Accuracy Measurement of GNSS Driven PPS Signals Across Different Geographical Locations

Ahmad Byagowi, Michel Ouellette, Oleg Obleukhov



Problem Formulation

It is a challenge to extend the measurement of precision synchronization across geographically distributed systems.

- PTP is designed for Local Area Networks
- Requires PTP compliant switches such as transparent clocks and boundary clocks
- For a long-distance signal transmission, speed of light becomes a consideration
- Global navigational satellite system can provide a solution however, the measurement will rely on the specs provided by the constellation
- A method is needed to constantly gauge and validate the global synchronization between the set of local area networks, equipped with PTP
- New technologies such as miniaturized atomic clocks may provide a poter solution



Background

PTP takes advantage of:

- Hardware Timestamping
- Compliant Switches
- Higher message rates

These are not available/guaranteed across a wide area network

GNSS (GPS, BeiDou, GLONASS, GALILEO,...) are capable to deliver time

- Time of the day
- 1 Pulse Per Second

Relying solely on GNSS carries risk

• It gets delivered via an antenna

Atomic clocks provide better holdover performance



External Timestamping and OGM







Atomic Clock Football







Time Stamps

event	index 0 at	1602092041.493678572	event index 0 at 1602092041.493678568	event index 0 at 1602092041.493678556	event index 0 at 1602092041.493678560	event index 0 at 1602092041.493678568
event	index 0 at	1602092042.493678600	event index 0 at 1602092042.493678588	event index 0 at 1602092042.493678584	event index 0 at 1602092042.493678584	event index 0 at 1602092042.493678596
event	index 0 at	1602092043.493678608	event index 0 at 1602092043.493678584	event index 0 at 1602092043.493678584	event index 0 at 1602092043.493678588	event index 0 at 1602092043.493678580
event	index 0 at	1602092044.493678596	event index 0 at 1602092044.493678584	event index 0 at 1602092044.493678580	event index 0 at 1602092044.493678584	event index 0 at 1602092044.493678568
event	index 0 at	1602092045.493678604	event index 0 at 1602092045.493678596	event index 0 at 1602092045.493678592	event index 0 at 1602092045.493678600	event index 0 at 1602092045.493678588
event	index 0 at	1602092046.493678608	event index 0 at 1602092046.493678604	event index 0 at 1602092046.493678596	event index 0 at 1602092046.493678608	event index 0 at 1602092046.493678596
event	index 0 at	1602092047.493678612	event index 0 at 1602092047.493678600	event index 0 at 1602092047.493678588	event index 0 at 1602092047.493678600	event index 0 at 1602092047.493678588
event	index 0 at	1602092048.493678604	event index 0 at 1602092048.493678588	event index 0 at 1602092048.493678580	event index 0 at 1602092048.493678588	event index 0 at 1602092048.493678584
event	index 0 at	1602092049.493678604	event index 0 at 1602092049.493678588	event index 0 at 1602092049.493678584	event index 0 at 1602092049.493678596	event index 0 at 1602092049.493678584
event	index 0 at	1602092050.493678608	event index 0 at 1602092050.493678592	event index 0 at 1602092050.493678592	event index 0 at 1602092050.493678608	event index 0 at 1602092050.493678588
event	index 0 at	1602092051.493678608	event index 0 at 1602092051.493678588	event index 0 at 1602092051.493678588	event index 0 at 1602092051.493678608	event index 0 at 1602092051.493678592
event	index 0 at	1602092052.493678612	event index 0 at 1602092052.493678596	event index 0 at 1602092052.493678596	event index 0 at 1602092052.493678608	event index 0 at 1602092052.493678596
event	index 0 at	1602092053.493678600	event index 0 at 1602092053.493678592	event index 0 at 1602092053.493678584	event index 0 at 1602092053.493678592	event index 0 at 1602092053.493678596
event	index 0 at	1602092054.493678592	event index 0 at 1602092054.493678584	event index 0 at 1602092054.493678580	event index 0 at 1602092054.493678592	event index 0 at 1602092054.493678592
event	index 0 at	1602092055.493678588	event index 0 at 1602092055.493678580	event index 0 at 1602092055.493678588	event index 0 at 1602092055.493678592	event index 0 at 1602092055.493678588
event	index 0 at	1602092056.493678592	event index 0 at 1602092056.493678580	event index 0 at 1602092056.493678592	event index 0 at 1602092056.493678600	event index 0 at 1602092056.493678584
event	index 0 at	1602092057.493678600	event index 0 at 1602092057.493678584	event index 0 at 1602092057.493678600	event index 0 at 1602092057.493678600	event index 0 at 1602092057.493678584
event	index 0 at	1602092058.493678596	event index 0 at 1602092058.493678576	event index 0 at 1602092058.493678584	event index 0 at 1602092058.493678588	event index 0 at 1602092058.493678584
