ISPCS Brescia '09

New Simulation and Test Results for IEEE 802.1AS Timing Performance

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Outline

- Introduction
- Overview of IEEE 802.1AS (update since ISPCS ‘08)
  - PTP profile
  - Synchronization and best master selection
- Simulation model
- Simulation results
- Test configuration and cases
- Test results

Introduction – 1

- IEEE 802.1 Audio/Video Bridging (AVB) Task Group is developing four standards for transport of high-quality, time-sensitive audio/video (A/V) applications over IEEE 802 bridged local area networks
  – Precise network timing (IEEE 802.1AS)
  – Resource reservation (IEEE 802.1Qat)
  – Traffic shaping, queueing, forwarding (IEEE 802.1Qav)
  – Profiles for AVB applications, i.e., parameters, configuration, etc. (IEEE 802.1BA)
- The current paper focuses on IEEE 802.1AS
  – Overview of the standard (update since ISPCS ‘08)
  – New simulation results
  – New test results

Introduction – 2

- IEEE 802.1AS is based on IEEE 1588v2, and includes a PTP profile
  - Bridge acts as a boundary clock (but with peer-to-peer transparent clock formulation of synchronization)
    - Bridge participates in best master selection; this is driven by 3 reasons:
      - Fast reconfiguration to control phase transients when GM changes
      - Scalability (without best master selection at each bridge, larger timeout values needed for larger networks)
      - Data spanning tree determined by RSTP not necessarily optimal for synch
  - End station acts as ordinary clock

Introduction – 3

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- Previously demonstrated via simulation that 802.1AS can meet the jitter/wander/synch requirements for A/V applications (see [5] and [6] of paper)
  - But this was based on earlier draft; some requirements have changed since then
- Subsequent test results reported at ISPCS '07 (see [7]) indicated ±500 ns synchronization could be achieved in 5 hop network with 1 Gbit/s links
- As of the preparation of these slides, the latest draft of P802.1AS is D6.1 (August 3, 2008)
- D6.2 is being prepared; planned recirculation ballot will close prior to November, 2009 IEEE 802 meeting
- Planned completion in 2010

PTP Profile Included in IEEE 802.1AS – 1

Blue indicates items that have changed since ISPCS '08

Profile Item	Specification
Best master clock algorithm (BMCA) option	Alternate BMCA (similar, but not identical, to 1588 clause 9)
Management mechanism	Still to be decided, likely will follow mechanism in other IEEE 802.1 standards
Path delay mechanism	Peer delay mechanism
802.1AS specifies default values; 802.1BA may specify additional ranges for each AVB profile	Sync interval: 1/8 s Announce interval: 1 s Pdelay interval: 1 s Announce receipt timeout: 2 announce intervals Sync receipt timeout: 3 sync intervals
Node types	Boundary clock (synchronization specified in manner similar to peer-to-peer transparent clock; BC and TC synchronization can be shown to be mathematically equivalent) Ordinary clock

PTP Profile Included in IEEE 802.1AS – 2

Blue indicates items that have changed since ISPCS ‘08

Profile Item	Specification
Transport mechanism	Full-duplex IEEE 802.3 IEEE 802.3 EPON Coordinated shared network (CSN, e.g., MoCA) 802.11 wireless; uses facilities of 802.11v (not part of PTP profile)
Optional features	Bridges/end-station required to measure frequency offset to nearest neighbor (but not required to adjust frequency); frequency offset is accumulated and used to correct propagation time and compute synchronized time Standard organization TLV is defined to carry additional information

PTP Profile Included in IEEE 802.1AS – 3

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Blue indicates items that have changed since ISPCS ‘08

Profile Item	Specification
Optional features (cont.)	Standard organization TLV is defined for use in Signaling message, to allow a node to request its neighbor to adjust message rate if it is going in or out of low power mode (to be used to support power management/Energy Efficient Ethernet (EEE) Path Trace feature, and TLV will be used, and is mandatory Other optional features of 1588 clauses 16 and 17 not used Annex K security protocol not used Annex L cumulative frequency scale factor not used (but cumulative frequency offset is accumulated)

