The Galileo C-Band Uplink for Integrity and Navigation Data

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Abstract. Galileo is a global, European-controlled, satellite-based navigation system. It will have a constellation of 30 satellites and a Ground Segment made by a Ground Control Segment (GCS) providing satellite monitoring and control, and a Ground Mission Segment (GMS) that is in charge of generating the navigation message (Navigation Function) and detecting system malfunctions (integrity function).

The System is designed to detect and broadcast real-time warnings to the users of satellite or system malfunctions regarding:

- ranging signal generation
- navigation message generation
- satellite orbit and attitude
- atomic frequency standard clocks and signals
- loss of sensor stations (GSS)

These warnings are transformed into integrity information that is transmitted to the user receivers where it is elaborated by complex integrity algorithms whose final result is the provision of the following information:

- stop using the Galileo system
- complete the current operation (i.e. landing) but then stop using the Galileo system
- use the Galileo system

The maximum latency between the time at which a malfunction is detected and the time at which the user integrity algorithm produces the "stop using the system" condition (Time-to-Alert) is 6 seconds. This latency includes the time needed to generate, uplink, downlink and process in the user receiver the integrity information produced by the GMS

This paper presents an overview of the Galileo System Architecture and describes the way the C-band uplink has been designed and dimensioned to fit to the stringent requirements of navigation data and integrity information dissemination.

1 The Galileo System Architecture

The Galileo System is designed to provide a high accurate global positioning service and information regarding the quality of this service (system integrity) at the same time. The integrity information is updated every second. Thus the system is designed to be synchronous modulo 1 second.

The system is composed by four segments:

- The Space Segment (30 satellites)
- The Ground Control Segment (GCS)
- The Ground Mission Segment (GMS)
- The Test User Segment (TUS) which includes the Test User Receivers

The space segment consists of a Walker constellation of 30 spacecraft in MEO orbits, expandable in the future to up to 36 satellites. The 27 operational satellites are distributed uniformly in 3 different orbit planes separated by 40° with the ascending nodes of the orbital planes separated by 120°. There is 1 spare satellite on each orbital plane, positioned between two operational satellites.

The constellation of satellites is controlled and commanded by two Ground Control Centres (GCC), each one made up by one GCS and one GMS, and a network of ground stations, namely 5 TTC stations operating in S-band (2.048GHz for uplink and 2.225GHz for downlink) and 9 ULS stations operating in C-band (5.005 GHz uplink only).

The S-band stations are used for satellite and constellation control. Telecommands are uploaded by the ground stations at 2.048GHz and telemetry downloaded by satellites at 2.225GHz. During nominal operations this link is operated in spread spectrum mode although a PM mode is foreseen for initial satellites deployment (LEOP/IOT) and contingencies. In this case the spacecraft are operated in FDMA mode and the frequencies are selectable among 8 different couples for uplink/downlink.

The C-band stations are used for uploading navigation and integrity data that are subsequently broadcast through the navigation signals to the users. These transmitting stations operate at 5.005GHz in spread spectrum.

The Galileo satellites carry 6-channels CDMA receivers to allow simultaneous access to 1 ULS and to up to 5 external uplink stations.

The system provides 4 different navigation services, namely the Open, Safety-of-life, Commercial and Public Regulated servicesn via simultaneous transmission to the users of three navigation signals at frequencies between 1.1GHz and 1.6GHz, as in Tables 1 and 2.

As can be seen there are 5 types of messages;

- the "Navigation message" containing:
  - time & clock corrections
  - ephemeris, almanacs
  - ionospheric corrections

Table 1. Galileo frequency plan.

Signal	Carrier-frequency	Polarisation	Transmitted bandwidth	Modulation
E5	1191.795 MHz	Right-hand circular	92.07 MHz	AltBOC
E6	1278.750 MHz	Right-hand circular	40.92 MHz	Constant envelope modulation
L1	1575.420 MHz	Right-hand circular	40.92 MHz	Constant envelope modulation

Table 2. Mapping of services on different signal components and message content/allocation.

		Message data content				
Services	Channel	Navigation	Integrity	Search & rescue	Supplementary	Service management
OS	E5a-I	Yes	No	No	No	No
OS/CS/SOL	E5b-I & L1-B	Yes	Yes	Yes	No	Yes
CS	E6-B	No	No	No	Yes	Yes
PRS	E6-A & L1-A	Yes	Yes	No	No	Yes

  - Broadcast group delay
  - SISA (Signal-in-Space Accuracy)
- the "Integrity message" containing:
  - **Integrity tables** for the global Integrity that include flags to indicate the integrity status of each navigation data broadcast by each satellite.
  - **Alerts** to be broadcast with an alert process that shall take less than 6s. This latency constraint is the major design driver for the complete Galileo system. Alerts are timely warnings to alert the users when the system cannot be used for navigation.
- The "Search and Rescue" message. Galileo supports the S&R service acting as relay of VHS distress beacons and by providing in the L-band downlink the capability to send up to 5 messages of 120 bits every 60 seconds or up to 7 messages of 80 bits every 60 seconds to those beacons equipped with a suitable Galileo receiver.
- The "Supplementary data" provided as part of the CS message on E6. The supplementary data is expected to provide weather alerts, traffic information and accident warnings, etc. This data is almost certainly geographically related and so could be shared between satellites.
- The "Service management data used to provide key management and other information to enable controlled access to the Galileo signals and message data.

