GAUSS Satellite Solution for Location-Based Services

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Acronyms

3GPP	Third Generation Partnership Project
ASMS-TF	Advanced Satellite Mobile Systems - Task Force
B/M	Broad/Multi
BLER	Block Error Rate
CMDA	Code Division Multiple Access
COM	Communication
EC	European Commission
EDC	Error Detection and Correction
EGNOS	European Geo-stationary Navigation Overlay Services
ESA	European Space Agency
ESTB	EGNOS System Test Bed
ETSI	European Telecommunications Standards Institute
FL	Forward Link
GAUSS	Galileo And UMTS Synergetic System
GEO	Geostationary
GIS	Geographic Information System
GGSN	Gateway GPRS Support Node
GNSS	Global Navigation Satellite System
GNSS-1	Global Navigation Satellite System phase 1
GNSS-2	Global Navigation Satellite System phase 2
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GW	Gateway
ID	Identifier

IP	Internet Protocol
ISO-OSI	International Organisation for Standardisation-Open System Interconnection
IST	Information Society Technologies
LBS	Location Based Services
LCS	LoCation-based Services
M-to-P	Multipoint-to-Point
MT	Mobile Terminal
MTB	Mediterranean Test Bed
MU	Mobile User
NAV	Navigation
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
POI	Point-Of-Interest
P-to-M	Point-to-Multipoint
P-to-P	Point-to-Point
PVT	Position, Velocity & Timing
RAN	Radio Access Network
RL	Return Link
RLC	Radio Link Control
RTD	Research and Technological Development
RTT	Round trip time
SBAS	Satellite Based Augmentation System
SES	Satellite Earth stations & Systems
SC	Service Centre
SIS	Signal In Space
SP	Service Provider
SW-CMDA	Satellite Wideband-CDMA
S-UMTS	Satellite-Universal Mobile Telecommunication System
TB	Transport Block
TTI	Transmission Time Interval
TX	Transmission
UDP	User Datagram Protocol
UT	User Terminal
WG	Working Group

Abstract

GAUSS (Galileo And UMTS Synergetic System) is a Research and Technological Development project co-funded by European Commission, within the frame of the 5th IST Programme. The project last two years, starting from December 2000, and it is now successfully completed.

GAUSS main goal is to demonstrate the feasibility of integrating Satellite Navigation GNSS and UMTS communication technology for the development of high quality location based services. The provided services envisage the transmission of small data packets carrying precise positioning & timing information, as required in road info-mobility and safety, emergency assistance and inter-modality applications.

A synergetic combination of GNSS-2 GALILEO and UMTS system was studied, and a Target System using such an integration for providing LBS was designed.

A Demonstrator was built up, by combining new purposely developed hardware and software components with existing facilities. A prototype of user terminal was realised, integrating off-the-shelf equipment and technologically advanced parts, based on GNSS-1, GALILEO and S-UMTS compatible units. Mobile e-safety and transport efficient management are the core of the developed applications, to provide reliable and effective services to citizens: road info-mobility and fleet management, inland waterways vessel traffic management and information, port/terminals appointment monitoring & control, dangerous goods transhipment supervision, emergency assistance.

A trial campaign run into real environments was performed in Summer 2002. GAUSS Demonstrator performances and benefits were validated with the direct involvement of an intermodal transport user, specifically operating in the inland-waterways and roads. Safety-of-life transhipment over the Po River were thoroughly tested and assessed. Applications for emergency assistance, Point of Interest inquiry, localisation and control of commercial fleet were also proven.

GAUSS successfully demonstrated integrated precise Satellite Navigation GNSS1 positioning based on EGNOS and Satellite UMTS packet communication, for provisioning of high quality LBS. Horizontal accuracy better than 3-m was achieved in the trial area (Northern Italy – Como Lake, Parma and Po River neighbourhoods). The MTB (Mediterranean Test Bed) was utilised because of the poor performance coverage of the ESTB system over the Italian regions. The new technology with respect to the current state-of-the-art, developed within the project was validated during the trial campaign, including the implemented broadcasting and multicasting communication of data packet compliant to 3GPP standard (current release 4). In this framework, GAUSS fruitfully contributed in the activities and results of ETSI SES S-UMTS Working Group and ESA ASMS-TF.

GAUSS results open the way to the development and exploitation of advanced technology supporting high quality, reliable and effective services to citizens for the transport sector and whole mobility domain, in view of GALILEO and UMTS scenarios: emergency and e-safety applications, fleet and freight transport management (rail, road, maritime and inland waterway), hazardous and valuable goods transportation, containers tracking.

GAUSS Scenario

The demand for mobile information services coupled with positioning technologies for delivering value-added services that depend on a user's location has rapidly increased during last years. In particular, services and applications related with improved safety and security look very attractive.
From the analysis of the state-of-the art, it comes that various technologies are currently available on the European market, while mobile industry is gearing up to launch a wide variety of location services like tracking, alarming and locating. These rely on various positioning techniques such as localisation either based on cell detection or triangulations and satellite navigation. Nevertheless, when addressing safety of life as well as security applications, severe hurdles have to be posed in the light of existing technologies. Existing navigation (e.g. GPS) and communication (e.g. GSM) systems are not able to completely satisfy the needs and requirements of safety-of-life-critical applications. As a matter of fact, the GPS system's main weaknesses today is its lack of integrity, which means its inability to warn users of a malfunction in a reasonable time, while the other positioning techniques do not provide satisfactory accuracy as well, and terrestrial communication networks are not capable to cope with stringent requirement in terms of service reliability and coverage.
In this context, GAUSS proposes an innovative satellite-based solution using novel technology and effective tools for addressing mobility challenges in a cost efficient manner, improving safety and effectiveness.

GAUSS Rationales

The GAUSS rationales for the proposed solution rely on a twofold consideration:

1. A navigation system intrinsically requires the capability of communicating the Mobile User position and timing related information to a Service Centre/Provider, and conversely obtaining the service-related content data;
2. The existing and available systems are not capable to completely fulfil stringent requirements for the navigation and communication capabilities, as those coming from classes of users in the inter-modality and specific personal info-mobility sectors.

As a matter of fact, GAUSS end-users manifest a common demand for an integrated system capable of providing added-value location-based services, from real time bundled navigation and data communication. Furthermore, they also have stringent and specific requirements for navigation and communications, in terms of:

- High integrity/continuity positioning and guarantee of performance for navigation,
- Highly reliable and available communications, featuring small latency with low-rate data transmission
- Very large population of Mobile Users with respect to the number of Service Centres/Providers
- Wide coverage areas, easily accessible from satellite.

GAUSS key concept is supporting integrated navigation and communication services, by combining GALILEO positioning and timing data with S-UMTS communication capabilities, in order to provide navigation related information (tracking, tracing, alarming, messaging, group broadcasting, fleet management information) oriented to mass and business markets transport & mobility management.

For the navigation functions, the use of GALILEO will ensure a guaranteed quality of service and adequate performances, in terms of accuracy and integrity, as required for safety and working condition improvements (such as restricted waterways - ports, coasts, rivers - and hazardous goods transportation). Furthermore, it also will enable to cope with liability and certification requirements that are needed for responsibility issues, in case of damages or accidents.

From the communication viewpoint, the challenges reside on the usage of the UMTS. This enables to fit GAUSS into an open market place: avoiding proliferation of standards and adoption of open interfaces to be defined by the business interest.

