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NAVISP-El1-011 PNT Resilient, Trustworthy, Ubiquitous Time Transfer

Final Presentation

11 January 2022

Agenda

- Project Overview
- Technology Review and Use Case Selection
  - Innovative Hybrid Timing Solution
- Prototyping and Timing Evaluation
- Study Conclusions
- Recommendations
- Q&A

Aim of the Presentation:

- **Summarise** study results
- Present preliminary **recommendations**

Project Overview [LM]

Objectives of the Study

"To develop an innovative hybrid solution of time dissemination, transfer and synchronisation to provide ubiquitous, accurate, secure and reliable timing services that are cost-effective for future commercial and mission-critical applications"

- Objective breakdown:
  - **Identify Use Cases** for which ubiquitous, accurate, secure and reliable time transfer and synchronisation will be required
  - **Identify and assess potential candidate terrestrial or space based technologies** that can complement GNSS time transfer for each of the use cases
  - **Develop hybridised solutions** for each of the use cases
  - **Design and develop an evaluation platform** to assess the potential candidate hybridised solutions
  - Identify the most promising technologies and to **produce a technology Development Roadmap** and TTM plan based on the gap analysis

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Project Team

- **Telespazio UK** (TPZ-UK) is the Prime contractor
  - Responsible for the overall project and technical delivery
  - Comprehensive navigation and timing experience
    - spanning engineering, simulation, service provision and user applications
- Supported technically by
  - **Chronos Technology Ltd** (CTL)
    - A leading international authority on resilient synchronisation and timing solutions
    - Serving numerous market sectors
      - Telecoms, Finance, Energy, Broadcasting, Defence, Security, Scientific, Enterprise IT

Work Logic

- The work was split into 4 key tasks:
  - **Task 1 - High Level Definition and Technology Assessment – use cases and technology identification and analysis**
    - Review of the existing and emerging terrestrial and space-based technologies for time Synchronisation
    - Define the use case for further study
  - **Task 2 - Design of the Evaluation Platform**
    - Design a demonstration plan and an evaluation platform
    - Carry out a SWOT analysis, conduct an evaluation of TTM, CAPEX and OPEX for selected technologies used for the demonstration.
  - **Task 3 - Development of the Evaluation Platform and Demonstration**
    - Develop the evaluation platform including all hardware, software and measurement utilities
    - Test execution and data collection
  - **Task 4 - Technology Evaluation and Recommendations**
    - Analysis of collected data during the testing
    - Perform a gap analysis, TTM, potential upgrade cost, Regulatory and standardisation

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Technology Review [DJ]

GNSS Time Vulnerabilities

- GNSS is the **key technology for timing dissemination**, thanks to:
  - Global availability,
  - High accuracy (ns),
  - No direct cost to users.
- However, GNSS is vulnerable, due to its **extremely weak signal at the end-user level** on the earth surface.
- The main **GNSS vulnerabilities** that can cause service loss:
  - Space Weather
  - Constellation error
  - RFI
    - Jamming
    - Spoofing
    - Meaconing

Assessment of Candidate Technologies

- Due to **vulnerabilities** an alternative timing technology is required to **complement GNSS**, in order to :
  - Improve robustness and overall system
  - Maintain availability and accuracy

- **Assessment Criteria** included:
  - Accuracy
  - Security
  - Reliability
  - Ubiquity
  - Cost and
  - Dependency on GNSS

- **Alternative Technology Assessment** took place:
  - MCMF
  - LEO Satellite-Based (STL)
  - Cellular Wireless Signal – LTE / 5G
  - eLORAN
  - Locata
  - LF Transmissions
  - Wireless Time Transfer via LoRaSync
  - White Rabbit
  - Synchronous Ethernet
  - IEEE 1588 PTP
  - GNSS Firewall technologies (BlueSky)
  - Oscillator Technologies (CSAC)

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Use Case Selection [DJ]

Selected UCs and Timing Requirements – 5G

- UC1A – **5G and Beyond – Network Synchronisation – TDD**
  - Time sync is needed to comply with the time slot alignment
  - Required accuracy is ±1.5μs wrt UTC

- UC1B – **5G and Beyond – V2X - high automation application**
  - Time sync is needed for trajectory alignment (relative positioning)
  - Timing is relative
  - Required accuracy is 3ms
- UC1C – **5G and Beyond – FoF - motion control**
  - Communication service is provided by a wireless 5G access point
  - Timing is relative within a small indoor area, no interaction is required with public network
  - Required accuracy is ±1.0μs

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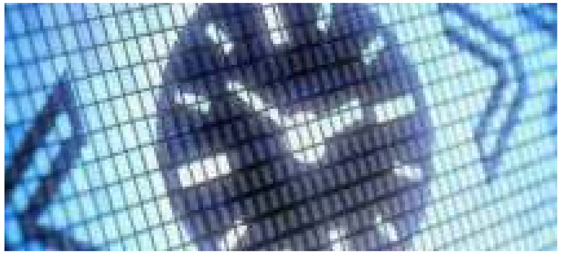
Selected UCs and Timing Requirements - Other

- UC2 – **Power Grid - PMU**
  - Time sync is required for the PMUs for monitoring of power stability and fault prediction in the power grid
  - Required accuracy is ±1.0μs wrt UTC



- UC3 – **Financial Market – High Frequency Trading (HFT)**
  - Time sync is required to time stamp all stock exchanges and trading to avoid stock market fraud
  - Required accuracy is ±100μs wrt UTC

- UC4 – **Avionics – Automation data stamping**
  - Time sync is required for data time stamping
  - Required accuracy is ± 10ms wrt UTC

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Innovative Hybrid Timing Solution [DJ]

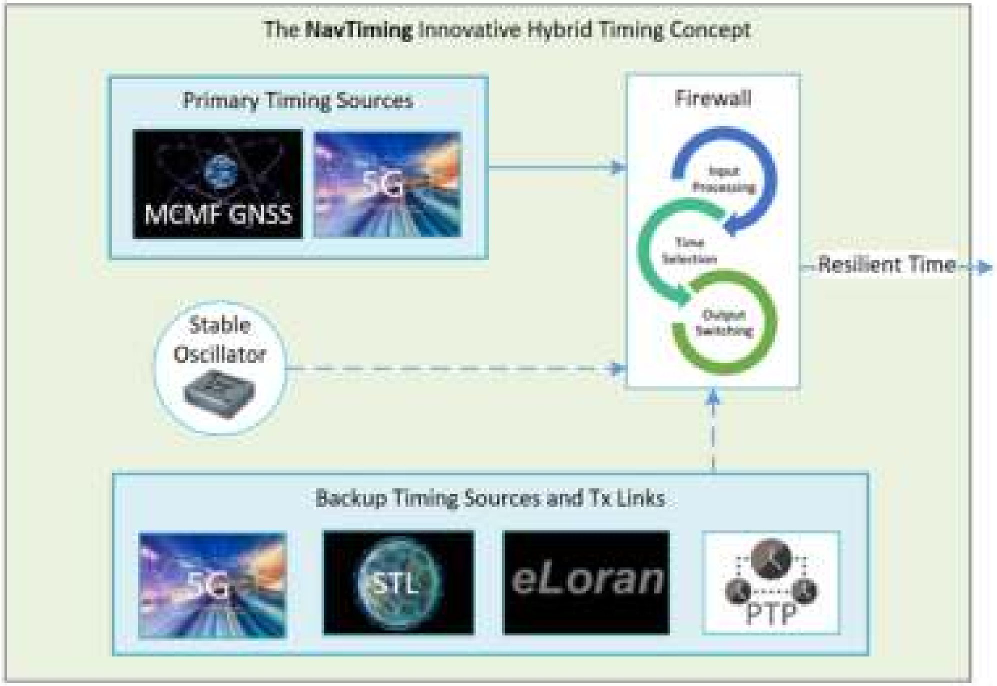
Design Requirements for An Innovative Timing Solution

