Effect of GNSS multipath on timing receivers

Measuring PRTC time under severe multipath conditions in dense urban environments

Akis Drosinos/Tim Frost
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Session objectives

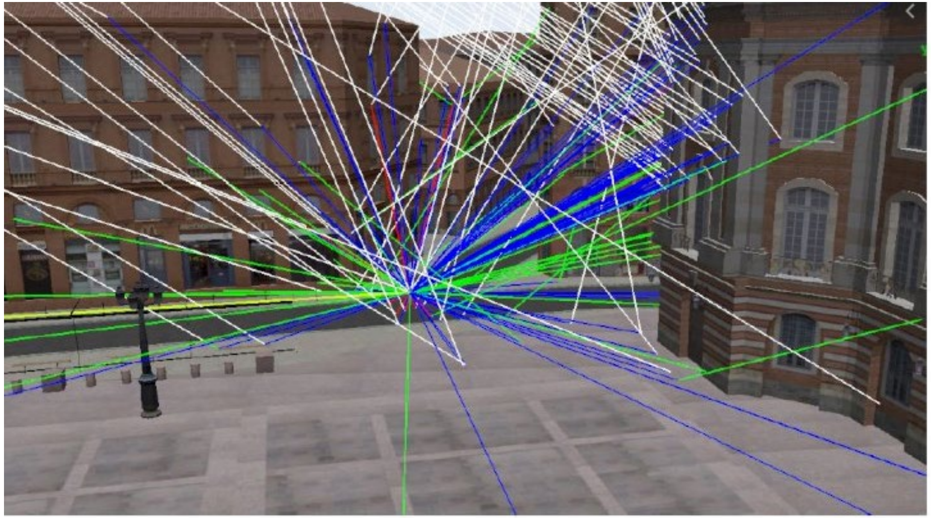
1. Talking you through the set-up that was used to conduct the measurements.
2. Presenting the experimental results of the effects multipath has on timing receivers in dense urban environments.
3. Discussing about the importance of introducing new testing methods to measure such effects.

Introduction

- Sometimes the GNSS-based PRTC’s might be installed in areas where there is not a clear view of the sky, e.g. in dense urban environments.
- Multipath will degrade the performance of the timing accuracy of the GNSS-based PRTC’s and therefore providing testing methods in order to “measure” this error is of utmost importance.

Multipath 1/2

Urban canyon environments



Multipath 2/2

Geometry & characteristics

- It depends solely on the environment around the antenna and is therefore very difficult to be modelled.
  - A constructive multipath interference results in an increase in the C/N0, while a destructive interference results in a decrease in the C/N0. [1]
  - Moreover, multipath interference might be constructive on one frequency and destructive on another. [1]
- In our tests, we considered GPS L1 and GLONASS L1 due to frequency limitations on the PRTC.

Time error measurement tests set-up 1/4

- Our set-up was based on Figures I.7 and I.8 of Appendix I in the G.8272/Y.1367 Recommendation.
- However, since those set-ups didn’t take into account non-ideal GNSS conditions, we introduced a 3D ray tracing software in order to simulate a realistic multipath environment.
- All runs were ~1 day long, static, and before the measurements, the DUT was always in “Position-Fix” mode, locked to GNSS.

Time error measurement tests set-up 2/4

- The atmospheric conditions, in the simulator, were normal and there were no other forms of interference present.
- Satellite clock or track errors were not applied either.
- The measured values, from the Packet and Timing Monitor device, where the:
  - 1 PPS absolute time error
  - 2-way time error (PTP measurement)

Time error measurement tests set-up 3/4

- For our tests we used the following equipment:
  - a GNSS signal generator with enough GNSS channels to simulate the multipath environment.
  - a GNSS-based PRTC/T-GM supporting PTP and 1 PPS, capable of tracking GPS L1 & GLONASS L1 frequencies.
  - a 3D ray tracing software.
  - a Packet Timing Monitor.