As far as the applications are concerned, GAUSS solution is specifically oriented to the transport and personal info-mobility sectors. It addresses end-users, both in the professional area (such as Fleet Owners, Fleet Managers, Freight and Goods Transport Companies, Service Providers, Drivers) and mass market, and is expected to significantly contribute in the improvement of their quality of life and job efficiency and safety. GAUSS applications are aimed at providing enhanced services, with the purpose of:

- Making inter-modal transport chains more attractive, by increasing its safety and efficiency, through the usage of the GAUSS novel technologies to the transhipment and transportation, integrated with driver information service for road drivers.

- Providing mobile users and road transport drivers with added-value information services, specifically tailored on their position, in order to increase their comfort, security and efficiency of mobility.

Furthermore, the GAUSS solution fully exploits the advantages coming from the usage of the satellite:

- Offering solutions for effectively complement terrestrial based systems (fast and large coverage, economically viable set-up cost, efficient provisioning of broadcasting and multicasting features, gap filler capability)
- Copying with the inter-modality stringent requirements for the communication services, in terms of coverage and service continuity.

Hence, the GAUSS project basic concept relies on the feasibility of a solution for the provision of **high quality Location-Based services**, characterised by:

– **Global coverage**

– **Continuity**

– **Integrity** and high **accuracy** (1-5 m) for positioning

– **Two-way** communications

– **Reliable**, **near real-time** communications

– **Time response guaranteed** within 25 sec

– **Point-to-point, broadcasting** and **multicasting** communication

– **Acknowledgement** (ACK message) supported.

GAUSS Users

The GAUSS solution addresses two classes of users profiles, belonging to info-mobility and inter-modality (road-river) markets. Specific applications exploiting the benefits achievable by the usage of the satellite were designed and developed. In particular, the utilisation of the S-UMTS enables to effectively complement and inter-work with terrestrial based systems, and cope with stringent requirements for coverage and service continuity (which are typical of emergency and inter-modality scenarios).

GAUSS **Info-mobility applications** basically provide services for intelligent and efficient in-vehicle mobility:

- **Information Services**. User positioning information integrated with other information (such as geo-referenced points of interest, traffic information, route, etc.) enable to offer a set of services aimed to improve the citizen mobility, by providing on-demand information, customised on the basis of the users' position

- **Emergency and Breakdown Assistance**. This application comprises a number of separate services currently in rapid expansion within the automotive sector. Essentially, by providing the vehicle location to a service provider, the appropriate response can be organised according to the nature of the problem, whether it is an accident, or a breakdown. The knowledge of the mobile user position together with the communication capability allows the emergency team to locate the notified event and provide assistance in the most efficient way. Furthermore, Emergency applications are characterised by their strong dependence on a reliable and robust system operation, on the accuracy of position determination and on integrity, with unambiguous information and timely response.

GAUSS **Inter-modality applications** address a scenario with road and river as core modes of transport. Applications for Vessel Traffic Management Information (Information, Traffic Organisation, Navigation Assistance Services), Inter-modal Transport Management, Emergency Assistance and Road fleet Management were developed. These applications take advantage of the usage of the GAUSS innovative technological solution, for the provision of accurate updated information and automatic tools, enabling effective and safe operations of ship transport and inter-modality efficiency. As a matter of fact, due to its nature, inter-modality integrates different types of transportation systems involving heterogeneous actors (such as Transport Organiser, Authority, Infrastructure Operator, Terminal Operator, Transport Operator, Mobile User, Customer), with a common need for having a precise tracking and tracing of their mobiles and transported goods. All players are interested in the position of the vehicle/vessel and they have the need for demanding requirements for accuracy, integrity, continuity and availability, along with robust and reliable user terminals under almost all circumstances and environmental conditions. Additionally, in this sector, the implementation of location-based services raises several legal issues, mainly connected to consumer's rights, privacy, liability and certification. Effectiveness of ship transport and improved quality of transport (in terms of safety and efficiency) of inter-modal operations is pursued.

These concepts are emphasised when transport involves dangerous goods, where application of regulatory regimes about positioning and tracking is a pre-requisite. This sector demands reliability and predictability, requiring a higher level of service quality compared to the management of “normal” goods transports. On the one hand the hazardous goods transport remote control aims at preventing and reducing any possible impact on environment pollution, and citizen safety in case of any induced disaster. This can only be retained by continuously monitoring and guiding the dangerous goods in transit, e.g. preventing trucks transporting hazardous goods from passing through restricted zones (e.g. natural resource areas, housing areas, etc.). On the other hand, the position of the vehicle can be determined immediately and accurate in case of an accident. Therefore the time of arrival of help at the site of the disaster could be reduced significantly. In order to enable such a kind of service, permanent control of the movements and alarming in case of planned route deviation have to be realised, in compliance with the current regulations. Security, delays predictability, typical transit times, bottlenecks avoidance are the advantages of technology applied to this sector, while maximising safety and minimising risks of possible damaging and environmental pollution.

GAUSS Services and Major Requirements

Very demanding requirements characterise the GAUSS location-based services to the end-users:

- **Navigation Performances**. Very precise positioning along with guaranteed integrity/continuity (necessary for timely location and rescue of the users in distress, for surveillance of dangerous goods traffic, for assisted navigation in restricted water and rivers)
- **Communication Performance**. Highly reliable, quasi real-time communications, with low-rate data transmission. Point-to-point communications, distribution (Broadcasting and Broad-catching) and collection (Broad-casting and Multicasting) of data shall be provided. The applied CMDA resource access techniques according to the S-UMTS standards ensure inter-networking compatibility.
- **Data Link**. Two-way communications, between the Service Provider and Mobile User, based on low-rate transmission of small formatted data packet message, carrying accurate positioning and timing information. Cyclic (on periodic basis) or asynchronous (on request or on event) transmission is allowed. Acknowledgement message capability is also supported.
- **Message Size**. A common flexible fixed-format message characterised by 424-bit cells (either single or up to 8 concatenated cells are allowed). This message is able to carry the required information for all the GAUSS applications. Furthermore, a wider class of Location-based services, requiring small data packet exchange at low bit rate transmission, can also be supported, as no modification is required to the GAUSS standard packet to accommodate in the messages the data required by other specific applications.
- **Service Coverage**. Service coverage should be at least guaranteed across all Europe extension.
- **Latency**. 25 sec maximum is requested for Safety Critical services; but up to 1 min maximum for Not Safety Critical services is tolerated.

- **Applications**. GAUSS applications specifically address two basic scenarios of Info-mobility for mass-market users and Professional Users involved in Vessel Traffic and Inter-modal Transport Management.

GAUSS Target System

An innovative solution is proposed, named Target System, in which the synergy between the navigation and communication systems is fully exploited, to provide attractive positioning and timing value-added services for mobility and transport management. Basic concept is the capability of supporting integrated navigation and S-UMTS communication services, by combining GALILEO positioning and timing data with communication capabilities, in order to provide navigation related information (tracking, tracing, alarming, messaging, group broadcasting, fleet management information) for transport, mass market and personal info-mobility.

