SATELLITE POSITIONING FOR eCALL: AN ASSESSMENT OF GPS PERFORMANCE

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ABSTRACT: The *eCall is a telecommunication service, promoted and fostered by the European Commission, aimed to provide the immediate notification of a road traffic accident, including delivery of a GPS-based position estimate, to a Public Safety Answering Point (PSAP) responsible for the area in which the traffic accident occured.*

In description of eCall operation, it is assumed that position estimation using GPS is flawless and robust enough to satisfy the requirements for eCall. However, the GPS limitations and vulnerabilities under specific conditions can have a significant impact on the success of the emergency procedures based on eCall.

Here the preliminary results of the performance analysis of the core GPS-based positioning for eCall are presented, based on the field campaign conducted on the Zagreb - Bjelovar regional road in northern Croatia.

Time series of positioning samples taken by single-frequency GPS receiver embedded in an Android-based mobile phone have been collected during the field campaign in regular time intervals in order to identify the areas with poor or no GPS coverage. A risk assessment was performed in order to identify the impact of poor GPS service. Methods and procedures were proposed for mitigation of GPS vulnerabilities and limitations in order to support the utilisation for eCall. The material presented in this article results from the state-of-the-art analysis conducted under the pan-European ICT PSP Harmonised eCall European Pilot (HeERO).

Future work will be focused on deployment of the mitigation methods proposed in this article, and field validation in the environments critical for satellite positioning.

KEY WORDS

1. satellite positioning vulnerability 2. GPS 3. eCall

INTRODUCTION

The eCall (1) is a telecommunication service, promoted by the European Union as an important contribution to road safety improvement. Based on in-vehicle sensors' readings, the traffic accident is to be identified, and both voice- and data-communication channels to be opened between the vehicle in accident and the Public Safety Answering Point (PSAP), from where the emergency services are to be allerted. The data communication channel is expected to automatically transfer the necessary data about the accident, including the vehicle's position, based on position estimate provided by satellite navigation (GPS, later GLONASS, Galileo, GNSS) unit, installed within the vehicle along with the mobile communication unit. The eCall specifications refer to standard GPS positioning service without deeper consideration of possible vulnerabilities and limitations of the position estimation process.

This article presents the results of a recent state-of the-art theoretical and practical assessment of the standard (non-assited and non-augmented) GPS performance for the eCall, based on a field campaign conducted in a real situation on the combination of motorways and regional roads in northern Croatia during the state-of-the-art analysisi phase of the pan-European Harmonsied eCall European Pilot (HeERO) project. The field results confirmed the assumption that the sole utilisation of a single position estimation methods will leave considerable gaps in performance, causing potentially dangerous effects on emergency operations and restoration of the traffic flow after the accident. In due course, the candidate assisting and augmenting methods for mitigation of satellite navigation as a fundamental method for the eCall position estimation were proposed. The article concludes with the assessment findings, and the outline of the near-term future activities.

BACKGROUND

The eCall service (1) is aimed to provide the immediate notification of the road traffic accident to the authorities. An accurate vehicle position estimate is among the essential information required for a successfull accident management and provision of emergency assistance to those involved in the acccident. The eCall specifications call for satellite navigation (GPS, later Galileo) as the major single method for vehicle position estimation. However, satellite navigation systems are prone to numeorus effects that may deteriorate their performance (14), (12), (10), (5).

Deteriorations of the satellite navigation performance result from:

- insufficient satellite signal availability,
- positioning error sources.

The insufficients satellite signal availability results from the effects of natural and artificial obstacles that blocks satellite visibility, thus preventing satellite signals transmitted in microwave radio spectrum to reach the satellite navigation receiver. The 3D navigation solution requires at least four independent satellite signals to be available all the time, in order to resolve the four un-knowns (three components of 3D position and user receiver clock bias) of the position estimation equation system (the same equation to be applied separately to the sets of different satellite's data)(12), (14):

$$\sqrt{((x_s-x_u)^2+(y_s-y_u)^2+(z_s-z_u)^2)}=c\cdot(t_{rec}-t_{trans}+t_b)$$

(1)

where:

x_s, y_s, z_s ... three components of the satellite position in common reference framework (WGS84), must be known to satellite navigation receiver,

x_u, y_u, z_u ... three (un-known) components of the user position,

t_{rec} ... satellite positioning signal time-of-arrival to satellite navigation receiver, determined by satellite navigation receiver

t_{trans} ... time of transmission of positioning signal from the satellite, known to satellite navigation receiver

t_b ... user receiver clock bias (error), un-known

Positioning error sources comprises threee main groups of error causes (12), (5), (14), as follows:

- satellite component and control component errors (satellite ephemerides, satellite clock error),
- user component errors (multipath, user receiver noise),
- errors due propagation media (ionospheric and tropospheric signal delays).

