Power Matters.

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GNSS Vulnerabilities and Mitigation

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Key Differences between GNSS for Timing Applications compared to General Navigation

1) The Timing Applications for Small Cell require operation in a Stationary Environment.

2) With Densification the location of a GNSS timing unit is the same edge environment as small cells including both indoor and urban canyon operation

3) Challenges of this stationary environment is that the unit is continuously exposed to the same environment which may include dispersive effects like multipath and reflections as wells as environmental noise. The satellite signal source do move slowly in the sky but constellation geometry effect will persist for long periods.

Impact of Stationary Local Environment on GNSS Reception*

1) Attenuation of the signals by roofs (10-20dB), floors (10dB) and even tinted windows (10dB),

2) Multipath fading effects,

3) Pseudo range errors resulting from path increases cause by path length increases both inside the building and, more importantly, from nearby structures.

4) Cross-correlation effects

5) Presence of CW interference sources

* Material From: *Femtocell Synchronization and Location* (A Small Cell Forum White Paper), May 8, 2012

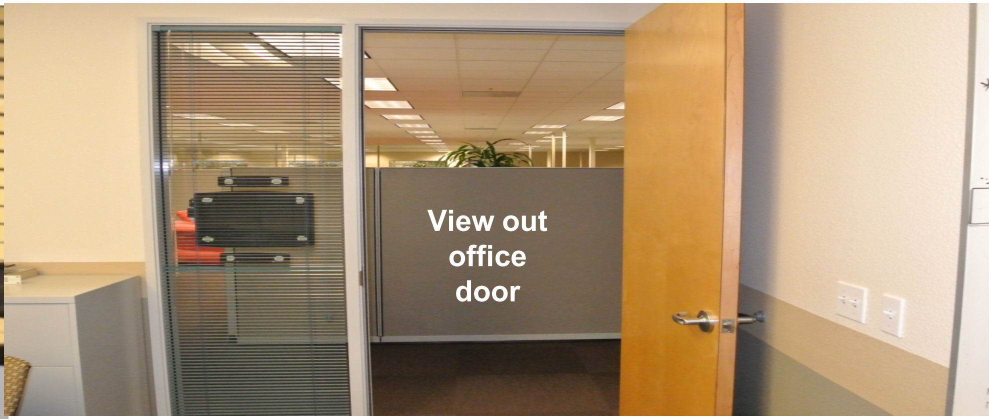
Application Scenario Definitions*

1) Outdoor or Indoor,
2) Building type
3) Rural, suburban, urban or dense urban
4) Topography

* Material From: *Femtocell Synchronization and Location* (A Small Cell Forum White Paper), May 8, 2012

Baseline Test: Laboratory Facility Test Location

Antenna location interior 2nd floor office

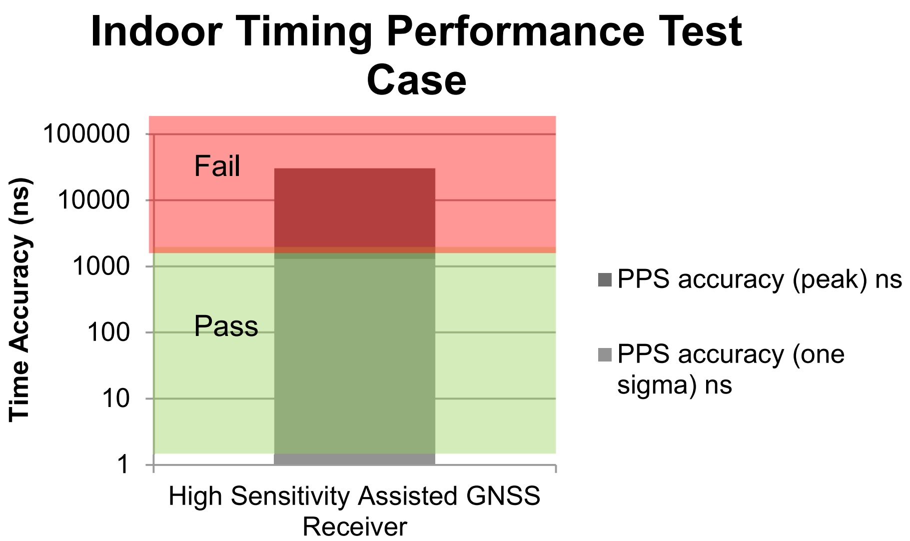


Baseline Performance Testing at our Laboratory Facility

- Antenna located in internal office 2nd floor inside file cabinet and instrumentation metal case.

