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COM302 - Computer Networking

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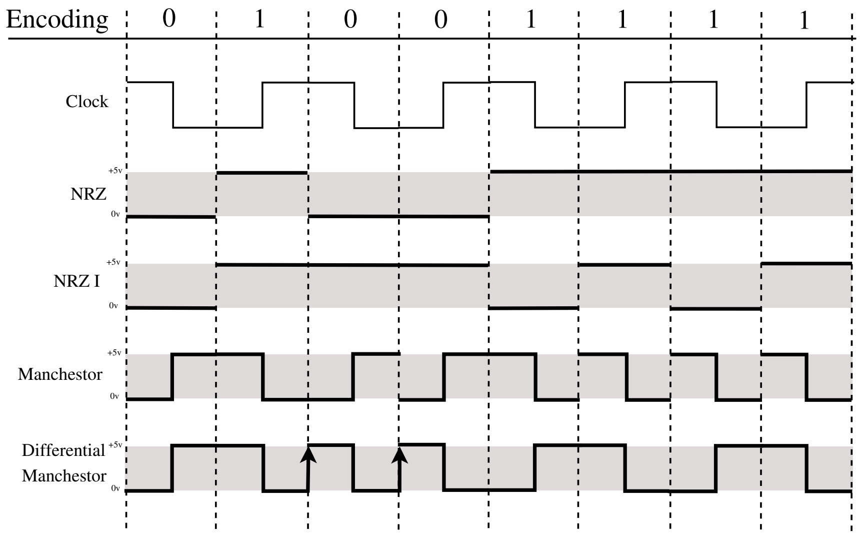
`Problem Session 1`

1. Encode: 0 1 0 0 1 1 1 1



2. A data transfer of 1000 bits takes place between a pair of nodes A and B via switches $S1$ and $S2$. $S1$ is a store and forward switch and $S2$ is a cut-through switch. The link speed is 10Mbps and the propagation speed of each link is 10 microsec. Switching delay at $S2$ is 20 microsec. Calculate the total time.
   Solution: Link speed = 10 Mbps
   Propagation time $t_{prop} = 10$ micro seconds
   Transmission time for 1000 bits, $t_{trans} = \frac{1000}{10 \cdot 10^6} = 100$ micro seconds

   Let the delay at Switch i be t^i_{SD}. Assume $t^1_{SD} = 0$, and given $t^2_{SD} = 20$ micro seconds

   Total time $t = t_{trans} + t_{prop} + t^1_{SD} + t_{trans} + t_{prop} + t^2_{SD} + t_{prop}$

   $= 100 + 10 + 0 + 100 + 10 + 20 + 10 = 250$ micro seconds

   Note: At cut-through switch, there is no transmission delay and after 20 microsec. of switching delay (time to transmit few bits of the packet + cpu processing time to identify the out-going port), the packet flows via the right output port.

3. A data transfer of 100 bits takes place between a pair of nodes A and B via store and forward switches $S1$ and $S2$. For each link the propagation time is 10 mico.sec. Calculate the total transfer time when the link speeds are

(i) Link speed of (A,S1) is 10Mbps (ii) Link speed of (S1,S2) is 2Mbps (iii) Link speed of (S2,B) is 10Mbps

Solution: Propagation time $t_{prop} = 10$ micro seconds. Assume the switch delay at all switches is zero. Let t_{trans}^{A-S1} be the transmission delay between A and switch $S1$.

$t_{trans}^{A-S1} = \dfrac{100}{10 \cdot 10^6} = 10$ micro seconds

$t_{trans}^{S1-S2} = \dfrac{100}{2 \cdot 10^6} = 50$ micro seconds

$t_{trans}^{S2-B} = \dfrac{100}{10 \cdot 10^6} = 10$ micro seconds

Total time $= t_{trans}^{A-S1} + t_{prop} + t_{trans}^{S1-S2} + t_{prop} + t_{trans}^{S2-B} + t_{prop}$

$= 10 + 10 + 50 + 10 + 10 + 10 = 100$ micro seconds

4. Calculate the total time required to transfer a 1.5 MB file in the following cases, assuming a RTT of 80ms, a packet size of 1 KB data, and an initial 2xRTT of 'handshaking' before data is sent.

   (a) The bandwidth is 10 Mbps, and data packets can be sent continuously.