The following main design concepts are at the basis of the GAUSS proposed solution:

- Two-way communication between Mobile Users and Service Centre/Provider, characterised by the exchange at low rate transmission, of small data packet carrying the required positioning information and content data
- Resource access based on CDMA (Code Division Multiple Access), in compliance to the UMTS standard, suitable adapted to support the transmission of short data packets via satellite at low bit-rate
- Fully exploiting the intrinsic advantages coming from the usage of the satellite of guaranteed large coverage and continuity and provisioning of broadcasting and multicasting services
- The open architecture, based on the adoption of current standards interface and protocols. Conformity to widely adopted standards guarantees flexibility and compatibility with current and future NAV and COM systems, and capability to be fully integrated with available infrastructure for providing complementary added-value services
- New developments starting from the usage of consolidated and existing technologies, for reducing design and development risks and costs.
- Tight harmonisation between the Terrestrial 3G Mobile System and the Satellite components for supporting the integrated NAV/COM Services, with the perspective of deploying a single highly-integrated network, based on:
  - Common Core Network, but distinct Radio Access Networks
  - And a future Single User Terminal (dual mode) for Satellite and Terrestrial access.

The radio access of the GAUSS system towards the external networks is conceived as a distinct RAN of the S-UMTS family, optimised for low-bit rate packet-based services. The standard interface towards the Core Network ensures compatibility and inter-operability with 3GPP systems. This is not against the common vision of the UMTS to be a system mainly aiming at the high bit-rate mobile service market. GAUSS has not to be intended as a competitor with other systems (UMTS itself), but a system capable of fulfilling effectively and efficiently the requirements of inter-modality and info-mobility applications compatible with the GAUSS concepts (small size messages, low bit rate). The background guideline of the designed architecture is that of pursuing an open standard for the communication services to be integrated with the navigation ones, rather that a proprietary standard. This is not against the common vision of the UMTS to be a system mainly aiming at the high bit-rate mobile service market. The UMTS has being designed to be a set of Radio Access Networks, each optimised for the specific context it operates within. In this architecture, the GAUSS system designed as S-UMTS compatible, being optimised for low-bit rate packet-based services, will just constitute one the specialised Satellite RANs of which the UMTS will consist of.

The GAUSS Demonstrator

The GAUSS Demonstrator is the system physical model built-up starting from currently available hardware and software components, with the purpose of emulating a fully representative environment for the 'Target System'. The assembled system was used as Testbed during the trail campaign carried on, to validate and prove the provided services, basically in the inter-modal and info-mobility application fields.

The Demonstrator is constituted of ad-hoc applications and the necessary navigation/communications facilities (ground station, satellites, user terminal), as representative as possible of the Target System. Existing infrastructures were largely used (mainly the navigation and communication satellites, the earth stations and some user terminal equipment), but also several new developments were included, all ones performed within GAUSS itself. The Demonstrator is based on the following architectural elements (see Figure 1):

1. The MTB (Mediterranean Test Bed) for precise positioning and integrity functions. The Mediterranean Test Bed is the Italian Satellite Based Augmentation Service (SBAS). The MTB is implemented to enable the testing of the wide area concept of enhancing GPS/GNSS-based navigation for civil aviation in Italy and elsewhere in the Mediterranean region. The MTB provides the ground network and facilities necessary to produce a SIS (Signal-In-Space) that

disseminates integrity and differential correction information on a wide area basis via an INMARSAT-3 F1 GEO satellite broadcast at the GPS L1 frequency (1575.42 MHz).

2. The L-Band INMARSAT 3F5 communication capacity
3. The INMARSAT Earth Station and Gateway equipment (located at Telespazio premises in Lario, near Como in Northern Italy)
4. A User Terminal
5. A ship or a Van equipped with the User Terminal
6. The Service Segment, which is the contact point of the GAUSS System and the users, for making use of the provided services.

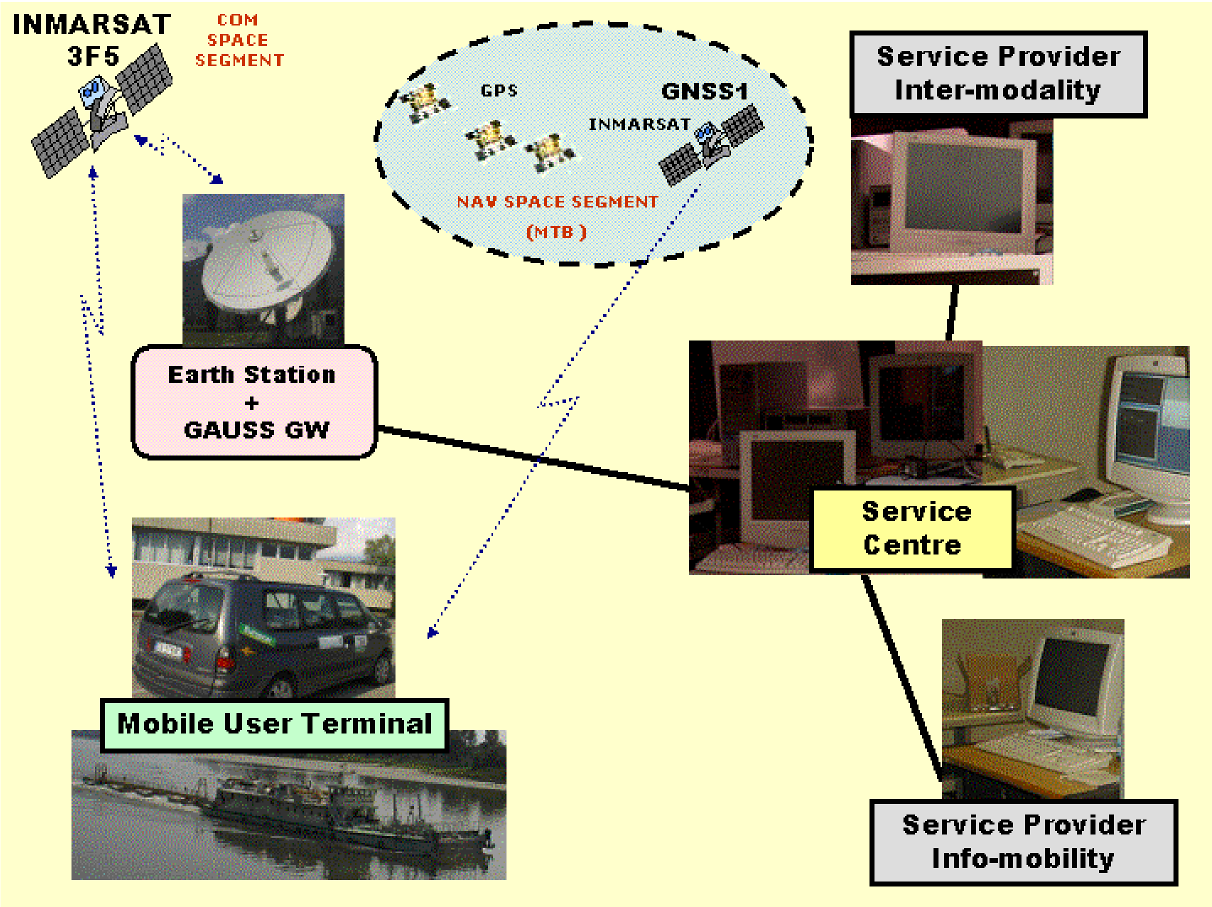

Figure 1 **GAUSS Trials Main Elements**

Figure 2 presents the Architecture of the GAUSS Demonstrator.

