) Let W denote the max window size measured in segments. Then, W*MSS/RTT = 15Mbps, as packets will be dropped if the maximum sending rate exceeds link capacity. Thus, we have W*1200*8/0.16=15*10^6, then W is about 250.
b) As congestion window size varies from W/2 to W, then the average window size is 0.75W=187.5 segments. Average throughput is 187.5*1200*8/0.16=11.25Mbps.
c) (250/2) *0.16= 20 seconds, as the number of RTTs (that this TCP connections needs in order to increase its window size from W/2 to W) is given by W/2. Recall the window size increases by one in each RTT.

6) Consider sending a large file of F bits from Host A to Host B. There are two links (and one router) between A and B, and the links are uncongested (that is, no queuing delays). Host A segments the file into segments of S bits each and adds 40 bits of header to each segment, forming packets of $L= 40 +S$ bits. Each link has a transmission rate of R bps. Find the value of S that minimizes the delay of moving the file from Host to Host B. Disregard propagation delay.

Time at which the 1st packet is received at the destination $= \frac{S+40}{R} \times 2$ sec. After this, one packet is received by the destination every $\frac{S+40}{R}$ sec because packets are transmitted back to back by Host A.

Thus delay in sending the whole file is,

$$delay = \frac{S+40}{R} \times 2 + \left(\frac{F}{S} - 1\right) \times \left(\frac{S+40}{R}\right) = \frac{S+40}{R} \times \left(\frac{F}{S} + 1\right)$$

To calculate the value of S which leads to the minimum delay, we take the derivative and equate it to zero,

$$\frac{\partial delay}{\partial S} = 0 \Rightarrow \frac{F}{R}\left(\frac{1}{S} - \frac{40+S}{S^2}\right) + \frac{1}{R} = 0 \Rightarrow S = \sqrt{40F}$$

(i) Flow control: a receiver controls its sender so that the sender won't overflow the receiver's buffer, through ***rwnd***.

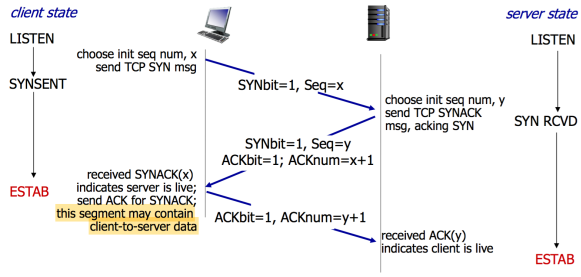
(ii) Congestion control: to control all senders in a network so that there won't be too much data for network to handle, through ***cwnd***.

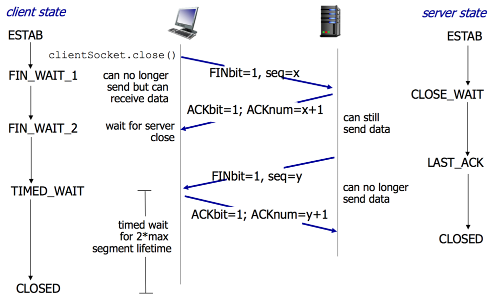
	GBN	SR	TCP
Total Tx Pkt	9	6	6
Seq.	0,1,2,3,4,1,2,3,4	0,1,2,3,4,1	0,1,2,3,4,1
Total Rx Pkt	8	5	5
			,1,1,1,5

(Circuit switched) $s + kd + \frac{x}{b}$ (1% + 2% + 2%)

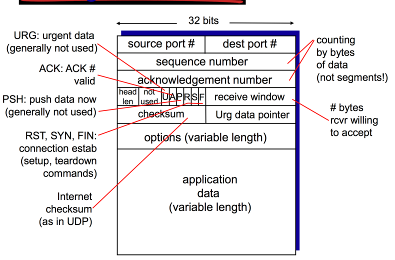
(Packet switched) $kd + \frac{x}{b} + (k-1)\frac{p}{b}$ (1% + 2% + 2%)

Time	A recv ACK	Event (lost, timeout, fast rtx)	Cwnd	A sends	R sending /R's queue
T = 0			1	1	1/
T = 1	1		2	2,3	2/3
T = 2	2		3	4,5	3/4,5
T = 3	3		4	6,7	4/5,6,7
T = 4	4	9 lost	5	8,9	5/6,7,8
T = 5	5	11 lost	6	10,11	6/7,8,10
T = 6	6	13 lost	7	12,13	7/8,10,12
T = 7	7	15 lost	8	14,15	8/10,12,14
T = 8	8	17 lost	9	16,17	10/12,14,16
T = 9	8	9 timeout	1	9	12/14,16,9
T = 10	8	Fast retransmit, 10 11 timeout	1		14/16,9
T = 11	8	12 13 timeout	1		16/9
T = 12	8	14 15 timeout	1		9/
T = 13	10	16 17 timeout	1	11	11/
T = 14	12		2	13,14	13/14
T = 15	14		3	15,16,17	15/16,17





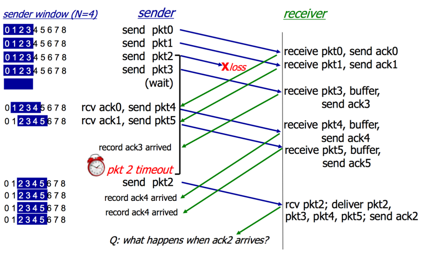
TCP segment structure



TCP ACK generation [RFC 1122, RFC 2581]

event at receiver	*TCP receiver action*
arrival of in-order segment with expected seq #. All data up to expected seq # already ACKed	delayed ACK. Wait up to 500ms for next segment. If no next segment, send ACK
arrival of in-order segment with expected seq #. One other segment has ACK pending	immediately send single cumulative ACK, ACKing both in-order segments
arrival of out-of-order segment higher-than-expect seq. # . Gap detected	immediately send *duplicate ACK*, indicating seq. # of next expected byte
arrival of segment that partially or completely fills gap	immediate send ACK, provided that segment starts at lower end of gap

Selective repeat in action



GBN in action