GNSS Local Component Integrity Concepts

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Abstract. This article presents a number of Local Integrity concepts for augmentation of the Galileo satellite navigation system. Several architectures are described that are suitable for the autonomous assessment and provision to users of Local Integrity, and sub-element functionalities are developed to support this. Performance results are presented from simulations conducted as part of the work.

Key words: Galileo, GNSS, GPS, Integrity, Local Component.

1 Introduction

This paper summarises work into Local Integrity for Galileo undertaken by EADS Astrium in the UK and Germany during 2003. The work formed part of the Galilei programme, funded by the European Commission's Galileo Interim Support Structure (GISS), forerunner of the Galileo Joint Undertaking (JU). The paper describes several Local Integrity concepts and describes architectures and sub-element functionality. Sub-elements analysed included LIM (Local Integrity Monitors), LIPF (Local Integrity Processing Facilities), DRS (Differential Reference Stations), LD (Local Dissemination) and PSL (Pseudolites).

2 Capabilities and Limitations of Existing Systems

2.1 GPS and Galileo Open Services and RAIM

Since it was declared fully operational in 1995 (UCSG, 1995), GPS has proven to be a very reliable system; however there exists a risk that malfunctions or anomalies somewhere in the system could occur. The GPS System's Control Segment monitors satellite and Signal-In-Space performance and should be able to detect any malfunctions in the Space Segment or Control Segment. There is, however, an "integrity delay": a latency period of up to 30 minutes or more between the onset of a malfunction condition and the time when it can be detected by the Control Segment and appropriate mitigation action implemented. For some users, notably "Safety-of-Life" (SoL) users, the integrity risk (i.e. the risk of system malfunction combined with the "integrity delay") is considered unacceptable.

RAIM is one solution to the GPS integrity risk; the alternative is to monitor the System using some external means and then to relay the monitor information to users. This second alternative led to the development of regional systems such as EGNOS and WAAS, and to global concepts such as Galileo's Global Integrity. Local systems have also been proposed and/or developed to address the integrity risk. Local concepts are developed in subsequent sections of this report.

Galileo's Open Service is designed to be at least equivalent to the GPS civil SPS capability in the 2010 timeframe (Dutton et al., 2002). The detailed signal characteristics are defined in the Galileo Signals in Space ICD (Hein, 2002). A Galileo user receiver can receive the Galileo satellite's Open Service transmissions on any of the "L1" carrier, the "E5a" carrier, the "E5b" carrier, or Commercial Service transmissions on the "E6" carrier. Open Service availability is designed to be 99.8%, globally. No integrity-related transmissions are included in the messages for Galileo's Open Service; hence this service should provide broadly the same level of confidence to users (in terms of low integrity risk, but with no guarantee), as stand-alone GPS services. In fact, the Galileo SISA update interval baseline figure of 100 minutes gives an indication of the probable maximum risk period for Open Service users.

If RAIM is implemented in an Open Service receiver, the SISA transmitted in the Open Service messages can be used to estimate the errors in the measured pseudorange (Hollreiser, 2003). The SISA, however, is only designed to statistically bound errors under non-fault conditions (Medel et al., 2002). It is essentially an estimate that quantifies the "expected" ephemeris and satellite clock errors based on past performance and relatively recent measurements. It is not possible for the SISA to bound range errors for non-nominal conditions, nor does SISA seek to bound errors that are outside the domain of what could be termed the "signal generation" process (thus propagation or multipath anomalies and any user errors are outside of the SISA boundaries). The Galileo SISA can be considered equivalent to the User Range Accuracy (URA) included in GPS transmissions in terms of its component parameters and its use to estimate user ranging and positioning performance.