- The current generation GNSS timing receiver required an externally supplied manual precise position to even work at all.

- The receiver operated with a peak error of 29.1 microseconds and the peak error is 22 times larger that the rms error (large error excursions).



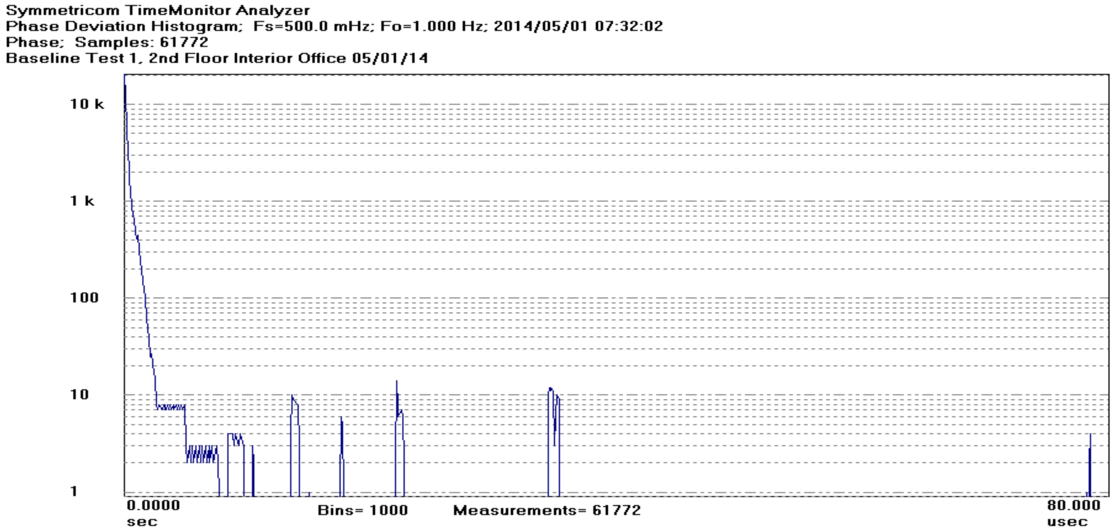
Baseline Performance Testing PPS at our Laboratory Facility

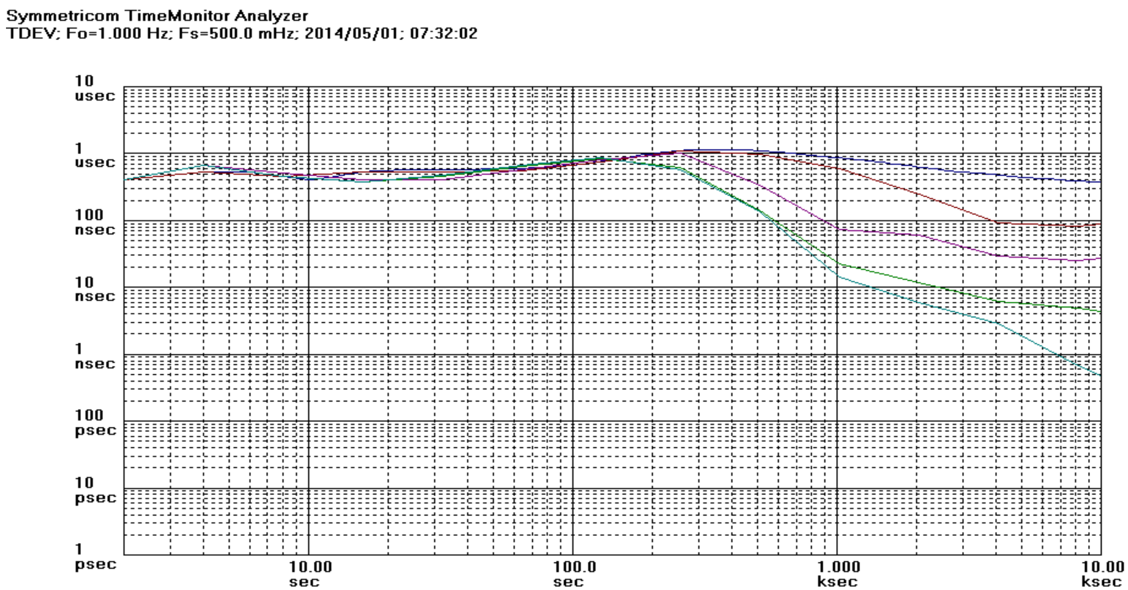
- Antenna in equipment chassis place inside file cabinet

- Assisted Operation: Ephermeris Assist-30 minute update
- Unit could not achieve fix so precise position provided manually

- The PPS time error is a single sided distribution very similar to the distribution of packet delay variation. This suggest analysis with floor statistics.

