Synchronizing 100 Billion Devices

Massive Scale Long-Distance Time Distribution & Measurement

Richard Hoptroff, Chief Time Officer

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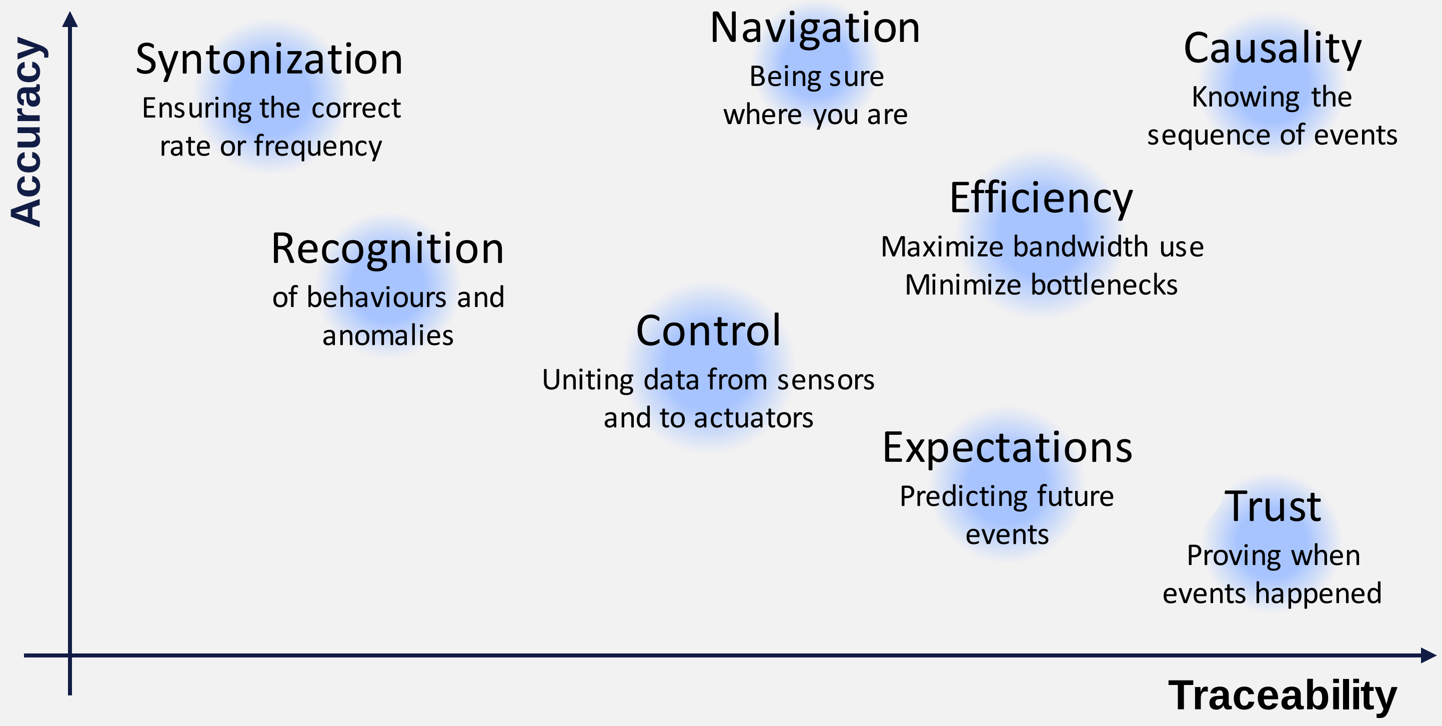
Synchronizing 100 Billion Devices

- Today, as an industry, we focus on ensuring time traceability for a few million clocks
- ARM estimate that by 2035, there will be 100 billion devices with real-time clocks
- What would it take for all those clocks to be provably in sync to within 100μs?
- And do it without satellites?

Why Do We Need Mass-Scale Time?