Time error measurement tests set-up 4/4

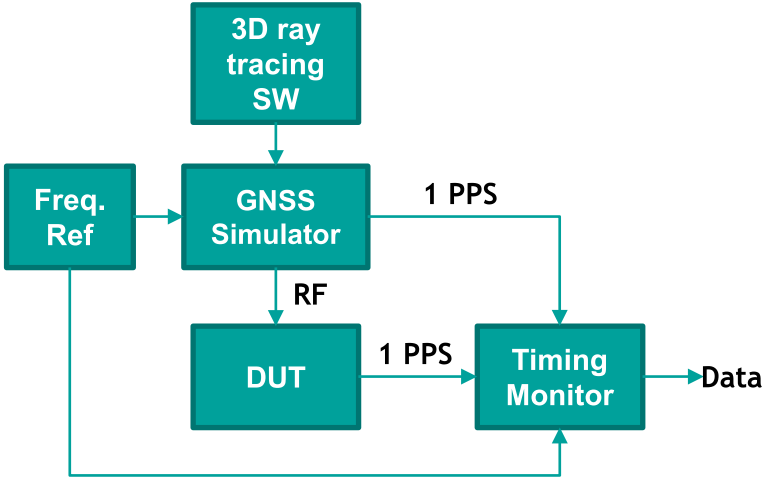


Figure 1: 1 PPS measurement set-up

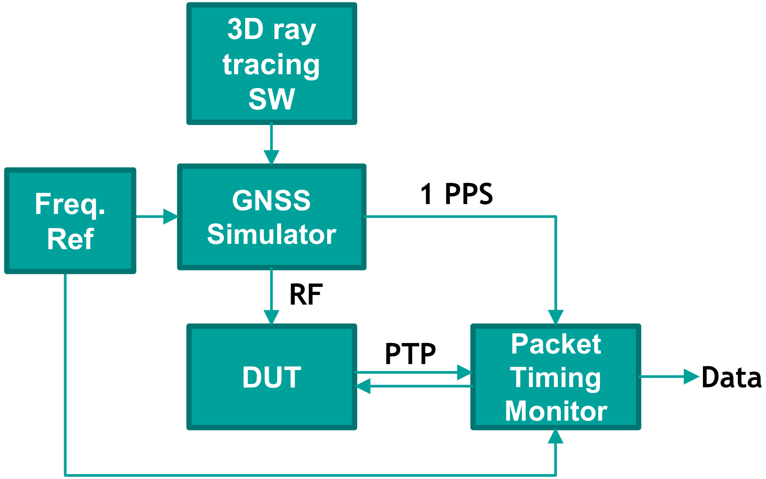


Figure 2. PTP measurement set-up

Simulated Scenes

- The dense urban environments, for which we ran our experimental tests, are:
    1. San Francisco, California
    2. Manhattan, New York
    3. Shanghai, China

San Francisco 1/3

3D scene

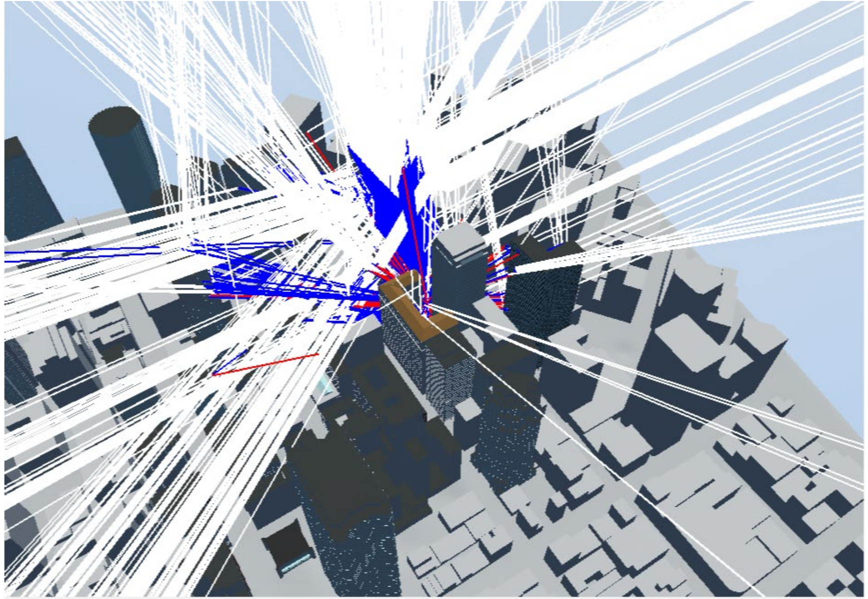


Figure 3: San Francisco multipath environment

- The white lines represent the direct signals
- The blue lines represent the refracted signals
- The red lines represent the reflected signals