The design drivers for the GAUSS Demonstrator consisted of new hardware and software developments based on:

- Integrated utilisation of off-the-shelf units and technologically advanced parts

- Application of current standards to architecture, protocols and interfaces, for guaranteeing interoperability and flexibility
- Use of existing consolidated technologies for reducing development risks.

Existing elements:

- The MTB Navigation system, based on GPS signals augmented with SBAS techniques - objective is 3m horizontal accuracy.
- The INMARSAT 3F5 capacity for communication and Lario07 earth station.

  For the GAUSS Demonstrator, use of ITALSAT F2 EMS capacity was planned at the beginning of the project. During the GAUSS AIT phase, the ITALSAT F2 was withdrawn from the service because of a failure. The GAUSS demonstration has been recovered by using the INMARSAT 3F5 capacity. No modification was needed to the GAUSS Demonstrator components due to the new satellite set-up, but only limited adjustment of the Frequency Plan in Transmission and Reception were necessary, according to the authorisation of the IMARSAT Spectrum Manager and NOC (Network Operator Centre).

New hardware and software developments:

- An advanced multi-mode user terminal capable of handling, in integrated manner,
  - The COM and the NAV signals
  - An access system tailored upon location-based services (requiring low-rate and bursty resources) and S-UMTS compatible
- The Gateway at the Lario07 Earth Station
- Applications for mass and professional markets, based on use of GIS technology, standards and open-source components (CORBA, LINUX Operating System, Freeware Map Server).

The advanced multi-mode User Terminal is composed of:

- A unique integrated digital receive front-end capable of handling the full navigation (GPS, EGNOS, GALILEO) and communication (S-UMTS) band segments signals,
- The GNSS1 (GPS + EGNOS) receiver, designed for precise positioning and navigation operations within a Satellite Based Augmentation Service environment
- The SW-CDMA modems and the UMTS compatible access system, specifically tailored to location based services (low-rate, small packet transmission standard)
- The applications, based on use of GIS (Geographic Information System) technology, standards and open-source components.

The Gateway and Lario07 Earth Station includes:

- CDMA modems for RL and FL (as in the User Terminal)
- UMTS compatible access & control subsystem, including the upper layer based on the 3GPP Release 4
- UMTS packet transmission standard (as in the User Terminal)
- RF subsystem and antenna of the Lario07 (LRO07) Earth Station
- Application Adaptation Layer, connected to the Application subsystem via Internet connections.

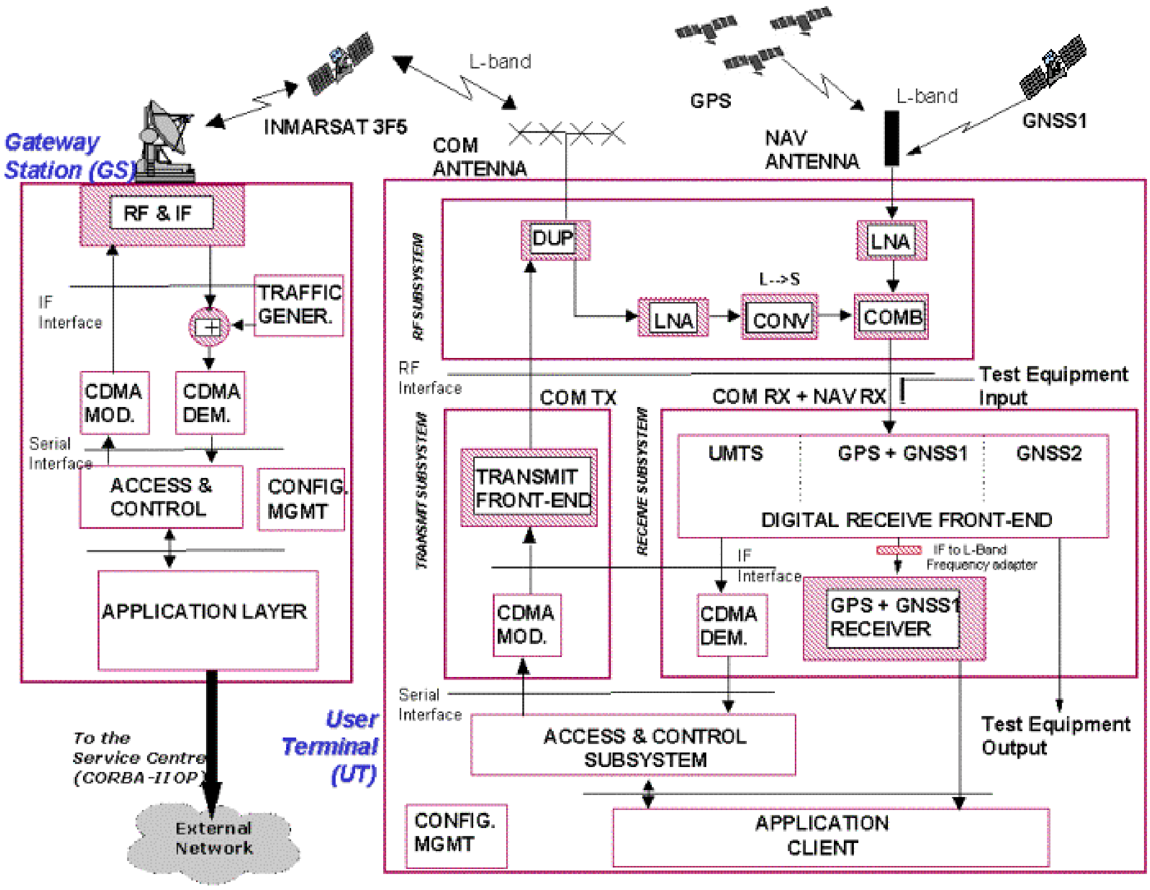

Figure 2 GAUSS Demonstrator Architecture

The trial campaign had the purpose of validating and qualifying in real environments, the developed applications and the technical feasibility of the GAUSS solution concepts. For the Navigation System, the MTB (see next figure) was utilised because of the poor performance coverage of the ESTB system over the Italian regions. The MTB SBAS signal allowed obtaining position accuracy better than 3 m along the Po River and demonstration areas. Time response of about 25-30 seconds was measured.