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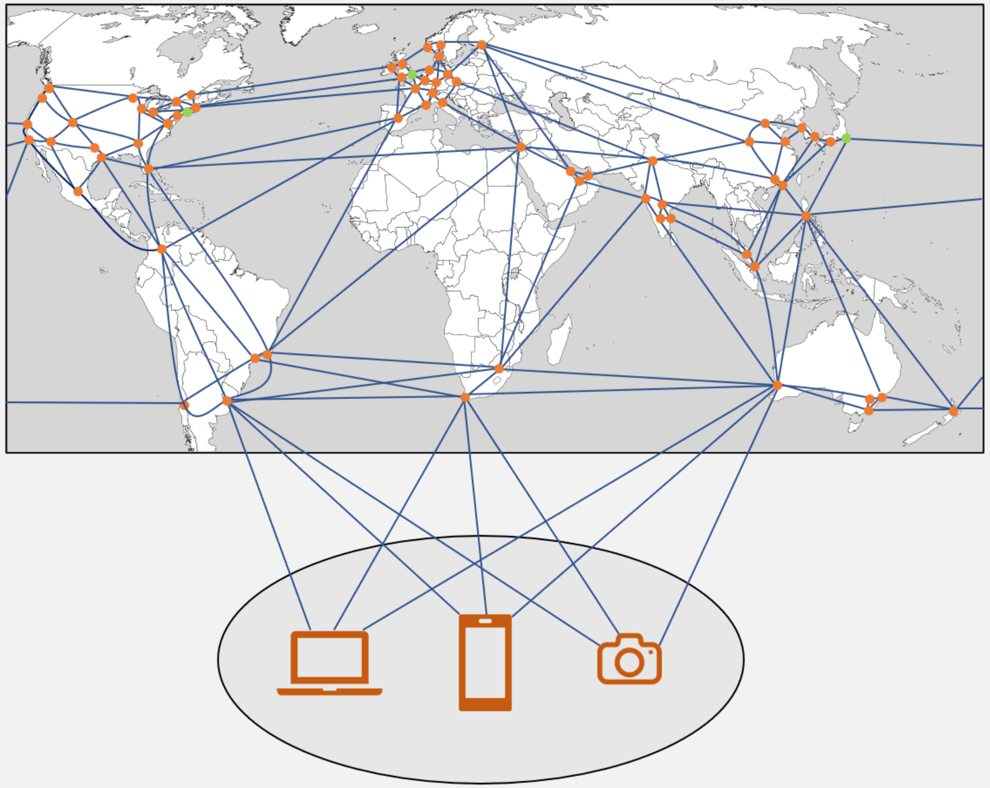
Time Sync Considerations