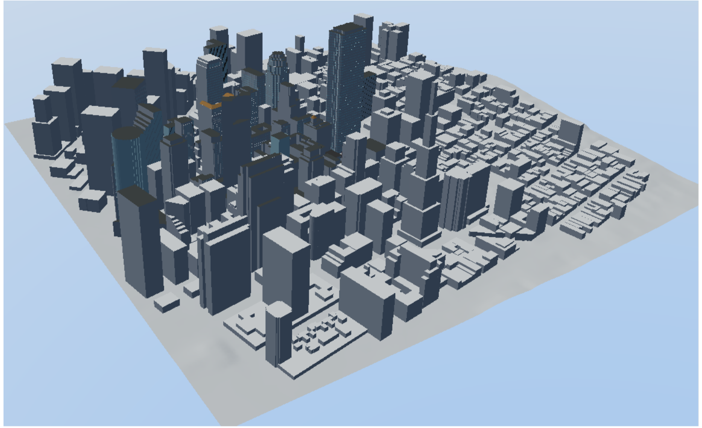


Figure 4: San Francisco 3D scene

San Francisco 2/3

Open sky conditions

Time Error Analysis

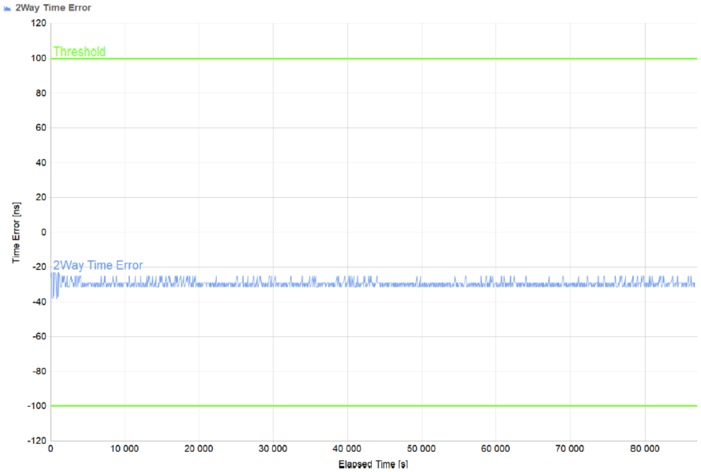
Offset Removal Applied	Off
Zero Offset	-23 ns

Mean [ns]	-24.899
Min [ns]	-32
Max [ns]	-20
Max-Min [ns]	12

Figure 7. 1 PPS absolute time error under open-sky conditions

Time Error Analysis

Include Correction Field	On



Mean [ns]	-29.623
Min [ns]	-38.5
Max [ns]	-23
Max-Min [ns]	15.5
Fwd Messages	1386244
Rev Messages	1386244
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 8. 2-way time error under open-sky conditions

San Francisco 3/3

Multipath conditions

Time Error Analysis

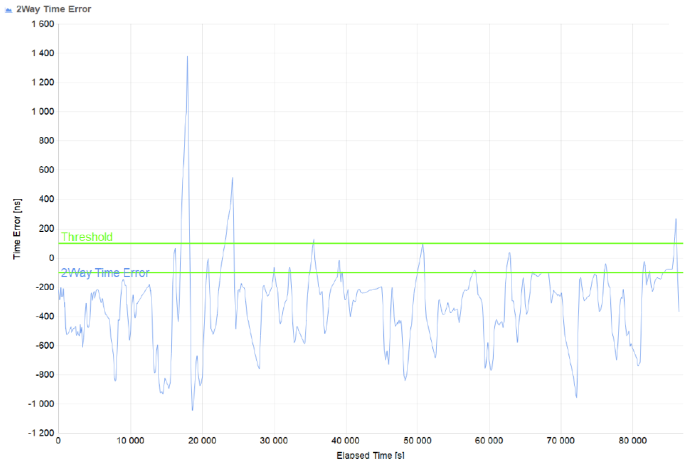
Offset Removal Applied	Off
Zero Offset	-213 ns

Mean [ns]	-233.901
Min [ns]	-942
Max [ns]	1482
Max-Min [ns]	2424

Figure 5. 1 PPS absolute time error under multipath conditions

Time Error Analysis

Include Correction Field	On



Mean [ns]	-326.92
Min [ns]	-1045
Max [ns]	1379.5
Max-Min [ns]	2424.5
Fwd Messages	1382268
Rev Messages	1382269
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 6. 2-way time error under multipath conditions

