A Secure EGNOS Local Element for Precise Positioning of Rescue Operations on GPRS and VHF Channel

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Abstract—**This paper describes the work performed in the design of a network-based positioning system exploiting the advantages of the European Geostationary Navigation Overlay System (EGNOS) tailored to support operation of Alpine Rescue Teams in the management of search and rescue operations. The positioning system is based on the raw pseudorange measurements collected by the users and transmitted to a Local Element over cellular or Very High Frequency (VHF) radio channels. This latter exploits frequencies reserved for rescue teams and ensures good coverage in mountain environments. The results demonstrate that the system fully exploits the improvement given by the EGNOS signals, ensuring a suitable level of accuracy in the positioning for a larger time with respect to standalone Global Positioning System (GPS) positioning.**

I. INTRODUCTION

This paper presents an automated monitoring system developed in collaboration with the Corpo Nazionale Soccorso Alpino e Speleologico (CNSAS) able to support the rescue operation. The project aims to improve the current operative scenario of the alpine rescue teams through a new system architecture based on the Global Positioning System (GPS) data transmission over Very High Frequency (VHF) or General Packet Radio System (GPRS) channels. Moreover the development of localization technologies offers several possibilities enabling to obtain a satisfactory accuracy level. In particular, continental augmentation system based on geostationary satellites can be exploited, in order to reach high level of accuracy in the localization services. In this work the use of the European Geostationary Overlay System (EGNOS) developed by the European Space Agency (ESA), the European Commission and the EUROCONTROL is addressed.

II. CURRENT SITUATION

The system developed aims at helping the management of the operations of Alpine Rescue Teams during operation on the mountains for search and rescue. In many cases the coordination of the workforce is not supported by advanced technologies as far as the localization sector. According to the CNSAS indications, the current support to the operation, as far as the localization is concerned, is described in Figure 1. Each rescuer is equipped with a GPS handset and a radio transceiver which works over a reserved VHF frequency band. These channels ensure an adequate coverage in mountain environment.

During rescue operations, the rescuer's position obtained with a GPS receiver is communicated via voice to the Local Element, through VHF radio link. It has to be remarked that it is not mandatory for the rescuers to be equipped with GPS receivers; at the operational control center the coordinator can manually record the positions received on maps in order to accurately monitor all the teams involved in the operation area. In this way the coordinator is able to give prompt guidance to the rescuers.

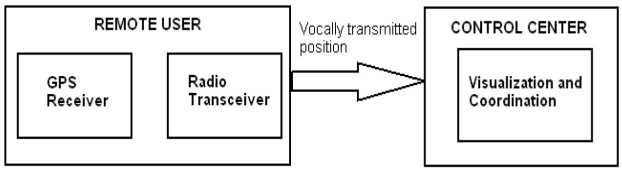

Figure 1: Current operative scenario of CNSAS teams

The Alpine Rescue Teams are composed by a large number of volunteers who need to be efficiently guided towards the operation point. Short time of intervention and a very good training of the rescuers is often essential to assure safety of the rescued people. Despite of the engagement of the member of the Alpine Rescue Team and their knowledge of the mountain area, the actual effectiveness of their operations can be eased and improved designing an automated monitoring system able to provide a complete view of the rescuers on the field in real time.

In the present system, the reliability of the representation of the workforce is highly dependent on the ability of each rescuer to use the GPS receiver and the continuous communication of the position to the control center.

In addition the position accuracy is completely defined by the employed GPS receiver. These conditions do not allow to know the rescuers position with high level of accuracy, especially as far as the altitude is concerned. Considering the morphological characteristic of the typical operation area, composed by a great number of steep slopes, the knowledge of altitude parameter is fundamental to localize people.

Another important aspect to highlight is that mass market GPS receivers do not guarantee a sufficient level of availability and reliability due to the critical environment as canyons or dense foliage forests limiting the visibility of GPS satellites.

