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EGALITE Project: EGNOS and Galileo Timing Service Extension and Consolidation

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Presentation Content

- Context of Timing Services
- Introduction to EGALITE project: context, objective & tasks
- EGALITE Main results & challenges
- Conclusions & Recommendations from EGALITE

Introduction to Timing Services

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Introduction to Timing Services

- Timing capabilities inherent to GNSS Systems.
- Provision of a **timing** service means marking of an event wrt a reference time (usually to UTC).
- Using **Synchronization** techniques, difference between times generated by more than one time source can be estimated.
- EGNOS and Galileo provide capabilities for timing within their offered services.
- Synchronisation between devices at different locations can be established and maintained by using GNSS timing receivers which retrieve the GNSS reference time.

Introduction to Timing Services

- Even if T&S market is small, Timing capabilities have the particularity to be exploited by **Critical Infrastructure** in sectors which are strategic for the functioning of the modern society, such as Telecom, Energy and Finance

- Importance of timing capability offered by EGNSS is thus substantial enough to give it the category of a **proper Service in itself**. That is why the European Commission has already taken steps for the definition of a dedicated Timing Service (both for Galileo and EGNOS).

- Establishing a Timing Service would serve to recognize relevance of its users and to better respond to their needs.

Introduction to Timing Services

- To implement a proper Service implies to put all the necessary elements in place to be able to **meet a certain level of performances** and to ensure that it is maintained over the system lifetime.

- Declaring the **minimum level of performance** means that the users can rely on that minimum level of service to build their applications.

- Designing a proper Service also implies to take into account the **needs of its users** and its evolutions, in order to provide them with appropriate solutions.

- On user needs, interactions with the user community have led to the identification of a need for future GNSS-based timing systems to provide a high level of **resilience**. **Robustness** and **trust** in the provided service is perceived as a higher priority given that the level of achievable accuracy is more than sufficient for the majority of the current timing applications

Introduction to EGALITE project: context, objective & tasks

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Introduction to EGALITE Project

- **EGALITE Objective:** consolidation of Initial Timing Service concept and analysis of additional features to be considered for the complete EGNSS Timing Service Definition, both for Galileo and for EGNOS, in particular:
  - Galileo Integrity for Timing Services
  - EGNOS Integrity for Timing Services
  - High Accuracy for Timing Services
  - Legal Time Traceability Service

- Elaboration of a roadmap for standardization and certification for the defined Timing Services