- The **timing requirements** for critical applications/infrastructures include:
  - Resiliency
  - High accuracy
  - Security (against external threats)
  - Ubiquity
  - Availability
  - GNSS Dependency
  - Cost effectiveness

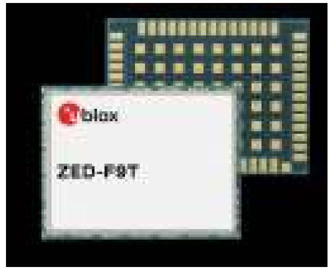
- The **GNSS complement** should:
  - Enable resilient timing
  - **Independent** (if possible) of GNSS
  - **Dissimilar to GNSS** in terms of failure modes
  - Provide **similar performance levels** to GNSS
  - **Easily integrated** with GNSS at chip-level

Proposed Innovative Hybrid Timing Concept

- **The Key Components of the Hybrid Timing "system-of-systems"**
  - **Primary Timing** Sources
    - MCMF-GNSS
    - 5G
  - **Alternative Timing** Sources
    - Time Transfer via LEO (STL)
    - eLoran
    - PTP
  - **GNSS Firewall**
    - Spoofing & jamming detection
  - Enhanced **Oscillator Discipline** Mechanism
    - CSAC



Capabilities of the Key Components of the Hybrid Timing



- **Multi-Constellation and Multi-Frequency (MCMF)**
  - MC provides robustness against single system failure
  - MF provides resilience to interference and jamming (due to frequency diversity)
  - Accuracy in nanosecond

- **Satellite Time and Location (STL)**
  - Global coverage with 66 Iridium satellites and traceable to UTC
  - Accuracy in nanosecond - delivering timing even with no GNSS signals
  - 1000x stronger than GNSS signal - reaching indoor and overcoming jamming issues
  - Cryptographic security provides resilience to intentional spoofing

- **Enhanced Loran (eLoran)**
  - National UK coverage and traceable to UTC
  - Accuracy in microsecond - delivering timing even with no GNSS signals
  - 3-5 million times stronger than GNSS signal. reaching indoor and overcoming jamming issues

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Capabilities of the Key Components of the Hybrid Timing

- **Precision Time Protocol (PTP)**
  - Accuracy in sub-microsecond
  - Local-wide area coverage

- **GNSS Firewall (BlueSky)**
  - Identify and protect the GNSS system from spoofing and jamming
  - Switching to an alternative backup timing source
  - Accepts an alternative source of UTC

- **Chip Scale Atomic (Clock CSAC)**
  - Reduced SWaP clock compared to the conventional atomic clocks.
  - CSAC can provide an extended holdover period.
  - Improve the resilience of the system during timing service outage
  - CSAC could bring the accuracy and stability of atomic clocks to portable receivers with reduced SWaP

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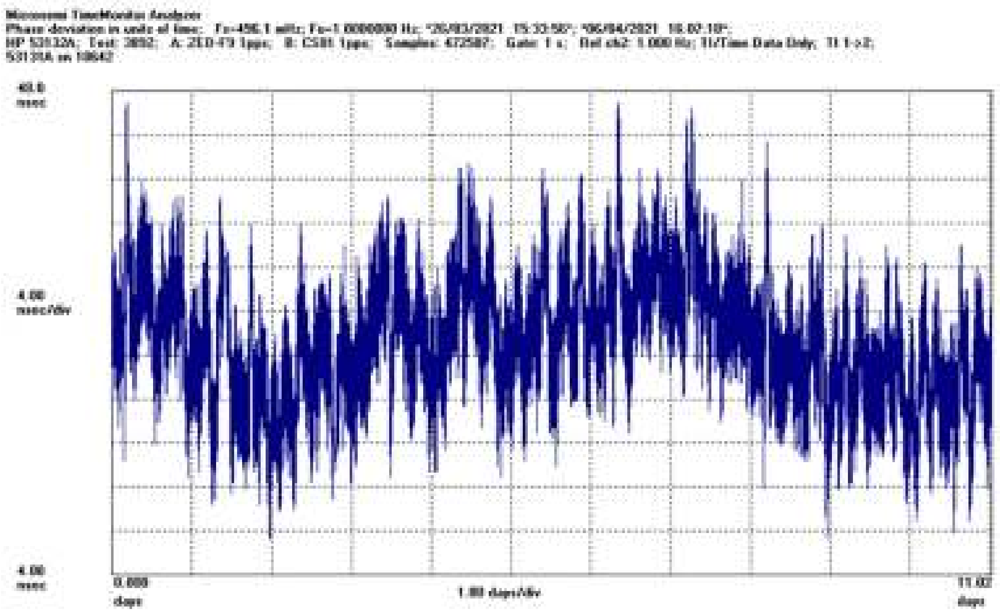
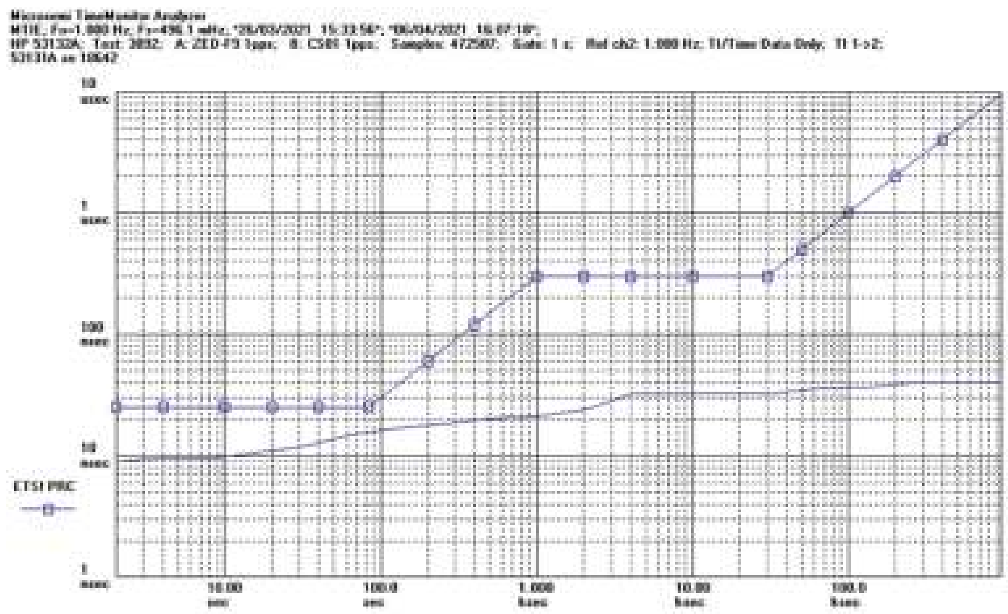
Test Results and Data Analysis [CD]

