55th CGSIC Meeting - Timing Subcommittee

Tampa, Florida, 14 September 2015
9:00 a.m. - 12:30 p.m.

Chair: **Włodzimierz Lewandowski, ESA PB-Nav**
Co-Chair: **Victor Zhang, NIST**

9:00 Introduction – *Włodzimierz Lewandowski, ESA PB-Nav*
9:10 Report from NIST – *Victor Zhang, NIST*
9:30 Report from USNO – *Stephen Mitchell, USNO*
10:00 Report from APL – *Mihran Miranian, The Johns Hopkins University Applied Physics Laboratory (APL)*
10:20 Coffee Break
10:40 Delivering NIST Time to Financial Markets via Common-View GPS Measurements – *Mike Lombardi, NIST*
11:00 Status of ELORAN demonstration – *Ed Powers, Stephen Mitchell, USNO*
11:20 A Common Clock Reference For All GNSS – an update – *Tom Stansell, Stansell Consulting*
11:40 Time and Navigation Exhibition at the Smithsonian: Progress Report – *Carlene Stephens, Andrew Johnston, National Museum of American History*
12:00 Discussion
12:30 Session End

CGSIC Timing Subcommittee

Introduction

Włodzimierz Lewandowski

ESA-PB-NAV

AREAS BEING SERVED

- **Coordinated Universal Time (UTC)**
- **International Timing Centers**
- **Global Navigation Satellite Systems**
- **Telecommunications Industries**
- **Two-Way Satellite Time Transfer (TWSTFT)**
- **Two-Way Optical Fiber Time Transfer (TWOTFT)**
- **Power Grids and other Industries**
- **As Research and Comparison Tool**
- **Other**

Topics

- Rapid UTC
- Fiber optic time transfer
- Caesium Fontains for GNSS

Characteristics of UTCr

- **Based on daily data reported (daily) by contributing laboratories**
- **Weekly access to daily values of [*UTCr*-*UTC*(*k*)]**
- **Automatically generated weekly solution over four weeks of data (sliding solution)**

Implementation of UTCr

- **September 2011**: UTC contributing laboratories have been invited to participate on a voluntary basis to a pilot experiment.
- **January 2012**: Pilot experiment started, with the target of reporting to the CCTF in September 2012.
- **July 2013**: Operational production of UTCr.

Impact of a rapid realization of UTC

- **On UTC contributing laboratories:**
  - **More frequent assessing of the UTC(K) steering, and consequently better stability and accuracy of [UTC(k)];**
  - **Traceability to UTC is enhanced.**

- **On users of UTC(K):**
  - **Access to a better "local" reference, and indirectly, better traceability to the UTC "global" reference.**

- **On GNSS:**
  - **Better synchronization of GNSS times to UTC, through improved UTC and UTC(k) predictions: case of UTC(USNO) for GPS, UTC(SU) for GLONASS, UTC(k) used in the generation of Galileo ST, BeiDou ST and Gagan ST.**

Publication

- **Every Wednesday before 18:00 UTC**
- **on**
- **ftp://tai.bipm.org/UTCr/Results/**

