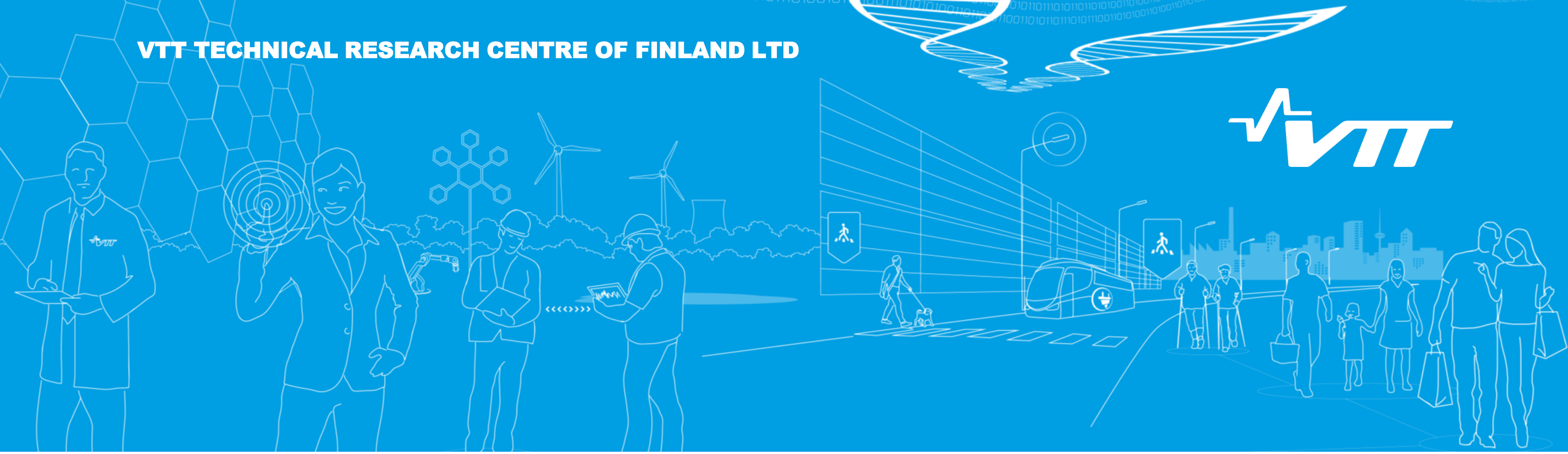


Tarkka aikasynkronointi ja aikalinkit kriittisessä infrastrukstuurissa

MATINE TUTKIMUSSEMINAARI 16.11.2017

Anders Wallin
VTT MIKES Metrologia

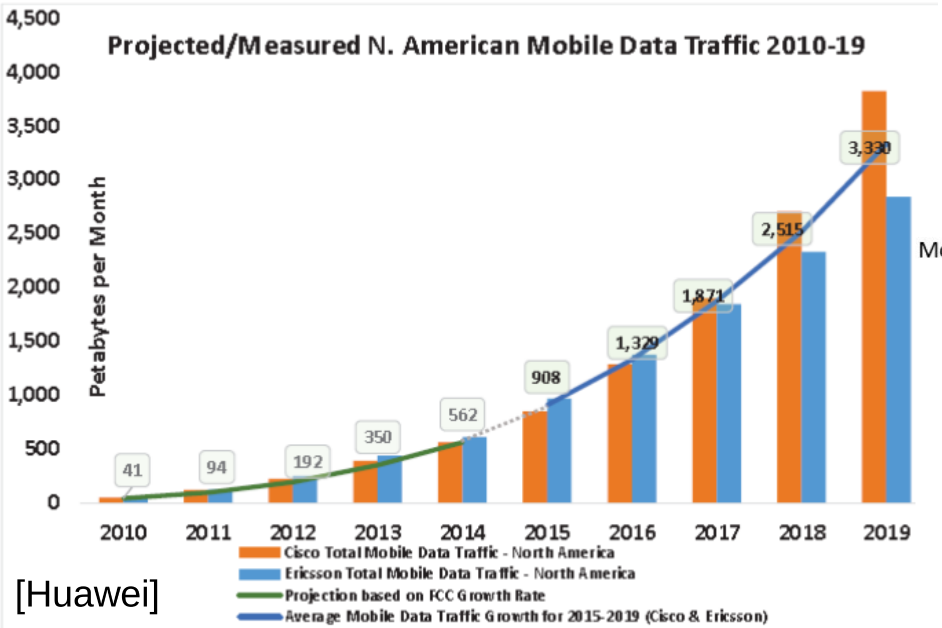
Tarkka aika

- Tarpeet ja standardit
  - ITU PRTC ja ePRTC vaatimukset televerkoille
  - Digitaalinen sähköasemastandardi (IEC61850)
  - Hajautettu passiivitutka / paikannus
  - Aikaleimaus ja sähköinen kauppa (MIFID-2 EU direktiivi)
- Haasteet
  - GNSS häirintä ja harhautus
  - Televerkkojen epäsymmetriat
  - Pitkä jäljitettävyysketju
- Ratkaisut
  - Ajan lähde: UTC-laboratorio
  - Ajansiirtotekniikat
  - Tarkkaa aikaa PTP White Rabbit ajansiirrolla
    - Kajaani, Metsähovi, jne. pilottihankkeet

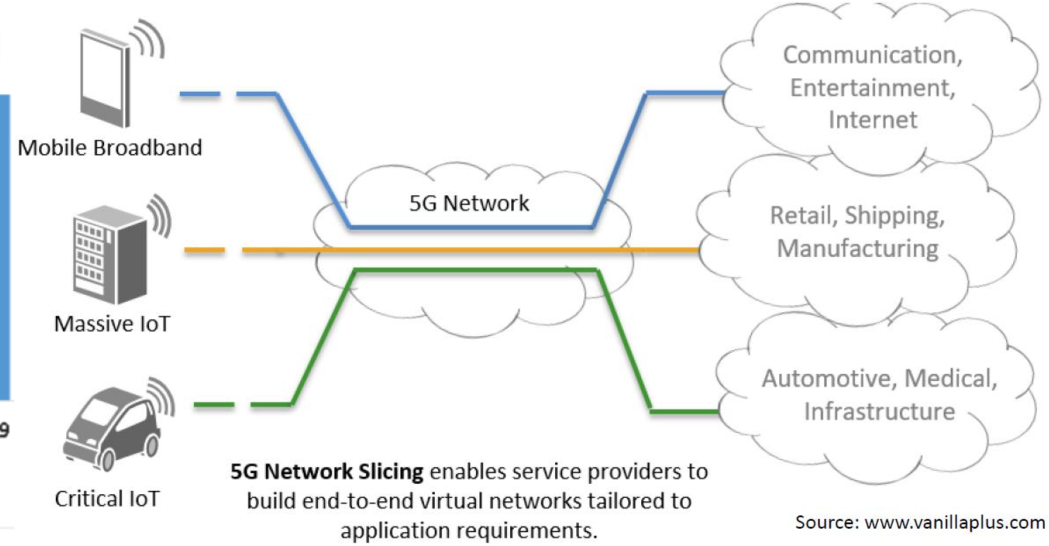
Tarkan ajan tarpeet ja standardit

- Televerkot
- Energiaverkot
- Paikannus
- Aikaleimaus

Telecom



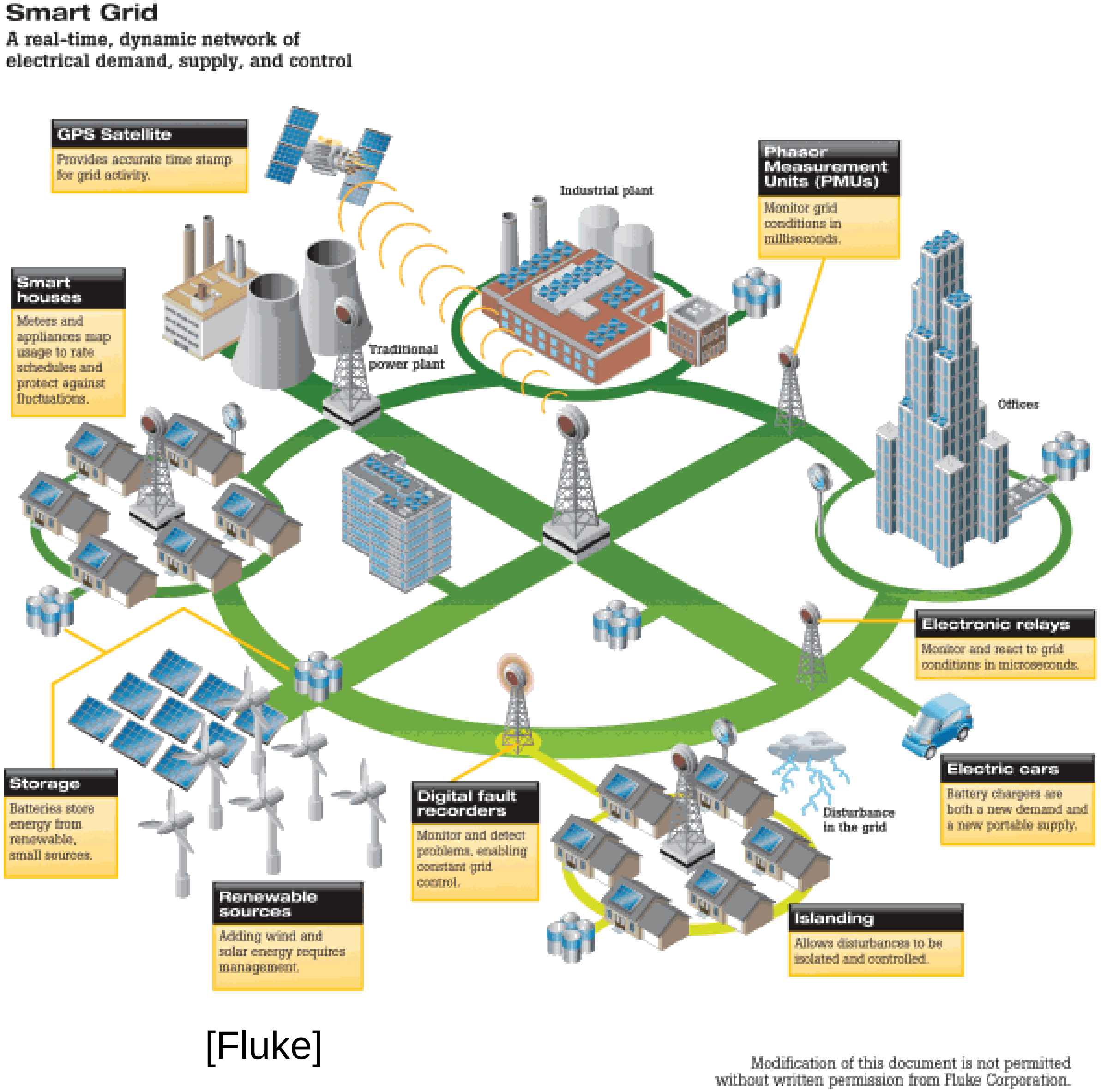
[Huawei]



