REPORT ON TIME & SYNCHRONISATION USER NEEDS AND REQUIREMENTS

OUTCOME OF THE EUSPA USER CONSULTATION PLATFORM

GALILEO   EGNOS   Copernicus

EUSPA
European Union Agency for the Space Programme

Change record		
Issue/ Revision	**Changes**	**Date**
1.0	First issue	18/10/2018
2.0	Refer to Annex 4	01/07/2019
3.0	Refer to Annex 5	01/09/2021

TABLE OF CONTENTS

TABLES, FIGURES AND BOXES

TABLES

FIGURES

01

INTRODUCTION AND CONTEXT OF THE REPORT

G NSS provides a unique offering to Timing and Synchronisation (T&S) user communities by delivering a free and highly accurate time and synchronisation capability available worldwide. GNSS has been rapidly adopted by the T&S user communities, in particular for Critical Infrastructure operations and is even considered as a breakthrough technology in particular for Telecom.

Despite its long experience in GNSS, the T&S Sector is still very active with many challenges ahead, linked to an increased need for reliability and security, supported by an evolution of the regulation and ever increasing requirements by users in regards to accuracy, stability and reliability, often driven by the introduction of new technology in industries requiring time and synchronisation.

The User Consultation Platform (UCP) is a periodic forum organised by the European Commission and the GSA involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers, application developers and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. The event is a part of the process developed at the GSA to collect user needs and requirements and take them as inputs for provision of user driven Galileo and EGNOS services. In this context, the objective of this document is to provide a reference for the European GNSS Programmes and for the T&S community reporting periodically the most up-to-date GNSS user needs and requirements in the T&S market segment. This report is considered a "living document" in the sense that it will serve as a key input to the next UCP event where it will be reviewed and subsequently updated. The UCP will be held periodically (e.g. once per year) and this report will be also periodically updated, to reflect the evolution in the user needs, market and technology captured during the UCP.

The report aims to provide the GSA with a clear and up-to-date view of the current and potential future user needs and requirements in order to serve as an input to the continuous improvement of the services provided by the European GNSS systems and their evolutions.

Finally, as the report is publicly available, it serves also as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of location technologies.

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by combination of several signals and sensors. Therefore the report does not represent any commitment of the European GNSS Programmes to address or satisfy the listed user needs and requirements in the current or future versions of the EGNSS services.

1.1 METHODOLOGY

The following figure details the methodology adopted for the analysis of the Timing user requirements.

The analysis is split into two main steps including a *"desk research"*, to gather main insights, and a *"stakeholders consultation"*, to validate main outcomes.

More in details, the *"desk research"* was based on a secondary research and aimed at providing a preliminary structured analysis:

- Leveraging on the Timing and Synchronisation applications' segmentation as included in the GSA GNSS market report, additional relevant applications have been identified and included; and

- For each application identified, the function and level of performance required has been determined.

As a result of this activity, a first draft of the Timing and Synchronisation User Requirements document has been produced.

In the second step, the *"stakeholder consultation"* one, main outcomes included in the document have been validated and updated. In this regards, preliminary validation interviews with selected stakeholders have produced the current document to be used as an input for the UCP review and finalisation.

GNSS PROVIDES A UNIQUE OFFERING TO TIMING AND SYNCHRONISATION (T&S) USER COMMUNITIES BY DELIVERING A FREE AND HIGHLY ACCURATE TIME AND SYNCHRONISATION CAPABILITY AVAILABLE WORLDWIDE

Figure 1: Timing & Synchronisation User Requirements Analysis methodology

OVERALL METHODOLOGY

1 — Desk Research

Identification of all existing Timing applications along with the function that they perform

- All Timing applications covered in Market Report nº5

User level dimension and characterisation

- Identification of the key GNSS user level dimensions to describe Timing user requirements
- Identification and definition of GNSS performance criteria relevant to Timing

Segmentation of Timing Applications

- Definition and classification of applications
- Focused on GNSS usage (not device-based)

Definition of the functions and level of performance required for each application

- Timing user requirements analysis based on open Secondary research information
- GNSS limitations, market/techno trends and drivers
- Table matching the main applications with the performance criteria

User requirement analysis – *draft 1*

SECONDARY RESEARCH INFORMATION

GNSS magazines - Coordinates, GPS World, Inside GNSS; ESA website; Articles on Google Scholar; Thesis and dissertations on specific database; European regulation or standard; Google

2 — Stakeholders Consultation

Validation interviews

- Interview guide
- Selection of the consulted stakeholders
- Primary research: Interviews and reporting

User requirement analysis – *final version*

User Consultation Platform

- User requirements submitted to the first UCP forum for review and finalisation
- Update, validation and expansion of the User Requirement analysis at each UCP

2019 update

1.2 SCOPE

This document is part of the User Requirements documents issued by the European GNSS Agency for the Market Segments where Position Navigation and Time (PNT) play a key role. Its scope is to cover user requirements on PNT solutions from the strict user perspective and the market conditions, regulations, and standards that drive them. Therefore, the document includes an analysis of the market trends on this particular segment, then performs a detailed analysis including the prospective uses of GNSS in this market finalising with a specification of user requirements in a format that can be used for System Engineering activities.

In more detail, this report is laid out as follows. It starts with a summarised market overview for Timing **(section 4)**, where market evolution and key trends, the main market players and user groups are presented.

Then it moves on to the analysis of GNSS user requirements for Timing **(section 5)**. Section 5 is organised as follows:

- Section 5.1 identifies and defines the GNSS performance parameters that are relevant in the analysis of the user requirements for Timing & Synchronisation and presents an overview of Timing applications extracted from GSA Market Report 5 but also from other sources. It also provides definitions of these applications. They have been typified into different categories according to their usage and a detailed overview of GNSS user requirements is provided.

- Prospective use of GNSS in Timing is addressed in section 5.2. It assesses GNSS technology trends, along with the other technologies that are used in the Timing community.

- GNSS limitations for Timing are described in section 5.3.

- Section 5.4 identifies the drivers for user requirements in Timing

- Section 5.5 analyses the main relevant regulations.

- Section 5.6 is a conclusion on the GNSS user requirements analysis for timing and synchronisation applications.

Finally **section 6** summarises the main GNSS user requirements for Timing in the applications domains analysed in this report.

The document is intended to serve as an input to more technical discussions on Systems Engineering and evolution of the European GNSS systems so that space infrastructures are effectively linked to user needs.

02 EXECUTIVE SUMMARY

Electricity transmission, Telecom networks operation, Timestamping of financial transactions, Air Traffic Management Systems, Satellite platforms, TV Broadcast are only a few examples of applications relying on GNSS for timing and synchronisation purposes. Indeed, although relatively unknown to the general public, the timing and synchronisation capability offered by satellite navigation systems has become an essential and critical feature of our **most vital infrastructures**.

The scope of this document is to analyse the user requirements of the following T&S applications:

- **Telecom**: Digital cellular, Public Switched Telephone Network (PSTN), Professional Mobile Radio (PMR), Satcom

- **Electricity transmission**[1]: Phasor Measurement Unit (PMU)

- **Finance**: Banks, Stock Exchanges

However, there exist other applications relying on GNSS for timing and synchronisation such as: Transportation Systems, Water and Wastewater Systems, Scientific applications (astronomy, particle physic, geophysics, metrology), Digital TV Broadcast, LTE small cells networks (femto, pico and microcells) and Internet of Things (IoT) related applications.

The following table summarises the T&S user requirements for the three selected applications.

> **TIMING AND SYNCHRONISATION CAPABILITY HAS BECOME AN ESSENTIAL AND CRITICAL FEATURE OF OUR MOST VITAL INFRASTRUCTURES**

Most of the domains concerned are currently evolving. Consequently as a next step it is recommended that the user requirement analysis is **updated on a yearly basis** to reflect the latest information in the domain. In particular, lessons learnt from the implementation of the MiFID2 directive in Finance or of the PMU in power grid should provide interesting material. In the Telecom domain, 5G definition is still in discussion and could have an impact on T&S user requirements.

Moreover, it is suggested to expand the analysis to other sectors, in particular **IoT** and **Small Cells,** which appear to be very promising in terms of market potential.

Finally, an emphasis should be placed on users' expectations regarding EGNSS proposition, especially in relation to the new opportunities opened by the provision of an **authenticated, robust and resilient EGNSS Timing service**. In particular, a characterisation of the requirements for robustness should be initiated (e.g. threats & vulnerabilities analysis – overall and per application). The EGNSS value proposition in the T&S domain is not always very well-known and the promotion & awareness effort should be continued towards these user communities (e.g. by participating to the relevant conferences and standardization forums).

---

1   Distinction is made here with Power Grid » which includes Electricity transmission and distribution.

	Telecom	Electricity transmission	Finance
Main trends	• PSTN networks mature but rapid growth in mobile cellular networks with investment in 4G • SATCOMs and PMR are minor in comparison • 5G might require even further synchronisation accuracy depending on the technology adopted • LTE Advanced and other technologies offering more bandwidth and additional services require phase synchronisation instead of the traditional frequency synchronisation • Operators and Carriers have to invest into making their networks phase synchronisation ready or deploy more GNSS equipment near the base station (or both, in a balanced approach)	• Infrastructure increasingly operated with reduced security margins • More disparate sources of energy will appear (domestic solar or wind turbine) requiring even more synchronisation of the network nodes • Electrical power transmitted over longer distances, making the system potentially more vulnerable to widespread problems • Modern substations are using Ethernet based communication and require synchronisation over the network instead of installing and operating a separate cable infrastructure for synchronisation	• Banks and Stock Exchanges rely on very powerful IT systems and networks requiring a high level of availability, security and reliability • Highly interworking market with Banks and Stock Exchanges operating worldwide, regulation enforcement shall be harmonized to enable effectiveness
Current GNSS Use	• GNSS derived timing is widely used as either a primary source of timing information or as a redundancy solution • In the SATCOM domain, GNSS derived timing used for TDMA timing on the satellite links and terrestrial links; and NTP type services for IT/network/satellite monitoring/control • Within the PMR and digital cellular domains, GNSS derived timing is used for the synchronisation of timeslots and for handovers between base stations. • Within the PSTN domain, GNSS derived frequency is typically used as a backup in case frequency information from atomic clocks are lost. GNSS derived timing can be used for time of day, traffic timing and time slot management. • Many networks employ local oscillators enabling service to be temporarily maintained in case of loss of GNSS.	• Transmission System Operators are the main GNSS users (Wide Area Monitoring System/Wide Area Control System) • WAMS are using PMUs (Phasor Measurements Units) as a source of T&S information for: Network Monitoring (current use) and Automatic Protection (future use) • Use of WAMS is becoming widespread (smart grids) • Automatic Protection requires a high level of accuracy and redundancy at PMU level • PMU deployed across remote locations of the power network (nodes) - Internal time references currently based on GPS receivers.	• GNSS used for Synchronisation and Time Stamping functions - log events or quotes in a chronologic manner • GNSS receivers are installed in datacentres • Widespread use of transfer protocols like NTP/ PTP to distribute time (a Primary Server can be connected to about 1500/2000 NTP clients) • PTP is increasingly considered and provides sub-µs accuracy • GNSS spoofing can lead to a particular issue especially for systems relying on PTP, if the synchronisation solution infrastructure has not been designed in a proper way

	Telecom	Electricity transmission	Finance
Main potential future drivers for GNSS	• Resilience and reliability • GNSS Authentication • Improved robustness to interference • Nanosecond accuracy for massive MIMO and COMP mode in 5G • High availability • Accuracy Low(1ms) / medium (1µs) for Timing, Low (1ms) /High (100 ns) for Synchronisation • Calibration of hardware equipment delays	• Resilience and reliability • GNSS Continuity of service • Improved robustness to interference • GNSS Authentication • Accuracy medium for T&S (1µs) and even high (<100ns) for fault location • Calibration of hardware equipment delays	• Resilience and reliability • Security • Traceability • High availability • GNSS Authentication • Low (1ms) /Medium (1 µs) Accuracy for T&S • Calibration of hardware equipment delays
Main stakeholders having a role in the user requirement definition	• Communications network operator • Network equipment provider • Radio spectrum regulator (States & international agreement) • ETSI, ITU-T & ITU-R	• TSOs, ENTSO-E • PMU vendors • IEC, IEEE	• System integrator, financial institutions • ESMA
Competing / complementary technologies	• Time distribution using transfer protocols over IP (e.g. NTP or PTP) • LEO satellite constellation • Atomic clocks (Time keeping) • OCXO and TCXO (Time keeping)2 • Wide scale metrology network Frequency and/ or time distribution • eLoran or other radio based time distribution systems currently under development		

2019 update

---

2   Time keeping solutions will always need time transfer to be synhronized/monitored regularly. This time transfer can be GNSS/eLoran/STL/fiber.