Manhattan 1/4

3D scene

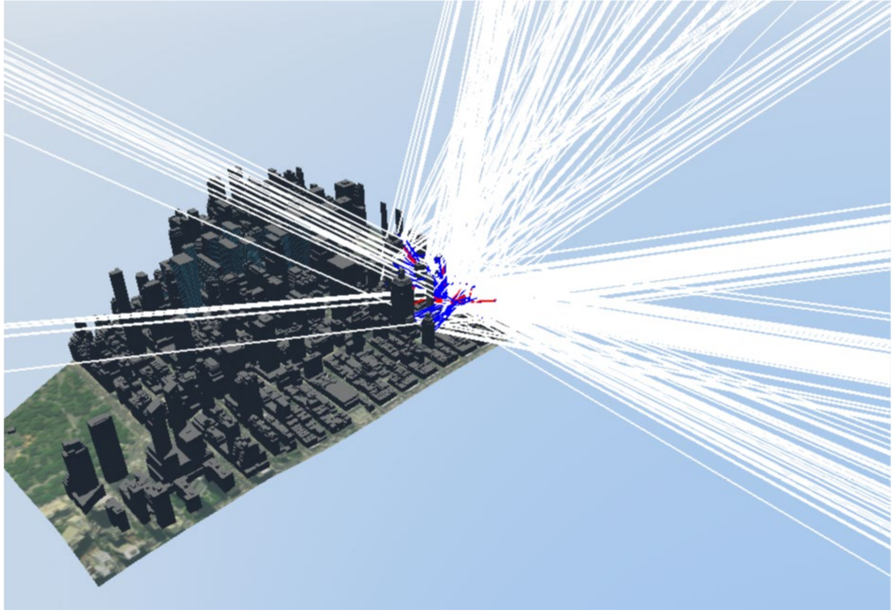


Figure 9: Manhattan multipath environment

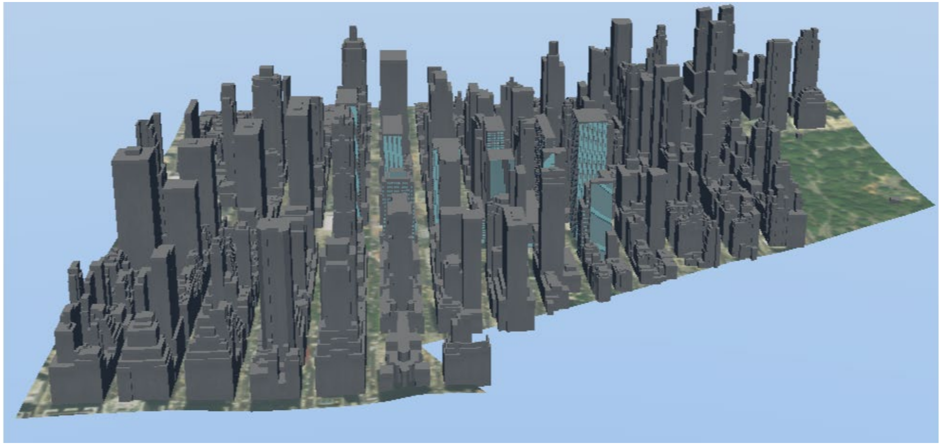


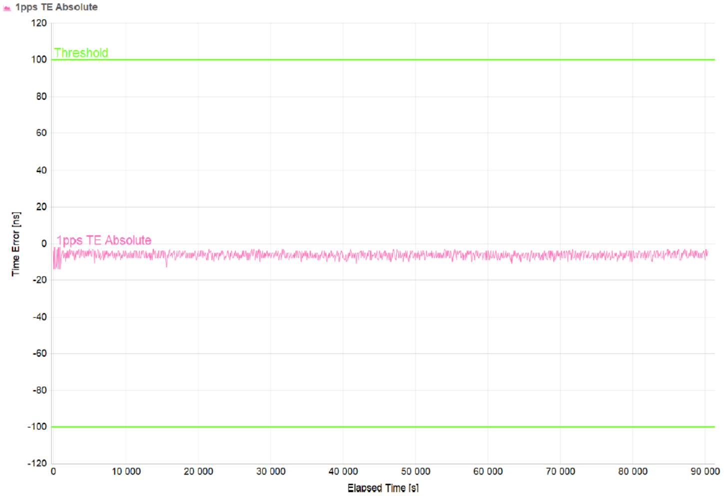
Figure 10: Manhattan 3D scene

Manhattan 2/4

Open sky conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-4 ns

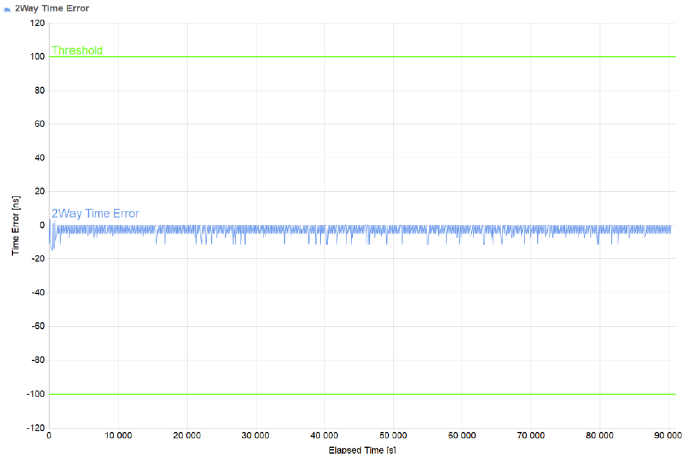


Mean [ns]	-6.442
Min [ns]	-14
Max [ns]	-2
Max-Min [ns]	12

Figure 13. 1 PPS absolute time error under open-sky conditions

Time Error Analysis

Include Correction Field	On



Mean [ns]	-1.233
Min [ns]	-15
Max [ns]	3.5
Max-Min [ns]	18.5
Fwd Messages	1444967
Rev Messages	1444954
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 14. 2-way time error under open-sky conditions

Manhattan 3/4

Multipath conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-48 ns

Mean [ns]	32.345
Min [ns]	-436
Max [ns]	144
Max-Min [ns]	580

Figure 11. 1 PPS absolute time error under multipath conditions

Time Error Analysis

Include Correction Field	On

Mean [ns]	26.224
Min [ns]	-441.5
Max [ns]	136.5
Max-Min [ns]	578
Fwd Messages	1389047
Rev Messages	1389030
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 12. 2-way time error under multipath conditions

Manhattan 4/4

GNSS status of the DUT

Latitude : N40:45:32.698
Longitude : W73:58:53.175
HGT Val Ellipsoid : 52.5 m
HDOP : 0.6 m