Furthermore, the positions available at the operational control center could be affected by different errors coming from misunderstandings between the rescuers and the coordinator. In this case, the transmission via voice over VHF radio link does not guarantee the position integrity.

III. SYSTEM REQUIREMENTS

This section provides notions coming from a deep analysis of alpine rescue team requirement related to a coordination system they need, in particular according to the indications provided by the Alpine Rescue Team of Piemonte region, in Italy, as described in Section II.

First of all, the monitoring coordinating system has to be available and reliable in every environment situation and ensure the communications with the control center for the exchange of information between control center and rescuers. For this reason it is necessary to analyze the coverage and availability of communication technologies in mountain environment. It is important to highlight that in mountain environment the coverage of Global System for Mobile (GSM) network [3] is not assured. According to the experience of representatives of Piemonte alpine rescue teams, above an altitude of 2500 m, the GSM network does not offer any possibility of coverage. Furthermore, the availability of GSM channels is limited. In fact the distribution and the size of the cells is planned in order to ensure the coverage according to the number of potential users in the geographic area. The GSM infrastructure is generally organized in macro cells, differently from urban areas where the system is organized in micro cells (sometimes even overlapping in coverage). Consequently the number of available GSM slots is not as big as in urban environment, therefore the availability of GSM network and related services is not assured, especially when the number of users dramatically increases such as during holidays.

Even more critic, is the exploitation of the GPRS for higher rate data communication that requires a larger number of time slots of the GSM frame. For this reason in mountain regions the GPRS service could not available, even in presence of GSM coverage.

For their communications, the alpine rescue teams are using the VHF Radio channel that provides an high level of availability and reliability in the areas of interest. According to the Italian frequency planning, the CNSAS has been assigned frequency of 71.5 MHz [2] over the whole national territory. More specific, in Piemonte region is provided of a VHF repeaters network system working on 71.5 MHz. Anyway, it is important to underline that VHF channel has been primarily designed to be available for vocal communications, in particular for emergency communications, with higher priority respect to any data communication link that can be setup using the same radio channels.

In addition, it is important to ensure the security of the data channel and the integrity of the exchanged information among rescuers and coordinator during the rescue operations. For this reason in the design phase it is important to underline the modalities of the exploitation of communication channel, with the definition of a proper secure communication protocol.

Furthermore, localization system must guarantee an high level of accuracy in the positioning. According to the Piemonte Alpine rescue teams opinion, the knowledge of the positions within an error range of 3-5 m in the horizontal plane is required for enabling an efficient patrolling of the rescuers. Most problem related to the GPS accuracy is the altitude measurement: for interventions conducted in mountain slope it is essential to know altitude within an acceptable error range, such as 5 m previously mentioned, because horizontal coordinates (latitude and longitude) in that situations do not give enough positioning information.

The support infrastructure must be very user-friendly in order to allow short time of training of the volunteers of alpine rescue teams; most of the technical functionalities must be transparent to the rescuers and the coordinator.

Another critical aspects for the results in the interventions is the battery consumption of portable devices. If the power supply ran down during an intervention, it creates a very dangerous situation also for the rescuer; in order to avoid this inconvenient, every project related to the Alpine Rescue Team coordination must take care the consumptions of the mobile equipment.

The project design must take care about cost effort both in the choice of devices and, most of all, the costs for the exploitation of the system features, such as cost effort for using the communication channel.

The rescuers equipment must be resistant for operating in hostile environment and in very uncomfortable and dangerous situations.

Last but not least, a fundamental requirement of alpine rescue teams in order to be able to make rescue operations is the safety of their volunteers, that would be strengthened by a reliable monitoring of the position of the rescuers during interventions in order to be able to help them when necessary.

IV. GOALS OF THE PROJECT

In light of the general requirements previously stated, the scope of this work has been the design of an improved monitoring system for helping the rescue operations.