event	index 0 at	1602092059.493678592	event index 0 at 1602092059.493678580	event index 0 at 1602092059.493678584	event index 0 at 1602092059.493678588	event index 0 at 1602092059.493678584
event	index 0 at	1602092060.493678584	event index 0 at 1602092060.493678576	event index 0 at 1602092060.493678576	event index 0 at 1602092060.493678580	event index 0 at 1602092060.493678580
event	index 0 at	1602092061.493678584	event index 0 at 1602092061.493678568	event index 0 at 1602092061.493678572	event index 0 at 1602092061.493678576	event index 0 at 1602092061.493678568
event	index 0 at	1602092062.493678596	event index 0 at 1602092062.493678568	event index 0 at 1602092062.493678568	event index 0 at 1602092062.493678584	event index 0 at 1602092062.493678564
event	index 0 at	1602092063.493678600	event index 0 at 1602092063.493678568	event index 0 at 1602092063.493678568	event index 0 at 1602092063.493678576	event index 0 at 1602092063.493678564
event	index 0 at	1602092064.493678592	event index 0 at 1602092064.493678564	event index 0 at 1602092064.493678576	event index 0 at 1602092064.493678576	event index 0 at 1602092064.493678568
event	index 0 at	1602092065.493678604	event index 0 at 1602092065.493678572	event index 0 at 1602092065.493678580	event index 0 at 1602092065.493678588	event index 0 at 1602092065.493678588
event	index 0 at	1602092066.493678608	event index 0 at 1602092066.493678592	event index 0 at 1602092066.493678584	event index 0 at 1602092066.493678604	event index 0 at 1602092066.493678600
event	index 0 at	1602092067.493678608	event index 0 at 1602092067.493678596	event index 0 at 1602092067.493678584	event index 0 at 1602092067.493678608	event index 0 at 1602092067.493678600
event	index 0 at	1602092068.493678616	event index 0 at 1602092068.493678588	event index 0 at 1602092068.493678592	event index 0 at 1602092068.493678604	event index 0 at 1602092068.493678600
event	index 0 at	1602092069.493678612	event index 0 at 1602092069.493678604	event index 0 at 1602092069.493678596	event index 0 at 1602092069.493678608	event index 0 at 1602092069.493678600
event	index 0 at	1602092070.493678604	event index 0 at 1602092070.493678592			
event	index 0 at	1602092071.493678596	event index 0 at 1602092071.493678584	event index 0 at 1602092071.493678576	event index 0 at 1602092071.493678576	event index 0 at 1602092071.493678568
event	index 0 at	1602092072.493678592	event index 0 at 1602092072.493678580	event index 0 at 1602092072.493678572	event index 0 at 1602092072.493678580	event index 0 at 1602092072.493678568
event	index 0 at	1602092073.493678596	event index 0 at 1602092073.493678592	event index 0 at 1602092073.493678584	event index 0 at 1602092073.493678596	event index 0 at 1602092073.493678580
event	index 0 at	1602092074.493678612	event index 0 at 1602092074.493678600	event index 0 at 1602092074.493678588	event index 0 at 1602092074.493678600	event in two 0 st 1002002071 102070500
event	index 0 at	1602092075.493678608	event index 0 at 1602092075.493678596	event index 0 at 1602092075.493678592	event index 0 at 1602092075.493678600	event
event	index 0 at	1602092076.493678576	event index 0 at 1602092076.493678572	event index 0 at 1602092076.493678572	event index 0 at 1602092076.493678580	event
event	index 0 at	1602092077.493678584	event index 0 at 1602092077.493678580	event index 0 at 1602092077.493678576	event index 0 at 1602092077.493678576	event
event	index 0 at	1602092078.493678584	event index 0 at 1602092078.493678584	event index 0 at 1602092078.493678588	event index 0 at 1602092078.493678584	event
event	index 0 at	1602092079.493678568	event index 0 at 1602092079.493678564	event index 0 at 1602092079.493678572	event index 0 at 1602092079.493678568	event
event	index 0 at	1602092080.493678572	event index 0 at 1602092080.493678576	event index 0 at 1602092080.493678576	event index 0 at 1602092080.493678564	event
event	index 0 at	1602092081.493678568	event index 0 at 1602092081.493678568	event index 0 at 1602092081.493678564	event index 0 at 1602092081.493678564	event
event	index 0 at	1602092082.493678572	event index 0 at 1602092082.493678576	event index 0 at 1602092082.493678580	event index 0 at 1602092082.493678584	event
event	index 0 at	1602092083.493678572	event index 0 at 1602092083.493678576	event index 0 at 1602092083.493678576	event index 0 at 1602092083.493678588	event
event	index 0 at	1602092084.493678580	event index 0 at 1602092084.493678580	event index 0 at 1602092084.493678576	event index 0 at 1602092084.493678592	event
event	index 0 at	1602092085.493678604	event index 0 at 1602092085.493678596	event index 0 at 1602092085.493678596	event index 0 at 1602092085.493678608	event