Additional Network Assumptions – 1

- All bridges/end stations are "time-aware", i.e., meet the requirements of 802.1AS
  - No ordinary bridges
  - Peer-delay mechanism (full-duplex 802.3) and respective media-specific mechanisms (other media) used to detect non-802.1AS bridges
  - Except for peer delay, the 802.1AS protocol will not run on ports where a non-802.1AS bridge is detected
- Oscillator frequency of at least 25 MHz (40 ns granularity)
- ±100 ppm frequency accuracy
- Ethernet links are 100 Mbit/s or faster

Additional Network Assumptions – 2

- Jitter and wander generation requirements consistent with inexpensive oscillators
- 802.11 links are 100 Mbit/s (i.e., meet requirements of IEEE 802.11n)
- 802.11 links support the localization features of 802.11v
- All time-aware systems are 2-step clocks
  - Always send Follow_Up and Pdelay_Resp_Follow_Up
- Bridges adjust time and frequency instantaneously, i.e., they do not do any PLL filtering
  - All filtering is done at end stations; this allows cost of filtering to be borne by applications

Additional Network Assumptions – 3

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- 802.1AS network is single PTP domain (domain number 0)
- PTP timescale is used

Synchronization in IEEE 802.1AS

- Detailed description of synchronization in IEEE 802.1AS was given in ISPCS ‘08 paper [10]; see Annex for corresponding presentation material
- Measure propagation delay using peer delay mechanism (full-duplex 802.3) or media-specific mechanism for other media
- Use successive responseOriginTimestamp values from peer delay measurement to measure neighbor frequency offset
- Accumulate frequency offset in TLV attached to Follow_Up
- Update correction field using propagation delay measurement and residence time corrected for cumulative frequency offset

Best Master Selection in IEEE 802.1AS

- Detailed description of best master selection in IEEE 802.1AS was given in ISPCS '08 paper [10]; see Annex for corresponding presentation material
- Mechanism is very similar to default BMCA, except
  - No qualification of Announce messages
  - No pre-master state
  - No uncalibrated state
- BMCA is expressed using a subset of Rapid Spanning Tree Protocol of IEEE 802.1D and 802.1Q
- A time-aware bridge (i.e., BC) or end-station (i.e., OC) need not be grandmaster-capable

Simulation Model – 1

- A new simulation model was developed to reflect changes since the previous simulations (see [5] and [6] of the paper) were performed
  - Mainly the measurement of nearest-neighbor frequency offset and accumulation in standard organization TLV attached to Follow_Up
- The new model incorporates the above, and also is discrete-event based (rather than a discrete time approximation used in [5] and [6])

Simulation Model – 2

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- For simplicity, the clocks are modeled as one-step (this results in modeling of fewer events)
- Events include sending and receiving of Sync, Pdelay_Req, and Pdelay_Resp
- On each event, an event handler function runs, and then schedules the next event
- The events are stored in chronological order, in a linked list
- A fixed time step between events is used to integrate endpoint filters
- The simulator is implemented in C on a Linux system

Parameters For Simulation Case – 1

Parameter	Value
Number of nodes, including grandmaster	8 nodes (7 hops)
Sync interval	0.125 s
Pdelay interval	1.0 s
Free-running, local oscillator (in node) frequency tolerance	± 100 ppm (actual frequencies chosen randomly at initialization, from uniform distribution over this range)
Residence time	1 ms
Pdelay turnaround time	1 ms