Ionospheric delay (3), (12), (7) is the major single contributor to the overall satellite navigation error, while multipath (12) can provide the considerable contribution to it in a harsh environments for satellite positioning (urban areas, mountains, forests etc.). While specific design of satellite navigation aerials and receivers can considerably lower the multipath impact of the local environment on satellite navigation performance deterioration (12), the ionospheric delay can cause considerable effects despite the attempts to provide global corrections of the ionospheric impact on satellite signal propagation (7).

With the positioning error important role in position estimation, the eCall service performance may suffer from the age of position estimates. In the areas with suitable satellite signal coverage, position estimates (samples) can be taken at regular, sufficiently narrow time intervals, so in the case of the accident the latest position sample given within the Minimum Set of Data (MSD) will appropriately represent the actual position of the accident. However, in case of limited satellite visibility, the eCall service will use the latest position estimate, which may be too old, thus representing inaccurately the actual position of the accident.

Conclusion can be drawn from the arguments above that satellite navigation systems (currently operational American GPS and Russian GLONASS, and emerging Chinese Beidou and European Galileo) cannot be used in general as the sole position estimation system, providing position estimates required by eCall specifications. The positioning service availability issue was challenged in the experimental field campaign conducted on the roads in northern mainland Croatia.

FIELD CAMPAIGN

The field campaign was arranged in order to challenge the standard GPS performance for eCall on the road route in northern Croatia. The route started in the Croatian capital Zagreb and closed at the regional centre Bjelovar, as presented on Fig 1. The route comprised 80 km-long trip on combination of motorways (Zagreb semi-orbital A3 motorway, Zagreb - Gorican A4 motorway, Vrbovec semi-orbital motorway A12/D28) and regional roads (Cugovec - Bjelovar, D28). Chosen route led through the flat landscape, with the occasional gentle-sloping hills. However, the proximity of intensive industrial activity in both city of Zagreb and the regional centres (Bjelovar and Vrbovec) provides frequent encounters with artificial infrastructures (bridges, high buildings etc.) with potential effects on satellite navigation performance. Figs 2 and 3 present horizontal view of the travelled route and the vertical profile of the terrain, respectively, as observed by GPS receiver during the field campaign.

Fig 1 Zagreb - Bjelovar route area (map courtesy OpenStreetMap.org)

A single-frequency standard GPS receiver in an Android-based mobile phone was used as a satellite positioning sensor, installed in a Renault Scenic vehicle used in a field campaign. No assistance or augmentation services (i. e. EGNOS, DGPS etc.) were operational during the field campaign. The GPS data logging application on an Android-based mobile phone was set to collect positioning samples every 10 seconds. Positioning samples were aggregated in a GPX file for further processing and analysis.