All RAIM schemes use some form of redundant measurement consistency to "guarantee" measurement integrity. This need for redundant measurements reduces RAIM availability and continuity. Dixon (1999) reported continuities of 80-90% for aircraft horizontal precision approach guidance using GPS alone, rising to approximately 100% for combined GPS and GLONASS (assuming 22 operating GLONASS satellites). Van Dyke (2001) found availabilities of between 27% and 99.999% for approach with vertical guidance (APV-I) for GPS (or Galileo) alone and between 99.4% and 99.999% for combined GPS/Galileo. The range of values reflects assumptions about user range error. Worse performance was reported for the more stringent requirements of APV-II; readers are referred to the source material for details.

2.2 Regional and Global Integrity Systems

The European Geostationary Navigation Overlay Service (EGNOS) provides satellite based augmentation services in Europe. Various test signals have been transmitted since 2000, and full EGNOS operation is presently planned to commence early in 2004. After a certification process, EGNOS is planned to be used for safety-critical applications such as aircraft CAT I approach or navigation of ships through narrow channels. EGNOS augments the two existing satellite navigation systems, the US GPS and Russian GLONASS, enhancing system performance in terms primarily of accuracy and integrity. The Wide Area Augmentation System (WAAS) provides essentially the same services over the United States, as does the Multifunction Satellite Augmentation System (MSAS) for the Japan area. WAAS Initial Operational Capability (IOC) was declared in July 2003 (IOC, 2003).

These Systems use a network of terrestrial monitoring stations to measure the ranging performance of navigation satellite transmissions, which are relayed to central processing facilities. Here, measurements are gathered, integrity checked, and corrections generated. Geostationary satellites then relay the data to users over a GPS-like ranging signal. These augmentation systems thereby improve navigation accuracy and transmit Integrity Alerts to users should satellite signals deviate from predefined operational norms. A Time to Alert of 6 seconds is specified, this being the period from the onset of a fault until the user is advised of the problem. Between these two events the Augmentation System must detect and confirm that a fault condition exists and upload the Alert to the geostationary satellite, for broadcast to Users.
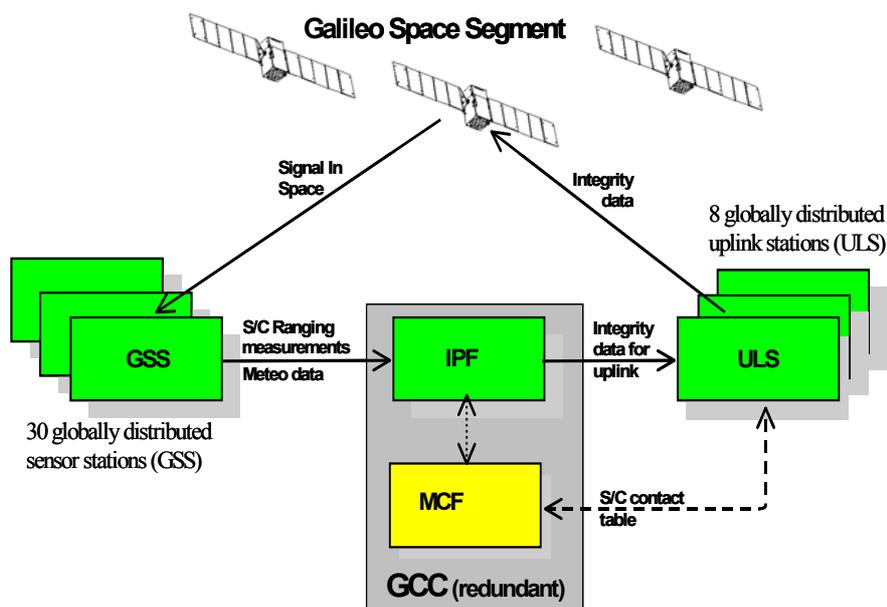

Fig. 1 Simplified Galileo Integrity Architecture.

The Galileo Integrity Scheme takes GNSS augmentation two steps further than the Regional Systems described above. Firstly the Signal in Space (SIS) Integrity is monitored globally. Secondly the integrity transmissions are included as an intrinsic part of the Galileo SIS and distributed globally.