Parameters For Simulation Case – 2

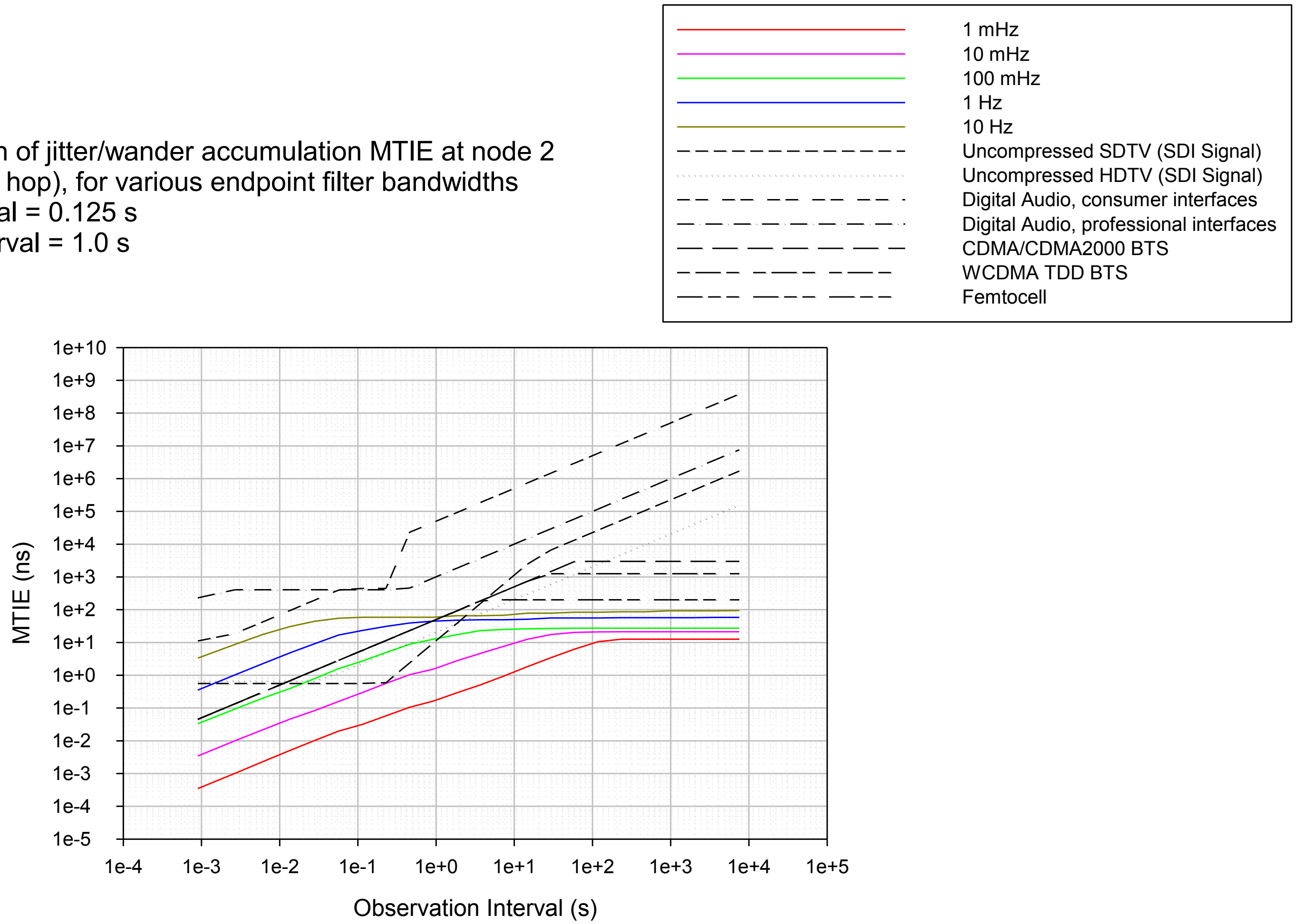
Parameter	Value
Link propagation time	500 ns (assumed symmetric)
Phase measurement granularity of local oscillator	40 ns
Free-running oscillator noise/ instability	None modeled
Endpoint filter 3 dB bandwidth	1 mHz, 0.01 Hz, 0.1 Hz, 1 Hz, 10 Hz
Endpoint filter gain peaking	0.1 dB
Simulation time	10,010 s
Maximum time step	0.001 s

Jitter and Wander Requirements and Simulation Results

- Results are given in the form of Maximum Time Interval Error (MTIE) relative the to the grandmaster, at nodes 2 – 8
- Results are compared with MTIE masks derived from the jitter and wander requirements for respective applications
  - Uncompressed video (both standard and high definition); see [1] of paper for description of requirements (and source references)
  - Professional and consumer audio; see [2] of paper for description of requirements (and source references)
  - Various cellular base station technologies (see [14] and [15] of paper for requirements)
  - See [3] of paper for how to derive MTIE masks

Jitter/Wander Simulation Results – Node 2 (1 Hop)

Comparison of jitter/wander accumulation MTIE at node 2 (i.e., after 1 hop), for various endpoint filter bandwidths
Sync Interval = 0.125 s
Pdelay Interval = 1.0 s



