Tutorial on Time-Synchronization for AAA2C based on IEEE Std 802.1AS™-2011

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November 7, 2012

Abstract

This presentation provides an overview of time synchronization using IEEE Std 802.1AS™-2011 with special emphasis on deployment as part of Automotive AVB

Agenda

- **802.1AS goals / applications**
- **Overview**
- **Grand Master selection**
- **Time propagation**
  - Media-independent
  - Media-dependent
- **Deriving the media clock**

802.1AS goals

Distribute a single, accurate time reference that is optimized for audio and video synchronization (and useful for other things)

- **Accurate**
  - Worst-case error less than +/-500ns in a standard AVB LAN
- **Completely Immune to LAN traffic bursts and jitter**
  - Only equipment failure degrades time accuracy
- **One time reference for the entire LAN/Subnet**
  - A Profile of IEEE Std.1588™ -2008 (PTP, or Precision Time Protocol)
  - LAN-specific measurements
    - 802.3 measurements follow generic 1588
    - 802.11 measurements follow IEEE Std 802.11v™ -2011 “TimingMeasurement”
    - Coordinated Shared Network (CSN) measurements defined also
- **Self configuring**
  - Grand Master (G.M.) clock is selected automatically
    - Time stabilizes in a fraction of a second
  - Clock tree reconfigures automatically if Grand Master is lost

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

Automotive applications of 802.1AS

- **Reference for time-aligning multiple media renderers**
  - Audio rendered by two networked amplifiers
  - Audio and video rendered separately (lip sync)
- **Reference for frequency-synchronizing audio**
  - E.g., lock the amplifier D/A clock frequency to incoming I2S
- **Timestamping sensor samples for subsequent fusion**
  - Video-cameras, etc.
  - Question: Is timestamping the samples enough, or also need simultaneous sampling?

To be added in IEEE p802.1ASbt (part of AVB Gen2)

- **Fault-tolerance / redundant paths**
- **Link Aggregation**
- **Improved startup time**
- **Additional features for control applications**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

- **Fast startup (Power-Up → Audio [& Camera])**
  - Store parameters in Flash
    - Preconfigure the Grand Master (G.M.) node
    - Store previous Path Delay measurement, NeighborRateRatio
  - Custom Sync-startup sequence
    - E.g., two Sync/Follow-up messages in rapid succession
- **OEM-designated Grand Master device**
  - Configure "Ultimate Priority" node, and other backups as needed
- **Allow in-line Ethernet diagnostics equipment**
  - Disable legacy hub detection function (`neighborPropDelayThresh`)

Automotive:

- **Other optimizations of "default" 802.1AS?**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

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High level architecture

- **Grand Master selection**
  - G.M.-capable stations advertise themselves via ANNOUNCE messages
  - If a station hears from station with “better” clock, it does not send ANNOUNCE
    - Configurable “Priority” field overrides clock quality
    - MAC address is tie breaker
  - Bridges drop all inferior ANNOUNCE messages
    - Forward only the best
  - Last one standing is Grand Master for the Bridged LAN
    - G.M. is the root of the 802.1AS timing tree
    - G.M. periodically sends the current time
- **Propagation of time**
  - Bridges in the tree propagate time toward the leaves
    - Taking queuing delay into account (aka “Residence Time”)

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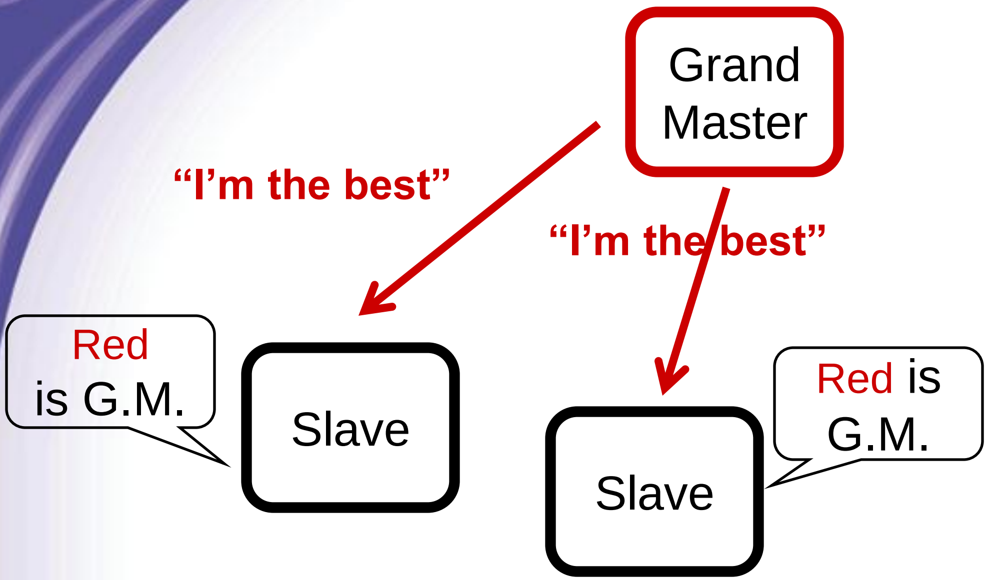
Grand Master selection – Steady state



Steady state:

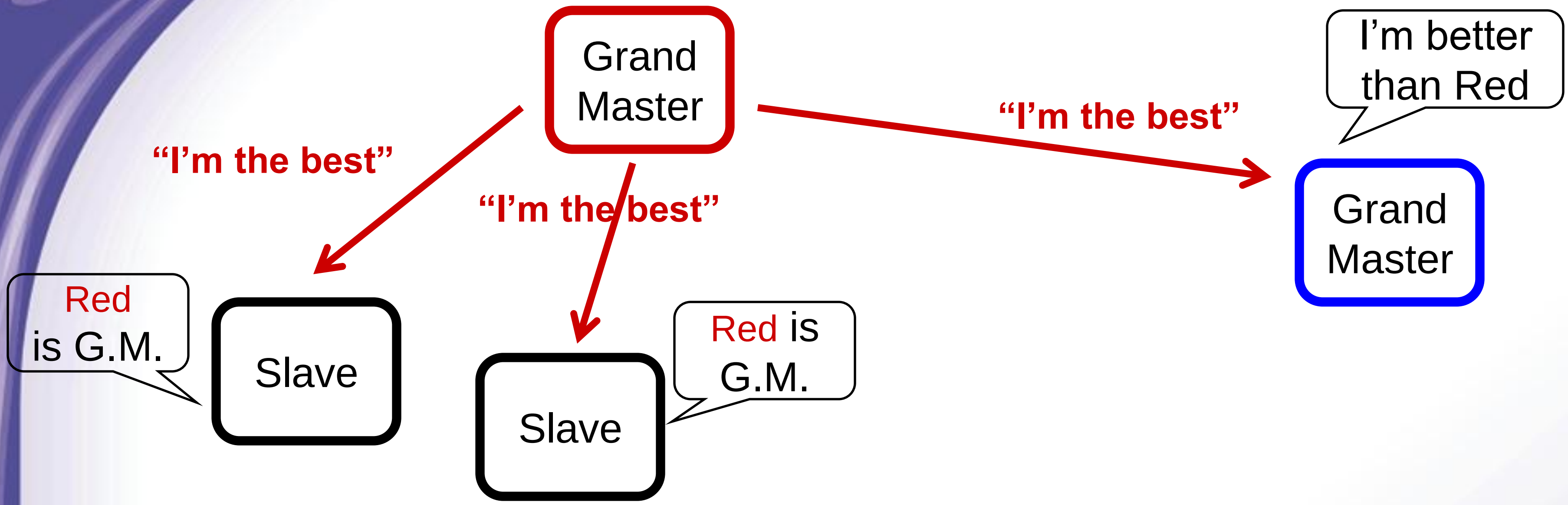
- **The G.M. sends ANNOUNCE**
- **Slaves determine the best G.M. (including self)**
  - …using simple bitwise compare
  - And do not send ANNOUNCE messages
- **Everyone knows their role**
- **All is well**

Automotive:

- **Optimization: Pre-configure Slaves, G.M.**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf

Grand Master selection – New, better G.M. (1)

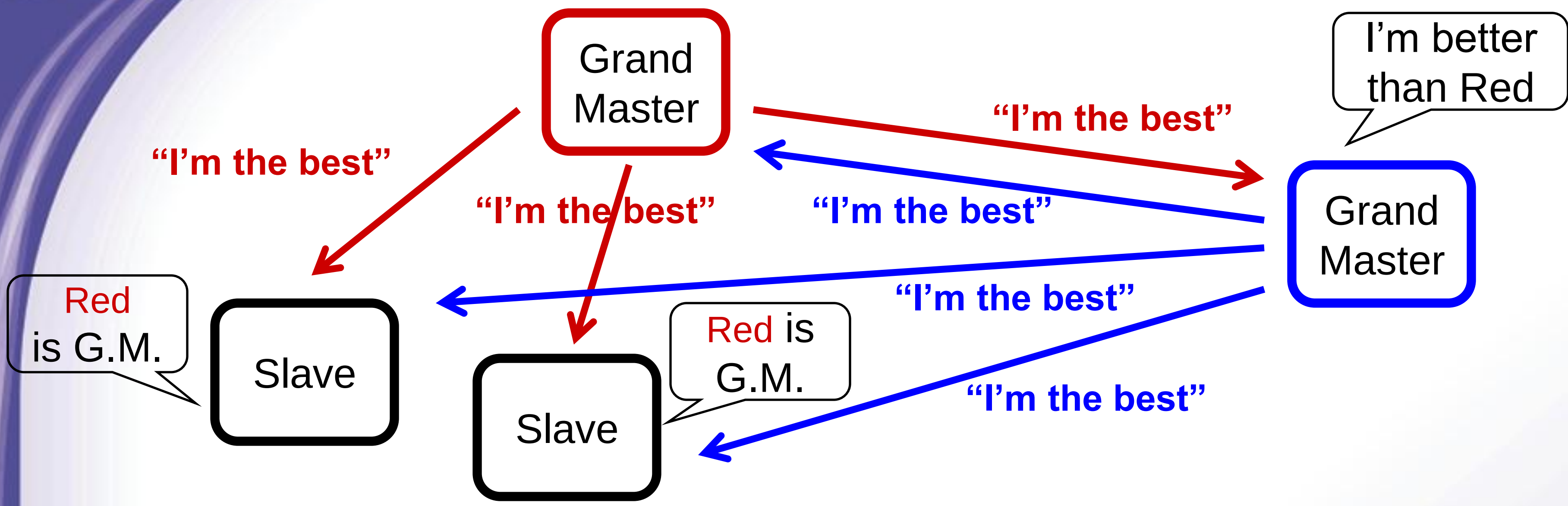


- **Blue station with better clock appears**

Automotive:

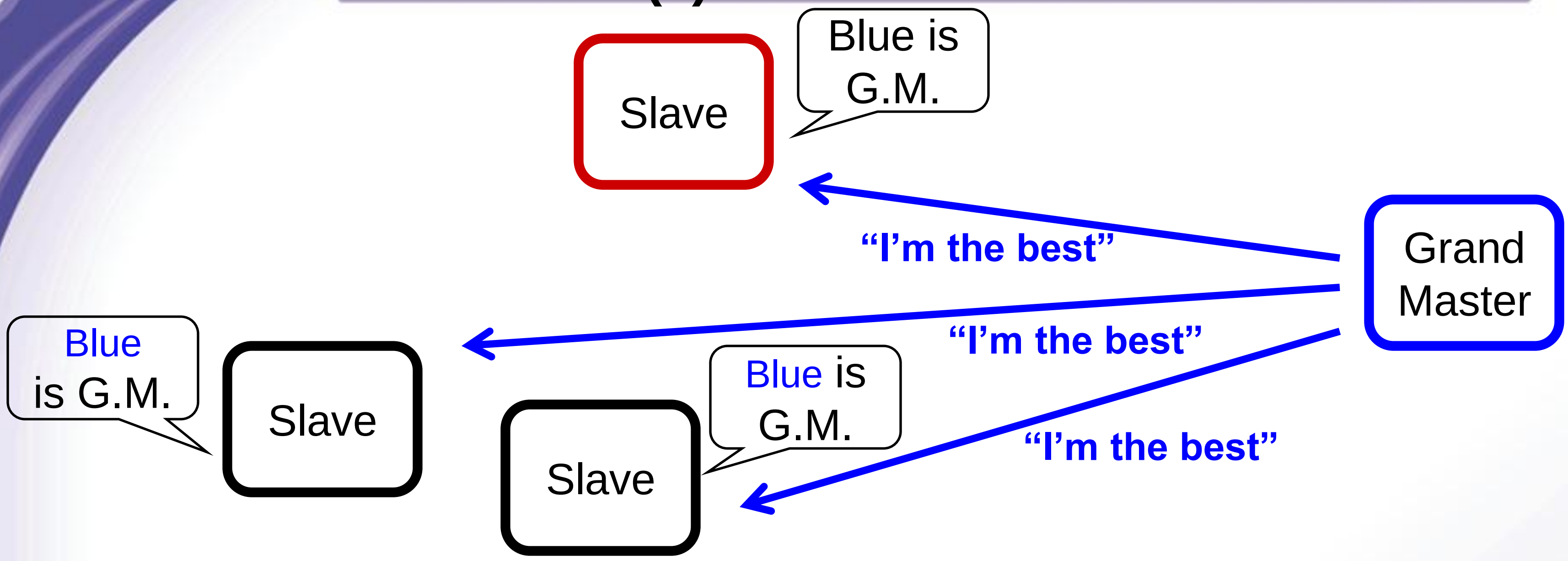
- **This situation can easily be eliminated if desired**

Grand Master selection – New, better G.M. (2)



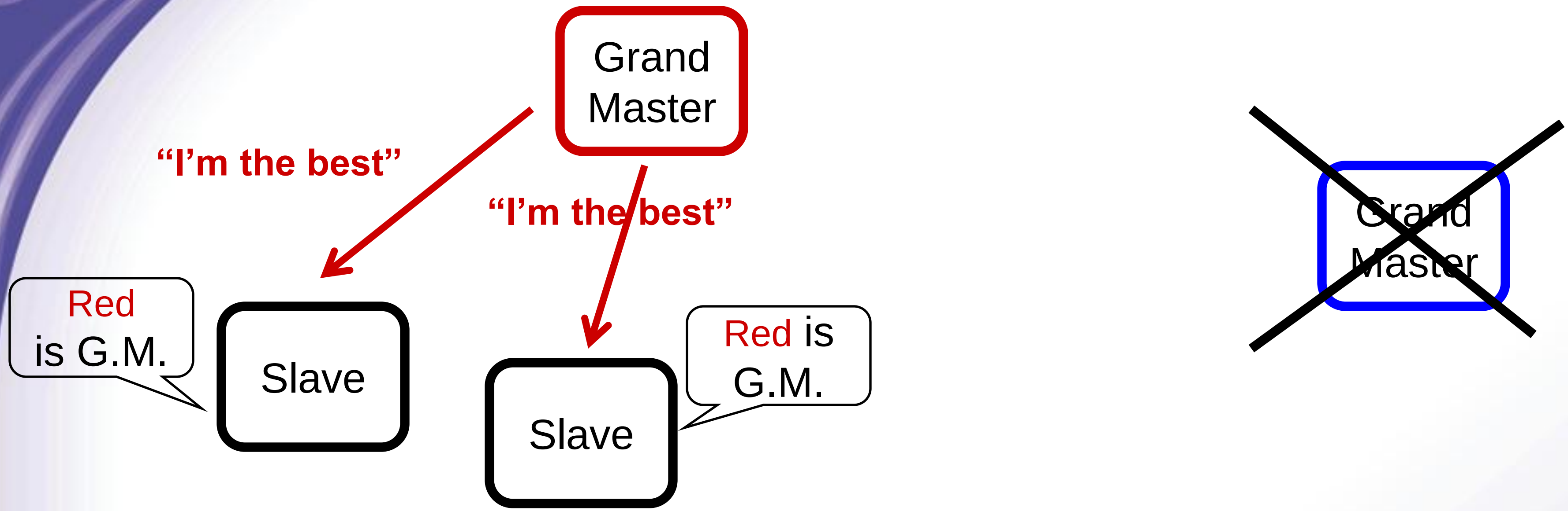
- Blue station with better clock appears
- Blue sends ANNOUNCE
- Stations all realize blue is superior
  - Including Red

Grand Master selection – New, better G.M. (3)



- Blue station with better clock appears
- Blue sends ANNOUNCE
- Stations all realize blue is superior
- Red stops sending ANNOUNCE
- Blue is quickly the undisputed G.M.

Grand Master selection – Lost G.M.