The Galileo system architecture for global integrity is illustrated in Fig. 1. A more complete description of the Galileo Ground Segment is given in Lugert et al. (2002). The satellite transmissions (SIS) are monitored at a number of globally distributed monitor or "Sensor" stations (GSS). The monitored data includes the navigation data and measurements of satellite pseudorange and pseudorange rate. The monitored data is relayed over a communications network to the Control Centre (GCC). Within the GCC, the Integrity Processing Facility (IPF) has the responsibility to assess satellite (and sensor station) health with respect to the once-per-second measurements received. Integrity data are created and relayed to Uplink Stations (ULS), which send the information to selected "connected" satellites. The term "connected" refers to satellites in receipt of continuous Integrity information from the Galileo Ground Segment. Connected satellites transmit "live" integrity information about the Galileo constellation health to users.

Galileo SoL Users have to confirm two separate satellite visibility tests (Hollreiser, 2003) before initiating any "critical" operation such as final approach in aviation. Firstly there is a "conventional" constellation availability assessment – are there sufficient satellites for navigation or RAIM? Secondly, are there at least two "connected" satellites available? Unless both these constraints are met, any critical operation should not be initiated. The reason for having two "connected" satellites is to maintain continuity of service by mitigating against the risk that one is lost during the operation.

Regional and global augmentation systems have a challenging TTA budget; in addition they only have the capability to detect and alert users of certain error types. Ephemeris and spacecraft clock errors can be detected, but propagation uncertainties (due to ionosphere, troposphere, multipath and RF interference) and receiver errors cannot.

3 User Requirements from Local Augmentation Systems

There exist several user requirements, which cannot be fulfilled by using GNSS SIS alone. Such application classes include applications in road, aviation, rail (train control) and maritime (harbour navigation).

Tab. 1 Performance Requirements for Different Application Classes.

Application Class		A	B	C	D
TTA		1s	6s	10s	>10s
Integrity Risk	H	$\leq 10^{-7}$/h	10^{-7}- 10^{-5}/h	10^{-5}- 10^{-3}/h	$\geq 10^{-3}$/h
	V	$\leq 10^{-7}$/h	10^{-7}- 10^{-5}/h	10^{-5}- 10^{-3}/h	$\geq 10^{-3}$/h
AL	H	7.5 m	12 m	12 m	12 m
	V	10 m	20 m	20 m	20 m
Example		Aviation PA, train control, maritime docking	Marine control, oil platform position	Air surveil, regulatory enforce	Emergency route guidance, public transport

Tab. 1 gives an overview of the performance requirements of these applications. To provide such services, local navigation augmentation systems together with the appropriate communication infrastructure are needed. Such augmentation systems or Local Elements help to achieve the required position, availability, integrity and continuity values.

4 Local Integrity Concepts

Several concepts were considered wherein the Local Element was completely autonomous from the Galileo System. These various architectures included Local Monitors (LIM and DRS) that capture the Galileo SIS transmissions. The SIS interface is the only direct real-time interface between the Local Elements and the global Galileo System. This represents a fundamental point in responsibility for the integrity information provided to the User; since all tasks associated with monitoring and processing the integrity are performed locally, so too all responsibility lies locally. This brings the following benefits:

- Complete Local control and a very high degree of autonomy from the Global System;

- Local revenue-generating potential which is independent of the Galileo System;

- No need for a communications link between the Local System and the Galileo Global System thereby limiting costs of the Local installation and the recurring costs of running the site.

The configuration also brings additional responsibilities:

- The duty to maintain not just the LD communications link to the User but also the monitoring (LIM & DRS)

facilities, all of which facilities may require certification for purpose;

- The Service Guarantee associated with the Local Integrity Message is 100% Local responsibility / liability. By implication, any User position solution, which uses Galileo Global measurements that are passed as "OK" by the Local System, is "Guaranteed" by the Local System.

The coverage area of the Local system is constrained both by the LD transmission mechanism and by the visibility of satellites to local monitors. Since only line-of-sight measurements can be made, the applicability of the resultant integrity information is only to users with similar line-of-sight.

