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Smartphone GNSS positioning performance improvements through utilisation of Google Location API

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***Abstract* - A wide-range utilisation of Global Navigation Satellite Systems (GNSS) across technology and socio-economic domains renders the satellite navigation one of the pillars of the modern civilisation. Tackling and overcoming the inherent shortcomings and emerging threats to provision of robust and resilient GNSS Positioning, Navigation and Timing (PNT) services have become a research subject of the utmost importance. An open access to the GNSS positioning estimation process is fundamental for development of advanced methods for robust and resilient GNSS position estimation. Recent introduction of Google Android 7.0 revision allows for direct access to raw GNSS pseudoranges observed by smartphones. Here we address the opportunities for GNSS positioning estimation improvements, given through exploitation of Google Android Location API, in creation of bespoke GNSS position estimation process in navigation application domain of a GNSS Software-Defined Radio (SDR) receivers in smartphones. We present and validate opportunities for improvement of GNSS position estimation process through utilisation of distributed computing architectures, trusted sources of GNSS augmentation data and utilisation of GNSS positioning methods suitable for targeted classes of GNSS applications Authors are members of European GNSS Agency's GNSS Raw Measurements Task Force, and co-authored the white-paper on GNSS-related Google Android Location API applications.**

Keywords – GNSS; positioning performance; position estimation; Software-Defined Radio (SDR); Google Location API

I. INTRODUCTION

The assurance of the satellite navigation system's quality of Positioning, Navigation and Timing (PNT) services is the central pre-requisite for development of the growing number of Global Navigation Satellite System (GNSS) applications in various segments [12], ranging from Location-Based Services (LBS) and emergency services to Intelligent Transport Systems (ITS) and autonomous vehicles and vessels. The essential problem in the resilient GNSS development lies in immediate identification and mitigation of sources of GNSS PNT quality of service deterioration, mostly caused by the effects of the GNSS positioning estimation error sources [5]. While majority of those effects belong to the User Equivalent Ranging Error sources (Fig 1 and [11]), the mitigation of their effects requires the proper identification of the nature of the problem and deployment of the mitigation (correction) method most suitable for the nature of its cause [5], [10].

The introduction of the software-defined radio (SDR) concept [5], [9] in satellite navigation developed a hidden revolution in the GNSS resilience development by allowing for deployment of the bespoke correction models suitable for the position estimation conditions [4]. Still, the opportunities have not been exploited so far, due to rather conservative approach in the GNSS SDR design that utilises strictly proprietary signal processing and navigation methods and algorithms developed by a GNSS receiver manufacturer, and prohibited for access and modifications by third-party developers.

In recent developments, the Google LLC company, a subsidiary of Alphabet Inc., has announced its Location API's support to manufacturer-independent direct access to the Android smartphones raw (un-corrected) GNSS pseudorange observations [8]. The Location Application Programming Interface (API) is available in all the Android 7+ operating systems running the smartphones and the other computing devices, regardless of its or GNSS manufacturers.

Here we address the importance of opening raw GNSS pseudoranges for third-party developments, and present the methodology for the utilisation of the Google Location API for development of resilient GNSS applications through utilisation of bespoke models in a software-defined GNSS radio receiver. This manuscript extends and details the authors' involvement in the European GNSS Agency's GNSS Raw Measurements Task Force, and their contribution to preparation of the white paper on utilisation of the Google Location API [8].

II. GOOGLE LOCATION API FOR GNSS POSITIONING PERFORMANCE IMPROVEMENT THROUGH GNSS SDR UTILISATION

The GNSS position estimation process encompasses three essential signal domains: Radio Frequency (RF) domain, Base-Band (BB) domain, and Navigation Application (NA) domain [1], [4], [5]. The raw GNSS pseudoranges emerge as the results of the signal processing in BB domain, and are processed further in the NA domain [4], [5]. The GNSS pseudorange measurement process is affected by numerous causes of measurement errors [11], [12], as depicted in Fig 1.

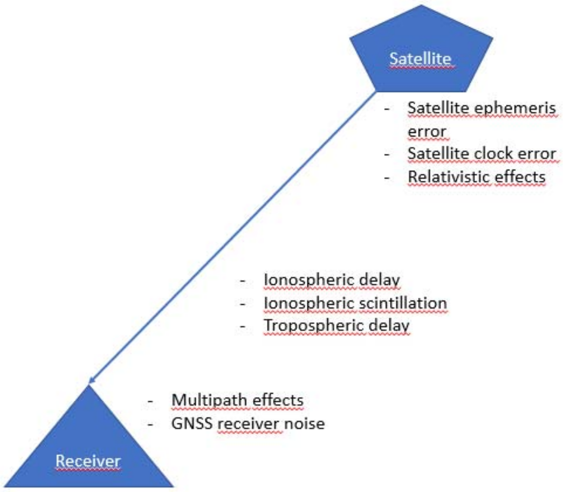

Fig 1Sources of GNSS pseudoramge measurement (ranging) errors

Raw GNSS pseudorange measurements thus comprise the actual (true) distance between the satellite's and the user's aerials, enlarged by the effects of pseudorange error sources [4], [11]. The pseudorange measurement errors can be split by their nature into systematic and stochastic errors [9], [4], yielding the pseudorange measurement model as depicted by equation (1):

$$\rho = d + \Delta d + \delta d \qquad (1)$$

where:

d … real (actual) distance between the satellite's and user's aerials (true pseudorange)

