GAUSS PROJECT TRIALS RESULTS

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1 ACRONYMS

3G	Third Generation	IHO	International Hydrographic Organisation
3GPP	Third Generation Partnership Project	IMO	International Maritime Organisation
A.R.N.I.	Azienda Regionale per la Navigazione Interna	IOR	Indian Ocean Region
ACK	Acknowledge	IP	Internet Protocol
ADC	Analog to Digital Converter	ISO-OSI	International Organisation for Standardisation-Open System Interconnection
ADNR	European Committee for Standardization		
AFC	Automatic Frequency Control	IST	Information Society Technologies
AGC	Automatic Gain Control	LBS	Location Based Services
API	Application Programming Interface	LCS	LoCation-based Services
ASMS-TF	Advanced Satellite Mobile Systems - Task Force	MT	Mobile Terminal
B/M	Broad/Multi	MTB	Mediterranean Test Bed
BER	Bit Error Rate	M-to-P	Multipoint-to-Point
BLER	Burst Loss Error Rate	MU	Mobile User
BPF	Band Pass Filter	NAV	Navigation
CEN	European Committee for Standardization	NLES	Navigation Land Earth Station
CMDA	Code Division Multiple Access	NMEA	National Marine Electronics Association's
COM	Communication	NOC	Network Operator Centre
DAC	Digital to Analog Converter	NS-R S	Not Safety-Related Services
DFA	Data Flow Diagram	PDCP	Packet Data Convergence Protocol
DFRE	Digital Receive Front-End	PDU	Protocol Data Unit
D-GPS	Differential GPS	POI	Point-Of-Interest
DRFE	Digital Receive Front-End	P-to-M	Point-to-Multipoint
DRFEAU	Digital Receive Front-End Analog Unit	P-to-P	Point-to-Point
DRFEDU	Digital Receive Front-End Digital Unit	PVT	Position Velocity & Timing
DSP	Digital Signal Processor	RAN	Radio Access Network
EC	European Commission	RfMS	Reference Monitor Stations
ECAC	European Civil Aviation Conference	RIMS	Reference Integrity Monitor Stations
E-CS	Emergency-Call Services	RL	Return Link
EDC	Error Detection and Correction	RLC	Radio Link Control
EGNOS	European Geo-stationary Navig. Overlay Services	RTCM	Radio Techincal Commision for Maritime Services
EMS	European Mobile System	RTD	Research and Technological Development
ESA	European Space Agency	RTT	Round trip time
ESTB	EGNOS System Test Bed	SBAS	Satellite Based Augmentation System
ETSI	European Telecommunications Standards Institute	SC	Service Centre
EU	European Union	SES	Satellite Earth stations & Systems
FL	Forward Link	SIS	Signal In Space
GAUSS	Galileo And UMTS Synergetic System	SP	Service Provider
GAUSS	Galileo And UMTS Synergetic System	S-R S	Safety-Related Services
GEO	Geostationary	S-UMTS	Satellite Universal Mobile Telecomm. System
GIS	Geographic Information System	SW-CMDA	Satellite Wideband-CDMA
GNSS	Global Navigation Satellite System	TB	Transport Block
GNSS-1	Global Navigation Satellite System phase 1	TTI	Transmission Time Interval
GNSS-2	Global Navigation Satellite System phase 2	TX	Transmission
GPS	Global Positioning System	UDP	User Datagram Protocol
GSM	Global System for Mobile Communications	UMTS	Universal Mobile Telecommunication System
GW	Gateway	UT	User Terminal
ID	Identifier	WG	Working Group

2 ABSTRACT

GAUSS is a Research and Technological Development project co-funded by European Commission, within the frame of the IST (Information Society Technologies) V Programme. It is a two-year project, starting from December 2000, and successfully completed.

The GAUSS Team involves a Consortium of nine European companies, including ARNI (Azienda Regionale per la Navigazione Interna, I), ASCOM (CH), ERICSSON Telecomunicazioni (I), GMV (E), TELEFONICA (E), THALES Navigation (F), TTI Norte (E), Space Engineering (I) and TELESPAZIO (I) as project co-ordinator.

GAUSS objective was to design and demonstrate the feasibility of a system providing Location-based services, from the integration of Satellite Navigation and Communications, within the contexts of GALILEO and the UMTS technology. The GAUSS proposed solution supports highly reliable, near real-time two-way communication between Mobile Users and Service Centre/Provider. The services considered for GAUSS are based on exchange at low data rate transmission of small data packets carrying very accurate positioning & timing information, as typically required by Info-Mobility and Inter-Modality oriented applications. These services are characterised by bursty and unbalanced traffic, generated by a large number of Mobile Users towards a relatively small number of Service Providers, and viceversa from the Service Providers towards widely geographically sparse Mobile Users (i.e. greater amount of traffic in the return link with respect to the forward link).

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

- broad-casting (i.e. data distribution from a Service Provider to Mobile Users)
- broad-catching (i.e. data collection from MUs to a SP)
- point-to-point schemes.

Resource access is based on CDMA (Code Division Multiple Access), according to the UMTS standard. A Demonstrator was built up by combining existing facilities with innovative hardware and software components, ad-hoc developed by some of the Consortium Partners. The former ones constitute the ground and space segments, the latter ones include the advanced user terminal and the applications. The assembled system was used as test-bed during the trail campaign, to validate and prove the provided services and developed applications.