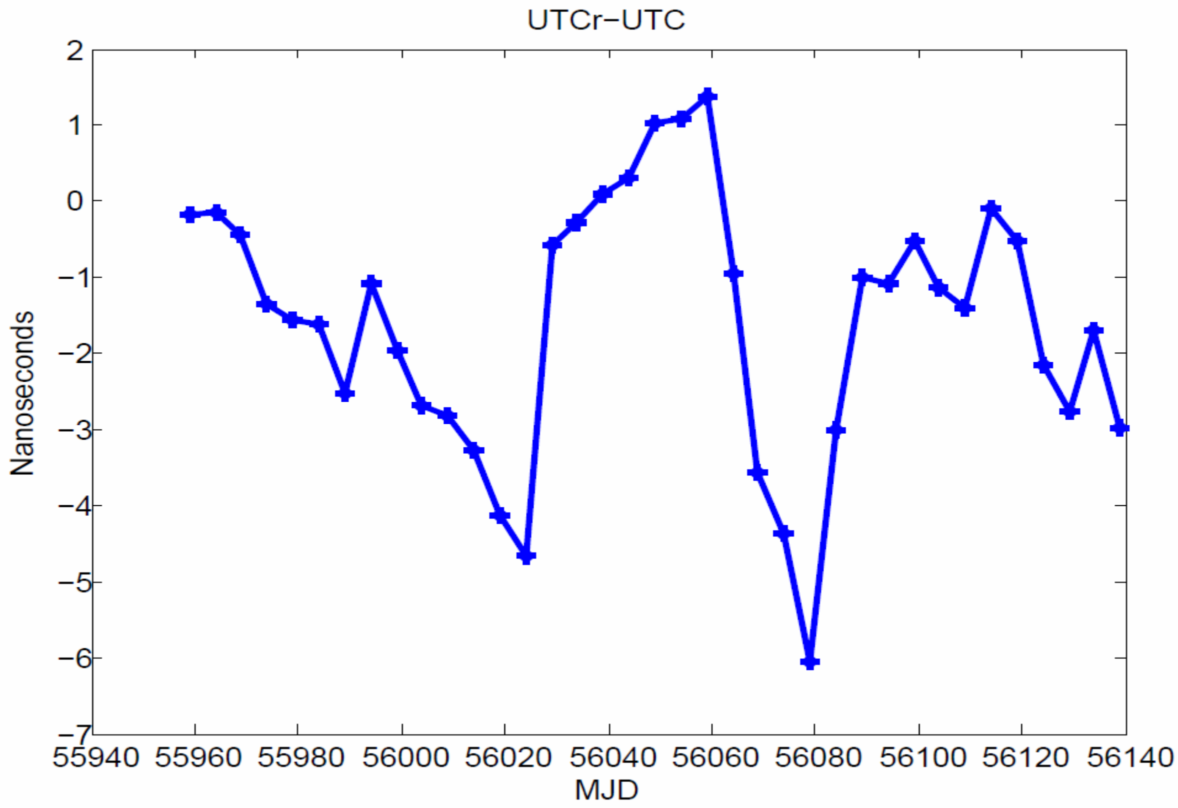
UTCr_1211
2012 MARCH 21, 13h UTC

The results in this page are established by the BIPM Time Department in the frame of the pilot experiment on a rapid UTC, UTCr. The computed values [UTCr-UTC(k)] are reported.

Date 2012	0h UTC	MAR 12	MAR 13	MAR 14	MAR 15	MAR 16	MAR 17	MAR 18
	MJD	55998	55999	56000	56001	56002	56003	56004
Laboratory k					[UTCr-UTC(k)]/ns			
AOS	(Borowiec)	-2.6	-2.4	-1.9	-1.3	-1.9	-1.9	-1.2
BEV	(Wien)	11.9	11.3	10.3	6.5	0.4	-2.3	-5.7
CAO	(Cagliari)	-6291.7	-6290.8	-6293.1	-6291.4	-6298.8	-6308.3	-6300.0
CH	(Bern)	-12.5	-12.3	-12.0	-10.9	-9.8	-9.2	-9.3
CNM	(Queretaro)	-13.8	-15.0	-15.5	-14.9	-17.3	-18.4	-17.1
CNMP	(Panama)	75.8	81.4	85.5	83.1	83.8	83.0	88.0
DTAG	(Frankfurt/M)	6.8	5.1	5.8	5.7	6.8	6.4	7.7
IFAG	(Wettzell)	-620.2	-619.1	-623.8	-627.3	-627.8	-626.7	-627.4
IGNA	(Buenos Aires)	6691.8	6700.6	6711.9	6724.6	6737.0	6747.7	6762.6
INTI	(Buenos Aires)	-26.4	-32.2	-32.6	-32.7	-32.5	-31.6	-36.7
IPQ	(Caparica)	-23.1	-29.1	-27.5	-24.7	-22.6	-16.5	-12.5
IT	(Torino)	1.2	2.3	2.6	3.0	3.4	3.8	4.0
KRIS	(Daejeon)	-8.3	-8.7	-9.4	-	-	-	-
LT	(Vilnius)	42.4	39.1	32.9	35.0	30.1	37.5	43.8
MSL	(Lower Hutt)	67.0	61.2	55.3	-	-	-	-
NAO	(Mizusawa)	54.8	49.9	52.4	54.7	50.1	49.0	50.8
NICT	(Tokyo)	2.5	2.7	2.6	3.1	3.4	3.2	3.2
NIM	(Beijing)	-7.1	-7.5	-8.3	-8.9	-9.8	-9.8	-10.7
NIMT	(Pathumthani)	987.6	1008.5	1026.4	1042.7	1058.3	1074.2	1090.9
NIS	(Cairo)	-782.1	-784.0	-783.8	-786.8	-794.0	-797.0	-799.5
NIST	(Boulder)	-4.1	-5.0	-4.2	-3.9	-6.6	-6.3	-5.2
NMIJ	(Tsukuba)	-8.7	-8.4	-8.5	-8.2	-7.7	-8.0	-8.2
NMLS	(Sepang)	-664.4	-665.1	-667.1	-667.0	-670.4	-672.4	-674.5
NRC	(Ottawa)	-18.1	-14.2	-15.1	-13.9	-13.8	-14.0	-13.6
NTSC	(Lintong)	0.8	2.2	2.1	5.0	4.3	4.5	3.8
ONRJ	(Rio de Janeiro)	-12.3	-9.7	-6.9	-7.5	-7.8	-4.7	-1.9
OP	(Paris)	-24.5	-22.8	-23.7	-21.8	-21.4	-21.8	-24.5
ORB	(Bruxelles)	-0.4	-0.1	0.5	0.0	0.4	-0.5	-1.0
PL	(Warszawa)	15.8	16.5	18.1	16.1	15.0	12.4	12.8
PTB	(Braunschweig)	-3.2	-3.4	-3.6	-3.5	-4.0	-4.0	-4.6
ROA	(San Fernando)	-2.8	-2.2	-2.7	-3.1	-3.5	-3.8	-4.4
SCL	(Hong Kong)	13.8	11.5	5.2	5.5	2.8	-5.8	-2.0
SG	(Singapore)	9.6	9.3	7.5	7.8	7.8	7.4	6.6
SP	(Boras)	-15.7	-15.6	-15.5	-15.6	-15.5	-15.6	-16.0
SU	(Moskva)	1.4	1.2	2.0	2.2	0.6	0.3	0.9
TL	(Chung-Li)	6.4	6.5	5.5	4.9	4.2	2.7	1.3
UME	(Gebze-Kocaeli)	103.3	100.2	104.3	109.5	107.7	105.3	107.1
USNO	(Washington DC)	-0.7	-1.1	-1.2	-1.3	-1.5	-1.5	-1.5
VSL	(Delft)	10.0	8.1	3.6	3.2	4.4	4.5	4.6