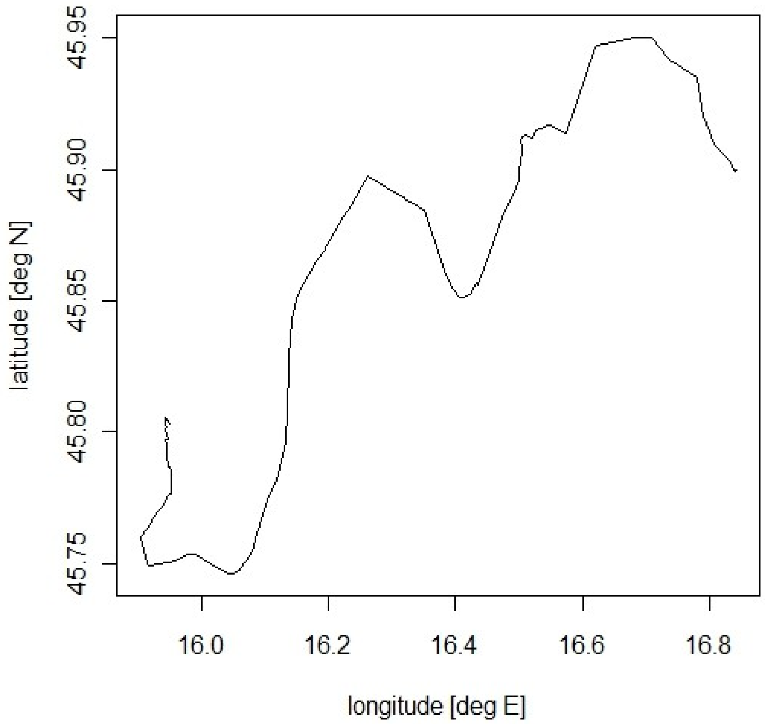

Fig 2 Zagreb - Bjelovar route, as observed by GPS receiver during the field campaign

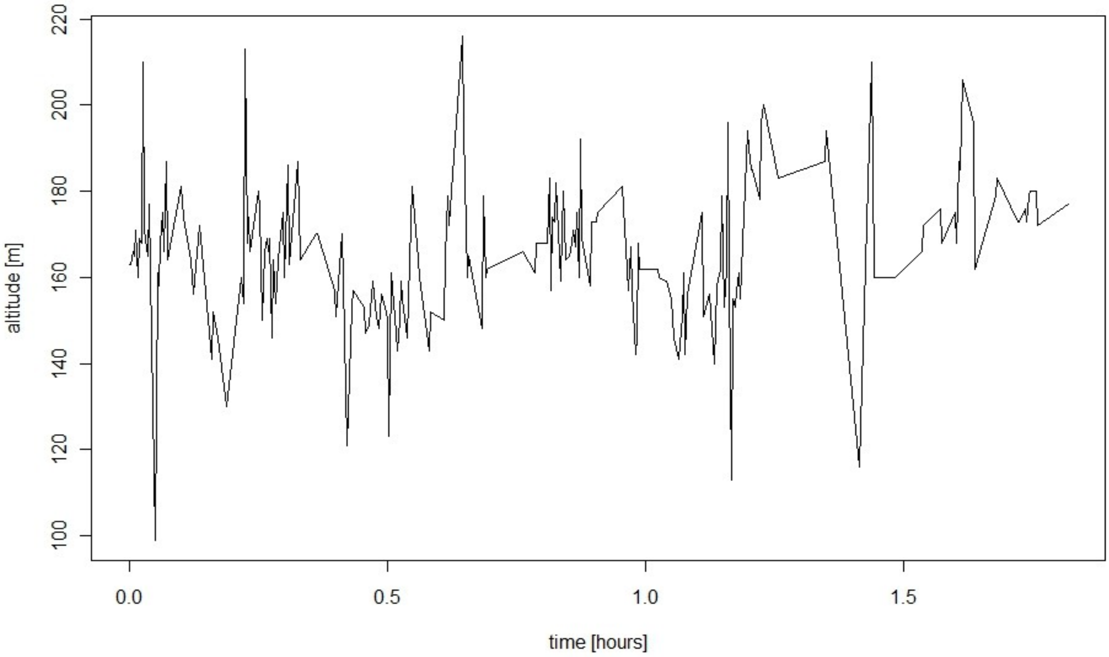

Fig 3 Vertical terrain profile of the route travelled

DATA ANALYSIS METHODOLOGY

Collected GPS positioning sample consisted of a time stamp and estimated position, expressed by longitude, latitude and altitude, as depicted on Fig 4.

Observed data sets were used in reconstruction of the travelled route and vertical profile of the terrain. At the same time, collected time stamps of individual positioning samples were processed (4) in order to identify scheduled, but missing positioning samples. A series of time-difference parameters between successive positioning samples *dt* were identified, as a measure of missing positioning samples, as follows:

$$dt(t) = t_{sample}(t + 10\,s) - t_{sample}(t)$$

hr	min	sec	latitude	longitude	altitude
06	28	11	45.8041370	15.9464836	163.0
06	28	20	45.8039546	15.9470201	163.0
06	28	35	45.8034182	15.9480071	166.0
06	28	45	45.8037937	15.9472132	165.0
06	29	00	45.8035576	15.9476638	171.0
06	29	10	45.8037508	15.9472775	160.0

Fig 4 Organisation of GPS positioning sample data

The GPS positioning samples collected during the field campaign were processed by the software developed in R environment (13). Collected positioning samples were mapped onto a digital map in order to identify the areas potentially critical for satellite navigation performance.