The overall system design aims to realize a prototype of an integrated localization-communication system able to provide a real time support for the coordination of the Alpine Rescue teams during their interventions. In particular to the final goal is an automatic network-assisted localization system which integrates EGNOS features in order to ensure a high level of accuracy and integrity of positioning, in order to be able to match the requirement described in Section III.

Since a key point of the system is the link between the rescue teams and the control center, different communication channels are used to ensure total coverage over the operational area. The GPRS is employed because it ensures a large coverage in suburban areas but, as already remarked, does not offer enough level of coverage in mountain regions. On the other hand the VHF radio link using frequency channel of the Alpine Rescue Teams and guarantees coverage in absence of GSM networks.

The infrastructure must guarantee the integrity of data exchanged and the security in the channel exploitation. For this reason it is necessary to regulate the use of the communication channel. Furthermore it must continue to allow voice communications over VHF link with higher priority respect to data communications.

The system should also guarantees high accuracy in the estimation of users' position. For this reason it is important to analyze all techniques proposed in order to increase GPS accuracy. Today continental augmentation system based on geostationary satellites are in charge of providing ionospheric, ephemeris and timing corrections are available. In Europe is available the EGNOS. The system is oriented to exploit EGNOS features.

EGNOS corrections lead to an higher accuracy level of both in horizontal and in vertical coordinates respect to the only Global Navigation Satellites System (GNSS) . Within the described monitoring system EGNOS corrections are downloaded and applied at Local Element level. This choice is justified above all by the characteristic of EGNOS availability in mountain areas. In Europe EGNOS geostationary satellites are seen with an elevation angle that can cause visibility problems in mountain environment. As an example, in the western Alps EGNOS geostationary satellite Inmarsat 3 F2, AOR-E has an elevation angle of about 30°; in mountain canyons this elevation angle could be not high enough to allow the reception of a satellite signal.

Furthermore in the Alps the EGNOS satellites broadcast from the South direction, consequently all the signals come from them can be obstructed at the same time (e.g.: rescue operations conducted on a north slope).

For this reason in mountain areas, the exploitation of EGNOS signal is very difficult and, even if there are GPS handsets enabled to use EGNOS signal on the market, the best solution is that of applying EGNOS parameters on Local Element side instead of user equipment.

Moreover this solution mitigates other problems of battery consumption related to the reception of the EGNOS parameters by the user equipment. Experimental test conducted with GARMIN receiver demonstrates that a commercial GPS receiver, after receiving EGNOS signal, takes until 6 minutes to download the complete set of EGNOS correction; in addition EGNOS parameters have short time validity and consequently they must be continuously downloaded .

System design aims also at matching the requirement of usability of the devices making transparent to the volunteers most of the system operations. Furthermore portable devices are chosen in order to match requirement of robustness due to operation environment.

V. SYSTEM ARCHITECTURE

From a general standpoint, the system structure follows the framework of a Network Assisted Local Element, as foreseen in the Galileo architecture, i.e. a localization system integrated into an existing wireless infrastructure ensuring a positioning services within a limited geographic area where the navigation solution of the user is calculated by a remote node of the network itself.

The current system architecture is illustrated in Figure 2. It is composed by two main parts: User Terminal, which is the mobile equipment for the rescuers employed in the field and the Local Element, which directly provides the support for the coordinator by means of the management of user terminals.

The user terminal performs GPS raw measurements and sends essential GPS data for the Position Velocity Time (PVT) computation to the Local Element by means of available communication channel (GPRS or VHF).

The Local Element applies EGNOS corrections in the computation of the rescuers positions, which are sent back to the user terminal and immediately displayed on a digital map together with the additional pieces of information related to the operation management (directions, orders, etc.).