PDOP : 100.0 m
Fix Quality : 1
Used Satellites : 17
Receiver Status : Tracking
Operation Mode : Position_fix
Antenna Status : OPEN

Current GNSS Satellite View:

Index	GnssID	SatID	SNR	Azimuth	Elev	PrRes
1	GPS	2	45	358	71	2
2	GPS	4	45	69	43	6
3	GPS	5	44	269	31	1
4	GPS	10	45	215	50	2
5	GPS	12	45	256	37	4
6	GPS	13	44	58	22	6
7	GPS	17	44	135	10	3
8	GPS	23	43	34	7	1
9	GPS	24	44	273	10	1
10	GPS	29	44	313	9	-1
11	GPS	30	44	297	26	-2
12	Glonass	3	41	98	57	3
13	Glonass	4	40	354	65	-21
14	Glonass	13	42	41	52	4
15	Glonass	14	40	180	68	5
16	Glonass	15	41	202	14	15
17	Glonass	20	41	312	7	12

Figure 15. GNSS status of DUT under open sky conditions

GNSS Status

Latitude : N40:45:31.050
Longitude : W73:58:51.060
HGT Val Ellipsoid : 14.6 m
HDOP : 1.7 m
PDOP : 100.0 m
Fix Quality : 1
Used Satellites : 6
Receiver Status : Tracking
Operation Mode : Position_fix
Antenna Status : OPEN

Current GNSS Satellite View:

Index	GnssID	SatID	SNR	Azimuth	Elev	PrRes
1	GPS	3	31	170	29	-885
2	GPS	6	20	161	18	-938
3	GPS	14	44	71	43	339
4	GPS	22	9	54	17	121
5	Glonass	3	40	210	63	-298
6	Glonass	14	16	272	47	126

Figure 16. GNSS status of DUT under multipath conditions

- There is a big difference in the ellipsoidal height, the pseudorange residuals and in the satellites that were used from the receiver.
- Also, the CN0 values are much smaller in Figure 16.