Syntonization

event	index	0 at	1602092041	.4936785 <mark>7</mark> 2	event index 0 at	1602092041.4936785 <mark>6</mark> 8	event index 0 at	1602092041.4936785 <mark>56</mark>	event index 0 at 1602092041.49367	35 <mark>60</mark> event	t index 0 at 1602092041.493678568
event	index	0 at	1602092042	.4936786 <mark>00</mark>	event index 0 at	1602092042.493678588	event index 0 at	1602092042.4936785 <mark>84</mark>	event index 0 at 1602092042.49367	85 <mark>84</mark> e∨en†	t index 0 at 1602092042.493678 <mark>.</mark> 96
event	index	0 at	1602092043	.4936786 <mark>08</mark>	event index 0 at	1602092043.4936785 <mark>84</mark>	event index 0 at	1602092043.4936785 <mark>84</mark>	event index 0 at 1602092043.49367	35 <mark>88</mark> event	t index 0 at 1602092043.493678 <mark>5</mark> 80
event	index	0 at	1602092044	.4936785 <mark>96</mark>	event index 0 at	1602092044.4936785 <mark>8</mark> 4	event index 0 at	1602092044.4936785 <mark>8</mark> 0	event index 0 at 1602092044.49367	85 <mark>84</mark> event	t index 0 at 1602092044.493678 <mark>5</mark> 68
event	index	0 at	1602092045	.4936786 <mark>0</mark> 4	event index 0 at	1602092045.4936785 <mark>96</mark>	event index 0 at	1602092045.4936785 <mark>9</mark> 2	event index 0 at 1602092045.49367	36 <mark>00</mark> event	t index 0 at 1602092045.493678 <mark>5</mark> 88
event	index	0 at	1602092046	.4936786 <mark>08</mark>	event index 0 at	1602092046.4936786 <mark>0</mark> 4	event index 0 at	1602092046.4936785 <mark>96</mark>	event index 0 at 1602092046.49367	36 <mark>08</mark> event	t index 0 at 1602092046.493678 <mark>96</mark>
event	index	0 at	1602092047	.4936786 <mark>12</mark>	event index 0 at	1602092047.4936786 <mark>0</mark> 0	event index 0 at	1602092047.4936785 <mark>88</mark>	event index 0 at 1602092047.49367	36 <mark>00</mark> event	t index 0 at 1602092047.493678 <mark>5</mark> 88
event	index	0 at	1602092048	.4936786 <mark>0</mark> 4	event index 0 at	1602092048.4936785 <mark>88</mark>	event index 0 at	1602092048.4936785 <mark>8</mark> 0	event index 0 at 1602092048.49367	35 <mark>88</mark> event	t index 0 at 1602092048.493678584
event	index	0 at	1602092049	.4936786 <mark>0</mark> 4	event index 0 at	1602092049.4936785 <mark>88</mark>	event index 0 at	1602092049.493678584	event index 0 at 1602092049.49367	35 <mark>96</mark> even⁺	t index 0 at 1602092049.493678584
event	index	0 at	1602092050	.4936786 <mark>08</mark>	event index 0 at	1602092050.4936785 <mark>9</mark> 2	event index 0 at	1602092050.4936785 <mark>9</mark> 2	event index 0 at 1602092050.49367	36 <mark>08</mark> event	t index 0 at 1602092050.493678 <mark>5</mark> 88
event	index	0 at	1602092051	.4936786 <mark>08</mark>	event index 0 at	1602092051.4936785 <mark>88</mark>	event index 0 at	1602092051.4936785 <mark>8</mark> 8	event index 0 at 1602092051.49367	86 <mark>08</mark> event	t index 0 at 1602092051.493678 <mark>9</mark> 2
event	index	0 at	1602092052	.4936786 <mark>12</mark>	event index 0 at	1602092052.4936785 <mark>96</mark>	event index 0 at	1602092052.4936785 <mark>96</mark>	event index 0 at 1602092052.49367	36 <mark>08</mark> event	t index 0 at 1602092052.493678 <mark>5</mark> 96
event	index	0 at	1602092053	.4936786 <mark>00</mark>	event index 0 at	1602092053.4936785 <mark>9</mark> 2	event index 0 at	1602092053.4936785 <mark>8</mark> 4	event index 0 at 1602092053.49367	35 <mark>92</mark> event	t index 0 at 1602092053.493678 <mark>5</mark> 96