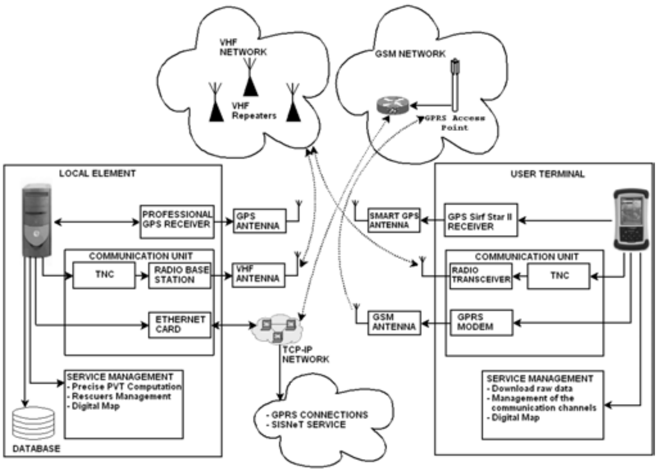

Figure 2 Developed architecture for the automated management of CNSAS teams.

Basically, the PVT computation is moved from the GPS user receiver to the Local Element and the consequently application of EGNOS correction by the Local Element side. This solution foresees that Local Element is always able to receive EGNOS parameters, improving the localization service performance. Furthermore, it is important to highlight that the automatic exchange of data drastically reduce the impact of human errors described in Section III.

As far as the integrity aspects are concerned, it must be remarked that in such a system the position integrity is not given only by the information on the reliability of the signal broadcast by the satellites. Such parameter is expected to be broadcast by the EGNOS system itself as soon as the system will be certified also for safety of life operations. The integrity of the estimated position is actually dependant also on the

reliability of the software for pseudorange calculation and on the integrity of the communication link.
For this reason it is necessary to regulate the data link, through coding system and communication between the user terminal and the Local Element is regulated by a protocol at the application level. Such a communication protocol allows the multi-connections management and assures integrity of data exchanged. In order to guarantee secure communications over communication link, each rescue member must be authenticated by the Local Element system.

A. Local Element

The Local Element is the actual provider of the localization service and the technological support for the operations coordinator.
In an emergency situation, the coordinator of the operations is responsible for decisions interventions. He must be able to quickly coordinate the rescue operations, using the instrument provided by the Local Element. This can be located in a fixed station near the operation zone or a special vehicle which reach the emergency zone. The main idea considers the realization of a Local Element, controlled by a software for Personal Computer and composed by a professional GPS receiver, an EGNOS receiver and communication unit.

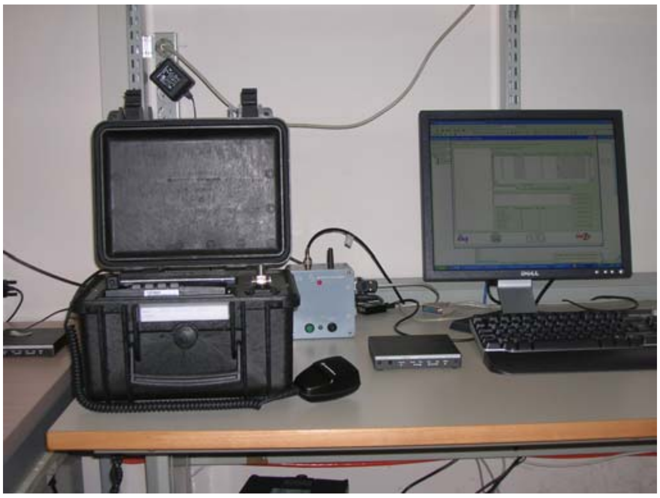

Figure 3 Prototype Local Element: VHF radio station, Nav/Com module and PC.

Figure 3 shows the prototype of the Local Element developed.
The services provided by the Local Element must be available both via GPRS and VHF radio channel, by means of a proper communication unit.
The communication unit is composed by two different parts: a radio terminal that contains a Terminal Node Control (TNC) for the modulation and demodulation of digital data for analog channel. and a radio transmitter connected to a VHF antenna with high gain to improve the VHF coverage.
GPRS communications are routed through the GSM infrastructure to the TCP-IP network. For these reason the communication unit must integrate an Internet interface allowing TCP-IP connections management.

