Performance Evaluation of Satellite-based Search and Rescue Services: Galileo vs. Cospas-Sarsat

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Abstract—The European satellite navigation system Galileo is a highly promising technology with communication capabilities providing an enhanced Search-and-Rescue (SAR) service in combination with the current Cospas-Sarsat system. Our development focuses on a high reliable hybrid communication infrastructure for wide area fire fighter missions. The combination of a terrestrial network infrastructure and the enhanced Galileo SAR service supports communication out of coverage in distress situations. The improved Galileo SAR service is compared to the actual Cospas-Sarsat implementation in this paper. Architectural building blocks which are particular belonging to either Cospas-Sarsat or Galileo are highlighted. Simulation results reflect disparities in quantitative figures from which performance indicators for the SAR service quality are deduced. The necessity of Galileo SAR for high reliable and fast applications in emergency situations is shown and an optimal number of additional Galileo satellites carrying SAR payload is derived.

I. INTRODUCTION

The European satellite navigation system Galileo offers a promising technology to enhance the navigation resolution and provides communication capabilities in combination with the presently available Search-and-Rescue (SAR) service of the Cospas-Sarsat system. Our current research in the project Galileo4FireBrigades, accomplished in cooperation with the German Aerospace Center (DLR), focusses on real time emergency communication services for fire fighters. Even if no terrestrial network is available, a hybrid communication architecture ensures out-of-coverage communication by using enhanced SAR service of the prospective Galileo satellite system in combination with terrestrial networks. The current Cospas-Sarsat system is going to be enhanced by additional Galileo and GPS satellites carrying SAR payloads to increase the service integrity. Thereby capabilities for new ranges of applications are available. The enhanced Galileo SAR Service offers an integrated feedback channel which is also, from the psychologically point of view, essential for the endangered person and shall also decrease the number of false alerts. The communication flow of a Galileo SAR call is shown in figure 1. The message of the distress beacon is sent to the space segment and then forwarded to a Local User Terminal (LUT) which represents a Ground Station. In case the caller doesn’t have a Global Navigation Satellite System (GNSS) receiver to indicate the position, the satellites can localize the person using the Doppler Effect or a combined Frequency of Arrival/Time of Arrival (FOA/TOA) procedure. The message reaches the Search-and-Rescue Coordination Center from which emergency service is sent out to recover the caller. The Return Link Service (RLS) is accomplished by adding SAR payload to the Open Service (OS) navigation data stream. The Return Link Service Provider (RLSP) adds the generated return messages from the Mission Control Center (MCC) to the navigation data stream. New service applications are possible with reliable up- and downlink satellite architecture e.g. new short message services to establish a communication between rescuers and casualties could be reasonable. The Return Link message embedded in the navigation stream should ensure fast recovery operations e.g. in navy scenarios when each ship encodes the navigation stream. The overall service integrity rises by adding several Galileo satellites to the existing system and shall make this service also usable among fire fighters e.g. to deliver important sensor data directly to the operation controller. The objective of this paper is to prove the real time capability of SAR Services using the Galileo Satellite Communication Simulator (GSCS) framework developed by CNI which offers real time satellite movements and a multiscale simulation architecture including best-in-class tools for protocol, mobility and radio channel modelling. A second simulator, the Galileo
System Simulation Facility (GSSF) by ESA is used for coverage and visibility analysis and for cross-validation. This paper is arranged by presenting a brief introduction to the specific SAR Systems namely Cospas-Sarsat and the prospective Galileo SAR segment. The key performance indicators of the systems are highlighted before the needed capabilities for an adoption among fire fighters are examined. Simulation results are discussed before this paper is wrapped up with a conclusion.

II. SEARCH AND RESCUE SERVICE

A. Cospas-Sarsat

The international humanitarian Cospas-Sarsat system [5] for worldwide Search-and-Rescue operations was established in 1982 and saved about 21,000 lives in over 5,700 emergency missions [6]. Figure 2 shows the overall architecture and the message flow of the system. The 121 Mhz emergency frequency is not going to be supported after February 2009 [6].

1) User Segment: Three generations of distress beacons are specified:
   - First generation beacons rely on the determination of their position by utilizing the Doppler shift.
   - Second generation beacons calculate their positions using the Global Navigation Satellite System (GNSS).
   - Third generation beacons are not in operation yet and should support the Galileo specific return link service.

It is expected that more than 400,000 first generation beacons will be in service in the year 2015.

