Independent validation of Galileo global and regional integrity performance using GalTeC

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BIOGRAPHY

Walter Ehret

graduated as an Aeronautical and Space Engineer from the Technical University (TU) of Braunschweig, Germany in 1996. Since 1996 he is involved in research and engineering activities related with Satellite Navigation. He is currently working as Systems Engineer at THALES ATM in Stuttgart where he is involved in Galileo related tasks and particularly Integrity related issues.

Dr. Hua Su

is the GNSS Systems Engineer at Thales ATM, Germany. He holds BSc and MSc from a Chinese technical university and Dr. –Ing. from the University FAF Munich, Germany. He has worked on GPS precise orbit determination, differential GPS, satellite navigation and GPS receiver software development for more than 20 years. From 1996 to 2000, he worked as Research Associate at the Institute of Geodesy and Navigation (IfEN) of the University FAF Munich for EGNOS and Galileo projects. After joining Thales ATM, he has been involved in EGNOS System AIV project (Assemble, Integration and Validation) charging EGNOS system performance analysis and tests for 4 years. From May 2005 he works for Galileo projects regarding Galileo integrity analysis and data processing.

Oswald Glaser

is currently working as Senior Systems Engineer at Thales ATM in Stuttgart and holds a diploma degree in electrical engineering of the Technical University of Graz in Austria of 1982. Since 1985 he is working in the aeronautical industry, mainly in projects that are closely related to satellite navigation. Starting with the combination of satellite navigation with inertial navigation, later on he worked on the application of GNSS in Airport Surface Movement and Control. The last years he focused on the application of the future Galileo system for Ground Based Augmentation Systems in aeronautics.

Dr. Helmut Blomenhofer

After finishing University he was Research Associate at the Institute of Geodesy and Navigation (IfEN) of the University FAF Munich from 1990 to 1995 and did research and software development in high-precision kinematic Differential-GPS.

From March 1995 to December 1997 he was at Daimler-Chrysler Aerospace AG (Dasa); NFS Navigations- und Flugfuehrungs-Systeme being responsible for the development of an Integrated Navigation and Landing System (INLS) for aircraft precision approaches and automatic landings. From January 1998 to 2001 he was the EGNOS Programme Manager at the EADS subsidiary Astrium GmbH located at Friedrichshafen.

Since 2002 he is GNSS Business Development Director at Thales ATM, Germany.

Eduarda Blomenhofer

is Managing Director of NavPos Systems GmbH, a German SME which specialised in the satellite navigation related systems engineering, software development and consultancy. She owns an Engineer Degree in Surveying/Geodesy from the Porto University, Portugal. She is working in satellite navigation since 1990, with activities on high precision differential GPS algorithms and software for real time applications, data processing and service volume simulation for GPS, Glonass, GBAS, SBAS and Galileo.

SYNOPSIS

With the Galileo development programme now well on its way, the technical performances and merits driving the downstream business opportunities have been given considerable attention by the Galileo Concessionaire. The establishment of facilities to analyse, validate and survey operational availability of services and their underlying technical performances are essential to guarantee Galileo objectives. One of such facilities is the [Gal]ileo [Te]chnology [C]enter GalTeC, representing one of the first Galileo Service Center prototypes, currently under development in joint cooperation by Thales ATM GmbH and NavPos Systems GmbH, supported by the DLR. This paper describes the GalTeC project.

Currently the first of two experimental Galileo satellites - Giove A has been placed in orbit and transmits successfully Galileo like signals for institutional and experimental analyses. Later in 2006 the second experimental Galileo satellite - Giove B will be launched. Finally in 2008 with the In-Orbit-Validation phase, the Signal and Service evaluation programmes will start using signals of four Galileo satellites. The evaluation will take place at systems level as well as externally by independent assessment. GalTeC will be such an independent GNSS data processing and system performance validation facility. As such it features four main branches, the precise Reference Orbit Determination Service, the Service Level Prediction and the Data Analysis Service complemented later on by a Network of Regional/User Ground Stations.

The Galileo services validation will be performed in the following two domains. First - in the Signal in Space (SIS) domain, i.e. precise Galileo satellite orbits and related reference parameters such as reference signal in space error SISRE and reference signal in space accuracy SISRA will be determined. These reference parameters will be compared with the original broadcast SISA and SISMA from Galileo SIS. Performance Indicators will be generated in order to show the historical system performance.

Second - in the user domain, the global and regional Horizontal and Vertical Protection Levels will be computed based on the reference SISRE and SISRA, the broadcast SISA/SISMA and the global and regional ground station network. Statistical analysis will be performed on these results to show the Galileo integrity performance in the user domain.

The paper first describes in detail the objectives of the GalTeC project. Then an overview of the development status is given together with an outlook for possible types of services which could be provided to users and service providers. Additionally, some results of validation of Galileo integrity performance will be presented, using service prediction data including some scenarios as well as using real GPS measurements. As an outlook, GalTeC not only focuses on suitable validations of Galileo system performances but examines options to enhance the Galileo integrity performance in regional and local areas.

INTRODUCTION

Today Satellite based navigation services play an increasingly important role in modern society. The provision of the navigation, positioning and timing service provided by GPS is widely used. However, the system is under military control, and consequently legal guarantees of operation required by modern business can not be given. On the other hand the market for GNSS related products is recognised as an important economic factor and service guarantees and liabilities will be needed.

Accordingly, the European Commission (EC) and ESA in parallel launched initiatives towards an independent European Galileo satellite constellation and associated augmentations and systems including the integration of the EGNOS service. The Galileo service will comprise state-of-the-art global positioning and timing service, independent integrity service, Search and Rescue (SAR) as well as commercial services that are still under study. With the architecture defined so far, Galileo will be interoperable with other services and service guarantees can be offered. Local operators may add a number of Local Services, such as local differential correction signals or availability augmentations.

The quality of the signals is monitored by the ground segment and corresponding integrity messages are broadcasted via the Galileo satellites for safety-of-life applications. Orbit ephemeris and clock synchronisation are calculated from measurements made by a world-wide network of stations. The space segment consists of a constellation of 30 satellites (27 + 3 in-orbit spares) distributed over 3 orbital planes in MEO altitudes. As the outcome of the In-Orbit-Validation Phase, there will be 4 Satellites and the associated ground segment to provide initial operations from 2008 onward. The Galileo Full Operational Capability is expected to be achieved 2 years later [1].

Based on the Galileo Services there will arise various downstream applications and value added services on global, regional and local levels. It is expected that along with these services there will also arise the need to get Galileo service performance information and analysis. In the Galileo project it is planned to give to independent regional Galileo Service Centres access to the Galileo Ground Mission (via the Service Provision Facility - SPF) as e.g. pointed out in [2].

Thales has started an initiative, supported by the German Aerospace Centre (DLR) to develop a suitable tool to satisfy these needs and to support the introduction of Galileo world wide. This development is called GalTeC - Galileo Technology Centre and will be one of the downstream Galileo Service Centres.

GALTEC MISSION

The basic scope of GalTeC is to provide services related with the provision of Galileo Satellite-Only services through the Galileo Operating Company (GOC). However it will also provide services linked to the other GNSS systems - GPS, GLONASS as well as EGNOS.