Introduction to EGALITE Project

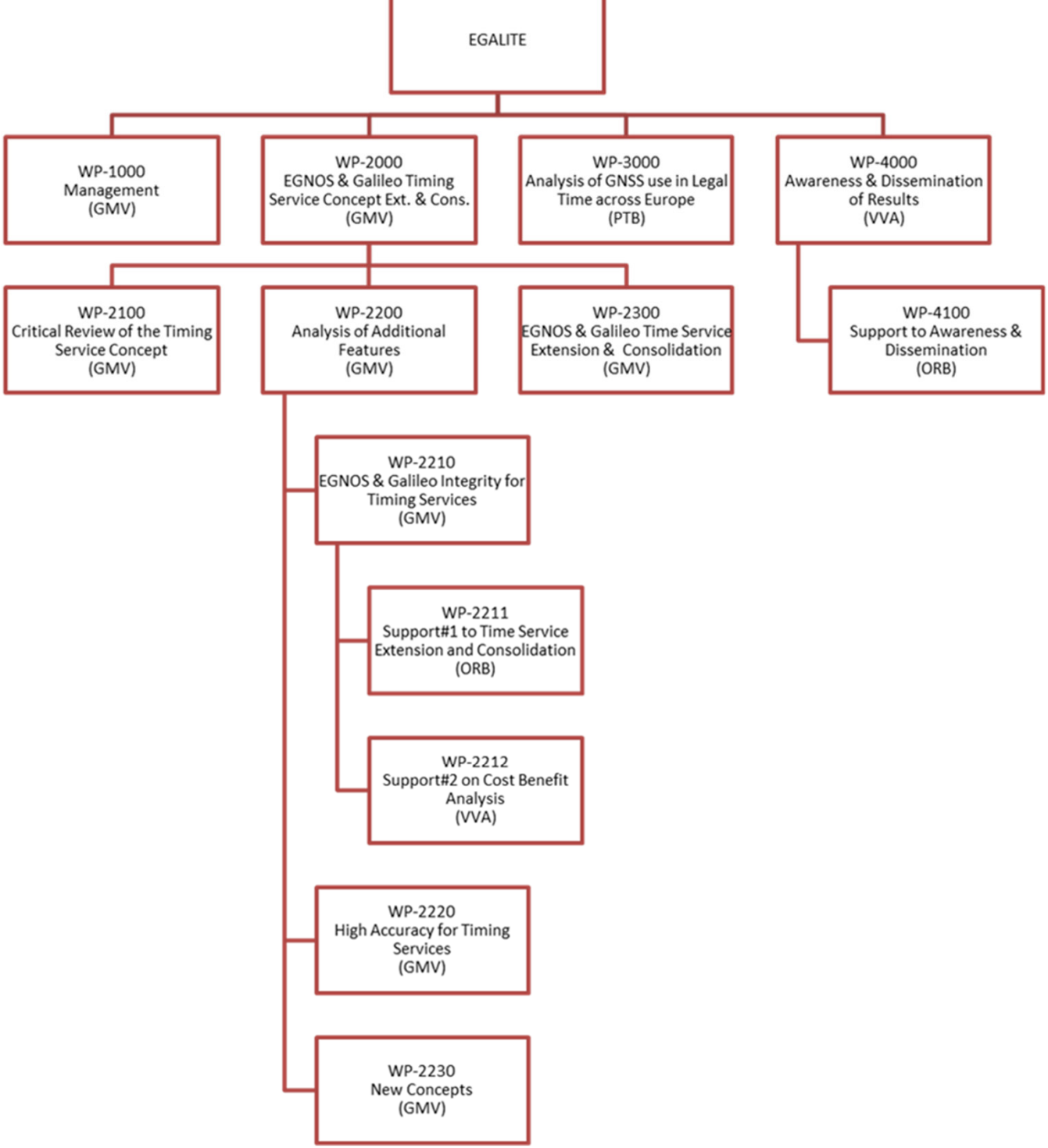
- The project was performed by a team lead by **GMV** (SP), and with **PTB** (DE), **ORB** (BE) and **VVA** (BE), as subcontractors.

- **Project Duration:** 12 months; Startup date: 09/2018

- EC/EUSPA have been supervising the development of the different project activities.

Introduction to EGALITE Project

- **EGALITE Tasks:**



Galileo Integrity for Timing Services

Galileo Integrity for Timing Services

- Identified through consultation to the Timing GNSS Users community the **need** of **integrity** at least for critical infrastructure applications to enhance reliability and robustness of timing solution

- In order to offer a reliable GNSS timing service to the users with end-to-end committed performances, EGALITE has developed a study for adding integrity capability in the Galileo Timing Service Definition:

  - GNSS Timing Safety Analysis

  - Architecture for Galileo Timing Service with integrity capability
    - Timing flags and minimum user equipment characteristics
    - Robustness measures at receiver level, standardisation and certification

GNSS Timing Safety Analysis

- Top safety requirement:
  - Critical infrastructure,
  - Timing applications not SoL -> a failure condition of "major" class has been selected **P < 10-5 failures per hour**.

Failure Condition Class	Quantitative Safety Requirement (failures/h)	Development Assurance level
Catastrophic	$P < 10^{-9}$	A
Hazardous	$P < 10^{-7}$	B
Major	$P < 10^{-5}$	C
Minor	None	D
No safety effect	None	E

Blanquart, J.P. *et al* "Similarities and dissimilarities between safety levels and security levels", Embedded Real Time Software and Systems, ERTS 2012.

- 3 **Service Levels** based on Maximum Tolerable Errors (MTE) for the error on the UTC determined from Galileo SIS:
  - Service Level 1 with MTE = **1000 ns**.
  - Service Level 2 with MTE = **100 ns**.

