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Update of Network Time Mechanisms for Improving Computer Clock Accuracy

draft-marlow-tictoc-computer-clock-accuracy-01.txt

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Introduction

- draft-marlow-tictoc-computer-clock-accuracy-00.txt was discussed at Internet Engineering Task Force 80 and 81 and through the Timing over IP Connection and Transfer of Clock (TICTOC) mail list
- New mechanisms beyond those identified in Network Time Protocol v4 (NTPv4) Standard (RFC5905) to provide increased time synchronization accuracy for operating system clocks' time and frequency
  - By providing improved estimates when a packet is put on the network, transferred across a network, or taken from the network
- The Internet-Draft identifies a set of candidate mechanisms for experimentation and standardization
- Experimentation performed at Naval Surface Warfare Center, Dahlgren Division (NSWCDD) and experiments described in Dr. Mills' book
  - (Mills, David, L., 2011, "Network Time Synchronization—the Network Time Protocol on Earth and in Space, Second Edition", CRC Press)

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Version 01 Updates

- **Security and network robustness added to performance as primary goals**
  - **Candidate mechanisms need to provide a particular level of performance while working through a particular set of security hazards and network errors**
  - **The difference in security and network robustness needed to operate on the Internet versus on a protected private network**
- **Network Time Protocol (NTP) interleaved standards action decision expanded beyond accuracy potential benefits**
  - **Reference Dr. Mills' statement about the NTP interleaved benefit with longer protocol data units (e.g., to support server authentication)**
  - **Ability to gain measurement data via Interleaved Symmetric mode**

Version 01 Updates (Cont'd)

- Future development of a set of common metrics and/or a benchmark methodology ID
- Need for more data and guidance in selecting NTP operational modes
  - Tradeoffs between Client/Server and Interleaved Broadcast modes
  - Use of Interleaved Symmetric mode to provide accuracy vs. additional measurement data
- Analysis of the experiments and those described in Dr. Mills' book

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Approach

- Examine methods for improving NTPv4 time synchronization performance within a security threat and/or network error context
- Solicit comments and contributions on mechanisms described and on additional mechanisms that should be considered
- Discuss conclusions to motivate standardization and experimentation
  - Depending on the standardization difficulty and potential benefits offered, potentially recommend more than one standardization action

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Use Case Targeted

- A dense concentration of computing elements connected by a network
- A satellite-based time source (i.e., GPS) is used for synchronizing primary time servers
- Secondary time servers and leaf computing elements are synchronized to the primary time servers over the network
- In this use case there are
  - Approximately 150 computers where there are 3 to 4 levels of time servers
  - Time servers may have to communicate to each other through layer 2 and layer 3 network switches (could be 10 to 20 different layer 2 subnetworks)
  - All computers connected together through gigabit or faster network connections
  - Some groups of computers will need to synchronize to each other to within a microsecond
  - Other groups of computers only have to be synchronized to each other to within a millisecond
- There is one interconnected time synchronization scheme where NTP, Precision Time Protocol (PTP) , or a combination of both is used to meet all time synchronization needs

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Mechanisms Considered

- **NTP Interleaved**
  - An extension of the NTPv4 protocol included in the current NTP distribution
  - Uses an Institute of Electrical and Electronics Engineers (IEEE) 1588 PTP-like feature that provides a follow-up packet with a better estimate of when a previous NTP packet was sent on the network and a message exchange sequence to determine network mean path delay
  - Designed to be backward compatible with earlier NTP versions
- **Use of IEEE 1588 PTP and 802.1AS, "Mechanisms in the Underlying Network Service" (e.g., Network Interface Controller [NIC])**
  - Determine if using special capabilities in the underlying network service can improve NTP timestamp estimates
  - Need security and/or network robustness considered

Mechanisms Considered (Cont'd)

- **IEEE 1588 PTP to synchronize computer clocks**
  - **Considers bringing the IEEE 1588 synchronization all the way to the computer clock through a standardized clock discipline algorithm**
    - **Use PTP as the means of obtaining extremely accurate time information from across the network**
    - **Use NTP algorithms to keep local clocks synchronized**
    - **Need security and/or network robustness considered**
  - **Computing elements synchronized by IEEE 1588 are candidates to be time servers (by the use of NTP) for computing elements not synchronized by IEEE 1588**

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Initial Experimentation

- **Previous experiments were run to test Interleaved modes available in NTP v4.2.6**
  - **Two clients used Interleaved Broadcast mode; average offset = 9 usec, std. dev. = 8 usec**
  - **Two clients used unicast client/server mode; average offset = 11 usec, std. dev. = 10 usec**
  - **Two clients used normal broadcast mode; average offset = 49 usec, std. dev. = 58 usec**
  - **Results showed that Interleaved Broadcast mode results slightly better than unicast client/server results**