The services will comprise on the one hand, recent and past GNSS function and performance monitoring and on the other hand prediction capability about the near future situation in GNSS services. Today there are already several such services offered for GPS from different sources, be it Almanac provision, Bulletins, NANU, Visibility etc. The GalTeC philosophy is understood as a single source for such bundled GNSS information provision but with main focus on Galileo.

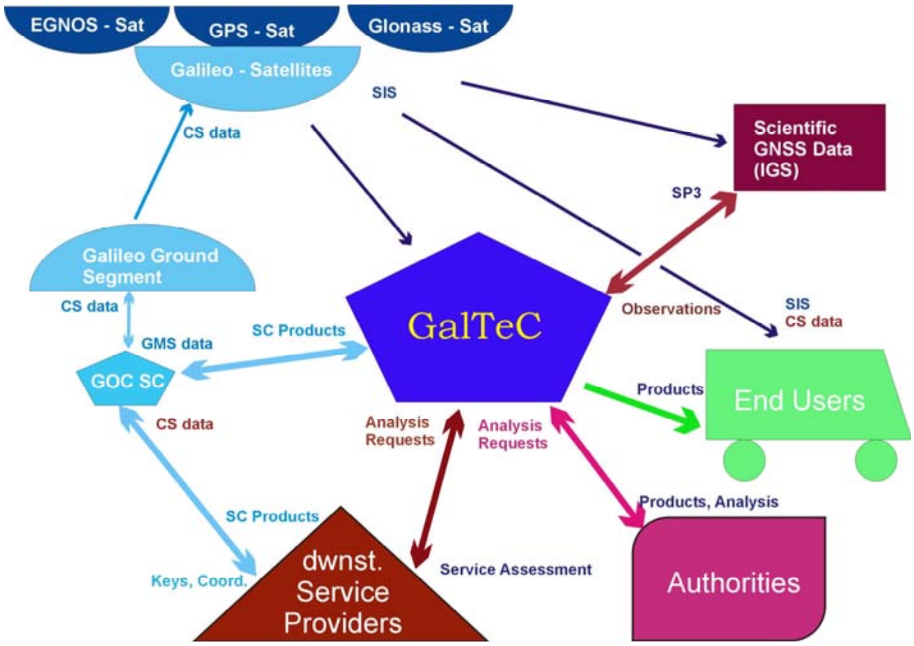

Figure 1: GalTeC Context

Such the GalTeC can be found between the GNSS Systems and mainly Galileo System and the End User on the other hand and between Galileo System and downstream Commercial Service provider on the other hand. The latter can also be SAR service providers and also Galileo Regional Integrity providers. The SAR service providers must assess the visibility of Galileo satellites to the users-in-distress as well as to ULS and MEOLUT and the resulting assessment of service availability and capability. Regional Integrity providers need also to assess which Galileo satellites over the Region can transmit the data with which elevations for which time frame etc.

GalTeC is a very flexible environment and there will be several types of operations possible, but all are more or less non-automatic in the current development scope:

<u>Routine:</u>

1. One or more GalTeC operator(s) will collect (download, order, etc.) routinely GNSS raw and computed data from sources like IGS for selected Stations and place them in a dedicated structure on the GalTeC data base.
2. Internal and external users with proper access rights can download this data directly
3. Based on this raw data, the GalTeC will generate its own precise Orbit and Clock data as reference for the comparison.
4. Routine analysis is performed delivering, satellite status, information broadcast (e.g. SISA/IF, URA, Ephemeris, SBAS data, making then some statistical analysis and graphical presentation.
5. A comparison between reference and broadcast data + applied user algorithms (xPL, integrity Risk, PVT) will be made and graphically represented (Accuracy, Integrity, Continuity...). In the Galileo IOV phase especially a view on Key Performance Items is drawn.
6. Simulations will be performed to extrapolate results to a service area in post analysis and predictions for the near future.
7. All results will be compiled in a summary report files which then are again placed in the user accessible data base

8. users externally and Internally can download the routine products in different time intervals

Individual GNSS Performance Analysis:

1. Users (internal or external) can request by e-mail or comparable means a dedicated analysis for a dedicated time slot and dedicated area or single position. This might for example help clarifying any experienced GNSS Positioning anomaly.
2. The GalTeC team will propose a detailed analysis, not offered with the routine products.
3. The analysis involving different GalTeC modules run in special configuration solving a problem or trouble shooting.
4. Results are compiled and delivered in a study like way (e.g. Technical Note) to the customer (or Internal Report).

Service Assessment:

1. A service provider who offers or plans a service based on GNSS or using Galileo broadcast capabilities (e.g. Commercial Service, External Regional Integrity Service, Search and Rescue) can request formally or commission a service dimensioning analysis.
2. The GalTeC team will then define a dedicated individual set of analysis to be performed.
3. The analysis is performed involving different GalTeC modules, but mainly the Simulation or Prediction tool.
4. Results are compiled and delivered in a study like way (e.g. Report) to the customer.

GALTEC ARCHITECTURE

Physical

The GalTeC architecture will basically consist of a scalable server/client architecture with several computer systems (COTS Hardware) on which the different software-based functions will be realised.

The basic HW mounted in a single 19' rack consists of the three GalTeC servers with the required mass storage integrated. These three integrated and scalable servers are based upon the same most recent dual core technology and are equipped with the same chip sets though they have different processing purposes and partially are operated under different operating systems (LINUX and MS Windows). The GalTeC simulation and service prediction server is equipped with two dual core processors and is operated under MS windows. In the same way also the server for orbit determination has two dual core processors but is operated under LINUX in order to provide highest performance and to allow distributed computing. Actually the Analysis and Service Server has only a single dual core processor, but this can be upgraded if the need for that becomes evident during the project. These servers are also equipped with an Intelligent Platform Management hardware for maintenance purposes that is accessible also when the server is ‘down’. An integral part is also an (short-time) uninterruptible power supply, networking components and, at the moment, the GPS/EGNOS receiver. This GNSS receiver can be replaced or be complemented by a Galileo receiver in future. For maintenance and configuration reasons in the rack integrated is also a single set of display/keyboard/mouse device that can be switched to each of the servers by a switching device.

For normal operations there will externally to the rack a dedicated GalTeC client computer that is connected to the GalTeC servers via a Local Network. It consists of one Client desktop computer with two monitors, one keyboard/mouse and an isolated Internet access. This GalTeC client computer is located in proximity of the rack and can in future be complemented by further GalTeC client computers.

Additionally, non-GalTeC clients that can be any local working station within the local intranet that can be connected to the three GalTeC servers individually to perform the calculations/analysis/data handling etc. remotely. The only condition is that they have the software for server access installed and set up.

The various analysis and evaluation programmes on the GalTeC servers need access to the internet in order to download actual data from various sources delivering GNSS measurement data and evaluated data. This access to the Internet is realised via a dedicated proxy server within the intranet according to the IT safety and security rules.

More difficult and sensitive is the external access to the GalTeC services from the Internet. Actually the external access to GalTeC is given through the dedicated GalTeC Internet Server. For security reasons the GalTeC Internet services are actually not provided by the GalTeC server itself, though this is planned for the future, requiring specific security measures.

