ADVANCED SIGNAL AND DATA PROCESSING WITHIN THE GAUSS PROJECT

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THE GAUSS SOLUTION

GAUSS (Galileo And S-UMTS Synergetic System) is a Research and Technological Development project co-funded by the European Commission, within the frame of the Information Society Technologies (IST) Programme. GAUSS main innovation is to analyse and demonstrate the potential synergy between Satellite Navigation and Communications, by proposing a solution for providing value-added services oriented to the mobility and transport management.
The main concept on which the GAUSS solution is based on, envisages the synergetic integration of the GALILEO Navigation and S-UMTS Communication systems, to provide advanced location-based services specifically addressing Info-Mobility and Inter-Modality. In particular, the two systems are integrated by fitting the Navigation Related Communication Services (NRS) being considered for Galileo, in the more general S-UMTS network, through:

- the provision via satellite, of the low-rate communications services being considered in the context of the Galileo programme, that are highly synergetic with navigation;
- the development of integrated user terminals that can support the required NAV and COM functions with maximum hardware reuse.

The technological issues of such a concept rely on the development of a Demonstrator, realised by means of existing and available facilities together with ad-hoc designed components. The former ones constitute the ground segment and space infrastructures, the latter ones include the advanced user terminal and the innovative services and applications.
In this framework, the project has the two-fold objective of new technological development and advanced applications, based on the integrated positioning/communication satellite systems and GIS (Geographic Information System) technology.
In addition to the applications, the GAUSS Demonstrator basically comprises communications equipment (COM) and navigation equipment (NAV).
The COM equipment consists of a real GEO communication system (the communication capacity at L-band from EMS - European Mobile Satellite) payload, interconnecting one User Terminal, interfaced to the Application Client, to a Gateway Station, interfaced to the Application Server. In order to match the satellite downlink frequency with UMTS frequency, the User terminal digital receiver front-end will be equipped with a receiver frequency translator (from L-band to S-band). The access chip rate will be adapted to the available payload bandwidth, but the modems will be anyway capable to support the chip-rate packet-oriented envisaged by the SW-CDMA standard. For the Demonstrator NAV equipment, in lack of Galileo signals, use will be made of the available navigation signals; therefore the User Terminal will be equipped with a GPS + GNSS-1 receiver (the GNSS-1 signal will be provided by an existing Satellite Based Augmentation System – SBAS).
At the Gateway Station side, existing station equipment will be used from the antenna down to RF and IF, therefore the S-UMTS-compatible packet-oriented CDMA modem (modulator + demodulator) will be interfaced with such equipment at IF level (70 MHz). The modem, which performs the physical-layer functions, will have to be developed on purpose for the GAUSS demonstration. The modem will have the capability to operate at various chip-rates (sub-multiples of the currently specified S-UMTS chip rate) such as to offer maximum flexibility with regard to the available transmission media. Still at the Gateway Station, an Access & Control subsystem will be responsible for all baseband

signals handling, for managing the whole access system (Medium Access Control, Radio Link Control and Radio Resources Control) through the available signalling channels, and for supporting the required interfaces with the Application Client/Server.
The User Terminal will basically comprise the Antennas, the RF subsystem, the Transmit subsystem, the Receive subsystem and the Access & Control subsystem and the Application Client. The RF subsystem comprises a Low-Noise Amplifier connected to the NAV antenna and a duplexer connected to the COM antenna for separating the transmit and receive branches. Another LNA is connected to the COM receive branch; after this LNA, a converter is used to translate the receive COM L-band into S-band (i.e. the S-UMTS band), and the converted signal is then summed with the L-band NAV signal by an RF Combiner, which directly feeds the Digital Receive Front-End. The Transmit subsystem includes a Transmit Front-End with an off-the-shelf power amplifier (no development required) and a CDMA modulator, to be developed for GAUSS. The modulator, as well as the demodulator (part of the Receive subsystem) which both perform physical-layer functions, will have the capability to operate at various chip rates (similarly to the Gateway Station modem). The Receive subsystem comprises the already mentioned flexible Digital Receive Front-End, intended to separate and convert to IF the three COM / NAV bandwidth segments, a variable chip-rate S-UMTS demodulator, to be developed ad hoc for GAUSS. The Access & Control subsystem, interfacing to the Application Client, has functions specular to those supported by the homologous subsystem in the Gateway Station.