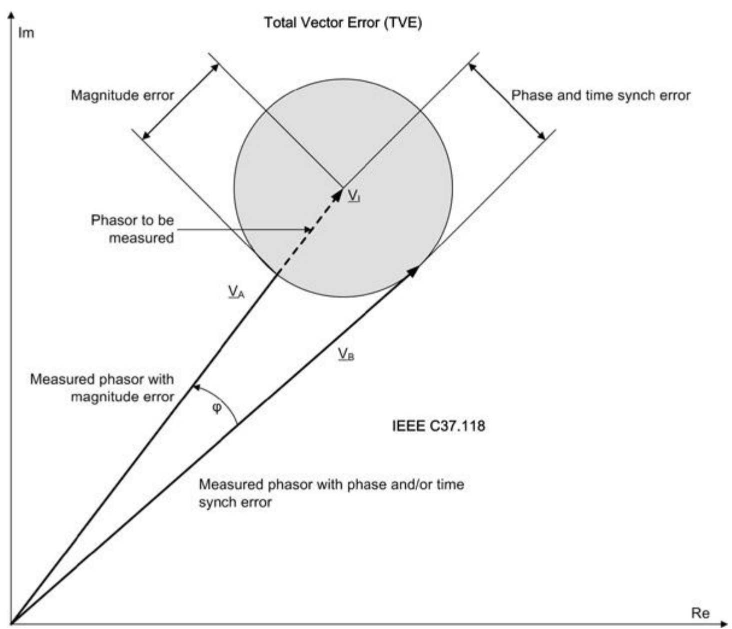
PRC Primary Reference Clock	→	PRTC Primary Reference Time Clock	→	ePRTC Enhanced Primary Reference Time Clock
Performance = 1 part in 10^{11} (frequency)		Performance = 100 nS (time, phase, and frequency)		Performance = 30 nS (time, phase, and frequency)
ITU-T G.811 (Pub. 1988)		ITU-T G.8272 (Pub. 2012)		ITU-T G.8272.1 (Pub. 2016)

[Microsemi]

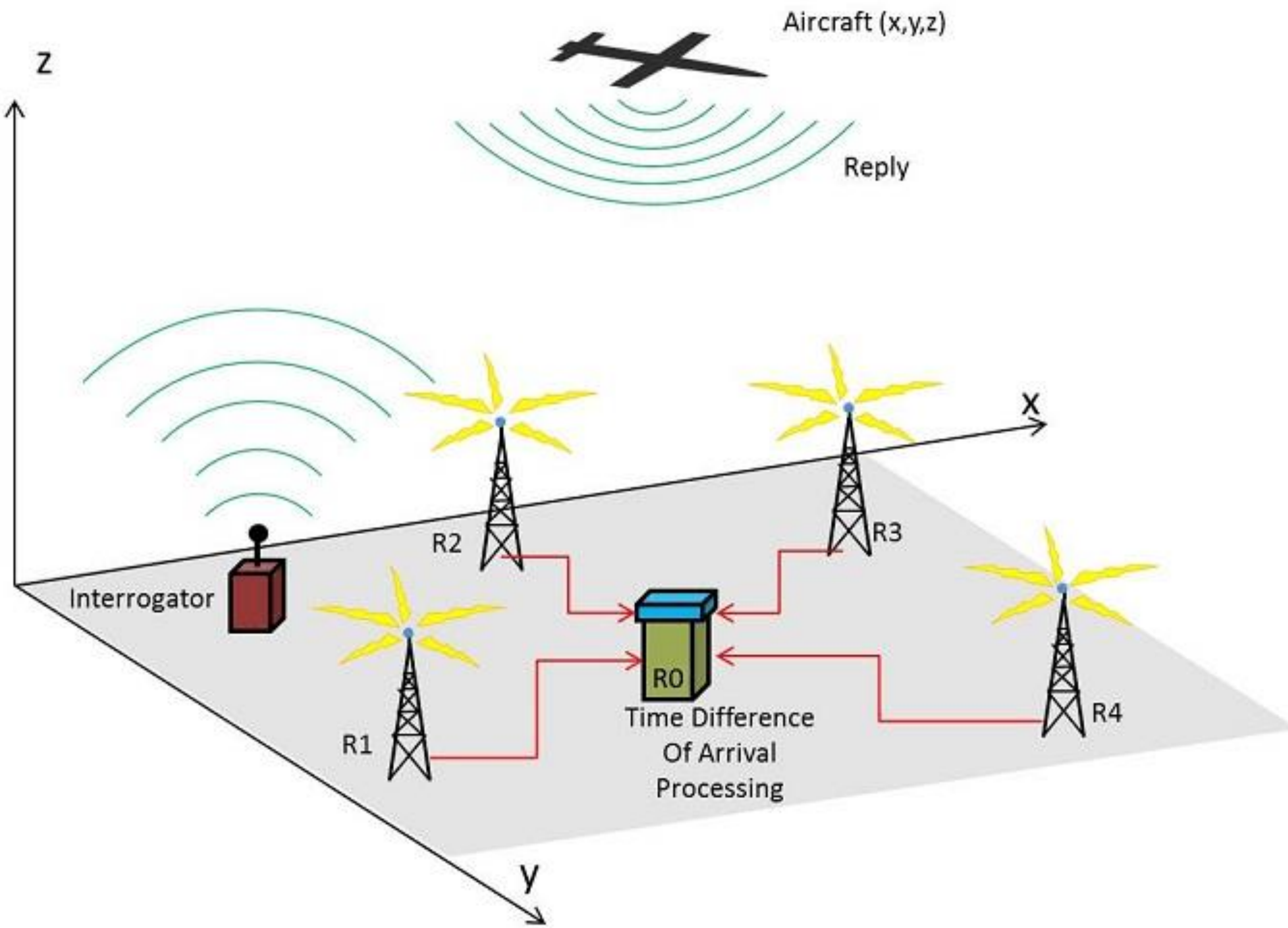
Energy



[Fluke]



Navigation



Aircraft (x,y,z)
Reply
z
x
y
Interrogator
R1
R2
R3
R4
R0
Time Difference
Of Arrival
Processing

Finance / e-Commerce

Business Clocks – What requirements will apply with MiFID II?

1. **Reference time**: Operators of trading venues and their members or participants shall synchronise the business clocks they use to record the date and time of any reportable event with the **Coordinated Universal Time (UTC)**
2. **Level of accuracy**: Applicable for operators of trading venues and their members

	Gateway-to-gateway latency[1]	Max. divergence from UTC	Granularity of timestamp
Trading venues	>= 1 ms[2]	1 ms	1 ms or better
	< 1 ms[2]	100 µs	1 µs or better
HFTs	-	100 µs	1 µs or better
Voice trading	-	1 s	1 s or better
RFQ	-	1 s	1 s or better
Negotiated Transactions	-	1 s	1 s or better
Other trading activity	-	1 ms	1 ms or better