The key advantages of scenarios with Local monitoring is that (a) Time To Alert (TTA) can be greatly improved compared with techniques using Global measurements, and (b) signal propagation effects including ionospheric and tropospheric delay uncertainty can be monitored (and compensated) in the vicinity of the user receiver. The TTA improvement is due to a combination of the facts that all processing is typically carried out at a single site thereby minimising any data transmission latency, and that there are physically less data to process than for Global or Regional Integrity.
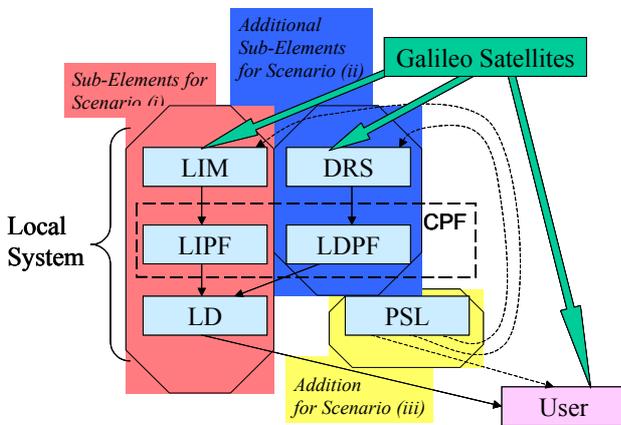

Fig. 2 Generic Architecture for Local Element using Local Monitoring.

Tab. 2 Local Monitoring Scenarios.

Ref.	Scenario Description	Sub-Elements Included
(i)	Local Integrity from Local Measurements	LIM, LIPF, LD
(ii)	Local Integrity and Local Differential Corrections from Local Measurements	LIM, LIPF, DRS, LDPF, LD
(iii)	As scenario (ii), with pseudolites added	LIM, LIPF, DRS, LDPF, PSL, LD

Fig. 2 illustrates a generic architecture for Local Integrity from Local measurements. The figure shows a compound illustration of all major functional sub-elements. Various combinations of the sub-elements were investigated as distinct "scenarios"; those dealt with in this report are summarised in Tab. 2.

4.1 Scenario (i) Issues

Only Integrity data (no differential information) is provided to users in Scenario (i). The Local Integrity Monitor (LIM) monitors the Galileo transmissions (SIS) and passes measurements to the Local Integrity Processing Facility (LIPF) where "Local Integrity" is decided.

For all autonomous Local Element scenarios, the LIM provides the (only) interface between the Local System and the Galileo Global System. The LIM is responsible for receiving the Galileo SIS and producing User Data and SIS Measurements. In Fig. 3 the first two functional stages of a LIM are similar to the RF Front End and Signal Processing stages of a conventional Galileo receiver, although typically built and tested to certified standards. Unlike a conventional Galileo receiver, however, the third functional stage of the LIM is an Integrity Processor rather than a Navigation Processor. The LIM could include functionality to derive local position and time; for simplicity that functionality is ignored in this work.
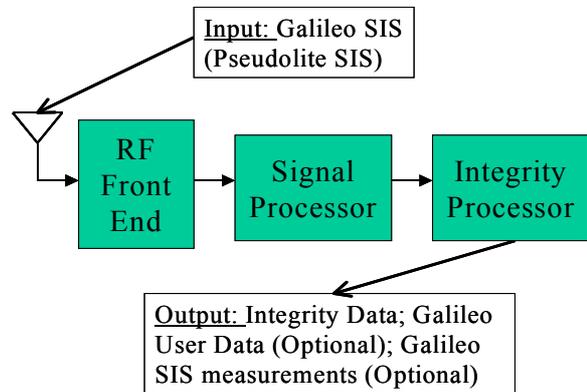

Fig. 3 LIM High-Level Functional Architecture

The Integrity Processor accepts pseudorange and carrier phase measurements together with the de-spread code signal from the Signal Processor. From the de-spread code, the navigation message is recovered. The Integrity processor must apply pseudorange corrections for tropospheric delay, ionospheric delay and satellite clocks. Beyond this point the Integrity Processor could operate in one of two ways. Either it could operate in a "User like" configuration, or it could operate in a "differential station like" configuration.