event	index	0 at	1602092054	.4936785 <mark>92</mark>	event index 0 at	1602092054.493678584	event index 0 at	1602092054.4936785 <mark>8</mark> 0	event index 0 at 1602092054.49367	35 <mark>92</mark> event	t index 0 at 1602092054.493678 <mark>5</mark> 92
event	index	0 at	1602092055	.4936785 <mark>88</mark>	event index 0 at	1602092055.4936785 <mark>80</mark>	event index 0 at	1602092055.4936785 <mark>8</mark> 8	event index 0 at 1602092055.49367	85 <mark>92 e∨en†</mark>	t index 0 at 1602092055.493678588
event	index	0 at	1602092056	.4936785 <mark>92</mark>	event index 0 at	1602092056.493678580	event index 0 at	1602092056.493678592	event index 0 at 1602092056.49367	36 <mark>00</mark> e∨en†	t index 0 at 1602092056.493678584
event	index	0 at	1602092057	.4936786 <mark>00</mark>	event index 0 at	1602092057.493678584	event index 0 at	1602092057.493678600	event index 0 at 1602092057.49367	86 <mark>00</mark> event	t index 0 at 1602092057.493678584
event	index	0 at	1602092058	.4936785 <mark>96</mark>	event index 0 at	1602092058.493678576	event index 0 at	1602092058.493678584	event index 0 at 1602092058.49367	85 <mark>88</mark> e∨en†	t index 0 at 1602092058.493678584
event	index	0 at	1602092059	.4936785 <mark>92</mark>	event index 0 at	1602092059.493678580	event index 0 at	1602092059.493678584	event index 0 at 1602092059.49367	85 <mark>88</mark> e∨en†	t index 0 at 1602092059.493678584
event	index	0 at	1602092060	.4936785 <mark>8</mark> 4	event index 0 at	1602092060.493678576	event index 0 at	1602092060.493678576	event index 0 at 1602092060.49367	35 <mark>80</mark> event	t index 0 at 1602092060.493678 <mark>5</mark> 80
event	index	0 at	1602092061	.4936785 <mark>8</mark> 4	event index 0 at	1602092061.493678568	event index 0 at	1602092061.493678572	event index 0 at 1602092061.49367	35 <mark>76</mark> e∨en†	t index 0 at 1602092061.493678568
event	index	0 at	1602092062	.4936785 <mark>96</mark>	event index 0 at	1602092062.493678568	event index 0 at	1602092062.493678568	event index 0 at 1602092062.49367	35 <mark>84</mark> event	t index 0 at 1602092062.493678564
event	index	0 at	1602092063	.4936786 <mark>00</mark>	event index 0 at	1602092063.493678568	event index 0 at	1602092063.493678568	event index 0 at 1602092063.49367	35 <mark>76</mark> event	t index 0 at 1602092063.493678564
event	index	0 at	1602092064	.4936785 <mark>92</mark>	event index 0 at	1602092064.493678564	event index 0 at	1602092064.493678576	event index 0 at 1602092064.49367	35 <mark>76</mark> event	t index 0 at 1602092064.493678568
event	index	0 at	1602092065	.4936786 <mark>0</mark> 4	event index 0 at	1602092065.493678572	event index 0 at	1602092065.493678580	event index 0 at 1602092065.49367	35 <mark>88</mark> event	t index 0 at 1602092065.493678588
event	index	0 at	1602092066	.4936786 <mark>08</mark>	event index 0 at	1602092066.493678592	event index 0 at	1602092066.493678584	event index 0 at 1602092066.49367	36 <mark>04</mark> event	t index 0 at 1602092066.493678600
event	index	0 at	1602092067	.4936786 <mark>08</mark>	event index 0 at	1602092067.493678596	event index 0 at	1602092067.493678584	event index 0 at 1602092067.49367	36 <mark>08</mark> event	t index 0 at 1602092067.493678600