   (b) The bandwidth is 10 Mbps, but after we finish sending each data packet we must wait one RTT before sending the next

   (c) The link allows infinitely fast transmit, but limits bandwidth such that only 20 packets can be sent per RTT

   (d) Zero transmit time as before, but during first RTT we can send one packet, during second RTT we can send two packets, during the third we can send four packets, and so on.

   Solution:
   Why Handshaking? Data transmission is an interrupt as far as a system is concerned. It is just another task that the system is expected to perform and therefore, there is a priority associated with it. Before, the sender initiates a transmission, it has to check whether the receiver is up or not for which the sender sends a special bit that incurs one RTT. Further, the sender must find out whether the receiver is willing to perform a data transfer. The receiver may decline the request if there is an high priority job running at the CPU. This check incurs another RTT. Overall, we need two RTTs to ascertain the availability and willingness of the receiver towards data transfer.

   Let us follow the following two strategies to calculate the total time:

   Strategy 1: Data transmission is said to be complete if the last bit of the data sent by the sender reaches the receiver.

   Strategy 2: Data transmission is said to be complete if there is an acknowledgement from the receiver.

   Note that $RTT = 2 \cdot t_{prop}$

   (a) Solution using Strategy 1: Initially, we need two RTTs for handshakes. Transmission time $t_{trans} = \dfrac{1.5 \times 10^6 \times 8}{10 \times 10^6}$

   Total time $= 2RTTs + t_{trans} + t_{prop} = 2 \times 80 \times 10^{-3} + \dfrac{1.5 \times 10^6 \times 8}{10 \times 10^6} + \dfrac{80 \times 10^{-3}}{2} = 1.4s$

   For Strategy 2, the total time $= 2RTTs + t_{trans} + t_{prop} + t_{trans}^{ack} + t_{prop}^{ack}$, where t_{trans}^{ack} and t_{prop}^{ack} are the transmission time and propagation time needed for the last acknowledgement packet.

(b) Solution using Strategy 1: Initially, we need two RTTs for handshakes. Packet size = 1KB. The number of packets is 1500.
Transmission of 1500 packets incurs $1500 \cdot t^{pkt}_{trans}$, where t^{pkt}_{trans} is the transmission time for a single packet. Also it is easy to see that there is a waiting time of $2RTTs$ between adjacent packet transmission. Since the propoagation time for a packet $t^{pkt}_{prop} = \frac{RTT}{2}$, each of the packets reach the receiver within the waiting time. Hence, t^{pkt}_{prop} need not be taken into consideration as it overlaps with the waiting RTT. This is true till 1499 packet transmissions. However, we need to add the propagation time for the last packet.
$1500 \cdot t^{pkt}_{trans} = t_{trans} = \dfrac{1.5 \times 10^6 \times 8}{10 \times 10^6} = 1.2s$

Therefore, the total time $= 2 \cdot RTTs + 1500 \cdot t^{pkt}_{trans} + 1499 \cdot RTT + t^{pkt}_{prop}$

For Strategy S1, the total time $= 1501.5 \times RTT + 1.2s = 121.32s$

For Strategy S2, note that each packet is acknowledged by the receiver.
$= 2RTT\ + t^{p1}_{trans}\ + t^{p1}_{prop}\ + t^{a1}_{trans}\ + t^{a1}_{prop}\ + RTT_1 + \ldots + RTT_{1499} +\ t^{p1500}_{trans}\ + t^{p1500}_{prop}\ + t^{a1500}_{trans}\ + t^{a1500}_{prop}$, where $t^{pi}_{trans}, t^{pi}_{prop}, t^{ai}_{trans}, t^{ai}_{prop}$ denotes the transmission time of a packet, the propagation time of a packet, the transmission time of an acknowledgement, the propagation time for acknowledgement, respectively. Note that the t^{pi}_{prop} and t^{ai}_{prop} overlaps with the weighting time RTT_i. Therefore, the total time $= 1502 \times RTT + t^{ai}_{trans} \times 1500 + t^{pi}_{trans} \times 1500$

(c) Since the link allows infinitely fast transmit, the transmission time $t_{trans} = 0$
Since the number of packets per RTT is 20, we need 75 RTTs to send 1.5 MB file.
For Strategy 1, the total time $= 2RTT + t_{trans} + 74.5RTT = 76.5RTT$. **Note:** the last set of 20 packets reach the receiver in $\frac{RTT}{2}$.
For Strategy 2, the total time $= 2RTT + t^{pkt}_{trans} + 75RTT + t^{ack}_{trans} = 77RTT$

(d) Since there are 1500 packets to send, we need $11RTT$ for data transfer.
During RTT-x, 2^{x-1} packets are sent. Thus, $2^0 + 2^1 + \ldots + 2^{x-1} = 1500$. Clearly, $x = 11$.

