Question 2

Denote the first and second transmitted packets by A and B, respectively. In addition, for packet X (either A or B) and node W (either server, router, or client), let

- $t(X \text{ in } W) =$ time last bit of packet X arrives at the input queue of node W
- $t(X \text{ out of } W) =$ time last bit of packet X leaves node W, and
- $t(X \text{ queueing in } W) =$ queueing time of packet X in node W.

Thus,

$$\begin{aligned}
t(A \text{ in router}) &= L/R_s + d_{prop} \\
t(A \text{ out of router}) &= L/R_s + d_{prop} + L/R_c \\
t(A \text{ in client}) &= L/R_s + L/R_c + 2d_{prop} \\
t(B \text{ in router}) &= 2L/R_s + d_{prop} \\
t(B \text{ in client}) &= 2L/R_s + t(B \text{ queueing in router}) + L/R_c + 2d_{prop}
\end{aligned}$$

a) If $R_s < R_c$ then

$$\begin{aligned}
t(B \text{ queueing in router}) &= \max\left(0, t(A \text{ out of router}) - t(B \text{ in router})\right) \\
&= 0
\end{aligned}$$

and the inter-arrival time at the client $= L/R_s$.

b) If $R_s > R_c$ then queueing occurs since

$$\begin{aligned}
t(B \text{ queueing in router}) &= t(A \text{ out of router}) - t(B \text{ in router}) \\
&= L/R_c - L/R_s \\
&> 0.
\end{aligned}$$

c) If server sends second packet T seconds after sending A then

$$\begin{aligned}
t(B \text{ in router}) &= T + 2L/R_s + d_{prop} \\
t(B \text{ queueing in router}) &= \max\left(0, t(A \text{ out of router}) - t(B \text{ in router})\right) \\
&= \max\left(0, L/R_c - T - L/R_s\right).
\end{aligned}$$

So, $T = L/R_c - L/R_s$ suffices to ensure no queueing of B.
