Time Stamp Accuracy needed by IEEE 802.1AS

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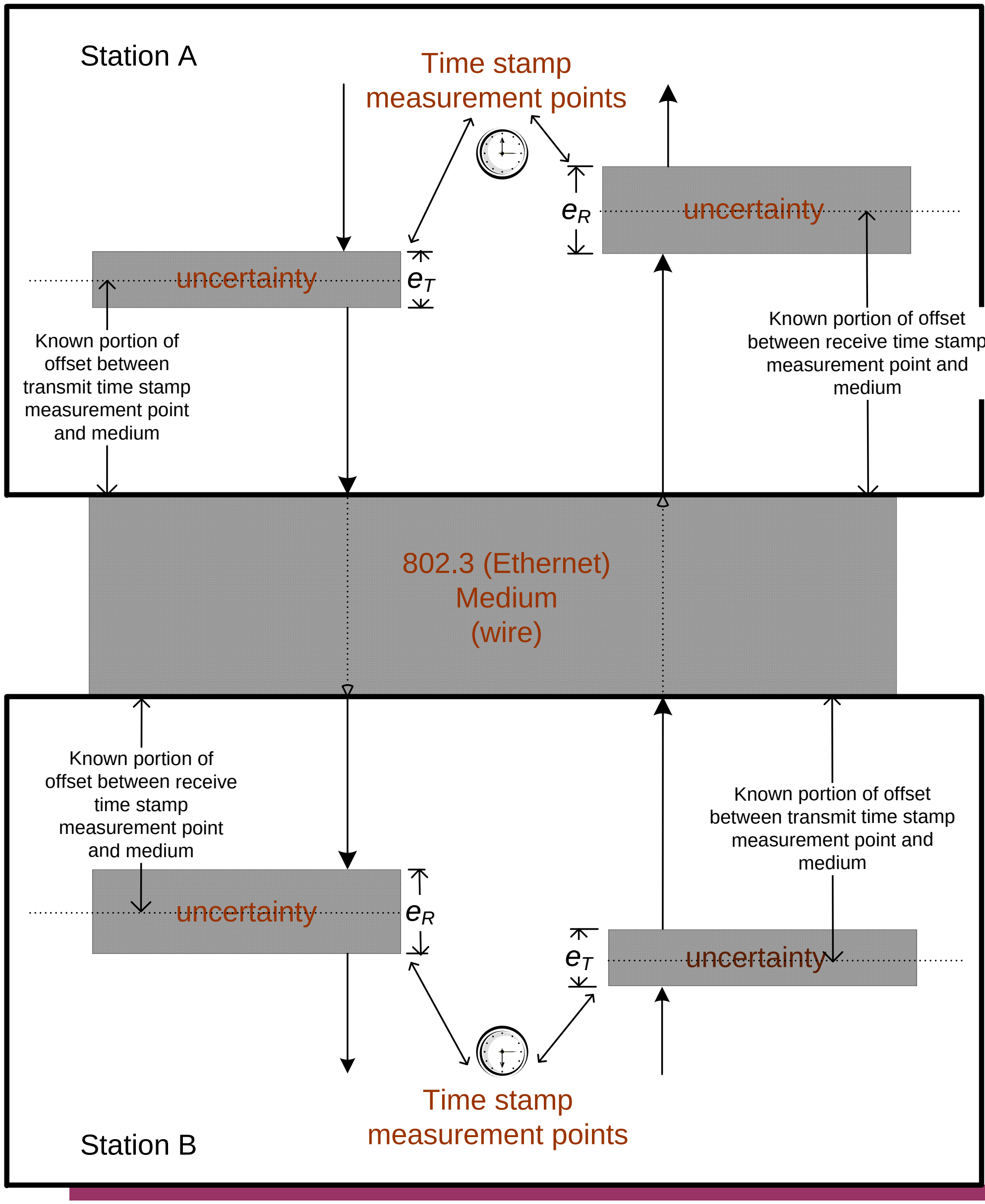
Introduction