2) Space Segment: The initial space segment of Cospas-Sarsat consisted of four low-earth-orbit (LEO) satellites which were optimized for Doppler localization accomplished by the high relative movement towards the earth. But the processing time for an emergency call is very high because the coverage area of the satellites is limited. This observation correlates to the service availability and reliability. A further extension of the system was to add three geostationary (GEO) satellites in order to minimize the time delay of processing a distress message. But these satellites have no possibility to locate the beacon, hence the beacon has to include its position in the distress message calculated by the Global Navigation Satellite System (GNSS). Currently five LEOs and three GEOs are in full service.

3) Ground Segment: Currently two different types of Local User Terminals are implemented in the Cospas-Sarsat ground segment. 46 ground stations [5] for the LEO satellites and five for the GEO satellites provide a nearly global coverage. A direct connection to Mission Control Centers (MCCs) via a fibre optic network ensures a small propagation delay. The message is then sent to a Rescue Control Center (RCS) in the SAR Network from where rescuers are sent out to the emergency area.

B. Galileo SAR

The idea of the enhanced Galileo SAR is that prospective satellites carry additional SAR payload fully compatible to the existing Cospas-Sarsat system (cf. Figure 2). SAR distress messages will be detected by the Galileo satellites in 406 Mhz band and will then be broadcasted to the dedicated medium-earth-orbit (MEO) LUT using 1544 MHz band.

1) Space Segment: The Galileo space segment consists of 30 MEO satellites on a Walker 27/3/1 constellation, from which a not yet defined number will be equipped with SAR payload. These MEOSAR satellites offer localisation capabilities using a combined TOA/FOA procedure with an accuracy of five meters. The operation height of 23,260 km offers a large coverage area and visibility of a specific satellite for hours. Hence the Return Link Service can be accomplished using the same satellite. Multiple satellites in range can also receive the distress message in order to improve the service reliability.

2) Local User Terminals for MEO satellites: New techniques to build up LUTs for MEOSAR satellites are depicted in [7], but are out of scope of this paper. Especially localisation schemes and channel conditions are necessary to be considered in the design phase of MEOLUTs.

3) Return Link Service Provider: The planned Return Link Service Provider is the integral enhancement of the planned Galileo SAR service. An acknowledgement for the caller can be added to the navigation data stream. Average data rates of 10 bit/s and 6 ACKs per minute can be achieved by this strategy.

III. SIMULATION FACILITIES

A. Galileo Satellite Communication Simulator

An event-driven satellite communication simulator based on OMNeT++ simulation engine [12][13] is set up for performance evaluation. The proposed Galileo Satellite Communication Simulator (GSCS) [1] bases on a Multiscale Simulation Approach [2] and is able to model all relevant wireless communication aspects. A sophisticated satellite mobility model based on NORAD's...
(North American Aerospace Defense Command) Simplified General Perturbation No. 4 and Simplified Deep Space Perturbation No.4 (SGP4/SDP4) [10][11] algorithms is implemented. The calculated satellite positions are highly accurate in combination with the actual NORAD Object Catalog which is generated by a large ground sensor network for observing satellites and moving objects in earth’s orbit.

1) Multiscale Simulation Model: The simulation model is enhanced by a multiscale simulation approach [2] which relies on the tight coupling of the protocol simulation, accomplished by OMNeT++ [12], to an industry standard Radiowave Propagation Simulator (RPS) [14] and a CNI proprietary MOBILE Object Simulation Environment (MOOSE) [15] to model the mobility of the user segment. The synchronisation of these modules is accomplished by a Central Event Broker [2] which controls the data flow between the simulation systems.

2) Galileo Satellite Mobility Model: The actual Two Line Element (TLE) sets can be downloaded on [8] and [9] either as a full object catalog or a system specific set. The parameters of the TLE format used by the SGP4/SDP4 algorithms are shown in figure 3. Table I describes the various abbreviations of the TLE format. Each TLE data set consists of three lines whereas line 0 consists of a 24 character name and line 1 and 2 contain the described data to accomplish the calculation.

TLE data is not available for future satellite launches, hence we created new TLEs using Galileo System Simulation Facility (GSSF) [16] to obtain orbit data. An existing TLE of the first Galileo satellite GIOVE-A (Galileo in Orbit Validation) was the reference for 27 Galileo operational satellites. Table II shows the relevant parameters, which have been transferred to the TLE format.

3) Communication Delay Model: The communication delay model is mandatory for an exact validation of the real time capability of the SAR service. Figure 4 shows a satellite crossing a distress message and clarifies arising time delays. Modelled time delays are explained in table III where most of them rely on the current satellite constellation. All delays are worst case assumptions.