These results should not be used as a prediction of UTC.
UTC remains available from the monthly Circular T at
(http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication).

Comparisons between UTCr and UTC

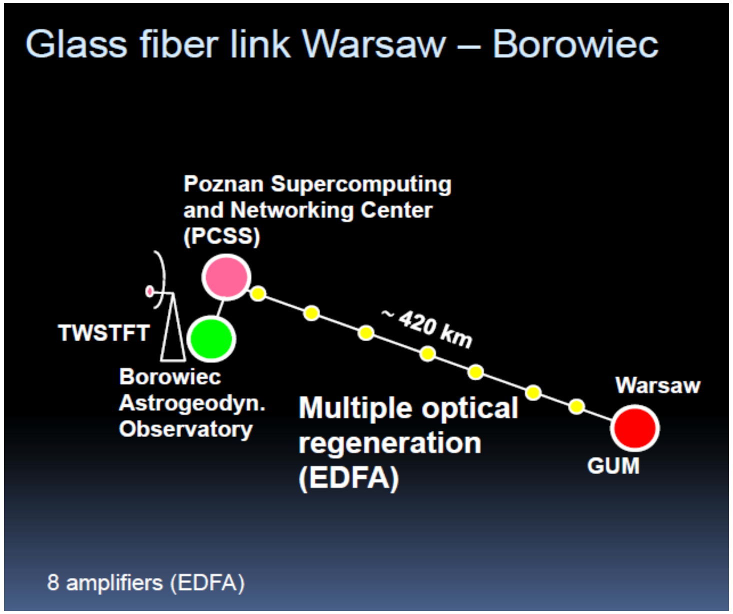


Based on first six months (February to July 2012)

Oncoming Optical Fibre - TWOTFT

- Long-term goal: Compare the optical clocks ~10^{-18}@day
- More than 14 UTC laboratories actively involved
- Already operational UTC(AOS)-UTC(PL) by AGH
- Immediate Applications in UTC:
  - Validate the BIPM GNSS calibrator with u_B ~ 200 ps
  - Validate the new GNSS and TW**S**TFT techniques
- **New challenges**
  - the theoretical issues
  - the practical issues: data processing, format, programs …