MCMF-GNSS Timing

TIE = ±16ns wrt UTC

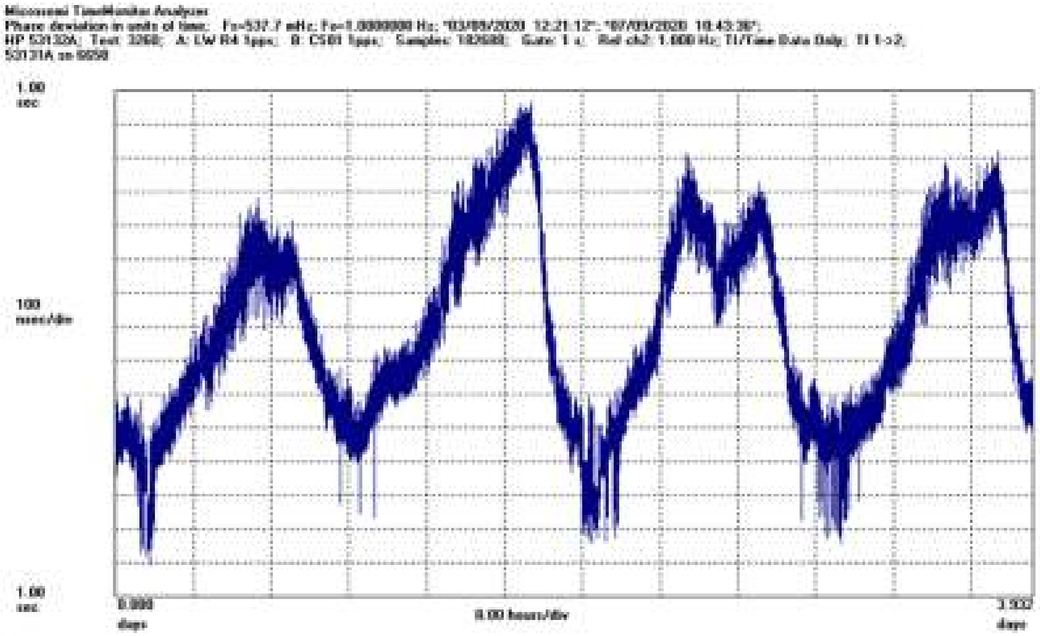


MTIE = 30ns

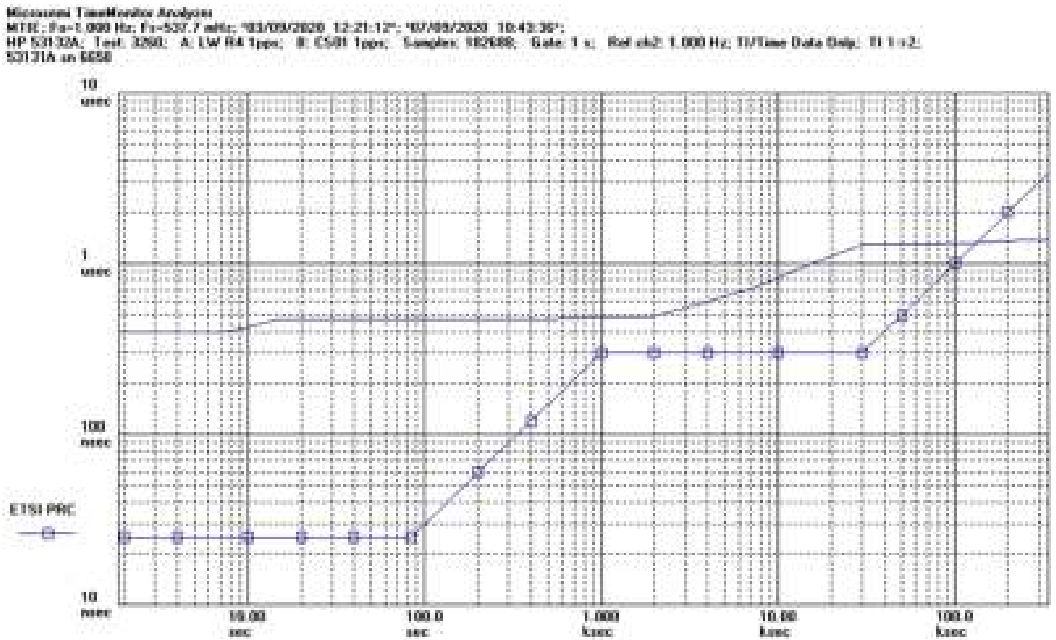


R4 198KHz LF Timing

TIE = ±800ns wrt UTC



MTIE = 1.6μs



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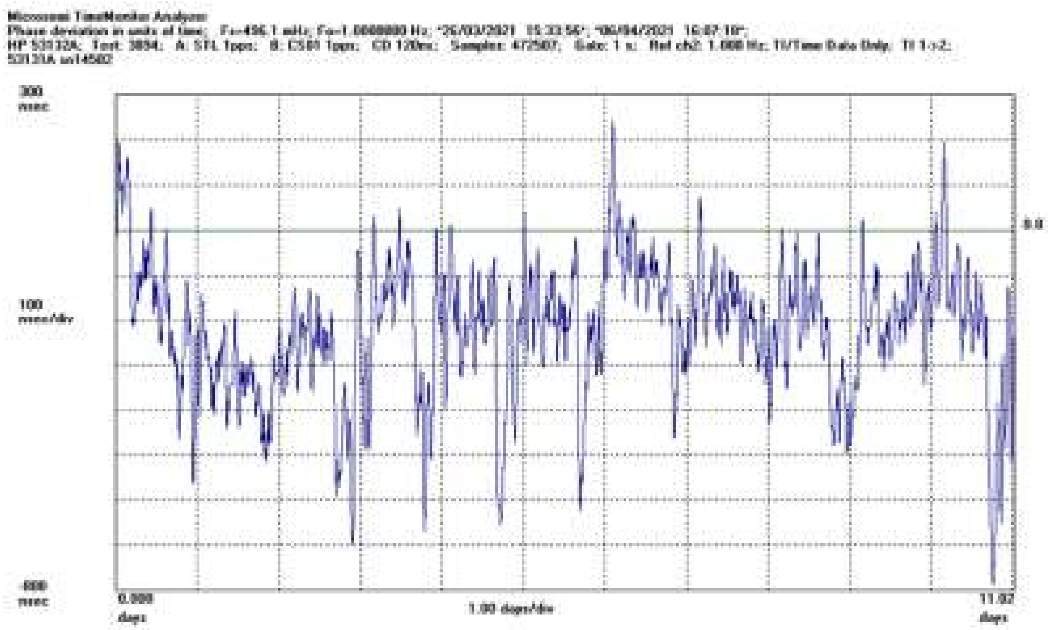
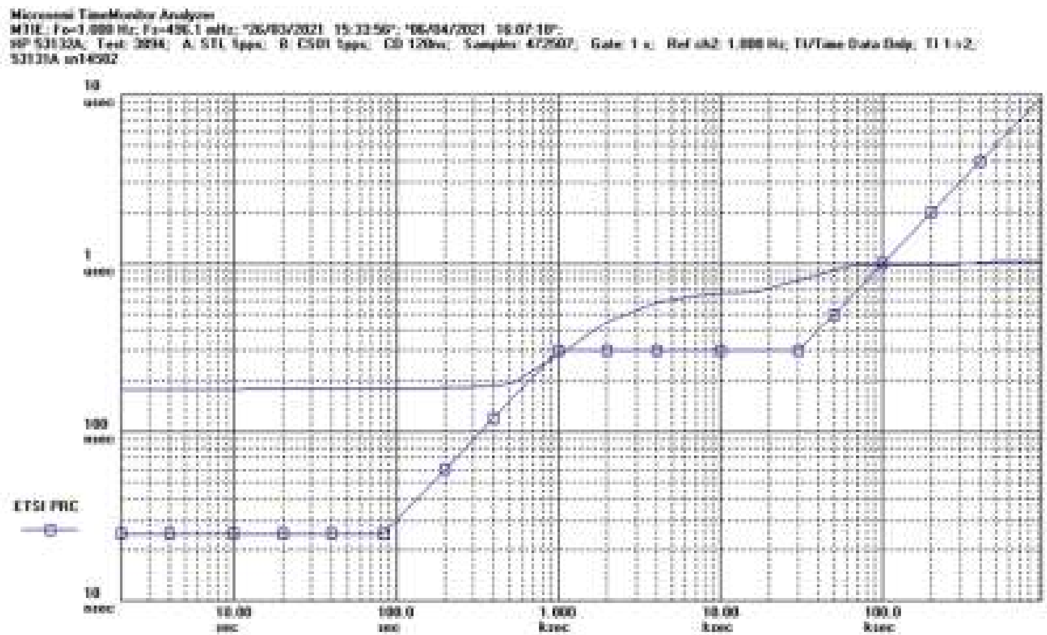
STL Timing