Δd … systematic pseudorange measurement error

δd … stochastic pseudorange measurement error

ρ … raw pseudorange

Systematic pseudorange measurement error sources are of known nature [9], [11], and their impact may be described with the appropriate correction models, provided by GNSS core and augmentation systems operators. For instance, GPS-based positioning is supported by provision of satellite clock offset correction model, Klobuchar model for GPS ionospheric time delay correction [3], [11], [5], and Saastamoinen tropospheric correction model [11]. Galileo system uses its own NeQuick model for the ionospheric time delay correction [11]. In general, the correction models embedded within the system are largely of general (global) nature, and often fail in taking account of the local disturbances [3], [11], [1]. This causes that the unknown portion of systematic pseudorange measurement errors remains at large [9].

Stochastic (random) pseudorange measurement errors cannot be described by correction models, and often remains uncorrected, causing the over-all position estimation errors [9]. In specific utilisation scenarios, random errors can be mitigated by exploring the nature (statistical description) of the process causing them.

A GNSS receiver processes raw GNSS pseudoranges in the NA domain by attempting to correct the pseudorange measurement first [4], [11], as depicted in Fig 2. The process shown takes the advantage in utilisation of the GPS-embedded correction model on raw GPS pseudorange measurement, before proceeding to GPS position estimation process [4], [5].

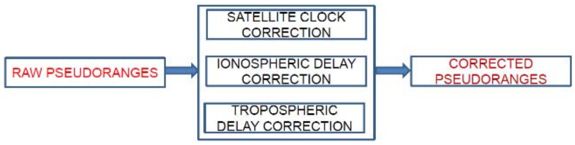

Fig 2 Position estimation in Navigation Applications (NA) domain

The utilisation of corrections removes the modelled systematic pseudorange measurement errors, thus reducing the over-all GPS position estimation errors, particularly when utilised in now prevailing Software-Defined Radio (SDR) GNSS design environment [10], [4]. Fig 3 depicts the optional utilisation of the GNSS ionospheric delay correction models in the RTKLIB, an open-source GNSS software-defined radio receiver.

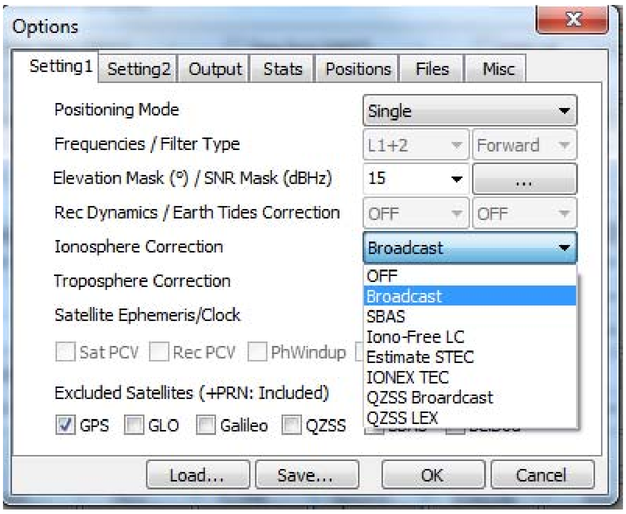

Fig 3 Configuration options for a software-defined GNSS radio receiver (RTKLIB library)

We propose the generalised methodology for exploitation of the Location API through utilisation of the position estimation model, as depicted in Fig 2. Implementation of the proposed generalisation impacts the GNSS receiver design trends, since it opens room for further transparency and distributed design approach.

The availability of raw pseudorange measurements through Android 7 API renders the NA domain process design more flexible and efficient in further error reduction through the opportunity to introduce bespoke correction models for un-corrected systematic errors, and even for random errors. In an analogy with the regional EGNOS Klobuchar-like ionospheric correction model tailored for Europe and Africa, the transparency in raw pseudorange measurement access allows for introduction of bespoke models that will suit targeted geographic region, or a scenario of GNSS positioning environment.

Our team has identified the anomalous daily pattern of the GNSS ionospheric delay in the Northern Adriatic Sea region in quiet space weather conditions in Summer period. Instead of a single maximum at around 1400 local time, the GNSS ionospheric delay demonstrates a multi-maxima pattern when observed in quiet space weather Summer conditions in the Northern Adriatic (Fig 4). The anomaly identification led to development of the Brcic-Kos model [2] for the Northern Adriatic, that allows for more accurate correction of GPS ionospheric delay in the observed region during quiet space weather conditions in Summer time [2]. Translated into appropriate format, the GNSS ionospheric delay estimates can be fed into GNSS SDR receiver directly, thus acting as a bespoke regional model with favourite quality over the standard global correction models (Klobuchar or NeQuick models) [5].