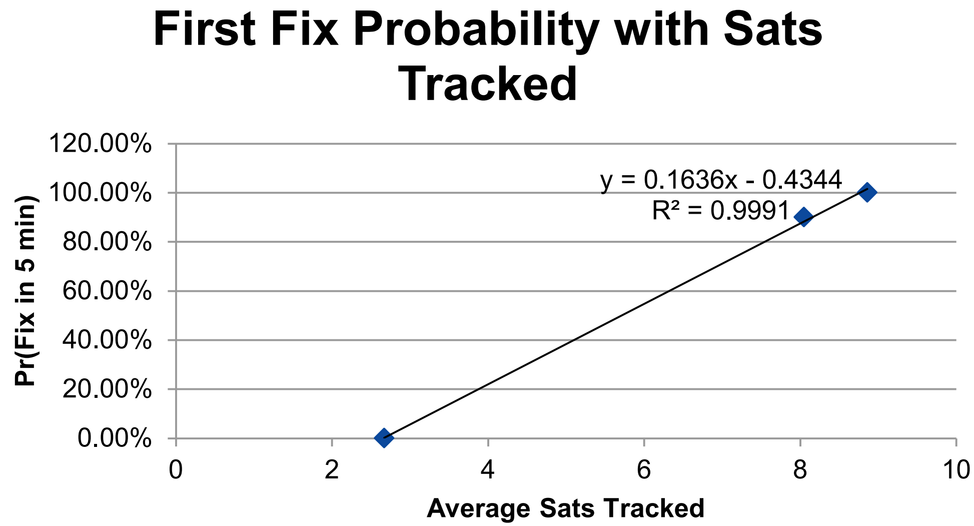
- Floor stability percentile TDEV overlay graph shows following
    - For observation Tau greater than 5 minutes we begins to see improvement in stability.
    - At a 20 minute window the improvement is very significant 884 ns compared to 16 ns (35 dB gain)
    - A mitigation approach utilizing a stable local frequency is intriguing.

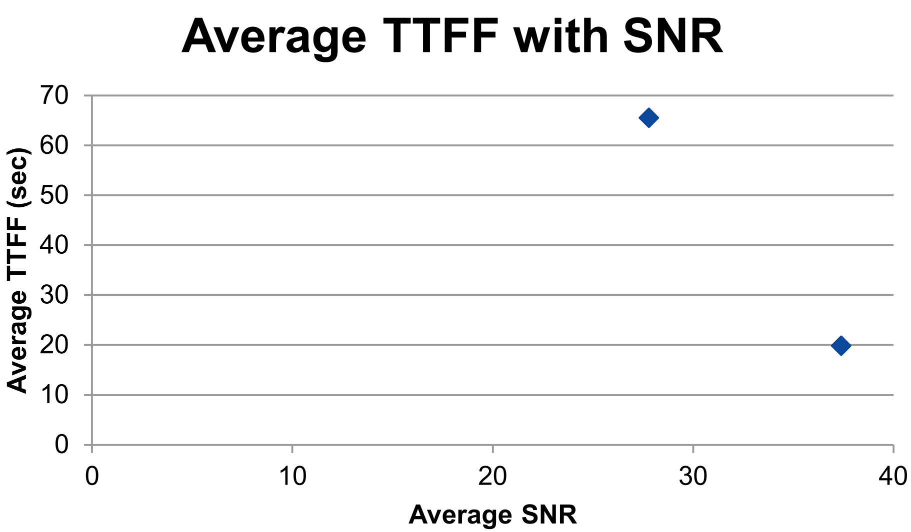




Baseline Performance Testing (First Fix) at our Laboratory Facility

- Tested with 3 attenuation scenarios:
  - Patch antenna with no anti-static bag
  - Patch antenna in anti-static bag
  - Patch antenna with double anti-static bag.
- Ten factory cold restart trials performed for each scenario.
- Without precise position fix no time service can be provided.
- Probability of a fix in first 5 minutes strongly correlated with average satellites tracked.
- Given a fix the average time to first fix correlated with average SNR.
- General observation:
  - Average GPS sats tracked above 8.0 yields high probability of fix.
  - Average SNR at 21.4 dB yielded no successful tracks.