- **If Blue disappears, all G.M.-capable stations send ANNOUNCE**
- **Eventually, only Red sends ANNOUNCE**
- ***Note: New G.M. communicates time & frequency relationship to previous G.M.***

Automotive:

- **Will this be required?**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.p

ANNOUNCE comparison

- **The credentials passed in ANNOUNCE messages are compared (in order of decreasing importance):**
  - Priority (settable by management)
  - Multiple **“quality of my clock”** fields
  - MAC address

Automotive:

1. **Grand Master configured at manufacture**
   E.g., the Head Unit
2. **Several options for subsequent behavior**

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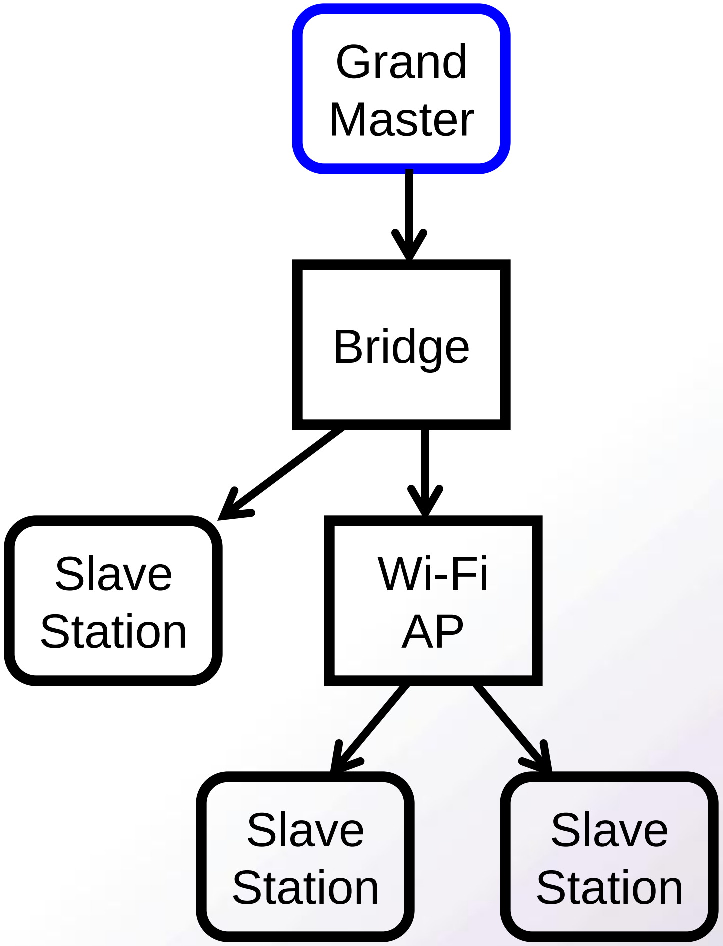
Time is propagated across the LAN / subnet

- **Bridges [/APs] relay:**
  - The best ANNOUNCE
  - The G.M.'s time
- **Links can be**
  - 802.3 Ethernet
  - 802.11 WiFi
  - Almost anything compatible with IEEE 802
- **Let's look at one bridge**

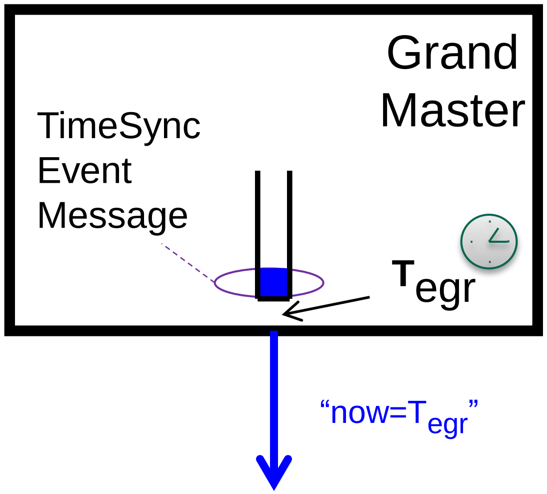


Grand Master selection – Bridges help decide

- **Bridges filter inferior ANNOUNCE**
  - Bridges forward best ANNOUNCE messages
  - Bridges drop inferior ANNOUNCE messages
  - Benefits:
    - Reduction in network traffic
    - Faster G.M. selection
- **Announce messages establish the Clock Tree**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