The GAUSS Demonstrator includes the following components:

- The Mobile User Terminal installed on a car (van) or on a boat. An innovative multi-mode user equipment was developed, consisting of the following main components:
  - An integrated NAV / COM digital receive front-end (DFRE), able to de-multiplex the NAV signals (the current GNSS1 band and the simulated Galileo bands), and the COM signal in the S-UMTS band;
  - For COM: a transmit front-end, and a baseband & control section operating in CDMA and supporting the upper protocol layers (UMTS packet transmission standard based – for short packet); a RF subsystem, including the L→S bands conversion;
  - For NAV: a GNSS (GPS, EGNOS) navigation receiver, the GNSS1 System (MTB - Mediterranean Test bed, ESTB / EGNOS System Test Bed) for navigation;
- The Communication capacity on the INMARSAT 3F5 Satellite
- The Gateway, located in LARIO Telespazio premises
- The Lario07 Station
- The Service Centre
- The Service Provider.

The GAUSS Demonstrator reflects all the main elements of a complete user platform for service provisioning: mobility assistance, safety and transport efficient management are the core of the developed applications. Applications were developed, specifically to provide reliable and effective services to the 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 inter-modal transport user, specifically operating in inland-waterways and roads. Safety-of-life applications for assisted vessel navigation and for management of hazardous goods (gas) transhipment over the Po river were thoroughly tested and assessed. Applications for emergency assistance, Point of Interest inquiry, localisation of commercial fleet were also proven.

GAUSS successfully demonstrated integrated GNSS1 precise positioning based on EGNOS and satellite UMTS packet communication. 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). Horizontal accuracy better than 3-m was achieved in the trial area (Northern Italy - Lario - Como Lake, Parma and Po river areas), thanks to the navigation functions based on GPS signals augmented with SBAS techniques. The MTB (Mediterranean Test Bed) was utilised because of the poor performance coverage of the ESTB system over the Italian regions.

In this paper, the results of the GAUSS trial campaign are reported, along with their assessment and evaluation in terms of possible enhancements and future exploitations.

3 GAUSS PROJECT OVERVIEW

3.1 Project Summary

GAUSS is a Research and Technological Development project, of the European Commission IST 5th Programme. It is a two-year project, starting from December 2000, and now successfully completed.

GAUSS demonstrated the realistic feasibility of a system, integrating Satellite Navigation GNSS-1 and UMTS communication technology for the development of high quality location based services, for road info-mobility and safety, emergency assistance and intermodality applications. A Demonstrator was built up, by combining new hardware and software ad-hoc developed components, along with the use of existing facilities. A prototype of user terminal was realised, integrating off-the-shelf equipment and technologically advanced parts, based on GNSS1, GALILEO and S-UMTS compatible units. Mobility e-safety and transport efficient management are the core of the developed applications: 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 inter-modal transport user (ARNI, Partner of the GAUSS Consortium), specifically operating in inland-waterways and roads. Safety-of-life applications for assisted vessel navigation and for management of hazardous goods (gas) transhipment over the Po river were thoroughly tested and assessed. Applications for emergency assistance, Point of Interest inquiry, localisation of commercial fleet were also proven. These were proven by using INMARSAT L Band capacity for communication (with a L→S conversion in the RF unit of the user terminal), due to unavailability of an S-UMTS system, and EGNOS test bed systems, due to unavailability of real EGNOS operative system. Furthermore, GALILEO signals were simulated in the digital receive front-end, due to lack of GALILEO real signals.

The project was carried by an industrial Consortium, involving of nine European companies, with proven experience and complementary skill in the fields of telecommunication, equipment manufacturing, communication and navigation system engineering, service provisioning. The work allocation is in line with the companies market and technological prospects, in view of future developments taking benefits from the experience and know-how acquired in the GAUSS project. The participation of the direct users (one of the Consortium Partners) to the trials enabled to evaluate the GAUSS services also in terms of market opportunities, cost benefits ratio and operating practises.

GAUSS URL: http://Galileo.cs.telespazio.it/gauss

3.2 Project objectives and main results

The GAUSS project goal was to design and demonstrate a realistic integration between satellite navigation and communication, with reference to GALILEO and S-UMTS, for provision of Location-Based Services. The technological issues of such a concept relied on the development of a Demonstrator, with the purpose of building up a realistic implementation of the proposed GAUSS system. The GAUSS Demonstrator is based on the integration of existing infrastructures along with ad-hoc designed components, developed in the framework of the project itself. The former ones constitute the ground segment, the latter ones include the advanced user terminal and the applications. In this context, GAUSS has a two-fold objective: new technological development and realisation of innovative applications oriented to info-mobility and inter-modality. The need for such developments does not only arise from the unavailability of the required equipment on the market, but also from the intention to realise, within the project, innovative equipment which will expectedly be strategic for the success of the proposed system.