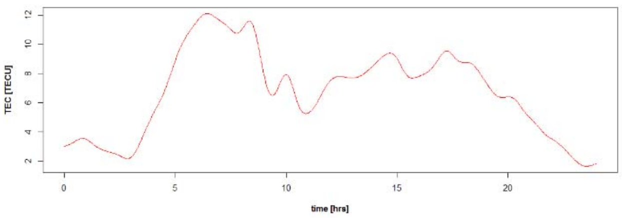

Fig 4 A case of non-specific GNSS ionospheric delay daily pattern, observed in the Northern Adriatic region in quiet space weather Summer conditions

In the other potential use-case, a bespoke model targeting a specific positioning environment (for example, oak forest) may reduce the multipath effect, that has already been identified as a GNSS random error source [11]. Such a model can be applied directly in the GNSS SDR receiver to raw GNSS pseudorange observations provided by Google Location API, thus improving the GNSS position estimation accuracy.

Bespoke models must be carefully developed, verified and validated, and trusted (certified), while being developed with patience and care. Well-designed bespoke model can reduce the GNSS pseudorange measurement error significantly, thus providing the more accurate and clean input to the GNSS position estimation process, and allowing for more robust and resilient GNSS applications development [12].

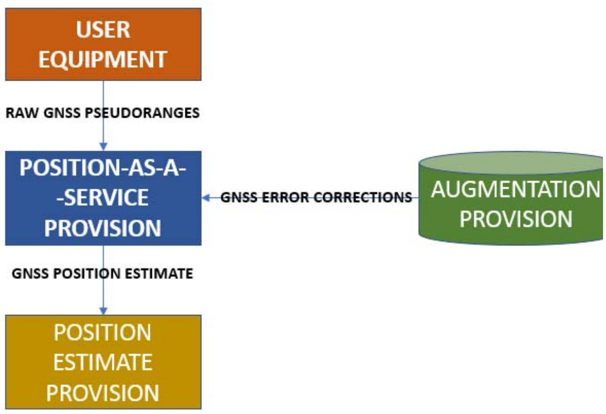

Fig 5 Positioning-as-a-Service using Location API

Availability of the Location API in question opens room for additional improvement through utilisation of the advanced computer engineering concepts and infrastructures. The already proposed concept of distributed GNSS SDR receiver [6] gains attraction through utilisation of Location API that can serve as a gateway for raw GNSS pseudoranges distribution to the computing facilities (independent servers [7], or a cloud computing system [6]) capable of conducting GNSS position estimation process efficiently and more accurately due to their enhanced computing performance and a potential access to trusted GNSS augmenting data for the improved error correction. The approaches establish a framework for Position-as-a-Service (PaaS), as depicted in Fig 5. PaaS may be considered a new development from various perspectives. Firstly, it allows for modification of existing and development of entirely new approaches in mathematics of positioning. Additionally, the realisation of PaaS will require the modification of existing and development of the new position estimation and data visualisation algorithms. Further to this, computational aspects of cloud-based PaaS should be addressed, with potentially new architectures and concepts emerging from the specific requirements for position estimation in real-time. Finally, PaaS will initiate research in establishment of the appropriate business environment, with dedicated stakeholders contribution to be fine-tuned to allow for achievement of the quality of position estimation suitable for a wide range of related information and communication services.

III. CONLUSION

Transparency of the GNSS position estimation process has improved significantly after the wide-spread introduction of the GNSS software-defined radio receiver design. This allows for conceptual introduction of bespoke software-based signal processing and position estimation methods and algorithms that facilitate robust and resilient GNSS positioning performance and operation. The introduction of Google Location API renders the access to raw GNSS pseudoranges the foundation for a completely novel design of the GNSS SDR Navigation Application domain. Being manufacturer- and GNSS system-independent, Location API allows for the GNSS SDR Navigation Application domain (i. e. development of position estimation methods and error correction models) to be designed and developed independently and adapted to the requirements of the immediate positioning environment (space weather, ionospheric, multipath etc.) conditions.

Here we presented the generalised methodology for the Google Location API deployment in GNSS SDR Navigation Application domain design, that allows for integration of bespoke, independent and third-party developed correction models into GNSS positioning process, rendering it resilient to various source of GNSS ranging errors. We proposed the concept of Position-as-a-Service, and addresses the impact of the proposal on research in related technology and business disciplines. Our research will further to exploitation of utilisation of the distributed computing concept for even more robust, resilient and efficient GNSS position estimation process based on the raw GNSS pseudorange observations.

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