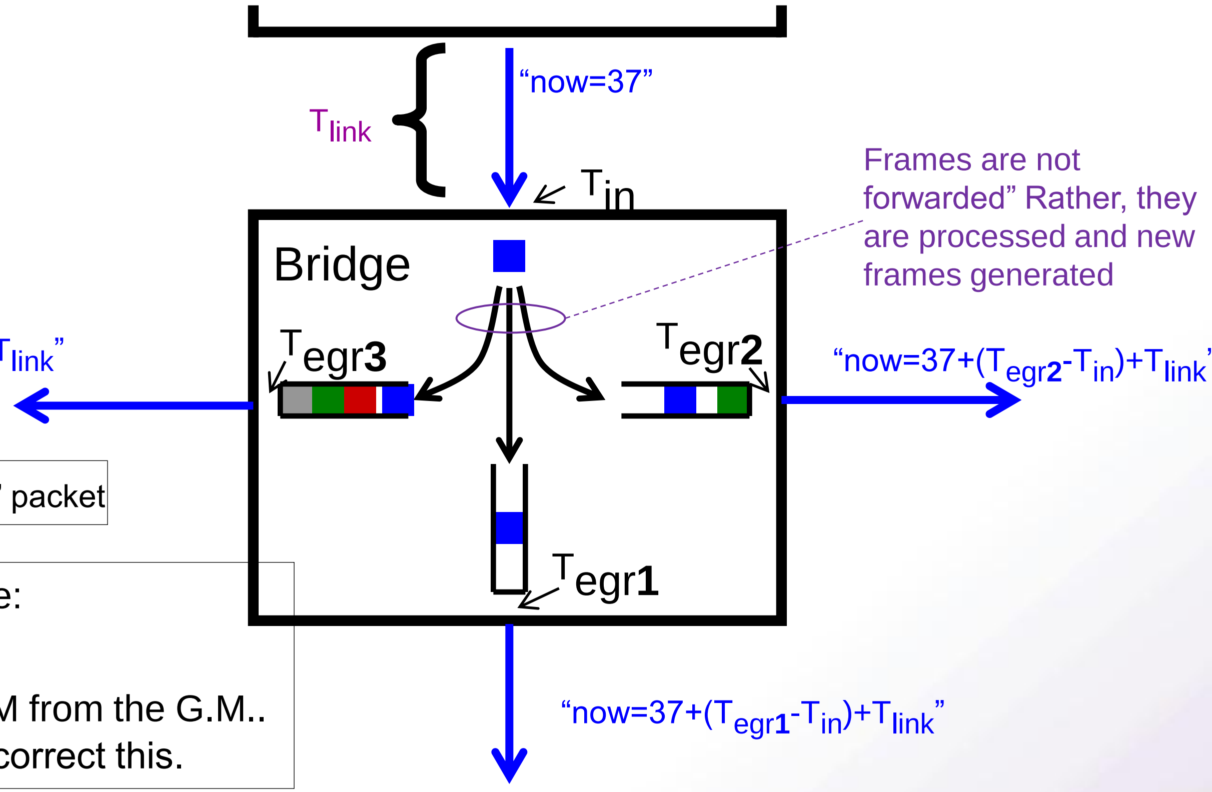
Grand Master responsibilities



- **Transmit an Event message each Sync Interval**
- **Hardware captures the egress or Tx time (T_{egr})**
- **Pass T_{egr} downstream**
  - Usually in a Follow-Up message
- **Time need not be synchronized to time-of-day**
  - For most applications, but UTC offset can also be provided

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

Propagating time through a bridge



■ is a hypothetical "time measurement" packet

Note: This picture almost complete:

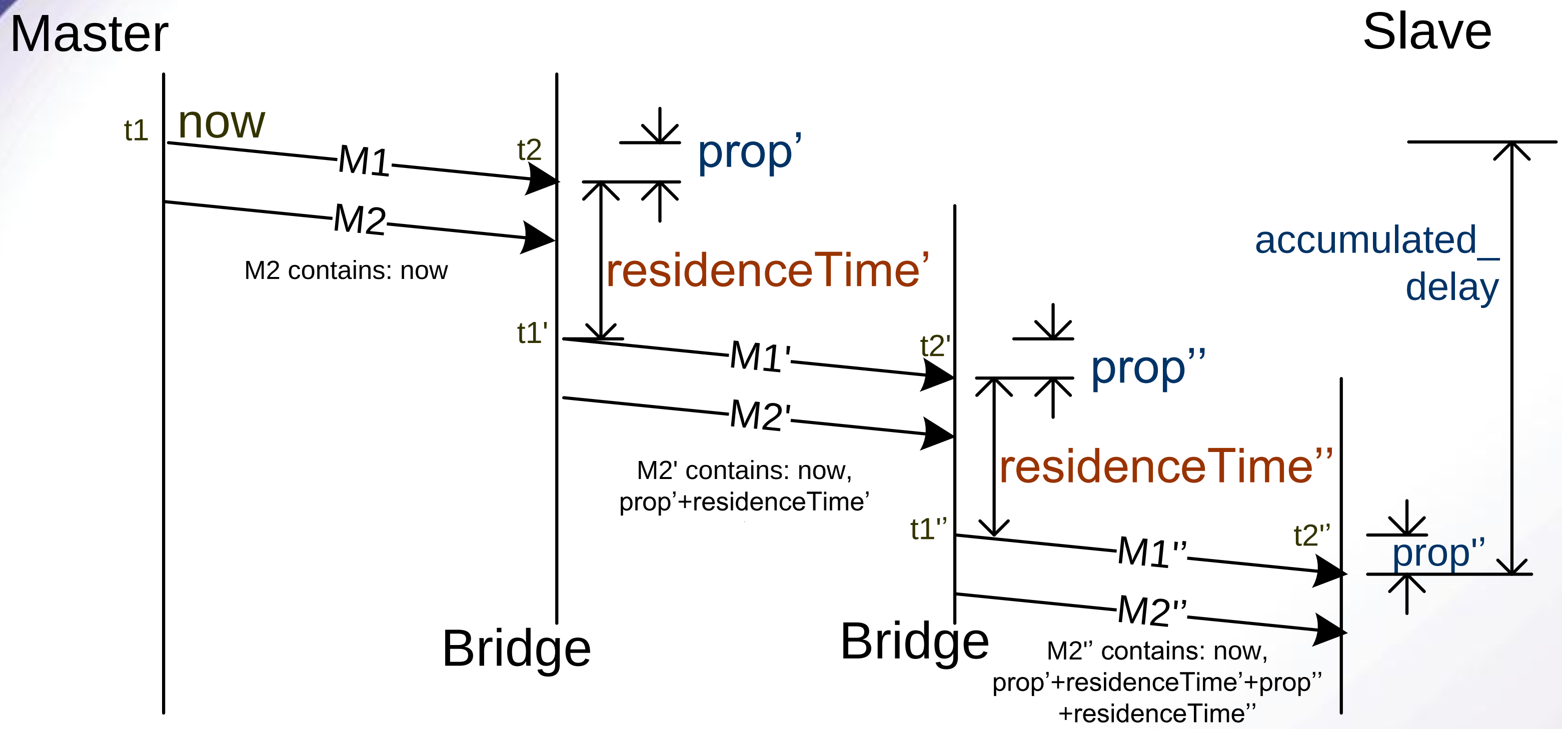
$$(T_{egr}-T_{in})$$

can be off by as much as 200PPM from the G.M..
802.1AS computes "rateRatio" to correct this.