Shanghai 1/4

3D scene

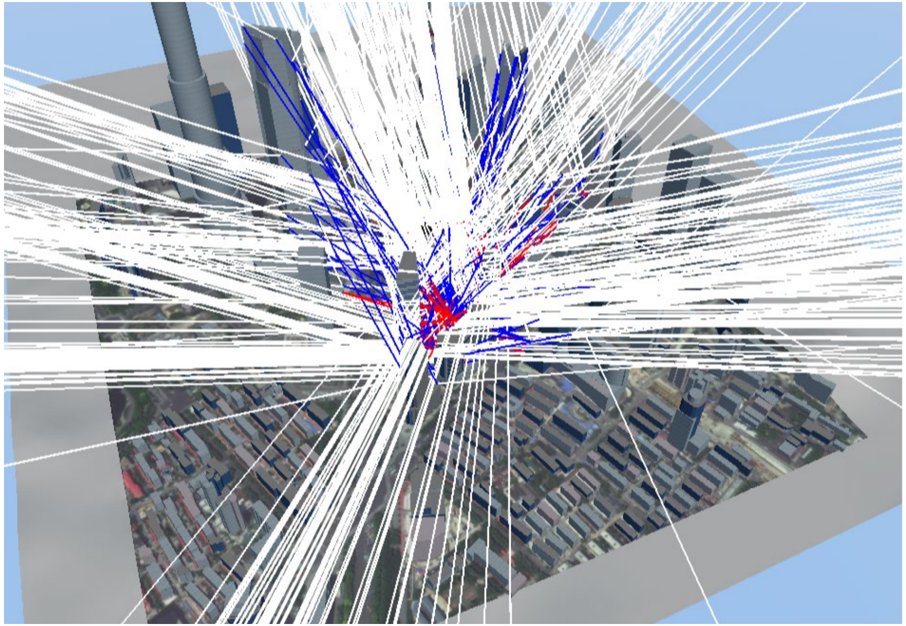


Figure 17: Shanghai multipath environment

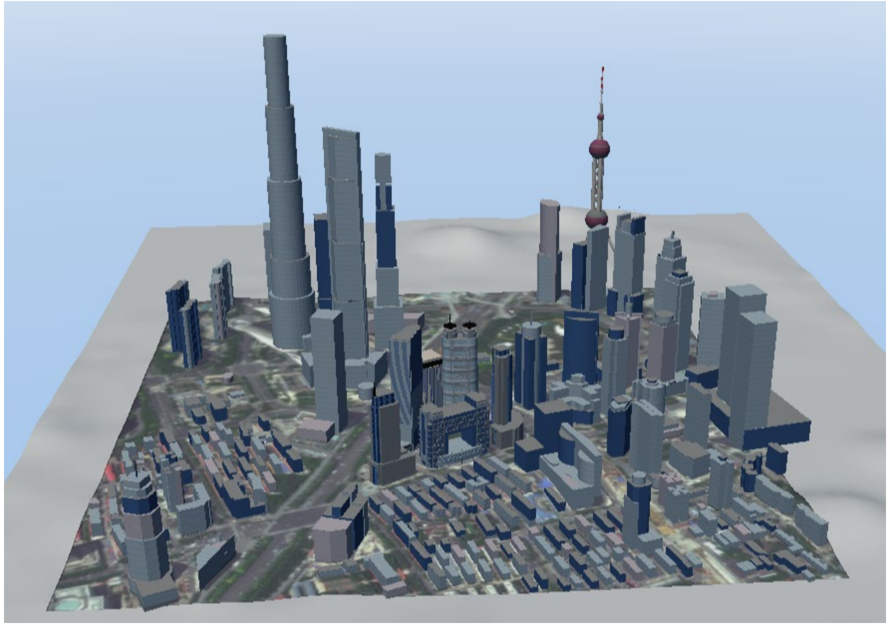


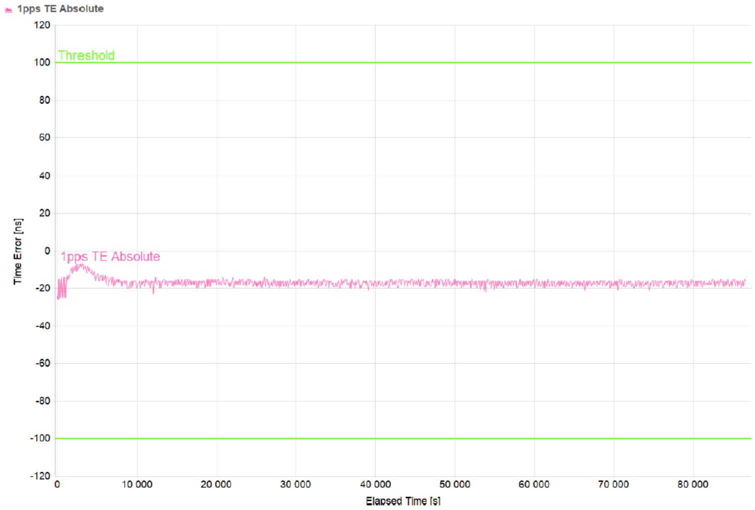
Figure 18: Shanghai 3D scene

Shanghai 2/4

Open sky conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-24 ns

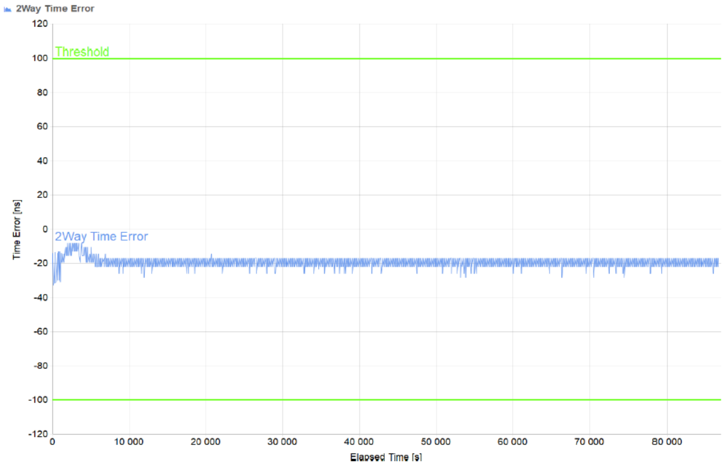


Mean [ns]	-16.784
Min [ns]	-26
Max [ns]	-7
Max-Min [ns]	19

Figure 20. 1 PPS absolute time error under open-sky conditions

Time Error Analysis

Include Correction Field	On



Mean [ns]	-20.565
Min [ns]	-33
Max [ns]	-8
Max-Min [ns]	25
Fwd Messages	1385223
Rev Messages	1385223
Forward Rate	16.00/second