GAUSS main rationales rely on the feasibility of a solution for the provision of **high quality Location-Based services**, characterised by: **global coverage, continuity,** high **integrity/continuity** positioning and guarantee of performance for navigation (1-5 m **accuracy** for positioning), **two-way** communication between Mobile Terminal (Mobile User) and Service Centre/Provider(s), communication **reliable**, **near real-time,** small latency featuring, with **time response** (time elapsed between the instant of message sending and the relevant answer reception) **guaranteed** within 25 sec, **bursty** traffic in the RL, **unbalanced traffic** with greater amount of traffic in the Return Link with respect to the Forward Link, due to greater amount of Mobile Terminal with respect to the Service Centre/Provider(s), **point-to-point, broadcasting** and **multicasting** communication, , Messages from Mobile Terminal always carry **Position-Velocity & Timing** (PVT) data, messages from Service Providers carry **service provisioning or acknowledge** (ACK).

The services considered for GAUSS are based on low-bit rate transmission of small data packets carrying positioning & timing information, as required by typical Info-Mobility and Inter-Modality oriented applications. The typical data flow implies the possibility for the Service Provider to send requests and/or information to one or more Mobile Users. On the other side, the users may either transmit information to the SP on scheduled basis or else demand information or communicate ‘on request’ or ‘on event’.

GAUSS successfully demonstrated integrated Satellite Navigation GNSS1 precise positioning based on EGNOS, and satellite UMTS packet communication, for provisioning of high quality location based services. 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 had fruitfully contributed to the ETSI SES S-UMTS Working Group activities and results.

Horizontal accuracy better than 3-m was achieved in the trial area (Northern Italy - Lario, Como Lake, Parma and Po river areas). The MTB (Mediterranean Test Bed) was utilised because of the poor performance coverage of the ESTB system over the Italian regions.

From a technological viewpoint, GAUSS innovative components are mainly located in the prototype User Terminal, integrating off-the-shelf equipment and technologically advanced parts (with respect to the current state-of the art), based on GNSS1, GALILEO and S-UMTS compatible units:

- An integrated NAV / COM digital receive front-end able to de-multiplex the Navigation signals (including the current GNSS1 band and simulated Galileo E1 and E5 bands and the Communication signal, in the S-UMTS band
- An access a control subsystem and transmit front-end, operating in CDMA and supporting the upper protocol layers (based on UMTS packet transmission standard 3GPP – for short packet)

- Broadcasting and multicasting communications in compliance to 3GPP release 4, developed and proven with real satellite capacity
- Applications for emergency assistance, road mobility safety and efficient management of intermodal road-river transport, based on freeware software, combined with use of standardised maps and symbols (IHO – International Hydrographic Organisation) and standard protocols (CEN, IMO, EU normative ADNR).

Additionally GAUSS project actively and fruitfully contributed to many standardisation fora and working groups, in their activities of creating standards and recommendation in different topics: 3GPP and S-UMTS (ETSI) in particular for broadcasting and multicasting of small data packets, Location-Based and Emergency services with reference to GALILEO, application of innovative telematics to river navigation and transport of dangerous goods.

4 THE GAUSS DEMONSTRATOR

4.1 Demonstrator Architecture

The GAUSS Demonstrator is a set of equipment designed mainly to study and optimise the integration between navigation and communication systems. The studied and implemented satellite communication system is based on the S-UMTS standard. The navigation system is compatible with the GPS/GNSS1 and GNSS2 standards.