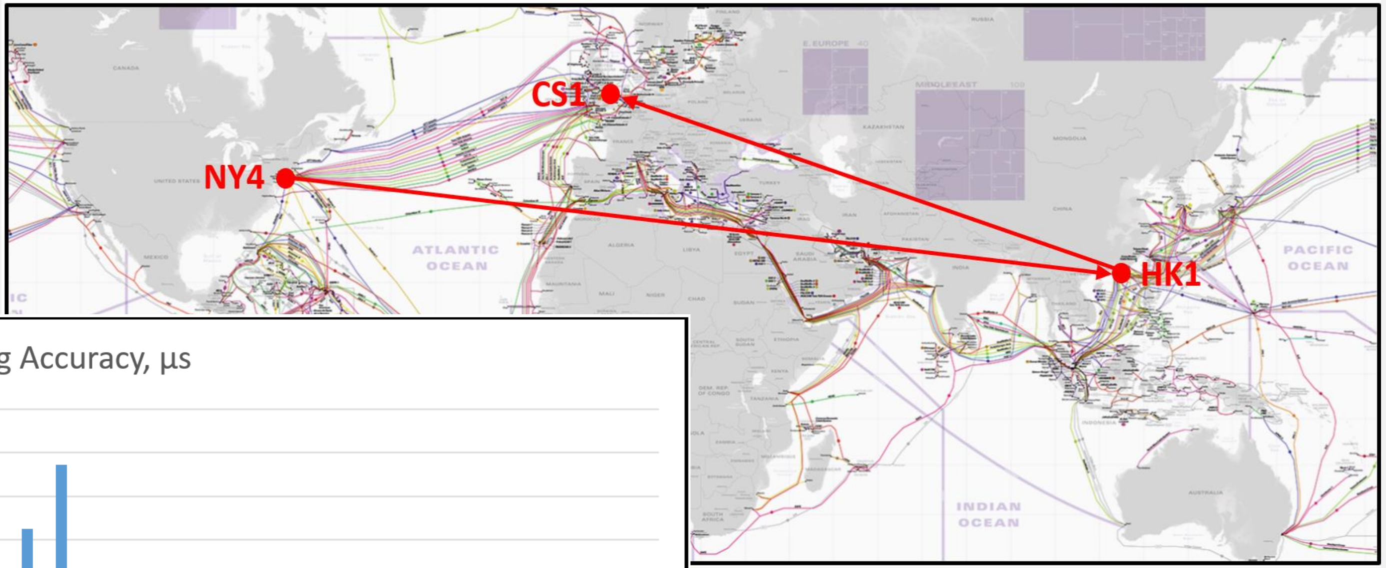
Accuracy	How wrong might my clocks be?
Resilience	What is the cost to me of an interruption in service?
Threats	What is the impact on society if service is disrupted?
Immutability	How provable must my records be?
Scalability	How easy is it to deploy at scale?
Traceability	Can I prove my chain of comparisons back to UTC?
Hassle-Free	How easy is it to manage?
Cost	How much will it cost to achieve?

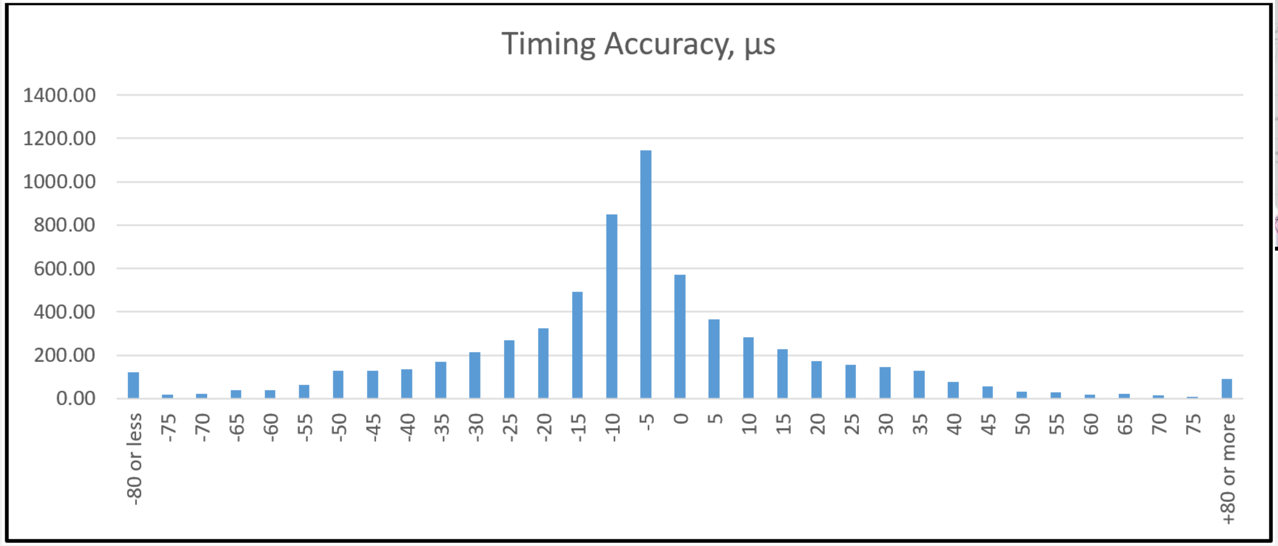
Proposed Solution: Cloud-Based Time Fabrics