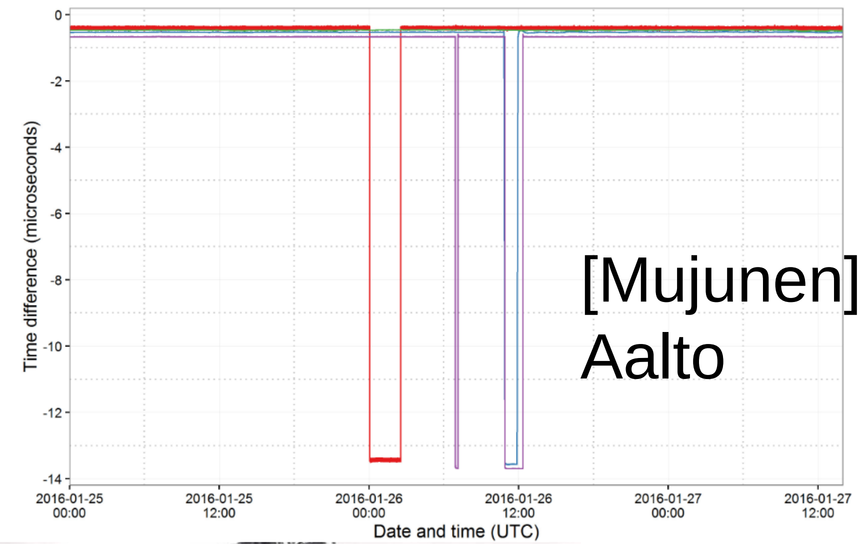
µs = microsecond, ms = millisecond, s = second

Tarkan ajan haasteet
- GNSS
- epäsymmetriat televerkoissa

GNSS Threats

GNSS System incidents

- SVN23 Incident - 26th January 2016
- 13 micrsecond jump on some receivers



[Mujunen]
Aalto

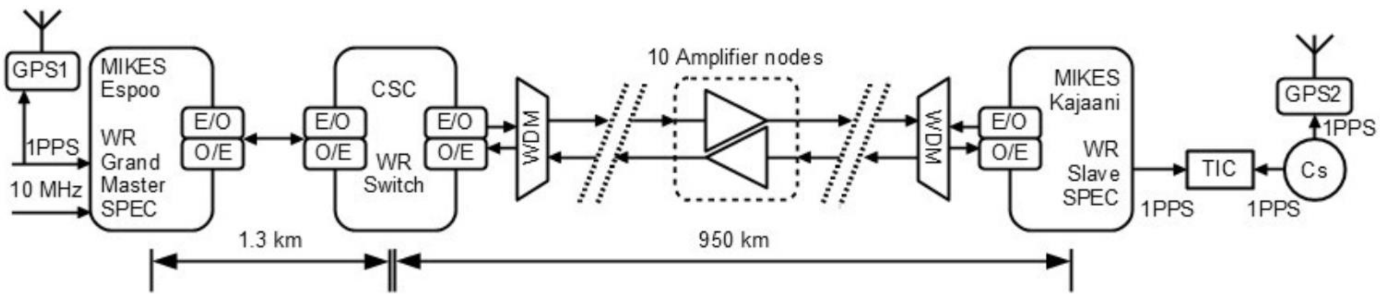
Unintentional Interference

[ITSF2016]

Intentional jamming/spoofing!

US $42 / Piece
made-in-china.com

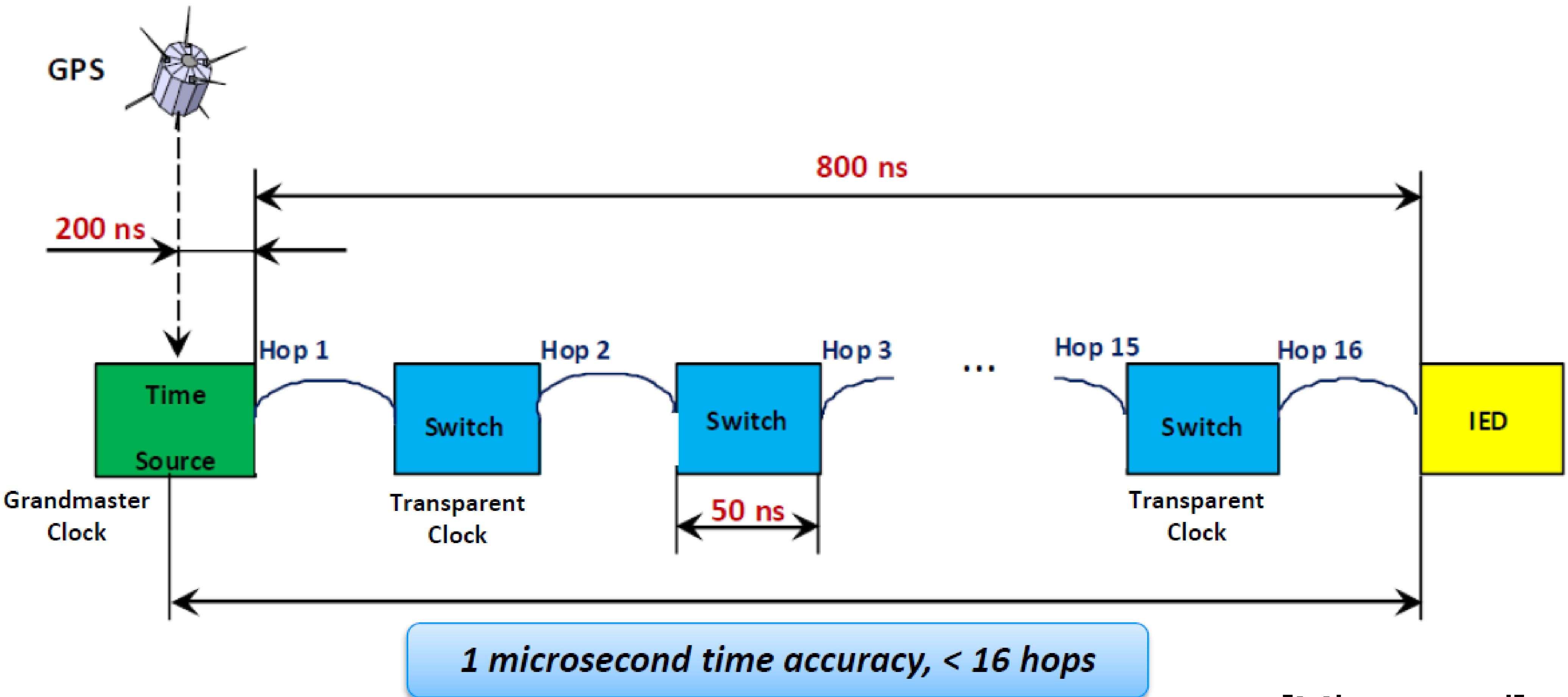
Asymmetries in typical DWDM networks



- Uplink delay ≠ downlink delay !!
- Dispersion control fiber length not controlled
- PTPv2 / SyncE support in:
    - Switches
    - Media-converters
    - Other E/O or O/E converters on the path

Link	Round-trip-time	Observed Asymmetry
Kajaani, 1000km	~10 ms	~4 µs
MATINE, 280 km	~ 2.5 ms	~1 µs
Metsähovi 50 km	~ 500 µs	Low!?

Traceability-chain

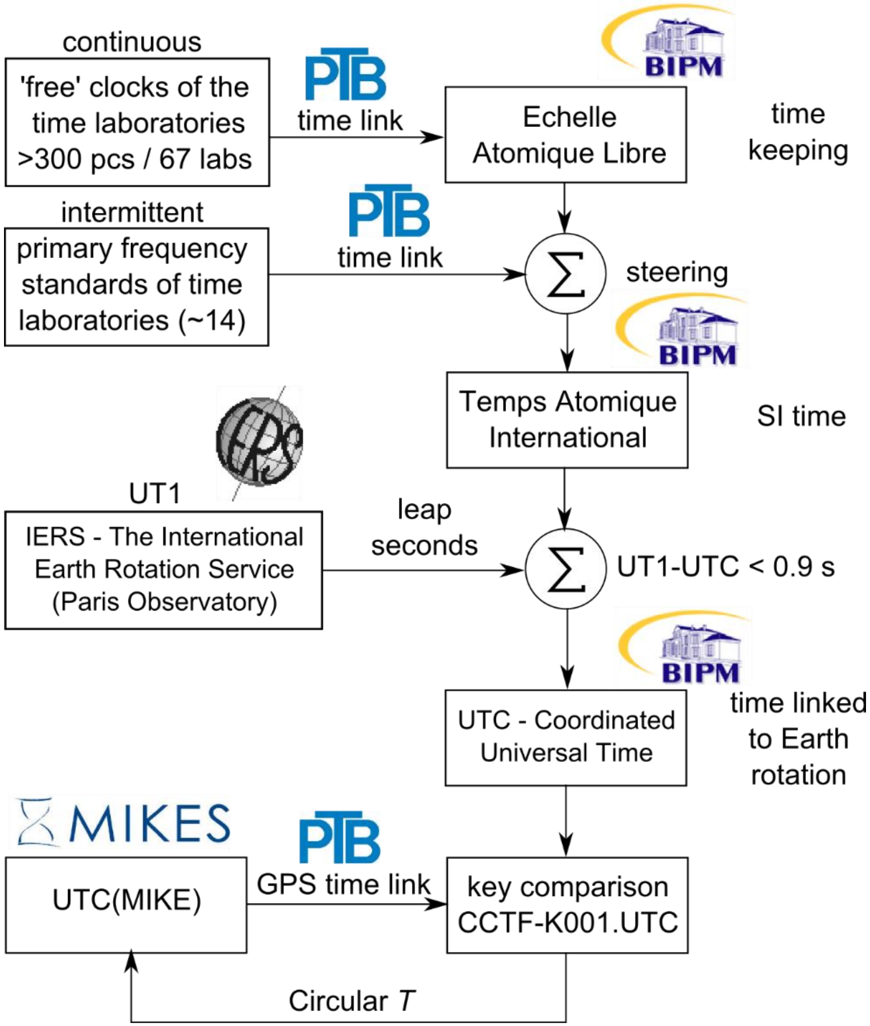


[Microsemi]