Reverse Rate	16.00/second

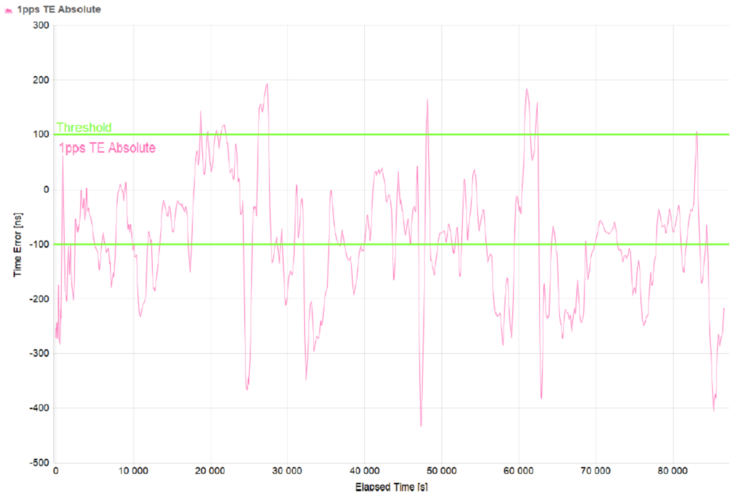
Figure 21. 2-way time error under open-sky conditions

Shanghai 3/4

Multipath conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-253 ns



Mean [ns]	-94.295
Min [ns]	-434
Max [ns]	193
Max-Min [ns]	627

Figure 19. 1 PPS absolute time error under multipath conditions

- Unfortunately, there was no valid PTP measurement for this scene. Something must have gone wrong.
- The 1 PPS time error has an absolute mean value of 94.3 ns, but it deviated a lot with a maximum value of +193 ns and a minimum of – 434 ns.
- The measurements for the open sky conditions are within the PRTC-A and B limits.