- **Time is sent from master over the link with frames that are LAN/media-specific**
  - Illustrated abstractly here by a Blue frame
- **Bridge accurately measures how the long Blue frame is in the bridge**
  - Called "Residence Time"
- **Also compensates for link delay (T_{link}) and rateRatio**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

End-to-end time synchronization across the LAN



Grand Master initiates M1 every Sync Interval

Each Bridge measures the actual delay of M1:

delay = prop + residenceTime * rateRatio

And carries the *accumulated*_delay in another message, M2

Slaves compute: *currentTime at t2’’ = now* plus *accumulated_delay*

Note: Message interval on each link may be different

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

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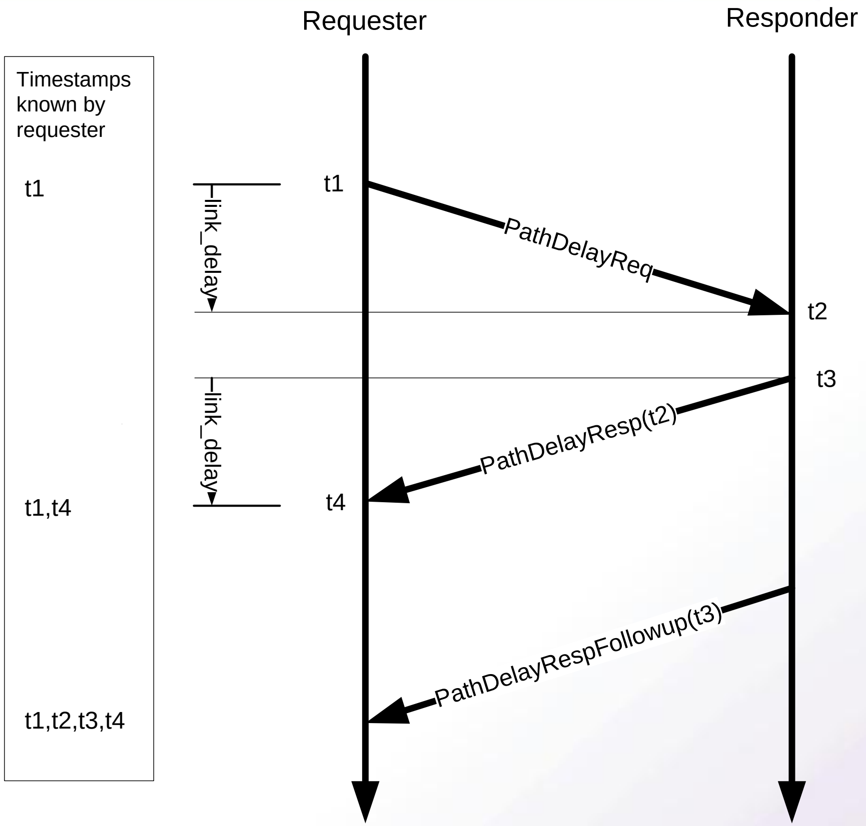
    - 802.3 links *[For 802.11 / Wi-Fi links, follow URL below]*
- Deriving the media clock

802.3 protocol (step 1 of 2)

Measure link delay:

1. **Requester schedules PathDelayReq for transmission**
2. **As it passes out the PHY, t1 is captured**
   Using the master's free-running clock
3. **Time t2 captured as passes from PHY to MAC**
   Using the slave's free-running clock
4. **Responder schedules PathDelayResp for transmission, sends t2**
5. **Timestamps t3 and t4 captured**
   Using local free-running clocks
6. **PathDelayRespFollowup carries t3 to requester**



If link delay is fixed & symmetric:
link_delay = [(t4-t1) – (t3-t2)] / 2

NeighborRateRatio is computed using these and previous timestamps

Automotive:

- **Link_delay can be pre-configured or stored**
- **Also NeighborRateRatio?**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1

802.3 protocol (step 2 of 2)

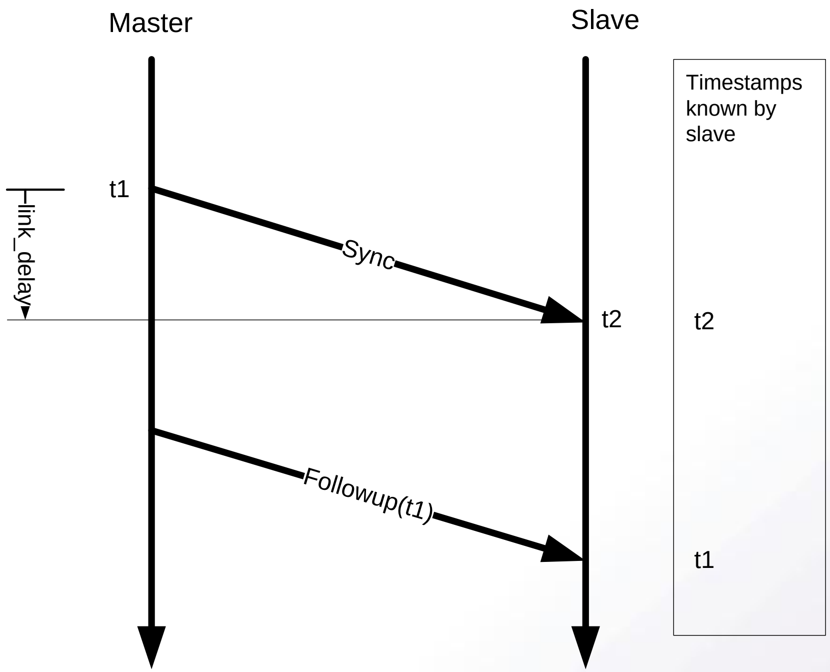
Synchronize clocks

1. **Master schedules Sync for Tx**
2. **As it passes out the PHY, t1 captured**
   Using master's free-running clock
3. **Time t2 captured when it arrives**
   Using the slave clock
4. **FOLLOWUP carries t1 to slave**

If link delay is fixed & symmetric:

Slave's clock offset
= t2 – t1 – link_delay

Note: APs & bridges do this too, and communicate the 'residence time' per Sync in the Followup frame



Automotive:

- **Time is needed ASAP**
- **Quickly send multiple Sync/Followup**
- **Then slow to 8/second**
- **Profile under definition**