03 REFERENCE DOCUMENTS

Id.	Reference	Title	Date
[RD1]	GSA Lot4 SC1, D1 V2.0	Market research and quantification of the timing and synchronisation	19 January 2014
[RD2]	GSA Lot4 SC1, D2.2 V2.0	Existing and Potential GNSS TS applications and products	30 October 2014
[RD3]	Spoofing GNSS Timing Receivers	Spoofing GNSS Timing Receivers, Tim Frost (Calnex) and Guy Buesnel (Spirent), proceedings ITSF 2015	November 2015
[RD4]	DEMETRA Time Service User Needs Analysis	DEMETRA "Time Service User Needs Analysis" D05 Public abstract	15 May 2015
[RD5]	Market Report 4	GSA GNSS Market Report Issue 4	March 2015
[RD6]	Delivering a national timescale using eLORAN	Delivering a national timescale using eLORAN, Chronos	07 June 2014
[RD7]	Roseline	Revolutionizing how we keep track of time in cyber-physical systems, URL: http://nsf.gov/news/news_summ.jsp?cntn_id=131691	July 2014
[RD8]	Timing Accuracy Down to Picoseconds	Timing Accuracy Down to Picoseconds, URL: http://gpsworld.com/timing-accuracy-down-to-picoseconds	05 October 2015
[RD9]	Market Report 5	GSA GNSS Market Report Issue 5	May 2017
[RD10]	Technology Report 1	GSA GNSS Technology Report Issue 1	October 2016
[RD11]	Guidelines for GPS Traceability	Guidelines on the Use of GPS Disciplined Oscillators for Frequency or Time Traceability, EURAMET Technical Guide No. 3, Version 1.0	March 2016
[RD12]	Impact of GNSS lost on UK economy	The economic impact on the UK of a disruption to GNSS, London Economics commissioned by Innovate UK	June 2017
[RD13]	Legal Traceability of Time, NIST	Legal Traceability of Time, NIST: http://tf.nist.gov/general/pdf/1433.pdf	2001
[RD14]	Security and resilience	Critical Infrastructure Security and Resilience, International Committee on Global Navigation Satellite Systems	November 2014
[RD15]	5G the future of mobile communications	5G the future of mobile communications, Martin Kingston (RAN) and Andy Sutton (Network Strategy)	November 2015
[RD16]	GNSS Security and Robustness	GNSS Security and Robustness, Shankar Achanta (Schweitzer Engineering Laboratories, Inc)	September 2015
[RD17]	Model-Based Evaluation of GPS Spoofing Attacks on Power Grid Sensors	Model-Based Evaluation of GPS Spoofing Attacks on Power Grid Sensors Ilge Akkaya, Edward A. Lee, Patricia Derler University of California at Berkeley	-
[RD18]	UTC Traceable Time for the Financial Sector using PTP	UTC Traceable Time for the Financial Sector using PTP, NPL Elisabeth Laier, proceedings ITSF 2015	November 2015
[RD19]	GPS & precision timing's role in the financial services sector	GPS & precision timing's role in the financial services sector, Andrew F. Bach (Juniper Networks)	September 2015

Id.	Reference	Title	Date
[RD20]	RTS25 Draft regulatory technical standards on clock synchronisation	Annex I MiFID II / MiFIR / MiFID/MiFIR Draft Regulatory Technical Standards - RTS25 "Draft regulatory technical standards on clock synchronisation"	28 September 2015
[RD21]	FINRA Regulatory Notice Consolidated Audit Trail (CAT)	National Securities Exchanges and FINRA Issue Joint Guidance on Clock Synchronisation and Certification Requirements Under the CAT NMS Plan	March 2017
[RD22]	NPL Time used by UBS and TMX Atrium	UBS and TMX Atrium use new NPL network timing service www.npl.co.uk/news/ubs-and-tmx-atrium-use-new-npl-network-timing-service	Sept 2016
[RD23]	2008/114/EC Directive	2008/114/EC Directive on the "identification and designation of European critical infrastructures and the assessment of the need to improve their protection"	December 2008
[RD24]	Homeland Security Researching GPS Disruptions, Solutions	Inside GNSS News, Homeland Security Researching GPS Disruptions, Solutions, Latest News, Dee Ann Divis http://insidegnss.com/homeland-security-researching-gps-disruptions-solutions/	June 10, 2014
[RD25]	Critical Infrastructure Vulnerabilities to GPS Disruptions	Critical Infrastructure Vulnerabilities to GPS Disruptions Sarah Mahmood, Program Manager, Resilient Systems Division Homeland Security Advanced Research Projects Agency Science & Technology Directorate	4 June 2014
[RD26]	GPS disruptions effort to assess risks to critical infrastructure and coordinate agency actions should be enhanced	"GPS disruptions effort to assess risks to critical infrastructure and coordinate agency actions should be enhanced", GAO-14-15	November 2013
[RD27]	Consultation with Mr Jiri Luhan	Consultation report with Mr Jiri Luhan	February 2012
[RD28]	Consultation with Mr Gilles Boime	Consultation report with Mr Gilles Boime (Spectracom)	February 2012
[RD29]	Consultation with Mr Pedro Estrela	Consultation report with Mr Pedro Estrela (IMC Financial Markets)	February 2012
[RD30]	Consultation with Mr Mats Larsson	Consultation report with Mr Mats Larsson (ABB)	February 2012
[RD31]	GSA-MKD-TS-UREQ-233690	Report on Time & Synchronisation User Needs and Requirements	November 2017
[RD32]	GSA-MKD-T-S-MOM-246199	User Consultation Platform 2018 – Minutes of Meeting of the Timing and Synchronisation Panel	03.12.2018
[RD33]	MIFID2/RTS25	COMMISSION DELEGATED REGULATION supplementing Directive 2014/65/EU of the European Parliament and of the Council with regard to regulatory technical standards for the level of accuracy of business clocks	07.06.2016
[RD34]	High Precision Time (White Rabbit) Pilot	https://www.eurexchange.com/exchange-en/resources/initiatives/technical-changes/high-precision-time-white-rabbit-pilot	16.07.2018

2019 update

04 MARKET OVERVIEW AND TRENDS
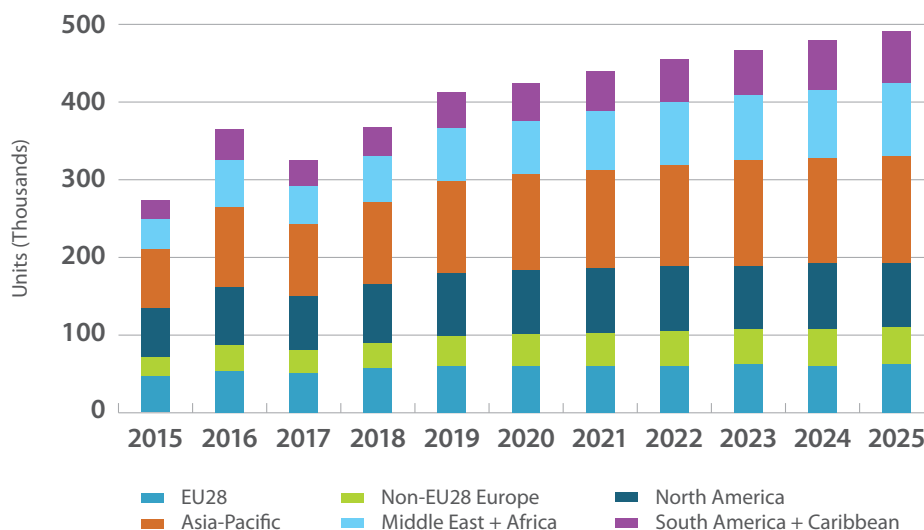
4.1 MARKET EVOLUTION AND KEY TRENDS

As described in the latest issue of GSA market report [RD9], the GNSS T&S segment is mainly driven by the Telecommunication sector, which represents around 90% of the overall GNSS device shipments. The GNSS installed base in the three segments (Telecom, Energy and Finance) should reach 2.4 mln units in 2020 (including small cells). Overall GNSS T&S shipments are expected to grow at a CAGR of 5.3% over 2017 – 2025, driven by the Telecom market which will grow at 5.7% over this period. EU28 and North America should represent around 40% of the shipments in 2017 but Asia Pacific and Middle East should gain market share in the next decade. In terms of revenues, the T&S market could reach €1.2 bln in 2020 and then plateau up to 2025, benefiting from dynamic sales in telecom which will be limiting the effect of price erosion.

Rapid growth is expected in Mobile Cellular Networks with investment in 4G, reaching a peak in 2015/2016. The digital Cellular Segment is the most dynamic for T&S due to the number of LTE base stations expected to be deployed in Europe and its increased dependency on accurate synchronisation (it evolves into LTE- Advanced). LTE Small Cells rollouts and 5G investments are expected to revitalize shipments between 2018 and 2022. For PMR, the network infrastructure continues to grow and along with it, so does GNSS stock. PSTN, PMR and SATCOM are all considered to be mature.

In the Energy segment, Asia and North America are ahead of Europe as regards the deployment of PMUs. This is particularly the case in China which has become the largest market in power transmission and distribution and has therefore been at the cutting edge of smart grids technology. USA has also been very active in synchrophasor deployment as a response to Energy challenges in the country. It is the result of significant R&D efforts supported by the US Department of Energy (DOE) over a decade. The Finance industry is clearly driven by North America which represents nearly half of the market. Europe is also very active with new regulation expected to modify the overall landscape [RD9].

Shipments of GNSS devices by region

Shipments of GNSS devices by application

Legend:
- Public Switched Telephone Network
- Digital Cellular Network
- Small Cells
- Bank applications
- Professional Mobile Radio
- Satellite Communication
- Phasor Measurement Units
- Stock Exchanges
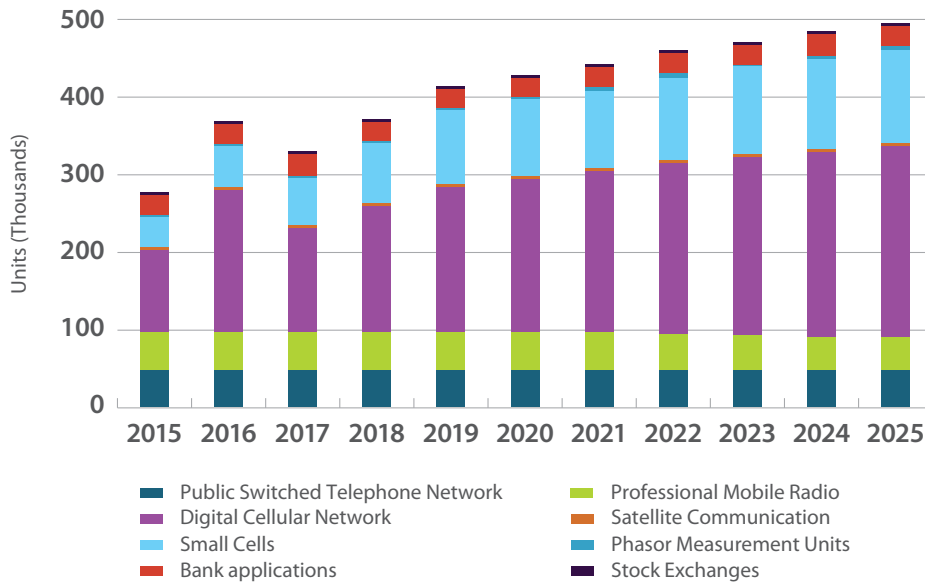
Note: the figures above include the small cells GNSS market.

4.2   MAIN MARKET PLAYERS

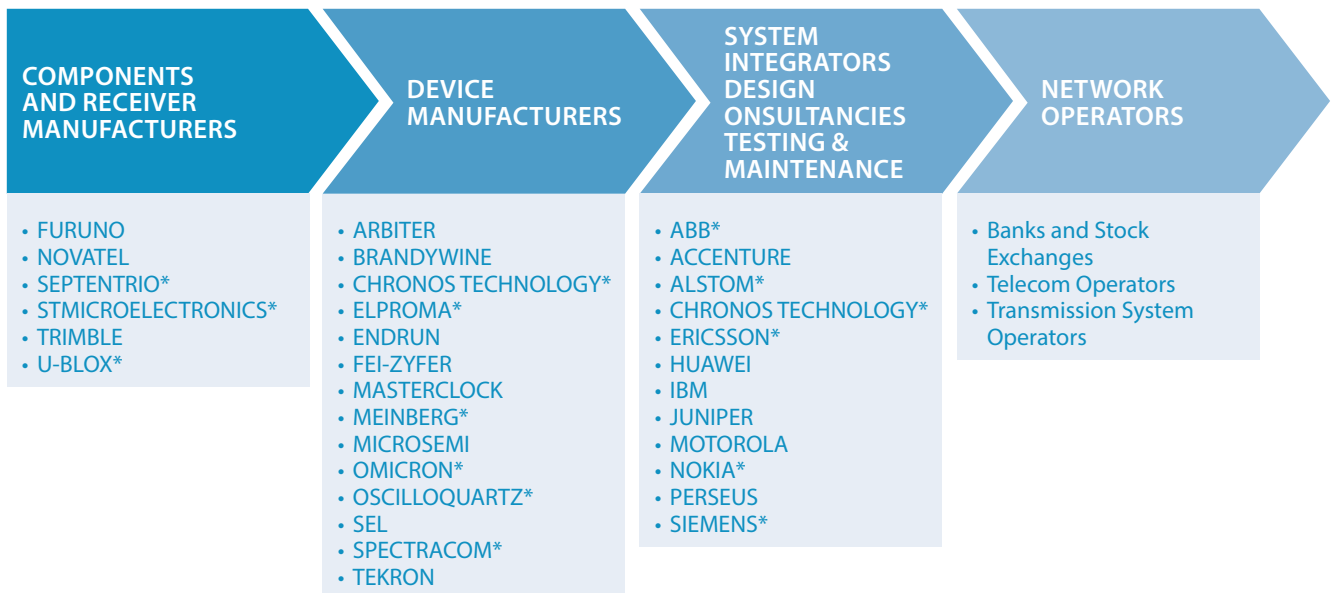Price of a GNSS timing device can range from €250 (standalone module) to €10,000 (high end receivers) or more, depending on the application. For Electricity transmission and Telecom, typical device prices are in the order of €3,000-€6,000.