DIGITAL SIGNAL PROCESSING

To serve the purposes of the GAUSS Demonstrator four main products will be developed which will be instrumental for the realisation of low-cost user terminals capable of supporting navigation and UMTS-compatible communications services:

- Digital Receive Front-End
- CDMA modems
- Access & Control Subsystem
- Applications.

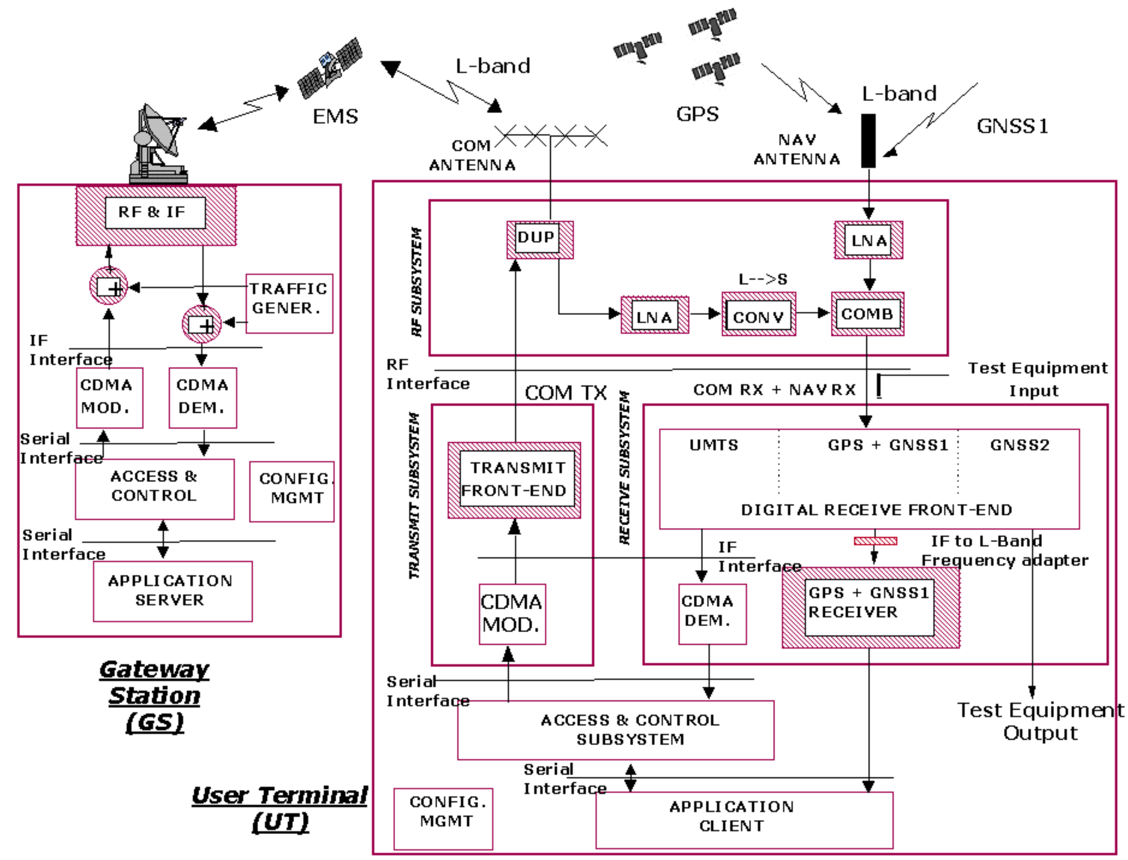

Fig. 1 GAUSS Demonstrator

Integrated COM/NAV navigation front-end

A very innovative digital front-end will be developed, allowing to use a single receiver for simultaneously handling multiple navigation and communication signals spread across a wide segment of the radio spectrum. In particular, the receiver front end of the GAUSS system will be capable to simultaneously process three services: GPS, GALILEO SAS (Safety of Life Services) and UMTS. Furthermore, the digital processor will be software-re-configurable such as to enable separating variable band segments across the input frequency range, thus offering a significant flexibility of accommodating future requirements with virtually no change for the hardware platform.
The processing consists of the separation of the following 4 bands assigned to the three services:

1. GPS L1 in the band form 1563 to 1587 MHz;
2. GALILEO E1 in the band form 1587 to 1591 MHz;
3. GALILEO E5 in the band from 1188 to 1214 MHz;
4. UMTS in the band from 2195 to 2200.