TIE = ±600ns wrt UTC



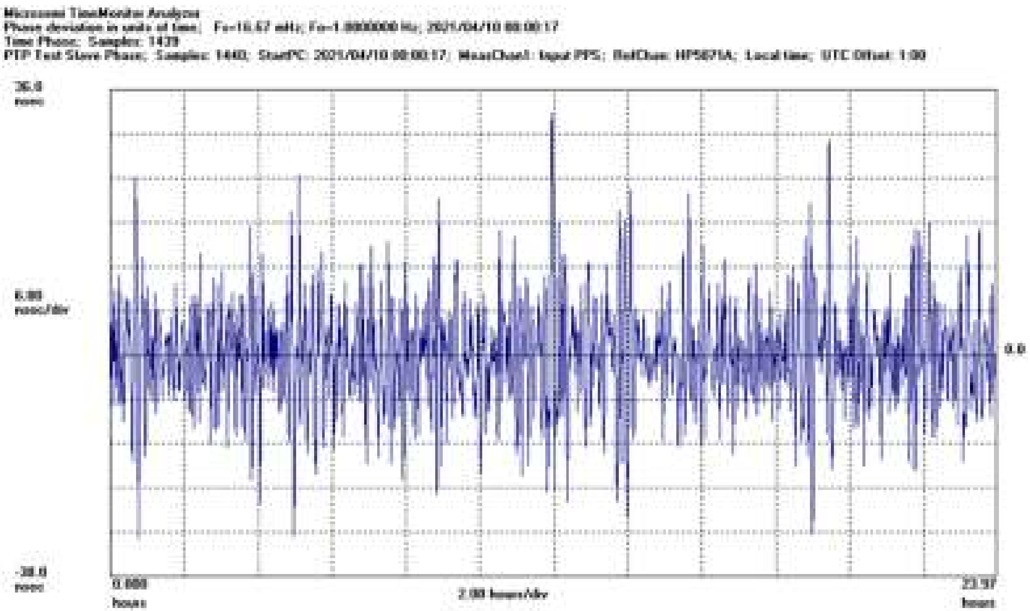
MTIE = 1.0µs

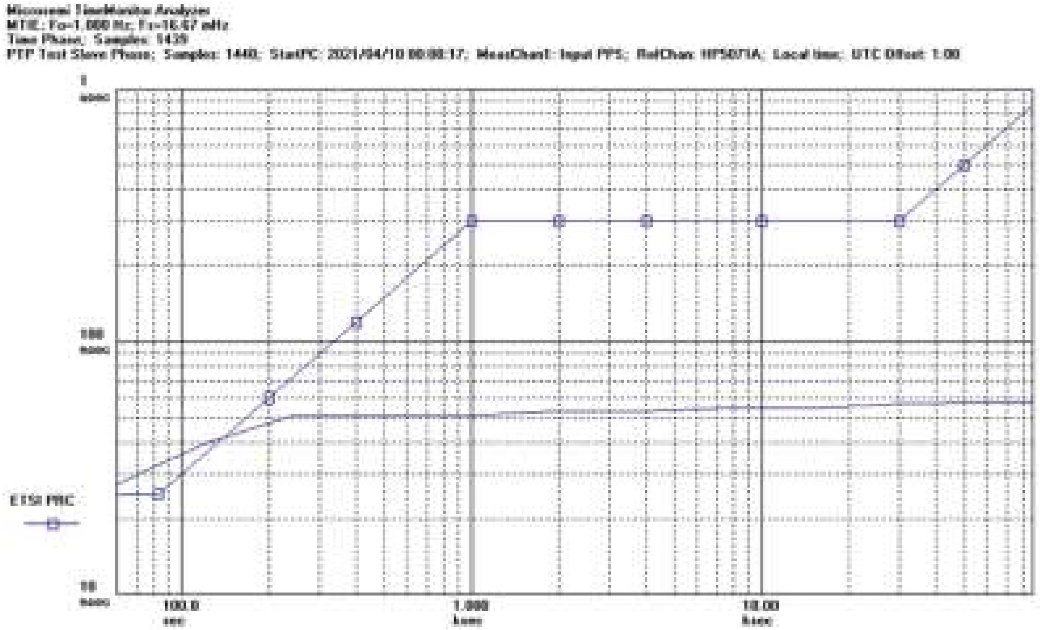


PTP Timing

TIE = ±40ns wrt UTC

MTIE = 50ns

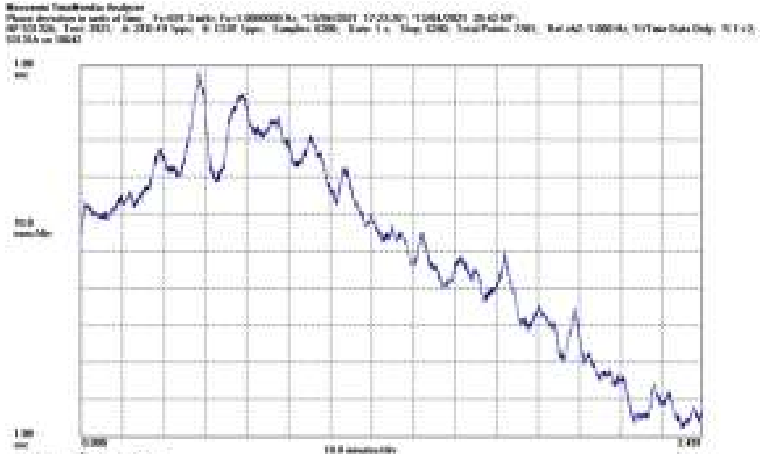




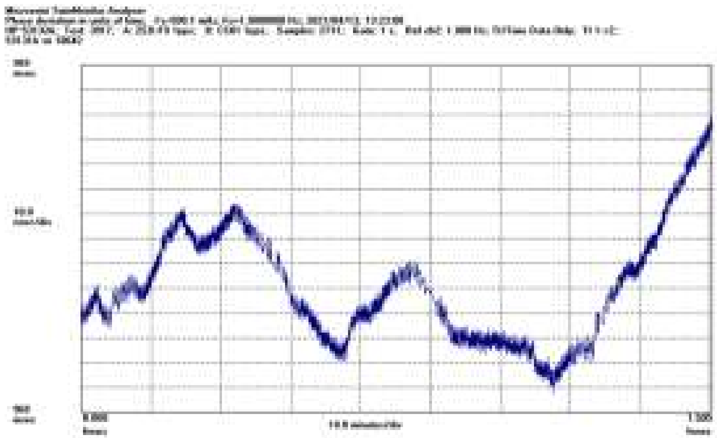
Performance Evaluation of Hybrid Timing against Spoofing