ASSESSMENT RESULTS

The time series of time-difference between successive standard GPS positioning samples *dt* is presented on Fig 5. Statistical analysis of the *dt* time series revals the mean time-difference between successive positioning samples of 33.4 s, with median of 13.0 s and standard deviation of 3.3 s. Considerable number of missing scheduled positioning samples was identified, as it is evident from statistical analysis, visual inspection of *dt* time series, and hystogram analysis (as depicted on Fig 6). The latter reveals that 126 out of 196 collected positioning samples (64.3%) were delivered with time difference less than 20 s. Considering the 130 km/h speed limit imposed on Croatian motorways, the position reporting uncertainty, expressed in the equivalent distance, yields up to 722 m. As this can be apprehend acceptable from the perspective of eCall utilisation, it is important to note that those samples were collected in flat rural areas, mostly on motorways.

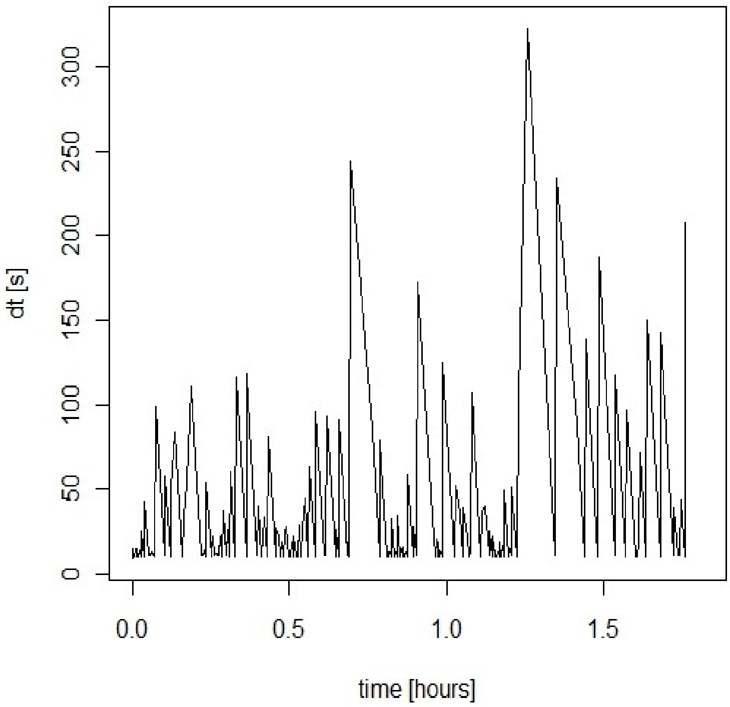

Fig 5 Time series of time-difference between successive position samples (dt in hours, time in hours)

On the less acceptable side, there was 37 out of 196 (18.9%) of positioning samples with more than 50 s time-difference between the successive samples, with the largest time difference observed totalling 322 s. Those samples were mostly taken either in the hilly area in the outskirts of Bjelovar, or in the outskirts of Zagreb, on local and regional roads with the speed limit of 70 km/h, thus determining the position reporting uncertainty of 6 261 m.

Evidently, the sole utilisation of satellite navigation systems for position estimation of the vehicles involved in an accidentan may cause provision of misleading information to emergency services, in situations when the time is essential in saving lives, cutting costs and time of medical recovery by provision of the appropriate medical assistance, and prevention of additional accidents.

