KFUPM - COMPUTER ENGINEERING DEPARTMENT

COE-341 – Data and Computer Communication

ARQ Design Problems

<u>Problem 1 (Textbook problem 7.4):</u>

In the shown figure, frames are generated at node A and send to node C through node B. The following specifies the two communication links:

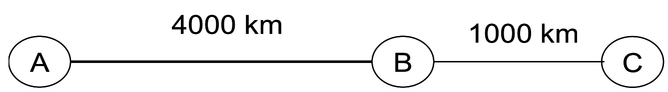
- The data rate between node A and node B is 100 kb/s
- The propagation delay is 5 μsec/km for both links
- Both links are full-duplex
- All data frames are 1000 bits long; ACK frames are separate frames of negligible length
- Between A and B sliding window protocol with a window size of 3 is used
- Between B and C, stop-and-wait is used.
- There are no errors (lost or damaged frames)

a) What is the minimum time on line AB for transmitting 3 frames and being able to transmit again?

b) Using the time window computed in part (a) determine the minimum rate required between nodes B and C so that the buffers of node B are not flooded.

Hint: In order not to flood the buffers, the average number of frames entering and leaving node B must be the same over a long interval.

c) What is the efficiency of the communication on EACH of the two links?



Solution:

Link AB: TframeAB = frame length / RAB = 1000/100 = 10 msec

TpropAB = 4000 km X 5 μsec = 20 msec

Link BC: TframeBC = frame length / RBC = x = unknown

TpropBC = 1000 km X 5 μsec = 5 msec

a) For link AB – WTframeAB = 3X10 = 30 msec, while TframeAB+2TpropAB = 10+2X20 = 50 msec ➔ WTframeAB < TframeAB+2TpropAB ➔ Utilization is less than 100% (i.e. node A has to wait for ACK From B to advance its transmit window)

Therefore, A can send three frames and be ready to transmit again after: TframeAB + 2 TpropAB = 10 + 2 X 20 = 50 msec

Hence the minimum time to transmit three frames and be ready to transmit again is 50 msec

b) One link BC: time, in milliseconds, to transmit one frame and be ready to transmit again = TframeBC + 2 X TpropBC = x + 10

Therefore the time, in milliseconds, to transmit three frames and be ready to transmit again is equal to = 3 (x + 10) = 3x + 30

In order to prevent flooding 50 ≥ 3x + 30, or x ≤ 6.666 msec

Therefore 1000 / RBC ≤ 6.666 ➔ RBC ≥ 150 kb/s

The minimum bit rate on link BC for preventing flooding of buffers is equal to 150 kb/s

c) Efficiency (utilization) of link AB: a = TpropAB/TframeAB = 20/10 = 2; W = 3

Since W < 2a + 1 ➔ Efficiency = W/(2a+1) = 3/(2X2+1) = 60%

Efficiency (utilization) of link BC: a = TpropBC/TframeBC = 5/6.666 = 0.75;

➔ Efficiency = 1/(2a+1) = 1/(2*0.75+1) = 40%

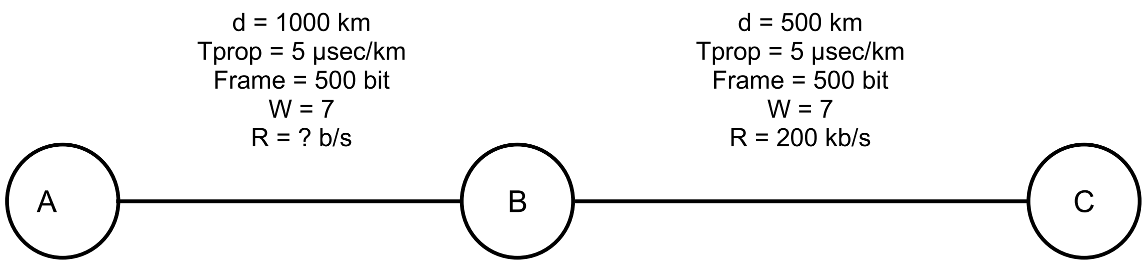
Problem 2:

It is desired to DESIGN a communication link from Qaurayyat (A) to Riyadh (B) and from Riyadh (B) to Dammam (C). The figure below shows three nodes: A, B, and C connected using two links. If links AB and BC both operate sliding window control protocols with $W = 7$.

a) (100 point) What is the maximum data rate, *R_AB*, for link Qurayyat-Dammam such that the receive buffer at Riyadh node does NOT overflow.