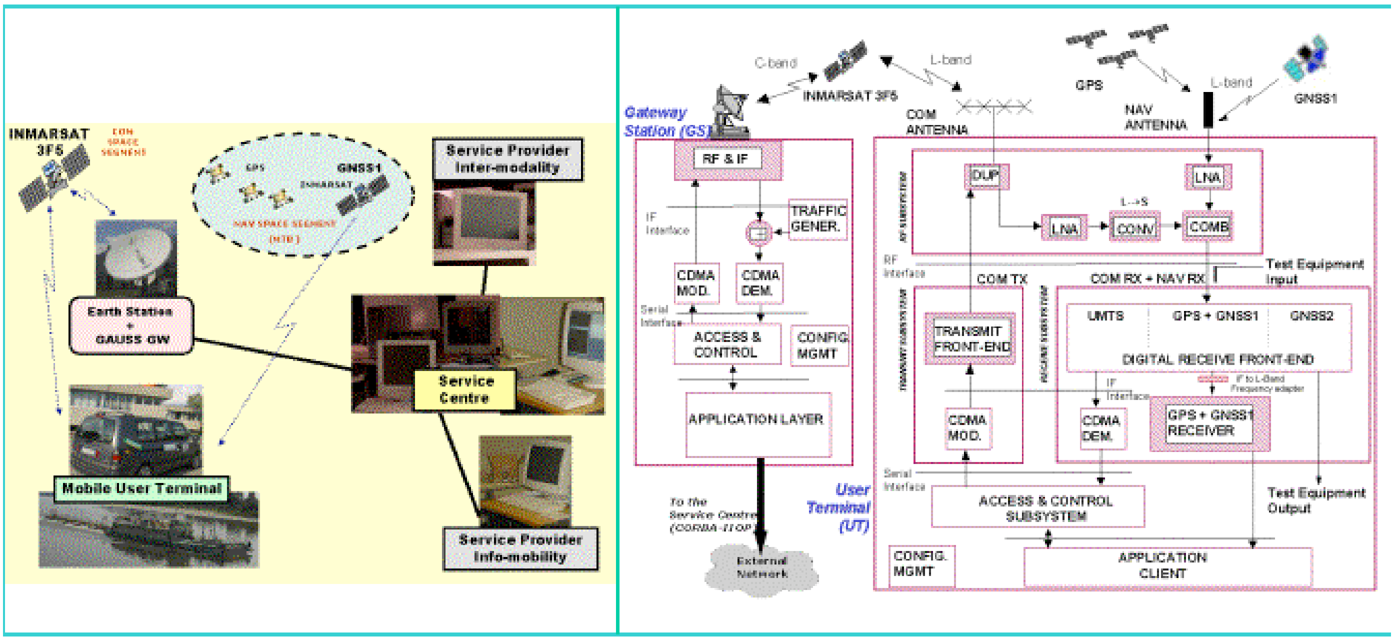


Figure 1 GAUSS Demonstrator elements and architecture

Figure 1 presents the architecture of the GAUSS Demonstrator, showing its main elements, some of them being existing facilities and some being developed by different companies which are Partners of the project Consortium

Existing elements:

1. The MTB (Mediterranean Test bed) for NAVIGATION, based on GPS signals augmented with SBAS techniques, with the objective of reaching 3-metres horizontal accuracy. MTB (Mediterranean Test Bed) is the Italian SBAS facility operated by Telespazio and generating the signal-in-space transmitted through the INMARSAT IOR (Indian Ocean Region) satellite. MTB is available as a complementary objective to the ESTB, in two operation modes: stand-alone independent operations and MTB-ESTB joint operations. For the GAUSS trials, due the poor coverage of the ESTB system over the Italian regions, use of MTB system in stand-alone mode was done, expanding the reference station network by purposely installing one RIMS 1 at Lario Telespazio premises (see **Figure 2**). This enabled to achieve performance in the North of Italy is about 2,5-meters horizontal accuracy, in compliance with the 3-meters requirements during the river navigation phase (static test were carried out demonstrating the capability of fulfilling the GAUSS requirements for positioning accuracy)

1. The INMARSAT 3F5 L Band COMMUNICATION capacity. For the GAUSS Demonstrator, use of ITALSAT F2 EMS (European Mobile System) capacity was planned at the beginning of the project. Due to critical anomalies, the ITALSAT F2 was withdrawn from the service, and the EMS payload capacity was not available at the time of the trials. The GAUSS trial campaign was recovered by using the INMARSAT 3F5 capacity. No modification was needed to the GAUSS Demonstrator components for 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

3. The Lario07 Earth Station (located at Telespazio premises), the relevant antenna and RF subsystem.

Figure 2 MTB GAUSS trial geographical characteristics

New hardware and software developments:

4. An advanced multi-mode user terminal (mounted on a car and on a ship), capable of handling, in integrated manner the COM and the NAV signals and an access system tailored upon location-based services (requiring low-rate and bursty resources) and S-UMTS compatible
5. The Gateway equipment
6. The Service Segment (Service Centre and Service Providers), running applications, based on use of GIS technology, standards and open-source components (CORBA, LINUX Operating System, Freeware Map Server).

The above three elements include GAUSS main innovations and new developed equipments. As mentioned, new technology was developed and proven in the trial campaign. This is based on the exploitation of existing and consolidated technology, integrated with ad-hoc innovative hardware and software developments, and represents a step further with respect to the current the state-of-the-art, available as off-the-shelf equipment on the market. Extensive use of current standards to architecture, protocols and interfaces was done for guaranteeing interoperability and flexibility.

4.1.1 The GAUSS Prototype User Terminal

One of the GAUSS objectives was to contribute to the development of an integrated user terminal that is capable to support the required navigation and communication functions. A maximum re-use of available and existing consolidated technologies enabled to reduce design and development risks and costs. This effort is orientated to future low-cost, small size, low power consumption, highly re-configurable user terminals.

A prototype **multi-mode Mobile Terminal** was produced using ad-hoc developments and off-the-shelf items: The advanced multi-mode User Terminal is composed of:

- An integrated NAV / COM digital receive front-end (DFRE), able to de-multiplex the full navigation bands (GPS, EGNOS, simulated GALILEO E1 and E5 signals) and the communication signal, in the S-UMTS band
- An RF subsystem, including the L➔S bands conversion, for the communication functions, a transmit front-end, and a baseband & control section operating in CDMA and supporting the upper protocol layers (UMTS packet transmission standard based – for short packet). It includes the SW-CDMA modems and the UMTS compatible access system, specifically tailored to location based services (low-rate, small packet transmission standard)

- For the navigation functions, the GNSS1 (GPS + EGNOS) receiver, designed for precise positioning and navigation operations within a Satellite Based Augmentation Service environment (RTCM 1 & 3)
- The application based on standard graphic system for position visualisation on digital maps (GIS - Geographic Information System - technology and freeware map server, standards and open-source components)

4.1.2 The Gateway

The Gateway, located in Lario and connected to the Service Centre (Rome) via Internet connection, 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)

4.1.3 The Service Segment

The Service Segment is the contact point of the GAUSS System and the users, for making use of the provided services. The GAUSS Demonstrator includes all the elements of a complete Service Segment (see Figure 1):

- The Service Centre, located at Rome Telespazio premises, connected to the Gateway via an Internet connection
- Two Service Providers, the Inter-modality Service Provider, where the specific inter-modality applications run (located at ARNI premises in Boretto) and the Info-mobility Service Provider, where the specific info-mobility run (located at Rome Telespazio premises). The Inter-modality Service Provider is connected to the Service Centre via an Internet connection, the Info-mobility Service Provider via LAN (for logistic convenience).
- The application component at User Terminal side runs on a notebook, connected to the User Terminal Upper Layer. Two different applications are available on the notebook, for inter-modality and info-mobility.