Figure 3 Pictures of the GAUSS Trials

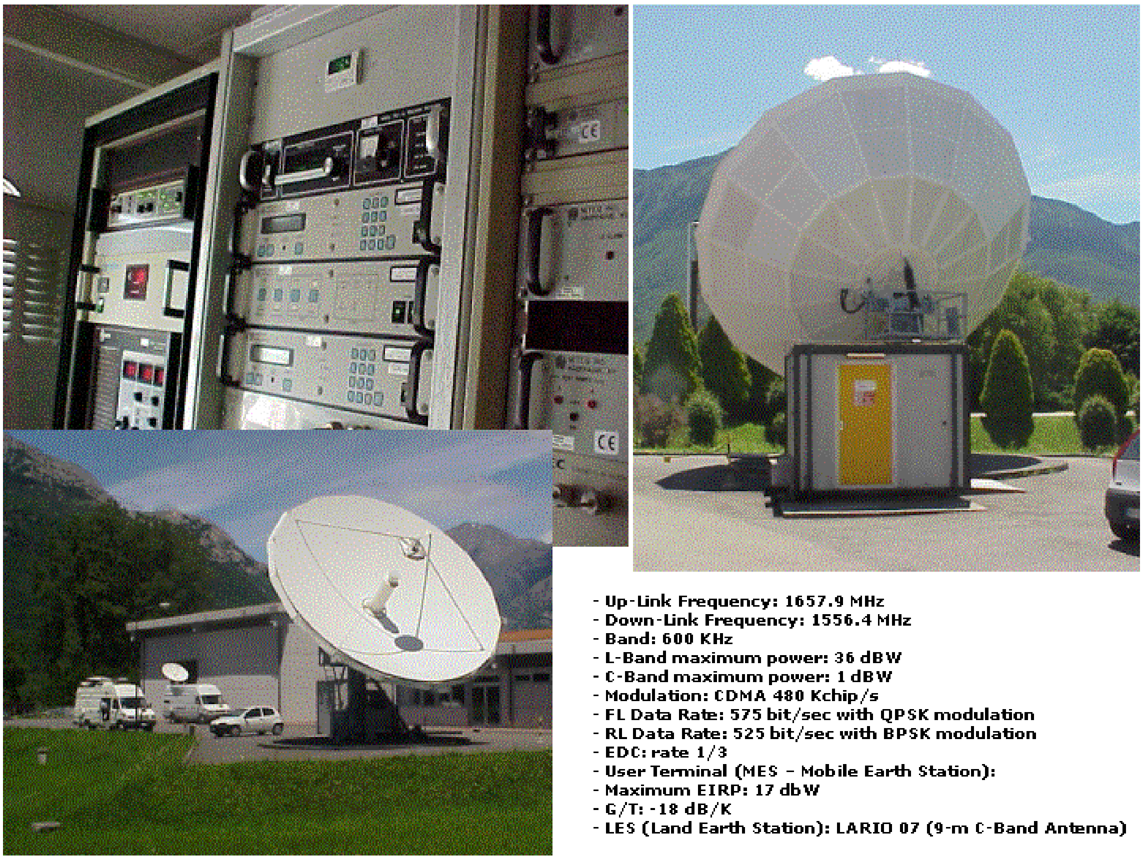

Figure 4 The Lario07 and link budget parameters

GAUSS Data Transmission

As previously mentioned, the services considered for GAUSS are characterised by highly reliable, near real-time two-way communication between Mobile Users and Service Centre/Provider, based on exchange at low data rate transmission of small data packets carrying very accurate positioning & timing information. The traffic is typically bursty and unbalanced, being generated by a large number of Mobile Users towards a relatively small number of Service Providers, (i.e. greater amount of traffic in the return link with respect to the forward link). A certain amount of traffic is also generated with bursty characteristics from the Service Providers towards widely geographically sparse Mobile Users (broadcasting/multicasting and two-way communications).

The GAUSS system supports both asynchronous and synchronous communication, based on:

- Broad-casting (i.e. data distribution from a SP to MUs)
- Broad-catching (i.e. data collection from MUs to a SP)
- Point-to-point schemes.

At the application, GAUSS messages are formatted in cells (the **GAUSS Cell**), characterised by a common flexible structure for all GAUSS services and applications:

- Fixed length (53-byte), including the header and the information field
- Messages up to 8 concatenated cells long (424-bytes) are supported. Messages generally comply with the size of a single 424-bit GAUSS cell. Longer messages can be transmitted by fragmenting them into more cells (up to 8). The application has the task of reconstructing the originally sent messages, along with the check for completeness and the eventual request for selective repetition.
- Two different message formats, for MU ➔ SP messages (B/M-catching and P-to-P services) and for SP➔ MU messages (B/M-casting and P-to-P services)
- Contents of the packet data fields are depending on the specific applications (e.g. the PVT data auxiliary optional data). Message contents (the auxiliary data) have been defined for all GAUSS Demonstrator applications, based on standards: CEN (European Committee for Standardization) standard for info-mobility applications, IMO (International Maritime Organisation) river guidelines and recommendations for inter-modality/river, EU normative (ADNR – European Agreement on the International Carriage of Dangerous Goods on Rhine) for dangerous goods classification and transport on river.

GAUSS 53-bytes cell is encapsulated into UDP (User Data Protocol) fragment and mapped in a Transport Block (TB) of fixed size (75 byte): the so-called **GAUSS Data Packet**, that is the bit stream including the GAUSS cell plus the overhead for EDC and preamble for burst transmission.

The **Packet Transmission Mode** design adopted in GAUSS enables to comply with the following criteria:

- Fulfilling the GAUSS requirements, based on small data packet communication
- Compliance with the requirement of routing through a Terrestrial Network with minimum adaptation.
- Standardising to the maximum feasible extent the services for what is concerning the physical layer, leaving the applications the task of managing all specific requirements.
- Flexibility. The GAUSS cell, while providing the specific GAUSS types of services, is definitively capable to support a wider class of Location-based services, requiring small data packet exchange at low bit rate transmission. As a matter of fact, no modification is required to the GAUSS standard packet to accommodate in the messages the data required by other specific application.

For the Packet Data Transmission GAUSS project had actively contributed to the ESTSI SES S-UMTS Working Group. GAUSS contributed to the **TR 102 061 Packet Transmission Mode**, as a system where S-UMTS packet data transmission had been designed, implemented, tested with real satellite capacity.

GAUSS Demonstrator Access & Control Subsystem

The access scheme proposed for GAUSS is compliant with the current assessed release 4 of the UMTS), appropriately adapted for effectively supporting the envisaged services, considering their nature:

- Highly-bursty low-rate communications
- Transmission of structured short data packets.

The adaptations mainly affect:

- The radio access scheme designed to use as much of the work done for S-UMTS as possible
- The radio protocol layer designed to be compliant to the standard.

The Upper Layer in the GAUSS Demonstrator has the same structure as the one described in 3GPP and it is depicted in Figure 5, while the communication between UT and GW is shown in Figure 6. A1 is the radio interface between the User Terminal and the Gateway Station and it is the equivalent of the S-UMTS Uu (S) through-satellite radio interface between the User Equipment and the USRAN; A2 is the equivalent in the Demonstrator of the Gi interface (which connects the GGSN to an external packet-network).

On top of PDCP the IP protocol is used (for the user plane) while UDP, which is a transport layer connectionless protocol (layer 4 in the OSI model) is used for the communication with the Application Layer, which takes place through the 53 byte cells. These GAUSS cells are always encapsulated in TBs of fixed size, which are sent to the physical layer.