Assume: all links operate full-duplex lines and error free channels. Furthermore, ACK frames are separate frames of 100 bits in length and the processing time for data or acknowledgment frames require 0.5 milliseconds each.

b) (50 point) Repeat the problem assuming the link bit rate from Riyadh to Dammam is 400 kb/s



Solution:

<u>For buffer of node B not to overflow ➔ incoming frames/second on link AB should be less or equal to outgoing frames/second on link BC</u>

a) For link BC: Tf_{BC} = 2.5 msec, $Tprop_{BC}$ = 2.5 msec, $Tproc_{BC}$ = 0.5 msec, $Tack_{BC}$ = 0.5 msec, W_{BC} = 7

$W_{BC} X Tf_{BC}$ = 7X5 = 17.5 msec,

$Tf_{BC}+2Tprop_{BC}+2Tproc_{BC}+Tack_{BC}$ = 2.5+2*2.5+2*0.5+0.5 = 9 msec

➔ $W_{BC} X Tf_{BC} > \{Tf_{BC}+2Tprop_{BC}+2Tproc_{BC}+Tack_{BC}\}$ → U_{BC} = 100% (Transmission on link is continuous)

$Throughput_{BC}$ = R_BC/500 = 400 frame/sec

For link AB – The rate R_AB (in kilobits per second) is not known:

Tf_{AB} = 500/R_AB; $Tack_{AB}$ = 100/R_AB; $Tprop_{AB}$ = 5 msec, $Tproc_{AB}$ = 0.5 msec; W_{AB} = 15

$W_{AB} X Tf_{AB}$ = 7*500/R_AB,

$Tf_{AB}+2Tprop_{AB}+2Tproc_{AB}+Tack_{AB}$ = 500/R_AB + 2*5 + 2*0.5 + 100/R_AB;

If ($W_{AB} X Tf_{AB} > Tf_{AB}+2Tprop_{AB}+2Tproc_{AB}+Tack_{AB}$) ➔ U_{AB} = 100%, and

$Throughput_{AB}$ = R_ABX1000/500 frames/sec (1)

If ($W_{AB} X Tf_{AB} < Tf_{AB}+2Tprop_{AB}+2Tproc_{AB}+Tack_{AB}$)

➔ $U_{AB} = W_{AB} X Tf_{AB} / \{Tf_{AB}+2Tprop_{AB}+2Tproc_{AB}+Tack_{AB}\}$, or

$Throughput_{AB} = U_{AB}$XR_ABX1000/500;
(2)

Figure 1 shows the throughput of link AB (i.e. plot of equations (1) and (2)) versus values of R_AB.

