Performance Assessment of a Commercial GPS Receiver for Networking Applications

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***Abstract*— Recent years have seen an exponential increase of DVD equipped and navigation assisted cars. Nowadays a car trip can be both entertaining for passengers and computer assisted for drivers. In a further integration of automotive and information technologies, cars will be able to communicate to each other and to the Internet supporting safety, infotainment and pollution prevention applications. The research area which investigates topics, Vehicular Ad hoc NETworks (VANETs), is being widely investigated by both industry and academia. Position information plays a central role in many communication routing schemes designed for VANETs. This trend is justified by the feasibility of algorithms that route packets based on geographical proximity to the destination and by the widespread availability of navigation systems in cars. Geographical information is usually assumed accurate and precise. None of the algorithms available in literature, to the best of our knowledge, take into account possible position estimation errors.**

This paper is a first step in assessing the precision of a commercial GPS receiver for the support of vehicular communications. As we shall see, the performance of the receiver under investigation heavily depends on the type of urban area within this is employed. We believe that a strong understanding of the accuracy of such estimates is important to improve the performance and reliability of a vehicular network infrastructure.

***Index Terms*— GPS, VANET, Vehicular Networks, Ad Hoc Networks, GPSR, Geo-routing**

I. INTRODUCTION

The work presented in this paper derives from an equipment assessment campaign performed for the Campus Vehicular Testbed (CVeT) project [1]. CVeT, a joint UCLA-ISMB project, will be the first campus vehicular testbed available for research. Within this activity, we are analyzing all the factors that can affect the performance and cost effectiveness of a VANET.

The wide spread of GPS equipped devices encourages application and network designers to rely on position information to build more robust and feasible systems. Such trend can also be found in the design of routing techniques for Mobile Ad hoc NETworks (MANETs).

MANETs are auto-configurable networks at first designed for military purposes. Their most popular instantiation, in both the academic and industrial communities, are VANETs. This can be explained by the great expectations upon such type of technology, the safety of streets could greatly benefit by the deployment of a vehicular network which is able to foresee accidents.

In brief, in both MANETs and VANETs any node (e.g. computer with a wireless interface) can behave as a host and as a router. A major research challenge in such field is to find algorithms which efficiently route information, under high mobility, between any source-destination pair. A VANET will be probably composed of a MANET, where the information will flow between cars, without the aid of an infrastructure, and of an infrastructure network which cars will use to connect to the Internet. An infrastructure could include, for example, both 3G networks and WiFi hotspots, but also new customized networks which are able to more efficiently interact with the vehicular grid.

Many routing strategies which are optimized for VANETs benefit of node position information. A car, say car A, unable to route packets through the infrastructure to car B, can still try to deliver packets through the vehicular grid. If the network graph between car A and car B is connected an intuitive per-hop routing strategy is to forward packets to the closest to destination next hop, given that the position of the destination is known. The family of routing schemes which rely on geographical information are known as Position Based Routing (PBR) strategies.

In PBR literature, geographical information is in general assumed to be accurate. This assumption relies on the fact that, in a VANET scenario, GPS systems are typically integrated with map-matching algorithms. In the case the received GPS signal is low or disturbed, a map-matching scheme adjusts a car's position based on the streets' topology knowledge.

The scope of this paper is to: (a) show the results obtained in two GPS experimental setups, and; (b) briefly comment on these results and indicate some future directions of work. To the best of our knowledge, this is the first work that, based on experimental data, approaches the feasibility of geographical

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routing in a vehicular network from the position precision standpoint.

This paper is organized as follows. In Section II overview geographical routing approaches in vehicular networks, we then overview the major error sources for a GPS receiver in Section III. A description of the experiments is given in Section IV. A description of the result's analysis methodology may be found in Section V, while the post processing results and a discussion on such results in Section VI. We finally conclude in Section VII.