The signals are transmitted by each satellite and comprise ranging codes and timing information. The timing information is included as part of the navigation message containing additional information relating to the satellite itself, the overall constellation and the integrity of the service.

The multi-frequency signals transmitted allow improving the accuracy of the fix since user receivers can calculate the corrections for ionospheric effects.

The 40 Galileo Sensor Stations (GSS) perform constantly measurements on the L-band navigation signals to detect faulty satellites. These measurements are transmitted to both GCCs. The GSSs are located in different geographical location to perform a worldwide monitoring of the navigation signals.

A simplified overview of the Galileo architecture is shown as in Fig. 1.

The single elements (MGF, CMCF, etc.) in the GCC will be described in the next sections.

The GMS and the GCS within each GCC are linked to the remote ground stations through the MDDN (Mission Data Dissemination Network) and the SDDN (Satellite Data Dissemination Network) respectively.

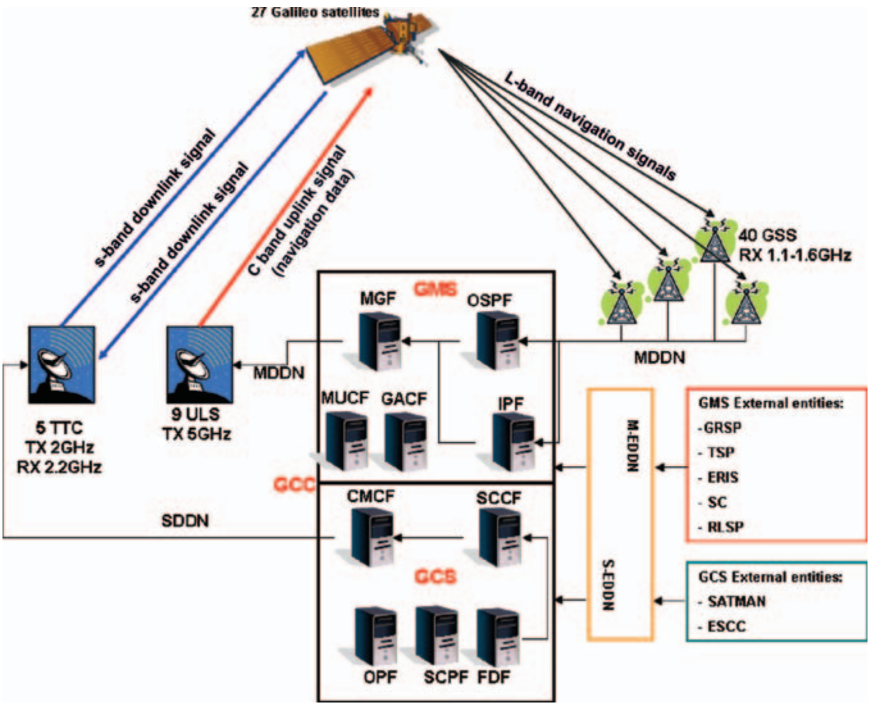

Fig.1. Galileo architecture overview.

The two ground segments are also connected to a number of entities external to Galileo. For the GMS they are namely:

– *GRSP* (Geodetic Reference Service provider). The GRSP provides the GTRF (Galileo Terrestrial Reference Frame which is linked to the ITRF
– *TSP* (Time Service provider). The TSP provides Galileo with the daily predicted value of the International atomic Time (TAI) with respect to the GST (Galileo System Time) and with frequency offset and the daily steering correction to be applied by GMS to GST
– *ERIS* (External Region Integrity System). The ERIS are external entities able to determine and distribute to users through direct (C-band) or indirect (GMS) uplink of integrity information regarding the Galileo navigation signals on a regional scale (Galileo provides indeed integrity information on a global scale).
– *SC* (Service Center). Service Centres are all those facilities implemented by the Service Providers to administrate navigation, timing, other navigation-related services and revenue-generating services offered to the users, distribute off-line Galileo data products, gather input data (commercial service data) to be disseminated by Galileo satellites, and manages CS users access control.
– *RLSP* (return Link Service Provider). The RLSP is the single interface with Galileo of the COSPAS-SARSAT, an international Search&Rescue system that processes distress signals from active beacons and interacts with the SAR community.