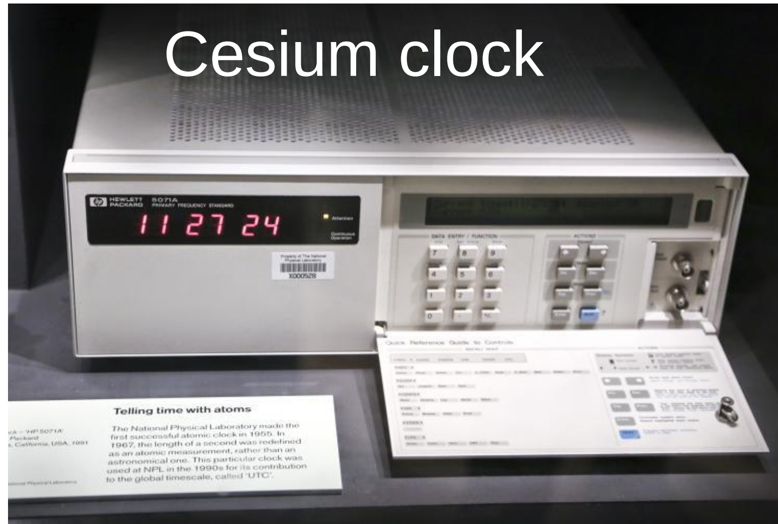
Ratkaisut tarkkaan ajan ylläpitoon ja ajansiirtoon

- UTC laboratoriot
- Ajansiirto televerkossa
- PTP White Rabbit tuloksia

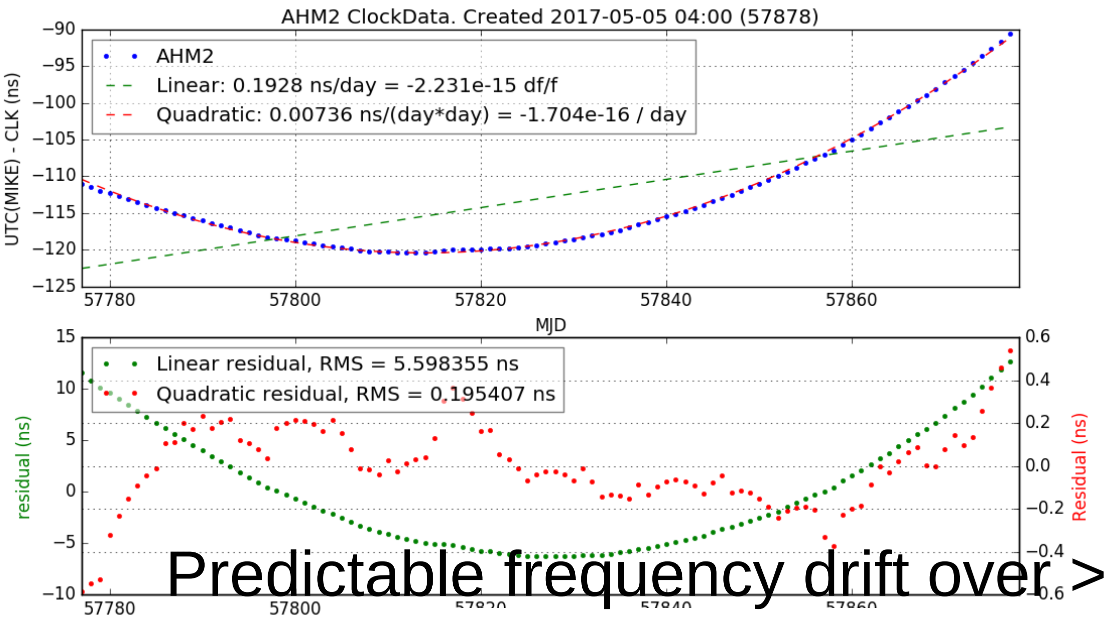
UTC timekeeping



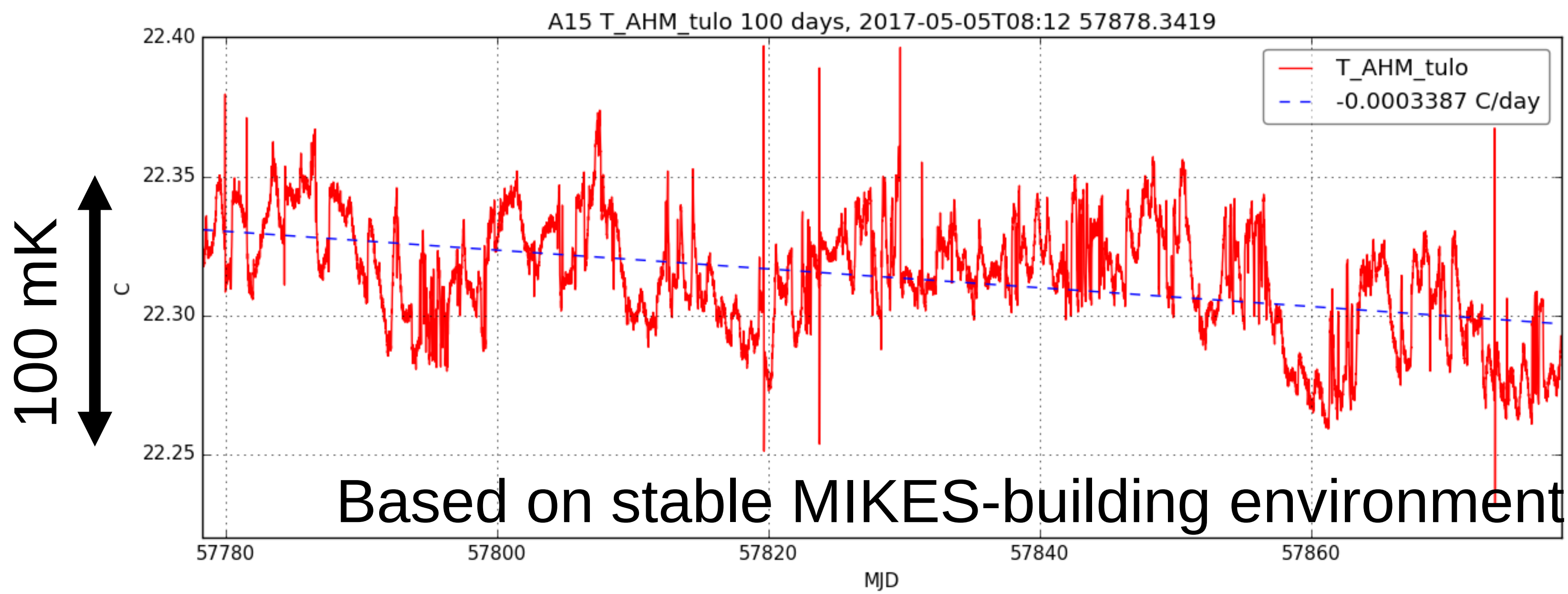
Active hydrogen maser



Active Hydrogen Masers



Predictable frequency drift over >100 days



Based on stable MIKES-building environment

Circular-T

CIRCULAR T 357 ISSN 1143-1393
2017 OCTOBER 10, 13h UTC

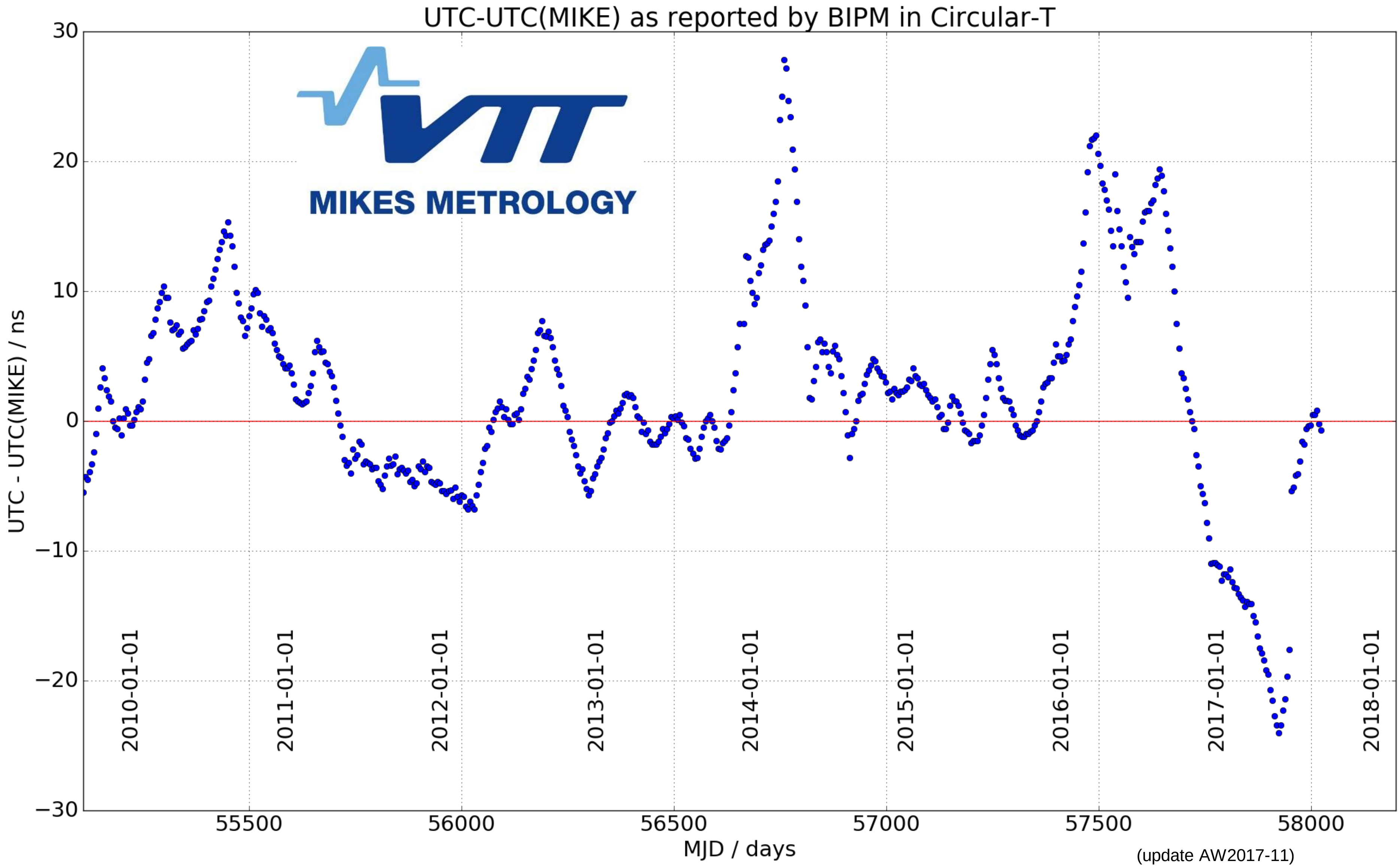
BUREAU INTERNATIONAL DES POIDS ET MESURES
ORGANISATION INTERGOUVERNEMENTALE DE LA CONVENTION DU METRE
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 FAX. +33 1 45 34 20 21 tai@bipm.org