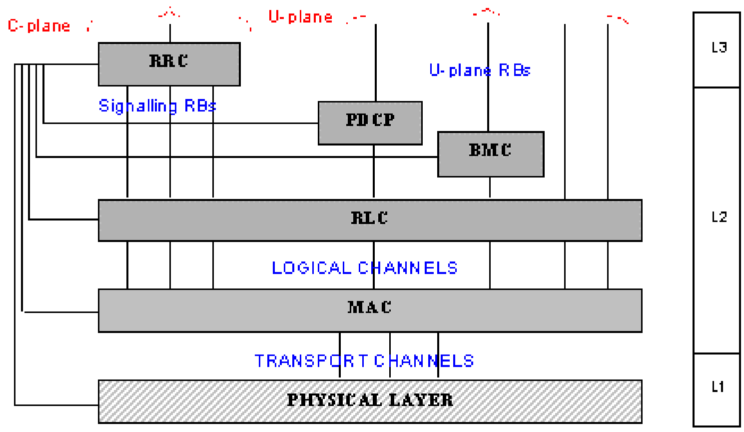

Figure 5 Upper Layer Protocol Stack

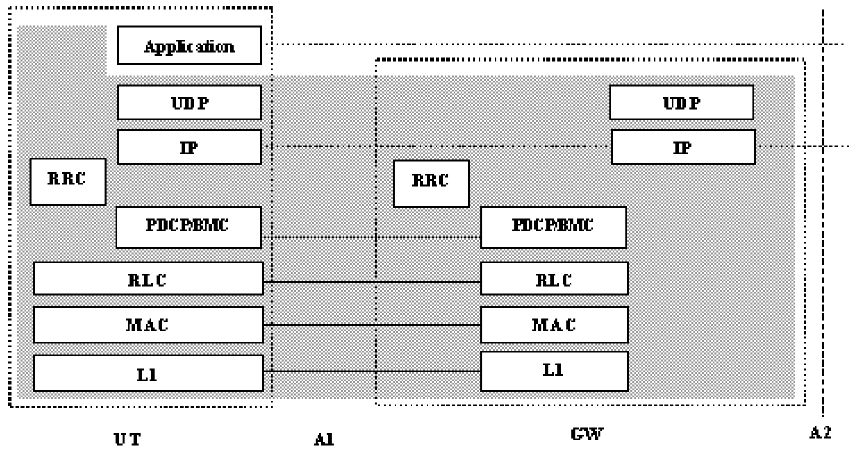

Figure 6 UT/GW communication

Next figure presents the Channel mapping in the Return and Forward Links, where the new channels are shadowed.

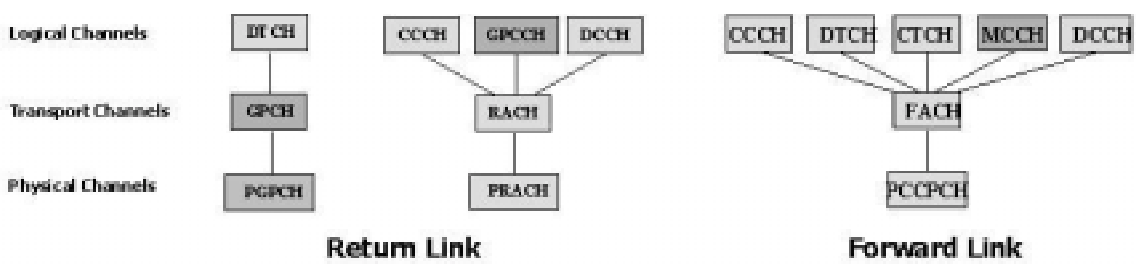

Figure 7 Channel mapping in the GAUSS Demonstrator Return and Forward Links

The main characteristics are the following:

- UMTS Release 4 compliant Access & Control System, with some compatible variants:
  - CCCH (Common Control Channel) used in the connection signalling procedures
  - DTCH (Dedicated Traffic Channel) point-to-point channel used for transfer of user information
  - CTCH (Common Traffic Channel) point-to-multipoint unidirectional channel used for broadcasting services
  - DCCH (Dedicated Control Channel) used for communicating the user(s) the “CDMA virtual codes” for multicasting services
- A new physical channel in the RL: PGPCH (Physical GAUSS Packet CHannel) with the corresponding transport channel GPCH (GAUSS Packet CHannel), used for the return link data transfer (DTCH corresponding logical channel)
- Two new logical channels: GPCCH & MCCH
  - GPCCH (GAUSS Packet Control CHannel) used for asking resource allocation to the scheduler in the GW before transferring data
  - MCCH (MultiCasting CHannel) point-to-multipoint channel used for the transfer of user information in multicasting services.

The new physical channel in the return link, the PGPCH and the corresponding new transport channel the GPCH, are used for the return link data transfer, that has been optimised for burstly low bit rate data transfer. GPCCH (GAUSS Packet Control CHannel) is the logical channel used for asking resource allocation to the scheduler in the return link data transfer. The return link data communication can be summed up in three main steps:

- A message is sent on the RACH channel in order to request resources. The message payload includes the number of bytes that is requested to be sent.
- The scheduler in the GW allocates the necessary resources and communicates back with an acknowledgement the time when data transmission must initiate.
- Data is transmitted through the PGPCH channel.

Broadcast and Multicast application data transfer takes place though CTCH/FACH/PCCPCH but a new logical channel (MCCH -Multicast Control CHannel) as been introduced for dynamic multicasting group handling. As the belonging of a user to a certain group is location based (and therefore dynamic), it is necessary to transfer the CDMA virtual code to all the users belonging to the group. This is done through signalling and in this way all the users involved are provided with the data necessary to “decode” the information addressed to them. Signalling is also necessary when one or more users must be deleted from a group and it is transmitted and handled in a similar faction.

For the access scheme, the RL is based on slotted ALOHA (with congestion) for bandwidth request and a scheduler assigns a data slot width to a specific user (without congestion), the Forward Link envisages a Direct Sequence CDMA Access Scheme.

GAUSS Demonstrator Forward Link Physical Layer

According to the S-UMTS specifications, the physical layer of the forward link in GAUSS has been based on the P-CCPCH (Primary Common Control Physical Channel) used as a 2^{nd} S-CCPCH (Secondary Common Control Physical Channel) in order to map on it the FACH (Forward Access Channel) transport channel.

Each TB 600 bits long, coming from the MAC (Medium Access Control) layer has been formatted into four frames introducing an adaptation overhead which transforms the original TB into an encoded TB (ETB) of 736 bits. A TTI (Transmit Time Interval) of 1280 msec has been adopted obtaining 320 msec as physical frame duration. The resulting information bit rate is then ETB/TTI = 575 bits/sec. After applying a 1/3 code rate and inserting the PS (Pilot Symbol) and FSW (Frame Sync Word) a channel bit rate of 3.75 Kbps is achieved corresponding to a QPSK symbol rate (SR) of 1.875 Ksps.

The UMTS standard specifies a 256 spreading factor (SF) for the P-CCPCH so the chip rate required to transmit the P-CCPCH is SR*SF = 480 Kcps. This chip rate has been obtained, also according to the bandwidth available at the gateway station (GW), scaling the standard UMTS chip rate (3.84 Mcps) by 8.

The acquisition processing at the user terminal (UT) side is based on a matched filter exploiting the property of the Gold code imposed to the transmitted string. The first 256 bits of this code are correlated and submitted to a threshold process in order to obtain a synchronisation whose precision is ½ chip. At the same time the acquisition also performs a coarse carrier frequency recovery within an error of +/- 1.875 KHz. The resulting mean acquisition time, estimated on many acquisition trials carried out at laboratory level, is about 300 msec.

The steady state at the end of the acquisition phase is controlled and assured by three loops working in parallel: The DLL (Delay Locked Loop), the AFC (Automatic Frequency Control) loop and the AGC (Automatic Gain Control) loop.