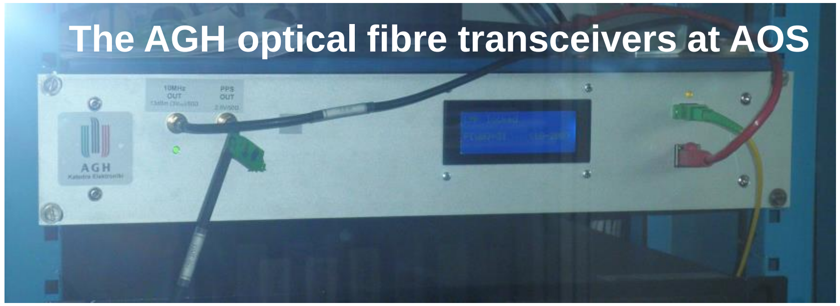
Oncoming Optical Fibre - TWOTFT

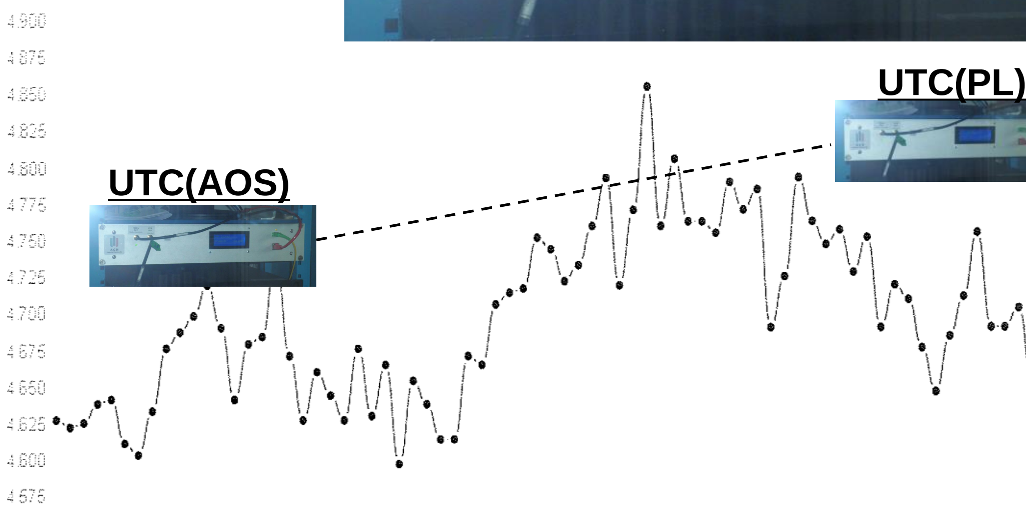


	determined quantity	estimate	sensitivity coefficient	standard uncertainty	uncertainty contribution
1	$\tau_{UTC(PL)\rightarrow REF}$ [a]	420.17 ns	1	100 ps	100 ps
2	$\tau_{REF\rightarrow RET}$ [a]	4 093 944.73 ns	0.5	100 ps	50 ps
3	$\tau_{\Delta\lambda}$ [b]	2.950 ns	0.5	19 ps	9.5 ps
4	τ_S [c]	-1.686 ns	0.5	5 ps	2.5 ps
5	τ_B [d]	0 ns	0.5	1.2 ps	0.6 ps
6	τ_H [e]	26.565 ns	0.5	8.8 ps	4.4 ps
	$\tau_{UTC(PL)\rightarrow OUT}$	2 047 406.45 ns	complex uncertainty:		112.3 ps

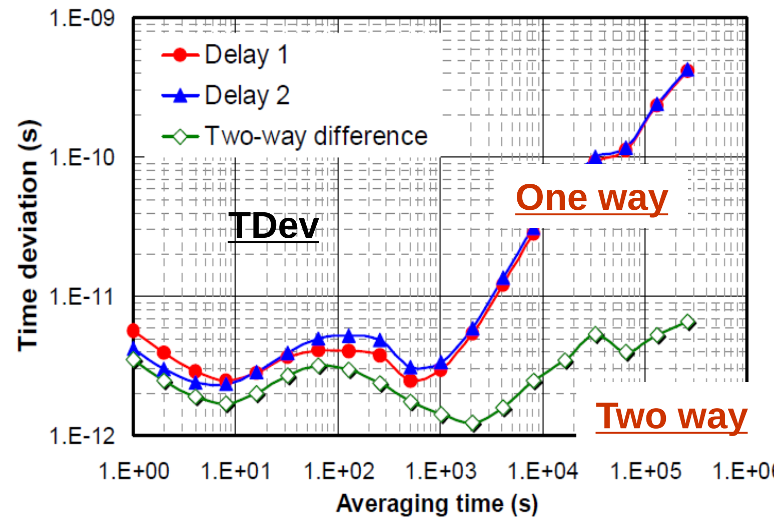
First Operational Optical Fibre Time Link
420 km between UTC Laboratories AOS-PL
Combined uncertainty **112 ps**