4.2 Data Transmission in GAUSS

From a functional viewpoint, the GAUSS Demonstrator provides data communication services, characterised by:

- Two-way communication, between the Service Provider and Mobile User (that is its subscriber)
- Low-rate transmission of small formatted data packet message, carrying accurate PVT information.
- Data Point-to-point, distribution from a SP to MUs (Broadcasting and Multi-casting) and collection from MUs to a SP (Broad-catching and Multicasting)
- Message exchange generated cyclically (on periodic basis), or asynchronously (on request or on event).
- Capability to require the acknowledgement message shall also be supported.

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) were 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.

4.2.1 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.

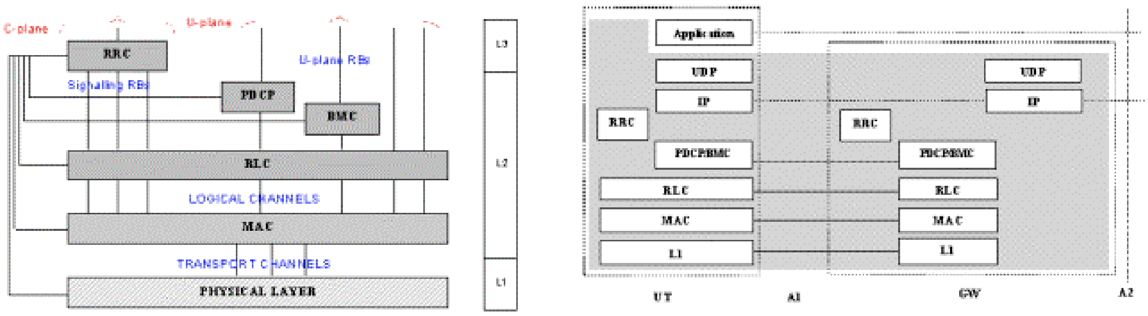


Figure 3GAUSS Upper Layer Protocol Stack (3GPP) and UT/GW communication

The Upper Layer in the GAUSS Demonstrator has the same structure as the one described in 3GPP. 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.

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

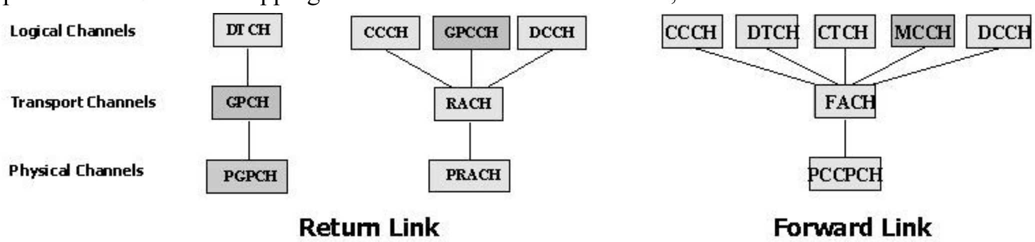


Figure 4 Channel mapping in the GAUSS Demonstrator Return and Forward Links

The main characteristics are the following:

- UMTS Release 4 compliant Access & Control System, with some compatible variants
- A new physical channel in the RL: PGPCH (Physical GAUSS Packet CHannel) with the corresponding transport channel GPCH (GAUSS Packet CHannel), used for the RL data transfer (DTCH corresponding logical channel)
- Two new logical channels: GPCCH & MCCHGPCCH (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 was 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.

4.2.2 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 2nd 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 was 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 was 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 was 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 _ 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:

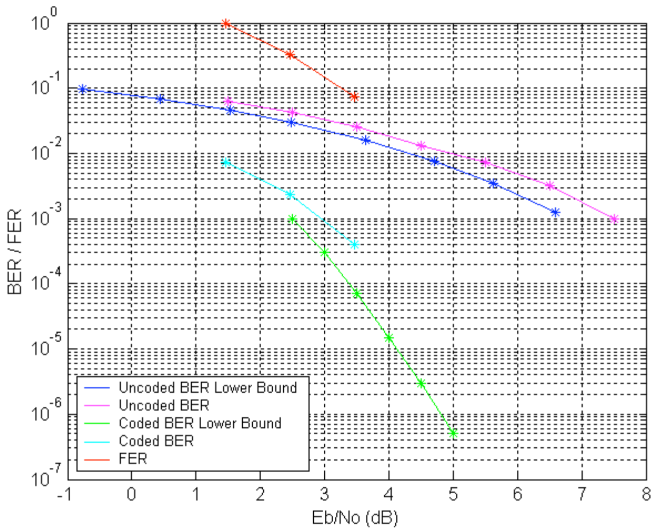


Figure 5 Performances of the Forward Link P-CCPCH

Both the uncoded and coded BER curves are shown. An implementation loss less than 1 dB was 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).