The DLL concerns the timing recovery and it is based on an early-late algorithm modifying the impulse response of the SRRC (Square Root Risen Cosine) input filter according to the delay found by the error detector. The AFC loop allows a carrier frequency tracking within a range of ±100 Hz when stimulated by a frequency step. Finally the AGC loop is used to force the signal amplitude to that necessary for the next de-spreading and de-scrambling algorithms.

The performances achieved for the P-CCPCH of the forward link are reported in the next picture:

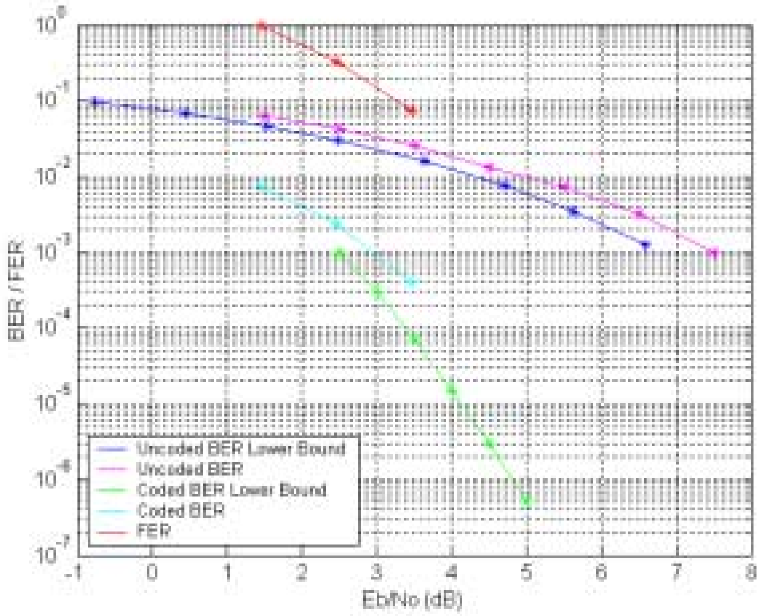

Figure 8 Performances of the Forward Link P-CCPCH

Both the uncoded and coded BER curves are shown. An implementation loss less than 1 dB has been obtained (as it is possible verify looking at the theoretical lower bounds reported in the picture) including the fixed point approximation of the digital processing and the losses due to the analog processing (ADC, DAC and filters).

Finally a Scattering diagram of the QPSK constellation is shown in the next picture:

The picture was extracted from the GUI controlling the UT demodulator. The PS is visible in the upper right because it is transmitted using a power greater than the data symbols one.

The forward link physical layer is based on a single multi-FPGA board (named SP6F2D) hosting a Digital Signal Processor used as controller. The board can be completely reconfigured in order to perform the function of CDMA modulator as well as the function of CDMA demodulator.

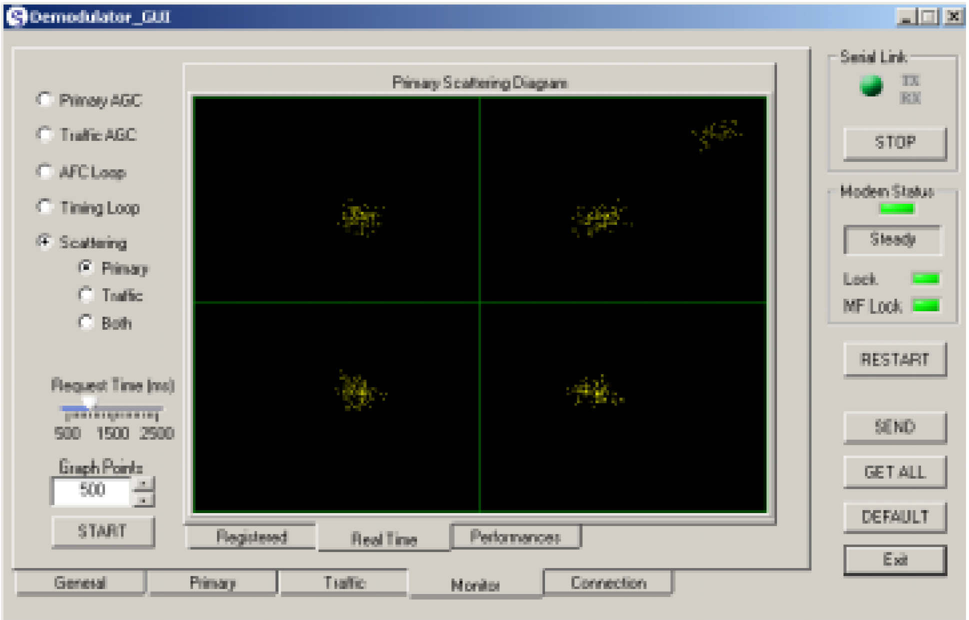

Figure 9 **Scattering diagram of the QPSK constellation**

GAUSS Demonstrator Digital Receiver Front-End

The aim of the Digital Receive Front-End (DRFE) is to separate and convert to IF the communication and navigation (COM and NAV) signals. This front-end is a very important development with regard to future terminals utilising common hardware to handle both COM and NAV services (a multi-mode terminal) with no need for housing separate COM and NAV receivers in the same container. The front-end processes a bandwidth containing multiple signals (GPS, Galileo and S-UMTS) and performs the separation of the various bandwidths. It is composed of an Analog Unit (DRFEAU) and of a Digital Unit (DRFEDU).

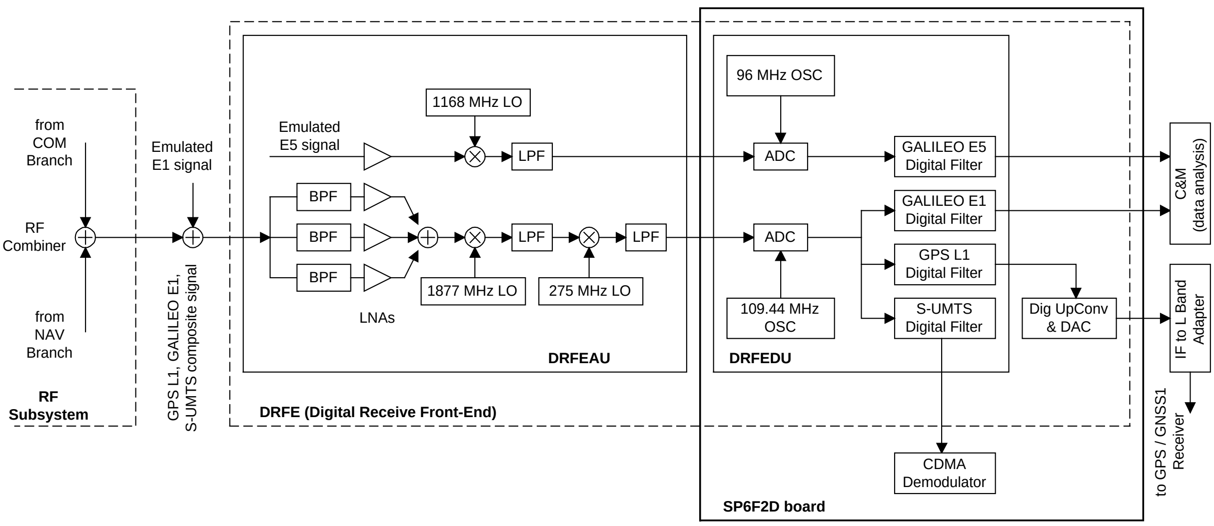

Figure 10 **Block diagram of the DRFE**

DRFEAU: The optimum solution should use a single chain MIXER-ADC able to manage the composite signal GPS+GALILEO/E1+GALILEO/E5+UMTS. This approach involves the use of a 3rd order harmonic of the down converting mixer and an ADC exploiting the under-sampling technique. The mixer spurious analysis and ADC jitter analysis strongly suggested us to implement a sub-optimal solution processing the signal GPS+GALILEO/E1+UMTS with a double mixer, single chain and processing the GALILEO/E5 signal apart. This approach involves only 1th order harmonics of the mixer. The down conversions carried out are well explained using the following table:

Signal	**Gross Band Limits [Bandwidth] (MHz)**	**First Down Conversion (f_{LO} = 1877 MHz, 1168 MHz for E5)**	**Second Down Conversion (f_{LO} = 275 MHz)**	**Central Frequency (MHz)**
GPS L1 plus GALILEO E1	f = 1563 … 1601 [38]	$f_1 = f_{LO} - f$ = 1877 – (1563..1601) = (314..276)	$f_2 = f_1 - f_{LO}$ = (314..276) – 275 = (39..1)	L1: 26.58 E1: 12.258
UMTS	f = 2192.5 … 2202.5 [10]	$f_1 = f - f_{LO}$ = (2192.5..2202.5) – 1877 = (315.5..325.5)	$f_2 = f_1 - f_{LO}$ = (315.5..325.5) – 275 = (40.5..50.5)	UMTS: 45.5
GALILEO E5	f = 1188 … 1214 [26]	$f_1 = f - f_{LO}$ = (1188..1214) – 1168 = (20..46)	NA	E5: 34.025

DFREDU: It consists mainly of two ADCs and of a filter bank. The analog to digital conversion is obtained using an ADC working at 109.44 MHz for the GPS+E1+UMTS composite signal and using an ADC working at 96 MHz for the E5 signal. The total useful bandwidth at the input of the first ADC is 50.5 MHz. The incoming signals are processed by digital IIR/FIR filters bank in order to recover the GPS, UMTS and GALILEO signals. At the end of this filtering procedure, the GPS signal is digitally up converted, converted in analog format and sent as input to an “IF to L band adapter”. The output of this adapter is used as input signal for a commercial GPS receiver. The output of the UMTS filtering branch is sent to the forward link demodulator and finally the output of the Galileo filtering branches are sent to a workstation in charged of testing the behaviour of the DRFE with respect to the Galileo bands. For each filter bank (UMTS, GPS, E1 and E5), first of all the incoming composite signal is digitally down converted, using the suitable central frequency (see previous table), in order to obtain a base-band complex signal. After this each channel has been processed as indicated below.

<u>UMTS:</u> A decimation by 57, through a FIR filter working at 1/57 of its input data rate (109.44/57 =1.92 MHz), is performed to select the wanted signal and obtaining output samples at 1.92 MHz.

GPS: A decimation by 2, through a FIR filter is used to reduce the sampling rate and a cascaded FIR filter is performed to select the wanted signal. After this the digital up conversion of the signal is obtained achieving samples at 109.44 MHz and an IF signal centred at 30 MHz.
Galileo E1 and E5: A low pass IIR(E1) or FIR(E5) filter is used to select the bandwidth of the wanted signals buffering the outputs in order to downloaded them off line.

GAUSS Demonstrator Return Link Physical Layer

The design of Return Link of the GAUSS Demonstrator was specifically tailored to the needs of the GAUSS location based services, i.e. the return link had to support highly bursty, low rate data services. Therefore delay was a minor issue in the return link. Nevertheless all components in the link were designed to be close to real-time operation. Since for simplicity reasons the components from different partners of the project were connected with serial interfaces and non-real-time operating systems were used, a careful design of the communication via these serial interfaces and of the host software on the physical layer hardware was mandatory.
In the GAUSS Demonstrator two transport channels were provided: a random access channel (RACH), which is specified in the S-UMTS standardisation documents and an additional GAUSS packet channel (GPCH) providing a non-continuous packet transmission.
The time scale in the return link is divided in consecutive super frames as depicted below. During RACH periods the user terminals are allowed to issue requests for transmission capacity based on a slotted ALOHA scheme. The scheduler in the gateway station then allocates GPCH slots according to the request and transmits this information via the forward link to the user terminal. Now the user terminal can transmit its data on a contention-free basis. Since all mobile terminals have timing and positioning information from the GAUSS navigation subsystem, it is possible to synchronise the return link signals in such a way that they are (quasi) synchronous at the satellite receiver. Since the burst duration in comparison with the round trip delay is very low, closed loop power control inherently is not meaningful for the GAUSS services.

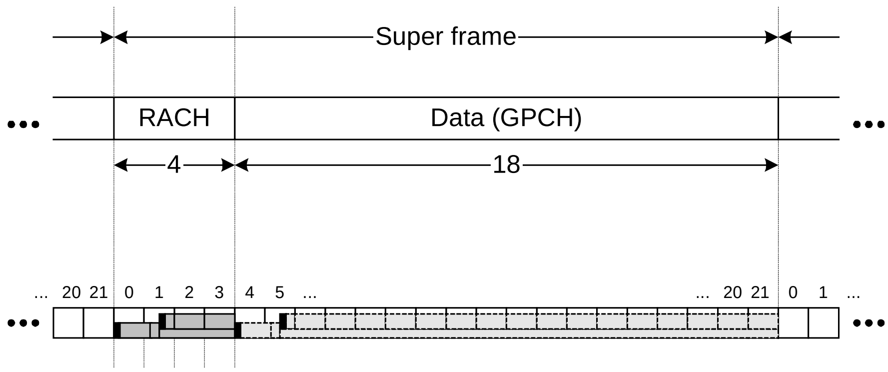

Figure 11 GAUSS RL Superframe

A lot of effort was spent to design and implement the access scheme for the return link described above in order to provide a realistic real-time behaviour of the physical layer for the GAUSS services. Therefore maintaining an absolute time reference in the physical layer and the synchronisation of the MAC layer to the physical layer is mandatory. This is a quite difficult task regarding the serial interface between the physical and MAC layer and the non-real-time operating systems involved. The primitives for interface between the physical and MAC layer considered in the GAUSS Demonstrator is compliant to the S/T-UMTS standard.

The mapping of transport blocks to radio frames and the air interface is designed to be compliant to the S/T-UMTS standards. An additional physical channel is introduced on which the GW receiver searches for transmitted signal in a wide frequency range. This synchronisation emulation channel (SECH) is invisible to the upper layers and emulates the tight coupling of the forward and return link in real systems where the UT is roughly synchronised to the GW.

The GAUSS Demonstrator aimed at very low rate data services and operates on a chip clock, which is eight times lower than in S/T-UMTS. Therefore the symbol duration in GAUSS was very long and frequency offsets had to be compensated very carefully. This required very accurate frequency estimation and tracking algorithms in the GW receiver. In order to emulate additional users in the return link, a traffic generator was included at the GW, which was synchronised to the access scheme in the return link. A comprehensive set of configuration and management commands are handled by the UT modulator and GW demodulator, which can be issued by a dedicated Configuration & Management software and are sent via a dedicated serial interface.

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