Shanghai 4/4

GNSS status of the DUT

```
Latitude                    :  N31:13:33.180
Longitude                   :  E121:28:51.115
HGT Val Ellipsoid           :  14.6 m
HDOP                        :  0.6 m
PDOP                        :  100.0 m
Fix Quality                 :  1
Used Satellites             :  17
Receiver Status             :  Tracking
Operation Mode              :  Position_fix
Antenna Status              :  OPEN

Current GNSS Satellite View:
```

Index	GnssID	SatID	SNR	Azimuth	Elev	PrRes
1	GPS	1	44	259	31	1
2	GPS	3	44	193	14	1
3	GPS	6	44	183	24	-1
4	GPS	14	45	146	35	-1
5	GPS	16	45	261	64	-2
6	GPS	20	44	284	20	-1
7	GPS	23	44	319	15	-1
8	GPS	29	44	54	27	-1
9	GPS	30	44	50	6	3
10	GPS	31	45	43	57	0
11	Glonass	6	41	113	37	5
12	Glonass	7	40	166	10	-2
13	Glonass	10	38	198	22	-5
14	Glonass	11	42	259	46	9
15	Glonass	20	41	53	27	7
16	Glonass	21	41	348	46	-5
17	Glonass	22	41	291	19	-5

Figure 22. GNSS status of DUT under open sky conditions

```
GNSS Status

  Latitude                    :  N31:13:36.332
  Longitude                   :  E121:28:54.960
  HGT Val Ellipsoid           :  18.6 m
  HDOP                        :  1.2 m
  PDOP                        :  100.0 m
  Fix Quality                 :  1
  Used Satellites             :  7
  Receiver Status             :  Tracking
  Operation Mode              :  Position_fix
  Antenna Status              :  OPEN

Current GNSS Satellite View:
```

Index	GnssID	SatID	SNR	Azimuth	Elev	PrRes
1	GPS	3	29	194	10	208
2	GPS	6	30	184	19	1019
3	GPS	16	28	251	60	1445
4	GPS	29	45	59	29	-487
5	Glonass	6	28	119	33	11
6	Glonass	11	30	268	48	1299
7	Glonass	21	40	339	46	325

Figure 23. GNSS status of DUT under multipath conditions

- The ellipsoidal height didn’t show large differences, but the pseudorange residuals were much larger in the multipath environment than the values in the open sky conditions.
- Also, the used satellites were much less under multipath conditions.
- The CN0 was a lot lower in the multipath run, when compared to the values in the open sky conditions.

Conclusions

- Time recovery is crucial in telecom applications and as we see in Table 1 below, multipath will degrade the performance of the timing accuracy of the GNSS-based PRTC's. Thus, being able to simulate this effect, and introduce new **testing methods**, will save companies time and money.

	San Francisco			Manhattan			Shanghai		
Time errors (ns)	1.Open Sky	1.Multipath	1.Absolute Difference (%)	2.Open Sky	2.Multipath	2.Absolute Difference (%)	3.Open Sky	3.Multipath	3.Absolute Difference (%)
abs mean 1 PPS TE	24.9	233.9	939.3574297	6.442	32.345	502.0956225	16.784	94.3	561.8446139
min 1 PPS TE	-32	-942	2943.75	-14	-436	3114.285714	-26	-434	1669.230769
max 1 PPS TE	-20	1482	7410	-2	144	7200	-7	193	2757.142857
max-min 1 PPS TE	12	2424	20200	12	580	4833.333333	19	627	3300
abs mean 2 way TE	29.6	326.9	1104.391892	1.233	26.224	2126.845093	20.565		
min 2 way TE	-29.623	-1045	3527.664315	-15	-441.5	2943.333333	-33		
max 2 way TE	-23	1379.5	5997.826087	3.5	136.5	3900	-8		
max-min 2 way TE	15.5	2424.5	15641.93548	18.5	578	3124.324324	25		

Table 1: Quantitative analysis of the results

Future Work

- Our future work on multipath measurements aims to the following:
  - Measurements from live multipath environments and comparison to the simulated results.
  - Measurements with L2 and L5 frequencies for GPS, GLONASS and Galileo.

References

- Paul D. Groves, Ziyi Jiang, Morten Rudi and Philip Strode, *A Portfolio Approach to NLOS and Multipath Mitigation in Dense Urban Areas*, University College London, Unite Kingdom [1] - https://discovery.ucl.ac.uk/id/eprint/1394968/1/ION_GNSS13_B6_2_Groves_et_al_1_0%20%28NLOS%29.pdf
- ITU-T G.8272/Y.1367, *Timing characteristics of primary reference time clocks* [2] – https://www.itu.int/rec/T-REC-G.8272/en
- Hannah, Bruce M. *Modelling and simulation of GPS multipath propagation. Diss. Queensland University of Technology, 2001.* [3] - https://eprints.qut.edu.au/15782/1/Bruce_Hannah_Thesis.pdf

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