The following figure depicts the overall value chain of the GNSS timing and synchronisation market, together with the main industrial actors and corresponding roles. This value chain is extracted from [RD9]. Companies mentioned in each block are not intended to be exhaustive and are mentioned as illustrations. This value chain is voluntarily high level and is further detailed for each sector considered (Telecom, Electricity transmission, Finance) in [RD1].

Figure 2: Value Chain – GNSS T&S for CI

COMPONENTS AND RECEIVER MANUFACTURERS	DEVICE MANUFACTURERS	SYSTEM INTEGRATORS DESIGN ONSULTANCIES TESTING & MAINTENANCE	NETWORK OPERATORS
• FURUNO • NOVATEL • SEPTENTRIO* • STMICROELECTRONICS* • TRIMBLE • U-BLOX*	• ARBITER • BRANDYWINE • CHRONOS TECHNOLOGY* • ELPROMA* • ENDRUN • FEI-ZYFER • MASTERCLOCK • MEINBERG* • MICROSEMI • OMICRON* • OSCILLOQUARTZ* • SEL • SPECTRACOM* • TEKRON	• ABB* • ACCENTURE • ALSTOM* • CHRONOS TECHNOLOGY* • ERICSSON* • HUAWEI • IBM • JUNIPER • MOTOROLA • NOKIA* • PERSEUS • SIEMENS*	• Banks and Stock Exchanges • Telecom Operators • Transmission System Operators

The first block is the **GNSS Chipscale producers** which are not pure players of the T&S market. These actors are selling their GNSS chipscales to many applications including mass market. Considering the volumes, the T&S market represents a small part of their revenues.

The added value and market specificities are added by the **GNSS Time product manufacturers**. GNSS Time equipment usually takes the form of rackmount equipment with specific interfaces supporting Time protocols such as PTP or NTP or synchronisation specific electrical or optical interfaces, for example IRIG B, which are often industry specific. However, there exist also Timing modules, particularly interesting for small cell synchronisation applications. The market is dominated by a small number of actors (most players are US companies), which main ones are the following:

- Microsemi (which acquired Symmetricom on 26/11/2013)
- Orolia/Spectracom
- Meinberg
- OscilloQuartz
- FEI-Zyfer
- Lots of other actors

Additional revenues can also be generated in the value chain through the provision of:

- Synchronisation infrastructure design **consultancy**;
- Maintenance, calibration and testing **services**.

These services are typically provided by **equipment resellers**. System integrators are used to integrate GNSS T&S equipment in complex system (network) depending on the target market segment (i.e. PMU manufacturers, PMR base station manufacturer) which is then used by the **network operator** (telecom, electricity transmission or finance).

4.3 MAIN USER GROUPS

4.3.1 TELECOM

In the telecommunication segment, GNSS end users are the **network operators**. The decision as to which timing solution is implemented within the network, whether it is GNSS based or not, is decided by the communications network operator itself. Different operators may have different approaches to timing solutions as standards only state requirements but not how they are met. It should be noted that the telecommunication operator might be an outsourcing provider, such as Ericsson, MBNL and Huawei. As such, telecom **backhaul equipment vendors** also have a role in the user requirement definition. The timing solution decision will be based on a combination of commercial and technical factors [RD28].

4.3.2 ELECTRICITY TRANSMISSION

GNSS end users of electricity transmission systems are the **Transmission System Operators** (TSO). TSO are operators that transmit electrical power from generation plants over the electrical grid to regional or local electricity distribution operators. Depending on country, TSO can also be in charge of the development of the grid infrastructure. The decision as to which timing solution is implemented within the network, whether it be GNSS based or not, is decided by the Energy network operator but the PMU / Substation manufacturer (e.g. ABB, Alstom) could also play a role in the decision process, by e.g. proposing to the operator a solution meeting the technical requirements. Finally, in the future, Distribution System Operators (DSOs) could become PMU users for regional distribution (in particular low cost PMU – but this is currently at research stage) [RD30].

European TSOs are organised in associations, the biggest one was UCTE until July 2009 when it was replaced by the ENTSO-E (European Network of Transmission System Operators for Electricity). In Europe, the ENTSO-E association gathers 41 Transmission System Operators of 34 countries (e.g. Terna in Italy, REE in Spain, National Grid in UK, RTE in France).

4.3.3 FINANCE

In the Finance segment, GNSS end users are the **financial institutions (Exchanges, banks and other users such as market makers or hedge funds)** [RD29]. System integrators do typically not play a major role in the selection of the synchronisation solution as this is very often driven by specific operational requirements of the end users (banks, exchanges, traders, ...) and, of course, by compliance requirements. Especially the compliance aspect prohibits that a system integrator is having the final say, as they typically do not have the knowledge to assess the impact of a synchronisation solution in regards to this compliance aspect. Usually a bank asks a system integrator to provide a solution meeting his requirement, whatever the technical solution. Nonetheless, considering that security of their infrastructure is at stake, financial institutions can request a specific system. Contrary to the Electricity transmission or Telecom segments, where a large-scale infrastructure is operated at country level, the Finance segments include a wealth of different actors (more than 4 000 banks in EU28). It is also worth noticing that the concept of Critical Infrastructure for Finance is less mature in Europe than for Electricity transmission and Telecom (e.g. 2008/114/EC Directive does not explicitly refer to the Finance domain). Moreover, in Europe, the **European Securities and Markets Authority** (ESMA) plays an important role as part of their standardisation activities.

05 GNSS USER REQUIREMENTS ANALYSIS

5.1 GNSS USE FOR TIMING & SYNCHRONISATION

5.1.1 OVERVIEW OF TIMING & SYNCHRONISATION APPLICATIONS

The scope of this document is to analyse the user requirements of the following T&S applications, which are linked to Critical Infrastructure:

- Telecom: Digital cellular, Public Switched Telephone Network (PSTN), Professional Mobile Radio (PMR), Satcom;

- Electricity transmission: Phasor Measurement Unit (PMU);

- Finance: Banks, Stock Exchanges.

However, there exist other applications relying on GNSS for timing and synchronisation such as:

- Transportation Systems,

- Water and Wastewater Systems,

- Scientific applications (metrology),

- TV Broadcast,

- LTE small cells networks (femto, pico and microcells),

- Industrial automation,

- Internet of Things (IoT) related applications.

It is recommended that these applications are further analysed in a subsequent version of this document.

5.1.1.1 INTRODUCTION

Timing and synchronisation are two distinct functions that can be fulfilled using GNSS.

Timing: is the marking of an event with respect to a reference origin, usually UTC (Coordinated Universal Time), or more precisely a realization of UTC maintained by a time laboratory, named UTC(k), as UTC does not exist in real time. The precise time user requires the time tagging of events (also called Time stamping). Time stamping refers to the use of an electronic timestamp to provide a temporal order among a set of events.

Synchronisation: deals with understanding the temporal ordering of events produced by concurrent processes. Two clocks can be synchronised between them and/or with respect to an absolute time. Synchronisation is particularly important to ensure successful communication between nodes of a network. It is also required in applications in which two events have to be initiated within a specific time frame. In this document, the term "synchronisation" refers to both phase and frequency synchronisation (frequency synchronisation is actually called synthonisation).

GNSS can be used to provide both services:

- **Timing:** GNSS provides a direct and accurate access to a prediction of UTC.

- **Synchronisation:** Either synchronisation between receivers at different locations can be established and maintained using GNSS reference time. Or, a master clock synchronized itself using the time provided by GNSS can redistribute this time to the slave clocks disseminated within the systems.

5.1.1.2 KEY TERMS DEFINITION
General

NTP (Network Time Protocol) is a protocol for clock synchronisation between computer systems over packet-switched, variable-latency data networks. NTP can usually maintain time to within less than tens of milliseconds over the public Internet. Over limited areas and with dedicated and high bandwidth connexion, NTP can provide 100 µs level timing accuracy. Better accuracy typically requires a carefully engineered network.

PTP: Precision Time Protocol (PTP/IEEE-1588) is a protocol for clock synchronisation between computer systems with a typical accuracy of sub µs (on private network and with network elements dedicated task). PTP was originally defined in the IEEE 1588-2002 standard. In 2008 a revised standard, IEEE 1588-2008 was released. A revision of the PTP standard is now in a forming stage and expected to be published in 2018. In order to avoid a single point of failure, the design of a PTP solution has to ensure that multiple Grandmaster clocks are available on the network. This requires putting extra effort into the configuration and setup of PTP slave devices, which is most of the time not possible due to limitations of the available PTP implementations.

IRIG-B: Inter-range instrumentation group time codes (IRIG time codes) are standard formats for transferring timing information created by the Telecommunications Working Group of the U.S. military's Inter-Range Instrumentation Group. IRIG-B has a bit rate of 100 Hz and a frame rate of 1 Hz.

SyncE: Synchronous Ethernet is an ITU-T standard for computer networking that facilitates the transference of clock signals over the Ethernet physical layer. This signal can then be made traceable to an external clock.

Stratum 1: In the context of NTP, stratum levels define the distance from the reference clock. A reference clock is a stratum-0 device that is assumed to be accurate and has little or no delay associated with it. It is a reliable source of UTC time such as GNSS receiver or an atomic clock. A server that is directly connected to a stratum-0 device is called a stratum-1 server. However, NTP/RFC5905 does not define any accuracy requirements.

Holdover: According ETSI, "An operating condition of a clock which has lost its controlling input and is using stored data, acquired while in locked operation, to control its output. The stored data are used to control phase and frequency variations, allowing the locked condition to be reproduced within specifications."

UTC: Coordinated Universal Time (abbreviated as UTC) is the international reference time scale by which the world defines clock rate and time. In force version of UTC is defined by the International Telecommunications Union Recommendation (ITU-R TF.460-6) and maintained by Bureau International des Poids et mesures (BIPM). As UTC is computed monthly for the past month, it does not exist in real time. The local realizations of UTC, called UTC(k), maintained in the Time Laboratories (k is the acronym of the laboratory) have therefore to be used as standard in real time. These realizations UTC(k) have also the role of legal time in some countries.

Resilience: The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions; it includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents [RD14]. It can be characterised with the two following parameters:

1. "Acceptable" level of degradation under stress (i.e. How many ns or us or ms can be accepted over a given period of stress);

2. Time to recovery from disruption (i.e. acceptable disruption duration without any impact on the operation).

The characterisation of the Resilience parameters is dependent upon:

- The network architecture;

- The level of criticality of the operation;

- The process to work under predefined degraded mode.

The resilience question is usually addressed at application level by the operators and it is not possible to provide an

2019 update

assessment which would be agnostic of the overall clock system. The resilience requirement is also met through the use of different back-up or alternative timing systems which are network and application specific.

Robustness: Robustness is a policy to prevent failures (while Resilience is based on the fact that failures are inevitable but with early detection and fast recovery would work better, and be easier to implement).[3]

Security: Security is the degree of resistance to, or protection from, harm. In the context of this report it involves reducing the risk to physical and cyber critical infrastructure caused by natural and manmade threats. [RD14]

Reliability: The ability of a system or component to function under stated conditions for a specified period of time (source IEEE).

Traceability: A traceable measurement is one that can be related to national or international standards using an unbroken chain of measurements, each of which has a stated uncertainty [RD13].

Telecom

LTE: is an abbreviation for Long-Term Evolution, commonly marketed as 4G LTE, it is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is based on the GSM/EDGE and UMTS/HSPA network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. The standard is developed by the 3GPP (3rd Generation Partnership Project) and is specified in its Release 8 document series. Its primary feature for users is faster data, although it also improves the efficiency and capacity of wireless networks.

Handover: is the process of transferring a phone session in progress from one base station (tower) to another base station, without interrupting the session.

SONET/SDH: Synchronous Optical Networking (SONET) and Synchronous Digital Hierarchy (SDH) are standardized protocols that transfer multiple digital bit streams synchronously over optical fiber using lasers or highly coherent light from light-emitting diodes (LEDs).

PMR: Professional Mobile Radios are field radio communications systems often used by Public Safety and Security users (e.g. police, ambulance). Several digital Professional Mobile Radio communication (PMR) systems are available on the market. They are based on the following standards: TETRA (ETSI standard), TETRAPOL (TETRAPOL Publicly Available Specification) and P25 (TIA standard).

Electricity transmission

SCADA system (Supervisory Control And Data Acquisition) is the traditional and most widespread monitoring system that gives a steady state view of power grid. It provides an adequate monitor and control for very slow phenomena. It gathers and compares data every 2-5 seconds and present very low synchronisation performances. However, SCADA systems cannot guarantee alone a safe and secure monitor and control of power grid anymore.