From a software standpoint the Local Element can be considered as a server accepting and managing several connections both via GPRS and via the VHF radio channel. (sharing vocal and data communications). Currently the Local Element is a passive server answering to asynchronous requests by the user terminals creating logical software links. .
The GPS receiver at the control centre is used to obtain ephemeris for the PVT computation. EGNOS parameters are provided by ESA server by means of a particular service named Signal In Space through the interNeT (SISNeT)[1]. The Local Element accesses the service by means of a TCP-IP connections to ESA server.
The Local Element implements the remote PVT computation by means of the elaboration of the satellite raw measurements sent by the user, the ephemeris parameters locally downloaded and the EGNOS corrections obtained from SISNeT.
The Local Element is then ready to send to the connected users computed positions and additional information.
Local Element integrates cartographic tool for using the digital maps. On these maps positions of all rescuers employed in the field, are automatically plotted.
The functionality outlined is offered by a cartographic tool named OZI Explorer. This software is the same currently used by CNSAS for the exploitation of digital maps. This software allows to use directly map files or to create maps by means of calibration of geographic images. The tool functionalities are integrated in a software of the Local Element .
The Local Element is equipped also of a database for the automatic storage of positions, and other data.
In this way it is possible to track and trace the movement of people involved in the rescue operations (also for post-intervention elaboration). As an example, after the interventions, the alpine rescue teams can elaborate the paths of the rescuers, with the final goal of mapping all possible mountain footpath and updating the maps In this work the post-processing capability of stored data has been used for a comparative analysis different possible solution for PVT computation and to effectively evaluate the impact of the EGNOS corrections.

B. User Terminal

The user terminal is the mobile equipment provided to the rescuers directly employed in the interventions.
The user terminal is a hybrid terminal composed by a rugged Personal Digital Assistant (PDA) able to control communication and localization devices in order to obtain the localization. PDA implements the Human to Man Interface. It provides an user-friendly equipment for the rescuers during the interventions in order to monitor and control the service activities. PDA software manages devices implementing user terminal functionalities. It offers an intuitive graphical interface for using the program and better understanding service output.
The PDA used is rugged to guarantee high resistance against shocks, humidity and cold temperature, in order to be used in mountain environment.
User terminal equipment includes commercial GPS chipset used to perform pseudoranges and time of reception of data.

The user terminal communicates with the Local Element through a proper communication unit. This one is composed by radio terminal for the exploitation of VHF channel and GPRS modem allowing GPRS connections.
The radio terminal is composed by a TNC for modulation\demodulation and a radio transceiver for the access to VHF channel. The GPRS connection is possible by means of a GPRS modem using AT commands for the configurations of Internet Connection.
User terminal is able to evaluate the availability of the channel for the communication. GPRS is usually the default communication channel and, where it is not available, the communication is switched over VHF channel communication.
The User Terminal software allows for requesting positioning both on user request and in automatic modality. When required, it has to select the essential data for the PVT computation and send them to the Local Element in the pre-established format. The choice of data to send and the format is a critical aspect of a system design, especially for the exploitation of VHF channel. It is important to obtain for each computation required as less amount of data as possible to be transmitted. In this system the amount of data is strictly dependent of the number of satellite in visibility, and then it is necessary to limit the quantity of data for each satellite.
After a request, the user terminal waits for the response, in particular the position computed. When it arrives, the software plots the position on a digital map thanks to the interaction with OZI Explorer CE, that is a reduced version of OZI Explorer for PDA.
User terminal is studied in order to optimize the exploitation of limited and mobile resources, take care for example of the battery consumption. It is important to analyze the exploitation of device in order to avoid waste of power.