The GCS interface with the following external entities:

- *SATMAN* (Satellite Manufacturer). The SATMAN provides a number of satellite parameters, such as the satellite mass at the manufacturing stage, that will be used by the GCS during the satellite lifetime.
- *ESCC* (External Satellite Control Centre). The ESCC are the external leased satellite control stations that will be leased to perform LEOP (i.e. the positioning in the initial orbit) and IOT (in-orbit testing) for each satellite before hand over to the GCC control.

1.1 Description of the GMS

The main functions of the GMS are:

- to monitor the navigation signals transmitted by the Galileo satellites
- to calculate all the navigation and integrity data that need to be broadcast in the navigation signals
- to collect data coming from external entities that need to be broadcast in the navigation signals
- to multiplex these data in single sub-frames
- to define the sub-constellation of satellites to which these sub-frames have to be uploaded
- to uplink this data to the spacecraft

In addition the GMS performs a number of other functions such as monitoring of GCS assets, monitor and control of networks and global archiving.

The list of elements in the GMS and a brief description of their functions are shown as in Table 3:

Table 3. Description of the elements in the GMS.

GMS element	Name	Function
GSS	Galileo Sensor Station	Production of SIS observables for navigation & integrity algorithms
PTF (*)	Precise Time Facility	Generation of GST (Galileo System Time) steered towards TAI.
OSPF	Orbit and Synchronisation Processing Facility	Production of satellites ephemeris, clocks, almanacs and SISA predictions for OS, CS, SoL and PRS
IPF	Integrity Processing Facility	Integrity data computation for PRS and SoL (integrity tables and integrity alerts)
MGF	Message Generation Facility	Multiplex of the data streams making up the C-band Uplink Messages (including the Galileo Navigation and Integrity data generated within the GMS, the SAR data provided by the RLSP, the commercial data provided by the GOC SC, integrity data provided by ERIS, and PRS data

(*Continued*)

Table 3. Description of the elements in the GMS.—cont'd

GMS element	Name	Function
SPF (*)	Service Products Facility	The SPF provides the interface between the GMS elements located in the GCC and the external world.
GACF	Ground Assets Control Facility	– Technical monitoring and control of ground assets – Support to the execution of the activities planned for maintenance and the related reporting – Data archival and retrieval (including long term archiving for GCS)
MUCF	Mission and Uplink Control Facility	– Overall mission management (long-term and mid-term planning) – Short-term planning – On-line supervision of the mission performance – Mission performances prediction or short-term forecast of services performances
MKMF (*)	Mission Key Management Facility	Management of the payload security units (C-band part)
PKMF (*)	PRS Key Management Facility	Management of the payload security units (PRS navigation service)
ULS	Up-Link Station	Modulation and transmission of C-band uplink signals
MDDN	Mission Data Dissemination Network	Communications network facility to provide intersite connectivity
M-EDDN (*)	Mission External Data Dissemination Network	Provision of communication services between GMS and external entities (GRSP, TSP. SC, RLSP, etc.)

(*) These elements are not shown in Fig. 1 for sake of simplicity

1.2 Description of the GCS

The prime role of the GCS within the Galileo system is to provide satellite control and management.

This is accomplished via the generation and uplink of Telecommands (TC) and the reception and processing of spacecraft Telemetry (TM). In addition the GAS is able to perform spacecraft positioning through a two way ranging process on the S-band signals.

Aside from its primary role in spacecraft management the GCS also performs specific functions with respect to the Ground Mission Segment (GMS).

In order to achieve the primary role, the elements within the GCS provide functions that comprise of both real time and non-real time processes. These range from planning through to execution of TC, TM and Ranging (RNG). The GCS also performs its internal monitoring to ensure the efficiency and robustness of the segment elements throughout the lifetime of the programme.

Within the GCC, the GCS provides facilities for the real time monitoring and control of the Galileo satellites and ground assets (SCCF, CMCF and SKMF).

These facilities perform the routine automated operations supervised by operators, although critical operations will likely be performed manually, with the support of automated procedures.

GCS non-real time operation functions are supported by the SCPF, OPF, FDF and CSIM facilities within the GCC.

The list of elements in the GCS and a brief description of their functions is shown as in Table 4:

Table 4. Description of the elements in the GCS.