In the "User like" configuration a User position is derived from the corrected pseudoranges and navigation data. This can be compared with the known pre-surveyed LIM location to determine accuracy. In addition a RAIM-like solution would be computed. Typically the Processor would use "n" subsets of "n-1" measurements (for "n" available range measurements). The range residuals or other test parameter from the RAIM solution would be compared with a pre-determined threshold. Faulty satellite measurements can thereby be fairly simply detected and isolated to a particular measurement. In addition, the magnitude of the fault is quantified by the size of the pseudorange residuals.

In the "Differential station like" configuration the receiver compares the measured pseudorange from each satellite with a predicted pseudorange to derive a range error. The predicted pseudorange is based on known LIM location and predicted satellite position based on the orbit data and known time of transmission. The range error is compared with predetermined threshold(s) to decide measurement integrity. The magnitude of any fault is quantified by the size of the range error.

Note that there is a slightly "grey" boundary between the LIM and the LIPF. The LIPF ultimately has responsibility to determine Local Integrity, however for the present work it is assumed that the LIM output includes an integrity assessment related to its measurements.

The LIPF is responsible for receiving satellite Integrity data (and optionally pseudoranges and navigation messages) from the LIM. From this Integrity data, Local Integrity is calculated. This leads to a slight "greyness" in the boundary between the LIM and the LIPF, since as defined in the preceding section the LIM will determine integrity data for each of the monitored satellites. In practice, some implementations are foreseen to combine the LIM and LIPF functions into a single element, thereby removing the issue. This is particularly true for configurations with a single LIM and a single LIPF. For the present work, the boundary is defined as follows:

- The LIM is assumed to derive integrity data for each satellite based on measurements from a single Integrity Receiver.

- The LIPF combines multiple measurements from several LIMs, optionally also taking account of measurement history (smoothing), and derives an Integrity answer for the Local Element based on all available information.

- Generation of "B-values" in line with LAAS specifications (EUROCAE, 2003) would be carried out in the LIPF if required.

The Local Dissemination (LD) receives Integrity Messages from the LIPF (and optionally the differential corrections message from the LDPF – see later), it formats the data for the local transmission medium and transmits data packets to users. Making the assumption that Integrity Flags similar to those currently planned for the Galileo System are to be used for the Local Integrity, there are basically two options for the Local Integrity Message contents. These are (1) Complete IF Table & checksum; and (2) only transmit "delta-bits" & checksum. The advantages of following the same broad approach for Local Integrity Information as for Global Integrity information are:

- Simplicity in Local System. This (a) avoids the risk of introducing additional potential failure mechanisms in the Local System, and (b) minimises Local System development and concept validation costs;

- Simplicity of processing in User Receiver. Again this minimises the risk of introducing potential failure mechanisms since the method of processing the Local Integrity Message can be the same as that for a Galileo Global Integrity Message.

It is anticipated that Forward Error Correction (FEC) would be included with LD radio transmissions for many applications. This improves the probability of the message being correctly received by the User, but is not considered part of the process of ensuring the validity of the Integrity message. A Checksum will however be included with Integrity Messages; at the User receiver the Checksum is checked and any anomalies rejected. It is an important point that the Checksum applies to message content, not to transmitted packet. In the event of transmitting "delta-bits", the Checksum transmitted should apply to the Users reconstructed IF Table rather than simply to the "delta-bits". In this way, the information held by the User and used in his Integrity determination process is confirmed, rather than simply addressing the transmission mechanism.

The user receives Local Navigation Messages as well as the Galileo SIS (and optionally PSL transmissions). He rejects any measurements for which a valid Integrity Flag is not received. He then produces a navigation solution (and optionally a RAIM solution) based on the measurements for which valid IFs exist.