event	index	0 at	1602092068	.4936786 <mark>16</mark>	event index 0 at	1602092068.493678588	event index 0 at	1602092068.493678592	event index 0 at 1602092068.49367	36 <mark>04</mark> event	t index 0 at 1602092068.493678600
event	index	0 at	1602092069	.493678612	event index 0 at	1602092069.493678604	event index 0 at	1602092069.493678596	event index 0 at 1602092069.49367	36 <mark>08</mark> event	t index 0 at 1602092069.493678600
event	index	0 at	1602092070	.4936786 <mark>0</mark> 4	event index 0 at	1602092070.493678592	event index 0 at	1602092070.493678592	event index 0 at 1602092070.49367	3592 event	t index 0 at 1602092070.493678592
event	index	0 at	1602092071	.493678596	event index 0 at	1602092071.493678584	event index 0 at	1602092071.493678576	event index 0 at 1602092071.49367	3576 event	t index 0 at 1602092071.493678568
event	index	0 at	1602092072	.493678592	event index 0 at	1602092072.493678580	event index 0 at	1602092072.493678572	event index 0 at 1602092072.49367	85 <mark>80</mark> event	t index 0 at 1602092072.493678568
event	index	0 at	1602092073	.493678596	event index 0 at	1602092073.493678592	event index 0 at	1602092073.493678584	event index 0 at 1602092073.49367	3596 event	t index 0 at 1602092073.493678580
event	index	0 at	1602092074	.493678612	event index 0 at	1602092074.493678600	event index 0 at	1602092074.493678588	event index 0 at 1602092074.49367	3600 event	
event	index	0 at	1602092075	.493678608	event index 0 at	1602092075.493678596	event index 0 at	1602092075.493678592	event index 0 at 1602092075.49367	3600 event	E Contraction of the second
event	index	0 at	1602092076	.493678576	event index 0 at	1602092076.493678572	event index 0 at	1602092076.493678572	event index 0 at 1602092076.49367	3580 e∨en†	
event	index	0 at	1602092077	.493678584	event index 0 at	1602092077.493678580	event index 0 at	1602092077.493678576	event index 0 at 1602092077.49367	3576 event	
event	index	0 at	1602092078	.493678584	event index 0 at	1602092078.493678584	event index 0 at	1602092078.493678588	event index 0 at 1602092078.49367	3584 event	
event	index	0 at	1602092079	.493678568	event index 0 at	1602092079.493678564	event index 0 at	1602092079.493678572	event index 0 at 1602092079.49367	3568 event	
event	index	0 at	1602092080	.493678572	event index 0 at	1602092080.493678576	event index 0 at	1602092080.493678576	event index 0 at 1602092080.49367	3564 event	
event	index	0 at	1602092081	.493678568	event index 0 at	1602092081.493678568	event index 0 at	1602092081.493678564	event index 0 at 1602092081.49367	s564 event	
event	index	0 at	1602092082	.493678572	event index 0 at	1602092082.493678576	event index 0 at	1602092082.493678580	event index 0 at 1602092082.49367	s584 event	
event	index	0 at	1602092083	.493678572	event index 0 at	1602092083.493678576	event index 0 at	1602092083.493678576	event index 0 at 1602092083.49367	ssaa even	A REAL PROPERTY AND A REAL
event	index	0 at	1602092084	.493678580	event index 0 at	1602092084.493678580	event index 0 at	1602092084.493678576	event index 0 at 1602092084.49367	s592 event	
event	index	0 at	1602092085	.493678604	event index 0 at	1602092085.493678596	event index 0 at	1602092085.493678596	event index 0 at 1602092085.49367	selve event	