GCS element	Name	Function
TTCF	Telemetry, Tracking and Command facility	The TT&C facility support the space-ground interface for telemetry acquisition and telecommand uplink as well as the provision for 2-way ranging. Each TT&C station acquires and controls the satellites in accordance with commands received from the SCCF via the CMCF.
SDDN	Satellite Data Dissemination Network	Communications network facility to provide inter-site connectivity
S-EDDN	Satellite External Data Dissemination Network	Provision of communication services between GCS and external entities (SATMAN and ESCC)
SCCF	Spacecraft Constellation Control Facility	The SCCF is the core element that supports realtime operations for both routine and special satellite operations. This element provides for telemetry and telecommand processing status displays, manual commanding facilities together with operations automation at both schedule and procedure levels.
GCS KMF (*)	GCS Key Management facility	The GCS Key Management Facility is responsible for all TM & TC related security key management, both on the ground and on the spacecraft including the ground based encryption / decryption of TM & TC with cryptographic devices. It also provides M&C for the spacecraft security units.
CMCF	Central M&C Facility	The CMCF monitors and controls all GCS assets (only monitors the GCS KMF), both in the GCC and at each TT&C station. Each TT&C station has its own local M&C and the CMCF M&C of the TTCF is performed via the SDDN to all TT&C sites. The CMCF provides a summary of TT&C station status to the SCCF that is required to coordinate and synchronise satellite operations.
FDF	Flight Dynamics Facility	The FDF supports orbit prediction, manoeuvre planning and attitude monitoring for both individual satellites and overall constellation management. It is also capable of performing orbit determination based on S-band two-way ranging data generated by the TT&C Facility.
OPF (*)	Operations Preparation Facility	The OPF comprises the editors to develop and maintain mission operations data, including the spacecraft databases and operations procedures,

(*Continued*)

Table 4. Description of the elements in the GCS.—cont'd

GCS element	Name	Function
		together with tools to perform overall consistency checking of configuration data and to support configuration control.
CSIM (*)	Constellation Simulator	The CSIM provides a simulation of the whole Galileo constellation of satellites, as well as the ground control network of TT&C stations.

(*) These elements are not shown in Fig. 1 for sake of simplicity

1.3 Description of the SSeg

Galileo satellites are composed of the following subsystems:

- Payload Subsystem including the navigation payload and the SAR payload
- Structure Subsystem
- Thermal Control Subsystem (TCS)
- Electrical Power Subsystem (EPS) with the following units:
  - Solar Arrays (SA)
  - Solar Array Drive Mechanisms (SADM)
  - Battery
  - Power Conditioning and Distribution Unit (PCDU)
- Harness
- Avionics Subsystem with the
  - on-board computer (Integrated Control and Data Handling Unit, ICDU)
  - Attitude and Orbit Control System, AOCS (based on earth sensors, sun sensors, gyros, reaction wheels and magnetic torquers),
  - Software (SW)
- Telemetry, Tracking and Command (TTC) Subsystem (with S-Band Transponder and two low-gain, omni-directional antennas)
- Propulsion Subsystem (mono-propellant system with one tank and 8 thrusters)
- Laser Retro-Reflector (LRR)
- Platform Security Unit (PFSU)

The main functions of the payloads embarked on board the Galileo satellites are:

- Provision of on-board timing signals
- Receiption & storage of up-linked navigation message data
- Receiption & storage of up-linked integrity data (from 6 simultaneous uplink channels in C-band)
- Assembly of navigation message in the agreed format
- Error correction coding of navigation message
- Generation of ranging codes
- Encryption of ranging codes as required

– Generation and modulation of L-Band carrier signals
– Broadcast of navigation signals
– Relay VHF S&R distress beacon in L-band (1.544GHz)

The list of units in the Navigation Payload and a brief description of their functions is shown as in Table 5:

Table 5. Description of the payload units.

Payload unit	Name	Function
USO	Ultra Stable Oscillators: – Passive Hydrogen Maser (PHM) – Rubidium Atomic Frequency Standards (RAFS),	Provision of timing signals. This is done by high precision on-board clocks, implemented as two (cold) redundant pairs per satellite, each pair including two different technologies, the Passive Hydrogen Maser (PHM) which is the p rimary reference clock and the Rubidium Atomic Frequency Standard (RAFS), both of them being operated simultaneously.
CMCU	Clock Monitoring and Control Unit	The whole clock ensemble is under the control of a dedicated (internally cold redundant) CMCU which performs the monitoring and switching functions (selection under Ground control) and generates a highly stable on-board reference frequency of 10.23 MHz which is distributed to the other payload units.
MISANT	Mission antenna (C-band)	The C-band receiving antenna (small aperture axially corrugated circular waveguide horn)
MISREC	Mission Receiver	The MISREC includes the Mission Processor function (MISPROC) and performs the 6-channel receive function in C-band
PLSU	Payload Security Unit	The data output from the MISREC is routed to the Payload Security Unit (PLSU) which performs COMSEC treatment of the incoming signal (authentication verification)
NSGU	Navigation Signal Generator Unit	The NSGU receives the up-linked navigation data from the PLSU and uses them to generate the navigation signals in the appropriate format, performs the PRN encoding and the modulation of the 3 navigation signals (E5, E6 and L1) and passes them to the FGUU
FGUU	Frequency Generator & Up Converter Unit	The FGUU performs the up- conversion into L-band of the 3 signals
NAVHPA	Solid State Power Amplifiers	The 3 L-band navigations signals (E5, E6 and L1) are fed into three different SSPAs
OMUX	Output Multiplexer and filters	Multiplexes E5 and E6 signals at the output of the SSPAs