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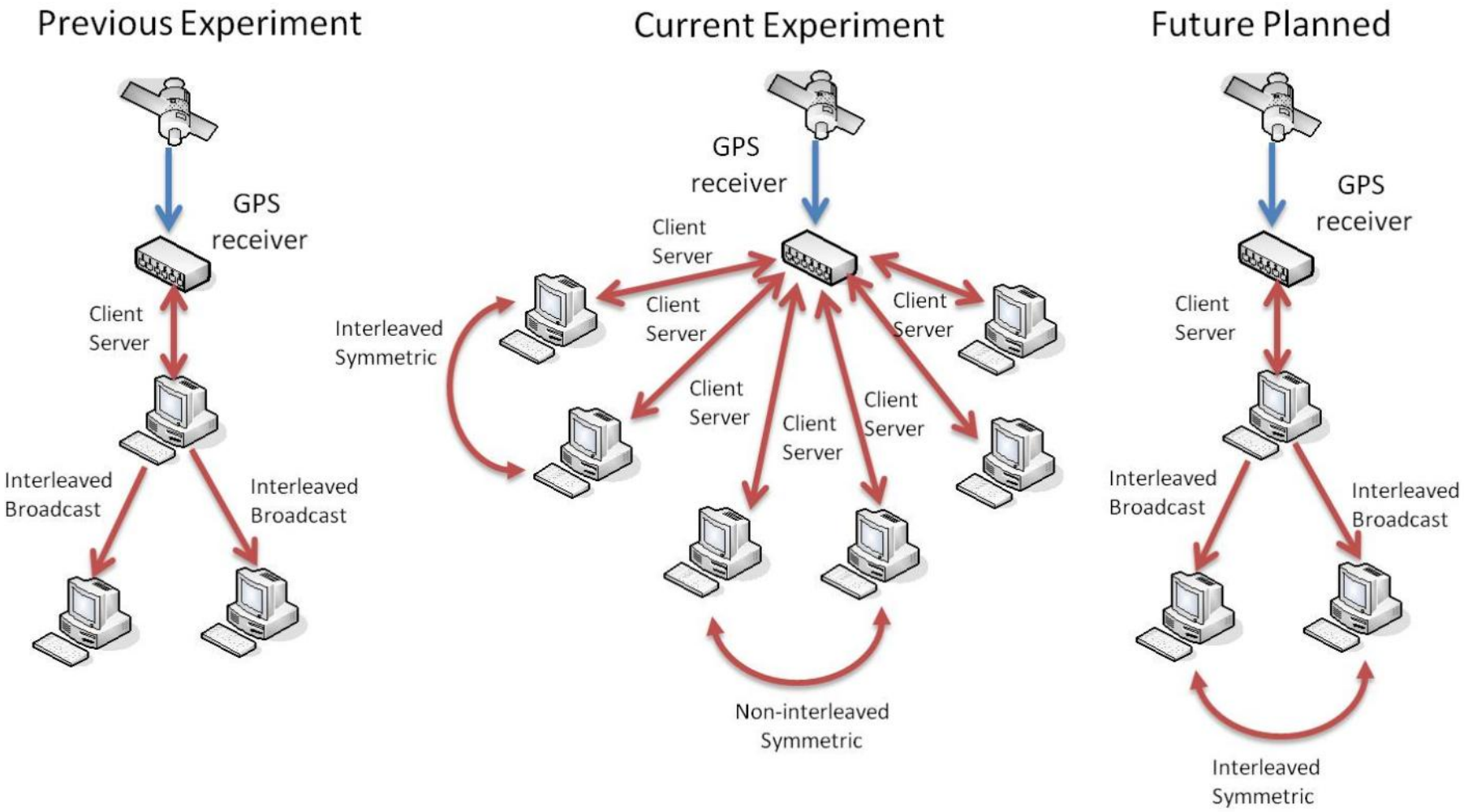
Initial Experimentation (Cont'd)

- Currently testing using Interleaved Symmetric mode with unicast client/server, similar to Dr. Mills' testing
  - In one experiment, six hosts synchronize to a stratum 1 server by way of the unicast client/server mode
    - Two clients peer with each other using Interleaved Symmetric mode
    - Two clients peer with each other using normal symmetric mode
    - Two clients do not peer with anyone else
  - In a second experiment, two clients synchronize with a stratum 2 server through the Interleaved broadcast mode
    - Clients peer with each other using Interleaved Symmetric mode
    - Results will be compared with Interleaved Broadcast results mentioned above
- Preliminary experiments with hardware-based PTP have been performed in the past where average offsets between PTP NICs and the PTP Grandmaster clock are in the hundreds of nanoseconds with standard deviations in the tens of nanoseconds