The contents of the sections of BIPM Circular T are fully described in the document "Explanatory supplement to BIPM Circular
available at ftp://ftp2.bipm.org/pub/tai/publication/notes/explanatory_supplement_v0.1.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties.
From 2017 January 1, 0h UTC, TAI-UTC = 37 s.

Date 2017 0h UTC	AUG 29	SEP 3	SEP 8	SEP 13	SEP 18	SEP 23	SEP 28	Uncertainty/ns			Notes
MJD	57994	57999	58004	58009	58014	58019	58024	uA	uB	u	
Laboratory k	[UTC-UTC(k)]/ns										
JV (Kjeller)	4.8	-6.2	-17.2	-16.6	-17.6	-19.0	-19.6	0.4	20.0	20.0	
KEBS (Nairobi)	-	-	-	-	-	-	-				
KIM (Serpong-Tangerang)	141.1	168.3	169.5	174.4	188.4	200.4	173.8	2.0	20.0	20.1	
KRIS (Daejeon)	35.5	40.3	44.3	47.7	50.6	52.2	52.9	0.4	11.1	11.1	
KZ (Astana)	-294.7	-322.8	-334.3	-331.1	-313.3	-298.9	-301.0	1.5	9.3	9.4	
LT (Vilnius)	158.7	144.0	145.4	157.0	152.5	168.8	181.8	2.0	11.3	11.4	
MASM (Bayanzurkh)	-411.6	-428.7	-451.6	-	-	-34.5	-60.0	0.7	20.0	20.1	
MBM (Podgorica)	51657.3	51989.6	52323.7	52643.4	52978.9	53335.9	53658.6	1.5	20.0	20.1	
MIKE (Espoo)	-0.4	-0.3	0.5	0.5	0.8	-0.2	-0.7	0.7	4.2	4.3	
MKEH (Budapest)	-65005.0	-65222.3	-65420.4	-65627.5	-65836.7	-66030.7	-66237.0	1.5	20.0	20.1	
MSL (Lower Hutt)	285.3	289.9	309.0	301.6	285.8	300.7	321.8	1.5	20.0	20.1	
MTC (Makkah)	1149.2	1164.1	1145.4	1170.6	1149.7	1204.2	1187.0	10.0	7.4	12.4	
NAO (Mizusawa)	99.4	86.1	93.0	95.8	97.0	89.5	75.7	2.0	20.0	20.1	
NICT (Tokyo)	-5.7	-5.8	-7.5	-6.9	-5.9	-4.2	-1.9	0.4	2.2	2.3	
NIM (Beijing)	5.2	4.5	3.8	3.3	3.9	3.7	2.9	0.7	1.9	2.0	
NIMB (Bucharest)	1813.1	1816.1	1803.5	1816.4	1818.9	1814.2	1808.5	0.4	7.2	7.2	
NIMT (Pathumthani)	203.3	208.9	214.5	217.7	219.5	218.6	221.5	1.0	20.0	20.1	
NIS (Cairo)	11.9	8.4	2.4	-19.9	-30.1	-48.5	-55.3	1.6	20.0	20.1	
NIST (Boulder)	0.5	0.6	1.1	1.7	2.2	2.2	1.4	0.4	4.9	4.9	

>75 laboratories in total



UTC-UTC(MIKE) as reported by BIPM in Circular-T
MIKES METROLOGY
UTC - UTC(MIKE) / ns
30
20
10
0
−10
−20
−30
2010-01-01
2011-01-01
2012-01-01
2013-01-01
2014-01-01
2015-01-01
2016-01-01
2017-01-01
2018-01-01
55500
56000
56500
57000
57500
58000
MJD / days
(update AW2017-11)

Time Distribution over Optical Fiber

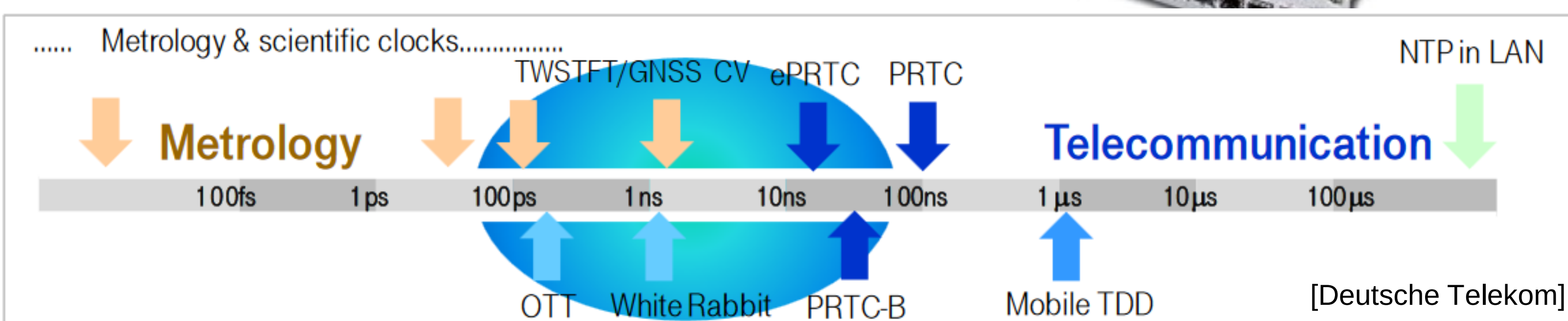
NTP: milliseconds

(software time-stamping, unpredictable delays in routers/switches/gateways)

PTP: microseconds
(hardware time-stamping)

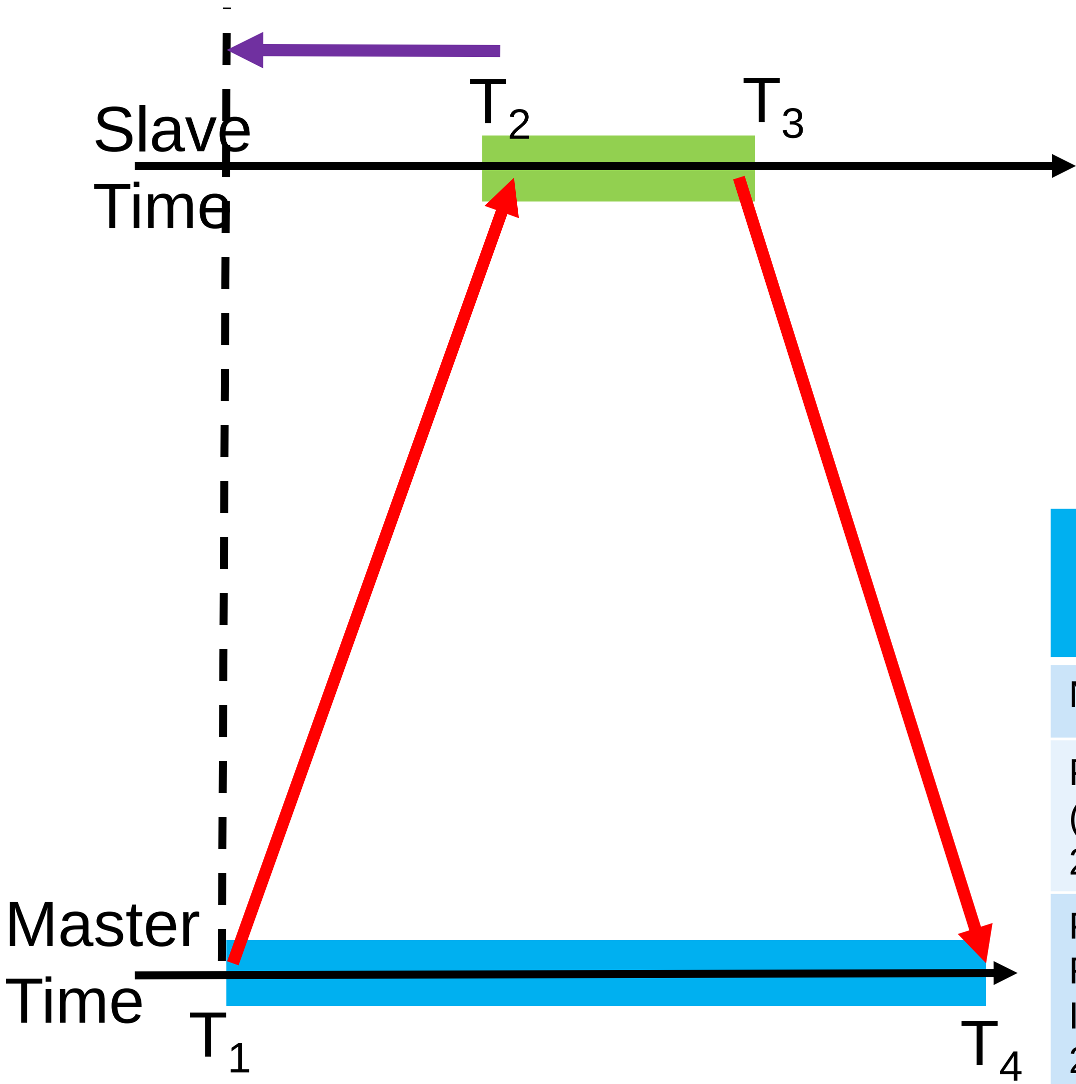
PTP = Precision Time Protocol
(IEEE 1588-2008, PTPv2)