Oncoming Optical Fibre - TWOTFT





The real-time clock comparison between UTC(AOS) and UTC(PL) through a fibre link, www.optime.org.pl/node/47



25 km fibre experiment at TL

Oncoming Optical Fibre - TWOTFT

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Table 7.2 The first 25 lines of the proposed TW%TFT data file T%PTB56.150 in unit ns for delay and ps for statistical terms
* tfptb56.150
* FORMAT    01
* LAB       PTB
* REV DATE  2011-08-03
* ES  PTB01 LA: N  52 17 49.787      LO: E  10 27 37.966   HT:   143.41 m
* REF-FRAME ITRF
* LINK   14 fibre: Dark Channel          Length: 420.00 Km    Amplifiers: 6
*           OPTICAL-TX: 1552.1500 nm RX: 1552.1550 nm
*           MODEM: Dedicated hardware    SIGNAL: 1 PPS on square wave
*           Link Stabilization:  YES
* LINK   16 fibre: AAA Network           Length:  72.00 Km    Amplifiers: 0
*           OPTICAL-TX: 1542.1000 nm RX: 1542.1500 nm
*           MODEM:  SATRE 037            SIGNAL: PRN, 20 Mcps
*           Link Stabilization:  NO
* CAL   xxx TYPE: CAL xxx BRIDGED    MJD: 55769  EST. UNCERT.:    x.xxx ns
* CAL   214 TYPE: CAL 141 BRIDGED    MJD: 55769  EST. UNCERT.:    5.000 ns
* CAL   213 TYPE: CAL 142 BRIDGED    MJD: 55769  EST. UNCERT.:    1.300 ns
* LOC-MON   NO
* COMMENTS  unit in 0.1 ps
*
--- data body proposition (I)