Initial Experimentation (Cont'd)



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Future Experimentation

- **Further work is needed to ensure valid offset measurements**
  - **The use of "ntpdate" may not be a valid way to accurately measure clock offsets; ntpdate makes measurements across the network and is also susceptible to errors caused by variations in network delay**
  - **Explore an out-of-band measurement technique**
- **Perform future experiments to measure the resiliency of the NTP interleaved while under network and processor load**
  - **Expand upon Dr. Mills' experiments**
  - **Compare results to other time synchronization methods**

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Future Experimentation (Cont'd)

- **Conduct experiments to determine how performance is affected when a more complex network configuration is used**
  - **Experiments up until now have been conducted in a configuration in which test workstations were connected to the same network switch**
- **Need for more data and guidance in selecting NTP operational modes**
  - **Tradeoffs between Client/Server and Interleaved Broadcast modes**
  - **Use of Interleaved Symmetric mode to provide accuracy vs. additional measurement data**

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Metrics/Benchmarking

- In working on the experiments and analysis, it became clear that a standard that defines time synchronization performance metrics is needed
  - Such a standard would enable better comparisons between the mechanisms considered
  - In addition to same definitions of the metrics used, better agreement should be obtained in experiments being conducted by different organizations
- Initiating work on a benchmarking methodology for network time offset performance ID appears to be the best path forward

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Analysis of Results

- **Analyzed NSWCDD and Dr. Mills' experiments**
  - **In NSWCDD experiments, Interleaved Broadcast was roughly 10 microseconds offset**
  - **Dr. Mills' lightly loaded experiment (backroom LAN) was ~3x greater**
- **This difference in offset could be caused by differences in**
  - **The size of the PDUs sent (backroom LAN used Autokey for all interleaved operations; greatly increases the PDU sizes)**
  - **The clients' processing power**
  - **The client and server operating systems**

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Conclusions

- Conclude interleaved capability can provide improvement to the accuracy achieved with NTPv4 standard's mechanism
  - Potential benefit with large PDU sizes (e.g., time server authentication)
  - Additional measurement data
  - Modest benefit with small PDU sizes
  - Recommend adding as option to NTPv4 standard
- Recommend that the other two mechanisms described in the draft be pursued in parallel through experimentation; NTP interleaved cannot provide accuracies in the range that PTP with hardware assists can
  - Need security and/or network robustness considered
- Develop a standard to define time synchronization performance metrics for network time synchronization devices that allows different experimental efforts be conducted in a way that results are comparable

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Backups

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Motivation for Increased Performance

- **Reasons to improve upon current NTP time synchronization performance:**
  - **Increased performance for existing product designs**
  - **New uses not currently available**
    - **Similar to how network speeds are increased every several years, and uses for increased network bandwidth soon follow**
- **Current methods to increase time synchronization performance involve**
  - **Use of a technology separate from the existing computer network (e.g., Inter-Range Instrumentation Group technology)**
  - **Use of PTP technology as defined in IEEE 1588 standard**

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Motivation for Increased Performance (Cont'd)

- With PTP, applications must interface with installed PTP hardware to read time from its oscillator
- NTP resiliency does not exist in PTP hardware oscillator
- Unknown results to time provided by PTP hardware when network switch in network path to time source is temporarily unavailable
- Benefits of pairing NTP algorithm resiliency with highly accurate PTP hardware-based time distribution

NTP/PTP Commonalities

- Both are packet-based protocols for exchanging time with time server over a computer network
- Both determine offset between two independent clocks
- Both implement a hierarchical tree structure for obtaining time from master time source through intermediary time sources to time clients
- Both assume symmetric network paths
- Both have unique methods for addressing asymmetric network delays

NTP/PTP Differences

- PTP uses hardware to measure delays as packets traverse intermediate network devices and corrects its received time information based upon those measured delays
- Because PTP has the ability to measure actual packet delays and correct for them, PTP can provide the most accurate measurement of clock offset between two clocks
- PTP does not define the method for synchronizing that clock once highly accurate time measurements have been obtained

NTP/PTP Differences (Cont'd)

- PTP is normally used to synchronize a hardware clock located on interface card and does not synchronize operating system clock
  - NTP possesses ability to synchronize operating system clock based on received clock offset measurements
- The NTP algorithms have a substantial resiliency so that operating system clocks remain stable despite network conditions
- NTP uses its algorithms to determine which of several consecutive time measurements are most accurate and uses that measurement