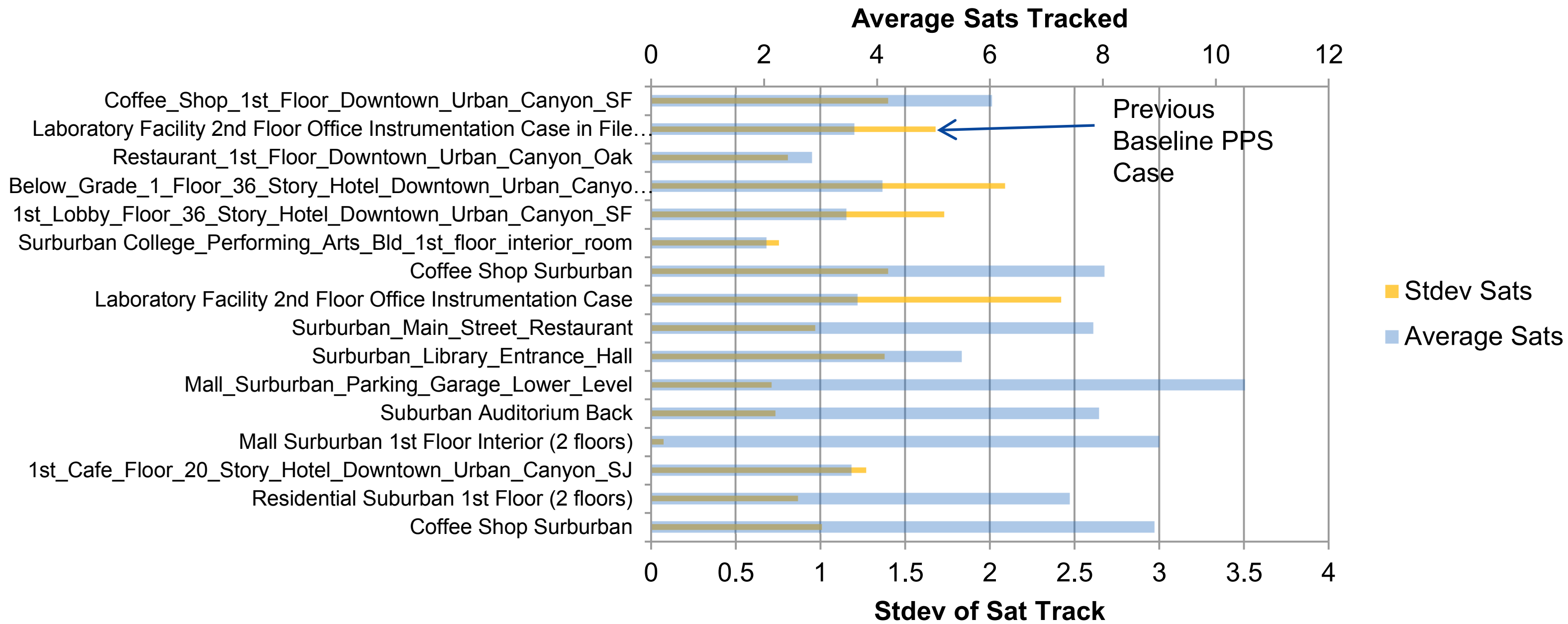
Indoor Performance Real World Survey (Summary Metrics)

- Two core operational metrics
  - Satellites Tracked
  - Signal To Noise Ratio (next slide)

- Indoor environment show a wide range of static average sats tracked from a min of 2.0 (College Arts Building) to a max of 10.5 (Mall Parking Garage)

- Environment also exhibits a range of dynamic spread of sats tracked with a low of 0.808 (Restaurant Oak) to a max of 2.42 (Lab. Facility)