Jitter/Wander Simulation Results – Node 8 (7 Hops)

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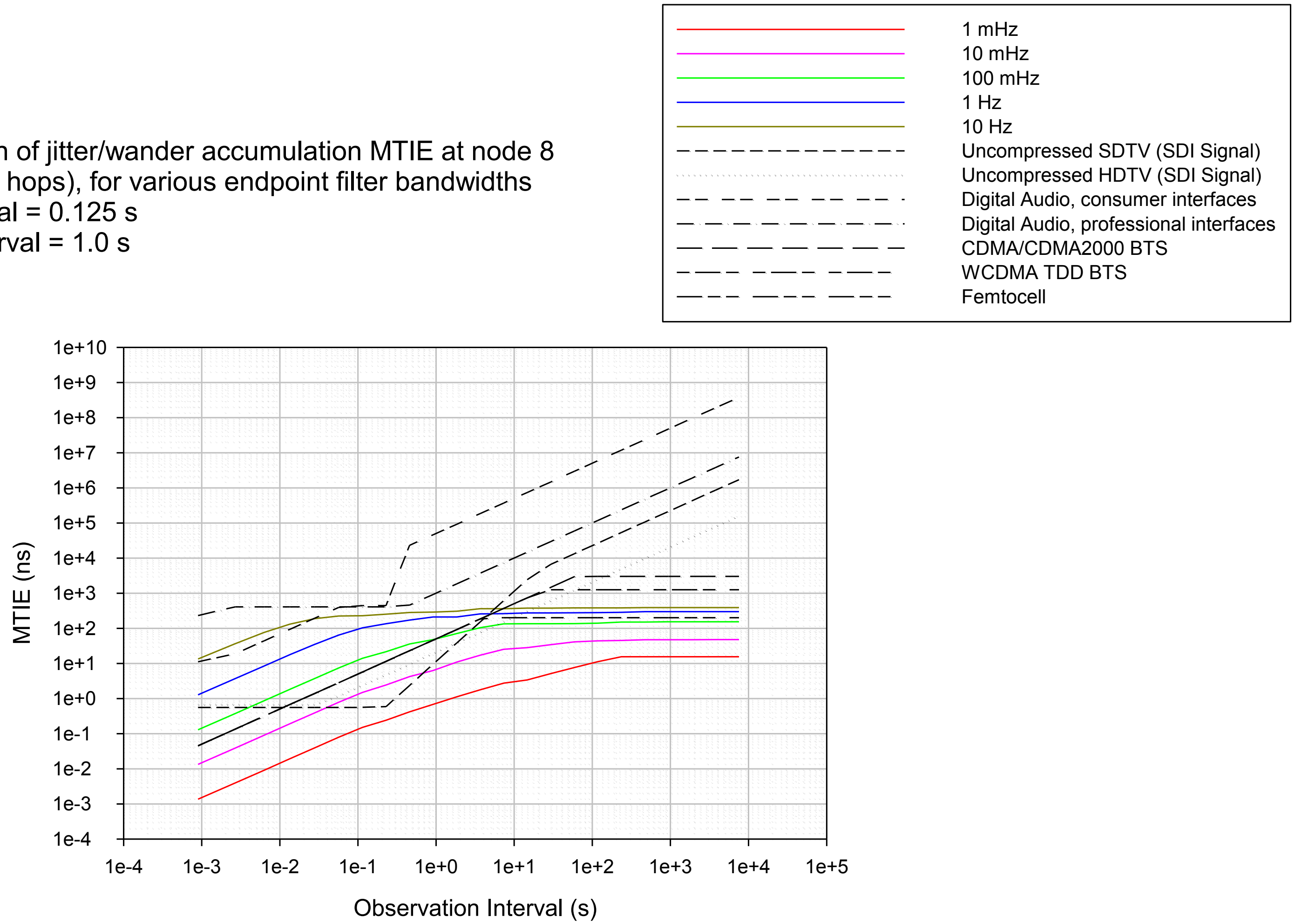
Comparison of jitter/wander accumulation MTIE at node 8 (i.e., after 7 hops), for various endpoint filter bandwidths
Sync Interval = 0.125 s
Pdelay Interval = 1.0 s



