Why do we need Synchronization?

- Event ordering
- Fairness in Race Conditions
- Security
- Event Forensics
Physicists noted that some materials generate very stable reference signals at predictable periods (cesium, rubidium).

If you count these periods ...

The SI definition of a second is the time that elapses during 9,192,631,770 cycles of the radiation produced by the transition between two levels of the cesium 133 atom.
Time Scales are Agreed Upon and “Local”

UTC (USNO)  
UTC (NIST)  
Mike Time
Time Accuracy and Precision are Distinct

- Precise, Not Accurate
- Precise & Accurate
- Accurate, Not Precise
The Path of Time Transfer

Time is measured at a source.

Time stamps are transferred from that source to end applications.

Delays are known or bounded.

Master Clock

00:00:00.000000

+/- X

+/- Y

+/- Z

00:00:00.000???
Time Transfer and Time Sources are Different

UTC(USNO) → U.S. Air Force

→ GPS

→ NTP

→ PTP

→ Application

→ PTRC

→ LTE

→ U.S. Air Force

→ GPS

→ GPS Rx

→ GPS Rx

→ GPS Rx

→ GPS Rx
Financial Business Clock Time Sources

- NTP, 27%
- GPS, 6%
- PTP, 6%
- CDMA, 2%
- Other Technologies, 3%
- Did Not Know, 16%
- Multiple Technologies, 40%

(FROM 2017 SEC CLOCK SURVEY)
Precise code phase alignment can give < 10 nanoseconds of precision

Distance (m) / Speed of Light (m/s) = Delay (Rule of Thumb: 1 ft / ns)
GPS is Vulnerable to Manipulation

Data Attacks

Broadcast by GPS

\[ t_{UTC} = W [\text{Modulo} (86400 + \Delta t_{LSF} - \Delta t_{LS}))], \text{ (seconds)}; \]

where

\[ W = (t_E - \Delta t_{UTC} - 43200) \text{[Modulo 86400]} + 43200, \text{ (seconds)}; \]


Repeaters or Unsynchronized Spoofers

GPS Rx locks on to dominate signal

Time will jump around.

Code Phase Synchronous Spoofers

GPS Rx locks on to dominate signal and that signal is very close to the real signal

Time may advance more or less quickly ... but at a high level, may appear accurate.
How GPS Time can be Subtly Spoofed

Spoofer

Path Delay

0100110110101011010101110101

Near Matched Delay

SV Transmits PN Sequence

0100110110101011010101110101

Rx Generates local copy and aligns it to transmitted sequence

Precision of alignment determines precision of time delay calculation

0100110110101011010101110101

0100110110101011010101110101
Review So Far

- Time is “made up”
- Time is Measured directly or Transferred
- GPS is a common source of time across all applications
- Timing and Synchronization requirements exist at a variety of levels across applications
- So... What happens when Synch breaks down?
<table>
<thead>
<tr>
<th>Application/Technology</th>
<th>Accuracy</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCDMA MBSFN</td>
<td>12.8 µs</td>
<td>[b-3GPP TS 25.346] sections 7.1A and 7.1B.2.1</td>
</tr>
<tr>
<td>LTE-TDD (wide-area)</td>
<td>10 µs</td>
<td>[b-3GPP TS 36.133]) section 7.4.2</td>
</tr>
<tr>
<td>LTE-TDD to CDMA</td>
<td>10 µs</td>
<td>[b-TS 3GPP TS 36.133] section 7.5.2.1</td>
</tr>
<tr>
<td>CDMA2000</td>
<td>3 µs</td>
<td>[b-3GPP2 C.S0002] section 1.3; [b-3GPP2 C.S0010] section 4.2.1.1</td>
</tr>
<tr>
<td>WCDMA-TDD</td>
<td>2.5 µs</td>
<td>[b-3GPP TS 25.402] sections 6.1.2 and 6.1.2.1</td>
</tr>
<tr>
<td>WiMAX (downlink)</td>
<td>1.428 µs</td>
<td>[b-IEEE 802.16] table 6-160, section 8.4.13.4</td>
</tr>
<tr>
<td>WiMAX (base station)</td>
<td>1 µs</td>
<td>[b-WMF T23-001], section 4.2.2</td>
</tr>
<tr>
<td>Primary Reference Time Clock</td>
<td>100 ns</td>
<td>[ITU-T G.8272] (Primary Reference Time Clock)</td>
</tr>
<tr>
<td>Enhanced PRTC</td>
<td>30 ns</td>
<td>[ITU-T G.8272.1] (Enhanced Primary Reference Time Clock)</td>
</tr>
</tbody>
</table>
# Power Grid Uses of Time