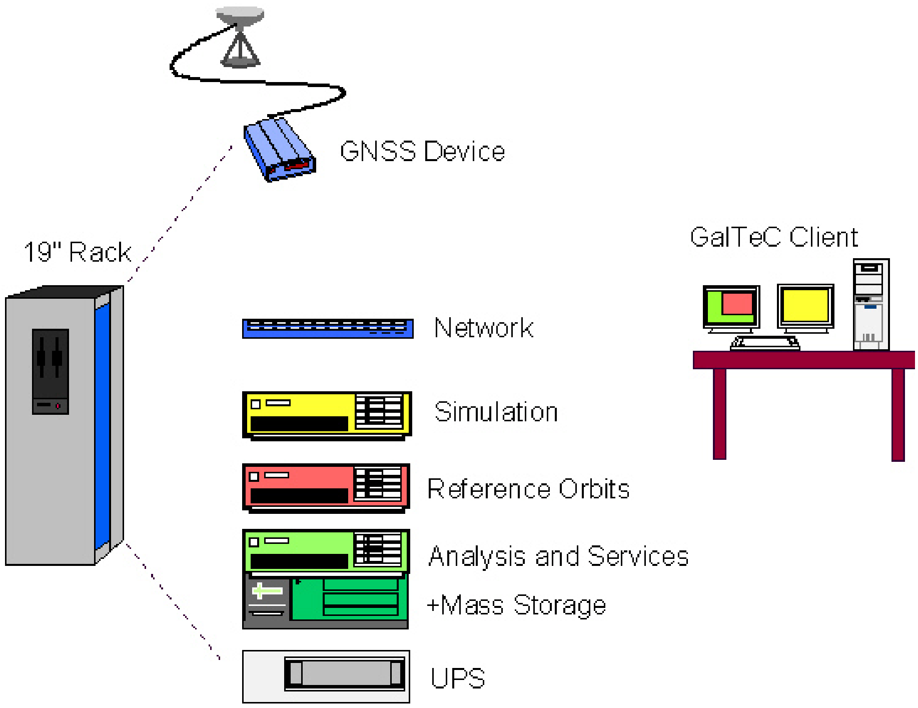

Figure 2: GalTeC Components

Figure 3: GalTeC main hardware

<u>Functional</u>

GalTeC is based on four main functionalities:

- Measurement of GNSS (GPS&Galileo) Observations
- Prediction and Service Volume Simulation of the GNSS performance
- Determination of a highly accurate reference of the GNSS performance in Post-Processing
- Analysis of the GNSS performance and generation of products

Therefore GalTeC will provide the following features:

Measurement:

- Monitoring Galileo system performance from independent user stations (Galileo receivers) deployed over Germany /Europe
- Interface to international GNSS service like IGS and air control service like DFS to exchange data and information

Prediction and Service Volume Simulation

- Performance analysis of past, current or future constellations using service volume simulation prediction based on constellation parameters like Almanacs
- Consultancy for commercial service providers for their access to the system, dimensioning of their service and prediction of the service performance

Reference System Determination

- Provision of highly precise satellite ephemeris (orbit and clock parameters) – for a posteriori assessment of GNSS system performance
- Independent SIS performance evaluation service covering the past and current system status of Galileo, SBAS, GPS, Glonass
- Trouble shooting in system and user domains
- Performance analysis and verification in user domain (GNSS receiver, air traffic and marine traffic applications etc.)

Analysis and Products

- Independent calibration of the major Galileo/GNSS system parameters (satellite force models, satellite clock models, propagation models, processing models etc.)
- Provision of the GalTeC products, orbit, clock, Galileo/GNSS ephemeris, raw observation

The development of the related Software packages are performed jointly by Thales and NavPos Systems, where the latter is fully responsible for the Simulation (or Prediction) package. The SW modules are developed in a modular way such that each can run in principle without the other.

Measurements	Simulation	Referencing	Analysis
collect: - GNSS receiver raw data - GNSS receiver processed data from - IGS and other network sources - GalTeC (mobile) receiver(s)	- Service Volume Simulation (as basis) - Substitution of missing Galileo real data - Extrapolation of single-point results to service area - value added Services Dimensioning (CS, SOL, ERIS, SAR)	- Reference High Precision Orbit & Clock data generation (post processing) - Prediction of orbits - Orbit and ranging quality factors (SISRE, etc.)	- Statistical Analysis - Formal reports generation - Routine services (GNSS status reports, etc.) - Customer specific analysis - Interfaceing with Galileo (Master) SC

Table 1: GalTeC Basic Functions

Prerequisite for the GalTeC services are the collection of Receiver GNSS measurements, i.e. pseudorange raw data and broadcasted data like Ephemeris, Almanacs, broadcast Integrity data etc. These will mainly be derived from international accessible sources like IGS, but also others if accessible. But also part of GalTeC will be a smaller number of own GNSS Receiver terminals. For comparison also Receiver processed data (Position, Time, ...) will be collected as well as precise Orbit/Clock data (SP3).

The GNSS data is then used to generate High Precision Reference data, i.e. Precise Satellite Orbits and Clocks in SP3 format. These are then used to determine Orbit and Clock errors on the basis of GNSS provided orbit and Clock parameters. Also generated are predicted Orbit and Clock behaviour for e.g. Performance prediction Simulations.

In parallel the Simulation or Prediction tool uses the collected original broadcast Ephemeris, Almanachs to compute out of the satellite geometry the PVT quality factors for a time and area window. To choose the correct model - input parameters are needed out of the analysis in a back loop for e.g. a single position (that of the Reference station).

The Analysis functions will then analyse the computed data, which comes more or less as text data from the Reference module and present the analysis in a more visual way (e.g. a classical trade-off: Is vs. Shall vs. Prediction). The services functions will be used to generate then the different reports with integrated graphics and final results in usual formats (ASCII, XML, PDF, ...) with integrated Text/Tables/Graphics.

The following figure shows (but not exhaustively) the interaction of GalTeC modules.