PTP White Rabbit: nanoseconds
(hardware time-stamping enhanced
by precise phase-measurement)



[Deutsche Telekom]

Time-transfer (principle)



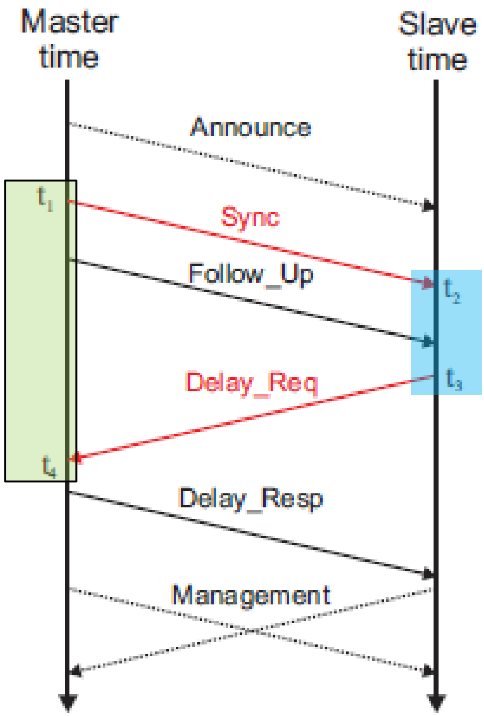
Round-Trip-Time
= (T4-T1) – (T3-T2)

Master-Slave-Delay
= 1/2 Round-Trip-Time ?

	Time-stamping	Time-stamp Accuracy	Allow for Link asymmetry?
NTP	Software	~ms	No
PTPv2 (IEEE1588-2008)	Hardware	~5-10 ns?	Usually no.
PTP White Rabbit IEEE1588-2018	Hardware SyncE + phase-measurement	< 1 ns	Allow for constant asymmetry

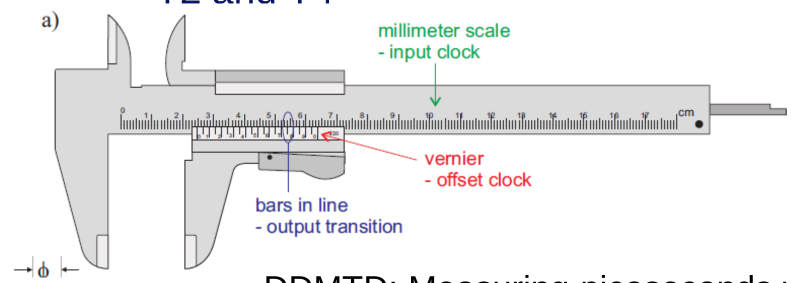
White Rabbit: Precision Time Protocol + Synchronous Ethernet

Step 1.
Hardware time-stamping of t_1-t_4
Gives coarse (8 ns) RTT

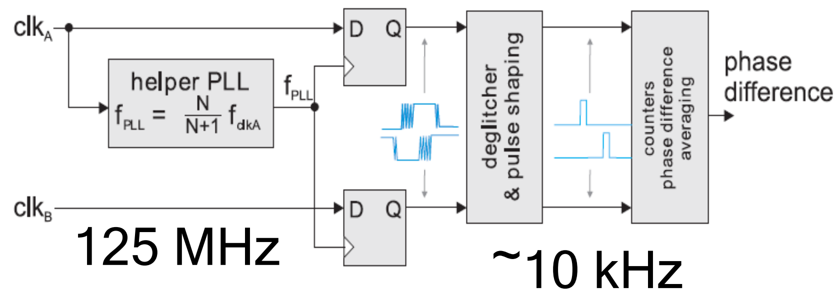


$$delay\_coarse = (t_4 - t_1) - (t_3 - t_2)$$

Step 2.
Phase measurement to enhance T2 and T4

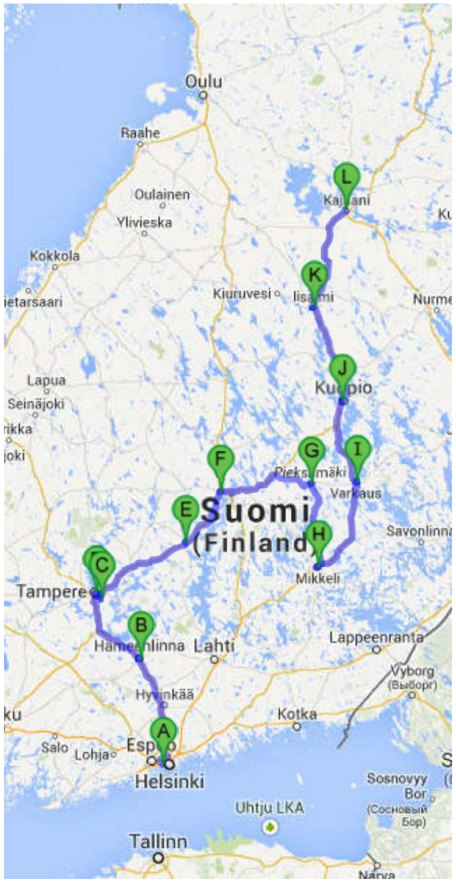


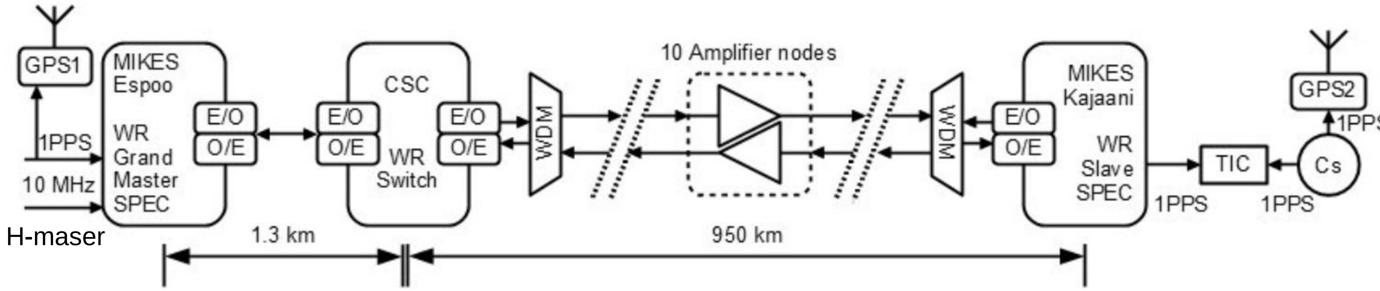
DDMTD: Measuring picoseconds with ~125 MHz clocks on FPGAs