WAMS/WACS (wide area measurements/control system) is the new system developed to respond to real time monitoring and control requirements. It estimates state, evaluates stress level and stability margin, monitors oscillation and thermal line rating in order to support congestion management and restoration stages/manoeuvring. WAMS system relies on a reliable communication system connecting power node.

PMU (Phase Measurements Units) measure voltage and current phasors and then time-stamp those measurements thanks to a GPS receiver and a phase-lock oscillator present in it. They should be installed at strategic places of the power grid in order to take a global picture of a grid's dynamics for power system planning, control and post-incident analysis. For instance, PMUS can be deployed at main substations and power plants. WAMS rely on PMU which provide voltage and current phasor measurements of the currents circulating in the adjacent branches and then transmit the data to the WAMS. Moreover, it should be highlighted that WAMS can be integrated with traditional SCADA systems giving a complete supervision of network.

Substation is a part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions. Between the generating station and consumer, electric power may flow through several substations at different voltage levels.

Finance

Stock Exchange is a form of bourse which provides services for stock brokers and traders to trade stocks, bonds, and other securities. Stock exchanges also provide facilities for issue and redemption of securities and other financial instruments, and capital events including the payment of income and dividends.

---

3   A resilient system will change its way of operations while continuing to function under stress, while a robust system at the end will reach a failure state without being able to recover.

5.1.2 TELECOM

5.1.2.1 SATCOM

SATCOM communications allow for radio, television, data and telephone transmissions to be transmitted anywhere in the world. A SATCOM operator's network infrastructure typically comprises of in space satellites and ground stations. The number and type of ground stations, gateways and satellites depend on the technology implemented. In simplistic terms SATCOM communications operate by transmitting a signal from the source to destination by bouncing signals between ground stations and satellites. SATCOM segments include broadcast, mobile and fixed voice, data and broadcast for civilian and military users [RD1] [RD2].

GNSS receivers are typically used in Satellite Control Stations and Telecommunications Gateways. The GNSS signal is used mostly for frequency control, but there are also some timing applications, mainly in satellite control stations.

Applications can include:

- Synchronisation and user mobility management (as per 3gpp standard). The synchronisation requirement is divided into:

  o TDMA timing on the satellite links and terrestrial links.

  o TTCM timing

  o NTP type services for IT/network/satellite monitoring/control/billing

It is estimated that each Satellite Control Station would have a minimum of four local GNSS receivers, but this can range up to ten dependent on a number of factors and criteria. GNSS receivers are typically backed up with local (atomic) oscillators, although the SATCOM industry has increased its confidence in GNSS derived timing as they have experienced little if no negative performance of the received GNSS signal.

The synchronisation requirements are typically based upon the recommendations set out in ITU G.811 (Stratum 1) (G.812 provides recommendations for slave clocks in telecoms networks) or proprietary technology. Accuracy requirements are mainly driven by proprietary technology requirements of the telemetry tracking loops but are likely to be around 100 ns accuracy.

SATCOM INDUSTRY HAS INCREASED ITS CONFIDENCE IN GNSS DERIVED TIMING AS THEY HAVE EXPERIENCED LITTLE IF NO NEGATIVE PERFORMANCE OF THE RECEIVED GNSS SIGNAL

5.1.2.2 PROFESSIONAL MOBILE RADIO (PMR)

In Europe, PMR services are provided by TETRA and TETRAPOL. TETRA, the predominant technology, was specifically designed for use by government agencies, emergency services, (police forces, fire departments, ambulance) for public safety networks, rail transportation staff for train radios, transport services and the military. TETRA's ability to set up one-to-many and many-to-many calls makes it the chosen tactical communications method for the emergency services.

GNSS derived timing is used to provide air interface synchronisation for roaming and assigning communication channels. This allows users to hand over from one base station service coverage area to another without dropping a call. TETRA requires a precision of 10 µs to allow for successful handover. Where feasible, GNSS receivers are located at every base station to allow signal handover from base station to base station. Loss of GNSS timing will cause graceful degradation as local oscillators act as failover (see Table 1 for typical performance of local oscillators). Due to limitations on volume of data that can be transmitted over existing PMR technologies and increasing functionality of LTE, there is speculation that PMR networks may be complemented by LTE technology to allow for high quality video streaming and broadband data services (this may still be under the management of specialist PMR providers). It is unclear whether this will provide a further opportunity for GNSS timing as the industry may opt for non GNSS time solutions or reduce the instances of GNSS receivers due to developments in protocols such as PTP [RD1] [RD2].

5.1.2.3 DIGITAL CELLULAR NETWORKS

Digital cellular networks, operated by mobile network operators, provide end users voice as well as data services. Digital cellular technology is constantly evolving as the demand for broadband data speeds continually increases.

Europe's digital cellular infrastructure comprises of a blend of GSM, UMTS and LTE deployments. LTE technology, the latest commercially available standard, is predicted to be the prominent technology and is increasingly reliant on precise timing information as it evolves into LTE- Advanced. Due to the number of LTE based base stations predicted to be deployed in Europe and its dependency on accurate synchronisation, the digital cellular segment is the T&S market's major economic driver.

There are two mobile wireless synchronisation approaches, depending on whether networks employ time or frequency division duplexing. Frequency division (such as WCMDA) uses the same equipment and approaches employed in fixed line circuits. Time division (such as CDMA, WiMax and LTE) requires frequency accuracy, phase alignment and (in some case) time alignment between all base stations within the network. It is unable to rely on traditional circuit based approaches as there is no time or phase relationship between the terminating points on the clock circuit. The most stringent requirements for LTE and LTE-Advanced demand frequency accuracies of <10 ppb and phase synchronisation of =1.1 µs, while compensating for delay variation and jitter [RD1] [RD2]. 3G is using synchronisation from the derivate of timing acquisition from GNSS external source and sometimes combined with a frequency distribution along the backhaul network to supply the RAN (Radio Access Network) from eNB. Requested frequency accuracy is ±5ppb. Timing need is for LTE-TDD (Time-Division Duplex). For extension of LTE-A service extending throughput to 100Mb with CoMP (Coordinated Multi-Point transmission and reception), requirement reaches 0.5 µs accuracy requirement for cells extend <800m [RD28].

Finally, advent of 5G network synchronization is bringing new challenges to the GNSS T&S community. In particular 5G introduces new layers with very precise timing reference requiring performance SLA monitoring. For instance, the anticipated performance at the end point for 5G (stage 2) is TAE <= 260[ns] TE +/-130[ns]. A stricter mobile network timing requirement could even be required for 3GPP High accuracy location capability: TAE<=10[ns] TE +/-5[ns] – though this figure is relative to radio neighbours sharing the same area. Moreover, network calibration and monitoring (i.e. verifying & testing this level of accuracy in the field) may even be more challenging than network synchronization delivery. In any case, 5G performance requirements are currently only anticipated and will finally be determined by the selection of implemented features.

2019 update

5.1.2.4 PUBLIC SWITCHED TELEPHONE NETWORK (PSTN)

PSTN is the world's collection of interconnected voice-oriented public telephone networks, both commercial and government-owned. It is also referred to as the Plain Old Telephone Service (POTS). Today, it is almost entirely digital in technology except for the final link from the central (local) telephone office to the user.

Use of GNSS derived synchronisation within European PSTN operators is dependent on whether atomic clocks are already incorporated into their networks. Large operators typically have access to their own atomic clocks installed within their networks in the 1970s and 80s prior to the availability of GPS.

The current accuracy performance of the GPS technology is matching the current and expected performance that would be required in the future.

The use of synchronisation references within telecom networks is used for the synchronisation of the network and has undergone (and continues to undergo) considerable changes. Traditionally telecom networks relied upon a central primary reference clock with timing distributed to the various network layers via SDH. The distributed clock signal was then re-filtered by various Synchronisation Supply Units (SSU) distributed within the network. Around 10 years ago this would in all cases have been based on Caesium primary reference clocks.

Developments over the last 10 years have resulted in flatter hierarchies with more primary reference clocks (often GPS based) and less distribution. This is typically implemented with a hybrid architecture where GPS Primary reference clocks are used at a mid-layer but the traceability to a caesium reference is maintained to ensure continued operation in the event of loss of GPS.

Another key change which has been occurring over the last decade is the move to packet based services which do not support traditional mechanisms for the distribution of synchronisation. This might lead some telecom operators to make use of GNSS based synchronisation. A contrario developing standards such as NTP and PTP are providing mechanisms to enable timing information to be distributed and hence an alternative source of synchronisation to be made available. GNSS usage within PSTN would decline as distribution over fixed infrastructure and new network architecture are adopted [RD1] [RD2].

5.1.3 ELECTRICITY TRANSMISSION

The electricity transmission sub-segment uses GNSS timing in systems providing frequent measurements relevant to the network status, but also to determine the location of faults along a transmission line.

In particular, GNSS can be used in the following equipment and systems[4]:

- Time reference and distribution systems: GPS use in the time reference and distribution systems can be considered as marginal in terms of volume of equipment and criticality of the time information:

  - Regarding SCADA applications, only 1 or 2 GNSS equipment are required on a particular network (i.e. at national level). The required level of accuracy for the timing information is indeed of several seconds (data gathered and compared every 2-5 seconds). Hence reliance on GNSS is not critical.

  - Regarding the communication networks synchronised using NTP/PTP protocols, 10 sources of GNSS time (about 20 receivers) seems to be sufficient at national level.

- Phasor Measurements Units (PMUs): The use of WAMS systems is becoming widespread in the electricity transmission domain, in particular to face the increased number of energy entry points, and those systems are using PMUs as a source of timing and synchronisation information. PMU deployed across remote locations of the network can be synchronised using GNSS signal (currently GPS).

Due to its higher performance requirements and its increasing importance in power grid PMU is the only sub-segment considered in the electricity transmission segment, although other parts of the grid would also benefit from increased accuracy, for example in order to increase the accuracy of measurements or sequence of events recording applications.

PMU can be used for two purposes:

- Network Monitoring: this is the main current use. Operators collect data to know the status of the network. This is not a very critical application. Customer acceptance is now very high but this took around 10 years to be implemented.

- Automatic protection: only 5 or 6 pilot projects have been launched. This is a critical application which requires a very high level of redundancy at PMU level.

Correct operation of a PMU requires a common and precise timing reference that may be internal or external to the PMU. The most important aspect for synchrophasor is to have the same time everywhere but not necessarily to have the right time. However, in PMUs, captured phasors may also have to be time-tagged based on the time of the UTC Time Reference.

THE MOST IMPORTANT ASPECT FOR SYNCHROPHASOR IS TO HAVE THE SAME TIME EVERYWHERE BUT NOT NECESSARILY TO HAVE THE RIGHT TIME

---

4   [RD-03] mentioned that substation automation using data from Intelligent Electronic Devices (IED) also needs time synchronisation although use of distributed time on one LAN is sufficient [RD2].

The current accuracy performance of the GPS technology is matching the current and expected required performance i.e. accuracy of 1 μs for automatic protection. In the future, if PMUs are deployed over smaller distance accuracy requirements could become more stringent (by a factor of 10, maybe between 0,3 μs to 0,05 μs) - indeed PMU measures difference of phase angle of the sine waves, and therefore if PMUs are located closely the difference will be small, hence a need for more accuracy [RD30]. This is however very prospective at this stage.

GPS-synchronised PMUs have the capability to provide a data acquisition system with the following accuracy:

- Time tagging with accuracy better than 1 μs (or equivalently 0.02 degrees of phase at 60 Hz).

- Magnitude accuracy of 0.1% or better.

Internal references consist currently of GPS receivers.

When the synchronisation source is not integrated in the PMU, the timing signal is provided to the PMU by means of an external source and a distribution infrastructure[5]:

- Network Time Protocol (NTP) with a specific network client accuracy of 0.5 - 10 μs (to achieve this level of accuracy with NTP specific clocks and software need to be implemented).

- Precision Time Protocol (PTP/IEEE-1588) with a typical accuracy of sub μs (with hardware slaves). IEEE 1588 standard becomes increasingly popular.

- IRIG-B also yielding a timing accuracy of 10 μs but less popular as it requires special cabling and computer cards.

5.1.4   FINANCE

Financial services rely on very powerful IT systems and networks requiring a high level of availability, security and reliability. Due to their influential status within the financial system and upon national economies, banks are highly regulated in most countries. Nevertheless, the current regulation is obsolete and the current timing requirements are no more linked to regulation but to technical needs although this situation is currently evolving (see section 5.5.2.3).

In the Finance sector, GNSS time is distributed throughout a network to up to several thousands of machines (client). Usually a GPS antenna is deployed on a roof and it is connected to a PTP or NTP server. It is highlighted that PTP is clearly the future (the whole industry works on it) as it provides sub μs accuracy (instead of millisecond for NTP). However, there is a significant issue with the current version of the PTP protocol which suffers from a single point of failure and is therefore not sufficiently reliable [RD29].

Availability of timing information is very important for banks and stock exchanges.