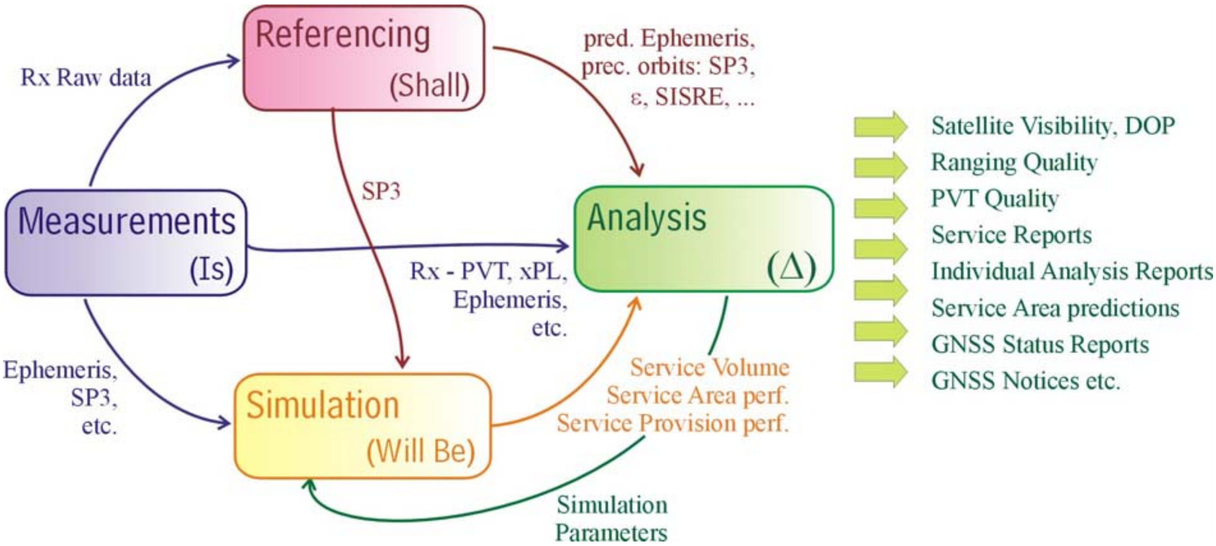

Figure 4: Interaction of GalTeC main Functions

The GalTeC will be connected internally to local users with own working stations for performing individual computations. There will also be one work station direct at the location of the server. Also there will be a connection to the Internet to give access to external users to GalTeC as well as from GalTeC to external data sources (as IGS). Finally it is planned to foresee a connection to the Galileo Ground Segment via its Service Center Interface, or to a dedicated Central Galileo Service Centre. Also GalTeC is planned to finally act as one of the first Galileo Service Centers.

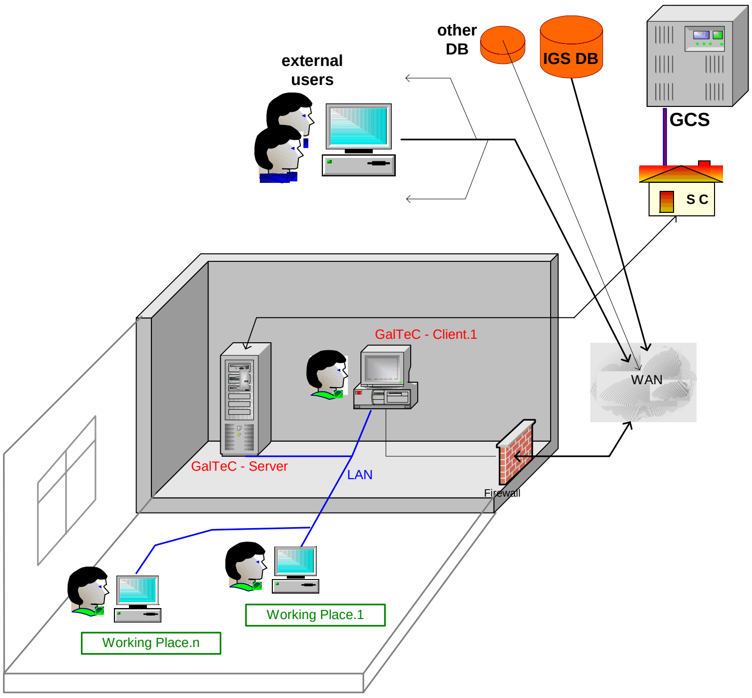

Figure 5: GalTeC communication lines

REFERENCE OD&TS

The reference orbit determination is a very important component for GalTeC. It provides the precise reference orbit for further data analysis and processing. The reference orbit determination is developed using Fortran 77/Fortran90 and provides the following major functions:

- Single and dual frequency of GPS/GLONASS/Galileo measurement processing
- Data from various receiver type processing and combination
- Precise GPS/GLONASS/Galileo satellite orbit determination
- Reference SISRE and SISRA for GPS/GLONASS/Galileo SIS computation
- Historical SISRA for GPS/GLONASS/Galileo SIS computation
- Assessment: SIS Accuracy of GNSS Satellites
- Reference DOC of GNSS orbit determination computation
- Reference SREW Computation
- Capability to process SLR observations to GPS/GLONASS/Galileo satellites, if the reflectors in the satellites installed and related SLR data available
- Supporting international data exchange formats: RINEX, SP3c, SINEX, IONEX, Clock RINEX, Troposphere SINEX, ANTEX, IERS ERP etc.

The major processing steps of reference orbit determination can be illustrated as follows