* EARTH-STAT  LI  MJD  STTIME NTL        TW        DRMS SMP ATL     REFDELAY     RSIG  CI S    CALR     ESDVAR   ESIG TMP HUM PRES
* LOC    REM           hhmmss  s        0.1ps     0.1ps      s     0.1ps         0.1ps          0.1ps      0.1ps  0.1ps  C   %  mbar
 PTB01  TIM01 14 56150 000400 119   265739347023X 1226X 120 119  0000000040870X 0020X 999 9 999999999  1035000X 2800X  12   98 1013
 PTB01  PTB01 14 56150 000700 119   266718670995X 2491X 120 119  0000000040870X 0020X 999 9 999999999  1035000X 2800X  12   98 1013
 PTB01  OCA01 14 56150 001000 119   264311268059X 1497X 120 119  0000000040870X 0020X 999 9 999999999  1035000X 2800X  12   98 1013
 PTB01   IT02 14 56150 001300 119   264702466195X 1937X 120 119  0000000040870X 0020X 213 1    479209X  1035000X 2800X  12   98 1013
 PTB01  ROA01 14 56150 001600 119   260338922342X 2520X 120 119  0000000040870X 0020X 217 1    298673X  1035000X 2800X  12   98 1013
```

It is suggested adapting the **ITU TWSTFT** data format for **TWOTFT**. Hence all the data exchanges, processing, calibrations, computations and the related methodology can be kept with only slight modifications. This will save huge time and man powers and speed up its applications.

Oncoming Optical Fibre - TWOTFT

Application of TWOTFT

- Time link calibrations within a few minute?
- Time transfers with 100 ps ?