Figure 4 User Terminal equipment: the prototype navigation and communication unit, the PDA and the VHF radio transceiver

Figure 4 shows the current prototype of the user terminal. The GPS chipset with SiRF Star II binary protocol and the GPRS modem are integrated in a proper box that offer COM interface for external exploitation. The PDA is rugged and communicates to other devices thanks to Compact Flash cards and one COM port. The PDA shows a map of the interest area. On the right there is a radio transceiver used by the Piemonte alpine rescue team.
In the future, the integration of Bluetooth will avoid the wired links.

VI. TESTS AND RESULTS

In order to validate the system architecture several significant tests have been conducted. Tests can be split into different type: static and dynamic tests. Static test are used to shown the improvement done by EGNOS application on a PVT computation; dynamic test demonstrates the integrity of communication channel exploitation.

A. Static Test

The static test performance have been evaluated comparing the computed solutions to a georeferenced position of the User Terminal receiver antenna.
As described in Section V, the local element has access to a database where GPS and EGNOS satellites data are stored. These data are used in the PVT computation of the users. The test campaign aimed at evaluating the effect of EGNOS corrections in the accuracy obtained for the PVT solution in the network based architecture.
Different results have been compared with respect to different elevation mask angles, for the same satellite constellation.
The results have been obtained over 40 hours of data in order to consider all possible satellite configurations and to average over different atmospheric conditions. For each set of collected pseudoranges collected by the User Terminal the Local Element calculated the PVT solution both with and without the application of the EGNOS corrections.

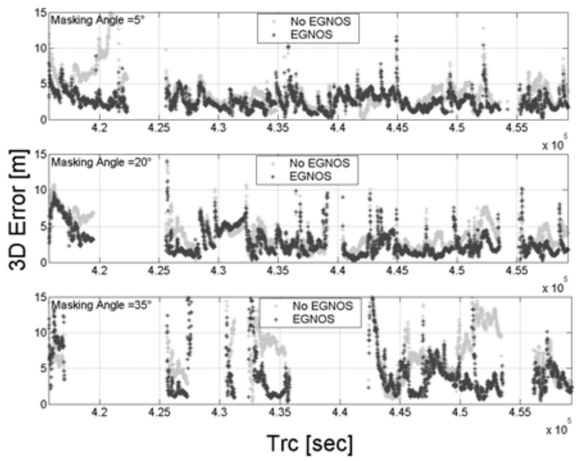

Figure 5 3D positioning error at different elevation masks (5°,20° and 35°) for GPS stand-alone measurements (light grey) and EGNOS corrected measurements (dark grey).

Figure 5 shows the 3D error (evaluated with respect to the georeferenced terminal position) with respect to the test time epoch, according to different elevation masks (5°,20° and 35°) both with (dark curve) and without (grey curve) EGNOS correction application. It is possible to observe that generally the application of EGNOS correction improves the accuracy of the positioning. It can be noted that the impact of EGNOS corrections in the PVT computation is more evident when the elevation mask raises. Since it is not unrealistic that in mountain environment the visibility mask angle is not larger than 35°, in such cases the standalone GPS positioning would not allow to obtain a level of accuracy in the position without integration of EGNOS correction. In some cases the error reduces, thanks to the use of the EGNOS corrections from 10 m to 5 m.

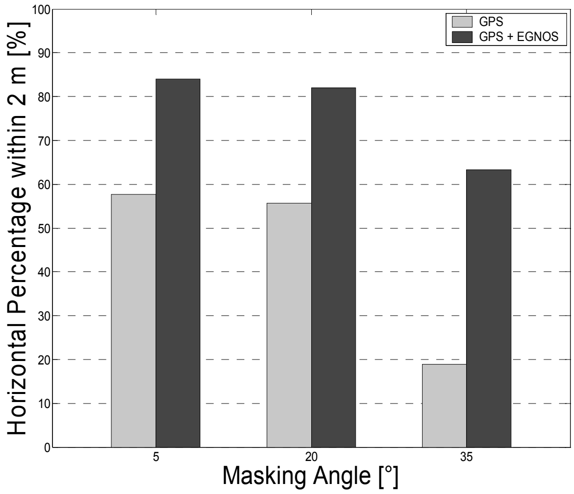

Figure 6 Percentage of computed position horizontal errors within 2 meters for different masking angles. Measurements without EGNOS corrections appear in light grey, with EGNOS corrections in dark grey