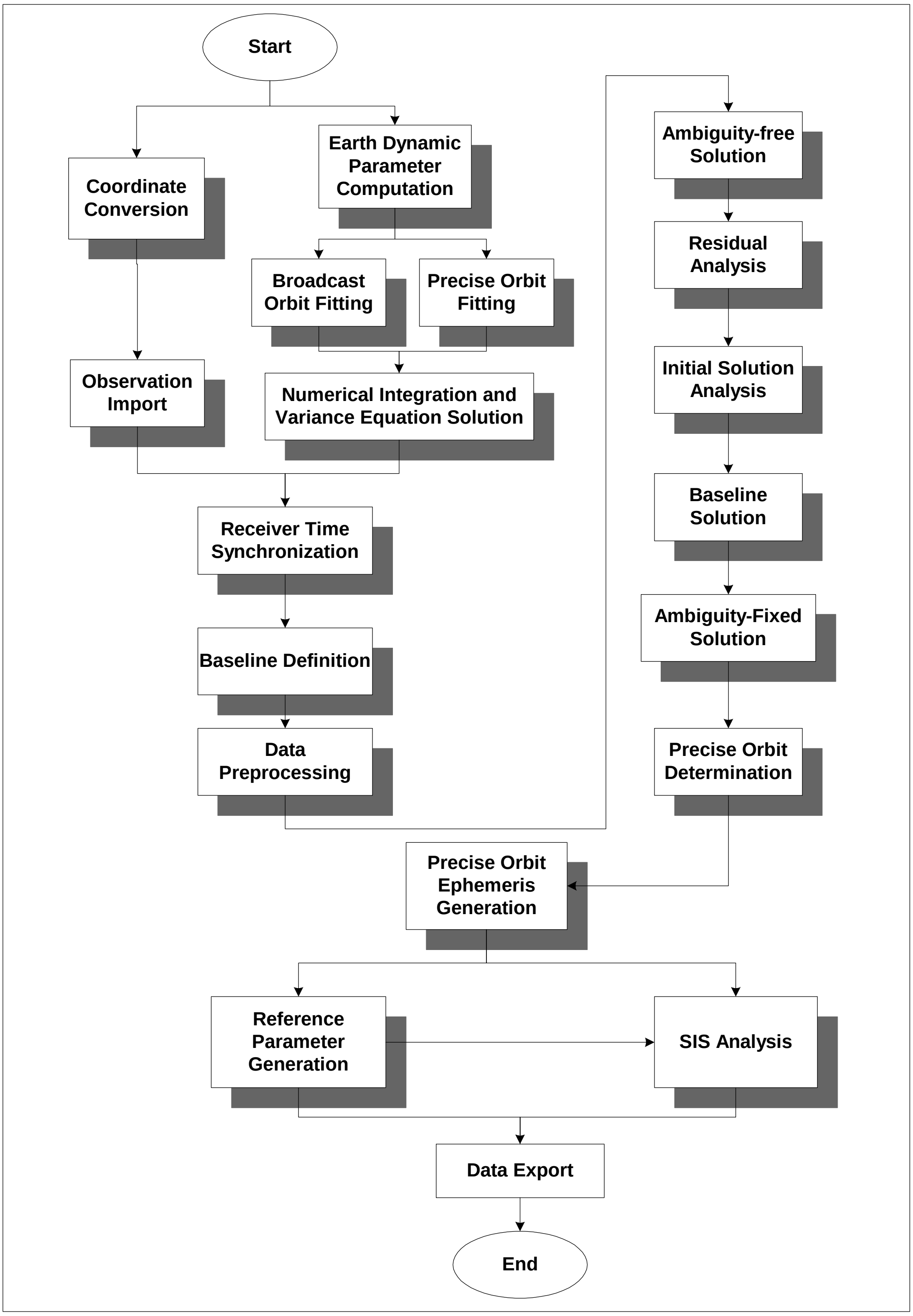

Figure 6: Major Function of Reference Orbit Determination

<u>Precise Obit Determination, SISRE and SISRA Computation</u>

The reference orbit determination is performed in GalTeC using pure carrier phase measurements from GSS stations and user monitoring station networks like DLR EVnet. The ground GSS stations and EVnet will collect pseudo-range and carrier phase measurements and provide them in offline to GalTeC for further data processing.

GNSS satellite orbits are determined using the dynamic method in batch processing mode. Assuming the satellite movement equation is

$$\ddot{\vec{x}} = -\mu \frac{\vec{x}}{|x|^3} + \frac{\partial R}{\partial t} = f(\vec{x}, t) \qquad \textbf{(Eq. 1)}$$

where,

$\ddot{\vec{x}}$ satellite acceleration vector in inertial coordinate system

$\vec{x}$ satellite position vector in the same coordinate system

μ the earth's gravitational constant

R the sum of various perturbation sources which can be described as

$$R = R_e + R_s + R_m + R_l + R_\Sigma$$

R_e is the geopotential model, R_s, R_m are solar and lunar attraction models, R_l the solar radiation pressure model and R_Σ other small perturbation models

Then batch processing mode can be expressed as

$$\vec{x}_k = \Phi_{k,k-1}\vec{x}_{k-1} + \Gamma_{k,k-1}\vec{w}_{k-1} \qquad \textbf{(Eq. 2)}$$

with the observation equation

$$\vec{y}_k = H_k \vec{x}_k + \vec{\varepsilon}_k \qquad \textbf{(Eq. 3)}$$

where

$\vec{x}_k$ *n* dimensional signal state vector such as satellite orbit and dynamic parameters

$\vec{y}_k$ *m* dimensional observation vector

$\Phi_{k,k-1}$ $n \times n$ dimensional state transition matrix

$\vec{w}_k$ dynamic system noise vector

$\vec{\varepsilon}_k$ observation noise vector

$\Gamma_{k,k-1}$ coefficient matrix of dynamic system noise vector

H_k $m \times n$ dimensional observation coefficient matrix

P_k weight matrix of parameters

The equations above can be solved together with numerical integration, i.e.

$$\left.\begin{aligned} \ddot{\vec{x}}'_k &= f(\vec{x}'_k, t) \\ P'_k &= \Phi_{k,k-1} P_{k-1} \Phi^T_{k,k-1} + \Gamma_{k,k-1} Q_{k-1} \Gamma^T_{k,k-1} \\ K_k &= P'_k H^T_k (H_k P'_k H^T_k + R_k)^{-1} \\ \tilde{\vec{x}}_k &= \vec{x}'_k + K_k (y_k - H_k \vec{x}'_k) \\ P_k &= (I - K_k H_k) P'_k \end{aligned}\right\} \qquad \textbf{(Eq. 4)}$$

SISRA, Signal-in-Space Reference Accuracy is a prediction of the minimum standard deviation of the unbiased Gaussian distribution which over-bounds the Signal-In-Space

Reference Errors (SISRE) predictable distribution for all possible user locations within the satellite SIS coverage areas.

Assuming SISRE is belonging to Gauss' normal distribution, otherwise, SISRE is a Gauss normal distribution over-bound of actual signal-in-space reference errors.

From the (Eq. 4), SISRE can be solved as follows

$$SISRE = (\bar{y}_k - H_k \tilde{\bar{x}}_k)$$

Therefore SISRA can be solved by

$$SISRA = \sqrt{SISRE/(n-m)} \qquad \textbf{(Eq. 5)}$$

where

m number of parameters used in the orbit determination.

From the Equation (5) it can be understood that SISRA is one of the products of complicated orbit determination processing. In order to be simple for problem analysis, SISRA can be written as follows

$$SISRA = f(n, M, \varepsilon, \cdots) \qquad \textbf{(Eq. 6)}$$

where

n number of GSS stations

M Galileo satellite force models

ε measurement errors

Equations (4) and (6) show that orbit determination and SISRA performance are dependent on the number of ground monitoring stations and their geographic distribution, satellite force models (earth perturbation, Sun and Moon attraction, solar radiation etc.) and measurement errors (interference, multi-path, ionospheric and tropospheric errors and receiver errors etc.).

Based on the discussion above, the SIS analysis major functions can be presented in the following diagram.