For Strategy 1, total time $= 2RTT + t_{trans} + 10.5RTT = 12.5RTT = 1s$
For Strategy 2, total time $= 2RTT + t^{pkt}_{trans} + 11RTT + t^{ack}_{trans} = 13RTT = 1.04s$

5. Consider a point-to-point link 50km in length. At what bandwidth would propagation delay at a speed of 2×10^8 meter per second equal transmit delay for 100 byte packets? What about 512 byte packets?
Solution: Length $= 50 \times 10^3 m$. We compute the propagation delay $t_{prop} = \frac{50 \times 10^3}{2 \times 10^8} = 25ms$.
If the propagation delay is equal to the transmission time of 100 bytes packet, then
$\dfrac{100 \times 8}{x\ \ bits/sec} = \dfrac{50 \times 10^3}{2 \times 10^8}$.
bandwidth $= x$ bits/sec $= \dfrac{100 \times 8}{25 \times 10^{-5}} = 3200\ Kbps$
If packet size is 512 bytes, then bandwidth $= \dfrac{512 \times 8}{25 \times 10^{-5}} = 16384\ Kbps$

6. Calculate the effective bandwidth for the following cases.
   (a) A 10-Mbps Ethernet through three store and forward switches. Switches can send on one link while receiving on the other.
   (b) Same as above with the sender having to wait for a 50 byte acknowledgement packet after sending each 5000 bit data packet.

Solution: Assume we transmit 5000 bits and $t_{prop} = 10\ ms$.
Total time $= 4 \cdot t_{trans} + 4 \cdot t_{prop}$
$x = 4 \cdot \frac{5000}{10 \cdot 10^6} + 4 \times 10 \times 10^{-3} = 42\ ms$
In x seconds, we transmit 5000 bits. Therefore in 1 second, $\frac{5000}{42 \times 10^{-3}} = 0.119\ Mbps$ or $119\ Kbps$.
In the second case, we have to consider the transmission delay and propagation delay of the acknowledgement packet.
Let $y = x + 4 \cdot \frac{50 \cdot 8}{10 \cdot 10^6} + 4 \cdot t_{prop} = 42\ ms + 0.16\ ms + 40\ ms = 82.16\ ms$
Effective bandwidth $= \frac{5000}{82 \cdot 16 \times 10^{-3}} = 0.0608\ Mbps$ or $60\ Kbps$.

7. Calculate the bandwidth $\times$ delay product for the following links. Use one way latency delay, measured from first bit sent to first bit received.
   (a) 10-Mbps Ethernet with a delay of 10 micro sec.
   (b) 10-Mbps Ethernet with a single store-and-forward switch with a packet size 5000 bits and 10 micro sec link propagation delay.
   (c) 1.5 Mbps T1-link, with a transcontinental one-way delay of 50 milli sec.
   (d) 1.5 Mbps T1-link through a satellite in geosynchronous orbit (35,900 km).
   Propagation delay=speed of light

   Solution: Delay bandwidth (DB) product denotes the number of bits on the wire during $t_{prop}(\frac{RTT}{2})$

   (a) $DB = (10 \cdot 10^{-6}) \times (10 \cdot 10^6) = 100\ bits$

   (b) Here the total DB is the sum of the DB from the sender to the switch, the number of bits in the switch, and the DB from the switch to the receiver. $DB = (10 \cdot 10^{-6}) \times (10 \cdot 10^6) + 5000 + (10 \cdot 10^{-6}) \times (10 \cdot 10^6) = 5200\ bits$

   (c) Trancontinental link is established between two countries via a gateway. Thus, the DB is the sum of the DB of two links where the first link is between the sender and the gate way and the other link is between the gate way and the receiver. $DB = 2 \times (1.5 \times 10^6) \times (50 \times 10^{-3}) = 0.15\ Mb$

