Dissemination Techniques for UTC(k)

Judah Levine
Time and Frequency Division
NIST/Boulder
jlevine@boulder.nist.gov
Outline

- Requirements of a time service operated by a timing laboratory
- The error budget for time dissemination
- Description of methods with examples – advantages and limitations
Requirements - 1

- Integrity
  - Time signals must be protected so they are not modified or changed during transmission
  - Easy:
    • Telephone service
    • Radio broadcast service
    • Authenticated Internet service
  - Hard:
    • Normal Internet services
Requirements - 2

- **Availability**
  - Service should not have single point of failure
    - Multiple sources at different locations
  - Minimize Time to Repair
  - Balanced with Cost
Requirements - 3

- **Accuracy**
  - Service should transmit UTC(lab) only when operating correctly
  - Should transmit nothing or error message when failed
Requirements - 4

- **Technical Traceability**
  - Each link between user and UTC should be calibrated with delay and uncertainty
    - Magnitude consistent with user requirements

- **Legal Traceability**
  - Traceability can be documented and proven in legal proceedings
    - Log files and documents show proper operation and also errors

- **Users are responsible for traceability with assistance from timing laboratory**
The Error Budget

- Internal accuracy of the time source
  - Usually not the limiting factor
- The transmission delay
  - This is usually the hard part
  - Uncertainty often limits traceability
- Statistics of the user’s clock and the measurement process
  - Is calibration interval consistent with accuracy requirement?
Methods of Time Dissemination

- Simple one-way method
- One-way method with model of delay
- Common-view
- Partial two-way method
- Full Two-way method
Simple one-way method - 1

- Ignore network delay completely
  - Delay $<<$ required accuracy

- Simple broadcasts
  - Low-frequency services (WWVB, ...)
    - 60 kHz, 2 $\times$ 50 kW covers most of US
  - Short-wave services (WWV, ...)
    - 2.5 MHz, 5 MHz, ... delay, coverage variable
  - Internet service in broadcast mode (NTP)
    - Delay, coverage very variable
Simple one-way method - 2

- Simple receiver and transmitter
- Transmission cost does not depend on number of receivers
- Receiver is passive
- Timing error < 1 s, often < 20 ms
- Traceability possible with *adequate* log files
Common-view method

Path delays are nearly equal and cancel in the difference.

Source clock cancels too.

Source

The time is $S$

$\Delta t = T_1 - T_2 = t(1) - t(2)$

$T_1 = t(1) - (S + \delta)$

$T_2 = t(2) - (S + \delta)$

Rcvr 1

Rcvr 2

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Common View Sources

- Television Broadcasts
  - Synchronization pulse in blank line
- FM radio signals
  - Stereo sub-carrier
- Phase of mains voltage
  - Within building or small area
- Loran signals (no longer in US)
- Source is used passively at no cost
Partial two-way method

- Delay is stable and is white pm
  - Measure only occasionally
  - Unique to PTP/1588
  - Useful only in special cases
Full Two-way

- Measure round-trip delay on every calibration
  - Delay is not stable and not white pm over longer periods
  - Transmission delay is one-half of measured value
    - Delay is symmetric on the average
- Telephone system using ACTS
- Internet using full NTP
Real-world limitations

- Inbound and outbound delays are not equal
  - Realized as a two-way physical circuit with some one-way components
    - Physical component dispersion
  - Realized with a reversible one-way physical circuit
    - Time dispersion
  - Realized using a packet network
    - Asymmetric queuing and routing delays
Effect of Asymmetry - 1

- Method assumes one-way delay is one-half of round-trip value. Time error is given by

\[ \epsilon = (k - 0.5)\Delta \]

\[ \Delta = \text{round trip delay} \]

\[ k = \text{outbound fraction} \]

\[ 0 \leq k \leq 1 \]
Effect of asymmetry - 2

Smaller delay has smaller asymmetry error

\[ k=0, \quad \varepsilon = -\Delta/2 \]

\[ k=1, \quad \varepsilon = \Delta/2 \]
NTP Service model

- Operate servers at many locations
  - Minimizes delay error for all users
  - No single point of failure
  - How are remote servers synchronized?
    - Time link to source of UTC(k)
- Performance limited by delay jitter and asymmetry
  - Few percent of round-trip measurement
    - Accuracy < 50 ms, often < 10 ms, maybe ~ 1 ms
Asymmetry – the bottom line

- Static asymmetry generally cannot be detected or removed
  - Limits accuracy of any protocol
  - Multiply-connected networks sometimes help in detecting asymmetry
Summary - 1

- One-way methods are simple and are good enough for many applications
  - Path delay can be ignored
  - Path delay can be modeled adequately

- Common-view depends on equality of delays along two one-way paths
  - Requires data exchange between stations

- Neither method can attenuate local effects
Summary - 2

- Two-way depends on equality of delay in opposite direction along a single path
- Limited by the symmetry of the link delay between the transmitter and the receiver
  - Magnitude of the delay not important
  - Message format not important
- Error in time data proportional to asymmetry and delay
  - Shorter paths will always have smaller errors
For more information

- List of publications of the NIST time and frequency division are in the publications menu of our web page: tf.boulder.nist.gov
- Many of these publications are on-line