- The idea is to achieve:
  - Global coverage
  - 1ms – 100us accuracy
  - 100bn scale
- Proposed Solution:
  - Cloud-based software boundary clocks to provide 100bn scalability if the market requires
  - Long distance connections to boundary clocks requires low latency layer 2 connectivity
  - Requires enhancements to NTP



Low latency for long distance





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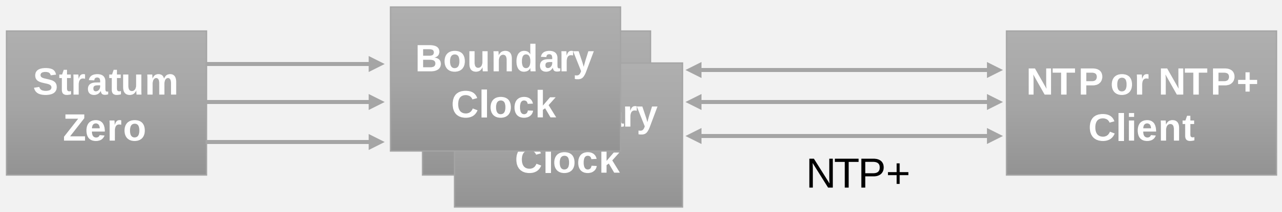
NTP+

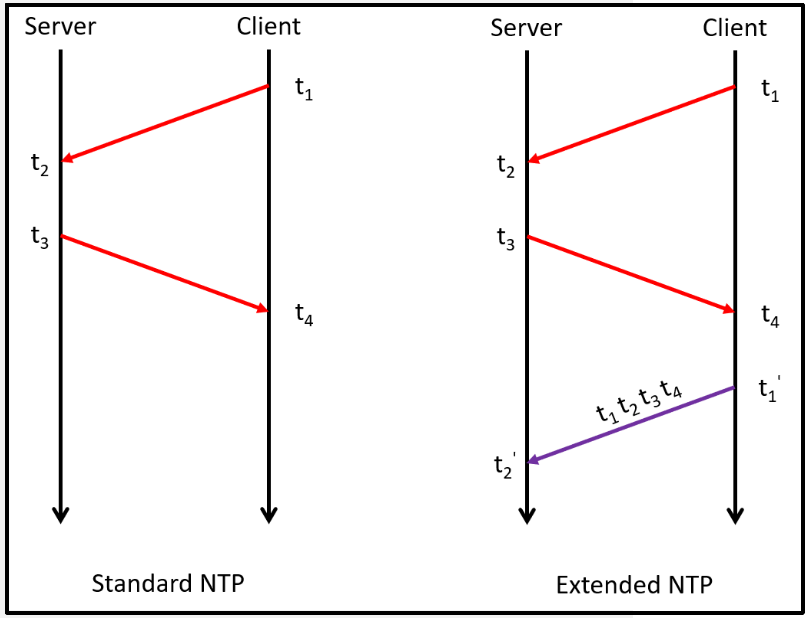
- NTP+ is proposed additions NTP using extension fields allowing:
  - Software Boundary Clocks (NTP servers) to know latency and clock offset of client devices
  - Self-organizing connectivity to the closest Software Boundary Clocks
  - Location requests allow the IP fabric to be mapped for geolocation
  - Client devices can use extension fields to upload data to the
- Extension field codes informally agreed with IETF
- Back-compatible with NTP



For details, see The Witness API: Using Metrology to Create Trust in Data,
R Hoptroff & S Kenny, URSI GASS 2020, Rome, Italy, 29 August – 5 September 2020
Copies available from info@hoptroff.com