(*Continued*)

Table 5. Description of the payload units.—cont'd

Payload unit	Name	Function
NAVANT	Navigation antenna (L-band)	The Navigation transmit antenna is operated in RHCP polarisation and consists of a high and a low band beam-forming network and a dual band array of radiating elements which provides a global coverage iso-flux radiation pattern
RTU	Remote Terminal Unit	The payload Remote Terminal Unit performs the communication functions between the payload and the avionics subsystem via the 1553B data bus

2 The Message Generation and the Uplink Chain

The Galileo Uplink baseband signal comprises a multiplex of data streams originating from both Galileo and external origins (External Regional Integrity Systems, Search & Rescue). The multiplexing function is implemented in the Message Generation Facility (MGF) in the GMS and onboard the spacecraft.

Each second a navigation and an integrity message is generated by the MGF using data provided respectively by the OSPF and IPF which process of the measurements made by the GSSs.

These messages are uplinked every second to the satellites through a dedicated network of 9 C-band uplink stations (ULSs) and broadcast to the users, by the satellites using the L-band frequencies.

Two different types of alerts are transmitted in the integrity message depending on the failure occurred:

- Satellite failure: an alert is broadcast indicating which satellite is not ok (NOK). These alerts are coded on 1 bit per satellite.
- Ground segment failure: an alert is broadcast indicating the estimated degradation of the positioning accuracy. These alerts are coded on 4 bits per satellite.

Integrity alerts for up to 36 satellites can be uplinked and broadcast simultaneously.

A simplified description of message generation performed in the MGF and of the uplink chain is shown in Fig. 2.

The Galileo up-link message is multiplexed in the GMS and contains, as described in section 2, the following information:

- Galileo Integrity data for the SoL service (generated by the IPF)
- Galileo Integrity data for the PRS service (generated by the IPF)
- Navigation data for all the services (generated by the OSPF)
- Search-and-Rescue return link data (acknowledgment of distress signal reception provided by the RLSP)
- Commercial Service data (provided by the SC)

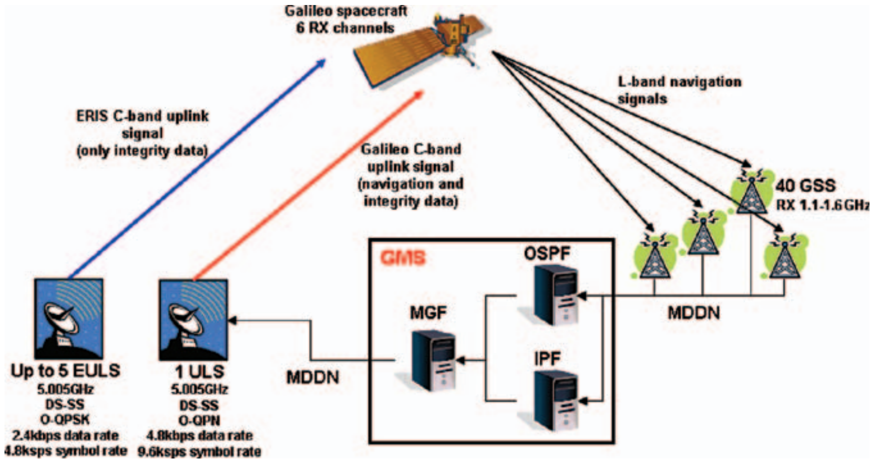

Fig. 2. The message generation and uplink chain.

The baseband message stream is sent by the MGF to the ULS where it is used to modulate the RF signal transmitted to the spacecraft.

Each Galileo satellite can be accessed simultaneously by 1 ULS to upload the messages generated by the MGF and by up to 5 EULSs (External Regional Integrity Uplink Stations) to upload regional integrity information generated outside the Galileo boundary. Therefore, an additional processing and multiplexing function is implemented in the satellites. In this way each satellite broadcasts the global integrity information generated by Galileo (GMS) and the regional integrity information generated independently by External Regions (ERIS).

This capability of allowing up to 6 simultaneous accesses to a single satellite along with the maximum time (133ms) allocated for uplinking the integrity information, have been some of the main design driver for this link.

The key requirements which have driven the design of this link are listed and discussed as in Table 6:

Table 6. C-band link: main design drivers.

