7 Concurrent and Distributed Systems (rmm1002)

(*a*) In the Network Time Protocol (NTP), a client (C) and a server (S) exchange (request, reply) messages to compute corrections to the time at C. Assume the time at S is always correct, and that C is synchronised to S at 13:30:00.

(*i*) Thirty days later the time at S is again 13:30:00 but C now believes the time to be 13:28:30. Define and compute *skew* and *drift* for C. [2 marks]

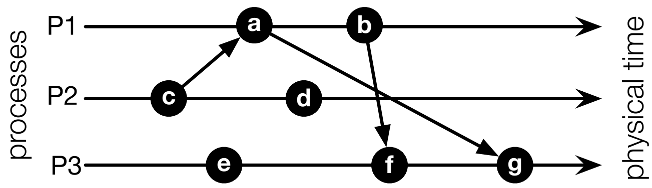
(*ii*) NTP estimates the *offset* and *delay* using four timestamps (T_0, T_1, T_2, T_3) from a request-reply message exchange. Two such exchanges occur between C and S, producing timestamps $(310.000, 400.100, 400.102, 310.202)$ and $(311.000, 401.150, 401.160, 311.410)$ respectively, denoting all timestamps as seconds since a common fixed point. Show on a diagram the point in the message exchange at which each timestamp $T_0 \ldots T_3$ is taken. Give definitions for *offset* and *delay*, and compute both for each set of timestamps. Which of the two offsets you have computed would you prefer to use to adjust the time at C, and why? [5 marks]

(*iii*) What happens to your estimates of offset and delay if network delays are no longer symmetric? [2 marks]

(*b*) It is often necessary to agree only on the *ordering* of events, not their times.

(*i*) $x \rightarrow y$ indicates event x *happens-before* event y. Define *happens-before*. Explain why it provides only a partial order on events. [2 marks]

(*ii*) *Vector clocks* can be used to implement *happens-before*. Give the vector clock values at each event, $a \ldots g$, and explain whether each of the following relations is true or false: $b \rightarrow c$, $c \rightarrow e$, $c \rightarrow f$, $d \rightarrow g$. If false, give the relation that does hold between the given pair of events.



[8 marks]

(*iii*) An earlier approach used *Lamport Clocks*, defining $L(x)$ such that, for two events x and y, $x \rightarrow y \Rightarrow L(x) < L(y)$ but $L(x) < L(y) \not\Rightarrow x \rightarrow y$. Explain how vector clocks resolve this issue and ensure $L(x) < L(y) \Rightarrow x \rightarrow y$.

[1 mark]