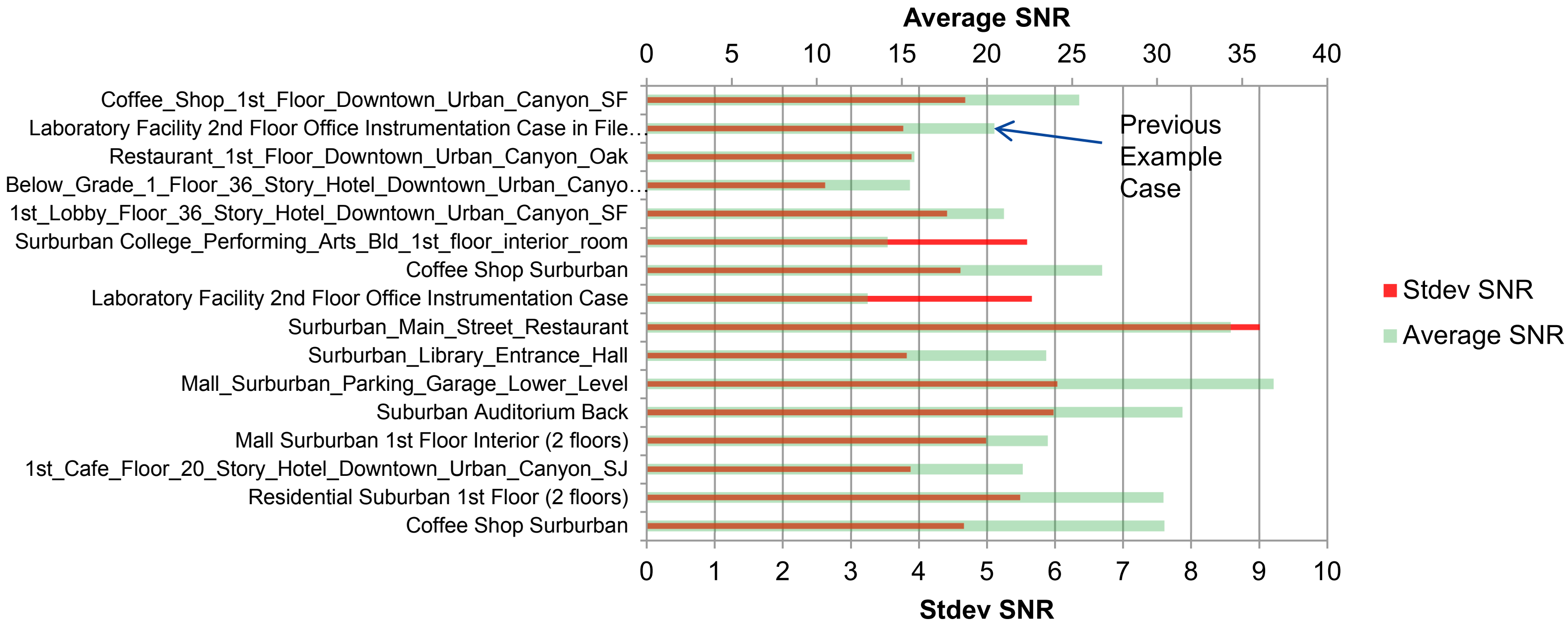
- Bottom Line without additional mitigation:
  - 53% of 17 surveyed locations have low probability of successful position fix.
  - 100% of the 5 urban canyon locations have low probability of successful position fix



Indoor Performance Real World Survey (Summary Metrics Continued)

- Signal To Noise Ratio
- Indoor environment show large range of static average SNR from a min of 12.98 (Lab Facility) to a max of 31.4 (Mall Parking Garage)

- Environment also exhibits large range of dynamic spread SNR with a low of 2.6 (below grade urban hotel) to a max of 9.0 (Main Street Restaurant)
- Bottom Line without additional mitigation
  - 41% of survey location below average SNR required to achieve a first fix in baseline.
  - 80% of urban canyon location are below average SNR required to achieve first fix.



Mitigation Approaches

1) Small Cell Synchronization Report suggests in section 7.3 the use of multiple sources of synchronization specifically external frequency references combined with AGPS can be an effective strategy.

2) A mitigation solution that addresses, time, frequency and positioning service requirements in a cost effective manner is advantageous. PTP and NTP are key components but do not directly address precision position service needs.

3) This study suggests the external frequency/time sources can be used not just as backup but as a means to stabilize the local oscillator and increase observation windows to potentially greatly improve performance in stationary environments.

4) Mitigation approached that will address the needs of a stationary timing environment are not emerging from the natural evolution of commercial navigation centric GNSS devices.