Synchronization

ptptool[5251510.811]	2	0	3	-4	4	-16	5	-12	6	8	<pre>ts2phc[5540574.899]: ens2f0 master offset</pre>	-20 s2 freq -27655
ptptool[5251511.728]	2	0	3	12	4	-4	5	-4	6	16	ts2phc[5540575.816]: ens2f0 master offset	-20 s2 freq -27661
ptptool[5251512.645]	2	0	3	0	4	-8	5	-8	6	8	<pre>ts2phc[5540576.733]: ens2f0 master offset</pre>	-16 s2 freq -27663
ptptool[5251513.561]	2	0	3	4	4	-20	5	-20	6	4	<pre>ts2phc[5540577.649]: ens2f0 master offset</pre>	-12 s2 freq -27664
ptptool[5251514.478]	2	0	3	-8	4	-32	5	-32	6	-20	ts2phc[5540578.566]: ens2f0 master offset	-4 s2 freq -27660
ptptool[5251515.395]	2	0	3	-8	4	-12	5	-16	6	-8	ts2phc[5540579.483]: ens2f0 master offset	-8 s2 freq -27665
ptptool[5251516.311]	2	0	3	-4	4	-8	5	-12	6	-4	ts2phc[5540580.399]: ens2f0 master offset	-8 s2 freq -27667
ptptool[5251517.228]	2	0	3	-8	4	-4	5	-16	6	-8	ts2phc[5540581.316]: ens2f0 master offset	-8 s2 freq -27670
ptptool[5251518.145]	2	0	3	0	4	8	5	-8	6	0	ts2phc[5540582.233]: ens2f0 master offset	0 s2 freq -27664
ptptool[5251519.061]	2	0	3	8	4	4	5	-8	6	-4	ts2phc[5540583.149]: ens2f0 master offset	-4 s2 freq -27668
ptptool[5251520.895]	2	0	3	-8	4	-16	5	-20	6	-16	ts2phc[5540584.066]: ens2f0 master offset	-4 s2 freg -27669
ptptool[5251521.811]	2	0	3	-12	4	-16	5	-20	6	-12	ts2phc[5540584.983]: ens2f0 master offset	-4 s2 freg -27670
ptptool[5251522.728]	2	0	3	-4	4	-8	5	-16	6	-4	ts2phc[5540585.899]: ens2f0 master offset	-8 s2 freg -27676
ptptool[5251523.645]	2	0	3	0	4	-4	5	-12	6	-4	ts2phc[5540586.816]: ens2f0 master offset	-16 s2 freq -27686
ptptool[5251524.561]	2	0	3	-20	4	-28	5	-32	6	-20	ts2phc[5540587.733]: ens2f0 master offset	-8 s2 freg -27683
ptptool[5251525.478]	2	0	3	-8	4	-20	5	-20	6	-4	ts2phc[5540588.649]: ens2f0 master offset	-16 s2 freq -27693
ptptool[5251526.395]	2	0	3	0	4	-8	5	-16	6	-8	ts2phc[5540589.566]: ens2f0 master offset	-16 s2 freg -27698
ptptool[5251527.311]	2	0	3	4	4	0	5	-12	6	0	ts2phc[5540590.483]: ens2f0 master offset	-12 s2 freg -27699
ptptool[5251528.228]	2	0	3	0	4	-4	5	-12	6	-4	ts2phc[5540591.399]: ens2f0 master offset	-8 s2 freq -27698
ptptool[5251529.145]	2	0	3	0	4	0	5	-8	6	-4	ts2phc[5540592.316]: ens2f0 master offset	-4 s2 freg -27697
ptptool[5251530.061]	2	0	3	12	4	8	5	4	6	8	ts2phc[5540593.233]: ens2f0 master offset	0 s2 freq -27694
ptptool[5251531.895]	2	0	3	8	4	0	5	0	6	8	ts2phc[5540594.149]: ens2f0 master offset	8 s2 freg -27686
ptptool[5251532.811]	2	0	3	-8	4	-8	5	-8	6	-8	ts2phc[5540595.066]: ens2f0 master offset	12 s2 freg -27680
ptptool[5251533.728]	2	0	3	-16	4	-12	5	-16	6	-12	ts2phc[5540595.983]: ens2f0 master offset	12 s2 freq -27676
ptptool[5251534.645]	2	0	3	-16	4	0	5	-12	6	-4	ts2phc[5540596.899]: ens2f0 master offset	12 s2 freq -27672
