A Cloud-based Approach to GNSS Augmentation for Navigation Services

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***Abstract* — The proliferation of services and applications requiring user positioning through a Global Navigation Satellite System (GNSS) is driving the need of more accurate and reliable positioning systems, especially for safety-critical applications such as Disaster Alerting. Satellite-Based Augmentation Systems (SBAS) could achieve this goal by compensating for certain disadvantages of GNSS in terms of accuracy, integrity, continuity and availability. In this paper, we propose a novel cloud-based architecture that centrally computes position augmentation and position integrity by using the European SBAS system, i.e., EGNOS/EDAS. We implement our solution in a real test-bed, demonstrating the feasibility of our proposal and obtaining performances that can support real-time applications.**

Keywords — GNSS; EGNOS/EDAS; Cloud; XaaS; NaaS; navigation; services

I. INTRODUCTION

Achieving reliable and accurate positioning is becoming crucial for the development of various applications such as Location Based Services (LSB), Road Application, and Disaster Alerting. Satellite-Based Augmentation Systems (SBAS) have been developed and deployed to complement existing Global Navigation Satellite Systems (GNSS) by improving their accuracy, reliability, continuity and availability. SBAS are very important in scenarios where accuracy and reliability are critical, especially for applications where people's lives are at stake or for which some form of legal or commercial guarantee is required. SBAS measure position errors from a given GNSS, compute corrections, including position integrity[1], and propagate such information through geostationary satellites that cover wide areas. The corrections are used by enabled GNSS receivers that decode the so called Signal-In-Space (SIS) to enhance the positioning, achieving higher accuracy and integrity. However, the reception of the SIS can be problematic in adverse conditions, including dense urban scenarios. Furthermore, the user device must support the SBAS system, implementing the specification reported in [1]. Also, the correction algorithm requires computational power and results in an energy consumption, both of which are generally constrained in hand-held devices. In order to overcome the aforementioned issues, we propose a novel Cloud-based architecture that can provide enhanced localization services to mass-market GNSS receivers. A similar approach, but focused only on service integrity, is proposed in [2].

Cloud Computing has recently emerged as a compelling paradigm for managing and delivering scalable services over the Internet, offering different service models according to the features delivered to the final user. This paradigm as reached widespread adoption, up to the definition of everything as a Service (XaaS). Following this trend, we can define our solution as Navigation as a Service (NaaS).

II. SYSTEM ARCHITECTURE

Our system is based on three main components. (i) The *SBAS Data Service (SDS)*, that provides SBAS corrections both for real-time and for post-processing applications through an Internet service. (ii) The *Cloud Application (CA),* that takes GNSS raw data from the user device and from the SDS, runs the augmentation algorithm [1] to obtain the enhanced Position Velocity and Time (PVT) plus the horizontal and vertical Protection Levels (PLs) – which define the position validity region – and finally communicates the PVT and the PLs back to the user device. (iii) The *User Device (UD),* that features a GNSS receiver capable of providing raw GNSS data to the cloud application through a cellular connection (3G/4G).

Note that our Cloud-based architecture is able to provide a scalable service, adapting its capability in real time according to actual request volumes. Moreover, it can be easily extended to include different augmentation services like local Ground-Based Augmentation System (GBAS), which can be either based on a dense network of reference stations, e.g., Differential GNSS, Real Time Kinematics (RTK) or Wide Area RTK (WARTK), or on a sparse deployment, e.g., Precise Point Positioning (PPP). Furthermore, differentiated services could be envisaged according to the application scenario and UD capabilities.

III. SYSTEM IMPLEMENTATION

Since we want to evaluate our system with a real test-bed, we use the EGNOS [3] augmentation system together with its terrestrial SDS called the EGNOS Data Access Service [4] (EDAS). EDAS offers different services including the dissemination of EGNOS data in real time without relying on the SIS.

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[1] It implements reliability by providing a validity region for the position

For what concern the cloud platform, we rely on Microsoft Azure, using the WEB API framework and a relational SQL database to implement our application. The CA continuously queries the EDAS FTP service and stores the corrections in a SQL database (rate below 1 kbps).