The finance community is increasingly concerned by GNSS threats (interference but primarily spoofing). Up to recently, considering the currently required accuracy (1 ms) unavailability of GNSS timing/synchronisation information in case of open GNSS services denial was managed by alternate solutions (e.g. NTP, local oscillator) even during a long period of time. This situation should rapidly evolve with the increased requirement for more accuracy (towards μs) and resilience.

Moreover, GNSS as a single source with no authentication is not a service answering the requirement for such CIS as recommended by the Network and Information Security Directive and ENISA policy. A complement solution shall be available.

5.1.4.1 BANKS

Banks rely on very powerful IT systems and networks requiring a high level of availability, security and reliability. Critical operations are performed in dedicated data centres.

GNSS equipment is used for Time Stamping functions, to log events in a chronologic manner and therefore be able to recreate causal links. Typical requirement in terms of accuracy is 1ms for most applications but there is an increased trend for more accuracy linked to regulation requirements (see section 5.5.2.3).

Banks operate centralized networks with much more machines than Stock Exchanges. Current PTP adoption is directly linked to the accuracy requirement.

Within a particular Bank organisation, time distribution for synchronisation applications is obtained by the use of transfer protocols (e.g. NTP, PTP). Today almost all the main

> IN THE FINANCE SECTOR, GNSS TIME IS DISTRIBUTED THROUGHOUT A NETWORK TO UP TO SEVERAL THOUSANDS OF MACHINES

---

5   (source: http://www.endruntechnologies.com/market-traders-time-synchronisation.htm).

European Banks are already equipped with timing and synchronisation equipment using GNSS technology. The number of implemented GNSS equipment is not foreseen to increase for this segment [RD1] [RD2].

5.1.4.2 STOCK EXCHANGES

The individual Stock Exchange servers apply time stamps to the trades they execute and to the quotes they establish (In the United States, the quotes are sent to the Consolidated Quotation System (CQS) which is an electronic service that provides quotation information for stock traded on the American Stock Exchange).

All stock exchanges are equipped with large data centres holding the exchanges' matching engines in racks of interconnected servers using GPS receivers as timing and synchronisation sensors. PTP adoption is underway in this sector.

It is assumed that today almost all of the main Exchanges are already equipped with the synchronisation equipment using GNSS technology. The number of implemented GNSS equipment is not foreseen to increase for this segment. The regulation requires implementing systems providing µs level accuracy.

As an illustration of GNSS use in Stock Exchanges, 10 000 NTP clients are operated by the New-York Stock Exchange (NYSE) fed by around 10 GPS receivers [RD1] [RD2].

5.2 PROSPECTIVE USE OF GNSS IN TIMING & SYNCHRONISATION

5.2.1 FUTURE TRENDS

GNSS has been used for Timing & Synchronisation since decades. In particular it strongly participated to the revolution of Telecom and can even be considered as a **disruptive technology** in this sector: without GNSS some telecom architectures would never have been developed (it would have been too complex and too expensive to rely on Atomic clocks only).

GNSS timing and synchronisation capabilities are increasingly exploited by **strategic sectors**. Overall, there is a general concern around Critical Infrastructure **protection** and **resilience** which should drive the future use of E-GNSS in this domain. A recent study by London Economics states that the UK could lose £1 billion per day if GNSS experienced a major disruption [RD12]. Such a disruption would cause more than just financial woes, as emergency care and everyday essential activities also would be adversely affected.

Note: this document focuses on the user requirements and do not consider the potential relevance of PRS for these applications.

5.2.1.1 TELECOM

User need related to Timing & Synchronisation heavily depends on the application. Overall, in the future, the accu-

racy requirements should not go below 100 ns even if 10ns timing accuracy could help future complex emission profiles or even create new markets not existing today. Moreover, advent of 5G could also lead to an increased level of accuracy.

Moreover, to respond to the increased GNSS spoofing threat, authentication and trustability are the main drivers to foster GNSS adoption in Telecom.

5.2.1.2 ELECTRICITY TRANSMISSION

There is an increased interest in GNSS authentication as well as for an improved robustness against interference (although experience with GPS is good in most cases) [RD30]. Independence and continuity of service would also be increasingly valuable. This is part of a global trend of a continuous security improvement. A current concern in the industry is that there is no real redundancy for the GPS part: TSOs WAMS experts recently concluded that there is need to increase measurements redundancy and signal reliability by using two independent time synchronisation sources [RD27] [RD30]. This becomes more important since electricity infrastructure is increasingly operated with reduced security margins and that Electrical power is transmitted over longer distances, making the system potentially more vulnerable to widespread problems. Moreover, more disparate sources of energy appear (domestic solar or wind turbine) requiring even more synchronisation of the network nodes.

5.2.1.3 FINANCE

GNSS **spoofing** is seen as an increased threat, in particular when high frequency trading is at stake [RD1] [RD2]. However, contrary to Telecom the Finance industry already put in place mitigation measures (e.g. architecture choice) [RD29]. Indeed, GNSS spoofing in an issue for GNSS source not connected with PTP or NTP technologies but network technologies can help identify and mitigate interference from the GNSS source [RD28]. Moreover there is more awareness on the GNSS spoofing threat even though the Finance industry would welcome a resilient GNSS solution.

Traceability is one of the most important requirements as it is now legally required – see section 5.5.2.3 and it is stressed that GPS is not fully traceable to UTC. Another major parameter is **Trustability** that requires three time sources to be available [RD29]. Moreover there is now a legal obligation [RD16] to be **accurate** at 100 μs (up to now the "legal" requirement was 1 s). This level of accuracy can be achieved with NTP but with a lot of difficulties whereas PTP provides easily this level of accuracy. However PTP in its current version has an issue of single point of failure which

can be overcome with some solution (which is therefore not the standard solution). A change of the PTP standard should be envisaged in PTPV3 to make it more robust [RD29].

Finally, even if the requirement for a robust GNSS is met, the Finance industry would always prefer to rely on **multiple time sources** [RD29].

5.2.2 GNSS TECHNOLOGICAL TRENDS

According to [RD2][6] and other GSA analysis[7] main technological trends of the GNSS Timing & Synchronisation equipments are:

- All products are GPS SPS L1; some are GLONASS G1 and Galileo E1 enabled (which is a relatively recent trend in product offer for Galileo). In more details:

  - Every timing product catalogued (100%) supports GPS L1 band, the next commonly supported overall is GLONASS G1 (46%) followed by Beidou B1 (28%) and Galileo E1 (27%).

  - Among European manufacturers, GLONASS G1 is the second most supported band (55%) followed by Beidou B1 (41%), then Galileo E1 (36%).

- Few dual frequency solutions exist (less than 10%). Support for L2 or L5 is expected to grow as chip manufacturers add bands for positioning applications (the timing products should inherit this).

- SBAS support is low (~15%). This historically low level of SBAS support was linked to a lack of requirements from Customers. However if manufacturers develop methods to utilise SBAS signals to improve performance or resilience it is expected to feature more in products in the near future.

- Half of product lines support at least one type of GNSS resilience feature: processing at least 2 GNSS constellations (40%); Anti-Interference (10%), Anti Spoofing (8%) and T-RAIM (7%).

- Most products provide holdover capabilities when no GNSS is available;

- Some products are very modular in terms of interface.

Typical holdover capabilities depend on the oscillator but typical periods are listed in table 1.

As a future technology trend, future receiver should improve their management of mixed multi-constellation solution. In particular T-RAIM should take into account constellation to

---

6   Links to products datasheets are available in [RD2].
7   Analysis made in 2017 on 260+ GNSS Timing solutions from 30 manufacturers.

constellation discrepancies. There is also some expectation that OS-Authentication could also be part of the process to protect against meaconing and spoofing [RD28].

For what concerns the GNSS Time product manufacturers, very few industry changes happened recently. Market entry is very difficult for new comers due to:

- Required R&D investment is very high (complex standards);

- Provider's reliability is a critical parameter for the customers;

- Limited size of the market.

It should be highlighted that time distribution using transfer protocol (e.g. PTP solutions) are on the new adoption raising cycle in financial services, and early adopters in Power Utilities area. The penetration is highly achieving in the telecom backhaul for mobile network with 300k equipment installed in China Mobile Network. The mitigation of technologies one to the other (PTP to GNSS) will secure the critical operations without deployment of many secured GNSS receivers. This could be considered as a threat to the GNSS time equipment business but it is stressed that T&S products manufacturers' portfolios include many solutions for T&S, one being based on GNSS.

5.2.3 OTHER T&S TECHNOLOGIES

R&D on timing and synchronisation has been very active over the past ten years, in particular to provide cheaper and more secure solutions. They have concerned new types of clocks (e.g. Chip Scale Atomic Clock) protocols (White Rabbit, Blink or Roseline) or non GNSS satellites solutions (STL).

A **Chip Scale Atomic Clock** (CSAC) is a small-sized atomic clock which only uses one hundredth of the power of a conventional atomic clock. Development of these clocks started in early 2000 with the US DARPA (Defense Advanced

Research Projects Agency) funding the first R&D activities on the topic. CSAC provides much more accuracy and stability than traditional crystal-based oscillators. First CSACs are now available for around 1 500$ and can be used in complement of GNSS receiver offering anti jamming or spoofing detection. Research on CSAC is still active in many countries (Switzerland, France, Germany, Japan, China, USA or Israel). However, CSAC are not mature yet but might capture some of the Quartz market in three years [RD28].

Another recent trend is the emergence of wide scale network time distribution. In particular, some scientific projects like **White Rabbit** have demonstrated the capability to transmit information with timing accuracy at sub-nanosecond level using Ethernet networks over fibre optics. Experimental demonstration of nanosecond-accuracy has already been performed and currently White Rabbit has been adopted by many data centres for financial applications [RD34].

2019 update

Another relevant initiative is The **RoseLine** project. Launched in June 2014 under a US $4 million grant it aims to develop new clocking technologies, synchronisation protocols, operating system methods, and control and sensing algorithms that will provide device software with visibility into and control over the quality of time information it receives from the underlying hardware. The project highlights the increasing contribution made by GNSS in areas outside positioning. In particular it shows the interest in the 'Internet of Things' area. Security of these devices is of utmost importance [RD7].

The United States Naval Observatory conducted several independent frequency synchronisation experiments in Washington, D.C., using an alternative PNT technology in multiple network configurations (called **Locata's TimeLoc**). The results suggest that sub-nanosecond time transfer using this technology may be possible over wide urban areas, and that it could thus serve as a GPS augmentation or back-up solution over wide areas for critical applications that depend on precise time [RD8].

> **R&D ON TIMING AND SYNCHRONISATION HAS BEEN VERY ACTIVE OVER THE PAST TEN YEARS**

Table 1: Oscillator drift rates and Stratum 1 typical holdover periods

Oscillator	Drift Rate If No GPS Signal	Stratum 1 Holdover Period
TCXO	1 ms for 1st day	5 min.
Premium OCXO (double oven)	10 to 20 µs for 1st day	1.5 hours
Rubidium	1 µs for 1st day	1 days

A concrete implementation of network time distribution is **NPL** *Time* which is offered by the British National Physical Laboratory. The service is offered entirely over fibre and is certified to meet regulatory requirements independently from GNSS. However, provision of this service depends on the coverage of current fibre networks and the access NPL has to these. NPL has already signed agreements to provide NPL Time to both UBS and TMX Atrium [RD22].

Another alternative that is sometimes mentioned is **eLoran** which can provide an interesting back-up to GNSS based solutions. Despite its limitations in terms of service coverage eLoran can provide several benefits complementary to GNSS based solutions: it provides timing synchronous to UTC within 100ns, it can be received indoor and it is resilient against GNSS jamming and spoofing and against space weather events. However, it might not be relevant for cost sensitive users, in particular in the finance industry [RD29]. Moreover, eLORAN seems to not really be overcoming GNSS RF limitation and suffer from single point of failure and low availability rate [RD28].

An additional solution recently came into the market: Satelles Time and Location Service **(STL)**. This service will provide positioning, navigation and timing information through Iridium's satellites at much greater signal strength than GNSS (300-2400 times the power), offering a resilient back-up to GNSS for critical national infrastructure. STL can achieve timing accuracy of 100ns. STL signal is transmitted in L-band (1626MHz) on a frequency near central GPS Coarse Acquisition signal and Galileo E1 Open Service (1575.42MHz), allowing combined GNSS / STL receivers. Device prices and subscription fees to access the service are not yet known but are likely targeting high end applications.

Finally, atomic clocks are used since a while as time keeping solutions. In this area a very futuristic technology would be **quantum clock** which is very prospective at this date [RD29] and is expected to remain expensive.

5.3 GNSS LIMITATIONS FOR TIMING & SYNCHRONISATION

Even if GNSS is massively used for Timing & Synchronisation there are several constraints that limit its further growth:

- Spoofing threats (including residual spoofing threats for GNSS that provide authentication function), and the possible remaining after strategies currently developed by the receiver manufacturers to improve the resilience to spoofing).

- Low resistance against interference

- Availability issue for Indoor/Urban use

- Receiver power consumption

5.4 DRIVERS FOR USER REQUIREMENTS IN TIMING & SYNCHRONISATION

The following table summarises the main drivers in the GNSS Timing & Synchronisation user communities.