<table>
<thead>
<tr>
<th>Grid application</th>
<th>Timing requirements (minimum reporting resolution and accuracy relative to UTC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced time-of-use meters</td>
<td>15, 30, and 60 minute intervals are commonly specified (ANSI C12.1)</td>
</tr>
<tr>
<td>Non-TOU meters</td>
<td>Ongoing, with monthly reads or estimates</td>
</tr>
<tr>
<td>SCADA</td>
<td>Every 4-6 seconds reporting rate</td>
</tr>
<tr>
<td>Sequence of events recorder</td>
<td>50 µs to 2 ms</td>
</tr>
<tr>
<td>Digital fault recorder</td>
<td>50 µs to 1 ms</td>
</tr>
<tr>
<td>Protective relays</td>
<td>1 ms or better</td>
</tr>
<tr>
<td>Synchrophasor/phasor measurement unit (30 - 120 samples/second)</td>
<td>Better than 1 µs 30 to 120 Hz</td>
</tr>
<tr>
<td>Traveling wave fault location</td>
<td>100 ns</td>
</tr>
<tr>
<td>Micro-PMUs (sample at 512 samples/cycle)</td>
<td>Better than 1 µs</td>
</tr>
</tbody>
</table>

**Communications protocols**

| Substation local area network communication protocols (IEC 61850 GOOSE) | 100 µs to 1 ms synchronization |
| Substation LANs (IEC 61850 Sample Values) | 1 µs |

From NASPI-2017-TR-001
## EU Finance Requirements in Effect Jan. 2018

### Level of accuracy for operators of trading venues

<table>
<thead>
<tr>
<th>Gateway-to-gateway latency time of the trading system</th>
<th>Maximum divergence from UTC</th>
<th>Granularity of the timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 1 millisecond</td>
<td>1 millisecond</td>
<td>1 millisecond or better</td>
</tr>
<tr>
<td>≤ 1 millisecond</td>
<td>100 microseconds</td>
<td>1 microsecond or better</td>
</tr>
</tbody>
</table>

### Level of accuracy for members or participants of a trading venue

<table>
<thead>
<tr>
<th>Type of trading activity</th>
<th>Description</th>
<th>Maximum divergence from UTC</th>
<th>Granularity of the timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity using high frequency algorithmic trading technique</td>
<td>High frequency algorithmic trading technique.</td>
<td>100 microseconds</td>
<td>1 microsecond or better</td>
</tr>
<tr>
<td>Activity on voice trading systems</td>
<td>Voice trading systems as defined in Article 5(5) of Commission Delegated Regulation (EU) 2017/583</td>
<td>1 second</td>
<td>1 second or better</td>
</tr>
<tr>
<td>Activity on request for quote systems where the response requires human intervention or where the system does not allow algorithmic trading</td>
<td>Request for quotes systems as defined in Article 5(4) of Delegated Regulation (EU) 2017/583</td>
<td>1 second</td>
<td>1 second or better</td>
</tr>
<tr>
<td>Activity of concluding negotiated transactions</td>
<td>Negotiated transaction as set out in Article 4(1)(6) of Regulation (EU) No 609/2014.</td>
<td>1 second</td>
<td>1 second or better</td>
</tr>
<tr>
<td>Any other trading activity</td>
<td>All other trading activity not covered by this table.</td>
<td>1 millisecond</td>
<td>1 millisecond or better</td>
</tr>
</tbody>
</table>

*From COMMISSION DELEGATED REGULATION (EU) 2017/574*
Some Scenarios – Financial Front Running

T = 0.000
Buyer buys 1000000 shares of ABC
Seller sells 100000 shares of ABC
T = 0.002

T = 0.001

T = 0.00000
Seller sells 1000000 shares of ABC
T = 0.00010

T = 0.00035
Buyer buys 100000 shares of ABC
T = 0.00200

Which ordering of events would you prefer? What if you could change your time stamp?
On January 25th, 2016, during the retirement of the last IIA satellite, an error occurring in the GPS system causing many receivers that used the UTC correction broadcast by the satellites to be ~13.7 microseconds deviant from truth.