The overall useful band is 59 MHz and the first two band are contiguous.
The design takes into account of several guard bands to allocate the transition bands of the analogue filters; the following guard-bands are defined:

1. GPS L1 10 MHz for lower frequencies internal to the allocated band;
2. GALILEO E1 10 MHz for higher lower frequencies;
3. GALILEO E5 no guard-band;
4. UMTS 2.5 MHz.

The minimum resulting minimum band is 74 MHz.
GALILEO E5 has no extra guard-bands because the signal has a main lobe of 15 MHz (i.e. the chip rate), so that the remaining band can be used as the real guard-band. GPS and GALILEO E5 are combined to constitute a single band, so that the guard bands are defined partially inside the GPS band. UMTS has a 50% guard-band.
The Front End architecture is summarised in Fig. 3. A bank of filters and a combiner defines a signal including only the bandwidths of the useful signals. The recombined signal is fed to a down-converter in order to generate additional replica of the signals thus reducing the input bandwidth to the ADC. The ADC converters down-sampled data at the minimum allowed Nyquist rate. The FPGA circuitry implements a digital filtering for the final separation of the signals in four data streams. The down-converter capability (detrimental for other applications) of generating spurious and harmonics is also considered. The presence of spurious is expected to increase the effect of a single down-converter, further limiting the input bandwidth and sampling rate of the AD converter. In absence of a real Galileo signal, the Digital Receive front-end performance on the Galileo band(s) will be assessed by means of standard test equipment injecting a test signal into the RF receive path and measuring the translation performance at an ad-hoc IF output port.
The results of an exhaustive MATLAB analysis is reported in Fig. 4. The first diagram indicates the spectrum of the useful signals. The second diagram shows the useful replica after down-conversion; the replica have different amplitude because they come from different spurious orders. The third diagram shows the useful replica at the output of the ADC. The final text line indicate down-conversion Frequency, ADC sampling rate and the Base-band.

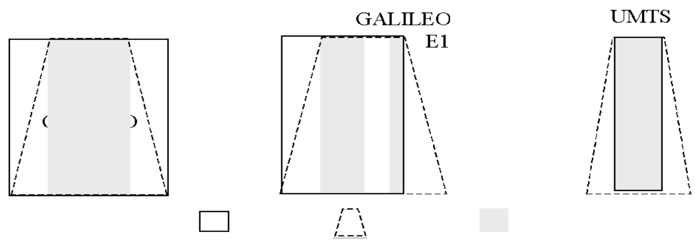

Fig. 2 Allocated bands, filters and guard-bands

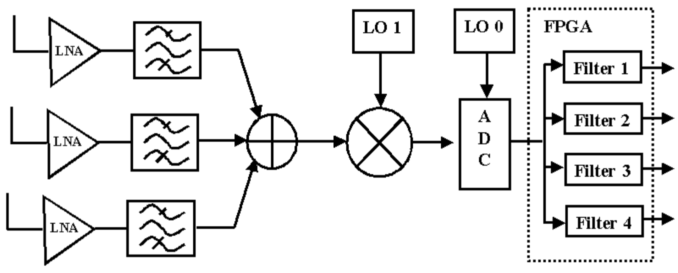

Fig. 3 Front End with IF filter bank and single down-converter

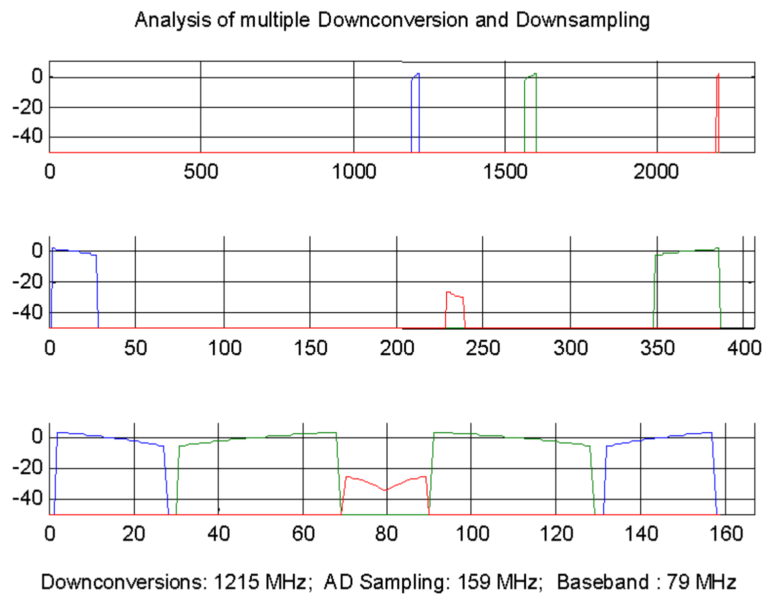

Fig. 4 Analysis of Front End with IF filter bank and down-converter with and spurious