4.2.3 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).

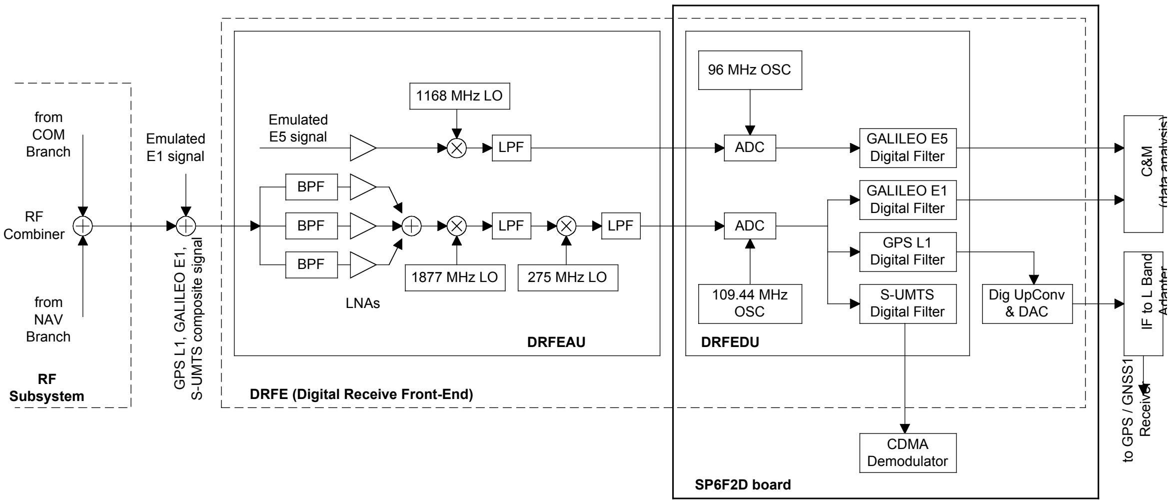


Figure 6 Block diagram of the DRFE

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 3^{rd} 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 1^{th} 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 was processed as indicated below.

UMTS: 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.

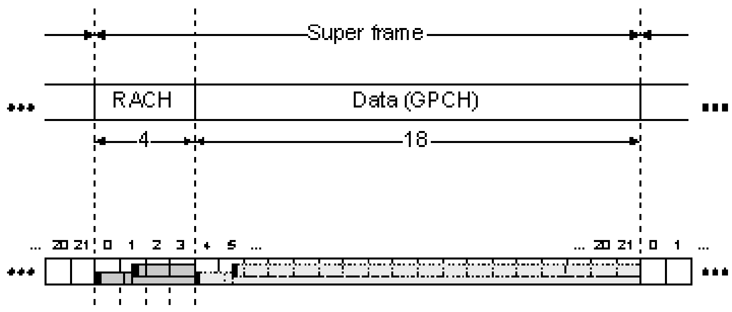
GPS: A decimation by 2, through a FIR filter is used to reduce the sampling rate and a cascaded FIR filter is performed to select the wanted signal. After this the digital up conversion of the signal is obtained achieving samples at 109.44 MHz and an IF signal centred at 30 MHz.

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.

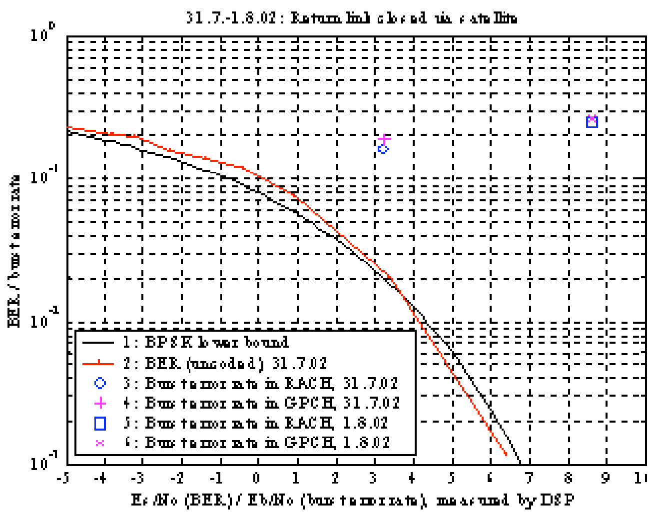
4.2.4 GAUSS Demonstrator Return Link Physical Layer

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.



GAUSS RL Superframe



BER and packet loss rate with link is closed via satellite

Figure 7 GAUSS RL main characteristics

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.

4.2.5 The GNSS1 receiver

A technologically advanced GNSS1 Navigation receiver was used for the User Terminal, based on a Thales Navigation off-the-shelf product for niche markets (usually maritime). It is capable to handle GPS and EGNOS signals, for precise positioning. The Navigation receiver is capable to manage the RTCM standard message generated by ESTB and MTB, for providing high quality services, in terms of reliability and performances. During trials, the receiver performances were validated a real environment with EGNOS, in the perspective of the future GALILEO services.

5 THE GAUSS TRIALS

5.1 Trial Campaign Description

A crucial phase of the project was the trial campaign, carried on using the assembled Demonstrator in a real environment, with the purpose of validating and proving the basic concept of the system and the provided services. Exhaustive trials were performed on Po river and on road in the neighbourhood of Parma and Como lake (see figures).

