2015 NIST Investigation of PMU Response to Leap Second

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Conclusions first:

- This presentation is short (10 minutes)
- 8 PMUs and 1 GPS receiver were tested
- 4 of the PMUs got their time via IRIG from the GPS receiver
- The other 4 use internal GPS receivers.
- All of the PMUs has issues and were not in compliance with IEEE C37.118.2 immediately following the leap second.
- The GPS receiver also had an issue immediately following the leap second.
What happened to the Receiver?

• The GPS receiver used in this investigation did not fully comply with IEEE-1344[^1,^2] in two ways:
  – The BCD second and SBS count repeated 23:59:59 and did not progress to 23:59:60 before going to 00:00:00[^3].
  – The Leap Second Pending bit transitioned from 0 to 1 at 23:58:59, (one second early) and from 1 to 0 during the repeated 23:59:59, one second before the transition to 00:00:00 as specified.

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[^1]: IEEE-1344 is the common name for the extension to IRIG published in the PMU standard. The latest version of this is in Annex D of C37.118.1-2011.
[^2]: Some technical changes happened between 1999, 2005, and 2011, use the 2011 standard!
[^3]: Specified by IEEE-1344 but the IRIG standard is ambiguous on SBS behaviour.
What did the PMUs do?

Table 10: Summary of PMU response to leap second

<table>
<thead>
<tr>
<th>PMU ID</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total period of time the SOC was not synchronized with UTC</td>
<td>17.000 s</td>
<td>47.000 s</td>
<td>4.000 s</td>
<td>0.150 s</td>
<td>1.933 s</td>
<td>4.000 s</td>
<td>2.000 s</td>
<td>3.000 s †</td>
</tr>
<tr>
<td>Pending bit was set at all</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Pending bit was set and cleared at the correct time</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Occurred bit was set at all</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Occurred bit was set and cleared at the correct time</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Number of seconds of TOD for which there were less the proper number of reports</td>
<td>1</td>
<td>1</td>
<td>many ††</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of seconds of TOD for which there was more than the proper number of reports</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

† PMU ID 8 was not synchronized with UTC for 1 second beginning 59 seconds before leap second and for 2 seconds immediately following leap second.

†† PMU ID 3 Beginning at the leap second and continuing at the time of writing, PMU ID 3 has sporadic periods where there are only 46 reports during a second. 14 reports are missing during these seconds.

Of the 4 PMUs using IRIG, only one of their behaviors could directly relate to the GPS receiver’s incorrect behavior, the other 3 had issues as not directly attributable to the problem in the IRIG.
What happens when the time is not synchronized?

- “Missing” reports (the time never happened)
- “Duplicated” reports (reports that should have had a different time stamp)

Example from PMU ID 1
What about the phase angles?

- for reports with incorrect time stamps, the phase angle “error” depends on the system frequency
  - At nominal frequency the phase angle is not changing.
  - So we ran the test at a constant 59.9Hz system frequency so you can see the phase angle “error”

![Phase Error Graph](image)

Again, an example from PMI ID 1
- For 17 seconds, it appears like the phase has a 36 degree error (at 59.9Hz)
- Note that there are no reports for the second immediately following the leap second
- And there are two sets of reports for the second between 17 and 18 seconds after.
What should be done about this?

• IRIG standard is ambiguous about leap second responses so the ambiguities should either be clarified or vendors using IRIG will need to respond to every possible interpretation.

• All vendors need to test their devices for response to leap second.
  – This may mean expensive GPS simulation hardware will be needed for those devices with GPS receivers.

• Think hard about our critical infrastructure without testing of LS response.

• Read the NISTIR report and learn from the experiences of others.
Questions?

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