Stand alone MCMF

STL backup and BlueSky Firewall



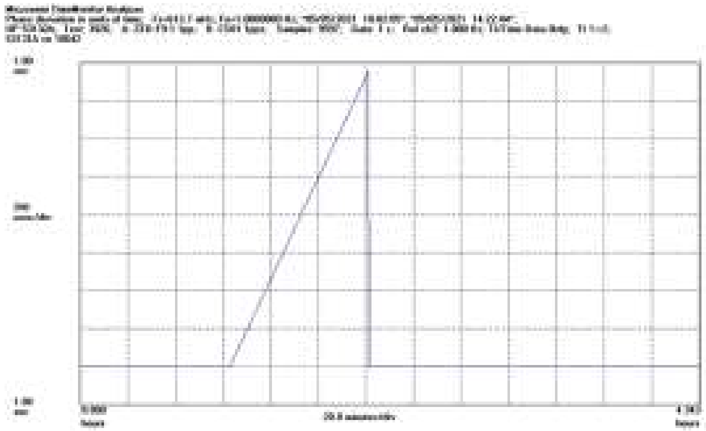
Radio 4 back-up and BlueSky Firewall



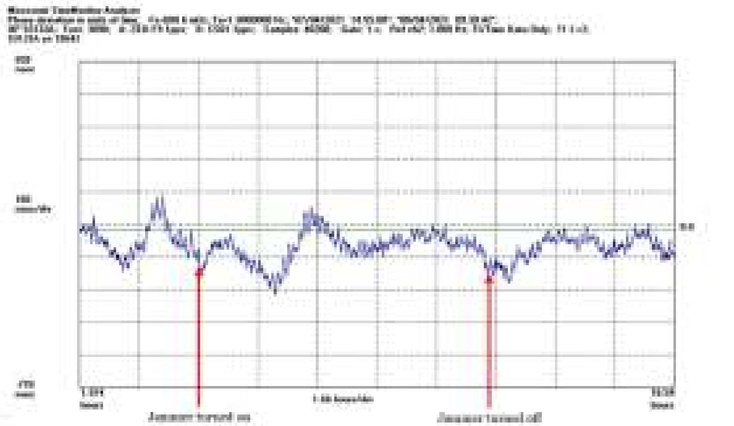
Holdover mode with CSAC

Performance Evaluation of Hybrid Timing against Jamming

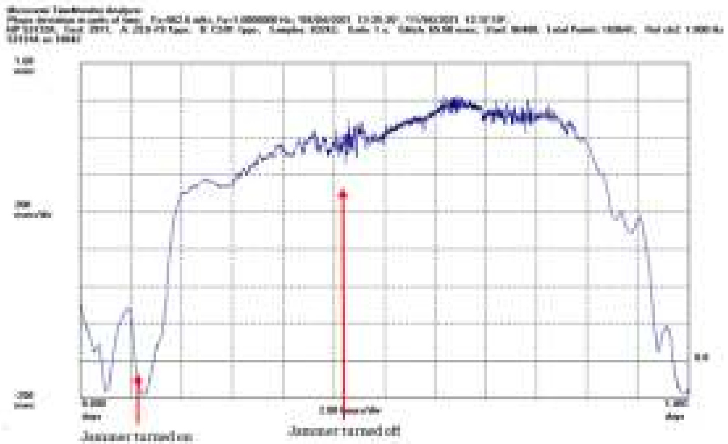
Stand alone MCMF



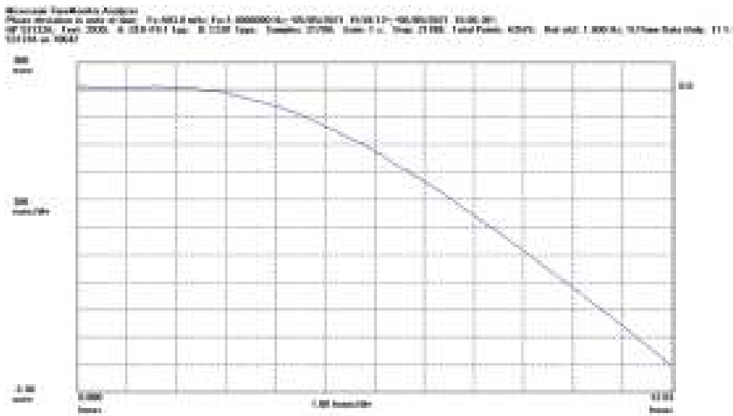
STL backup and BlueSky Firewall



Radio 4 back-up and BlueSky Firewall

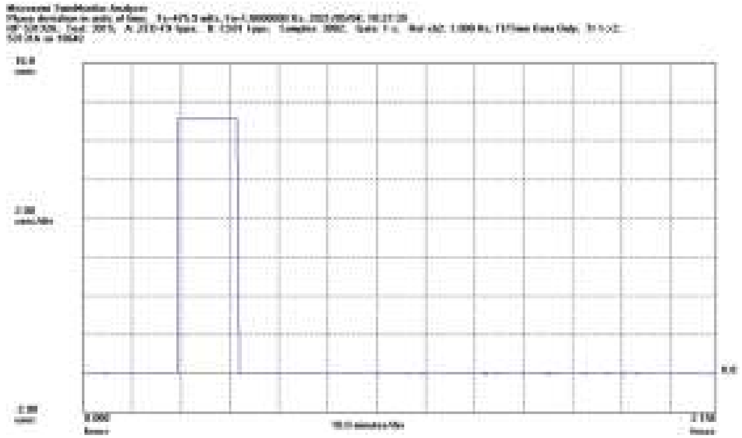


Holdover mode with CSAC

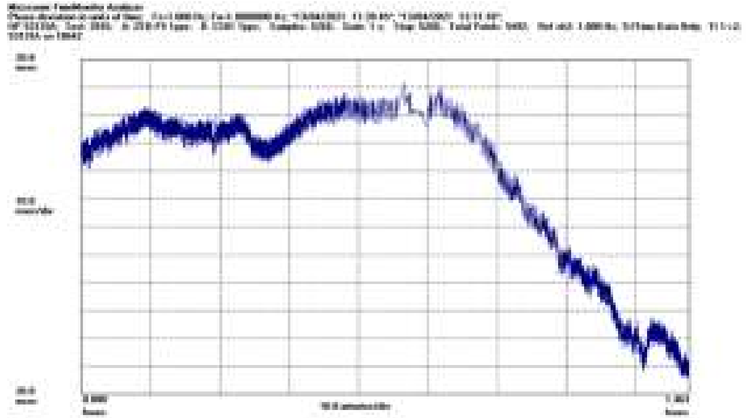


Performance Evaluation of Hybrid Timing against constellation error

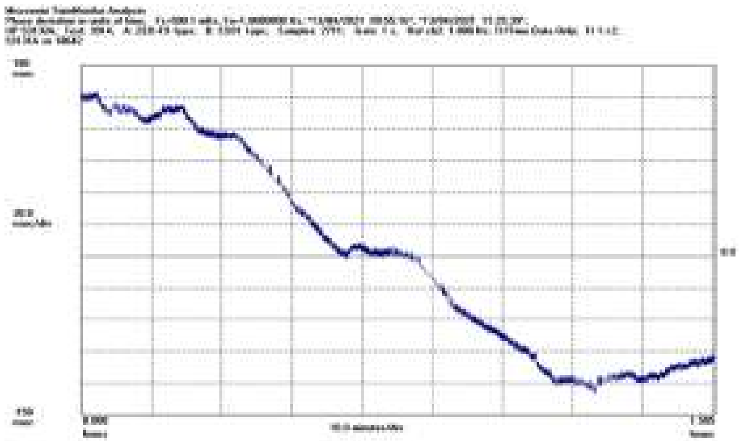
Stand alone MCMF



STL backup and BlueSky Firewall



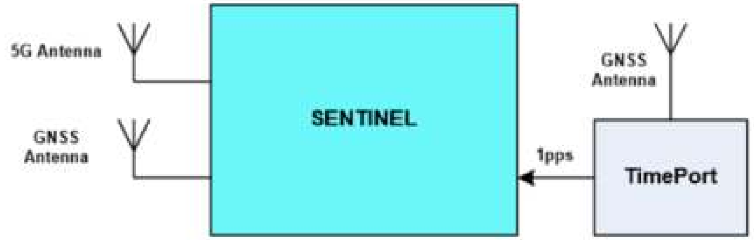
Radio 4 back-up and BlueSky Firewall



Holdover mode with CSAC

5G Testing

- **5G test plans** were halted
  - 5G user equipment unavailable to physically measure time transfer over 5G transmissions
- **Cellular modems** with time transfer capabilities
  - Some **Ublox** equipment existed with time transfer capabilities
  - *However*.. only 4G capable (5G on the roadmap)
- **Sentinel from Calnex Solutions**
  - Used to measure time transfer over 5G networks
  - Supported standalone 5G testing only
    - Testbed *integration* not possible due to lack of 1pps output
  - However, it did allow *synthetic* assessment of 5G capabilities
- **Testbed configuration**
  - Sentinel testbed included a “TimePort” device (battery powered GNSS-synchronised CSAC)
    - Designed for field test use as a portable timing reference