Applications were proven for emergency assistance, Point of Interest inquiry, vehicle localisation and control of dangerous goods transhipment, by using EGNOS precise positioning and UMTS packet communication via satellite.

Figure 8 GAUSS Demonstrator elements and link budget parameters

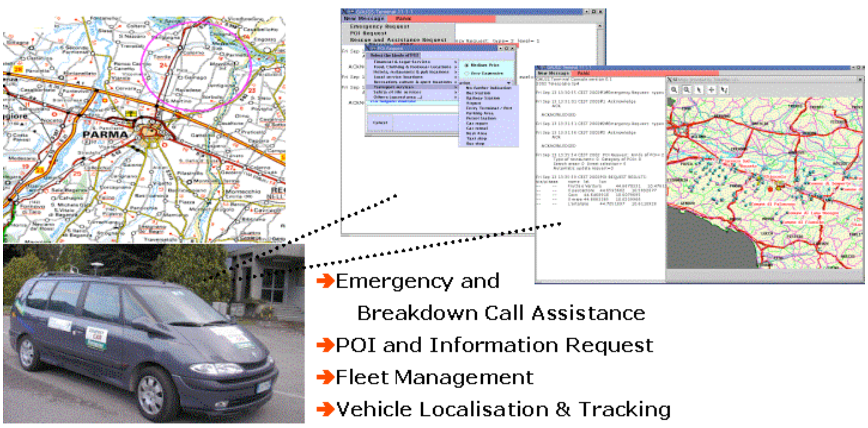


Figure 9 Info-mobility - Road

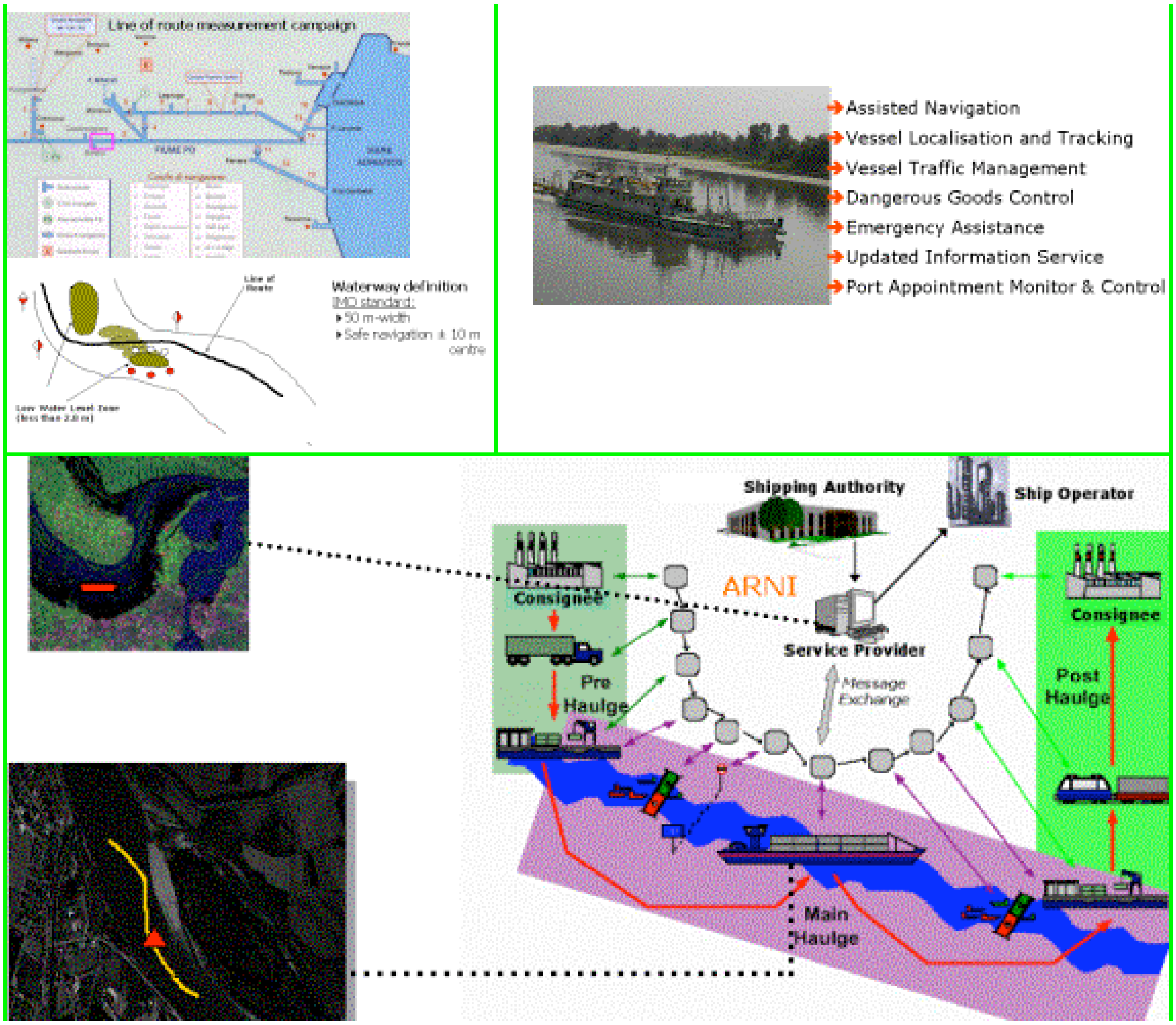


Figure 10 Inter-modality trials - Road-River

6 TRIAL RESULTS

Successful results were obtained during GAUSS trials, showing the following measures for the demonstrator performances:

- Time response within 30 seconds
- GAUSS messages up to 2 concatenated cells proven
- Multi-casting and broadcasting services, using UMTS protocol, developed and demonstrated
- Precise position monitoring (about 2,2 m)

Concerning the communication component of the demonstrator, the trials shown how the transmission in L-band is a difficult aspect, caused by lacking of regulations for transmission in L-band. Performances are strongly affected by interference, multipath and shadowing. Furthermore, transmission on L-band is often not regulated and spurious signals were experimented in the GAUSS demonstration, as big source of disturbance (some of them were known interferences at Lario Station, some others were random – in particular a random not authorised strong transmission by an Italian Television was detected). However, it was verified that overall performances of the system in terms of quality of provided services are not affected by these interferences.

Next table presents communication performances in the FL, showing affecting environment conditions and disturbing spurious transmissions in L-band. All the trials reported in the next table were recorded in different places near Boretto the beginning of August 2002. It shall be highlighted that, in most of operative conditions, good performances were experimented (BER negligible) and the links work properly. Nevertheless the trials highlighted that the link quality depends on the environmental conditions. As expected by the link budget, the factors influencing the link performances are the Ricean fading and the in-band interference. The Ricean fading is rather typical in transmissions concerning mobile terminals whose positions, and therefore the contour conditions, are not stationary. The presence of buildings can give a high contribution to the multi-path phenomenon. Furthermore the L band is often affected by interference because it is the most used band in the communication field.

Trial Number	Trial Conditions	Channel BER	Transmitted Frames	Transmitted TBs	Wrong TBs	Wrong Bits inside TBs
1	GAUSS Message	0	1800	450	0	0
2	Fixed Pattern	1.07E-2	1021	N.A.	N.A.	N.A.
3	Fixed Pattern	0	1308	N.A.	N.A.	N.A.
4	GAUSS Message	1.00E-2	4816	1204	1	2

Table 1 Forward Link Performances

Same concept can be applied to the performances of the DFRE. The performances of the pair DRFE plus GPS receiver are satisfactory. Nevertheless they were often affected, during the trials, by in-band interference. In some cases this interference caused a saturation of the chain designed to process certain levels of the incoming signal. This suggests to enlarge the dynamic of the DRFE in order to improve its robustness respect to interference phenomenon.

Concerning the access & control subsystem and the application, many test were performed, including stress test aimed at verifying the performances of the system in terms of packet lost and message recovery in case of any packet lost. With a pattern of about 1200 TBs we experienced no packet lost in the Return Link, while in the Forward Link only one packet got lost (and retransmitted by the A&C)

For the time response, it shall be noted that the performance achieved by the system (30 sec. for the time response) are satisfactory, considering that Internet was used for the connections among the Service Segment elements. Optimisation can be achieved by using dedicated terrestrial network connections, as usually done in running operative situations.

Broadcasting and multicasting messages were successfully proven: for broadcasting (SP➔MU), the message is correctly sent and received at UT side; for multicasting (SP➔MU), the message is correctly sent and received at UT side, only in case the UT is included in the multicast group, not sent and not received in case it is not included.

7 CONCLUSIONS

The trials demonstrated how the GAUSS **technology** and applications can improve mobility and transport management, by providing **innovative services** and creating favourable technical conditions for enhancing both the quality and the efficiency, while maintaining safety standards. The assessment, done with the important contribution of ARNI, participating as real user of the GAUSS technology and solution, verified the impacts that the GAUSS technology and applications produce, in terms of improved operational efficiency, service quality provision, working conditions and market opportunities. Furthermore, market studies showed that there are many niche markets, mainly professional customers in the transport sectors, taking advantages for the usage of the GAUSS provided technology and services.

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

Further development can be envisaged for **exploiting** the GAUSS solution towards other LBS related markets and for improving its performances and enhancing it towards other technologies (such as integration with terrestrial and wireless short-range technologies, and implementation towards GALILEO ready units).

GAUSS developed technology has a great potential, in particular should interoperability with terrestrial navigation and communication infrastructures be implemented, and in view of navigation infrastructures deployment (EGNOS operative and GALILEO systems). GAUSS is expected to boost the creation of reliable and effective services, capable of fulfilling the needs of different user classes for accurate and timely information exchange, collection, data processing and distribution. In particular the improved efficiency and safety will positively impact on the their operational activities, allowing a reduction of bottlenecks in inter-modality and an optimisation of the emergency assistance.

Hence, the demonstration is expected to have impacts in terms of very promising next developments and exploitations of the results achieved in the GAUSS project, in terms of:

- Advanced technology for supporting high quality, reliable and effective services to the citizens for the transport sector and whole mobility domain, in particular for safety-related applications
- Benefits achievable by the use of combined secure telecommunication, advanced software technologies and GNSS navigation, for location-based services oriented to safe and efficient transport management applications.