Telecom	Electricity transmission	Finance
• Resilience and reliability	• Resilience and reliability	• Resilience and reliability
• GNSS Authentication	• GNSS Continuity of service	• Security
• Improved robustness to interference	• Improved robustness to interference	• Traceability
• High availability	• GNSS Authentication	• High availability
• Accuracy Low(1ms) /medium (1µs) for Timing, Low (1ms) /High (100 ns) for Synchronisation	• Accuracy medium for T&S (1µs)	• GNSS Authentication
• Increasing demand for calibration of hardware equipment delays	• Increasing demand for calibration of hardware equipment delays	• Low (1ms) /Medium (10 µs) Accuracy for T&S
		• Increasing demand for calibration of hardware equipment delays

2019 update

5.5 POLICY AND REGULATORY FRAMEWORK

5.5.1 POLICY AND REGULATORY STAKEHOLDERS

In Telecom, the **Body of European Regulators of Electronic Communications** (BEREC) is the regulating agency of the telecommunication market in the European Union. Beside, each Member State has set up its own **National Regulatory Authorities** (NRA) in charge of regulating telecommunications. However, neither BEREC nor the NRA is directly involved in the definition of the Timing & Synchronisation architecture. Finally, spectrum regulation agencies (**ITU-R** world agreement, national agencies for enforcement) and telecom network regulation agencies (CCITT/ITU-T, national agencies for enforcement) are also involved in particular through their participation in Standardisation forums [RD28].

In electricity transmission **ENTSO-E** is a key stakeholder in the electricity transmission landscape. Security is one its main missions by pursuing coordinated, reliable and secure operations of the electricity transmission network. In particular ENTSO-E Sub-Group System Protection & Dynamics currently tackles the common protection concept [RD27]. Of course each **national TSO** has to follow its **national regulation**. For instance in France, the "energy code" ("Code de l'énergie") is the official French legal code bringing together various provisions relating to energy law. Another important organization should be mentioned: The **European Agency for the Cooperation of Energy Regulators** (ACER) which is an Agency of the European Union by the Third Energy Package established in 2010. Among others, ACER complements and coordinates the work of national regulatory authorities.

In Finance, the **European Securities and Markets Authority** (ESMA) and the **European Commission** are the main regulatory and policy stakeholders in Europe (see section 5.5.2.3).

Moreover the **European Commission** plays an increasingly important transversal role with respect to Critical Infrastructure protection (as explained in the following section).

5.5.2 REGULATIONS TOWARDS GNSS USER REQUIREMENTS

5.5.2.1 EC DIRECTIVE ON CRITICAL INFRASTRUCTURE PROTECTION

The European Commission issued in December 2008 the **2008/114/EC Directive** on the "identification and designation of European critical infrastructures and the assessment of the need to improve their protection" [RD23]. The 2008/114/EC Directive distinguishes the "critical infrastructure" from "European critical infrastructure". Indeed the Directive mentions that "*There are a certain number of critical infrastructures in the Community, the disruption or destruction*

of which would have significant cross-border impacts […]. The evaluation of security requirements for such infrastructures should be done under a common minimum approach."

Interestingly, the Directive does not explicitly refer to the Finance and Communication domains when Energy and Transport are mentioned (contrary to US initiatives): *"The sectors to be used for the purposes of implementing this Directive shall be the energy and transport sectors."* However, the Directive mentions that *"if deemed appropriate, subsequent sectors to be used for the purpose of implementing the Directive may be identified. Priority shall be given to the ICT sector".*

5.5.2.2 CURRENT US ACTIVITIES ON CI GPS DEPENDENCIES

In the US, the **National Protection and Programs Directorate**, Office of Infrastructure Protection (IP) of the Department of Homeland Security leads and coordinates national programs and policies on critical infrastructure issues. The Presidential Policy Directive PPD-21 "Critical Infrastructure Security and Resilience" identifies 16 critical infrastructure sectors, among which Energy, Financial Services, Information Technology, Transportation Systems, Water and Wastewater Systems. Noting that these sectors increasingly rely on GPS, United States **Government Accountability Office** (GAO) was asked to analyse the effects of GPS disruptions on the US critical infrastructure. The results of this analysis are provided in a report dated November 2013 [RD26].

The GAO report analysed the way the National Risk Estimate (NRE) of civilian GPS risks was performed by the Department of Homeland Security (DHS) and made several comments on the methodology used for the risk assessment. These results will not be thoroughly discussed here, but it shows that US are particularly concerned by the use of GPS in Critical Infrastructure. The report states that DOT and DHS are required to develop backup capabilities to mitigate GPS disruptions but have made limited progress (one ongoing action is researching possibilities for a nationwide timing backup – launched in 2012). It finally concludes that *"Federal agencies and experts have reported that the inability to mitigate GPS disruptions could result in billions of dollars of economic loss. Critical infrastructure sectors have employed various strategies to mitigate GPS disruptions, but both the NRE and stakeholders we interviewed raised concerns that since sector risks are underestimated, growing, and interdependent, it is unclear whether such efforts are sufficient"* and that *"GPS experts have raised a number of concerns about the sectors' ability to sustain operations during GPS disruptions".*

Moreover, Resilient Systems Division within Science & Technology Directorate of the Homeland Security Advanced Research Projects Agency is studying in detail the potential impacts of GPS disruptions to the nation's energy distribution and communications networks (See [RD25] for additional information).

5.5.2.3 MIFID II - RTS25

On 20 October 2011, the European Commission adopted formal proposals for a *"Directive on markets in financial instruments repealing Directive 2004/39/EC of the European Parliament and of the Council"* (MiFID II Directive), and for a *"Regulation on markets in financial instruments"* (MiFIR). The MiFID 2 was originally due to take effect from 3 January 2017. **2019 update** This date was postponed to 3rd January 2018.

The European Securities and Markets Authority (ESMA) received a mandate from the European Commission on 23 April 2014 to provide technical advice to assist the Commission on the possible content of the delegated acts required by several provisions of MiFID II and MiFIR.

2019 update ESMA has published a set of Regulatory Technical Standards (RTS) – including one on the level of accuracy of the business clock that has been endorsed by the European Commission as a delegated act applying from 3 January 2018 [RD33]. Proof of compliance to RTS25 is by documentation only [RD29].

There has been a real concern of finance stakeholders to cope with the regulation. Timing architectures have been revisited to mandate the certification of compliance. For HFT it was much more conservative than the best practice, but for common data traceability the accuracy should be improved to fit the confidence level necessary to protect operator against regulation authority claim [RD28]. The underlying requirement of 100% availability has been a design driver for the T&S network architecture [RD29].

The following table is extracted from [RD33] and specifies the level of accuracy required for a business clock depending on the trading activity. The most stringent application is related to high speed trading with a maximum of 100 µs accuracy from UTC and a granularity of the timestamp of 1 µs. The requirement for GNSS is therefore between 100ns and 200ns depending on the IT system architecture (the network itself and data processing are wider contribution to the error budget).

ONE OF THE REGULATORY TECHNICAL STANDARDS IS ABOUT THE LEVEL OF ACCURACY OF BUSINESS CLOCKS

Table 2: Level of accuracy for members of participants of a trading venue [RD33]

Type of trading activity	Description	Maximum divergence from UTC	Granularity of the timestamp
Activity using high frequency algorithmic trading technique	High frequency algorithmic trading technique.	100 µs	1 µs or better
Activity on voice trading systems	Voice trading systems as defined in Article 5(5) of [Commission delegated regulation providing regulatory technical standards for bonds and other non-equity instruments (RTS2)]	1 second	1 second or better
Activity on request for quote systems where the response requires human intervention or where the system does not allow algorithmic trading	Request for quotes systems as defined in Article 5(4) of [Commission delegated regulation providing regulatory technical standards for bonds and other non-equity instruments (RTS2)	1 second	1 second or better
Activity of concluding negotiated transactions	Negotiated transaction as defined under Article 4(1)(b) of Regulation (EU) 600/2014	1 second	1 second or better
Any other trading activity	All other trading activity not covered by this table.	1 millisecond	1 millisecond or better

2019 update Moreover, Article 4 of [RD33] states that:

Article 4

Compliance with the maximum divergence requirements

Operators of trading venues and their members or participants shall establish a system of traceability to UTC. They shall be able to demonstrate traceability to UTC by documenting the system design, functioning and specifications. They shall be able to identify the exact point at which a timestamp is applied and demonstrate that the point within the system where the timestamp is applied remains consistent. Reviews of the compliance with this Regulation of the traceability system shall be conducted at least once a year.

From this article, the issue of liability appears particularly important for Finance operators as they have to demonstrate that their system complies with the timing and synchronisation requirements of RTS25.

2019 update There is a need to justify how UTC is generated, which has implications for a financial operator to be able to prove how the time stamp has been created. The question of how to achieve UTC traceability is a key question. Laboratories call for having certified UTC sources from network connectivity. Regarding GNSS, a 3rd party receiver certification for UTC certification (traceability) would be important to reassure regulators (see also below requirements from FINRA Consolidated Audit Trail in the US). Financial operators

2019 update implement different architectures solutions but the use of multiple timing sources (e.g. GNSS, network based and local oscillator) is an option to meet this requirement.

5.5.2.4 CONSOLIDATED AUDIT TRAIL (CAT)

In the US, On November 15, 2016, the Securities and Exchange Commission (SEC) approved the National Market System Plan Governing the Consolidated Audit Trail (Plan). The Plan includes synchronisation and certification requirements with regard to business clocks that capture time in milliseconds. The regulation states that finance operators shall synchronize their Business Clocks at a minimum to within a fifty (50) millisecond tolerance of the time maintained by the atomic clock of the National Institute of Standards and Technology ("NIST"), and maintain such synchronisation. Moreover, it is required that each Industry Member certify that their Business Clocks satisfy the synchronisation requirements. The so called FINRA / CAT was due to be met before March 15th 2017 [RD21].

5.6 CONCLUSIONS

The **Timing** capability offered by satellite navigation systems is **at the core of most vital infrastructures**: Telecom networks operation, energy distribution, financial transactions. GNSS provides a **unique offering** to the Timing and Synchronisation user communities by delivering a free and highly accurate time and synchronisation capability available worldwide. This explains why GNSS has been **rapidly**

adopted by the T&S user communities, in particular for Critical Infrastructure operations.

In the meantime, **cyberattacks** on Critical Infrastructure are an increasing issue. GNSS is obviously subjected to these cybersecurity threats. As such, despite a long experience in GNSS, the T&S community is **facing many challenges** linked to an increased need for reliability and security, supported by an evolution of the regulation. With the advent of **new threats to GNSS** (jamming and spoofing) and the increased importance of protecting critical infrastructure, **resilience** has become mandatory. Moreover, impacts of the recent GPS timing anomaly (January 26th 2016) reinforced the need for **integrity** and **independence** of GNSS Timing. Finally, there has been an increasing demand for calibration of hardware equipment delays for both scientific and industrial applications.

2019 update

The GNSS **vulnerability** topic was thoroughly discussed at the latest three ITSF [8] conferences organised in 2016, 2017 and 2018. **Dependence** on GNSS of the timing and sync communities was highlighted several times. With its Authentication functions and improved performance **EGNSS (European GNSS) could contribute to mitigate cybersecurity threats in critical infrastructure.**

2019 update

The following table summarises the T&S user requirements taking into account all the information presented in the previous sections of this document focusing on the most stringent ones.

WITH THE ADVENT OF NEW THREATS TO GNSS (JAMMING AND SPOOFING) AND THE INCREASED IMPORTANCE OF PROTECTING CRITICAL INFRASTRUCTURE, RESILIENCE HAS BECOME MANDATORY

---

8   An annual event to showcase the latest time and synchronisation solutions, advances and challenges beyond Telecoms to include Finance, Broadcast, Transport, Utilities, IoT and Defence.

	Telecom	Electricity transmission	Finance
Main trends	• PSTN networks mature but rapid growth in mobile cellular networks with investment in 4G • SATCOMs and PMR are minor in comparison • 5G might require even further synchronisation accuracy depending on the technology adopted • LTE Advanced and other technologies offering more bandwidth and additional services require phase synchronisation instead of the traditional frequency synchronisation • Operators and Carriers have to invest into making their networks phase synchronisation ready or deploy more GNSS equipment near the base station (or both, in a balanced approach)	• Infrastructure increasingly operated with reduced security margins • More disparate sources of energy will appear (domestic solar or wind turbine) requiring even more synchronisation of the network nodes • Electrical power transmitted over longer distances, making the system potentially more vulnerable to widespread problems • Modern substations are using Ethernet based communication and require synchronisation over the network instead of installing and operating a separate cable infrastructure for synchronisation	• Banks and Stock Exchanges rely on very powerful IT systems and networks requiring a high level of availability, security and reliability • Highly interworking market with Banks and Stock Exchanges operating worldwide, regulation enforcement shall be harmonized to enable effectiveness
Current GNSS Use	• GNSS derived timing is widely used as either a primary source of timing information or as a redundancy solution • In the SATCOM domain, GNSS derived timing used for TDMA timing on the satellite links and terrestrial links; and NTP type services for IT/network/satellite monitoring/control • Within the PMR and digital cellular domains, GNSS derived timing is used for the synchronisation of timeslots and for handovers between base stations. • Within the PSTN domain, GNSS derived frequency is typically used as a backup in case frequency information from atomic clocks are lost. GNSS derived timing can be used for time of day, traffic timing and time slot management. • Many networks employ local oscillators enabling service to be temporarily maintained in case of loss of GNSS.	• Transmission System Operators are the main GNSS users (Wide Area Monitoring System/Wide Area Control System) • WAMS are using PMUs (Phasor Measurements Units) as a source of T&S information for: Network Monitoring (current use) and Automatic Protection (future use) • Use of WAMS is becoming widespread (smart grids) • Automatic Protection requires a high level of accuracy and redundancy at PMU level • PMU deployed across remote locations of the power network (nodes) - Internal time references currently based on GPS receivers.	• GNSS used for Synchronisation and Time Stamping functions - log events or quotes in a chronologic manner • GNSS receivers are installed in datacentres • Widespread use of transfer protocols like NTP/PTP to distribute time (a Primary Server can be connected to about 1500/2000 NTP clients) • PTP is increasingly considered and provides sub-µs accuracy • GNSS spoofing can lead to a particular issue especially for systems relying on PTP, if the synchronisation solution infrastructure has not been designed in a proper way.