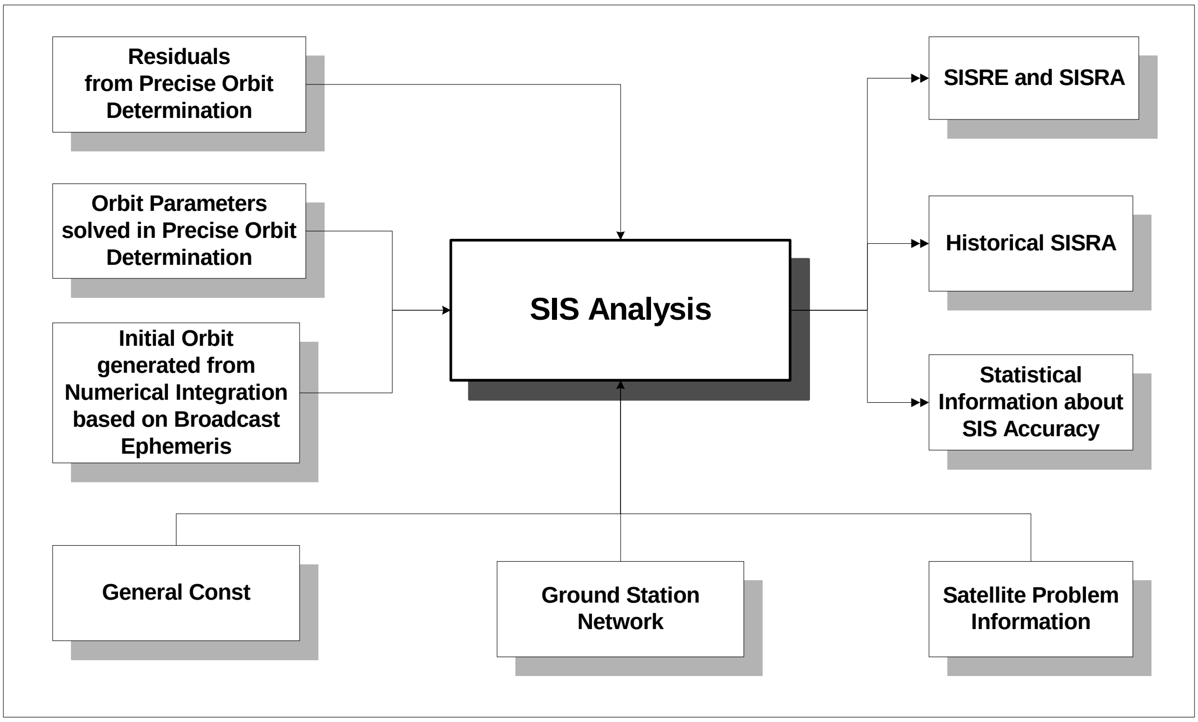

Figure 7: SIS Analysis Major Functions

One possible output of such calculations is shown exemplarily in the following figure where the orbit errors along the time axis are shown for a GPS satellite. The difference is generated by computing orbit tracks based first on GPS broadcast Ephemeris, then orbit tracks based on own generated SP3 Orbit and finally comparison. When viewing the below graph it is reminded that normally an ephemeris broadcast by GPS is valid for 2 hours nominally. The differences plot are related to the track direction of the satellite at a point. Radial means from the satellite to the Earth Center. Along means along the track (flight direction). Cross means horizontally 90 degrees to the track.

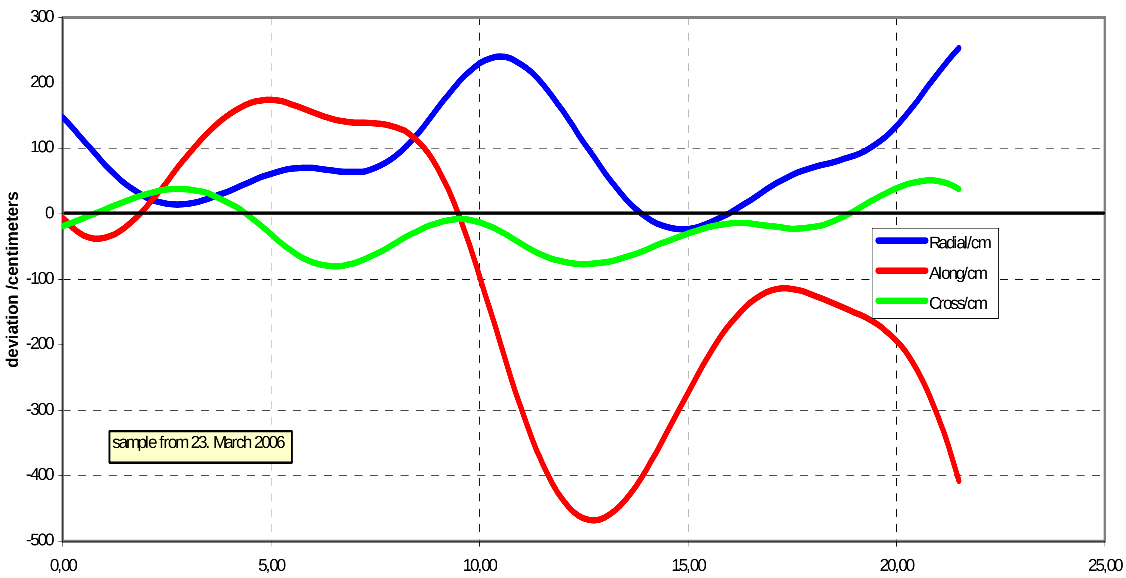

Figure 8: Orbit Errors plot example

SERVICE LEVEL PREDICTION

The Galileo Development leads to Initial services with 4 satellites in 2009. All Services will be provided , but at low service levels (accuracy, availability, ...). The direct Galileo Services Validation will not be feasible before Full Operational Capability.

For several services, the definition is not yet finalised e.g. the external Regions Integrity Services. For the Commercial Services on E6 (500 bits per second & per satellite to be allocated to 3rd party service providers), the definition is still quite open. Future Service Providers with new ideas for commercial services may need support for dimensioning and validation of these new services.

GalTeC shall allow the performance analysis, the calibration and the prediction of the specified Galileo Services. It shall also allow to consider GPS and/or Galileo in the analysis and also the inclusion of potential new GNSS services in terms of performance prediction and analysis, dimensioning and later validation.

For the prediction of the system performance and also for the design and dimensioning of the GNSS Services simulation is needed. For this purpose, the NavPos Systems Service Volume Simulator AVIGA® will be used and further developed to a GalTeC Prediction tool in the frame of the GalTeC project. The prediction tool offers the means to predict, analyse and evaluate Galileo Services.

- A main AVIGA Objective shall be the analysis of the GNSS performance at the user. AVIGA offers to run the performance analysis at point, over area and along routes in terms of
  - Accuracy,
  - Continuity of Service,
  - Integrity and
  - Availability.
- In addition, AVIGA shall allow to analyse the GNSS constellation performance in terms of
  - Visibility and
  - Geometry.

The AVIGA modular concept comprises:

- Performance analysis of past, current or future constellations;
- Performance prediction of future constellation;
- Consultancy for commercial service providers for their access to the system, dimensioning of their service and evaluation of the service performance.

SVS will be composed of modules, which will fulfil the following tasks:

- Space Segment Module: predicts satellites trajectories from standard almanacs, e.g. Almanac YUMA files, computes satellite trajectories from user – defined Keplerian elements; Broadcast Ephemeris or SP3 Precise Ephemeris.
- Visibility Module: evaluates visibility characteristics of satellite coverage accounting for mask skyline angles;

- DOP (or Geometry) Module: evaluates DOP and Position Error characteristics of satellite coverage, position accuracy is estimated from the position errors covariance matrix.
- Availability Module: evaluates availability of DOP and position accuracy. Models of satellite outages and navigation solution errors are used in this model. Integrity/Continuity Module consists of sub modules which can be also considered as independent modules:
  - RAIM: evaluates availability of the snapshot RAIM FD/FDE methods.
  - SBAS: evaluates availability of the SBAS Protection Levels.
  - Galileo: evaluates availability of protection level according to concept proposed for Galileo system, calculates the pertaining Integrity Risk.
  - Availability of Integrity Risk: analyses availability of Integrity Risk according to concept proposed for Galileo system
  - GBAS / Galileo LE: analyses performance of GPS, Galileo based LAAS systems
- Route Module: analyses performance along a specified route
- SISE Analysis Module: assesses satellite orbital and clock errors from SP3 and RINEX Navigation files.

Further modules which will be implemented or extended as part of GalTeC Phase II

- Data Dissemination Module: simulates disseminating of Galileo Messages from Ground Mission Segment via ULS network to world-wide or regional users
- Data-feed Service Volume Simulation: this module / feature will allow to inject real data to the SVS simulation.
- End-to-End Service Volume Simulation: This module will allow error components simulation on Galileo element level to analyse the Galileo Service performance and the impact of various errors sources.