- Global effect
- Not all satellites broadcast erroneous data
- Affected receivers needed to obtain their UTC offset from a bad satellite – i.e. not all receivers with a common skyview would have been affected
Suspect a GPS Problem? Call the Coast Guard

1) * Your Name: (Our Privacy Policy)
2) * Email Address:
3) * Telephone number: [i.e. - (703) 313-5900]
4) Preferred method and time to be contacted if additional information is necessary:
5) * What was the start time and date of the GPS disruption?
6) * Is the GPS disruption ongoing?
7) * Where did the disruption occur? (LAT/LONG, Nearest City or landmark)
8) GPS user equipment make and model (receiver manufacturer and model, antenna type, etc.)?
9) GPS installation type (aviation, marine, surveying, agriculture, transportation, timing)?
10) What was the elevation of the GPS antenna?
11) What GPS frequency are you using?
12) How many satellites were being tracked at the time of the disruption?
13) Which satellites were being tracked at the time of the disruption?
14) What was the GPS receiver being used for at the time of occurrence?
15) Summary (Please provide any additional information, unusual screen display indicating a problem and/or operator intervention that may have helped)

Date: 04/05/2018
Time:     Zone: Select Time Zone ▼
Select ▼

Lat Long City/Landmarks

Click Here For Choices ▼ Other:

Click Here For Choices ▼ Above Ground Level
Click Here For Choices ▼ Above Sea Level

Remaining Characters 3000
Effects (caused by an ~12 hour event)

- Of ~80 NIST clocks monitoring event, only 11% were unaffected
- Some high performance precision timing receivers took 1+ day to resynchronize to their previous levels of stability
- Many precision timing receivers entered into holdover (starting a countdown hours to out-of-spec performance)
- At least one telecommunications backhaul provider reported that it was necessary to manually reset affected precision timing receivers
- Some clocks located in telecom systems started to free run with no atomic discipline or back up
- Many organizations that should have been affected did not report any impact (did they even know how close they came to major issues?)
It is Really Hard to Get Away from GPS...

<table>
<thead>
<tr>
<th>Timing Source</th>
<th>GPS Dependent</th>
<th>Scale</th>
<th>Availability</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNSS</td>
<td>Yes</td>
<td>&lt; 100 ns</td>
<td>Global</td>
<td>Not appropriate for all environments; may be denied</td>
</tr>
<tr>
<td>GSM NTIZ</td>
<td>Yes</td>
<td>~1s</td>
<td>Regional</td>
<td></td>
</tr>
<tr>
<td>CDMA2000 Sync</td>
<td>Yes</td>
<td>1 ms</td>
<td>Regional</td>
<td></td>
</tr>
<tr>
<td>LTE R11+ SIB 16</td>
<td>Yes</td>
<td>10 ms</td>
<td></td>
<td>Not widely deployed. 10 ms may not be sufficiently precise.</td>
</tr>
<tr>
<td>Iridium Time (Satelles)</td>
<td>Yes</td>
<td>&lt; 500 ns</td>
<td>Global</td>
<td>Paid Service; May have higher availability than GNSS</td>
</tr>
<tr>
<td>eLoran</td>
<td>Yes</td>
<td>&lt; 100 ns</td>
<td>Europe, Asia, Middle East</td>
<td>Not available in the US</td>
</tr>
</tbody>
</table>
Upcoming 5G and IoT Sync Requirements

- Edge of network sync in TDD LTE is \(~ 1\) microsecond; 5G proposes to aggressively push this down – thereby increasing dependency on synch
- Synchronization requirements between cloud processes and events will become stricter
- IoT will need ways to synch local devices
Organizations that are working on this

- ATIS Synchronization Committee
- Resilient Navigation & Timing Foundation
- Network Time Foundation
- North American Synchrophasor Initiative (NASPI)
- National Space-Based PNT Advisory Board and PNT Executive Committee
Conclusions

- GPS remains the most convenient source of time transfer and is the only technology capable of meeting upcoming synchronization requirements efficiently.

- 2017 and 2018 are seeing many new synchronization applications being deployed across telecom, finance, transportation, and

- Sync needs to be done securely and deliberately.

- Secure Synchronizations Solutions exist today; advocacy is needed at a national level for an alternative system to GPS.
Selected References

- NIST Report on January 2016 Outage

- SEC Clock Survey

- NASPI
  - [https://www.naspi.org/sites/default/files/reference_documents/tstf_electric_power_system_report_pnnl_26331_march_2017_0.pdf](https://www.naspi.org/sites/default/files/reference_documents/tstf_electric_power_system_report_pnnl_26331_march_2017_0.pdf)
Apply What You Have Learned Today

- Next week you should:
  - Identify synchronization dependent applications within your organization

- In the first three months following this presentation you should:
  - Understand where these sync-dependent applications get their time from and their corresponding tolerances for failure

- Within six months you should:
  - Understand how to attribute system failures to synchronization outages
  - “Protect, Toughen, and Augment” your Timing Sources and Sync Methods

Michael Calabro
Calabro_Michael@bah.com