9   Time keeping solutions will always need time transfer to be synhronized/monitored regularly. This time transfer can be GNSS/eLoran/STL/fiber

	Telecom	Electricity transmission	Finance
Main potential future drivers for GNSS	• Resilience and reliability • GNSS Authentication • Improved robustness to interference • Nanosecond accuracy for massive MIMO and COMP mode in 5G • High availability • Accuracy Low(1ms) /medium (1μs) for Timing, Low (1ms) /High (100 ns) for Synchronisation • Calibration of hardware equipment delays	• Resilience and reliability • GNSS Continuity of service • Improved robustness to interference • GNSS Authentication • Accuracy medium for T&S (1μs) and even high (<100ns) for fault location • Calibration of hardware equipment delays	• Resilience and reliability • Security • Traceability • High availability • GNSS Authentication • Low (1ms) /Medium (1 μs) Accuracy for T&S • Calibration of hardware equipment delays
Main stakeholders having a role in the user requirement definition	• Communications network operator • Network equipment provider • Radio spectrum regulator (States & international agreement) • ETSI, ITU-T & ITU-R	• TSOs, ENTSO-E • PMU vendors • IEC, IEEE	• System integrator, financial institutions • ESMA
Competing / complementary technologies	• Time distribution using transfer protocols over IP (e.g. NTP or PTP) • LEO satellite constellation • Atomic clocks (Time keeping) • OCXO and TCXO (Time keeping)9 • Wide scale metrology network Frequency and/or time distribution • eLoran or other radio based time distribution systems currently under development		

2019 update

06 USER REQUIREMENTS SPECIFICATION

6.1 SYNTHESIS OF UR ANALYSIS

The requirements have been gathered according to the groups of applications described in paragraph 5.1. When a requirement is common to one or two groups the same nomenclature reference is used.

6.1.1 REQUIREMENTS FOR TELECOM

Table 3: Requirements for Telecom

Id	Description	Type	Source
GSA-MKD-USR-REQ-TSC-0010	The Timing & Sync system shall provide an accuracy of 100 ns for Satcom applications.	Performance (Accuracy)	[RD1] [RD2] [RD28]
GSA-MKD-USR-REQ-TSC-0020	The Timing & Sync system shall provide frequency accuracies of <10 ppb and phase synchronisation of =1.1 μs, while compensating for delay variation and jitter for LTE (requirement reaches 0.5 μs accuracy for cells extend <800m)	Performance (Accuracy)	[RD1] [RD2] [RD28] [RD31]
GSA-MKD-USR-REQ-TSC-0030	The Timing & Sync system shall provide an accuracy of 1 μs for PSTN	Performance (Accuracy)	[RD1] [RD2] [RD28]
GSA-MKD-USR-REQ-TSC-0040	The Timing & Sync system shall provide an accuracy of 10 μs for PMR	Performance (Accuracy)	[RD1] [RD2] [RD28]

6.1.2 REQUIREMENTS FOR ELECTRICITY TRANSMISSION

Table 4: Requirements for Electricity transmission

Id	Description	Type	Source
GSA-MKD-USR-REQ-TSC-0050	The Timing & Sync system shall provide an accuracy of 1 μs for PMU applications (Time tagging with accuracy better than 1 μs with a magnitude accuracy of 0.1% or better).	Performance (Accuracy)	[RD1] [RD2] [RD16] [RD24] [RD25] [RD26] [RD27]
GSA-MKD-USR-REQ-TSC-0060	The Timing & Sync system shall not only be dependent on GPS	Function (Independence)	[RD1] [RD2] [RD27] [RD31]
GSA-MKD-USR-REQ-TSC-0070	The Timing & Sync system shall provide continuity of service	Performance (Continuity of service)	[RD1] [RD2] [RD27]

6.1.3 REQUIREMENTS FOR FINANCE

Table 5: Requirements for Finance

Id	Description	Type	Source
GSA-MKD-USR-REQ-TSC-0080	The GNSS system shall provide a T&S function with 100ns to 200 ns accuracy for timestamping.	Performance (Accuracy)	RTS25 [RD28] [RD29] [RD31]
GSA-MKD-USR-REQ-TSC-0090	The Timing & Sync system shall be able to demonstrate traceability to UTC	Function (Traceability)	[RD1] [RD2] [RD29] NPL
GSA-MKD-USR-REQ-TSC-0100	The Timing & Sync system shall provide a high level of availability (99.9%)	Performance (Availability)	NPL [RD29]
GSA-MKD-USR-REQ-TSC-0110	The Timing & Sync system shall be secure	Function (Security)	[RD1] [RD2] [RD29] [RD18]
GSA-MKD-USR-REQ-TSC-0120	The Timing & Sync system shall be reliable	Function (reliable)	[RD1] [RD2] [RD29] [RD18]
GSA-MKD-USR-REQ-TSC-0121	The Timing & Sync system shall allow certification to satisfy the synchronisation requirements of 50 ms of UTC as maximum requirement	Function (certification)	[RD21] [RD31]

6.1.4   CROSS SECTOR REQUIREMENTS

Table 6: Cross-sector requirements

Id	Description	Type	Source
GSA-MKD-USR-REQ-TSC-0130	The Timing & Sync system shall be resilient	Function (resilience)	[RD1] [RD2] [RD24] [RD25] [RD26] [RD27]
GSA-MKD-USR-REQ-TSC-0140	The Timing & Sync system shall be able to detect and characterization GNSS interference	Function (interference detection)	[RD1] [RD2]
GSA-MKD-USR-REQ-TSC-0150	The Timing & Sync system shall provide service commitment	Function (service commitment)	[RD1] [RD2]
GSA-MKD-USR-REQ-TSC-0160	The Timing & Sync system shall get access to integrity information with a certain level of confidence	Function (integrity)	[RD1] [RD2] [RD32]
~~GSA-MKD-USR-REQ-TSC-0100~~	~~The Timing & Sync system shall provide robustness against GNSS spoofing threat~~	~~Function (Authentication)~~	~~[RD1] [RD2] [RD24] [RD25] [RD26] [RD27] [RD28]~~
GSA-MKD-USR-REQ-TSC-0110	The Timing & Sync system shall be trustable	Function (Trust)	[RD1] [RD2] [RD24] [RD25] [RD26] [RD28]
GSA-MKD-USR-REQ-TSC-171	The Timing & Sync system shall provide robustness against "Record and replay" GNSS spoofing attacks for PSTN	Function (Authentication)	[RD1] [RD2] [RD24] [RD25] [RD32]
GSA-MKD-USR-REQ-TSC-172	The Timing & Sync system shall provide robustness against "non-synchronised" GNSS spoofing attacks for DCN	Function (Authentication)	[RD1] [RD2] [RD24] [RD25] [RD32]
GSA-MKD-USR-REQ-TSC-173	The Timing & Sync system shall provide robustness against "synchronised" GNSS spoofing attacks for PMR	Function (Authentication)	[RD1] [RD2] [RD24] [RD25] [RD32]
GSA-MKD-USR-REQ-TSC-174	The Timing & Sync system shall provide robustness against "Record and replay" GNSS spoofing attacks for Satcom	Function (Authentication)	[RD1] [RD2] [RD24] [RD25] [RD32]
GSA-MKD-USR-REQ-TSC-175	The Timing & Sync system shall provide robustness against "non-synchronised" GNSS spoofing attacks for Finance applications	Function (Authentication)	[RD1] [RD2] [RD24] [RD25] [RD32]
GSA-MKD-USR-REQ-TSC-176	The Timing & Sync system shall provide robustness against "synchronised" GNSS spoofing attacks for Electricity transmission applications	Function (Authentication)	[RD1] [RD2] [RD24] [RD25] [RD32]
GSA-MKD-USR-REQ-TSC-0180	The Timing & Sync system shall be secure	Function (Trust)	[RD1] [RD2] [RD24] [RD25] [RD26]

2019 update

ANNEX 1 ANALYSIS OF RELEVANT INITIATIVES REGARDING GNSS REQUIREMENTS

The following projects or publications have been identified of relevance and are analysed in this chapter:

- DEMETRA

- Deep dive and SBIR

A1.1 DEMETRA

DEMETRA (DEmonstrator of EGNSS services based on Time Reference Architecture) was a H2020 funded project which started in January 2015 for 24 months. It aimed to define and develop a prototype of a European time disseminator, based on EGNSS. One of the deliverable produced is a "Time Service User Needs Analysis" for which, unfortunately, only a public abstract is available. The document claims to analyze the timing needs of legitimate end-users in the following key market sectors: Agriculture, Energy, Finance, Media, Science, Surveying, Telecommunications and Transport.

The importance of synchronisation is growing along with the movement towards greater precision requirements (agriculture, surveying), expanding networks that need to be monitored and controlled in real-time (energy, media), increased vigilance on rapid financial transactions (finance), bigger data global sets to co-ordinate (science), ever increasing endpoints connected to the internet (telecoms), safety-critical systems (transport, telecoms), etc.

The issue of reliability was identified as particularly important: *"many organizations are not aware how reliant they are on synchronisation and the impact of losing synchronicity to their business operations."* Indeed, it was also found by DEMETRA that apart from the telecommunications sector, there is a general lack of understanding on the importance of synchronisation. On the other hand, there is strong developed voice on the subject of Resilient Positioning Navigation and Timing (RPNT), that is 'promoting' the importance of synchronisation from the point of view that relying solely on GNSS solutions is a mistake that harbors a serious risk to society. It was recognized that end-user needs actually come from a) organizations gearing up for a new future

where everything is connected to everything and big IT Systems and Networks companies lead the way to informing legitimate end-users what they need and b) organizations pre-empting the standards and regulations that are on their way to be implemented and c) organizations that will start to consider risk, when procuring and installing timing equipment looking at resilience as an important factor.

The following performance criteria and features were identified important:

- Accuracy at point of consumption

- Service continuity

- Security

- Verification

- Latency

- Service provision support

A1.2 DEEP DIVE

The US Department of Homeland Security (DHS) was elected to do a "deep dive" into two particular sectors highlighted in the Presidential Policy Directive 21 (PPD 21) on Critical Infrastructure Security and Resilience as "being uniquely critical because of the enabling functions that they provide". The term Deep Dive emanates from a management technique which utilises a combination of approaches to help develop solutions for specific business challenges. Deep Dive is a focused team approach to developing solutions to specific problems or challenges. It is intended to harness the idea-power of everyone on a team in a focused, creative, energetic, fun, and ultimately useful way. A Deep Dive™ is a combination of brainstorming and rapid prototyping melded together into an approach which any change catalyst can use to identify actions to move an issue forward.

Aim of this study awarded to MITRE was to develop a detailed understanding of the current implementation of civil GPS and the level of CI sector reliance within the electricity subsector of the energy sector and the communication sector,

to quantify the associated sector specific vulnerabilities, and to assess potential sector specific and cross-sector threat mitigation technologies and methodologies. Results were presented in 2014 [RD24] [RD25] [RD26].

The study was broken down to the following elements

- Baseline Electrical subsector and Communication sector GPS dependencies

- Determine Threats and Vulnerabilities

- Evaluate detection and mitigation technologies

- Develop Deep-Dive Methodology Framework

The summary of studies of these elements is described below.

A1.2.1 ELECTRICAL SUBSECTOR

The study covered the sector as it exists today and as it is projected to look five years from now when the electric grid is expected to incorporate more synchrophasors which are considered as a key vulnerability and shift to a "smart-grid" approach incorporating more computer-based remote control and automation.

Findings and Recommendations from Baseline study

The most stringent timing requirements found range from one second down to less than one µs. GPS is still the primary reference for wide area synchronisation at the one µs level throughout the grid and there is few if any, timing backups able to last more than a few hours at that level.