Requirement	Source	Remark
The allocated band for the link is 5.000-5010 GHz	Band allocation for RNSS	The actual carrier frequency is selected taking into account that carrier, code and bit rate have to be in a fixed ration and derived by a common source. The modulation and chip shape filtering (on the TX side) are defined in such a way to have the highest possible chip rate still avoiding interference with adjacent services (radioastronomy)

(*Continued*)

Table 6. C-band link: main design drivers—cont'd

Requirement	Source	Remark
6 simultaneous CDMA accesses to each satellite	System requirement	Colliding requirements difficult to be met simultaneously.
ULS minimum elevation anglebetween 5° and 10° also in tropical regions where attenuation and scintillation effects are significant.	Minimization of the number of ULS sites and antennas	
No Up link power control	Simplification of system complexity	
The maximum time allocated to ULS processing and uplink (640bits of integrity information every second) is 133ms	System requirement for the maximum TTA (time-to-alarm)	Driver for the definition of the data rate for the Galileo uplink
ULS uplinked Information data twice the ERIS uplinked information data	ERISs do not uplink navigation data	Driver for the definition of the data rate and modulation scheme for the ERIS uplinks
Doppler compensation: +/− 11 KHz, step less than 2Hz	Constant data rate at receiver level	The Doppler, and its compensation affects both chip and symbol rates proportionally
Message structure and sequencing designed to allow the nominal broadcasting of NAV data to be interrupted and restored soon after integrity information transmission	System requirement for the maximum TTA (time-to-alarm)	Requires dynamic management of navigation and integrity messages.
On ground and/or on board Multiplexing of S&R and ERIS data	System requirement to support S&R service and ERIS autonomous integrity determination	

2.1 Message Design

The definition of the message structure and sequencing in both the uplink and the downlink has been one of the main challenges in the design of the Galileo system.

As described in Table 6 the two major constraints have been the management of integrity alerts and the reduction of the TTA, leading to a complex mechanism of dynamic management of alerts based on priorities. The structure of the message in the downlink allows the insertion of alerts in each 1 second interval. The C-band message is designed to allow simultaneous uplink of navigation and integrity data as described in Fig. 5.

Integrity alerts are transmitted as soon as they are received by the spacecraft, i.e. they take priority over normal integrity message transmissions. The message sequence generated by the MGF guarantees that even in case of alerts, the user will receive a complete navigation data batch in 30 seconds.

The message structure has been also optimised to allocate the S&R data and the ERIS integrity data without impacting the integrity performance.

Owing to the volume of data that must be uplinked to each satellite and the regularity of these transmissions, the uplink system is designed to be synchronous. A full data set contains thirty lines of code where each line is one second in length. This forms the uplinked page to which the receive system will be synchronised to. Synchronisation of the page is achieved by the satellite searching through the data to identify the first line within the page.

Once the uplink signal is stripped of the coding and modulation layers, it can be seen that the message is composed of one second frames per line. These frames actually contain separate Integrity and Navigation messages which are separately processed within the satellite.

Each integrity and message sub-frame then is fragmented down to multiple packets with dedicated descriptor headers identifying their purpose and application within the satellite transmitted signal. This structure allows for a simple and yet efficient provisions for each of the different services that the signal in space must provide.

The packets will thus contain updates of the ephemeris and almanac for each satellite providing the user with up-to-date information on the constellation.

2.2 The C-band Link Characteristics

The uplink transmission system adopts a phase continuous frequency compensation system to allow for the change in Doppler each satellite approaches and passes. Also, this allows to maintain a constant data rate at the C-band receiver output. The synchronism of the signal is also maintained between the carrier frequency, code rate, and symbol rate. This helps the receive system to maintain bit lock and synchronisation without the need for excessive on board buffering.

The uplink system uses commercially available 3m class Cassegrain antennas transmitting the right hand circular polarised signal to the satellites.

Compliance to the ITU requirements is met with the typical filtering processes as well as digital chip shape filtering to a 0.35 square raised root cosine.

The receive system is designed to be able to discriminate and demodulate simultaneously up to six C-band signals transmitted by ground stations accessing the satellites in CDMA mode. This also has to account for the varying ranges between each ground station (near-far range effect) as well as stringent atmospheric conditions of some of the locations (Rain attenuation and atmospheric scintillation).

The network of 9 ULS stations allows for one station to drop the uplink signal and another station to re-assume the link while still maintaining an overall seamless provision of the 2 necessary independent[1] integrity links to the end user (break-before-make system). The same design is adopted for both the Galileo and Regional integrity systems.

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[1] "Independent path" means the each user receives the integrity information from at least two satellites connected with two different ULS sites.

In order to achieve the overall stringent requirements, each ground station is carefully coordinated and synchronised through careful scheduling.