We create the UD by connecting an EGNOS SIS compatible GNSS receiver with a custom device able to perform on-board augmentation. The custom device is based on a Freescale i.MX53 board featuring an ARM® Cortex™ A8 core and a 3G modem. The GNSS receiver is the EVK MCM evaluation kit from NVS, embedding a mass-market multi-constellation GNSS receiver with 32 channels, and supporting raw data output in a specific format which we convert to the RINEX standard by using the RTKlib library.

The interface between the UD and the CA is implemented with HTTP Representational State Transfer (REST) while the interface between the UD and the SDS is based on the EDAS Networked Transport of RTCM via Internet Protocol (Ntrip): a protocol for streaming differential GPS (DGPS) data over the Internet in accordance with specification published by the Radio Technical Commission for Maritime Services (RTCM) [5]. Note that Ntrip is the de facto standard for real-time GNSS data communication.

In Figure 1 we sketch the system implementation, including the main components together with the main algorithms and messages that we use.

IV. SYSTEM EVALUATION

We evaluate our system with a real GPS and EDAS dataset, collecting one position sample every second for 1 hour by placing the antenna of the UD in open sky conditions. Then we use post-processing, i.e., we apply EDAS corrections after the collection of all raw position data. We verify that the Cloud-based solution computes the same positions as the on-board solution, obtaining a perfect match. We show in Figure 2 the position samples of the Cloud-Based solution, with and without EDAS correction, achieving an average longitude and latitude error reduction of 0.18 m and 2.78 m, respectively. We also check the PLs computed by the two solutions, obtaining identical results. We omit the latter for brevity. Next, we assess whether the Could-based solution could be used for real-time applications, which generally require to have both PVT and PLs with a temporal resolution within 1s.

We run the CA on a Small Azure instance, featuring a dedicated single core at 1.6 GHz with 1.75 GB of RAM, and we measure all delay components of our systems, namely the 3G network delay, i.e., the time required to send the REST request and to receive the response, the time required to get EDAS corrections from the pre-fetched SQL database, and the time taken by the augmentation algorithm.

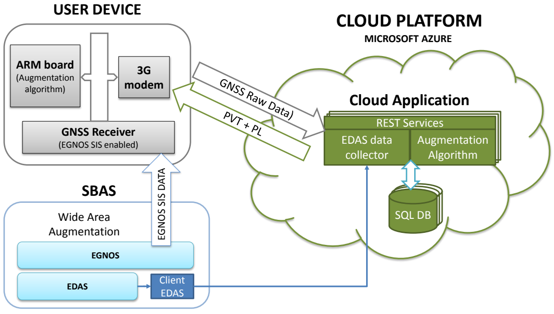

Fig. 1 System implementation details of the Cloud-based augmentation system

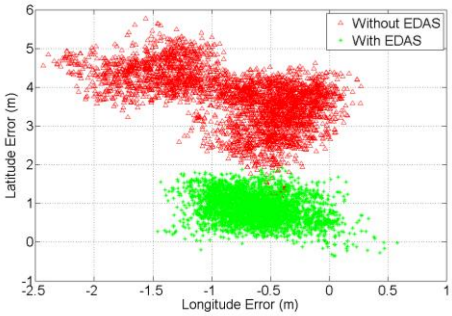

Fig. 2 Position samples with and without EDAS correction

We report in Table 1 the average and standard deviation of each delay contribution as well as the total delay achieved. We always obtain a total delay well below the 1s threshold, thus achieving the target performance. Note that a better performing Cloud setting, and an augmentation algorithm optimized for parallel programming, could bring substantial performance increase.

TABLE I. PERFORMANCE EVALUATION

System	**Delay contribution (μ, δ) [ms]**			
	Network	***SQL Extraction***	***Augmentation Algorithm***	***TOTAL DELAY***
Cloud	(198, 15)	(135, 5)	(511, 20)	(844, 50)

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CONCLUSIONS AND FUTURE WORKS

We proposed a Cloud-based architecture implementing position augmentation and integrity for GNSS enabled devices. We demonstrated the feasibility and the performances of our solution with a real test-bed, meeting the need of a general purpose LBS while being scalable and extensible according to the scenarios and the economic constraints.

Future works will include an optimized algorithm, a noSQL database, and a more extensive evaluation.

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