ptptool[5251535.561]	2	0	3	-4	4	-4	5	4	6	4	ts2phc[5540597.816]: ens2f0 master offset	4 s2 freg -27677
ptptool[5251536.478]	2	0	3	8	4	12	5	12	6	12	ts2phc[5540598.733]: ens2f0 master offset	4 s2 freq -27676
ptptool[5251537.394]	2	0	3	0	4	12	5	12	6	12	ts2phc[5540599.649]: ens2f0 master offset	4 s2 freq -27674
ptptool[5251538.311]	2	0	3	4	4	8	5	8	6	4	ts2phc[5540600.566]: ens2f0 master offset	20 s2 freq -27657
ptptool[5251539.228]	2	0	3	4	4	4	5	4	6	8	ts2phc[5540601.483]: ens2f0 master offset	16 s2 freg -27655
ptptool[5251540.144]	2	0	3	16	4	8	5	0	6	12	ts2phc[5540602.399]: ens2f0 master offset	4 s2 freq -27662
ptptool[5251541.061]	2	0	3	12	4	8	5	-4	6	12	ts2phc[5540603.316]: ens2f0 master offset	4 c2 free 37661
ptptool[5251542.895]	2	0	3	4	4	4	5	-16	6	0	ts2phc[5540604.233]: ens2f0 master offset	
ptptool[5251543.811]	2	0	3	4	4	4	5	-8	6	-8	ts2phc[5540605.149]: ens2f0 master offset	
ptptool[5251544.728]	2	0	3	4	4	4	5	-8	6	0	ts2phc[5540606.066]: ens2f0 master offset	
ptptool[5251545.645]	2	0	3	12	4	8	5	-4	6	8	ts2phc[5540606.983]: ens2f0 master offset	111
ptptool[5251546.561]	2	0	3	8	4	-4	5	-8	6	-8	ts2phc[5540607.899]: ens2f0 master offset	(1) (1) (1) (1) (1) (1) (1) (1) (1) (1)
ptptool[5251547.478]	2	0	3	12	4	-8	5	-12	6	0	ts2phc[5540608.816]: ens2f0 master offset	
ptptool[5251548.395]	2	0	3	-4	4	-8	5	-20	6	-4	ts2phc[5540609.733]: ens2f0 master offset	10
ptptool[5251549.311]	2	0	3	4	4	4	5	-8	6	4	ts2phc[5540610.649]: ens2f0 master offset	
ptptool[5251550.228]	2	0	3	20	4	12	5	4	6	12	ts2phc[5540611.566]: ens2f0 master offset	1000 24
	2	0	3	12	4	8	5	0	6	8	ts2phc[5540612.483]: ens2f0 master offset	
	2	0	3	0	4	-4	5	-12	6	0	ts2phc[5540613.399]: ens2f0 master offset	
	-	0	-	0		20	_	20	6	1.6		A CONTRACTOR OF A CONTRACTOR O



Discussion

- It is challenge to measure synchronization across a geographically distributed system
- A portable and miniaturized atomic clock provides a more reliable holdover performance
- Relying on GNSS for synchronization assumes correctness in the constellation and may require validation
- Using PPS input and PHC snapshot provides a trivial method for synchronization benchmarking
- A sync matrix can show any possible synchronization discrepancy across the network:

$$S_3 = \begin{bmatrix} ts_A - ts_A & ts_A - ts_B & ts_A - ts_C \\ ts_B - ts_A & ts_B - ts_B & ts_B - ts_C \\ ts_C - ts_A & ts_C - ts_B & ts_C - ts_C \end{bmatrix}$$



Conclusion

- It is necessary to validate the synchronization accuracy of a GNSS constellation
- Miniaturized atomic clock provides a method to validate synchronization across geographically distributed system
- Using the external time stamping of the NIC is a reliable and scalable solution for measurement of synchronization
- Using the Sync Matrix, the validity of synchronization can be verified