- Change in the UTC network configuration?

…. ….

➔ A new era of the ground based techniques is back …

RECOMMENDATION CCTF (2012):

Development of continental-scale fiber optical time and frequency transfer networks and support to studies of improved methods for intercontinental comparisons
The Consultative Committee for Time and Frequency (CCTF), considering

- **the continuing reduction in uncertainties and instabilities of frequency standards based on optical atomic transitions**
- **that the stabilities of the time and frequency transfer techniques currently used for long-distance comparisons around the world, GNSS and TWSTFT, are insufficient for the needs of comparisons between the new frequency standards,**
- **the demonstrated capability of fiber optical links to realise frequency comparisons over distances of up to the order of 1000 km,**

CCTF recommends that

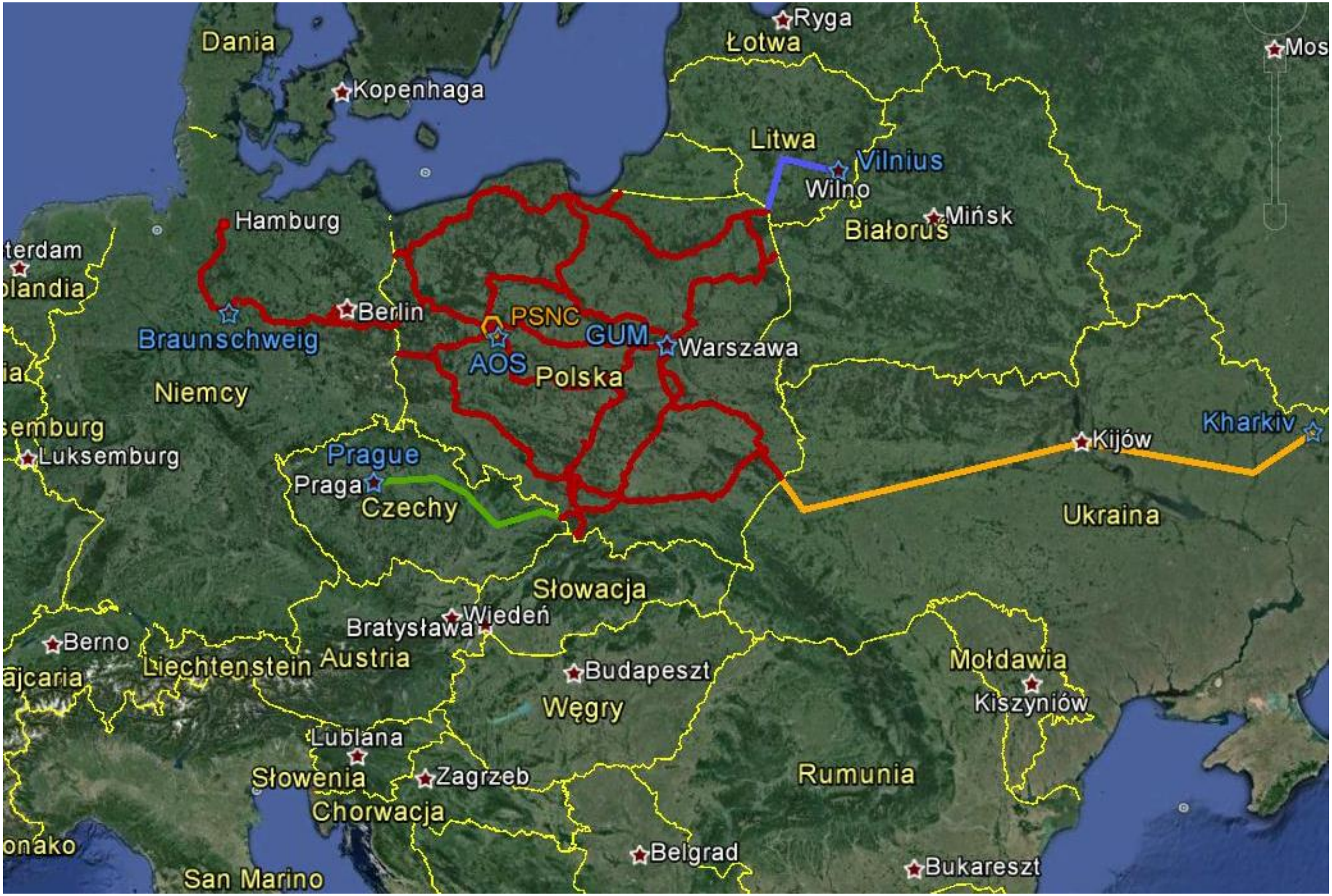
- metrology institutes vigorously pursue the development of continental-scale fiber optical time and frequency transfer networks,

- research aimed at significantly improving time and frequency transfer over intercontinental distances be actively encouraged and supported, and