  } To meet User Needs of most current T&S applications

  - Service Level 3 with MTE = **10-15 ns** -> long-term objective for future T&S applications

GNSS Timing Safety Analysis

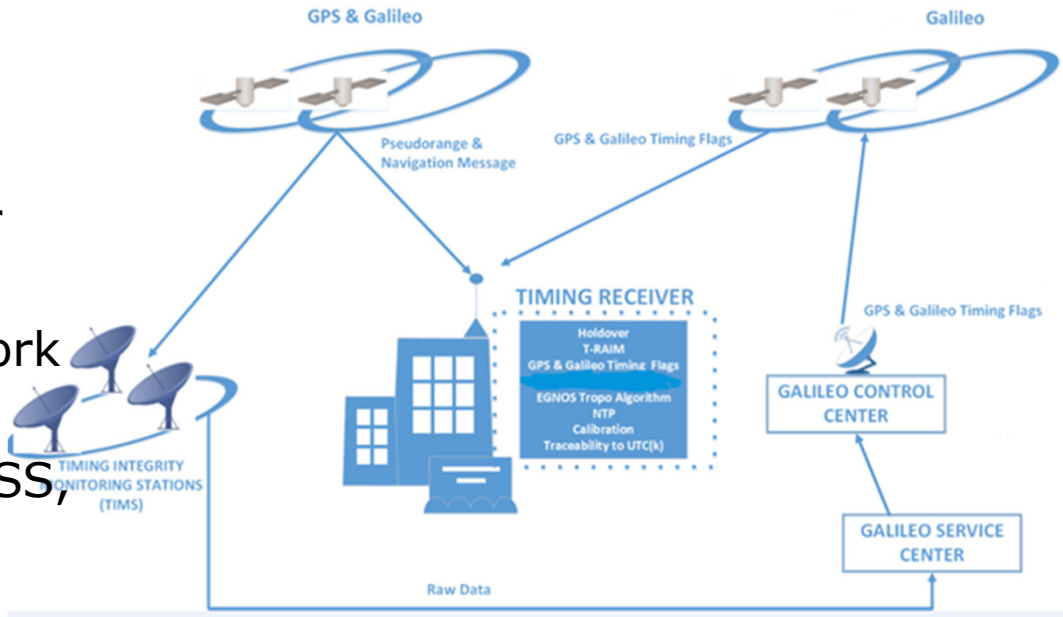
- **GNSS Timing Hazards** identified and characterized in terms of probabilities of failure (focused on safety, not on security)

- **Fault Tree Analysis** performed with and without mitigation barriers. For complying with the Top Safety Requirement:
  - Additional monitoring system needed to mitigate some of the hazards
  - Requested robustness measures at receiver level: T-RAIM, Holdover, certification, etc

- Need of Time Integrity Monitoring Stations also confirmed with dedicated experimentation showing that some of the timing hazards can only be mitigated with an additional monitoring system

Architecture for Galileo TS with Integrity

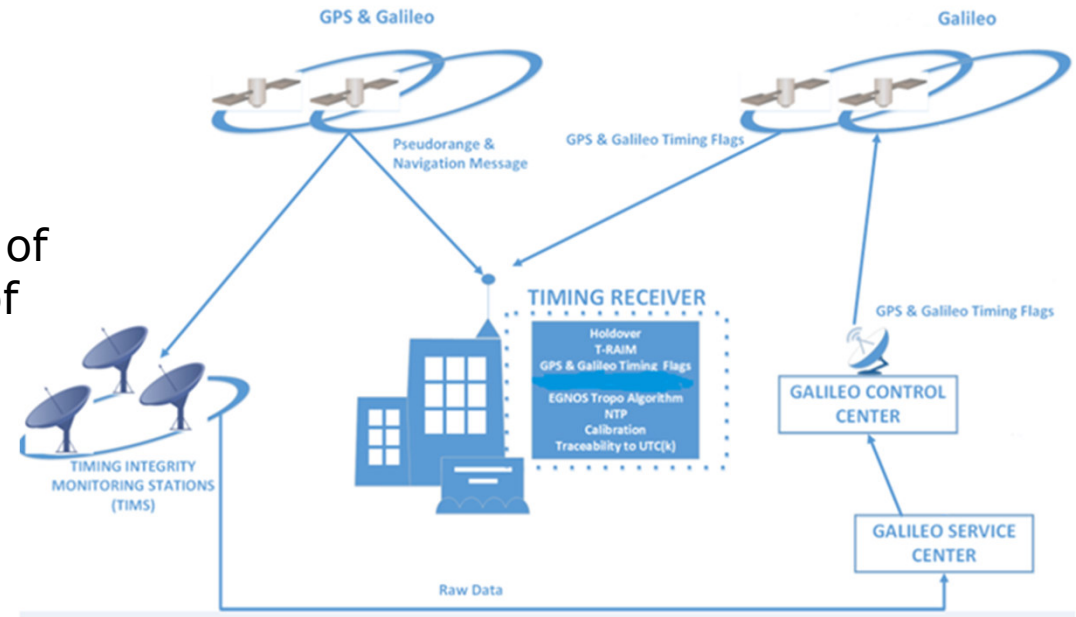
- User receives **GNSS Timing flags** for **Galileo per-satellite from Galileo** Navigation Message
  - Concept could be extended for disseminating flags for GPS
- Timing flags calculated based on network of **TIMS** (TIme Monitoring Stations)
- TIMS: calibrated multi-band, multi-GNSS, time-transfer stations:



  - Ideally, **TIMS** would be collocated **at UTC(k) laboratories**, in order to compare the timing solution from GNSS using UTC(k) as truth
- **Raw data** from TIMS (pseudoranges and navigation messages) streamed in RT to a **processing center**, possibly to be located at the Galileo Service Center (**GSC**) to generate Galileo timing augmentation flags.
- Calculated **flags** forwarded to **Galileo control centers** for uplink to the SVs
  - GSC acts as gateway for the Galileo Control Center;
- Analyses concluded that monitoring can be done through GSS properly calibrated, through additional TIMS, or both. Similar number of stations and locations to the GSS network would ensure global coverage and sufficient redundancy

Architecture for Galileo TS with Integrity

- Rx processes standard Galileo signals + augmentation flags
- **(PV)T algorithm** based on combination of classical **T-RAIM** after the **processing** of the **new integrity flags**



- Additional user algorithms :
  - DF processing for SL3 (10ns) users
  - Iono models for SF users
  - EGNOS tropospheric algorithm (MOPS) also recommended

Timing Flags and User Equipment Characteristics

- Use/Don't Use flags for timing users, for each Galileo SVs for each Service Level
  - Concept can be extended for multi-constellation users by disseminating flags for other GNSS satellites

Name	Length	Range		Unit	Description
		Min	Max		
For each of 24 Galileo satellites					
Timing Flag per SV	2	0	3	-	(0 0): Don't Use the satellite for timing for Service Level 3, 2 and 1 (1 0): Don't Use the satellite for timing for Service Level 2 and 1 (0 1): Don't Use the satellite for timing for Service Level 1 (1 1): Use the satellite for timing for any Service Level

- TTA: timing applications unattended and non SoL
  - Order of minutes (to be confirmed by T&S users community)

Requested Robustness Measures at Rx level

On top of the processing of Timing Flags, requested robustness measures at Rx level:

- **Calibration** at least for SL2 (100ns) and SL3 (10ns: periodic re-calibration)
- **T-RAIM**
- EGNOS Iono Algorithm for SL2 (100ns) in free position for SF users
- Tropospheric Algorithm (MOPS DO-229 Tropo model) for Galileo Timing Receivers
- Local Oscillator **Holdover**
- **Interference detection** capabilities (AGC and T-RAIM for jamming and spoofing detection and recovery switching to holdover mode)

Requested Robustness Measures at Rx level

- **Standardisation** & **Certification**:

  - In order the users could benefit from the committed **end-to-end performances**, the use of the service would imply the **certification** of Galileo Timing Service equipment.

  - Certification process to be defined based on a **standard** for the Galileo Timing Service User Equipment to be developed

  - Given the criticality of Timing Applications, it could be recommended the certification of the Hardware and the full SW processing + calibration of the TS Rx.

  - Certification approach could depend on the Service Level (Aviation-like for SL3 10ns or Performance Based Approach for others)

  - If FTA is evaluated including TRAIM and system-level monitoring, with current GSS calibrated (no additional stations/UTC connections) and performance-based certification, a Fault probability of 1.122 10-5 is obtained for GST product, while for UTC product in the order of 10-4.