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<th>Parameter</th>
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**TABLE I**

**TLE DESCRIPTION**

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**TABLE II**

**GALILEO ORBIT PARAMETERS**

Fig. 3. Two Line Element Format

**Fig. 4. Time Delay Analysis for one moving Satellite**

B. Galileo System Simulation Facility

The official Galileo validation phase [17] will be accomplished by using three major verification methods:

1) Galileo System Simulation Facility (GSSF)  
2) Galileo Signal Verification Facility (GSVF)  
3) Galileo System Test Bed (GSTB)

GSSF [16] is used for coverage estimation as described in the results section. It is able to simulate the complete Galileo system containing Space Segment, Ground Segment, User Segment and the Environment. Especially integrity performance and service volume analysis either in a global or regional scenario can be analysed. The important aspects for new high reliable communication services like reliability, availability, maintainability and safety can be visualized using GSSF.
IV. PERFORMANCE MEASUREMENTS

A. Visibility Analysis

The following visibility analysis plots have been accomplished by using GSSF. This discussion shall clarify the necessity of an extension of the existing Cospas-Sarsat system. At the end of this section we will derive an optimal number of Galileo satellites which should carry additional SAR payload. Figure 5 displays a coverage estimation of five Cospas-Sarsat LEOSAR satellites. The geostationary satellites are out of scope here because they have no localization capabilities and are limited to a maximal latitude of 80 degree. The created coverage plot shows a mean visibility of less than 0.5 satellites in average. Hence the service has to be improved either by adding several LEOSAR satellites or by adding SAR payload to future GNSS satellite launches. Thus figure 6 denotes the visibility plot of the complete Galileo system. Most of the territories are covered with more than eight satellites. The employment of each Galileo satellite with SAR payload is not inevitable. If the message is received by three or four satellites at a time, the processing can be fulfilled reliably. If the caller is using a first generation beacon which is not able to transmit the position, the localization can be executed by four satellites using a combined FOA/TOA method. Figure 7 depicts the combined Cospas-Sarsat Galileo coverage with an optimized number of MEOSAR satellites. We propose to equip at least nine Galileo satellites with additional SAR payload. This is the minimum configuration which is necessary for an adequate SAR service. This assumption will be proved regarding processing delays in the following section.

B. Time Delay

All relevant communication paths have been modelled adequately in our simulation model. The calculated delays (cf. section III) are gained from a measurement that considers the whole sending process until arrival at the Rescue Control Center. Especially time delays concerning processing and propagation operations have been taken into account. 50,000 cycles with a random position of the distress beacon have
been simulated to get almost plane results. Figure 8 shows processing delays against the degree of latitude. The coverage estimation of COSPAS-SARSAT shown in figure 5 correlates to the time delays calculated in the Galileo Satellite Communication Simulator. The time delay rises immensely between -40 and +40 latitude degree because the visibility of the five LEO satellites is very low in this region. Additional geostationary satellites of Cospas-Sarsat are balancing this debility of the LEOSAR system but without supporting first generation beacons. The full equipped Galileo system (27 SAR modules) does not show a time delay that is caused by missing availability of visible satellites. The delay is constant and represents the assumed propagation and processing delays in the signal processing chain. In the next steps the minimum number of needed SAR payloads for best performance results is analysed. Figure 9 depicts the optimization regarding time delay accomplished with GSCS. The Cospas-Sarsat system was taken as reference and higher bound. An optimal result is represented by Galileo consisting of 27 additional satellites carrying SAR payload as a lower bound. In order to optimize the number of necessary SAR payloads, the quantity of additional Galileo satellites is enhanced in every simulation step. A uniformly distribution in just one Galileo orbit was assumed in the first case. But the results have shown a limited performance. As a consequence the second step shows an optimized distribution over the whole satellite constellation. The distance between the satellites is thereby uniformly distributed. Figure 9 denotes an equal performance until four satellites have been distributed. That’s why the initial distribution is equally to the first distribution on just one orbit. The resulting constellation consists of nine SAR payloads distributed over the three Galileo orbits. The results show an almost equal performance compared to the optimal achievable performance.

V. CONCLUSION AND OUTLOOK

Our research has shown the difference between the current Cospas-Sarsat system for satellite based emergency calls and the enhanced SAR service of the Galileo system. The architecture of the systems have been discussed before a coverage analysis has shown the necessity of Galileo SAR. A minimum number of Galileo satellites carrying SAR payload has been derived and validated by the Galileo Satellite Communication Simulator in a time delay analysis. Our future work is considering the concept of a SAR gateway which is usable among fire fighters. An extensive channel and traffic analysis is necessary for further evaluations.

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REFERENCES