2.3 Coding Layers and Modulation

The Galileo C-Band uplink signal employs a CDMA Direct-Sequence Spread-Spectrum together with an Offset-Quadrature Phase Shift Keying (O-QPSK) of the carrier. The gold code sequences have been selected providing excellent orthogonality and thus cross correlation isolation between signals.

This modulation has been selected to optimise signal spectral quality through easing the achievement of ground station transmit chain linearity.

The link budget is reinforced by a combination of inner and outer encoding. As with typical communications systems a standard ½ rate convolution encoder is used on the uplink signal with the corresponding Viterbi decoder (with a 3-bit soft decision algorithm as per [2]) within the receive modules.

The different Reed Solomon codes chosen for each sub-frame are designed such that the frame error rate probability will be sufficiently low that it can effectively be ignored while minimising the processing overheads of the satellites. This is required to minimise the processing time and stringent transit times for the integrity signal such that the necessary Time To Alarm can be achieved. The strength of the Reed Solomon coding is also reinforced by bit randomisation in order to ensure a sufficient number of transitions, whatever is the data to be uplinked.

The order of the coding and modulation operations is described in Fig. 3.

At the transmission side (ULS) the application data (Navigation and integrity sub-frames) after randomization and inner Reed-Solomon coding are NRZ-M encoded.. The data stream NRZMi(t) at the output of the differential encoder (at the data rate fd = 4,826 bits/s) is input into the convolutional encoder as per CCSDS recommendation [1]. The convolutional encoder produces two branch streams (carrying different data) classically denoted G1 & G2, each at rate fd. The two streams, with G2 is logically inverted, are exclusive-ored with two different pseudo-random sequences (C1, C2) at rate fc = 1023 * 4826 chips/s having the origins aligned. One of the two sequences (Y'(t) in the figure) is delayed by one-half chip. The spread branch signals modulate the in-phase and in-quadrature carriers at nominal frequency $f^0 = \omega/2\pi$ = 5.0050275 GHz yielding the I and Q signals the sum of which is the modulated signal M = X'(t)* cos(ωt) + Y''(t) * sin(ωt). The process is described in Fig. 4.

The ERIS C-band uplink is very similar to the Galileo one except that the convolution encoder outputs only one data stream which is exclusive-ored with a single pseudo-random sequence, i.e. the ERIS data rate is ½ that of Galileo.

Fig. 3. Order of the coding and modulation operations.

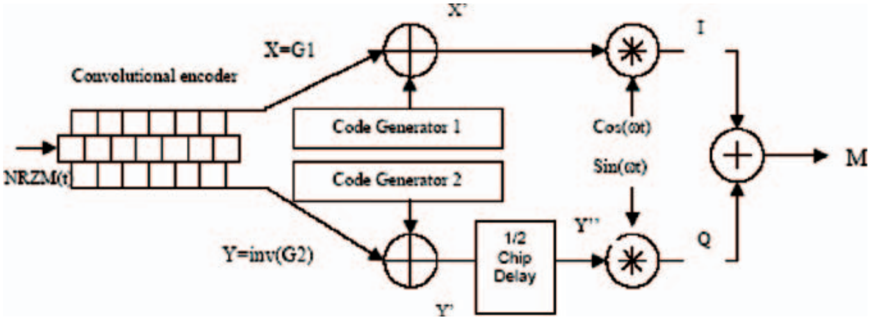

Fig. 4. Generation of the RF signal.

Table 7. Signal to interference ratio expected in some geographical locations candidate to hosting ULS stations.

	Signal / Interference [dB] (signal in nominal conditions at 10°)		Signal / Interference [dB] (signal in nominal conditions at 5°)	
	Power ratio with 5 interferers	Power ratio with a single interferer	Power ratio with 5 interferers	Power ratio with a single interferer
Kiruna	−9.17	−5.1	−12.71	−7.08
Kourou	−14.92	−10.8	−23.79	−18.16
New Norcia	−9.83	−5.7	−14.34	−8.71
Noumea	−11.60	−7.5	−17.82	−12.19
Papeete	−13.69	−9.6	−21.83	−16.26
Reunion	−12.29	−8.2	−19.15	−13.52
Santiago	−8.63	−4.5	−11.77	−6.14
Trivandrum	−15.01	−10.9	−23.06	−18.43
Vancouver	−9.97	−5.9	−14	−8.37

2.4 The Link Budget

The C-band link is dominated by self-interference. The useful signal is interfered by up to 5 signals transmitted by the other ULS/EULS. The presence of Galileo's intra-system interferers is indeed a special feature of the system. The total power of these unwanted signals far exceeds the thermal noise power at the receiver input because ULSs are operated without uplink power control.

The situation is made worse by the fact that the 9 ULS are located in geographical regions in which the effects of ionosphere, troposphere and rain can be largely different, as shown in Table 7.