NTP+ Extension Fields

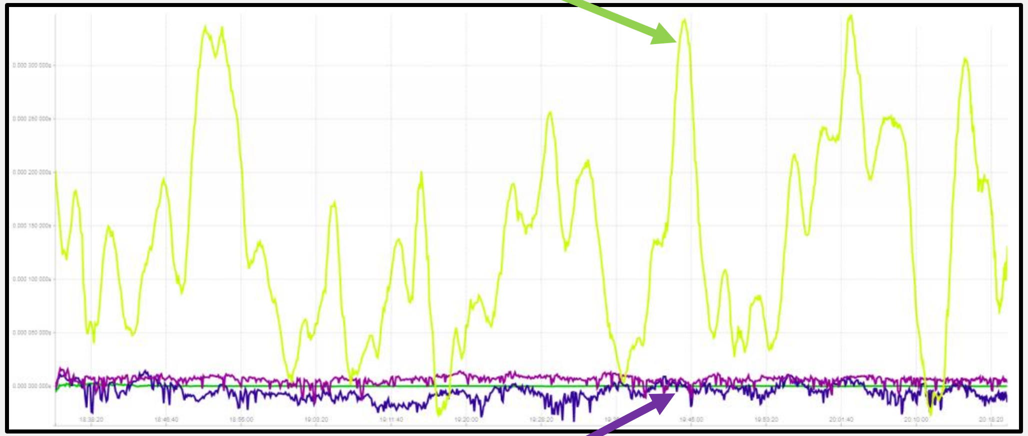
Extension Field	Sender	Field Code	Description	Bytes
Time Reflection	Client	0x010C	Tells server the T1-T4 of the last exchange	0x0024
Peer Request	Client	0x020C	Asks client to report which servers it is getting NTP+ info from and is reporting to	0x0010
Peer Response	Server	0x820C	Client response to Peer Request	0x0014
Server ID Request	Client	0x030C	Asks server to recommend other server IP addresses	0x0010
Server ID Response	Server	0x830C	Server response to Server ID Request	0x0010
Location Request	Server	0x040C	Server asks client what it claims its location is	0x0010
Location Response	Client	0x840C	Client response to Location Request	0x0010
Event Request	Client	0x050C	Client asks server to record event data in ledger	Varies
Event Response	Server	0x850C	Server confirms recording event data in ledger	Varies



Time Reflection allows the server to know the latency and clock offset

Being Close Matters – Time

NTPpool variable latency
1ms Accuracy



50 miles
10µs Accuracy

- Measured using portable atomic clock
- Choosing lowest latency routes improves time distribution dramatically: Implicitly less jitter

DataQube

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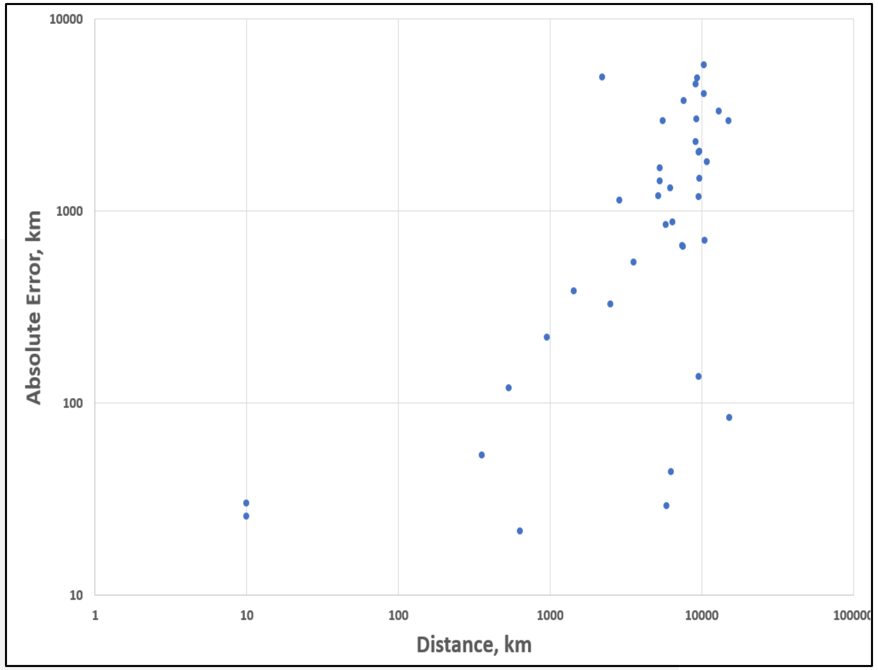
Being Close Matters – Location