The positioning and navigation receiver

The NAV receiver of the User Terminal is designed with a "Core Module" card which is the basic element. For the GAUSS demonstrator GPS + GNSS1 signal will be considered in absence of GALILEO signal. This module included in the receivers collects the navigation data and code/phase measurements, to compute position, velocity and time of the user. It has been designed to allow a great accurate positioning solution for applications such as:

- Real-time kinematics applications,
- Geodesic and topographic applications,

This GNSS module includes two ASIC components: one for RF and the other for digital signal processing. It also includes a DSP core which works at 40 MHz. The receiver is fitted with 11 channels working at the same time allowing tracking of 10 GPS satellites plus 1 to receive EGNOS geo-stationary information. Specific characteristics have been also developed to ensure high protection against multi-path effects. This module is connected to the integrated COM/NAV front end. The navigation module is also connected to an application dependant module. Thus a set of navigation message has been defined including: position (latitude, longitude ,altitude), velocity and integrity.
We can also remark we can take advantage of the NAV/COM integration at navigation level. Transmission of satellite position (Assisted-GNSS) could indeed enhance greatly positioning availability performance.

Spread spectrum coding with low rate bursty data

In GAUSS both the Gateway Station and the User Terminal CDMA modems will be realised compliant with the S-UMTS standard, introducing the additional operating modes needed for the purposes to be fulfilled. Significant efforts has to be paid for the modem algorithms, especially with regard to low data-rate operation. At this regard, the coherent modulation format currently specified for both T-UMTS and S-UMTS may no longer be appropriate, at least for the return-link. Non-coherent and differentially-coherent modulation formats will be investigated and their performance traded-off against the coherent approach by simulations and analyses. The field trials, to be performed through a real satellite (EMS), will then allow to verify unambiguously the real performance of the proposed air-interface scheme.
With a packed-based radio access and in presence of very bursty services, significant efforts has to be also devoted to the optimisation of the Medium Access Control (MAC) layer, to maximise system throughput. This layer is present in the Access & Control subsystem that will be implemented within the GAUSS demonstrator both at the User Terminal and at the Gateway Station.

The SBAS with MTB

The Mediterranean Test Bed (MTB) is the Italian facility owned by ENAV (the Italian civil aviation authority) and TELESPAZIO, which has been designed for providing capabilities of wide area GPS augmentation by generating the signal in space transmitted through the INMARSAT IOR satellite, containing the differential corrections and system

integrity data according to the MOPS RTCA DO229. Put into service in 1997 with a minimal architecture configuration, MTB is now undergoing an upgrading which extends the reference station network, with the capability of processing data coming both from EGNOS standard and WAAS standard stations, and with increased potential interaction with the ESTB. At present MTB is already capable of accepting the GIC/WAD ESTB generated data for up-link to the geostationary satellite and of sending to ESTB the WAAS reference station data, after conversion to the ESTB format. The Fig. 5 depicts the MTB architecture after completion of the on-going upgrading. A static User Platform, UP, is used as signal probe. The UP is capable of receiving and processing satellite based augmentation system (SBAS) data both from the AOR-E and IOR satellite navigation payloads. Core elements of the MTB are the Test bed Master Station (TMS), where the operation and application software is residing and runs and the Signal Generator System (SGS), which is dedicated to the generation and monitor of the signal transmitted to the satellite.
The TMS provides for the collection of data from the reference stations, directly from the MDM interface, as in the case of WAAS stations, or through an integrated interface which provides for format conversion of the EGNOS reference station data into the MTB accepted data. The data are then processed for station clock error estimation, generation of ionosphere grid data, for satellite state estimation, for calculation of the differential correction parameters and the generation of the SBAS messages. Currently, the MTB is configured to support: 33 satellites defined in the PRN mask (31 GPS and 2 GEO) and 16 ionosphere grid points defined in the IGP mask. The TMS software integrates also the interfaces for interoperation with ESTB. The Fig. 6 shows the TMS high level software architecture.
Kalman filtering techniques are extensively used to process and propagate data, starting from measurement data. Three processes are of particular importance:

- the real time processing
- the space vehicle state estimation
- the ionosphere grid estimation.