5G Testing

- **5G field trials** were undertaken
  - in a variety of **live 5G basestation** locations
    - Northwest of England (supported by EE and Calnex)
  - Line-of-Sight (LoS) at varying ranges and non-LoS
- **Manual calibration** supported
  - Distance from basestation to test equipment
- **TIE data captured** for each test site location
  - MTIE data being calculated post-trial

5G Basestation	Test Plan
Site 1	• Test at 30m distance • Apply 30m propagation delay compensation • Outdoor direct line of sight
Site 2	• Test at 30m distance • Apply 30m propagation delay compensation • Outdoor direct line of sight
Site 3	• Test at 30m distance • Apply 30m propagation delay compensation • Outdoor direct line of sight
Site 4	• Test at 200m+ range • Apply propagation delay compensation • Indoor non line of sight

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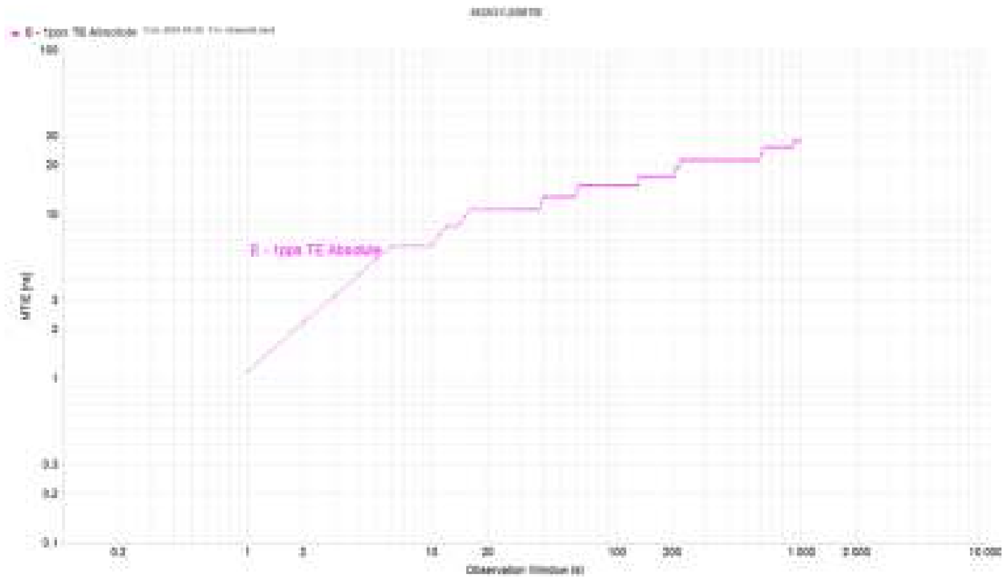
5G Baseline Testing Site 1 30m Direct Line of Sight

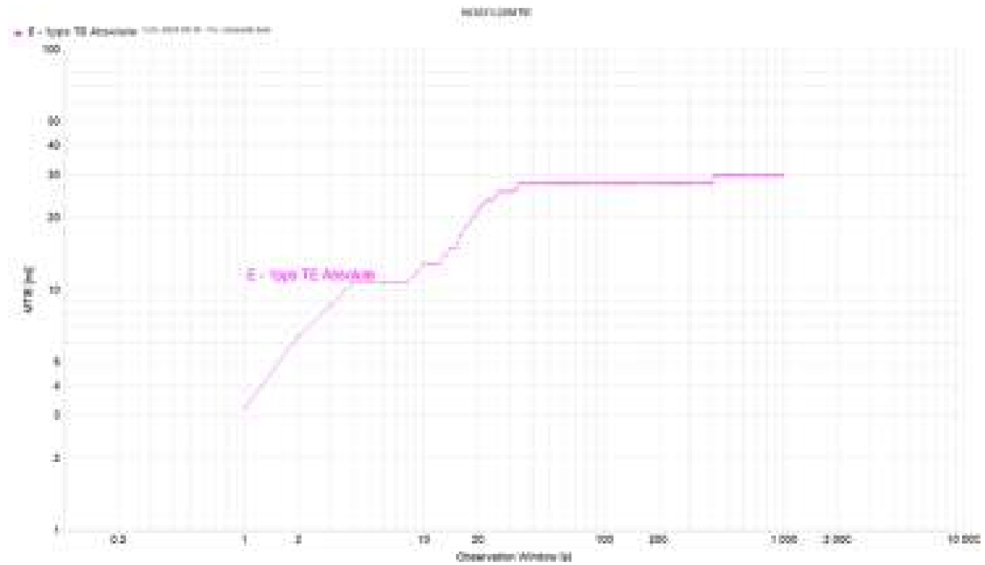
- Shows **very tight** time transfer accuracy



MTIE = 30ns relative to Basestation

5G Baseline Testing Site 2 30m Direct Line of Sight

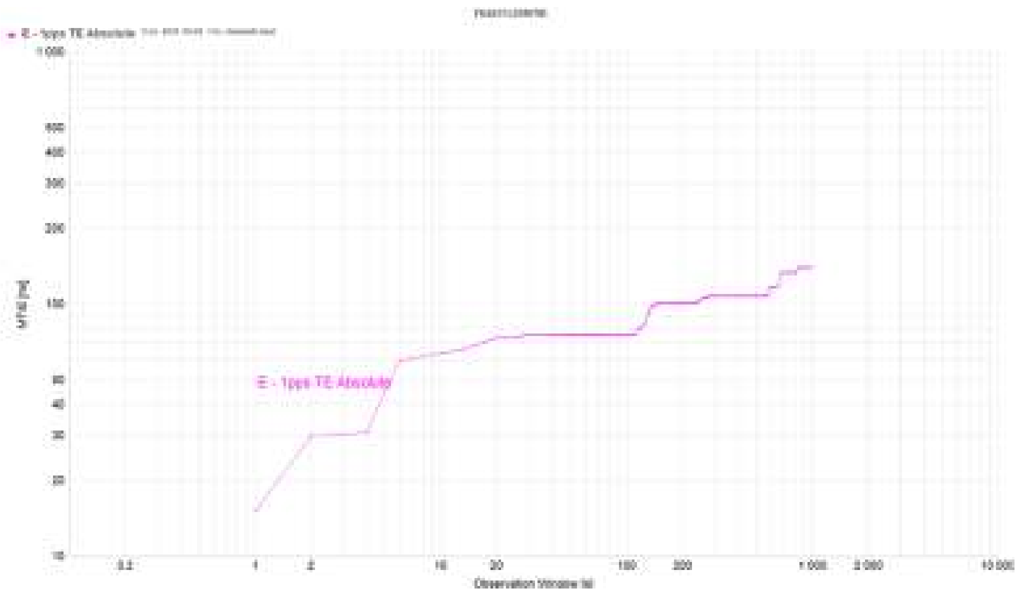
- Shows **very tight** time transfer accuracy



MTIE = 30ns relative to Basestation

5G Baseline Testing Site 3 400m Non Line of Sight (Indoors)