The prediction of the Galileo Services according to their specification, and also with further parameter settings, shall be done with the GalTeC Prediction Tool. The tool shall also allow the simulation of seldom failures of the system as e.g. erroneous behaviour and outages.

Example Outputs:

Figure 9 and Figure 10 show examples of the GNSS Services Accuracy Performance prediction for the GPS SPS and the Galileo OS.

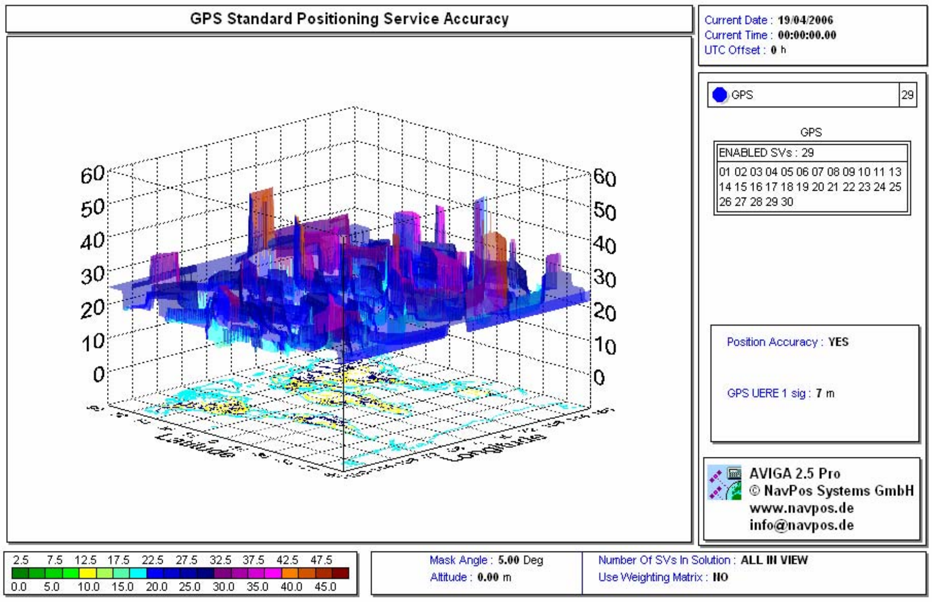

Figure 9: GPS Standard Positioning Service Accuracy

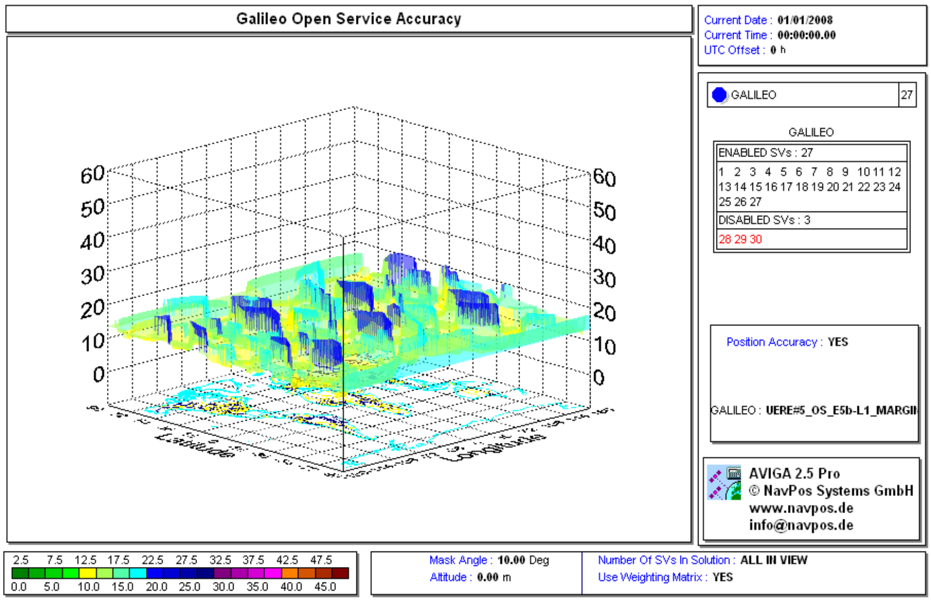

Figure 10: Galileo Open Positioning Service Accuracy

A further very important parameter for the performance assessment of the Galileo Safety of Life Service is the Signal in Space Error (SISE). For the provision of Galileo integrity, the main role is assigned to the integrity flags which are generated in the Integrity Processing Facility. The generation of integrity flags is based on the determination of SISE in real time. The value of SISE depends on the number ground sensor stations (GSS) and the satellite to GSS errors. Figure 11 shows the predicted snap-shot SISE values for a single satellite. A further means to determine and evaluate the SISE performance is done in post-processing. Figure 12 shows the difference between the GPS/SP3 reference orbit and the Broadcast Ephemeris data which were broadcast in real-time. A similar approach will be done to analyse the Galileo SISE orbit and clock accuracy.