- This presentation provides
  - A statement of the time stamp accuracy needed by IEEE 802.1AS
  - Background for this requirement
- Some of the material in this presentation has been presented previously, in somewhat different form, in Reference 1

Summary Statement

- IEEE 802.1AS needs the following time stamp accuracy
  - Transmit time stamp error $\leq e_T$
  - Receive time stamp error $\leq e_R$
  - $e_T + e_R \leq 48$ ns
  - 802.1AS does not care what the precise values of e_T and e_R are, as long as
    - whatever values are chosen apply to all PHYs
    - their sum does not exceed 48 ns
- The above is illustrated schematically on the next slide

Reference Points - 1



- ❑ Time stamp measurement point:
  - ▪ point in the protocol stack where the time stamp measurement is actually made
- ❑ It is desired to make the time stamp measurement at the interface to the medium
- ❑ If the time stamp measurement point is not at the interface to the medium, the difference between the time stamp measurement point and the interface to the medium may be measured in advance
  - ▪ this is the known portion of the difference between the time stamp measurement point and the interface to the medium

Reference Points - 2

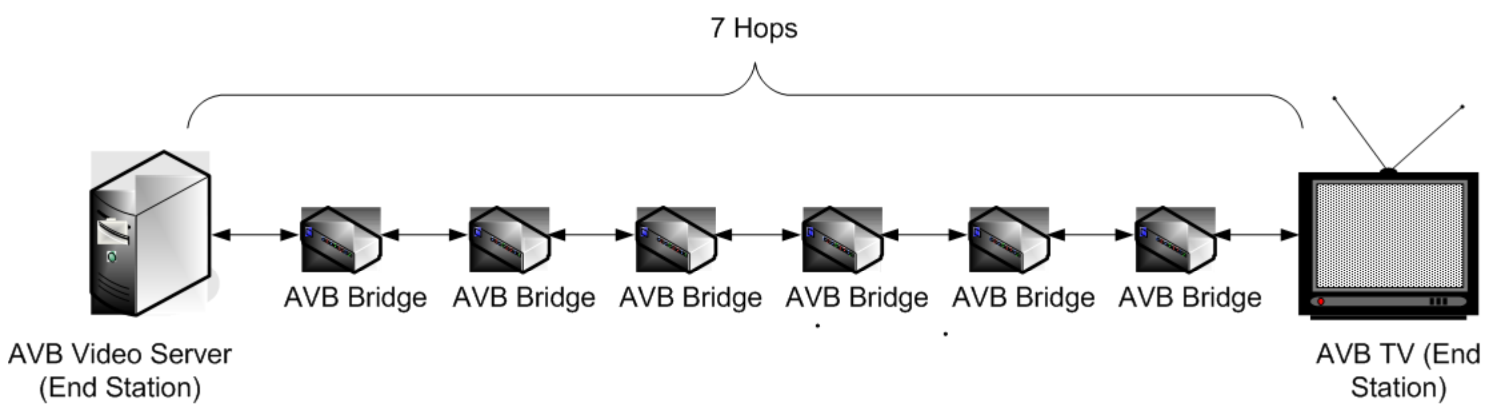
- The time stamp measurement is then corrected by this known portion of the difference between the time stamp measurement point and the interface to the medium
  - Note: for time synchronization, only the difference between the transmit and receive time stamp corrections is needed
    - The individual transmit and receive corrections may be needed for other purposes, e.g., measurement of link propagation delay
- The unknown portion of the difference between the time stamp measurement point and the interface to the medium is the uncertainty
  - $\pm e_T /2$ = transmit time stamp measurement uncertainty
  - $\pm e_R /2$ = receive time stamp measurement uncertainty
- e_T and e_R must be specified such that
  - they have fixed values
  - their sum does not exceed 48 ns

Reference Points - 3

- From the figure on the previous slide, the maximum asymmetry, i.e., maximum difference between the latency for transmission from station A to station B and the latency for transmission from station B to station A, is $\pm(e_T + e_R)$, or $\pm$48 ns
- The time error due to this asymmetry in latency in the two directions is one-half the asymmetry
  - i.e., $\pm(e_T + e_R)/2$, or $\pm$24 ns
- Note that the error for an actual PHY may be fixed (but unknown) or time varying