- national governments, metrology institutes, optical fiber network providers and operators, space agencies and other relevant bodies consult and coordinate with each other on access to the necessary infrastructures and on possible synergies with other applications of these infrastructures.

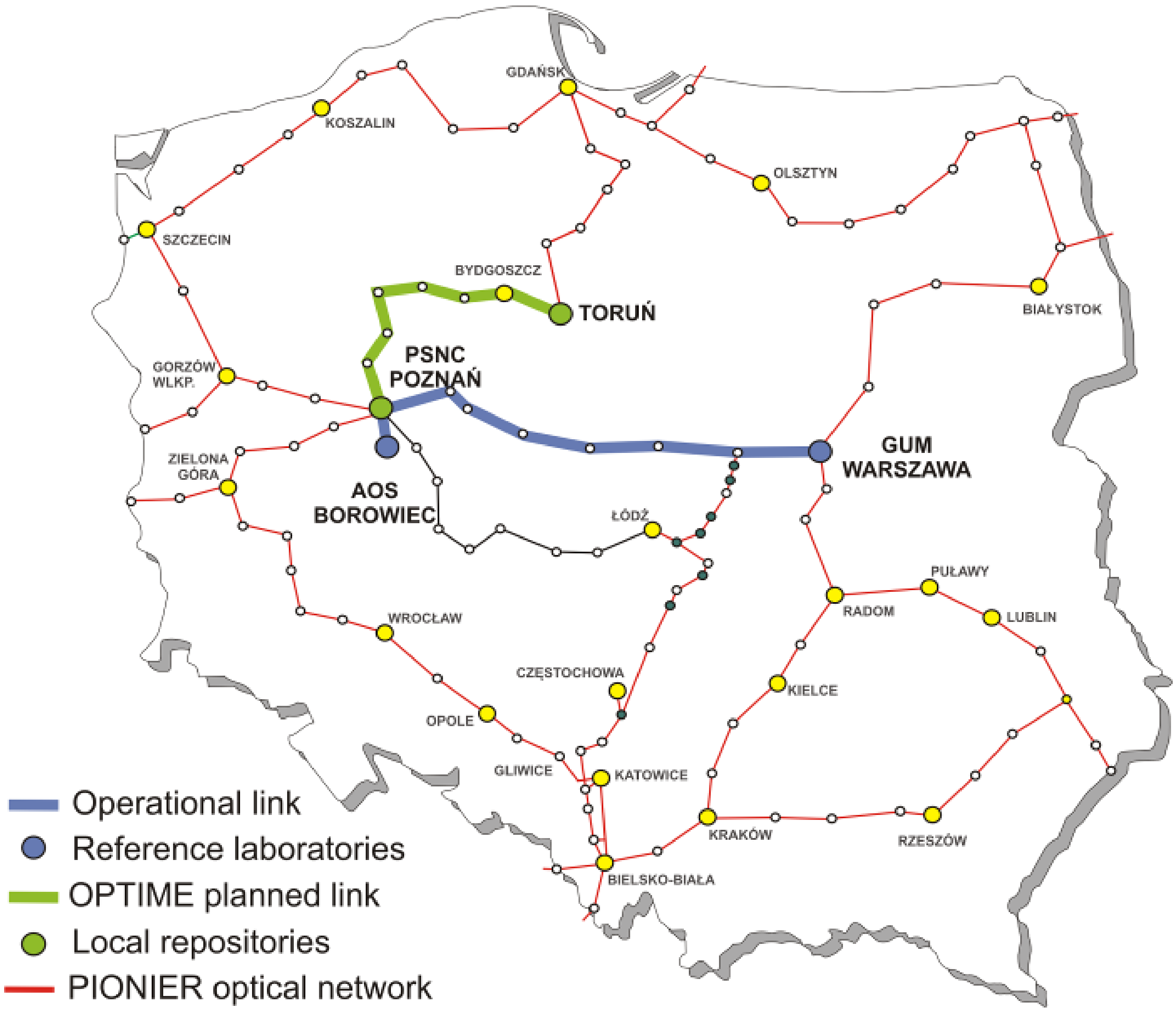
PIONIER INTERNATIONAL CONNECTIOS

(courtesy of Pionier International)



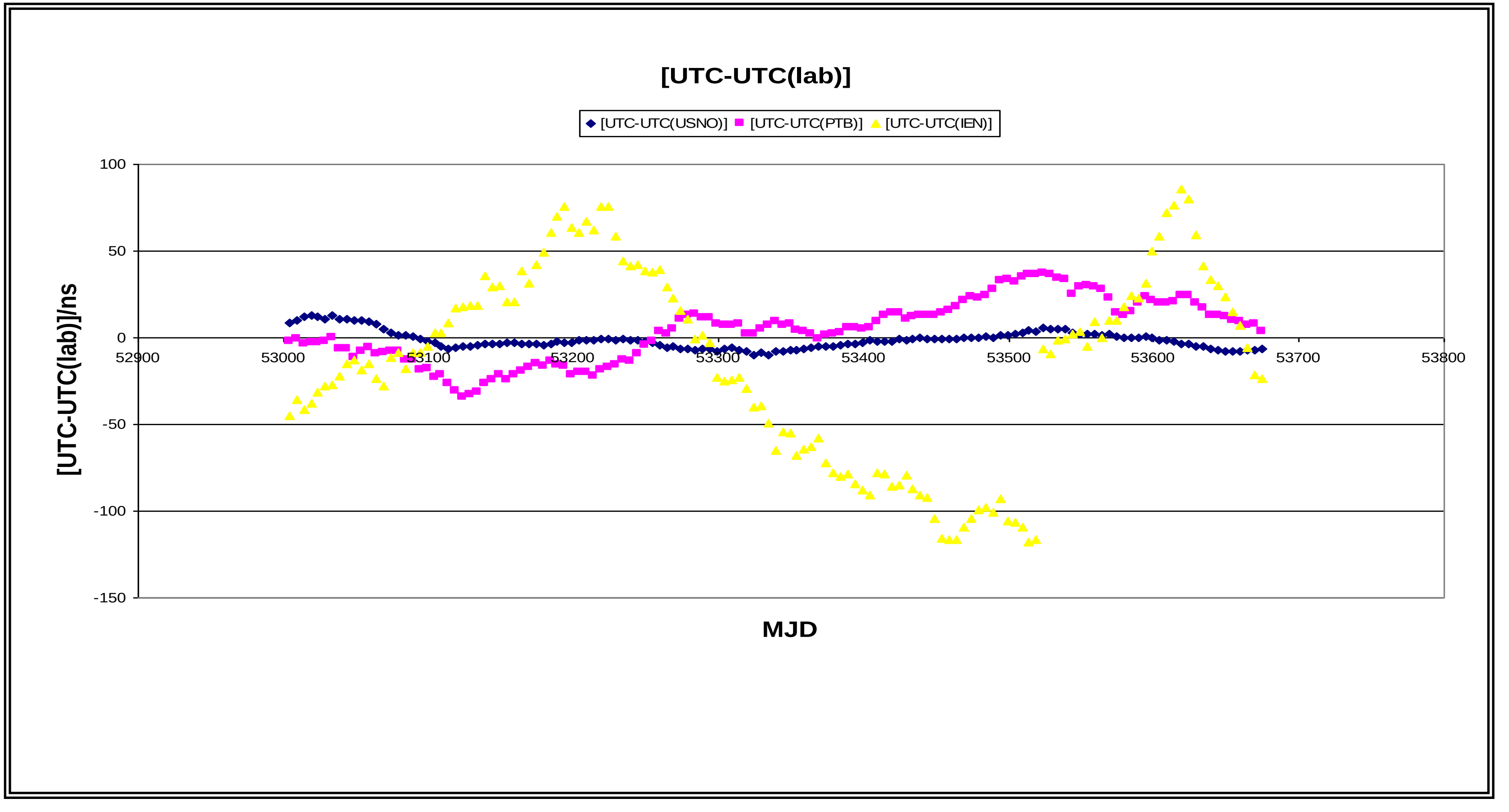
Dystribution of precise time and frequency in Poland

(courtesy of Pionier International)



Caesium Frequency Standards

Diferences to UTC of some local realizations



Meetings (past and future)

✓**23rd meeting of the CCTF WG on TWSTFT, BIPM, Sevres, 7-8 September 2015**

✓**20th meeting of the CCTF**
15 – 18 September 2015

- ✓ **CCL/CCTF Frequency Standards Working Group**
- ✓ **TAI WG Meeting of Contributing Laboratories**
- ✓ **Other WGs**

✓**World Radiocommunicatio Conference, 2-27 November 2015, Geneve**

✓**10th Meeting of the International Committee on GNSS (ICG-10)**
1-6 November 2015, Boulder, Colorado

- ✓ **GPS, GLONASS, Galileo, BeiDou, IRNSS, QZSS**

✓**PTTI 2016 and EFTF 2016**

Planned activities

- ✓ Informing on time metrology progress and needs
- ✓ Timing GNSSs interoperability
- ✓ Study of the impact of GPS constellation evolution on timing activities (L2C, L5, L1C)

Thank you
for your attention!

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