The histogram in Figure 6 shows the percentage of computed positions within an error of 2 meters in the horizontal plane respect to the true position, versus different values of the masking angle The grey bars represent the standalone PVT whereas the black bars show performance of the EGNOS corrected PVT.
For all the elevation mask angles considered, the percentage of positions within 2 meters, computed with EGNOS application is higher than the same PVT computations without EGNOS application With a mask of 5 and 20 degrees the improvement is about 25% but with a mask of 35 degrees (i.e. with low satellites availability) the improvement grows up to 40%. These results confirm that in a harsh environment with low satellites visibility, as dense forest, mountain or urban canyon, a Local Element able to apply the EGNOS corrections maintains high precision in the remote terminal positioning.

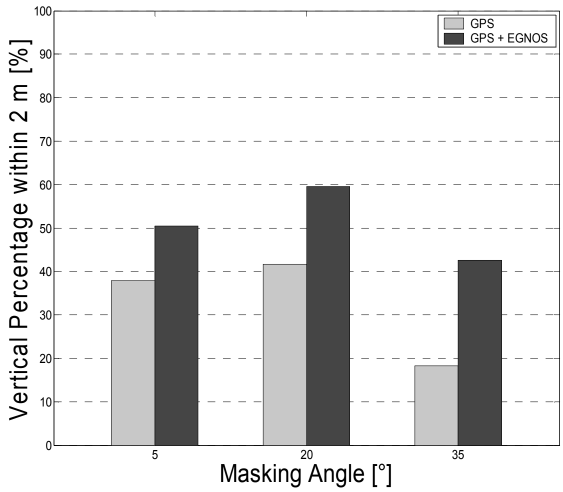

Figure 7 Percentage of computed position vertical errors within 2 meters for different masking angles. Measurements without EGNOS corrections appear in light grey, with EGNOS corrections in dark grey.

Figure 7 highlights that the EGNOS corrections introduction increases the system performance also for the vertical component. It has to be remarked that a precise estimation of the quote, is appreciated by the users of the systems since it allows to obtain altimeter profiles of the mountain footpaths, as a side results of the use of the system during the operations. These graphs confirm the relevance of the integration of the EGNOS features in the positioning procedure. where there is poor visibility of GNSS satellites.

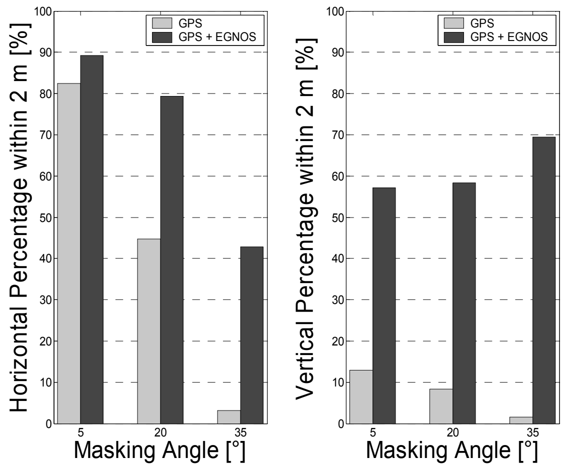

Figure 8 Percentage of computed position horizontal and vertical errors within 2 meters for different masking angles, evaluated over one hour of measurements. Measurements without EGNOS corrections appear in light grey, with EGNOS corrections in dark grey.

Figure 8 zooms out the performance obtained during one hour of measurements during a period of bad satellite constellation.