4.2 Scenario (ii) Issues

This concept is to provide both Integrity information and differential corrections to the User from the Local Element. The Central Processing Facility (CPF) comprises two major functions, namely LIPF and Local Differential Processing Facility (LDPF). These facilities could work essentially independently and in parallel. The LIPF could be identical to that from Scenario (i) above; an alternative is described in the next paragraph. The LDPF calculates differential corrections for the satellite

transmissions based on knowledge of its own and the satellite positions at time of transmission. The differential data and the integrity information are disseminated to users via LD.

An alternative option for the LIPF is to simultaneously confirm the integrity of the differential corrections and the satellite transmissions. In this case the LIPF can "block" differential corrections if the correction is considered excessively large, if the rate of change of corrections is outside some pre-determined threshold, or for other reasons. Indeed this leads to one of the simplest Integrity message mechanisms – if the User receives differential corrections for a particular measurement then SIS Integrity of that transmission is considered OK, if there are no corrections for a particular measurement then that measurement must not be used since it's integrity is "suspect".

The Differential Reference Station (DRS) has RF and Signal Processing stages similar to those described above for a LIM. These stages feed pseudorange and carrier phase measurements together with the despread satellite code signal to a differential Processor. The navigation message is recovered from the code, and the Differential Processor then applies pseudorange corrections for tropospheric delay ionospheric delay and satellite clocks to produce a corrected range parameter for each satellite. The corrected range is compared with the predicted (true) range to the satellites, this being the geometric distance between the satellite at time of transmission (calculated from precise orbit) and the DRS antenna (precisely surveyed location) to produce a differential correction for each satellite. Note that ionospheric and tropospheric corrections could optionally *not* be applied in the DRS, in which case the differential correction message would compensate for those errors as well as satellite and clock errors. A crucial point is to ensure a known standard process is followed so that a "double compensation" for errors is not accidentally made (RTCM, 2001).

A simplified differential range corrections formula is:

$$drc = \rho - c\left(dt_R - dt^S\right) - \rho_0$$

drc Differential range correction

ρ Measured Pseudorange

ρ_0 Geometric distance between satellite and DRS

c Speed of Light

dt_R Receiver Clock Offset

dt^S Satellite Clock Offset

Using the above algorithm it is then possible to calculate the individual range corrections for each satellite, which would then be passed to the LIM for integrity checking.

The inclusion of a DRS within this scenario alters the way in which the LIM produces the integrity flags. The integrity process is as follows:

- SIS received by the LIM receiver and the individual pseudorange are calculated

- The differential corrections from the DRS are then applied to these ranges through simple addition to the observed pseudoranges.

- The resulting range errors are then compared to an internal database of expected range errors

- If the calculated errors are outside of the estimated errors, then an integrity flag is raised and the range correction is not used any further.

The integrity checked differential corrections are then passed to the LIPF for formatting into the navigation message.

The LDPF receives DRS data and formats multiple data into a unified navigation correction message. In the case of a single DRS, the LDPF has essentially no role. For each satellite, the unified correction message is computed as:

$$drc^S = \frac{1}{m}\sum_{i=1}^{m} drc_i^s$$

drc^S The combined differential range correction for satellite *s*

m The number of DRS/LIM combinations with valid corrections for satellite *s*

drc_i^s The differential range correction for satellite *s* as calculated by DRS i.

Assuming a scenario with 12 Satellites and 4 pseudolites, and that Differential Correction for each source require 5 bytes (40bits) then the 16 sources need 640 data bits to transmit. Additional bits for integrity data are estimated as 60 bits. The Navigation Message size is therefore 700bits.

Using a VHF link for dissemination to the user, the size of the message is not a major concern since the data transfer rate of the communications link is assumed to be 31500bps. With the above message size, the message could be transmitted 45 times a second. This is consistent with meeting a user requirement for delivery of integrity and differential data within 1 second.