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

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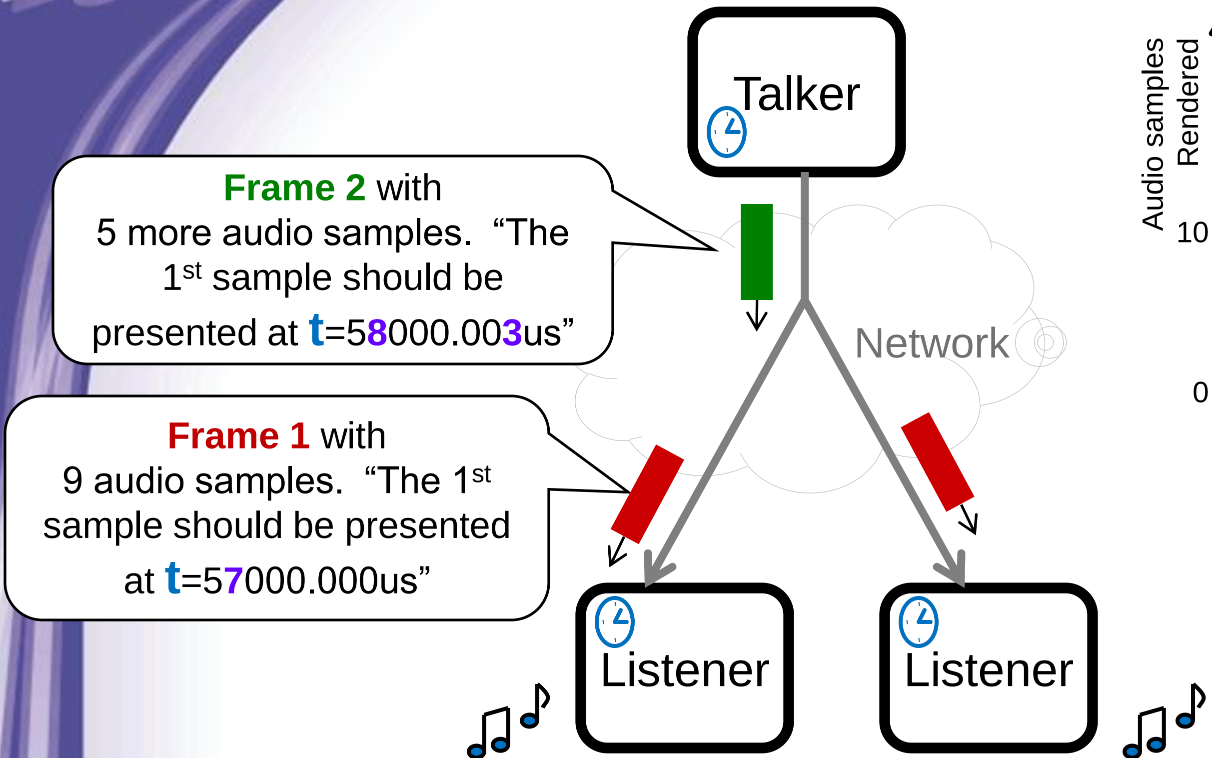
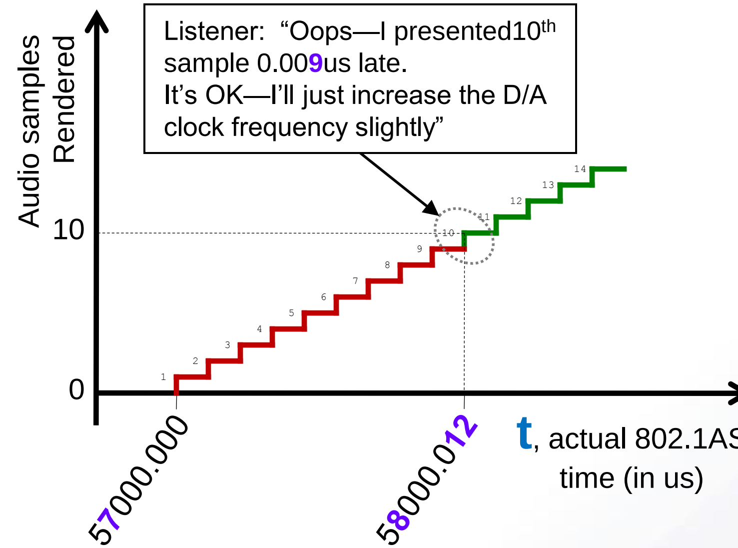
Example: Generating a media clock





58000.012 us
— 58000.003 us
0.009 us

- **Notes:**
  - Time (t) is 802.1AS time, known to all talkers & listeners
  - Nominal audio sample rate known beforehand, e.g.10KHz, 100us/sample above
  - 802.1AS time is "seconds since Jan 1, 1970 TAI" with precision of 1 nanosecond
  - This allows an ARBITRARY number of independent media clocks simultaneously

