Assumptions for Sources of Time Synchronization Error in IEEE 802.1AS
Rev 04

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Introduction

- This presentation provides a summary of assumptions pertaining to sources of error in 802.1AS time synchronization
  - A network that satisfies these assumptions will be capable of meeting the desired time synchronization accuracy of 1 μs over a maximum of 7 hops (see next slide for references for these assumptions)
- This work was requested in the April 30, 2007 AVB timing call, after an initial discussion of sources of error based on [2]

Assumptions Relevant to AVB Time Synch

❑Network diameter

- Maximum diameter of any spanning tree of the network is 7 hops
  - This includes end stations
  - This is a long-standing assumption for AVB, based on expected applications
  - See the master list of AVB assumptions [1] for more detail and background

❑Local oscillator quality

- $\pm$100 ppm or better free-run accuracy
- Rate for 100 Mbit/s Ethernet is nominally 25 MHz
- Rate for GbE is nominally 25 MHz in some cases and nominally 125 MHz in some cases

❑PTP clock quality

- End-point time synchronization accuracy for steady-state operation is 1 μs or better (i.e., $\pm$ 500 ns) over 7 hops
  - i.e., any 2 PTP clocks separated by at most 7 hops differ by no more than 1 μs
  - This assumption is based on requirements for digital audio in AES11-2003 [3] (the assumption is restated in [1])

Assumptions Relevant to AVB Time Synch (Cont.)

- PTP clock quality (cont.)
  - End-point time synchronization accuracy during GM changes is TBD
    - The value will be determined from the following assumptions given in [1], once they are made more precise
      - Crystal drift $\leq$ 1 ppm/s (note that [1] gives 4 ppm/s, but other recent discussions have used 1 ppm/s)
      - Assuming no spanning tree reconfiguration, on grandmaster changeover, the time between the last Sync of the old grandmaster and the time of the 1st Sync of the new grandmaster (holdover time) plus the time from the 1st Sync of the new grandmaster until the clocks in the domain have settled, shall be less than 2 Sec. Goal < 200ms? – need a contribution
        - » Note: Spanning tree may cause additional settling time of several seconds
- Assumptions on ***steady-state*** error sources present in network, to meet the above time synchronization requirement for PTP clocks
  - Maximum frequency drift rate of local oscillator $\leq$ 1 ppm/s (see note above on crystal drift) (this assumption, combined with maximum frequency offset of $\pm$100 ppm, results in maximum time synchronization error due to this effect of $<$ 1 ns (see [2]))
    - Note that here we are considering steady-state phase error accumulation, not error accumulation during grandmaster change or network reconfiguration
  - Effect of frequency measurement granularity is negligible
    - e.g., if 32 bits is used to express the measured frequency offset, the maximum frequency error *due to this effect* is 2.3×10^{-10}

Assumptions Relevant to AVB Time Synch (Cont.)

- Assumptions on error sources present in network, to meet the above time synchronization requirement for PTP clocks (Cont.)
  - Effect of PHY latency asymmetry and phase measurement granularity for 100 Mbit/s Ethernet
    - Any PHY latency asymmetry can be known as part of the design and compensated for to within 18% of the maximum allowable PHY latency
    - This means that of the allowable PHY latency asymmetry of IEEE 802.3 for 100BASE-X (table 24-3, plus additional 16 ns; see [2]) of 476 ns per hop, the maximum remaining uncertainty after compensation is 86 ns/hop, or 602 ns for 7 hops
    - The cumulative time synchronization error due to phase measurement granularity over 7 hops is 280 ns (40 ns allowance per hop)
      - This assumes that the variation of this error is sufficiently fast that, with a Sync interval between 10 ms and 100 ms, the effect of this variation can be reduced by endpoint filtering
    - All the above error components, taken together, leave a margin relative to the total 1 μs of approximately 111 ns (11%)
      - i.e., (1000 ns) – (602 ns) – (280 ns) – (7 ns) = 111 ns

Assumptions Relevant to AVB Time Synch (Cont.)

- Assumptions on error sources present in network, to meet the above time synchronization requirement for PTP clocks (Cont.)
  - Effect of PHY latency asymmetry and phase measurement granularity for GbE, assuming a 25 MHz nominal frequency for the local oscillator
    - Any PHY latency asymmetry can be known as part of the design and compensated for to within 25% of the maximum allowable PHY latency
    - This means that of the allowable PHY latency asymmetry of IEEE 802.3 for 1000BASE-X (table 40-14, plus additional 16 ns; see [2]) of 344 ns per hop, the maximum remaining uncertainty after compensation is 86 ns/hop, or 602 ns for 7 hops
    - The cumulative time synchronization error due to phase measurement granularity over 7 hops is 280 ns (40 ns allowance per hop)
      - This assumes that the variation of this error is sufficiently fast that, with a Sync interval between 10 ms and 100 ms, the effect of this variation can be reduced by endpoint filtering
    - All the above error components, taken together, leave a margin relative to the total 1 μs of approximately 111 ns (11%)
      - i.e., (1000 ns) – (602 ns) – (280 ns) – (7 ns) = 111 ns

Assumptions Relevant to AVB Time Synch (Cont.)

- Assumptions on error sources present in network, to meet the above time synchronization requirement for PTP clocks (Cont.)
  - Effect of PHY latency asymmetry and phase measurement granularity for GbE, assuming a 125 MHz nominal frequency for the local oscillator
    - Any PHY latency asymmetry can be known as part of the design and compensated for to within 35% of the maximum allowable PHY latency
    - This means that of the allowable PHY latency asymmetry of IEEE 802.3 for 1000BASE-X (table 40-14, plus additional 16 ns; see [2]) of 344 ns per hop, the maximum remaining uncertainty after compensation is 120 ns/hop, or 840 ns for 7 hops
    - The cumulative time synchronization error due to phase measurement granularity over 7 hops is 56 ns (8 ns allowance per hop)
      - This assumes that the variation of this error is sufficiently fast that, with a Sync interval between 10 ms and 100 ms, the effect of this variation can be reduced by endpoint filtering
    - All the above error components, taken together, leave a margin relative to the total 1 μs of approximately 97 ns (10%)
      - i.e., (1000 ns) – (840 ns) – (56 ns) – (7 ns) = 97 ns

References

1. Don Pannell and Michael Johas Teener, *Audio/Video Bridging (AVB) Assumptions*, July, 2008 – Denver, CO (annotated Sept 2008 – Seoul, Korea) (available at http://www.ieee802.org/1/files/public/docs2008/avb-pannell-mjt-assumptions-0908-v17.pdf).
2. Geoffrey M. Garner, *Sources of Time Synchronization Error in IEEE 802.1AS*, April 29, 2007 (available at http://www.ieee802.org/1/files/public/docs2007/as-garner-error-sources-time-synch-0407.pdf).
3. AES11-2003, *AES Recommended Practice for Digital Audio Engineering – Synchronization of digital audio equipment in studio operations* (Revision of AES11-1997), Audio Engineering Society, Inc., 2003.