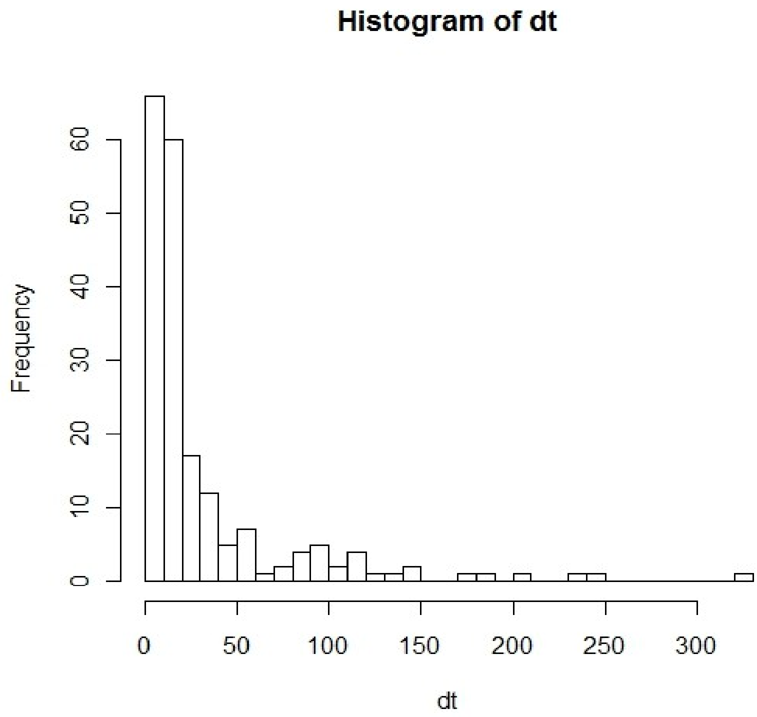

Fig 6 Histogram of time-diference *dt* between successive position samples (*dt* in hours, Frequency as the number of appearance)

PROPOSED MITIGATING TECHNIQUES AND METHODS

Modern vehicles are already equipped with numerous sensing devices, capable of provision of position-related information, or of assisting and augmenting positioning procedures. In addition, the eCall service, as a telecommunication service, may be augmented by network performance, and utilisation of network-based assistace and augmentation.

The standard GPS positioning performance can be enhanced by utilisation of satellite navigation augmentation systems, such as the European Geostationary Navigation Overlay System (EGNOS) (2). The EGNOS utilisation enhances the standard GPS positioning performance by provision of three additional GPS-like signals, thus improving availability of satellite signals and quality of position estimation process. However, the eCall in-vehicle systems (IVS) must be equipped with the so-called WAAS/EGNOS-enabled GPS receivers.

Majority of modern vehicles have a number of the so-called micro-electro-mechanical systems (MEMS), operating as sensors of acceleration (accelerometers). Apart form their main task in the vehicles, MEMS may be utilised as the inertial navigation systems augmenting the outcomes given by satellite navigation units within the car (5). Through the positioning systems' integration, a new system, comprising GPS unit and MEMS inertial navigation system (INS), can be developed, that will continuously provide accurate position estimates, with the temporal lack of GPS satellite loch overcome by MEMS (5).

Considering the growing number of car navigation devices installed in modern cars, the geospatial database in a car navigation system can be utilised in further system integration through utilisation of map-matching algorithms, thus contributing to sustained positioning performance and enhanced availbaility of position estimates (15), (8).

Finally, the utilisation of the public land mobile communication networks (every vehicle will have to have a mobile communication unit in support of the eCall service) provides an opportunity to utilise satellite navigation assistance and network resources in the process of position estimation (8).

Mobile communication networks may provide GPS and GNSS navigation data within the services called A-GPS and A-GNSS, which considerably improve the time required to yield the first positioning sample after the GPS/GNSS receiver loses the lock with the satellites (8).

Additionally, mobile communication networks supports several low-accuracy, but continuous position estimation services, that can be integrated with GPS and MEMS INS, with the aim to improve the availability of position estimates even further (11), (8), (6).
Proposed techniques and methods for mitigation of the GPS limitations are to be tested and verified within the later phases of the HeERO project.

CONCLUSION AND FUTURE WORK

Satellite navigation should be considered the fundamental method for postion estimation for telecommunication services (8). The peformance and mechanisms of satellite navigation offer the unprecedented quality of position estimation (12), (9). However, the vulnerabilities and limitations of satellite navigation systems must be considered and understood (14), (10), (7), and the augmentations should be provided to the core satellite positioning in order to sustain the required satellite navigation performance (8), especially in the matter of availability of the positioning service. Augmentation should focus on already deplloyed sensors with the vehicles (accelerometres - MEMS devices, mobile communication equipment that can provide less accurate but continuous positioning service based on network positioning) that can provide position-related readings. In addition, the availability of accurate and reliable geospatial data should be considered for utilisation with the aim to improve situation awareness and positioning performance for vehicles in accident. The augmenting systems are of particlular importance in critical environments for satellite positioning that provides significantly reduced satellite signal visibility, such as tunnels, urban areas, and mountainous areas.

Future work will address positioning sensors integration with the aim to sustain satellite navigation performance, and evaluation and validation of proposed augmenting systems and methods. Experimental validation of the benefits of mitigation techniques and methods for the eCall position estimation is to be performed through the forthcoming phases of the HeERO project activities.

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