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf Kevin B. Stanton

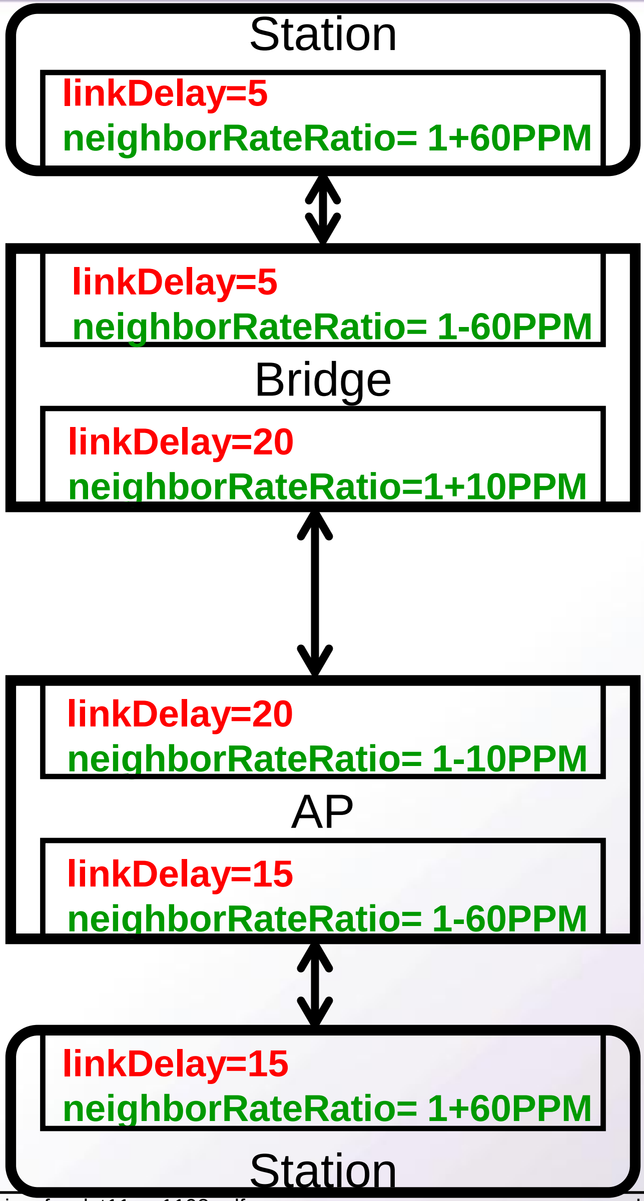
Backup

Link Delay and Neighbor-Rate-Ratio

All ports measure

- linkDelay to neighbor
- neighborRateRatio

Example values are shown



Note: No GrandMaster is needed here (yet)

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf

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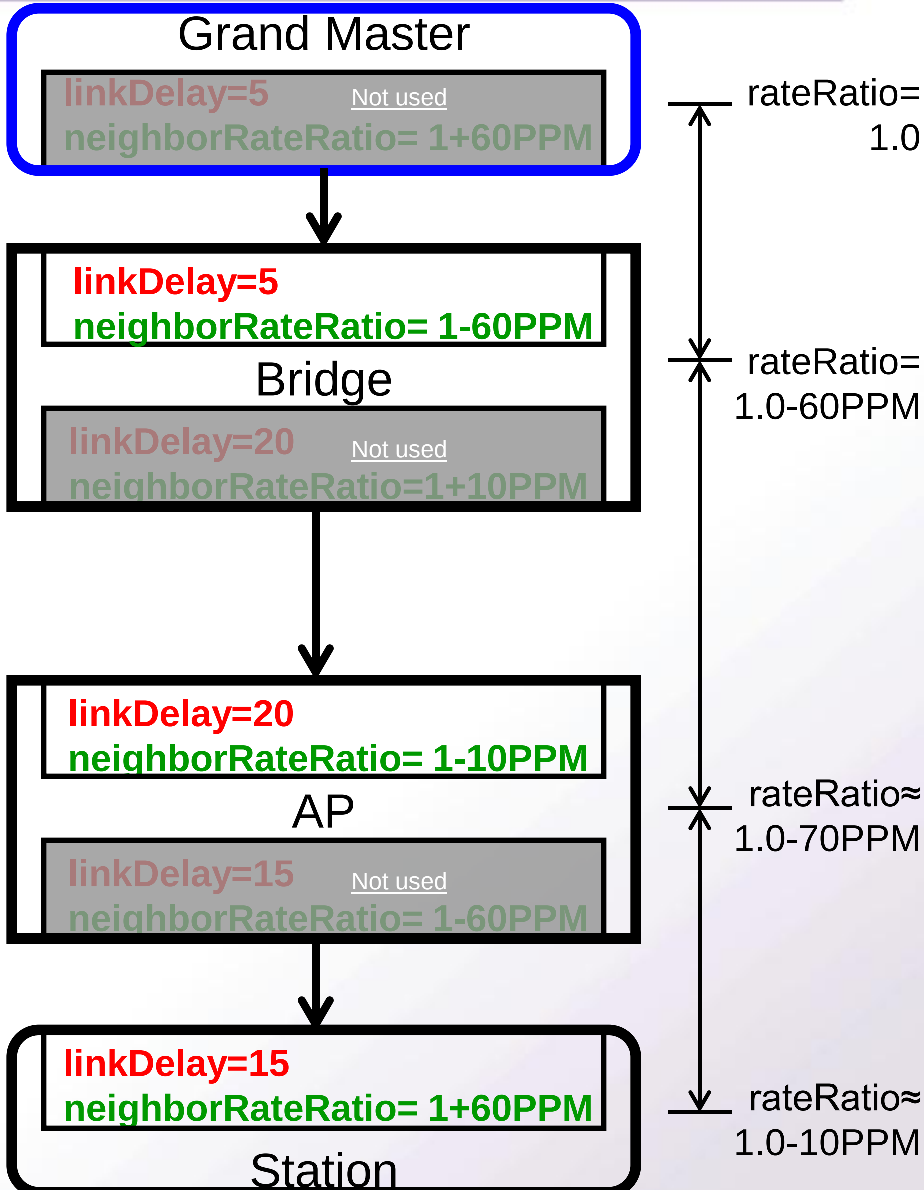
End-to-end Rate Ratio



As time is propagated downward, neighborRateRatio is accumulated at each hop

…using the approximation:

```
rateRatio +=
      (1-neighborRateRatio)
```

[Initial rate ratio is 1.0 at the G.M.]

Alternative is to do syntonization in Bridges, but cascaded PLLs are bad

Added benefit: When changing G.M., endpoints stabilize quickly because neighbor parameters are already measured

Derived from http://www.ieee802.org/1/files/public/docs2008/as-kbstanton-8021AS-overview-for-dot11aa-1108.pdf

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