   (d) Note that $t_{prop} = \frac{35900 \cdot 10^3}{3 \cdot 10^8} = 0.119\ s$. $DB = 2 \times (1.5 \times 10^6) \times 0.119 = 0.359\ Mb$

8. Hosts A and B are each connected to a switch S via 10-Mbps links. The propagation delay on each link is 20 micro sec. Switch begins retransmitting a received packet 35 micro sec after it has finished receiving it. Calculate the total time required to transmit 10,000 bits from A to B in the following cases. (i). as a single packet. (ii). as two 5000-bit packet sent one right after the other.
   Solution: **(i)** Given $t_{prop} = 20$ micro seconds. We compute $t_{trans} = \frac{10000}{10.10^6} = 1000$ micro seconds.
   The packet reaches the switch at $t_{trans} + t_{prop} = 1020$ micro sec. The packet is retransmitted after 35 micro sec. After 1055 micro sec., the packet starts transmitting from the switch. The packet reaches B after 1055 micro sec. $+ t_{trans} + t_{prop} = 1055 + 1000 + 20 = 2075$ micro sec.

   If the switch is a cut-through switch, then the packet reaches B after
   $t_{trans} + t_{prop} +$ switch delay $+ t_{prop} = 1000 + 20 + 35 + 20 = 1075$ micro sec.

   (ii) We compute $t_{trans} = \frac{5000}{10 \times 10^6} = 500$ micro sec. The first packet reaches the switch in 520 micro sec. After 35 micro sec. of switch delay, the switch retransmits packet 1 which reaches B at $520 + 35 + 520 = 1075$ micro sec. Immediately after the transmission of the first packet, A sends the second packet which reaches the switch at 1020 micro sec. While A transmits Packet 2 (and the switch is receiving on one end), the switch is retransmitting Packet 1 on the other end. The switch retransmits the second one after 35 micro sec. i.e., at 1055 micro sec, Packet 2 is ready to leave the switch. Note that at 1055 micro sec., the last bit of the first packet has finished its transmission from the switch and is in the transmission channel. Hence, after 1055 micro sec., the switch could retransmit the second packet without any issues. Therefore, at $1055 + 520 = 1575$ micro sec., Packet 2 is received at B. The transmission is complete at 1575 micro sec.

Remark: From the above example, it is clear that sending a single packet of 10000 bits takes 2075 micro sec., whereas sending the same as two packets of 5000 bits each incurs 1075 micro sec. The smaller is better. Let us analyze by splitting the packets further. We consider sending 4 packets of size 2500 bits each.

At the Sender	At the Switch	At the Receiver
Packet 1 ($P1$) leaves at 250μ	$P1$ reaches at $250+20$ and leaves at $250 + 20 + 35\mu$	$P1$ reaches at $250 + 20 + 35 + 250 + 20 = 575\mu$.
$P2$ leaves at 500μ	$P2$ reaches at $500 + 20 + 35 = 555\mu$	$P2$ reaches at $555 + 250 + 20 = 825\mu$.
$P3$ leaves at 750μ	$P3$ reaches at $750 + 20 + 35 = 805\mu$	$P3$ reaches at $805 + 250 + 20 = 1075\mu$.
$P4$ leaves at 1000μ	$P4$ reaches at $1000 + 20 + 35 = 1055\mu$	$P4$ reaches at $1055+250+20 = 1325\mu$.

Note that after every 250μ sec, a packet leaves the sender and a packet reaches the receiver. The overlap in time interval between the sender and the switch, and the switch and the receiver guarantees the reduction in the total time. The natural question at this time is, can we split the file further, say, 10 packets each of size 1000 bits? In general, what is the optimum value for the packet size. We next investigate by considering 10000 packets with packet size just 1 bit each.

At the Sender	At the Switch	At the Receiver
Packet 1 ($P1$) leaves at 0.1μ	$P1$ reaches at $0.1+20$ and leaves at $0.1 + 20 + 35\mu$	$P1$ reaches at $0.1 + 20 + 35 + 0.1 + 20 = 75.2\mu$.
$P2$ leaves at 0.2μ	$P2$ reaches at $0.2 + 20 + 35 = 55.2\mu$	$P2$ reaches at $55.2 + 0.1 + 20 = 75.3\mu$.
$P3$ leaves at 0.3μ	$P3$ reaches at $0.3 + 20 + 35 = 55.3\mu$	$P3$ reaches at $55.3 + 0.1 + 20 = 75.4\mu$.
...	...	...
P_{10000} leaves at 1000μ	P_{10000} reaches at $1000 + 20 + 35 = 1055\mu$	P_{10000} reaches at $1055 + 0.1 + 20 = 1075.1\mu$.