Background for the Time Stamp Accuracy Requirement - 1

- The time stamp accuracy requirement was arrived at by looking at the end-to-end network time synchronization requirement for Audio/Video Bridging (AVB), the AVB reference model, and the sources of time synchronization error
- AVB reference model
  - Synchronization is transported over a maximum of 7 hops
    - This includes both bridge-to-bridge and bridge-to-end-station hops (see below)
    - This is a long-standing assumption for AVB, based on expected applications
    - See the master list of AVB assumptions [2] for more detail and background



Background for the Time Stamp Accuracy Requirement - 2

- Desired PTP (i.e., 802.1AS) 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 [4] (the assumption is restated in [1])
    - AES11-2003 is a specification of the Audio Engineering Society, for synchronization of digital audio equipment for high-quality audio applications
    - The $\pm$500 ns synchronization requirement is intended to guarantee acceptable phase alignment of audio signals from multiple speakers in a room
      - "living room quality" audio, which is better than "telephone quality"
    - To achieve this, AES11-2003 requires that the time synchronization error be within $\pm$5%, or $\pm$18°, of the AES3 (i.e., digital audio) frame (see section 5.3.1.1 of [5])
      - For the 96 kHz frame rate, the time synchronization must be within $\pm$500 ns (see section 5.3.1.1 and Table 2 of [5])
- Assumptions on local oscillator quality
  - $\pm$100 ppm or better free-run accuracy
  - Rate for local oscillator is nominally 25 MHz
  - Crystal frequency drift $\leq$ 1 ppm/s (note that [2] gives 4 ppm/s, but other recent discussions in the AVB TG have used 1 ppm/s)

Background for the Time Stamp Accuracy Requirement - 3

- Sources of time synchronization error
  a) Phase measurement granularity, due to 40 ns granularity of local oscillator (note: a higher frequency oscillator is allowed, but not required)
  b) PHY latency and fiber latency asymmetry
  c) Accumulated phase error due to local oscillator frequency drift between phase measurement updates
  d) Granularity of measurement of nearest neighbor frequency ratio
- It is shown in Reference [3] and references cited there that the effect of (c) is negligible, i.e., is less than 1 ns, for the assumptions on crystal drift rate (see previous slide) and Sync message rates
- It is planned to use 32 bits to express measured frequency offsets, resulting in maximum frequency error of 2.3×10^{-10} ; therefore, the effect of (d) is negligible for inter-Sync message times of 1 s or less
- However, the effects of (a) and (b) are not negligible

Background for the Time Stamp Accuracy Requirement - 3

- For a maximum time synchronization error of 1 μs (i.e., ±500 ns) over 7 hops, an error of ±500 ns/7 = ±71 ns per hop would be allowed in worst case
  - This is for a worst-case condition, e.g., when the errors are static, or are slowly varying and beat slowly against each other
- The 40 ns phase measurement granularity results in a maximum latency measurement asymmetry of ±40 ns
- Then, the allowable error due to asymmetry due to PHY and fiber latency is ±31 ns/hop
- If a 10% margin is desired, i.e., ±7.1 ns/hop, then the allowable error due to asymmetry due to PHY and fiber latency is ±24 ns/hop
- This means that $\pm(e_T + e_R)/2 = \pm 24$ ns, or
  - $e_T + e_R = 48$ ns
- In other words
  - ±[(500 ns/7) – 40 ns – 7.1 ns] ≅ ±24 ns left for uncompensated PHY plus fiber asymmetry

References

1. Geoffrey M. Garner, *Assumptions for Sources of Time Synchronization Error in IEEE 802.1AS, Rev. 4*, prepared for January 5, 2009 802.1AS call.
2. 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).
3. 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).
4. 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.
5. AES3-2003, *AES Recommended Practice for Digital Audio Engineering – Serial transmission format for two-channel linearly represented digital audio data* (Revision of AES3-1992), Audio Engineering Society, Inc., 2003.