Synchronization of Television, Audio and Moving Pictures in a Digital Age

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Synchronization Requirements in a Digital TV Studio
Synchronization split into two parts:

- **Time labelling** – identifying and aligning media excerpts for editing and post-production
- **Signal alignment** – for seamless video and audio mixing

**Time Labelling**

- Current solution is defined in SMPTE 12M timecode (30 years old)
- Identifies individual frames
- Doesn’t support frame rates greater than 30Hz
- Doesn’t align well with other media (e.g. audio)
- Only supports 24 hours of continuous operation

**Signal Alignment**

- Primarily based on a “black-burst” stream – a video stream containing solely the colour black
- Supports alignment of analogue composite video to within 0.5ns, necessary to align phase of colour sub-carrier
- Requires dedicated cabling infrastructure and careful equalization to achieve the required performance
SMPTE and EBU created a joint task force to design a new synchronization/labelling scheme for a digital studio.

**Accuracy requirements:**
- Timing accuracy (jitter and wander) ±1µs between any two slave devices (±0.1µs preferred)
- Frequency accuracy ±0.225 ppm
- Frequency drift ±0.0226 ppm/s

**Other goals:**
- Includes sufficient information to allow generation of any current (and future) video and audio signal, synchronized to the reference
- Provides time-of-day and date information, including indication of local timezone and daylight savings time
- Runs over the existing Ethernet network interface (i.e. no new cabling infrastructure required)
- Slave implementation as simple and cheap as possible
- Time/frequency acquisition to be within a few seconds
Task Force Proposal
Common Synchronization Interface

- A common set of information, allowing:
  - Simple reconstruction of video and audio signals
  - Creation of acquisition timestamps for labelling
- Based on an “epoch”, when all video and audio signals are deemed to have zero phase
- Includes:
  - Time since epoch (seconds and fractional seconds), allowing signals to be created with correct phase
  - Control data, e.g. flags, version, lock status, datum type
  - Leap seconds, timezone and DST information
Datum Reference

CSI data is de-coupled from Datum reference

- CSI is valid at a given datum point
  - Type 0: next second boundary of network time reference
  - Type 1: specified future time given by network time reference
  - Type 2: defined reference point in a black-burst reference signal
- Not necessarily locked to time reference
- Allows locking to legacy, free-running video references
- Allows distribution of multiple independent references around the studio

Datum reference is distributed independently to the CSI

- Recommendation is to use IEEE1588 over the Ethernet control network, although other methods are allowed
- Use of IEEE1588 means both datum and CSI can be distributed over same network infrastructure
Network Asymmetry and Time Distribution
Reminder: Asymmetry

- Master frequency determined by comparison of timestamps
  - e.g. comparison of $t_1$ to $t_2$ over multiple sync messages, or $t_3$ to $t_4$ in delay_req messages

- Time offset calculation requires all four timestamps:
  - Slave time offset = \( \frac{(t_2 - t_1) - (t_4 - t_3)}{2} \)
  - assumes symmetrical delays
    - i.e. the forward path delay is equal to the reverse path delay

- Accurate time depends on a symmetrical network
- Time error = \( \text{fwd. delay} - \text{rev. delay} \)
Forward and reverse paths are routed independently in IP routing protocols, potentially causing asymmetry.

- Potential for asymmetry worse in larger networks
- Use managed networks with symmetrical paths
Network elements (e.g. switches, routers) generally read in the entire packet before forwarding
- Error check not complete until last bit received

Takes longer on a slow link than on a fast link

Read-in time of a 90 byte packet on a 1Gb/s network = 0.72µs

Delay difference on step from 1Gb/s to 100Mb/s = 6.48µs

Avoid data rate steps where possible, or explicitly correct for known data rate steps
Link Asymmetry

- Asymmetric link technology
  - e.g. xDSL, GPON, WiFi
  - Downstream delay usually shorter than upstream delay

- PHY Layer Component Forwarding Delays
  - Component delays (e.g. PHY devices) may not be the same in the forward and reverse direction
  - This may be true particularly in cases where equipment or components come from different vendors

- Differential Cable Delays
  - In twisted pair cables, each pair can be a different length
  - Delay skew between pairs can be as much as 50ns/100m
  - Use matched cables for controlled delay skew

- Asymmetric link delays are not solved by peer-to-peer transparent clocks
Achievable Performance
Test Network Diagram

- No transparent clock switches
- PTP traffic set to highest priority
Baseline Test: ITU-T G.8261 Test Case 13
Test Description Continued

<table>
<thead>
<tr>
<th>Total FW Load</th>
<th>Forward 64B</th>
<th>Forward 1518B</th>
<th>Forward 576B</th>
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<tr>
<td>80%</td>
<td>24%</td>
<td>48%</td>
<td>8%</td>
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<tr>
<td>20%</td>
<td>6%</td>
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<table>
<thead>
<tr>
<th>Total RV Load</th>
<th>Reverse 64B</th>
<th>Reverse 1518B</th>
<th>Reverse 576B</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>15%</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>10%</td>
<td>3%</td>
<td>6%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table - Individual Flow Rate for Disturbance Traffic on Forward and Reverse direction

Figure VI.11/G.8261 - Sudden Network disturbance load Modulation for 2-way

Measurement:
- Compare phase error between 1pps output of slave, and 1pps output of master
Test Results: Phase Deviation

Symmetricom TimeMonitor Analyzer  (file=00573.dat)
Phase deviation in units of time:  Fs=500.0 mHz; Fo=1.000000 Hz; *7/31/2009 12:04:24 PM*; *8/3/2009 9:28:14 AM*
HP 53132A; Test 573; TP500; n45152; 1.1.9e; Samples: 10834; Gate: 2 s; Stop: 10834; Total Points: 124914; Ref ch1; T1/T
5 SW w/QoS G.8261 TC13

Phase deviation, 50ns/division

Time, 30 minutes/division
Test Results: MTIE

Plateau at ≈250ns

Observation Interval, $\tau$
Conclusions and Deployment Recommendations
Conclusions

- ±250ns time accuracy is achievable
- Avoid data-rate steps
  - e.g. use all 1Gbit/s or 10Gbit/s networks
  - For accurate timing, faster is better!
- Manage the network for symmetrical paths
- Avoid inherently asymmetric link technology
  - e.g. ADSL, potentially some wireless technology
  - Native Ethernet links are good
- Avoid mixing switch types to minimise component asymmetry
- Keep cables short to avoid differential cable delays
  - Use matched cables if available
- Transparent clocks may aid performance in large networks
  - Don’t solve the problem of asymmetric link delays
Thank you for listening!
Any questions?