- Time delivery accuracy is better with clocks that are close.
- But also, estimating physical distance works better with clocks that are close
- We ran test sending time to clients devices in New York, London & Tokyo from 14 cloud locations.
- Very clearly physical distance was more closely correlated with latency for shorter distances

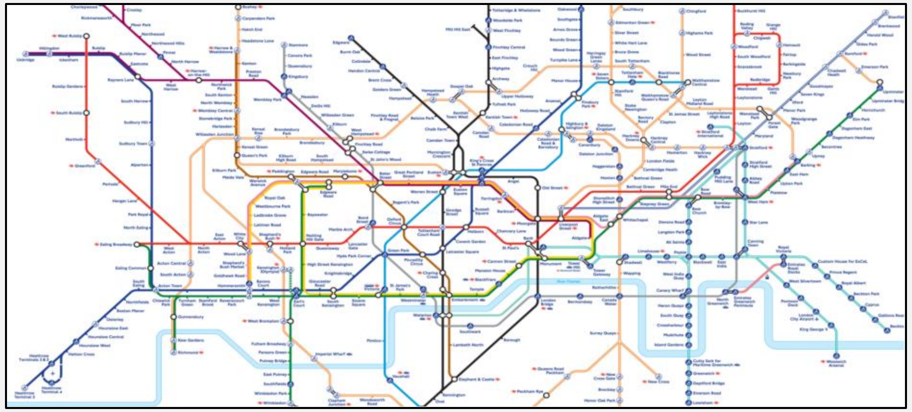


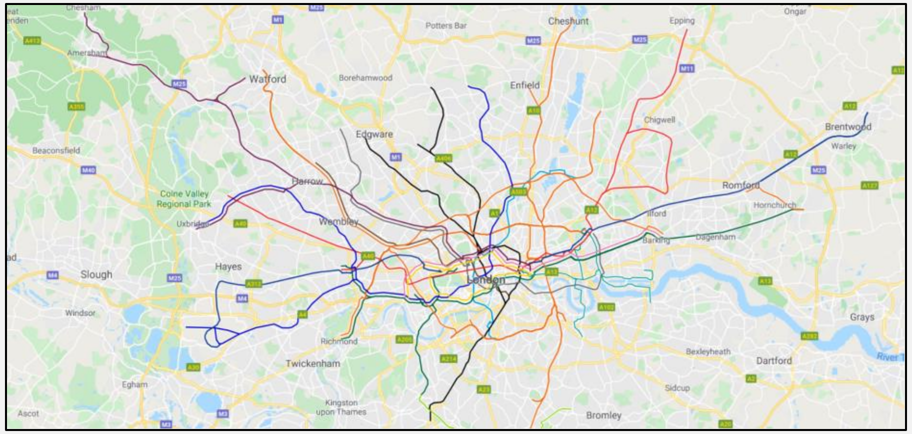
New York	Probe Region	RTD ms	Variance ms	Hops	Distance km
Amsterdam	EUR	247	3	14	9282
Dallas	NAM	135	2	12	10391
Frankfurt	EUR	248	6	16	9326
Hong Kong	SEA	50	0.3	8	2878
Kuala Lumpur	SEA	91	2	10	5318
London	EUR	241	3	10	9553
Milan	EUR	256	3	13	9709
Montreal	NAM	246	4	17	10383
Moscow	EUR	250	1	8	7474
Paris	EUR	243	1	13	9706
Singapore	SEA	76	0.2	11	5312
Tel Aviv	ME	282	6	13	9153
Tokyo	SEA	1.7	0.1	4	10