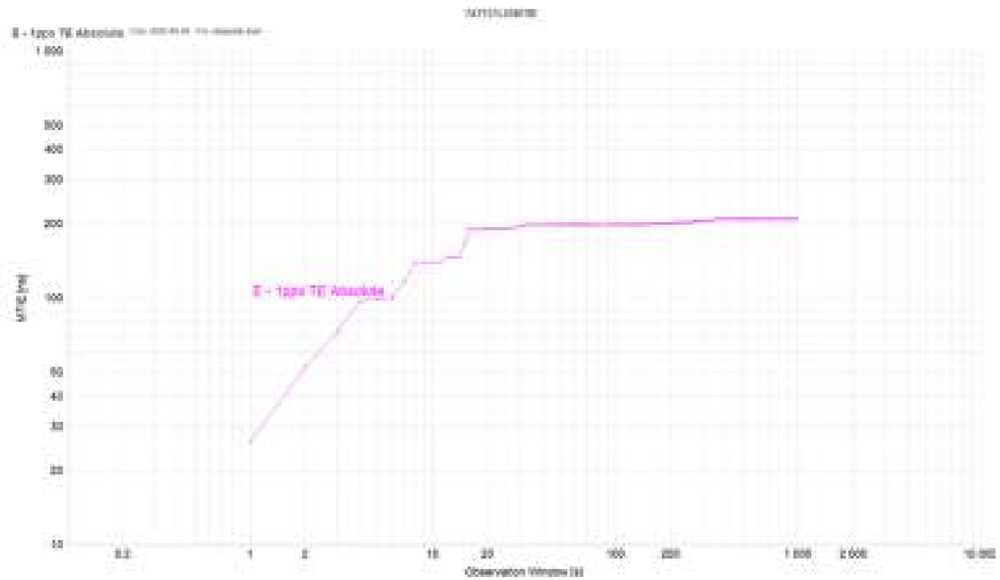
- Shows **good** time transfer accuracy



MTIE = 150ns relative to Basestation

5G Baseline Testing Site 4 30m Direct Line of Sight

- Shows **good** time transfer accuracy



MTIE = 200ns relative to Basestation

Summary Results

- Overall performance was **very promising**

Use Case	UC Accuracy Req	Scenario	Backup Timing Source	Accuracy Criteria	Accuracy Achieved	PASS/FAIL
UC1a 5G Network Sync	±1.5µs wrt to UTC	Spoofing / Jamming / Constellation Error	R4	±1.5µs	±840ns	PASS
			CSAC	±1.5µs/12hr	±1.5µs/6hr	PASS[1]
UC1b 5G V2X	3ms relative	Spoofing / Jamming / Constellation Error	5G	±10µs	±120ns	PASS[3]
			CSAC	±10µs/24hr	±7µs/24hr	PASS
UC1c 5G FoF	<=1µs	5G LoS	R4	±1µs	±800ns	PASS
			Iridium	±1µs	±500ns	PASS[3]
UC2 Power Grid	± 1µs 2σ wrt UTC: typical ± 100ns 2σ wrt UTC: extended	Spoofing / Jamming / Constellation Error	R4	±1µs	±840ns	PASS
			Iridium	±1µs	±540ns	PASS
UC3 Financial	± 100µs wrt UTC: typical ± 1µs wrt UTC: extended	Spoofing / Jamming / Constellation Error	R4	±10µs	±840ns	PASS
			Iridium	±10µs	±540ns	PASS
UC4 Avionics	10ms wrt UTC	Spoofing / Jamming / Constellation Error	Iridium	±100µs	±540ns	PASS
			CSAC	±100µs/24hr	±7µs/24hr	PASS

1. PASS criteria only achieved with the use of IEEE PTP V2 as the selected transmission protocol. The use of LoRaSync pushed the total phase error beyond the PASS criteria of ±1.5µs
2. Use of CSAC for holdover is only suitable for up to 6hrs before PASS criteria can no longer be met
3. *Synthetic* test verdict based on Steady State 5G test results

Demonstrator SWOT and TRL Analysis [DJ]

Strength and Weakness Summary

Subject	Strength	Weakness
Performance	• System **less vulnerable** to interference, jamming and spoofing • Supports a range of **flexible design options** and the system can be configured for specific applications • Supports **indoor scenario application**, when the system is backed-up by an STL or LF timing source • Wide ranging **accuracy** performance, from ms level to sub-µs level. • Global or wide area **coverage** through wireless time transfer (satellite-based or terrestrial-based). • Improved **resilience and threat awareness** via "Firewall" technologies. • Provides **Enhanced holdover** via CSAC • Supports **security** features (e.g. authentication and encryption), via some alternative timing technologies such as STL	• Backup **coverage** may be local or regional (excl. STL) • Backup **accuracy** provided not on par with GNSS • Backup **Ubiquity**, in general, not on par with GNSS (excl. indoor scenario)
Feasibility	• backup timing sources either relatively mature or have a **clear roadmap** for development (e.g. 5G)	• Additional **HW costs** • Service **subscription** could be required

Opportunities and Threats

Subject	Opportunities	Threats
Adoption	• The impact of GNSS outage due to **GNSS vulnerability** increases the need for resilient PNT • The **criticality of timing** to national infrastructure such as communications network, power grid and financial.	• Potentially **complicated standardisation** and regulation instead of voluntary choice, due to upgrade of the UE .
Technology development	• Supports **higher accuracy performance** by evolving existing technologies • System **cost reduction** to promote adoption, e.g. highly integrated HW/SW solution (such as existing GPS/ eLoran maritime receiver) • Support **software-level timing** hybrid	• The **evolution of 5G** has the potential to render some KPI requirements covered - without the need for additional system elements for some UCs

Candidate Technology TRL Summary

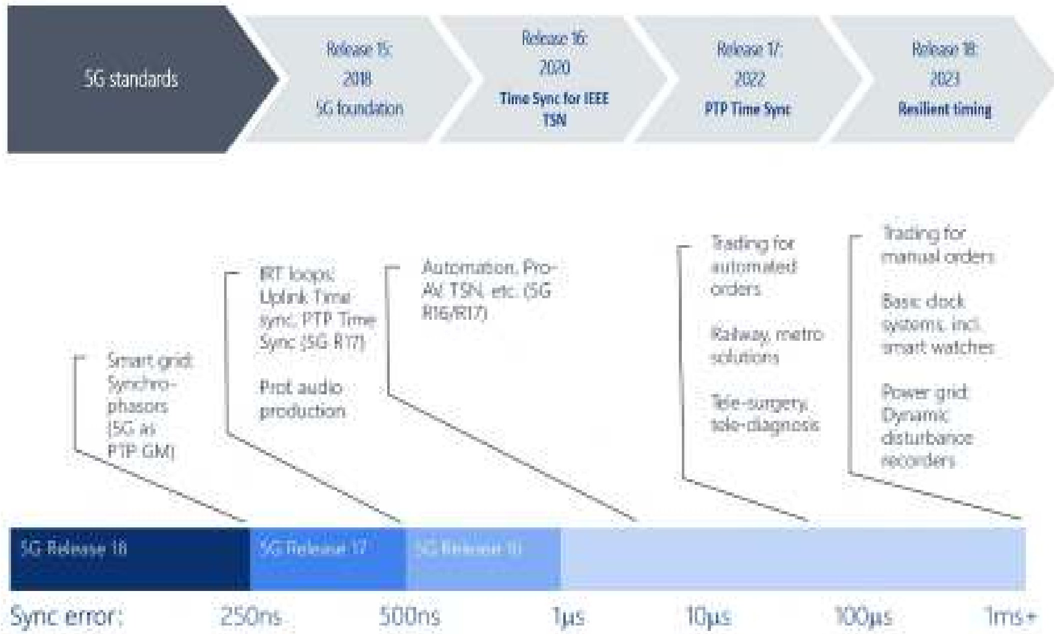
Technology	Description	TRL
GNSS	A space-based radio navigation system, capable of providing accurate positioning, navigation and timing (PNT). All four constellations in GNSS are in FOC providing free open service for civil users.	9
5G	A wireless technology with timing distribution capability. The 5G standards for accurate reference time delivery are still developing and evolving.	7
STL	A commercial system that uses a series of short data messages on the Iridium constellation of Low Earth Orbit (LEO) satellites. The system provides a commercial service to users around the globe.	9
eLoran	A low-frequency, long range Terrestrial Radio navigation System, capable of providing positioning, navigation and timing (PNT). A prototype has been demonstrated in an operational environment successfully in UK.	7
PTP	A timing standard used to synchronize clocks throughout a computer network on a local area network. This service is available commercially.	9
CSAC	A reduced SWaP clock, as compared to the conventional atomic clocks. CSAC is able to provide an extended holdover period, which can help to improve the resilience of a system during timing service outage. CSAC is the world's first commercially available chip scale atomic clock from Microsemi.	9
BlueSky	A GNSS firewall, which identifies and protects GNSS systems from spoofing and jamming threats. BlueSky is commercially available from Microsemi.	9