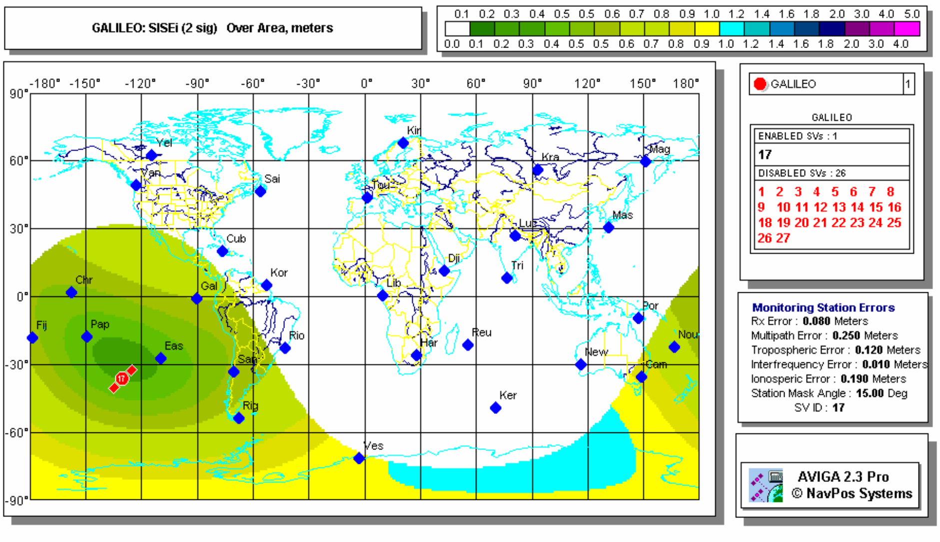

Figure 11: SISE as function of Galileo Sensor Station Visibility

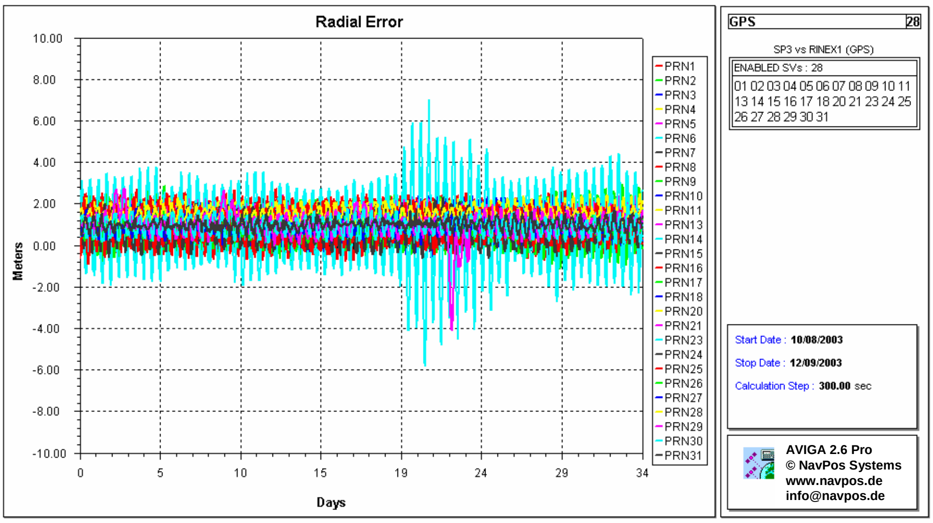

Figure 12: Analysis of the SISE/Orbit Accuracy as difference of GPS SP3 – GPS Broadcast Ephemeris

The Prediction Tool shall be used for the dimensioning of services and for the performance assessment in relation to the needed signal bandwidth. The signal bandwidth will probably play an important role in the service transmission cost estimation. The design and dimensioning is needed for the feasibility and cost estimation of a service. An application example for GalTeC will be to offer Service Providers the possibility to check needed data volume and distribution strategies for their planed Services.

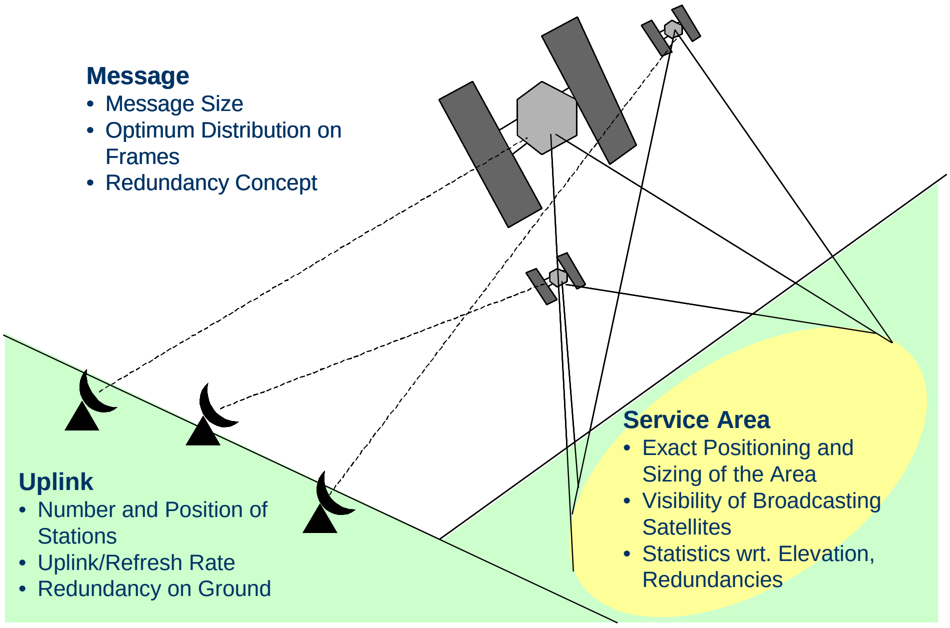

Figure 13: GNSS new Services Dimensioning for GALILEO

GalTeC as a tool could be used at Galileo Performance Centres and at Galileo Service Centers. The GalTeC Service Volume Simulation and Level Prediction Tool offers the means to predict, analyse and evaluate Galileo Services. GalTeC provides a reference for system independent service validation combined with means to dimension, plan and offer Galileo commercial services

SERVICES AND ANALYSIS PRODUCTS

Part of the Analysis has been described above. The main goal is to develop a set of services in form of pre-defined products that are of interest and "easy" to be interpreted by the users. It is therefore planned to analyse what is available today for GPS and GLONASS as well as for EGNOS. Part of the products are also standardised to a certain level like e.g. SP3 and RINEX products.

In the moment the products can be characterised wit the following attributes:

- Update Rate (hourly, daily, weekly)
- Actuality (minutes, hours, days)
- Format (RINEX, SP3, XML, HTTP, txt, PDF, PNG/JPG)
- Access (Public, Restricted, Individual)
- Product provision (Download, E-mail, FTP, HTTPS)
- Product (Routine, Alarm, Special)

and the following products are to be provided as a first shot:

- sorted Receiver (Rx) Raw Data, Rx Computed Data, GNSS (Transmitted) Tx Data
- Own Station Data
- Position Error of Stations
- real Protection Levels for Stations (over time & statistics)
- Protection Levels for Stations and Area (Simulated)
- Ranging Errors for Stations

— Satellite Orbit and Clock Errors in different formats (over time and statistics, e.g. SISA, SISRA etc.)
— Precise Orbits (SP3) based on own calculations and (partly) own measurements
— collection of NANU, Bulletins

The compilation of the single tables, plots, summaries will be developed in detail in the coming phase and also its structuring and representation in the externally accessible representation. The reports will be formatted in several formats for different use cases.

CONCLUSION AND FURTHER WORK

GalTeC in its final stage will offer functions which might be expected from a Galileo Service Center. One main capability will be independent validation of Galileo performance and of special interest the global and regional integrity performance. However it will be a prototype to gain experience on the way towards a fully fledged and liable Galileo or generally GNSS Service Centre.

The specification phase of GalTeC has been just recently concluded and the next phase the Software specification phase has been entered. The GalTeC is introduced to the public already in the specification phase to receive first feedbacks already in the design phase as consequently services shall be developed which are considered as useful for various users.

The development of GalTeC is foreseen in two steps, delivering a GalTeC Version 1 by end of this year (2006) and Version 2 in late year 2008, just short before Galileo launches its 4 IOV satellites. The first version will be dedicated to the development of the Reference Orbit&Clock software using GPS data for input, developing the Simulation capabilities and first Analysis functions. The main work has to be done with the Version 2 development where the Specifications are reviewed and adapted to the latest information available about Galileo (i.e. Signal and Services ICD's, Mission Requirements etc.) and the (central) Galileo Service Center.

Open Questions today are the availability of Galileo Signal (GSTB) within the project run time and related measurements from several sources. Also open today is the availability of the central Service Center specification and exchange conditions for information. It is expected that the GJU and later-on the GSA will make such kind of information available. Some limited access is given to the Thales team through participation in the Galileo development and particularly GMS verification programme, such that by end of 2008 a valuable and powerful tool will be available for experimentation. The capabilities will be demonstrated in the Galileo IOV phase.

ACKNOWLEDGMENTS

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