The analysis of the simulations made for the different geographical locations has suggested that the EIRP transmitted by the ULSs had to be maintained at the minimum possible level. For this reason the EIRP has been defined at two different levels, 52.8dBW for ULSs located in tropical regions where atmospheric attenuations can be really significant, and 50.8dBW for those ULS located at temperate latitudes or in very dry environments.

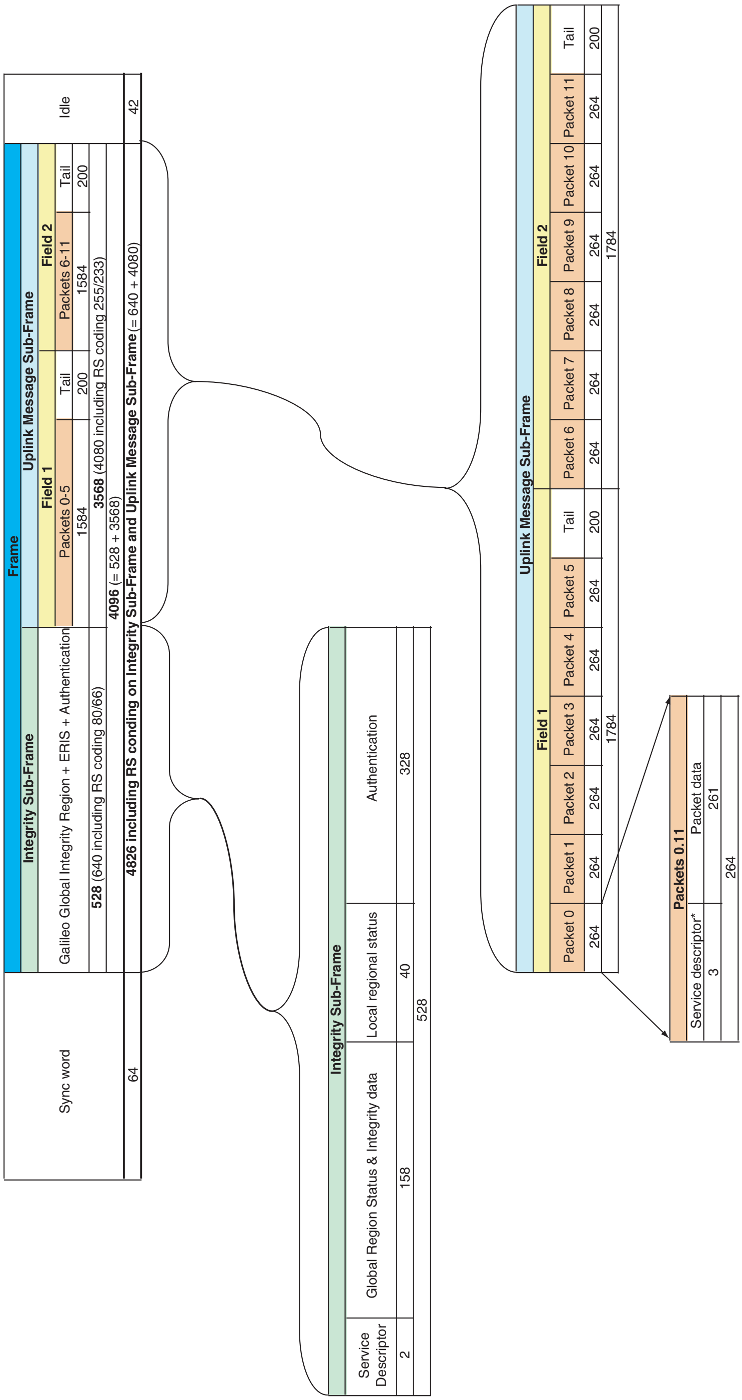

Fig. 5. Structure of the uplink message frame.

The EIRP for the EIRS uplink station has been set at 47.8dBW, taking into account that these station will not be operated below 10° elevation and that the ERIS uplink has 1/2 the data rate of Galileo.

3 Conclusions

Galileo is a satellite navigation system thought to provide global and regional integrity information to the users with extremely low latencies between the time when a failure/problem occur and the time at which the user is informed (receiver output). This capability has been the main system design driver and has led to a very complex mechanism to generate and disseminate integrity information. In particular, the requested integrity performances are based on a complex data dissemination concept of which the C-band uplink is a key part.

This link has been designed to: fulfill simultaneously all the constraints and to simplify at the maximum extend the complexity in the system.

References

[1] "*Radio Frequency and Modulation Systems - Part 1 Earth Stations and Spacecraft*", CCSDS 401.0-B, June 2001

[2] "*Channel Coding and Synchronization.Part 1: Synchronous*", Draft Recommendation for Space Data System Standards, CCSDS 131.0-R-1. Red Book. Issue 1, June 2000