4.3 Scenario (iii) Issues

This scenario extends Scenario (ii) by including pseudolite (PSL) transmissions from the Local Element.

In this instance, the integrity of the PSL transmissions must be confirmed by the LE and differential PSL corrections must be derived and supplied to the user.

The PSL transmissions could be used purely to relay data to the User (i.e. as a LD mechanism), or they could be used as additional ranging sources, thereby enhancing System availability for the User. For the latter option the synchronisation of pseudolites with Galileo System Time (GST) is essential. The use of a precision oscillator (rubidium or caesium standard) would greatly increase PSL cost, however the use of less stable oscillators would not facilitate sufficiently stable transmissions. LD differential data messages relating to each pseudolite could however include local (pseudolite) clock offset from GST. This would permit the PSL to operate effectively with only a relatively simple oscillator. With PSL synchronised to GST, the PSL transmissions can be treated in a receiver as independent ranging sources and therefore used to enhance the navigation solution and hence System availability in the vicinity of the Local Element.

The provision of differential pseudolite corrections does, however, introduce a new issue to the Local system. With Satellite transmissions the User's line of sight (LOS) is very similar to that of the DRS providing the User is in the vicinity of the DRS (this can mean within several tens to hundreds of kilometers depending upon the accuracy required and the system configuration). The LOS between PSL and User will, however, generally be very different from that between PSL and DRS. Corrections based only on LOS measurements are therefore generally inadequate, and vector corrections derived from multiple monitors are required.

5 Results Summary

A number of different Local Integrity Concepts were analysed. A summary of the key findings is presented in Tab 3. The application classes satisfied are the same ones listed in Tab. 1 above; alert limit (AL) has been reproduced in this table for ease of reference.

Application Class C and D requirements can be met without Local Augmentation, by using the Galileo SoL service. The same requirements could be met using Galileo OS augmented with Local Integrity.

Application Class B requirements can be met using LIM and DRS, and by providing integrity assured local differential corrections to users.

Application Class A requirements could only be met by implementing LIM and DRS and by using pseudolites in the local area. Locally implemented LIM and DRS,

augmented by GPS signals (but without pseudolites) could almost meet class requirements, but horizontal outages were found with respect to worst user location performance.

The "TBC" in Table 3 for User Processing Time reflects some uncertainty over this parameter. The Galileo baseline value for this parameter is 800ms for a receiver to process and react to IFs in the Galileo transmissions. For this work it was felt that 100ms represents a more appropriate reaction time to process and react to integrity data received over a high-rate data link. Both figures are included in the table for completeness.

6 Galileo Local Segment Programmes and Plans

The Galileo programme is of strategic importance for Europe (6FP, 2003). It will have a major impact on transport and other important sectors of the economy. As a consequence, the success of the programme will largely depend on the capacity of the European economy to introduce Galileo services in a wide range of applications and more generally to benefit from all opportunities offered by the infrastructure worldwide.

The stream of revenues generated by these applications will attract private sector investments. The EC communications on the Galileo programme focus on areas that are fundamental for the user recognition and its market penetration. The 6th Framework Programme (6FP) is the appropriate frame to support these activities (6FP, 2003). As a consequence in the thematic priority "Aeronautics and Space" an indicative budget of 100 M€ is planned to conduct corresponding tasks. These research activities will complement the ESA Galileo developments for the space and related ground segments, including Galileo local demonstrators (ESTEC, 2003).

In order to define the priorities and the appropriate timing of the Galileo 6FP related activities, the following main drivers are considered:

- The overall principles and objectives of the EC research framework programme;

- The top-level EGNOS and Galileo user segment development key points for which intermediate achievements are considered strategic milestones;

- The main European GNSS approach schedule at system level (EGNOS and Galileo);

- The long-term global plan for the GPS modernisation and development of other GNSS/SBAS systems/services in the world;

- The process for setting up the Galileo concession.