-> Round-trip-time measurement with sub-nanosecond precision

1000 km Espoo - Kajaani White Rabbit link

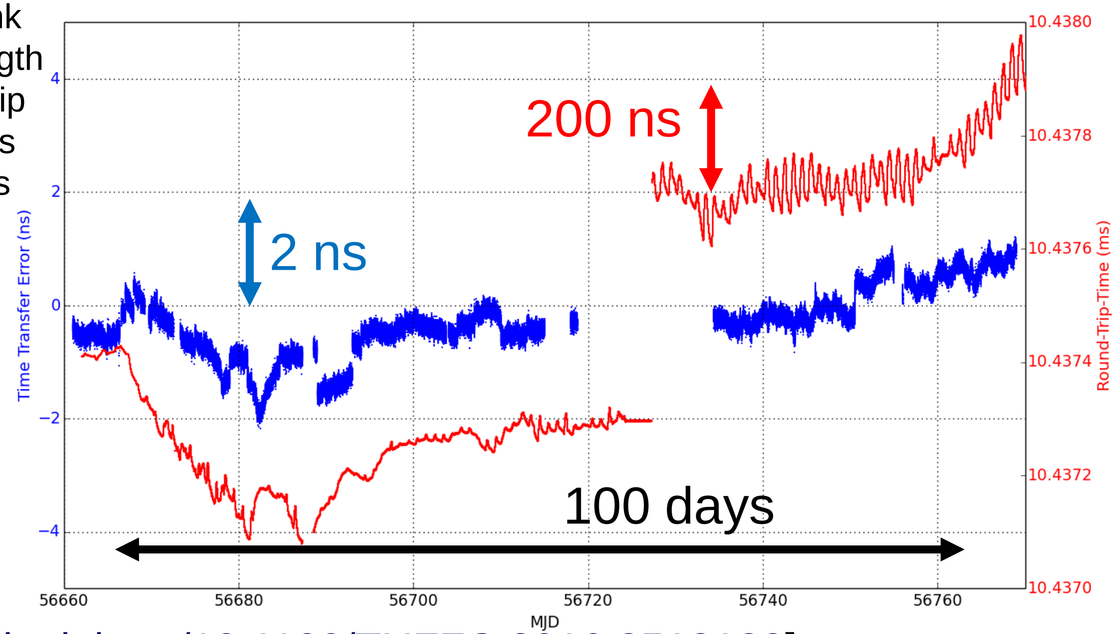




- ~~bidir~~ duplex SFPs and link
- ~~10 km~~ ~1000 km link length
- 10.4 millisecond round trip
- Uplink – downlink = ~4 us
- 12 amplifiers/multiplexers
- Longest span ~140 km

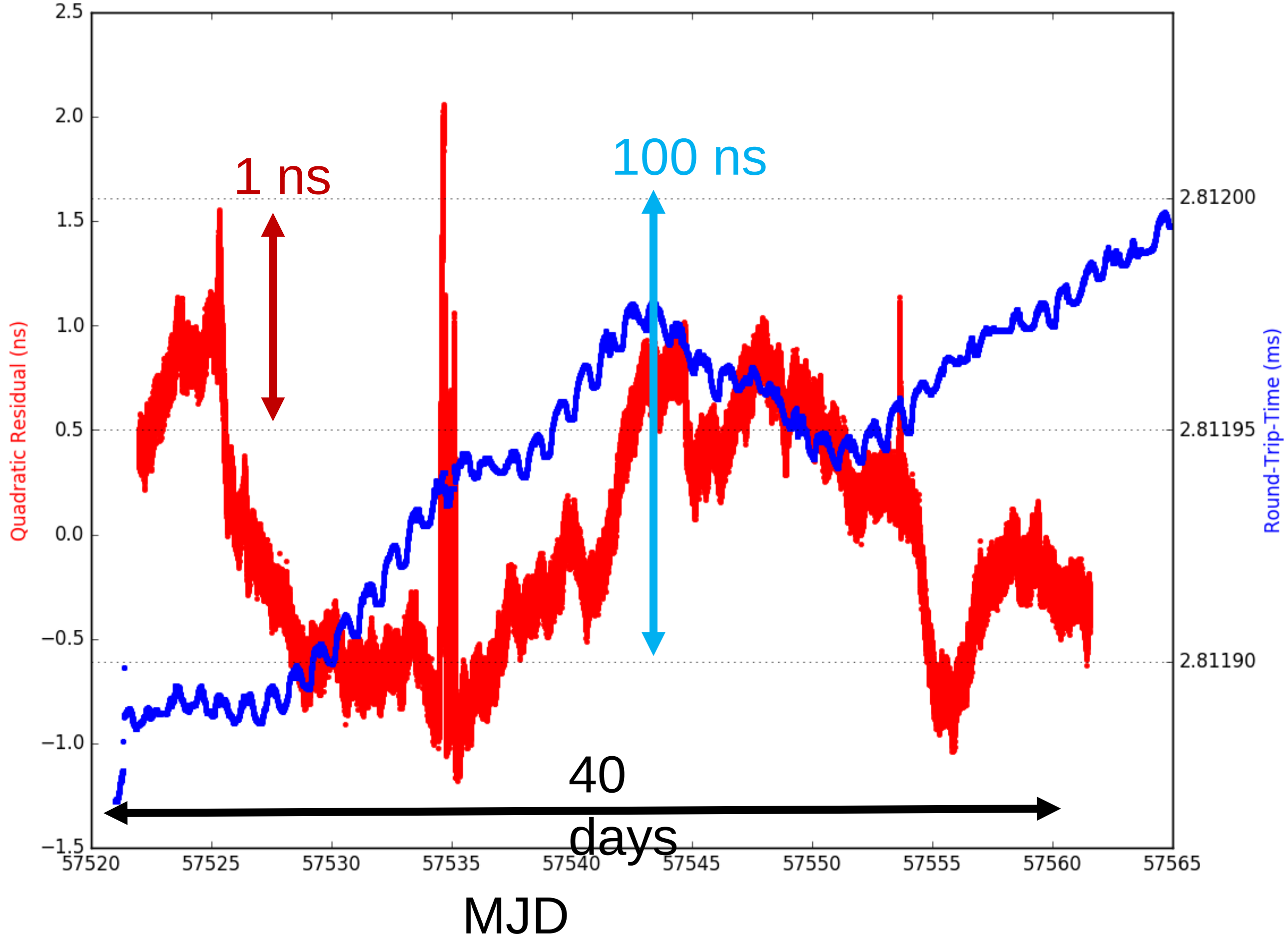
Issues:

- Network maintenance changes asymmetry
- Stability limited by Cs-clock and GPS-PPP

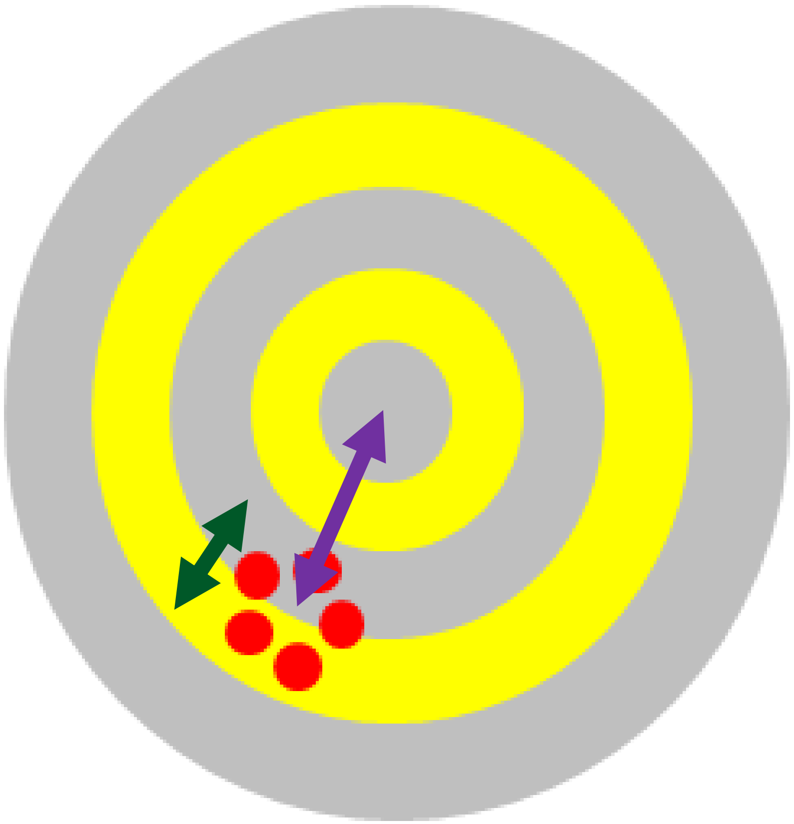


[Dierikx et al. http://dx.doi.org/10.1109/TUFFC.2016.2518122]

280km Link between H-maser clocks



Improving on Precision & Accuracy



1. Precision / Stability / random error

- Local Oscillator phase noise
  - use OCXO in WR-nodes?
- PLL between Reference-clock and WR-node
- Now at about ADEV(1s) = 1e-11

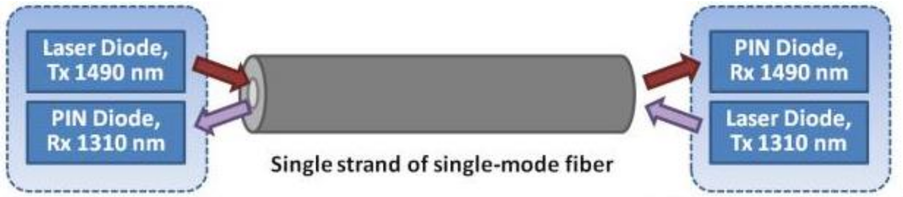
2. Accuracy / Systematic errors

Things that create asymmetric Propagation

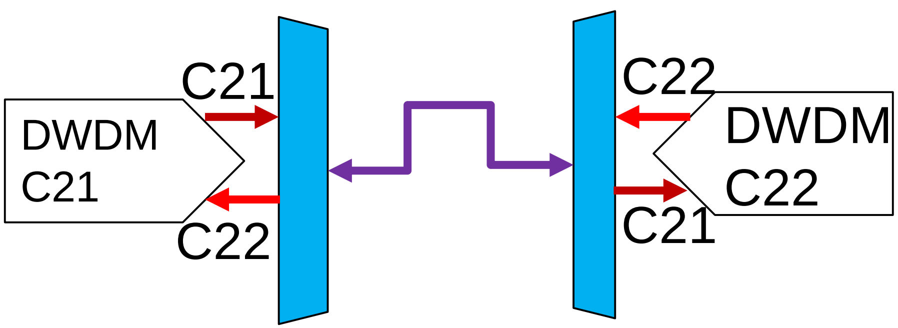
- Chromatic Dispersion
- Calibration of SFPs
- Calibration of nodes

Low Propagation Asymmetry Link

Standard White Rabbit recommends
1000BASE-BX10 SPFs: f_{TX} - f_{RX} = 27.7 THz



Use **<u>adjacent DWDM channels</u>** in a single fiber!?
f_{TX} - f_{RX} = 100 GHz (277-fold closer!)