Cost Benefit Analysis for the Galileo Timing Service Integrity Capability

Cost Benefit Analysis

- **Cost Benefit Analysis** performed for the Galileo Timing Service with integrity capability
  - Estimation of **investment** by EU
  - Estimation of **delta cost** of User Equipment (certification, etc)
  - Identification and estimation of **benefits** for the users
    - Compare scenario EGALITE Galileo Timing Service vs current Galileo Time Determination capability
      - Based on the inherent probabilities of failure computed in the Fault Tree Analysis and on the Top Safety Requirements for the Galileo Timing Service with integrity capability
- CBA aligned to the proposed technical concept

- **Positive** CBA results obtained for **all critical Timing applications:** of the order of hundreds of million Euros in the 2020-2035 timeframe

EGNOS Integrity for Timing Services

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EGNOS Timing Service

- Definition of EGNOS Timing Service conducted in EGALITE Project

- Two options:
  - Similar definition as Galileo Timing Service: EGNOS as an additional dissemination means of timing flags, similar architecture, similar robustness measures, not relying on ENT, not applying EGNOS corrections
  - Based on ENT and applying EGNOS corrections. Still the foundations of EGNOS Timing Service similar to Galileo Timing Service

Additional Service: Legal Time Traceability

Legal Time Traceability

- Several Timing applications could have the need to prove **traceability** to a national UTC(k) realization such as financial markets, electrical power grid, or applications with a need to generate logs/records and to provide time stamping evidences

- Traceability could be useful in the following cases:
  - To evaluate the actual error in timing solution (1PPS)
  - To link user timing solution to legal UTC(k) scale of his country

- EGALITE: possibility to develop **Legal Time Traceability Service** explored since users in EU commonly have to compute traceability to UTC with their own means
- No traceability services already available in EU and only a few outside EU.
  - NIST (National Institute of Standards and Technology) in US has similar service based on GPS

Legal Time Traceability

- EGNSS Legal Time Traceability Service:
  - Based on the well-established **Common View Time Transfer Technique**,
  - Generate **traceability evidences** in **post-processing** or **nearly real-time**

- Traceability to a UTC(k) time scale can be achieved a-posteriori by means of CV time transfer between receiver and UTC(k) laboratory, provided Rx can record GNSS raw data

- Based on **CGGTTS** files: common standard for CV Time Transfer

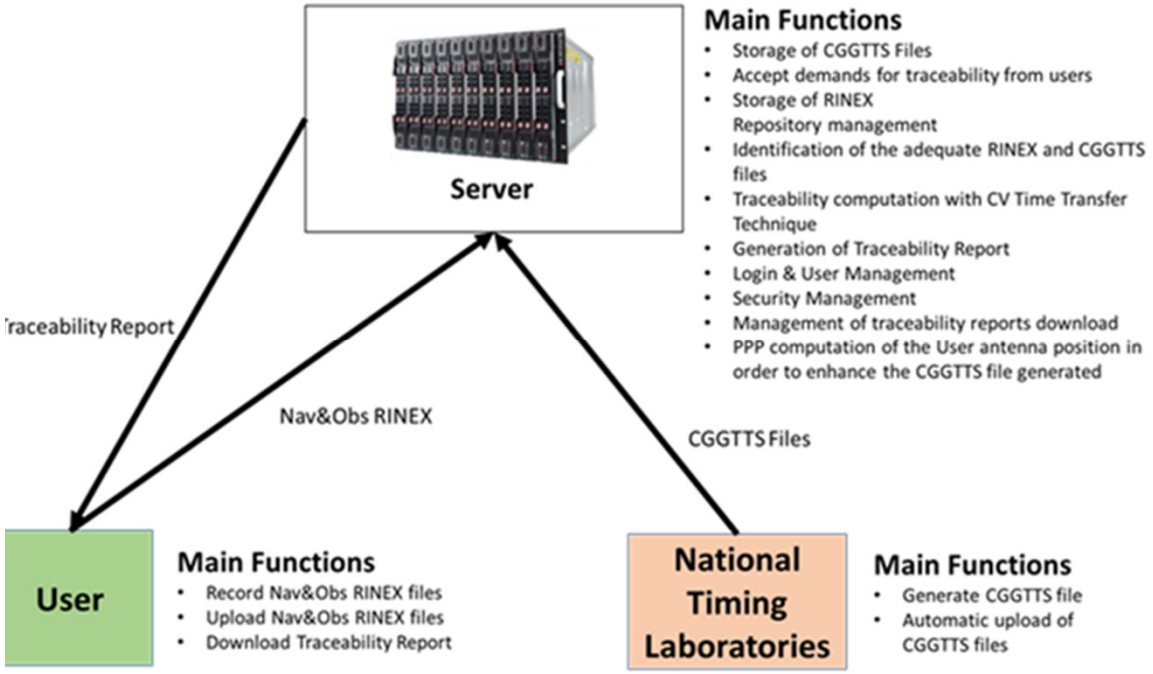
- On UTC(k) laboratory side, CGGTTS file provides difference between UTC(k) time scale and estimated GNSST from each SV in view

- Current CBA results **negative** but service could become useful in the future based on the evolutions of legislation

Legal Time Traceability

Architecture: European centralized Server in charge of computing traceability based on:

- CGGTTS files provided periodically by NMIs in EU in an automatic way
- GNSS raw data (RINEX format) provided by users
- Traceability reports would be disseminated to users and stored in Server.



