Clock Synchronization

Clock Synchronization

- Multiple machines with physical clocks. How can we keep them more or less synchronized?
- Internal vs. External synchronization
- Perfect synchronization not possible because of communication delays
- Even synchronization within a bound can not be guaranteed with certainty because of unpredictability of communication delays.
- But still useful !! Ex. – Kerberos, GPS

How clocks work

- Computer clocks are crystals that oscillate at a certain frequency
- Every H oscillations, the timer chip interrupts once (clock tick). No. of interrupts per second is typically 18.2, 50, 60, 100; can be higher, settable in some cases
- The interrupt handler increments a counter that keeps track of no. of ticks from a reference in the past (epoch)
- Knowing no. of ticks per second, we can calculate year, month, day, time of day etc.

Clock Drift

- Unfortunately, period of crystal oscillation varies slightly
- If it oscillates faster, more ticks per real second, so clock runs faster; similar for slower clocks
- For machine p, when correct reference time is t, let machine clock show time as $C = C_p(t)$
- Ideally, $C_p(t) = t$ for all p, t
- In practice,

$$1 - \rho \leq dC/dt \leq 1 + \rho$$

- ρ = max. clock drift rate, usually around 10^{-5} for cheap oscillators
- Drift => Skew between clocks (difference in clock values of two machines)

Resynchronization

- Periodic resynchronization needed to offset skew
- If two clocks are drifting in opposite directions, max. skew after time t is $2 \rho t$
- If application requires that clock skew < δ, then resynchronization period

$$r < \delta /(2 \rho)$$

- Usually ρ and δ are known

Cristian's Algorithm

- One m/c acts as the time server
- Each m/c sends a message periodically (within resync. period r) asking for current time
- Time server replies with its time
- Sender sets its clock to the reply
- Problems:
  - message delay
  - time server time is less than sender's current time

- Handling message delay: try to estimate the time the message with the timer server's time took to each the sender
  - measure round trip time and halve it
  - make multiple measurements of round trip time, discard too high values, take average of rest
  - make multiple measurements and take minimum
  - use knowledge of processing time at server if known
- Handling fast clocks
  - do not set clock backwards; slow it down over a period of time to bring in tune with server's clock

Berkeley Algorithm

- Centralized as in Cristian's, but the time server is active
- time server asks for time of other m/cs at periodic intervals
- time server averages the times and sends the new time to m/cs
- M/cs sets their time (advances immediately or slows down slowly) to the new time
- Estimation of transmission delay as before

External Synchronization

- Clocks must be synchronized with real time
- Cristian’s algorithm can be used if the time server is synchronized with real time somehow
- Berkeley algorithm cannot be used
- But what is “real time” anyway?

Measurement of time

- Astronomical
  - traditionally used
  - based on earth's rotation around its axis and around the sun
  - solar day : interval between two consecutive transits of the sun
  - solar second : 1/86,400 of a solar day
  - period of earth's rotation varies, so solar second is not stable
  - mean solar second : average length of large no of solar days, then divide by 86,400

- Atomic
  - based on the transitions of Cesium 133 atom
  - 1 sec. = time for 9,192,631,770 transitions
  - about 50+ labs maintain Cesium clock
  - International Atomic Time (TAI) : mean no. of ticks of the clocks since Jan 1, 1958
  - highly stable
  - But slightly off-sync with mean solar day (since solar day is getting longer)
  - A leap second inserted approx. occasionally to bring it in sync. (so far 32, all positive)
  - Resulting clock is called UTC – Universal Coordinated Time

- UTC time is broadcast from different sources around the world, ex.
  - National Institute of Standards & Technology (NIST) – runs radio stations, most famous being WWV, anyone with a proper receiver can tune in
  - United States Naval Observatory (USNO) – supplies time to all defense sources, among others
  - National Physical Laboratory in UK
  - GPS satellites
  - Many others

NTP : Network Time Protocol

- Protocol for time sync. in the internet
- Hierarchical architecture
  - primary time servers (stratum 1) synchronize to national time standards via radio, satelite etc.
  - secondary servers and clients (stratum 2, 3,…) synchronize to primary servers in a hierrachical manner (stratum 2 servers sync. with stratum 1, startum 3 with stratum 2 etc.).

- Reliability ensured by redundant servers
- Communication by multicast (usually within LAN servers), symmetric (usually within multiple geographically close servers), or client server (to higher stratum servers)
- Complex algorithms to combine and filter times
- Sync. possible to within tens of milliseconds for most machines
- But, just a best-effort service, no guarantees
- RFC 1305 and www.eecis.udel.edu/~ntp/ for more details