The real time processing provides for the generation of the SBAS messages (see Tab. 1) and for calculations performed at every epoch, including:

- verification of integrity of all data
- calculation of measurement residual for all filters
- computation of the satellite corrections and user differential range errors (UDRE)
- execution of the independent data verification and validation (IDVV).

Major algorithms applied by the real time processing include the background propagation of reference station data and Space Vehicle (SV) states to the current measurement time; the correction of the satellite measurements on geometric range, the pseudo-range smoothing, and the ionosphere and troposphere delay calculation. Consistency check is performed through the calculation of residuals and residual rates of corrected measurements with respect to the initial integrity check for any specified satellite. Satellite measurements coming from all reference stations are used to calculate the fast corrections and UDRE data. In order to validate the broadcast SBAS messages, an independent check is applied to the decoded SBAS , with emission of proper alarms, if necessary, by using an independent set of reference station data.
The SBAS message process propagates the data to the time of validity of the message and then formats the data into the 250-bit SBAS message. Default data are used for the UDRE degradation factor and Universal Time Co-ordinated (UTC) offset parameters. The SV state estimation uses an extended Kalman filter which propagates the satellite position, velocity, slow clock bias and slow clock drift.

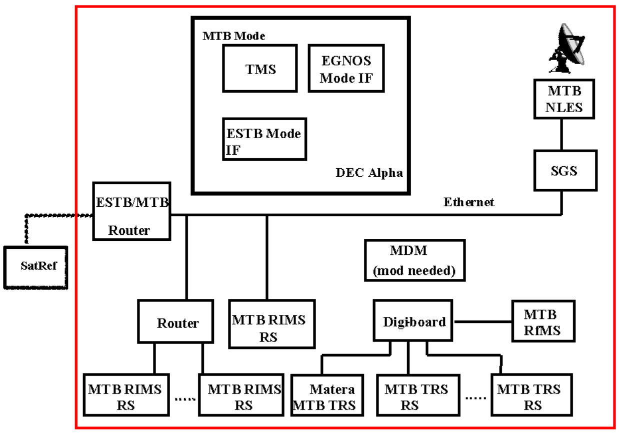

Fig. 5 MTB expanded configuration

Tab. 1 MTB Signal In Space

Type	Implemented	Exceptions
0	Yes	None (Only with MTB test mode configuration)
1	Yes	None
2-5	Yes	None
6	No	N/A
7	Yes	Hard-coded data used for UDRE degradation factor
8	No	N/A
9	Yes	None
10	Yes	None
11	No	N/A
12	Yes	Configurable, but constant, data used for UTC offset parameter
17	Yes	None
18	Yes	None
24	Yes	None
25	Yes	None
26	Yes	None
27	No	N/A
62	No	N/A (Raytheon-defined message)
63	Yes	None

The accuracy of the estimated state is improved through an estimation of the solar radiation parameters, reference station clock biases and troposphere errors. If the Kalman filtering process has converged, the estimated state is output, otherwise the broadcast data are output. The ionosphere grid algorithm estimates the ionosphere delay and the grid ionosphere vertical error (GIVE) within the coverage of the geostationary satellite.. The Kalman filtering is applied to all valid slant path ionosphere measurements from the correction stream and verification stream for the current epoch. The GIVE is computed from the ionosphere grid co-variance matrix for each stream and each grid point

Task of the SGS is to generate the MTB BPSK signal at IF (70 MHz) with FEC (Forward Error Correction) encoded data and GPS-like C/A (coarse acquisition) encoding. This signal, with the designated PRN 131 Gold Code 1012, is fed to the RF section of the GES, up-converted to C-band (6.456 GHz), properly amplified and transmitted to an INMARSAT-3 Satellite (IOR) which then retransmits the signal at L-band (1575.42 MHz). The SGS monitors the down-link signals at L1/L2 for GEO ranging closed loop control and signal quality verification. Significant SGS functions are:

- the addition of 250 bits of FEC to generate a correctly formatted 500 symbols per second data stream
- Modulo 2 addition of the 500 symbols per second data stream to the GEO Gold Code
- Performance of closed loop code and carrier control
- Performance communications via modem and RF interface.