A packet is delivered at the receiver after every 0.1μ sec. The total time is 1075.1μ sec. Thus, the optimum value for the number of packets is the number of bits with each packet contains just 1 bit. It is important to highlight that, at the switch, three tasks are done simultaneously; receiving a packet from the sender on one end, processing the packet and retransmitting the packet on the other end of the switch. Also, the switch must have sufficient buffer capacity to store the incoming packets.

9. Consider a closed loop network with bandwidth 100 Mbps and a propagation speed of 2×10^8 meter per sec. What would be the circumference of the loop be to exactly contain one 250 byte packet, assuming nodes do not introduce delay. What would the circumference be if there was a node every 100m, and each node introduced 10 bits of delay?

   Solution: 250 byte packet is along the wire, i.e., 250 byte packet denotes the delay-bandwidth product. Given $DB = 250 \times 8 = 2000$ *bits*. We compute $t_{prop} = \frac{2000}{100 \times 10^6} = 20$ micro sec.

Let the circumference of the loop (the length of the cable) be x m.
$\frac{x}{2\times10^8} \times 100 \cdot 10^6 = 2000$

Distance (circumference) $x = 4000\ m$
Solution to Part 2: Let x be the circumference. Since a node is introduced for every 100m, the number of nodes $= \frac{x}{100}$.
The number of bits in total in all nodes $= \frac{x}{100} \times 10$
The number of bits in the wire $= 250 \times 8 - \frac{x}{100} \times 10$
Equating the number of bits in the wire and the DB product, we get
$100 \times 10^6 \times \frac{x}{2\times10^8} = 2000 - \dfrac{x}{10}$
$x = 3333\ m.$
Aliter: Solution for Part 2 In Part 1, assume that a node is introduced for every 100m and the node holds 0 bits. 2000 bits are distributed in a wire of length 4000 m. Thus, in 100m, 50 bits are distributed. i.e., in every 100m, we find 50 bits. Now, the node placed at 100^{th}m introduces a 10 bit delay. Thus, for every 100m, there are 60 bits. Now, what should be the length of the cable for 2000 bits.
60 bits $\rightarrow$ 100 m
2000 bits $\rightarrow$ x m
$x = \frac{2000\times100}{60} = 3333$ m.

Inference from the above calculations: We discussed two solutions to Part 2 and in both, we implicitly assumed that 60 bits for every 100 m cable. i.e., 0.6 bits for 1 m. This is **incorrect** as 10 bits are with the node itself and the rest (50 bits) alone is distributed along 100 m cable. The calculations presented above do not distinguish this fact leading to incorrect solutions. In fact, the last cable (the cable connecting the last node and the first node) need not contain 50 bits. As per the above calculation, if we place a node for every 100 m, then $\frac{3333}{100} = 33.33$. This implies that there are 34 nodes, 34 cables. Thus, the total number of bits is, $34 \times 10 + 33 \times 50 + 0.33 \times 50 = 2006.5$ bits, however, there are only 2000 bits on the wire. Note that the last cable contains 33% of 50 bits. The correct version is presented next.

Let the circumference be x m. Then, 2000 bits $= \lfloor \frac{x}{100} \rfloor \times 60 + 10 + (x \bmod 100) \times 50$.
Note: every 100 m contains $50 + 10$ bits. 50 bits on the wire and 10 bits on the node. In the above expression, the second component '10' is for the number of bits in the first node.

Simplifying, we get, $1990 = \lfloor \frac{x}{100} \rfloor \times 60 + (x \bmod 100) \times 50$.
The above expression works fine when $x = 3320$ m. i.e., there are $1+33 = 34$ nodes, $33+1 = 34$ cables and the last cable contains 10 bits.
Intuitively, the above expression works fine when $x = 3300 + y$ and $y < 100$. We should ensure that the x chosen is such that 1990 - $\lfloor \frac{x}{100} \rfloor \times 60$ leaves a value less than 50.
Conclusion: The correct value of x, the circumference of the loop is 3320 m.