Simulation Results – Summary – 1

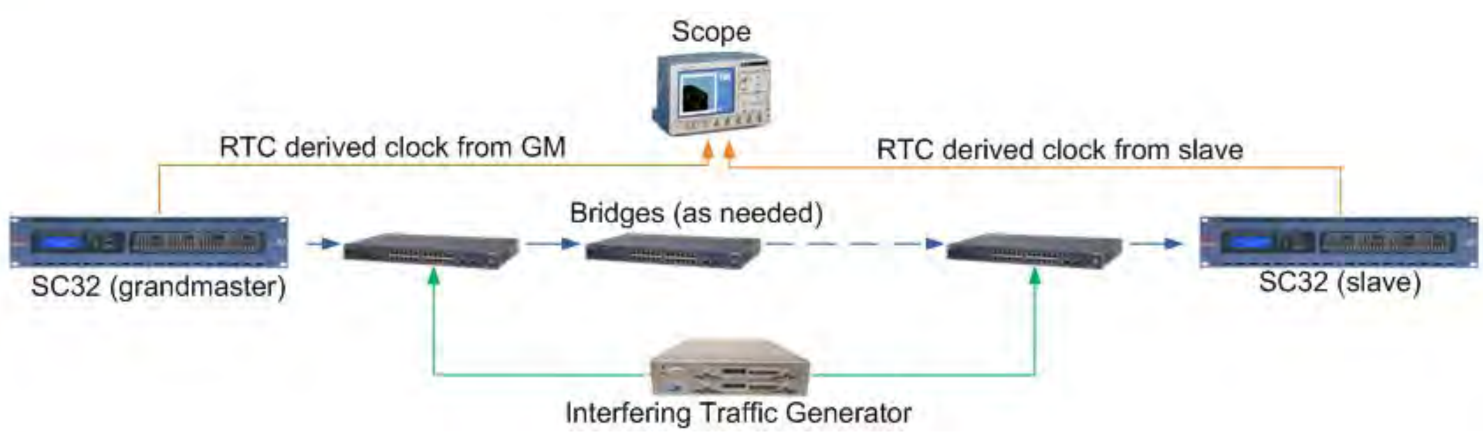
- For the single simulation run made here
  - All application requirements are met with a 1 mHz endpoint filter
  - All requirements except those for uncompressed SDTV are met with a 0.01 Hz endpoint filter
  - Professional and consumer audio requirements are met with a 1 Hz endpoint filter
  - Professional audio requirements are met with a 10 Hz endpoint filter
    - Note that professional audio equipment is required to tolerate more jitter than consumer audio equipment, and therefore larger jitter accumulation is allowed

Simulation Results – Summary – 2

- Note that these results include the effect of 40 ns phase granularity of the local oscillators, but do not include the effect of clock noise/instability
  - The current level for the jitter generation requirement in IEEE 802.1AS D6.1, Annex B (B. 1.3.1) is 1 ns peak-to-peak, measured through a 10 Hz high-pass measurement filter
    - This is small compared to 40 ns phase granularity
  - Currently are checking whether the wander generation requirement in IEEE 802.1AS, Annex B is consistent with inexpensive oscillators (it is small over the 1/8 s Sync interval compared to 40 ns phase granularity)

Test Configuration – 1

- 8 node (7 hop) configuration
  - Endpoints: 2 dbx® SC32 digital audio matrix processors with AVB Option Cards
  - Intermediate bridges: 6 Netgear®/BSS™ SW224 Prosafe 24 Port 10/100/1000 Mbps Smart Switches with AVB support
  - All links ran at 1 Gbit/s



Test Configuration – 2

- One SC32 was grandmaster, and the switches and second SC32 were slaves
- Each SC32 has a counter, i.e., real-time clock (RTC) that is incremented every 8 ns (i.e., local oscillator is 125 MHz)
  - The GM SC32 is free-running
  - The slave SC32 is adjusted with each Sync/ Follow_Up it receives
  - Adjustments are instantaneous, i.e., no endpoint filtering
  - Bit 20 of the RTC is used to form a 953.674 Hz square wave ($(1/2^{20})*10^9$ Hz)