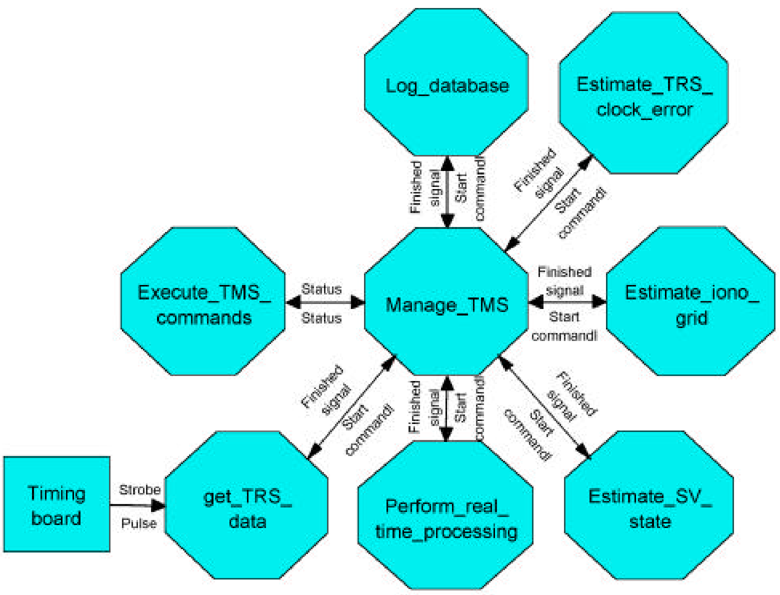

Fig. 6 TMS high level software architecture

Synchronicity control software, which runs on the SGS, supports communications with the signal generator, the GPS/GEO receiver and, with the data interface receiving navigation data from the TMS and SGS commands. Synchronicity provides phase and frequency commands to the signal generator unit based on control algorithms and GEO receiver measurements data. Synchronicity also formats and FEC encodes the wide area message and outputs it at one Hz intervals to the signal generator unit.

Data processing

Innovative applications, aiming at improving the citizens' and professional users' quality of life, will be developed and tested in the framework of GAUSS. These applications rely on the performances of the GAUSS Demonstrator, in particular on the precision of the positioning system and its integration with the communications system and observation infrastructures.

The key point of the GAUSS solution is to locate the service provisioning in a Service Centre, representing a unique and centralised backbone over which the services are built and relayed to the users and the main point of connection between the Service Providers and the external communication network (S-UMTS) over which the services are based. The GAUSS Service Centre is based on an open, modular and standard architecture, that allows the inclusion of new functionality in the network with a minimum impact on the applications over which end user services are based. The GAUSS Service Centre is composed by several functional modules and it is completely based on open-source components and standard protocols and data format for distributed application development. The major standards are:

- the W3 consortium protocols on TCP/IP (HTTP and HTML) and the XML language;
- the OMG standards (CORBA and UML).

One of the major innovation of the GAUSS project lies on this approach, that provides the Service Centre with very promising flexibility and interoperability features, bringing several benefits both to users and Service/Content Providers. Owing to its open and scalable architecture, Operators and Service Providers can easily interconnect to the GAUSS Service Centre for offering their services to the users.

GAUSS applications are developed on top of a distributed framework of CORBA components for integrated messaging and communication services. The framework is being developed for the future GALILEO system, but is designed to support the different existing positioning and communication networks seamlessly.

CORBA is the baseline framework over which all the different platform components exchange messages. The infrastructure, allows distributed management of services on TCP/IP networks, with a service management module responsible for the registration, loading, activation, unloading and removal of services.

For the scope of this paper the complexity of the CORBA framework can be reduced to 4 modules (Fig. 7):

1. Message receiver
2. Message processing
3. Message sending
4. Map service for infomobility applications.

The Message Receiver is in charge of the reception of messages from the GAUSS User Terminal. Every message received by the Message Receiver is processed to reduce it to a standardised form ("canonical message"). In this process the message, which usually conveys latitude, longitude, elevation and system time, is catalogued according to parameters such as:

- time of delivery by User Terminal;
- time of arrival in the Service Centre;
- communication channel;
- terminal identifier;

If additional information is carried by the message (for example a test message), this is attached to the canonical messages as a map (collection of key-value pairs of strings). Therefore any arbitrary message type can be handled by the same receiver. For the GAUSS message type, efficient use of the message payload is possible by defining an extensible set of standardised binary message formats. Each message format is defined by a unique service identifier number. The classified canonical message is then relayed along the message processing pipeline to one or more subsystems that are in charge of managing it.