Tab 3   Summary of Key Results

Delivery Mechanism	Time To Alert	AL (m)	Integrity Risk (WUL)	Satisfied Application Classes	Key Issues
Stand-alone Galileo	6.0 sec	H 12m V 20m	H $3 \cdot 10^{-2}$ V $3 \cdot 10^{-4}$	C, D	▪ Galileo SoL message delivers Integrity to users via SIS
Scenario (i) Local integrity from local measurements	0.6-1.3 sec	H 12m V 20m	H $3 \cdot 10^{-2}$ V $2 \cdot 10^{-4}$	C, D	▪ Uses Local Integrity Monitor stations (LIM) ▪ Local Derivation of Integrity ▪ High rate LD assumed ▪ User Processing Time TBC (800 or 100ms)
Scenario (ii) Local integrity and Differential from local measurements	0.7-1.4 sec	H 7.5m V 10m	H $2 \cdot 10^{-3}$ V $2 \cdot 10^{-4}$	B	▪ Uses LIM and DRS ▪ Local Derivation of Integrity and Differential corrections ▪ High rate LD assumed ▪ User Processing Time TBC (800 or 100ms)
As Scenario (ii) with GPS SIS added	0.8-1.5 sec	H 7.5m V 10m	H $5 \cdot 10^{-4}$ V $5 \cdot 10^{-14}$	B – A	▪ Uses LIM and DRS ▪ Local Derivation of Integrity and Differential corrections ▪ High rate LD assumed ▪ User Processing Time TBC (800 or 100ms)
Scenario (iii) Local integrity and Differential from local measurements (with Pseudolites)	0.9-1.6 sec	H 7.5m V 10m	H $7 \cdot 10^{-11}$ V $4 \cdot 10^{-14}$	A	▪ Uses LIM and DRS ▪ Local Derivation of Integrity and differential corrections ▪ High rate LD assumed ▪ Synchronised PSL enhances user performance in Local Service Volume ▪ User Processing Time TBC (800 or 100ms)

The first group of activities launched by the Galileo Joint Undertaking (which manages the 6FP) include Task B: "Local Component Development". Initial activities will focus on Core Technology Development and Implementation Planning. The second activities are expected to be launched early in 2004.

7 Conclusions and Recommendations

Existing GNSS Systems and the current generation of regional augmentation systems are unable to meet all current and future User integrity needs. Even the Galileo Global Integrity System, which will provide the Safety of Life Integrity Flags to appropriate users, will not be capable of meeting the most demanding user needs. In particular, certain user applications have been identified who have very stringent time to alert and integrity risk requirements that will not be met by Galileo's satellite-only services.

Local Augmentation could meet all foreseen User integrity requirements including Time to Alert and

Integrity Risk, however not all types of augmentation can meet all needs. The Local Integrity Concepts explored in this report all provided some performance enhancement compared with the baseline of the Galileo Safety of Life (SoL) service. Each concept was described and an appropriate architecture was derived including details of all important functional building blocks. Important algorithms were identified, and performance was estimated.

When Integrity Monitoring is implemented locally, the Local Augmentation System must completely underwrite any Local Service Guarantees. Local Integrity Monitors that capture and analyse the global Galileo transmissions permit complete local control of integrity data, and facilitate a high degree of autonomy from the Global System. This may facilitate local revenue-generating options.

Local Augmentation can improve the Time to Alert (TTA) when compared with the Galileo Global baseline. For the Galileo Global System, a 6 second TTA is specified, however this assumes that SoL signals on both

E5b and L1 carriers are continuously tracked. A further one-second delay is anticipated in cases where only a single carrier is tracked or if one carrier is lost. With Local augmentation, the TTA can be significantly improved; when Local Integrity Monitors are used, TTA of better than 1 second can be achieved.

Local Augmentation will improve availability of Integrity within the Local System Service Volume. When Integrity Data is relayed to users via local means, the requirement to have two or more "connected" satellites available prior to commencement of any critical operation is no longer relevant since an "integrity-assured" solution may be provided using the Local Integrity Data.

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