Gap Analysis, Development Roadmap & TTM [DJ]

Gap Analysis

Testing with 5G in lab is <u>not</u> considered possible at this stage:

- No clear roadmap for the release of **5G UE products**
- Theoretically UEs installed in a smart grid could get a common time reference from the **Rel-16 5G SIB9**
  - SIB is not yet being transmitted in live 5G networks
  - The granularity of the time information in the SIBs is currently limited to ~10 ms
    - UC applications chosen for this study require µs or ns level



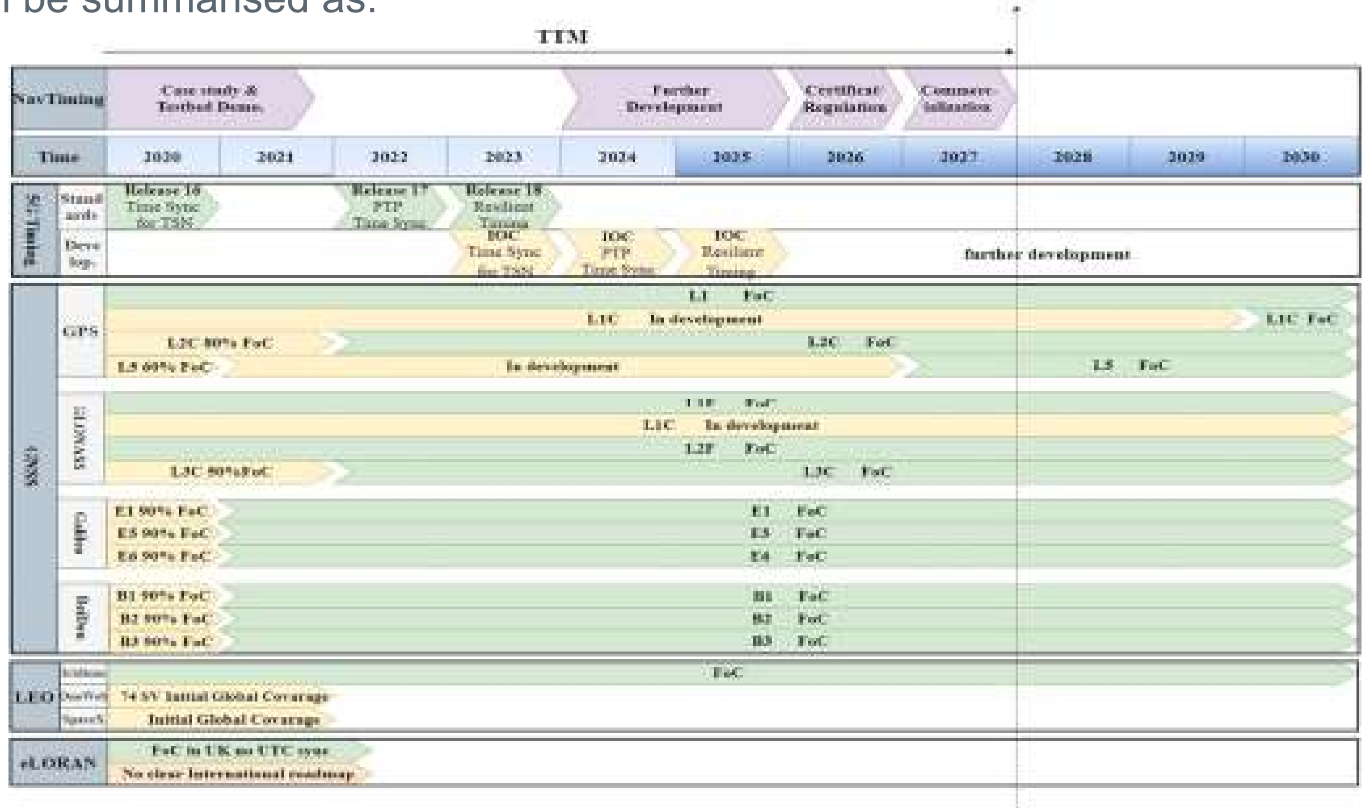
eLoran has <u>not</u> been included in the test architecture:

- UK transmitter at Anthorn is **not currently synchronised to UTC** due to a failure the atomic clock ensemble
  - **R4 198KHz LF timing service** was adopted as an alternative
- R adio4 performance provided accurate time synchronisation for most UC requirements within this project

Development Roadmap & TTM

The candidate technology roadmap can be summarised as:

- Currently there are three core constellation **frequencies** plus two frequencies from GPS
- Soon there will be two more **LEO-based services** with IOC available, in parallel with the Iridium constellation
- eLoran is at **Initial Operating Capability** (IOC) in the UK and the Far East, with no clear roadmap for wider international deployment
- Initial **5G services** for TSN, PTP and Resilient Timing Synchronisation are expected by 2023, 2024 and 2025 respectively



Innovative Hybrid Timing Concept – Steps to Commercialisation

- Currently, the solution designed during the project is **TRL 4/5**
  - The solution is validated but not fully demonstrable
- ~2 year **development plan**
  - Prototype demonstration in operational environment; and
  - System qualification in an operational environment
  - *However…*
    - start point depends on the IOC and availability of COTS - specifically for the target 5G technology (due from 2024)
- Finally, the solution would move forward through **standardisation and commercialisation** phase
  - Anticipated availability as a commercial product by 2027

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Potential Upgrade Costs

UC	Technology							CAPEX €	OPEX €
	MCMF	5G	BlueSky	CSAC	STL	PTP	eLoran		
1a and 2	✓		✓	✓		✓	✓	15,250	1,000
3	✓		✓	✓	✓	✓		12,650	5,600
4	✓		✓	✓	✓			9,650	4,600
1b and 1c	✓	✓	✓	✓				8,800	300
Basic	✓							400,00	0,00

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Study Conclusions [MB]

And so…

- CNI & other applications require **accurate, secure and reliable time** *inter alia*:
  - 5G/LTE
  - Avionics
  - Power Grids
  - Secure Communications
  - Financial transactions
- GNSS has done this for the last few decades with **sub-ns sync and traceability to UTC** (plus it's free at the point of use!)
  - But… **GNSS is vulnerable**
    - interference, spoofing, built environment, vegetation, indoors, etc.
- We have proposed an Innovative Hybrid Timing System

This Innovative Hybrid Timing Solution Provides:

- **Application support** to various Use Cases
  - Flexibility to choose alternative timing sources, adaptive to the requirement/application
- A wide range of **accuracy**
  - From ms level to sub-μs level
  - From different alternative timing sources
- Improved **holdover** performance
- Improved **resiliency** - less vulnerable to interference, jamming or spoofing (vs. GNSS)
- **Global coverage** or wide area (e.g. 1000 km) coverage
  - Through wireless time transfer (satellite-based or terrestrial-based)
- **Ubiquity**
  - Supporting indoor scenarios (by STL and LF signal)
- Support to **security** features such as authentication and encryption
  - Using alternative timing technologies (such as STL)

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Recommendations

- Additional **5G study**
- The definition of an **integrity standard** for timing
- A workshop might also be called to allow for **stakeholder evaluation**
- Assessment of potential **issues of implementation and operation**

Open Q&A Session

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THANK **YOU**
FOR YOUR ATTENTION

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