Test Configuration – 3

- Square waves derived from the GM and slave SC32s were compared using a Tektronix DPO7245 oscilloscope with TDSJIT3 jitter analysis software
  – Note that only the SC32s could produce the square waves; separate tests were run for each desired number of hops, with the slave SC32 located that number of hops from the GM SC32
- For each test, cases were run with and without interfering traffic
  – Interfering traffic was introduced at the first bridge (closest to the GM) and last bridge (closest to the slave) and broadcast to all other bridges and the endpoints

Test Configuration – 3

- Interfering traffic (cont.)
  - Since the 802.1AS messages flow from GM to slave, traffic introduced at the last bridge interferes with 802.1AS traffic only on the link from the last bridge to the slave
  - Traffic introduced at the first bridge consisted of 1500 byte frames, and the load was close to 100%
  - Traffic introduced at the last bridge consisted of 1500 byte frames, and the load was close to 10%
  - Therefore, for cases with interfering traffic, the link between the last bridge and slave was possibly overloaded, and the other links had close to 100% load
  - For the case of 1 hop (no bridges), there was no background traffic

Test Results – 1

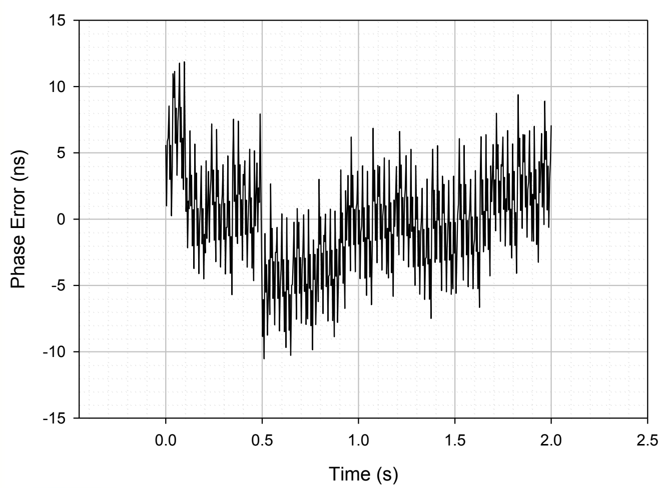
- Measurements were made for 0, 1, 2, 3, 4, 5, and 6 bridges between the slave and GM
- Due to limitations in the DPO7524 oscilloscope and TDSJIT3 software, the longest measurement interval attainable was 2 s

Peak-to-peak phase error (ns) for 2 s measurement interval

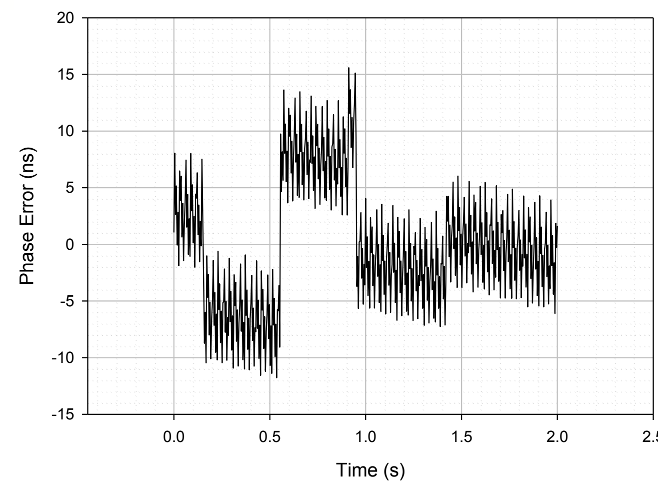
Number of hops	**1**	**2**	**3**	**4**	**5**	**6**	**7**
No background traffic	22.4	20.7	20.9	27.4	26.7	30.0	33.5
With background traffic	___	21.1	24.9	26.2	21.6	31.8	43.9