Table 7: Quantification of Timing Requirements for Power Grid/Smart Grid domains

Equipment/Function	Power Grid/smart Grid Domains						
	Gen.	Trans.	Dist.	Ops.	Market	Serv. Prov.	Cust.
Transmission Line Fault Location		1 µs					
Synchrophasors/Phasor Measurement Units	< ± 1 – 46 3 µs	< ± 1 – 46 3 µs	< ± 1 – 46 3 µs				
Substation Control/Re-Synchronisation		1 µs – 1 ms	1 µs – 1 ms				
Protective Relays		1 ms	1 ms				
Lightning Strike Measurement		1 ms	1 ms				
Quality of Power Supply Measurement		1 ms				1 ms	1 ms
Control Center/ EMS/SCADA/RTU	1 ms	1 ms	1 ms	1 ms			
Frequency Measurement		1 ms		1 ms			
Internet-based Market Transactions (NTP)				1 ms	1ms		1 ms
Disturbance Monitoring Event Recorders		2 ms	2 ms				
Bulk Metering	0.5 sec	0.5 sec	0.5 sec				
Customer Premise Metering						1 sec	1 sec
Smart Meters/Home Area Network						0.5 sec	0.5 sec
Distributed Energy Resources			< ± 1 – 46 3 µs				< ± 1 – 46 3 µs
SCADA Networks	1 ms	1 ms	1 ms	1 ms			
Synchrophasor Networks	< 26 µs	< 26 µs	<26 µs	< 26 µs			
Most Stringent Timing	**< ± 1 µs**	**< ± 1 µs**	**< ± 1 µs**	**26 µs**	**1 ms**	**1 ms**	**< ± 1 µs**

Threat & Vulnerability Analysis

Analysis took into account the following unintentional and intentional threats:

- Unintentional
  - RF Interference
  - Space Weather
  - Unintentional Jamming[10]
- Intentional
  - Intentional Jamming
  - Spoofing
  - Cyber attack

Equipment/networks most affected were the following:

- Transmission fault location
- Synchrophasor measurement units
- Substation control/re-synchronisation
- Distributed energy resources
- Synchrophasor networks

Impacts vary based on threat. Although the actual impact of a disruption depends on the cause, an attack with multiple low-power jammers could result in the loss of the ability to monitor and control the system.

Spoofing represents a different kind of threat and is considered as the most dangerous threat to the grid. With synchrophasor measurement units as they are today coordinated, spoofing attack could, in theory, bring down part of the grid [RD17].

A1.2.2 COMMUNICATION NETWORK SECTOR

DHS also looked at the communications network as it exists now and, given that its infrastructure is evolving more quickly, how that network is projected to be structured just three years later.

Study focused on the following sub-sectors:

- PSTN (public switched telephone network),
- Cellular Networks,
- Internet backbones.

Findings and Recommendations from Baseline study

Timing requirements ranged from 1.5 µs for cellular networks to 62.5 µs for the PSTN (public switched telephone network) and the Internet.

---

10   RF interference: all the "natural" potential interferer, eg. DAB, UWB that could have harmonic on GNSS frequency.
Unintentional jamming: for instance a person that wrongly (and unintentionally) manipulates an electronic emetter that finally happens to jam GNSS bands. Another example is a person having a personal jammer wanting to "only" jam a tracker in his vehicle and that in fact jam over a wider area.

Irrespective of the timing distribution mechanisms deployed, GPS remains the primary reference source and primary mechanism to achieve synchronisation:

- First net deployment should ensure that the precise timing required by LTE (Long-Term Evolution) and normally derived from GPS can be maintained during incidents.

- Micro-cells will require 1µs timing, unclear how it will be implemented

Loss of the signal would affect equipment ranging from SONET/SDH, SynchE, and clock nodes to mobile and landline switching centers and transceivers for cellular and micro-cell networks.

Threat & Vulnerability Analysis

Same types of threat as for Electricity subsector have been analyzed. Each threat affects the same set of timing dependent equipment but in different ways.

Due to the three clock sources (GPS receiver, local holdover oscillator, and landline), and monitoring by network operators, jamming and spoofing attacks will have limited impact on the PSTN and Internet backbone segments of the Communications Sector.

The cellular network is more vulnerable to jamming and spoofing attacks than the PSTN or Internet backbone. However, jamming and spoofing also have limited impact on the cellular network since these attacks would be directed at the edge of the network (cell towers) where the effects are localized.

A1.2.3 MITRE FINDINGS AND RECOMMENDATIONS FROM MITIGATIONS REPORT

A MITRE Corporation report on how to mitigate the risks to GPS suggested a range of options to mitigate the risks in several domains. For antennas it is recommended to place the antennas where they are less likely to be noticed by adversaries or to experience multipath interference (e.g. unobstructed sky view) and to use high gain directional, multi-band, fixed reception pattern antennas. Multi-GNSS receivers are also recommended but may not improve jamming resistance if same center frequency, spectral shape, received power characteristics. Training is important and equipment problem vs jamming/spoofing awareness shall be increased. Equipment integrating back-up timing such as Precision Time Protocol / or other local network timings or that could extend the holdover time shall be preferred (e.g. Symmetricom SyncServer SGC-1500 or Schweitzer Engineering Laboratories (SEL) Integrated Carrier Optical Network (ICON)). Number of GPS receivers needed shall be reduced by using:

- SONET/SDH with PTP over GigE

- SynchE with PTP

Commercially available stand-alone anti-jamming products providing detection, notification and in some cases suppression/rejection of jamming signals shall also be used (e.g. Hammerhead, J-ALERT, Signal Sentry 1000).

It shall be noted that while standalone anti-jamming products are emerging, commercially available spoofing detection and localization products have not appeared that are designed for private sector use.

Finally MITRE also suggested establishing a nationwide backup for timing signals, either eLoran or a system that would provide position navigation and timing information through the cloud.

INTERDEPENDENCIES BETWEEN CRITICAL INFRASTRUCTURES

The issue of **interdependencies** between critical infrastructures is to be highlighted. The interdependencies between critical infrastructures correspond to all the connections that permit an infrastructure to operate and vice versa. Indeed, some infrastructures can require the input of other resources provided by other networks to function to operate properly. Thus, there are strong interdependencies between networks through the exchanged resources. A failure of an infrastructure or the degradation of a resource can then lead to a cascade of failures – **domino effect** – and harm other entities (and not only the infrastructure in default). Considering the growing interconnection between infrastructures and the use of common resources or similar technologies, this highly complex phenomenon of interdependence is now identified.

ANNEX 2 DEFINITION OF KEY GNSS PERFORMANCE PARAMETERS

This Annex provides a definition of the most commonly used GNSS performance parameters, based on [RD10] and is not specifically focusing on the Timing & Synchronisation community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- System: the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to

- Overall: takes into account the receiver performance and the user's environment (for example if they are subject to shadowing).

Accuracy: the difference between true and computed position (absolute positioning). This is expressed as the value within which a specified proportion of samples would fall if measured. Typical values for accuracy range from tens of metres to centimetres for 95% of samples. Accuracy is typically stated as 2D (horizontal), 3D (horizontal and height) or time.

Continuity: ability to provide the required performance during an operation without interruption once the operation has started. Continuity is usually expressed as the risk of a discontinuity and depends entirely on the timeframe of the application (e.g. an application that requires 10 minutes of uninterrupted service has a different continuity figure than one requiring two hours of uninterrupted service, even if using the same receiver and services). A typical value is 1x10-4 over the course of the procedure where the system is in use.

Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver. This is usually expressed as the probability of a user being exposed to an error larger than alert limits without warning. The way integrity is ensured and assessed, and the means of delivering integrity related information to the user are highly application dependent. For safety-of-life-critical applications such as passenger transportation, the "integrity concept" is generally mature, and integrity can be described by a set of precisely defined and measurable parameters. This is particularly true for civil aviation. For less critical or emerging applications, however, the situation is different, with an acknowledged need of integrity but no unified way of quantifying or satisfying it. Throughout this report, "integrity" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used by other applications and sectors.

Robustness to spoofing and jamming: robustness is a qualitative, rather than quantitative, parameter that depends on the type of attack or interference the receiver is capable of mitigating. It can include authentication information to ensure users that the signal comes from a valid source (enabling sensitive applications).

In this document, characterisation of the robustness against GNSS spoofing is made as follows:

1. Identification of the different **types of attacks** using Humphrey's spoofing threat continuum

2. For each type of attack, assessment of:

- The **cost** of attack

- The **time** to put the attack in place

- The **capacity** needed to implement the attack

- Deduction form the information here above of the possible **profile of attackers**

Low, Medium, High, Very High susceptibility to spoofing are defined as follows:

2019 update

Note: for some users, robustness may have a different meaning, such as the ability of the solution to respond following a severe shadowing event. For the purpose of this document, robustness is defined as the ability of the solution to mitigate interference or spoofing.

	Susceptibility to spoofing	Types of attacks	Cost of attack	Time to put in place	Capacity	Profile of attackers
2019 update	Low	Plug and play	> €10	A few hours	Very little	End users Criminal
	Medium	Record and replay (using SDR)	Several €100s	Weeks	Limited	End users Criminal
	High	Non-synchronised attack (can be done with SDR)	Between €1000 and €100 000s	A few months	Significant	Organised crime
	Very High	Synchronised attack	More than €1000 000	From 6 months to a year	Formidable	Hostile nations

Indoor penetration: ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS, this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

Time To First Fix (TTFF): a measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds. Activation means subtly different things depending on the status of the data the receiver has access to:

- Cold start: the receiver has no knowledge of the current situation and thus has to systematically search for and identify signals before processing them – a process that typically takes 15 minutes.

- Warm start: the receiver has estimates of the current situation – typically taking 45 seconds.

- Hot start: the receiver knows what the current situation is – typically taking 20 seconds.

Latency: the difference between the time the receiver estimates the position and the presentation of the position solution to the end user (i.e. the time taken to process a solution). Latency is usually not considered in positioning, as many applications operate in, effectively, real time. However, it is an important driver in the development of receivers. This is typically accounted for in a receiver, but is a potential problem for integration (fusion) of multiple positioning solutions or for high dynamics mobiles.

Power consumption: the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GPS chips will use more power when scanning to identify signals (cold start) than when computing position. Typical values are in the order of tens of mW (for smartphone chipsets).

ANNEX 3 LIST OF ACRONYMS

ACER	European Agency for the Cooperation of Energy Regulators
CAGR	Compound Annual Growth Rate
CDMA	Code Division Multiple Access
CI	Critical Infrastructure
CSAC	Chip Scale Atomic Clock
CQS	Consolidated Quotation System
DARPA	Defense Advanced Research Projects Agency
DEMETRA	DEmonstrator of EGNSS services based on Time Reference Architecture
DHS	Department of Homeland Security
DOT	Department Of Transport
eLORAN	Enhanced Loran
EMS	Energy Management System
ENTSO-E	European Network of Transmission System Operators for Electricity
ESMA	European Securities and Markets Authority
ETSI	European Telecommunications Standards Institute
FSS	Financial Service Sector
GAO	Government Accountability Office
3GPP	3rd Generation Partnership Project
GLONASS	Global Orbiting Navigation Service System
GM	Grand Master
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS SPS	Global Positioning System Standard Positioning Service
GSA	European GNSS Agency
GSM/EDGE	Global System for Mobile Communications / Enhanced Data Rates
H2020	Horizon 2020
HFT	High Frequency Trading
ICON	Integrated Carrier Optical Network
ICT	Information & Communications Technology
IED	Intelligent Electronic Devices
IEEE	Institute of Electrical and Electronics Engineers
ION	Institute of Navigation
IoT	Internet of Things
IP	Infrastructure Protection
IRIG	Inter-range instrumentation group
IT	Information Technology
ITS	Implementing Technical Standards

2019 update

ITSF	International Timing & Sync Forum
ITU	International Telecommunications Union
LEDs	light-emitting diodes
LTE	Long-Term Evolution
MIFID	Markets in financial instruments Directive
NRE	National Risk Estimate
NTP	Network Time Protocol
P25	Project 25
PMR	Professional Mobile Radio
PMU	Phase Measurements Unit
POTS	Plain Old Telephone Service
PPD	Presidential Policy Directive
PSTN	Public Switched Telephone Network
PTP	Precision Time Protocol
R&D	Research and Development
RPNT	Resilient Positioning Navigation and Timing
RTS	Regulatory Technical Standards
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SDH	Synchronous Digital Hierarchy
SLA	Service Level Agreement
SONET	Synchronous Optical Networking
SSU	Synchronisation Supply Unit
TDD	Time-Division Duplex
TDMA	Time Division Multiple Access
TETRA	TErrestrial Trunked RAdio
TIA	Time International Atomic
TTCM	Turbo Trellis Coded Modulation
T&S	Timing and Synchronisation
TSA	Time Stamping Authority
TSO	Transmission System Operators
UCP	User Consultation Platform
UMTS/HSPA	Universal Mobile Telecommunications System / High Speed Packet Access
UTC	Coordinated Universal Time
WACS	Wide Area Measurements/Control System
WAMS	Wide Area Measurement System
WCDMA	Wideband CDMA

ANNEX 4

A s per EUSPAdocument reference GSA-MKD-TS-UREQ-250285 available here.

ANNEX 5

A s per EUSPA document reference EUSPA-MKD-TS-UREQ-250285 available here.

LINKING SPACE TO USER NEEDS

www.euspa.europa.eu

EU4Space

EU4Space

Space4eu

EU Agency for the Space Programme

EU Agency for the Space Programme