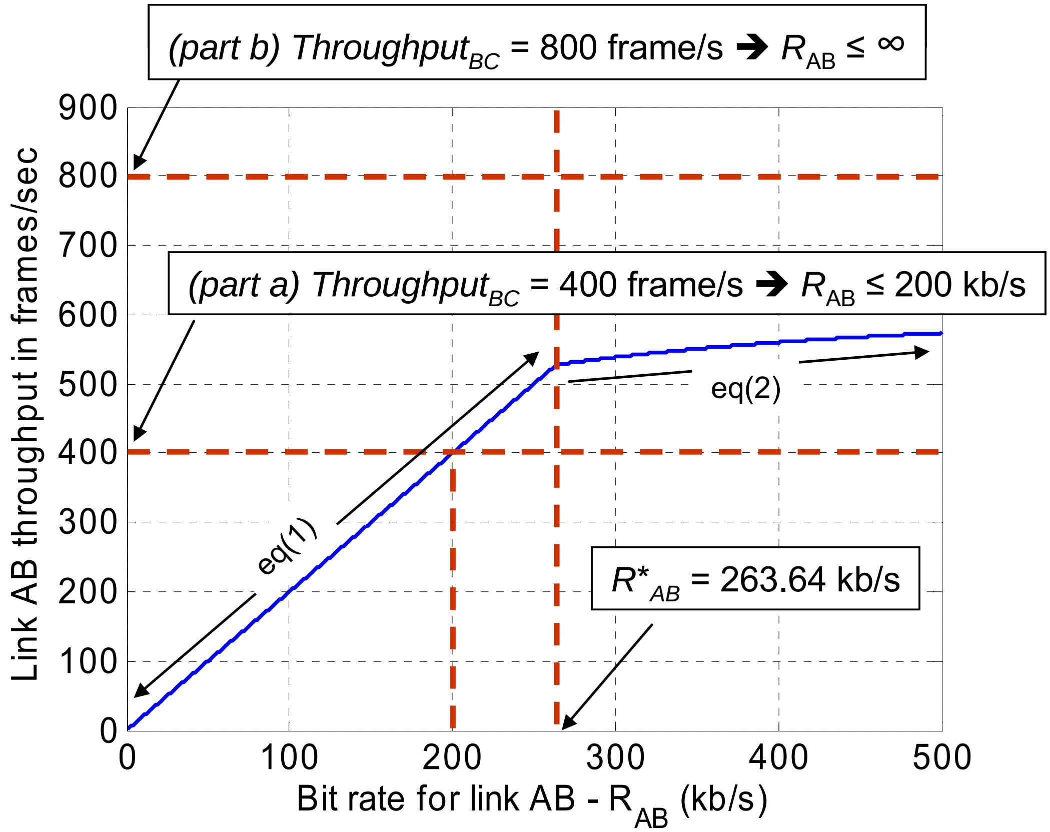


Figure 1: Link AB throughput in frames per second as a function of the link bit rate R_{AB} (kb/s).

The point corresponding to R*_AB can be obtained as follows:

$W_{AB} X Tf_{AB} = Tf_{AB} + 2Tprop_{AB} + 2Tproc_{AB} + Tack_{AB}$

➔ 7*500/R_AB = 500/R_AB + 2*5 + 2*0.5 + 100/R_AB ➔ R_AB = 263.64 kb/s

The matlab code used in producing the throughput curve is listed in Figure 2.

(a) For buffers of node B not to overflow, throughput of link AB should not exceed 400 frames/sec → equ(1) applies

i.e. R_AB*1000/500 ≤ 400 ➔ **R_AB ≤ 200 kb/s**

(b) When R_BC = 400 kb/s ➔ Still U_{BC} = 100%, and

$Throughput_{BC}$ = R_BC/500 = 800 frames/sec

For link AB, the maximum link throughput, Thr_{AB_∞}, in frames per second (i.e. when R_AB = ∞) can be computed by Lim {U_{AB}xR_ABx1000/500} as R_AB → ∞, i.e.

$Thr_{AB\_\infty} = W_{AB} x500/R\_AB/\{500/R\_AB + 2Tprop_{AB} + 2Tproc_{AB} + 100/R\_AB\} xR\_ABx1000/500$

$= W_{AB} x1000/\{600/R\_AB + 2Tprop_{AB} + 2Tproc_{AB}\}$

= 636.36 frames/sec as R_AB → ∞

i.e. Link AB can never have a frame throughput higher than 636.36 frames/sec

Therefore, R_AB can be as high as possible, or ➔ **R_AB ≤ ∞ kb/s**

```
clear all
LineWidth = 2;
FontSize = 14;
Tprop = 5;  % all in msec - R in kilobits
Tproc = 0.5;
Frame = 500;
ACK   = 100;
W  = 7;
R    = 1:1:500;
Tf   = Frame./R;
Tack = ACK./R;
R_Star = (W*Frame - (Frame+ACK))/(2*Tprop+2*Tproc);
fprintf('For R < [%7.2f]: Link U < 100%%\n',R_Star);
fprintf('For R > [%7.2f]: Link U == 100%%\n',R_Star);
Tframe = Frame./R;
Tack   = ACK./R;
U = min(ones(size(R)), W*Tframe./(Tframe+2*Tprop+2*Tproc+Tack));
for i=1:length(R);
end
Thr = U.*R*1000/Frame;
figure(1);
h = plot(R, U);
set(h, 'LineWidth', LineWidth);
set(gca, 'FontSize', FontSize);
xlabel('Bit rate for link AB - R_{AB} (kb/s)');
ylabel('Link AB Utilization');
grid on
figure(2);
h = plot(R, Thr);
set(h, 'LineWidth', LineWidth);
set(gca, 'FontSize', FontSize);
xlabel('Bit rate for link AB - R_{AB} (kb/s)');
ylabel('Link AB throughput in frames/sec');
```

Figure 2: Matlab code for producing throughput curve in Figure 1.