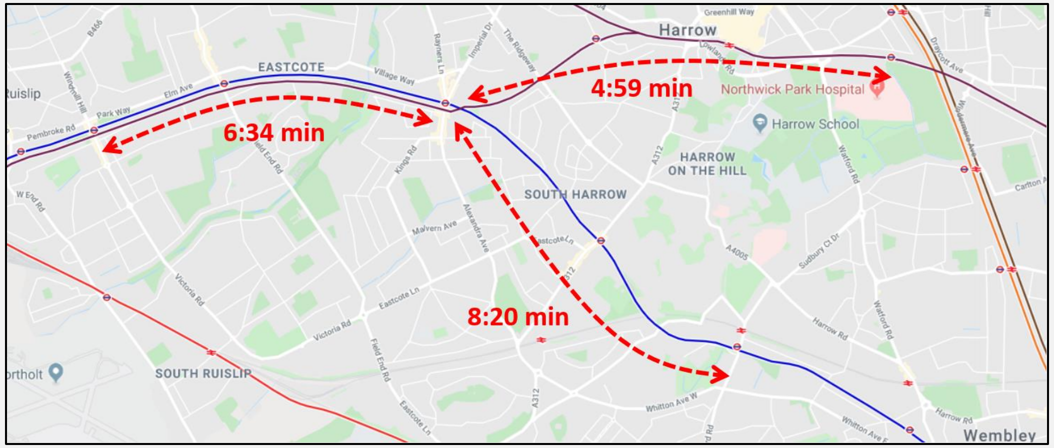
London	Probe Region	RTD ms	Variance ms	Hops	Distance km
Amsterdam	EUR	8.4	0.1	9	358
Dallas	NAM	112	0.1	9	7641
Frankfurt	EUR	15.7	0.1	10	637
Hong Kong	SEA	238.5	0.1	10	9626
Kuala Lumpur	SEA	175.8	0.2	15	10546
London	EUR	1.1	0.1	8	10
Milan	EUR	19	0.1	10	958
Montreal	NAM	77	0.5	13	5220
Moscow	EUR	59	0.3	10	2501
Paris	EUR	9.4	0.4	9	343
Stockholm	EUR	31	3	9	1433
Tel Aviv	ME	63	1	16	3557
Tokyo	SEA	232.4	0.1	12	9553

Tokyo	Probe Region	RTD ms	Variance ms	Hops	Distance km
Amsterdam	EUR	85	2	18	5862
Dallas	NAM	112	2	16	2205
Frankfurt	EUR	87	2	15	6202
Hong Kong	SEA	212	5	11	12960
Kuala Lumpur	SEA	245	7	12	15117
London	EUR	72.1	0.1	10	5571
Milan	EUR	100	5	15	6464
Montreal	NAM	9	0.3	16	535
Moscow	EUR	121	2	18	7510
Paris	EUR	77	0.2	17	5837
Singapore	SEA	245	2	15	15340
Stockholm	EUR	105	1	16	6319
Tel Aviv	ME	136	1	13	9116
Tokyo	SEA	164	0.3	13	10847

Geolocation







Wireless Last Mile Time Dissemination

- Most IoT devices are untethered and require a wireless “last mile”
- A GPS chipset for time sync is a significant additional cost
- 1ms time delivery over wireless IP (WiFi / 5G modem) can be achieved
- Fits naturally within the NTP+ framework

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Cranfield University

NPL National Physical Laboratory

Secure Time Sync For Airspace Management

- Terrestrial time synchronization provides a secure, resilient alternative to GPS
- Time delivery tests have demonstrated that sync is well within the 1ms requirements for sensor fusion
- The implementation is low cost
- The commercial opportunity has been recognized by OSL and Hoptroff and being actively developed

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OPERATIONAL Solutions

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Cranfield University

NPL National Physical Laboratory

Thank you

Email richard.hoptroff@hoptroff.com

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