Single-fiber DWDM MUX

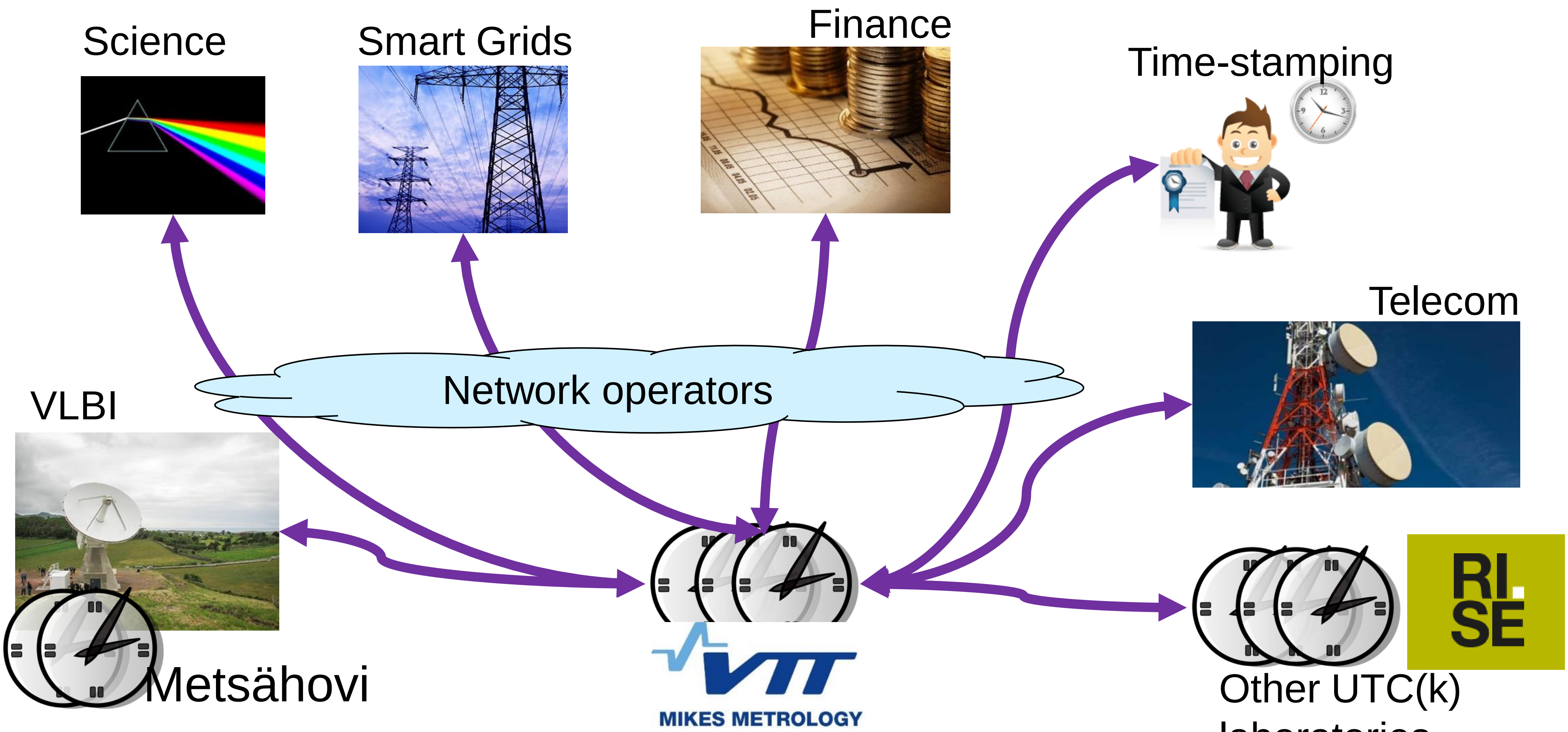
Example1:
100km link (1 ms RTT)
, alpha known to be 250 PPM
with 10% error
-> resulting time-transfer
<u>error of ~7.5 ns</u>

Example2:
100km link (1 ms RTT)
, alpha known to be 1 PPM
with 10% error
-> resulting time-transfer
<u>error of ~70 ps</u>

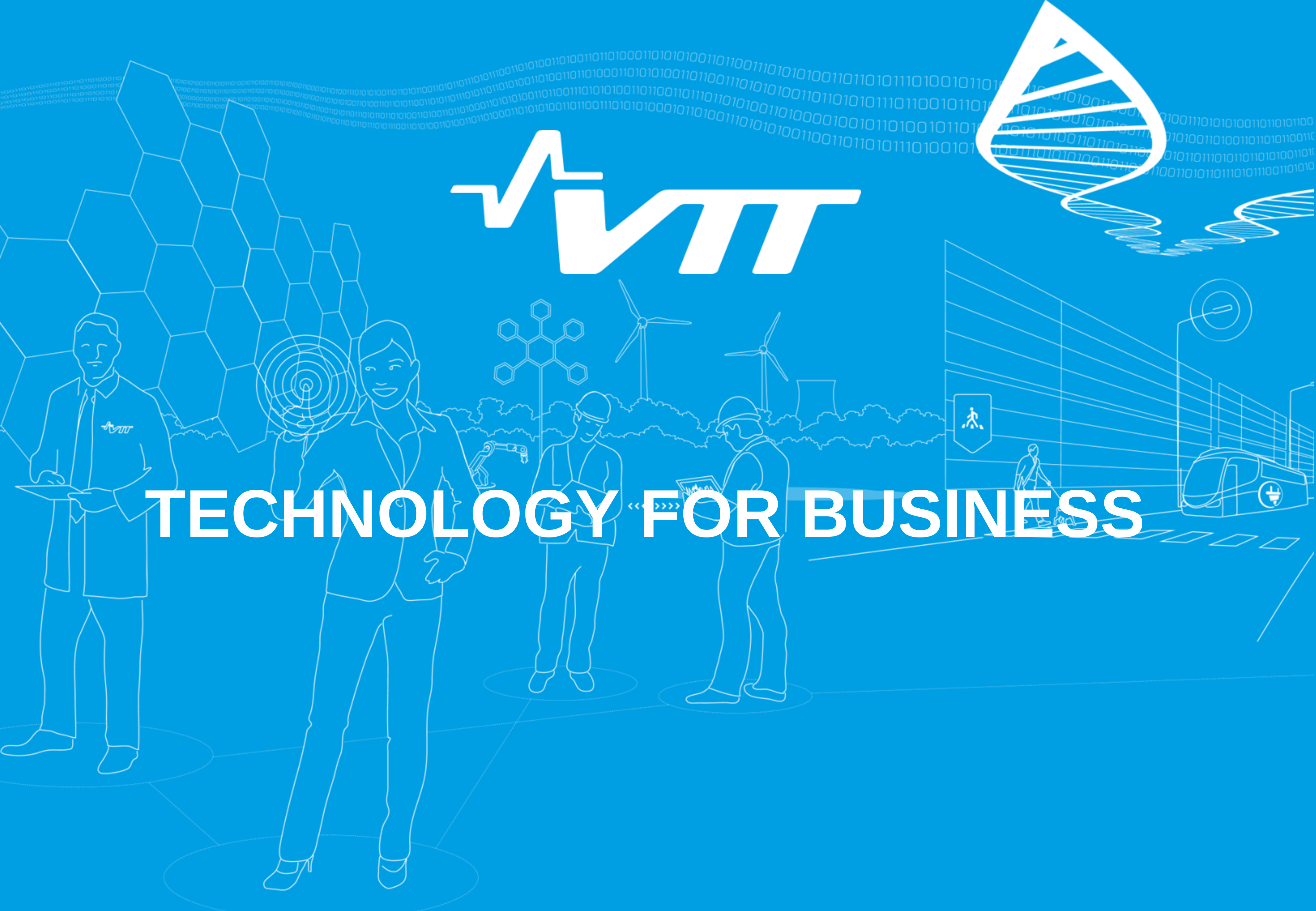
Summary

- Requirements
  - ITU PRTC and ePRTC for Telecom
  - IEC61850 for digital substations and Smart Grids
  - MIFID-2/RTS-25 for time-stamping in the Financial sector
- Threats and issues
  - GNSS Spoofing / Jamming
  - Netwwork propagation asymmetries
  - Support for PTPv2 and SyncE throughout the network
- Solutions
  - Your local UTC(k)-lab!
  - Upcoming IEE1588-2018 High Accuracy profile = White Rabbit
  - Low-asymmetry links
  - Best-practices guidelines for use of GNSS receivers
  - Galileo offers alternative and new signals wrt. GPS/GLONASS

Outlook



[images.google.com]


TECHNOLOGY FOR BUSINESS