Besides being catalogued and stored, the event carried by a message may eventually be communicated to other applications, which will react according to their specific business rules, thereby achieving the desired dynamic application behaviour in a distributed CORBA environment. Messages are archived in persistent storage into a database. Archiving is done sending messages in parallel to the message database and to the system log. The complete history of messages received from the User Terminals or transmitted to terminals by the GAUSS Service Centre is always available to the applications. A full log of messages, including malformed or damaged messages is always available for administrative purposes.

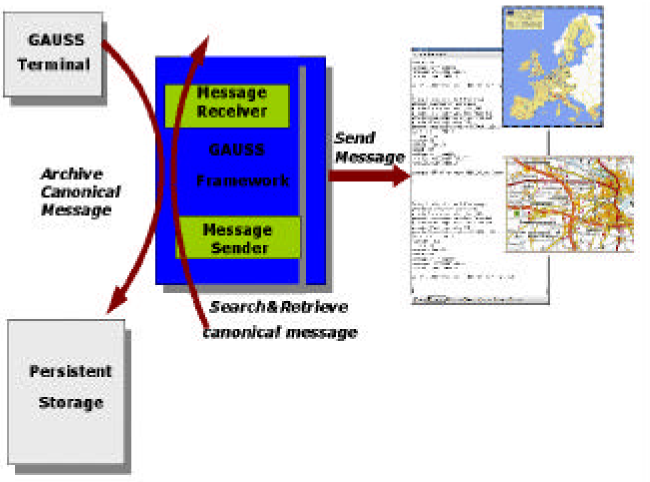

Fig. 7 Generation and distribution of positioning GIS integrated data

It is possible to query the whole message database and recreate the sequence of messages received from and transmitted to a specific terminal. It is possible to search messages by criteria such as terminal identifier and type of message. It is also possible to search by interval, within either a latitude-longitude box or a time window.
The Message Sending service is the counterpart of the Message Receiving. It allows to send messages to the GAUSS User Terminal. Again, this is accomplished by using an extensible architecture of distributed components on the ORB bus. Also the output message has a standardised binary representation, identified by a service identifier that fully qualifies the type of message transmitted by the GAUSS Service Centre to the terminal.

FUTURE PERSPECTIVE

In the near future, demand for accessing to multimedia information services based on the user position, is likely to increase. Analysing state-of-the art claims that today's service systems are often concentrated on one application or restricted to different operators and providers specific/proprietary solutions, in a quite fragmented situation. On the contrary, the volume and richness of information services is growing at an accelerated pace; future satellite navigation (EGNOS, GALILEO) will increase this problem. That leads to a reduced Service accessibility for customers, undergoing the variety and speed of new technological alternatives, end user devices and the necessity to cope with contracts to an increasing number of providers.
In this scenario, the challenge of GAUSS concepts is to demonstrate the benefits achieved by integrating existing and emerging navigation (GPS, EGNOS, GALILEO) and packet based mobile communication (S-UMTS) technologies. Starting from the experience of recent research and activities involving similar objectives, GAUSS innovative approach represents an effective step forward with regards to the mobility needs of different users, both individuals and businesses with the provisioning of seamless and ubiquitous location-based services. As a matter of fact, the Digital Receive Front-End represents a very important development with regard to future multi-mode terminals utilising common hardware to handle both COM and NAV services ("multi-mode terminal") with no need for housing separate COM and NAV receivers in the same container. The front-end samples a bandwidth containing multiple signals (GPS, GNSS1, Galileo and S-UMTS) and performs DSP to separate the various bandwidths. A suitable down-conversion strategy based on a single down-converter is pursued, which in conjunction with a carefully chosen A/D (analog-to-digital) sampling frequency allows to utilise a single high-speed A/D converter for all signals. The strategy of reprogramming firmware on common hardware will be pursued (Software Radio concept), this leading to a flexible, low cost, low power, small site terminal capable of supporting different S-UMTS RANs, even the terrestrial ones supporting higher-rate services, should one need it in the future ("multi-RAN terminal").