Test Results – No Background Traffic

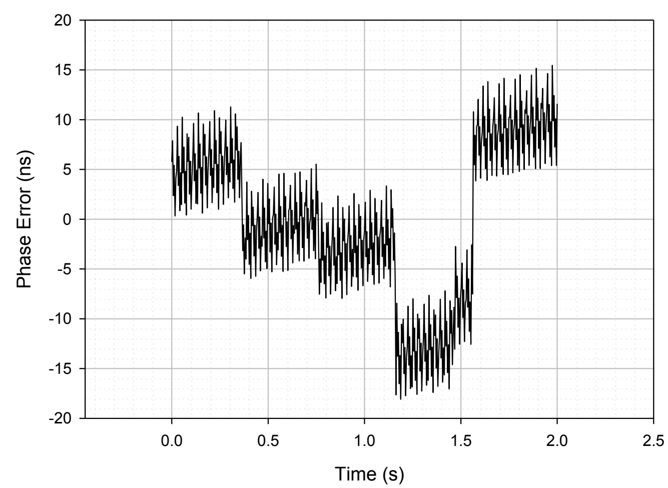
1 hop, no background traffic



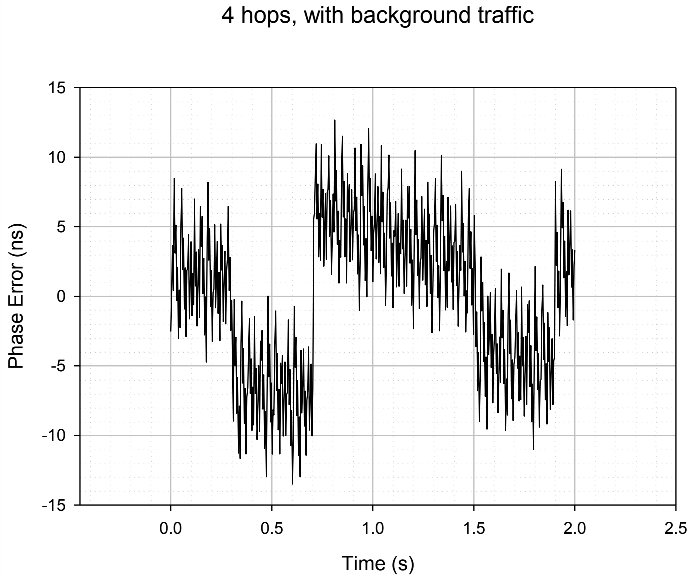
4 hops, no background traffic

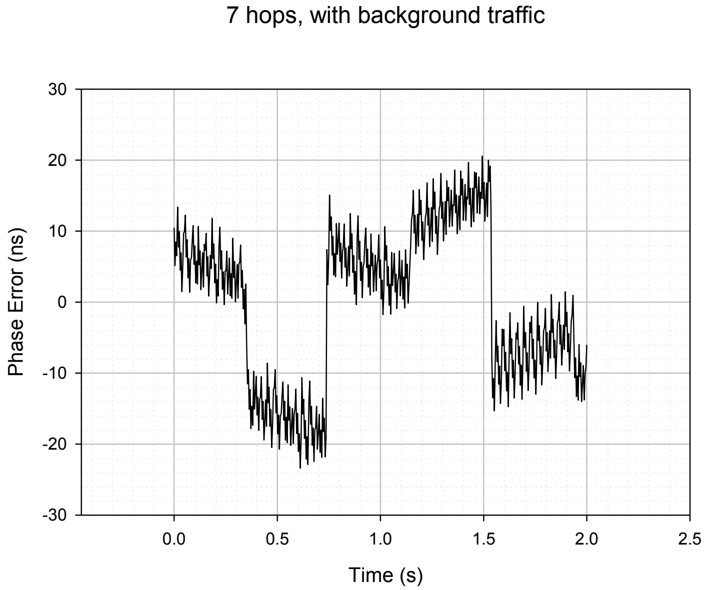


7 hops, no background traffic



Test Results – With Background Traffic



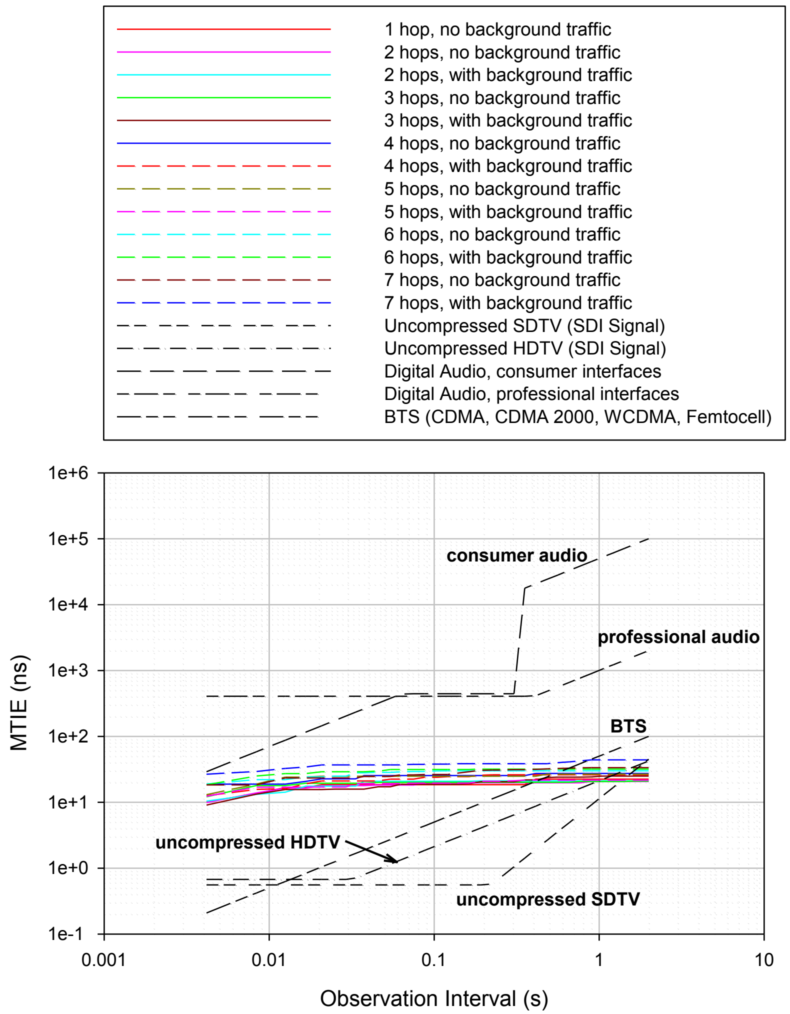


Test Results – 2

- The time synchronization requirement of ±500 ns relative to the grandmaster is easily met
- The main component of phase error is due to the effect of the 8 ns phase measurement granularity in measuring propagation delay and residence time
- The 8 ns truncation can result in 4 ns jumps in the propagation delay measurement and 8 ns jumps in the residence time measurement
- The peak-to-peak phase error generally increases with the number of hops, as expected
- The background traffic does not have significant effect

Test Results – MTIE

Unfiltered phase error MTIE, 1 - 7 hops, with and without background traffic



Test Results – 3

- The MTIE results meet the requirements for professional and consumer audio, for the range of observation intervals shown
  - However, note that the jitter requirement is 10 ns for observation intervals less than 2.5 ms (200 Hz high-pass jitter measurement filter) for consumer audio and less than 62.5 μs (8 kHz measurement filter) for professional audio
- The requirements for uncompressed video and cellular base stations are exceeded for shorter observation intervals

Test Results – 4

- Endpoint filtering is needed to meet the application jitter requirements
  - Consideration was given to filtering the measured data
    - However, meeting the cellular base station and uncompressed video requirements requires narrow bandwidth filters (i.e., < 1 Hz)
    - The 2 s of data collected for each case (the limit of the test equipment) is not sufficient duration for initial transients to decay

Summary – 1

- IEEE 802.1AS is compatible with IEEE Std 1588™ – 2008, in that it includes a PTP profile
  - The specific profile requirements were chosen to achieve low cost and still meet application requirements
- Support is added for IEEE 802.11, IEEE 802.3 EPON, and coordinated shared network (e.g., MoCA)
- Simulation results indicate that jitter/wander requirements for professional audio are met with a 10 Hz endpoint filter, consumer audio with a 1 Hz filter, cellular base stations and uncompressed HDTV with a 0.01 Hz filter, and uncompressed SDTV with a 1 mHz filter

Summary – 2

- Test results indicate that the time synchronization requirement of ±500 ns relative to the grandmaster, over 7 hops, is easily met
- The test results exceeded the jitter/wander requirements for the consumer and professional audio, cellular base station, and uncompressed video applications at shorter observation intervals because endpoint filtering was not performed