- Service foresees both Galileo and other GNSS users with low cost timing receivers with either DF or SF equipment
- Service would be provided **free of charge** to users and would implement a set of **security** and **anti-tampering** measures in order to provide a secure and reliable service.

High-Accuracy for Timing Services

High Accuracy for Timing Services

- **Advantages**: accuracy improvement?
  - **PPP** technology could in principle provide **sub-ns accuracy** but **calibration at the same level would be needed**. Current calibration methods are based on code instead of phase -> currently, calibration not possible at sub-ns level
  - No applications identified with accuracy needs better than 30-100ns
  - Galileo timing determination capability can be already considered HA

- **Disadvantages:**
  - Increased **cost** and **complexity** of user equipment especially for PPP
  - **Backward compatibility** with current timing Rx not maintained
    - ✓ Need of Galileo **E6 antenna**: replacement of User Equipment
    - ✓ Major changes in Timing Rx design for PPP. Reluctance from manufacturers since market is not demanding such accuracies
  - Operational impact: PPP **convergence time**

Not recommend including HA techniques in Extended and Consolidated Timing Service

Conclusions & Recommendations

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Conclusions

- **EGALITE** project funded by EC under H2020 framework program has studied the possibility to define a dedicated **Timing Service** based on **Galileo** and **EGNOS:**
  - Galileo Integrity for Timing Services
  - EGNOS Integrity for Timing Services
  - High Accuracy for Timing Services
  - Legal Time Traceability Service
- TS would provide **end-to-end committed performances** to T&S community
- Concept includes processing on user receiver following Standardization

- For each of new service features all aspects starting from the definition of the service, the mission requirements, an initial architecture, a concept of operations, the expected performances, the receiver processing and the standardization & certification were addressed.
- Furthermore, a roadmap for the standardisation and certification of the Timing Services have been developed identifying the needed activities and other attributes such as the duration and sequentiation

Conclusions

- **Integrity** capability has been proposed for the Timing Service.
  - Based on a Safety Analysis on GNSS Timing,
  - An architecture has been proposed based on **Timing Integrity Monitoring Stations** measurements processed by a Timing Service Processing Facility which would disseminate **timing flags** to the users in the Galileo Signal-In-Space
  - Additional measures at receiver level are proposed such as **T-RAIM**, **Holdover**, and calibration, etc.
  - **Positive CBA results** obtained for all critical Timing applications: of the order of hundreds of million Euros in the 2020-2035 timeframe

- **Legal Time Traceability Service** has been proposed to offer to EU users needing to demonstrate traceability to a UTC(k) time scale, a nearly real-time traceability service with robustness and security features
  - A high-level architecture for such a service has been proposed
  - Current CBA results negative but service could become useful in the future based on the evolutions of legislation

Conclusions

- **High Accuracy for Timing Services discarded** as current calibration techniques do not allow to reach calibration at sub-ns level, the market is not demanding this level of accuracy and due to the induced cost and complexity at user level

- **Dissemination:** Study results were presented at two ION-GNSS conferences and at the Workshop of Synchronisation and Timing System (WSTS), demonstrating a good external visibility and good feedback was received.

Recommendations from EGALITE

- It is recommended to launch an activity for developing and testing an end-to-end **Demonstrator** of the EGALITE **Timing Service Integrity concept**. This demonstrator would pave the way of the development of an operational system for the EGNSS Timing Service and would be useful to test different aspects related to the definition of the service

- It is recommended to launch an activity for developing and testing a **Demonstrator** of the **Legal Traceability Service** which could be used as a pre-operational system to be updated in the future towards an operational system

- It was recommended that the European Commission launches a Standardisation process for EGNSS Timing Receivers
  - ITT on the Standardisation of Galileo Timing Receiver recently issued

Thank you

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