It is possible to observe that over this time without EGNOS corrections application is not possible ensuring a suitable accuracy level in the positioning both in horizontal and vertical coordinates. In particular with a visibility elevation mask of 35° the percentage of standalone GPS positions computed with an error smaller than two meters is very low both in horizontal and vertical coordinates (under 5%).
All these results presented confirm that the use of the EGNOS corrections, whose availability is ensured by the network-based architecture, allows for reaching a level of accuracy in the positioning suitable to the search and rescue applications in mountain environments, where elevation angle of visible satellites can be 35° or even higher.

B. Dynamic Test

Several dynamic tests have been conducted in order to validate the robustness of the network-based architecture and the integrity of data exchanged over the communication channel.

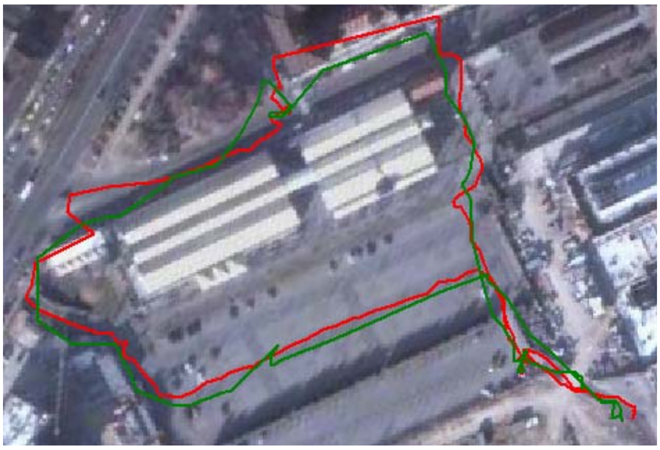

Figure 9 Dynamic test in urban environment. User Terminal based positioning (red trace) vs. network-based positioning (green trace)

To this aim, dynamic tests (at walking speed) in a urban environment have been conducted, since it represent a worst case for the propagation conditions of the communication links. As an example Figure 9 shows the results of a test that compares the positions computed by the local element (green track) with respect to a commercial GPS handset (red track).
The map shows an aerial view of the urban area chosen for the test..
During the test the GPS receiver has stored timestamped locally calculated positions meanwhile the User Terminal was sending raw measurements and receiving the positions computed by local element, as explained in Section V, over a GPRS channel. It is possible to observe that the tracks are quite similar and in some cases the green track is more precise than the red track.
The resulting paths demonstrate the integrity of the positions provided by the presented infrastructure, which relies on the integrity of the communication channel and the correct data matching between the data coming from the User Terminal and the data provided by Local Element.

VII. CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper a prototype architecture of a local Element for the provision of a network-based positioning service for mountain environment has been presented .The devised infrastructure aims at speeding up and simplifying the coordination procedures of rescue teams, guaranteeing an higher level of accuracy in the positioning and avoiding problems related to the manual operations.
This system can improve the effectiveness of the interventions of the Alpine Rescue Teams and consequently the safety of the people involved in mountain activities.
Current infrastructure is suitable for technical tests on the field, and the future work will improve some of the functionalities of the system. The integration of a cartographic server providing additional digital maps and other geographic information related to the operation area is under development.
To ensure the integrity of the positioning, a higher coding level has to be introduced on the communication channels in order to protect the pseudorange information exchange by User Terminal and Local Element. On the other hand, it would be desirable to introduce compression algorithms in order to bound the amount of data exchanged and consequently reduce the occupation time of the channel. This is important especially for the VHF radio channel that in this system is shared by voice and data communication. The current work is addressing the research of the optimal tradeoff between these two requirements.
A cryptography algorithm is also under design for the improvement of the security of the information exchanged.

ACKNOWLEDGMENT

Authors would like to thank Istituto Superiore Mario Boella research centre for providing the facilities exploited performing the tests in the Navigation Lab.

Special thanks to the CNSAS members for the cooperation in the definition of the system requirements and for the provision of the VHF radio devices .

The authors would like to thank also Dr. Carl Carter of SiRF Technology, Inc. for his kindness in providing the effective technical support

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