II. BACKGROUND ON VEHICULAR NETWORKING STRATEGIES

A geographic approach to routing in MANETs was first introduced in [2]. The protocol proposed in this work, Greedy Perimeter Stateless Routing (GPSR), assumes that a source knows its own position and the position of the destination. Packets are then routed, in a completely stateless fashion, from source to destination. At each node, say node n, if node n is not a local minimum (i.e. all node n's neighbors are not farther away from the destination than node n), this will forward packets to the closest to destination neighbor. If instead node n is a local minimum, there is no node closest than n to the destination, node n is a local minimum and there may still be a path leading to the destination. In such situation the protocol enters the perimeter mode. In brief, the perimeter mode is an implementation of the right hand rule and enables a packet to route around a gap which freezes its trip while in greedy mode. In order to operate in the perimeter mode, the network graph must be first planarized. The planarization of the graph can be simply thought as the creation of a new graph, with the same nodes and subset of the links of the original graph such that no links cross in the planarized graph.

A number of studies have shown that geographic based routing is able to offer significant improvements over topology based routing protocols such as AODV [3] and DSR [4], for example. These results have lead to the design of a number of optimizations and improvements of GPSR [5] [6] [7] and to the design of new geographically-assisted topology-based routing protocols [8].

The problem of the uncertainty of position in geographic routing protocols is first explored in [9]. In such paper the authors investigate the consequences of an inaccurate positioning of nodes on GPSR's planarization algorithm. The authors introduce a new landmark-based algorithm that is able, in the presence of a dense static sensor network, to efficiently route packets around large gaps in the network's graph.

III. OVERVIEW OF GPS MEASUREMENTS AND ERROR SOURCES

Since the main objective of this work is to assess the performance of a low cost Commercial Off-The-Shelf (COTS) GPS receiver in severe urban environments, it is now worth to overview the most important error sources for a single frequency GPS receiver.

In the navigation field, the User Equivalent Range Error (UERE) is used to characterize the combined effect of the error sources on the pseudo-range measurements (i.e.: estimated distance between the satellite and the receiver), which is fundamental in the user's position [10]. Roughly speaking, the error sources affecting the pseudo-range estimation can be due to the Control Segment (i.e. bias of the satellite clock, ephemeris parameters), to the atmospheric propagation (i.e. troposphere and ionosphere effects), to the receiver and to the antenna's surrounds (i.e. multipath, thermal noise). The UERE factor is related to the horizontal positioning error through the Horizontal Dilution Of Precision (HDOP) factor, which depends on the geometry of the satellites in view at the moment of measurements. The horizontal positioning error is an important parameter in the evaluation of the receiver's performance, and will be further considered in the following sections. The UERE factor is approximately equal to 6 meters and is obtained under the hypothesis that the error sources are uncorrelated. Note that the rounded values reflect the uncertainty in quantifying the actual errors, which strongly depend on the measurement scenario. As an example, if the receiving antenna is close to reflecting obstacles (i.e. which is likely the case of urban canyons) the error due to multipath can be triple in size [10].

Survey grade, multi-frequency receivers, based on carrier-phase measurements are able to further reduce the error on the pseudo-range measurements and achieve better positioning performance (UERE rms can be reduced to 0.5 m) but with an increased cost of the receiver, which can be up to $10,000.

This work mainly focuses on the performance of a low cost, code-based, stand alone GPS receiver and on its possible integration on an hybrid navcom platform for ad hoc network applications. For this preliminary analysis, the main goal of the activity is to highlight the receiver's capabilities in terms of precision. We here consider a single mass-market receiver in different scenarios in order to evaluate how its outputs can affect VANET requirements. All the tests hereby reported have been performed in urban environments.

IV. ON FIELD EXPERIMENTS

We here measure the performance of a low cost COTS GPS receiver in typical urban environments. The field experiments were performed in downtown Los Angeles which is a severe test scenario with narrow streets, high buildings shadowing the GPS satellites' signals. The receiver's performance are compared with the performance obtained, with the same receiver, in open sky conditions. The same experiments were repeated on a freeway, with no obstacles in proximity of the receiving antenna.

The receiver used in the investigation was the Hamlet HBTGPS20 Bluetooth GPS receiver, which is based on the Sirf Star III chipset. Such a chipset is able to track the GPS L1 C/A code and can use up to 20 channels; it is employed in both autonomous and aided-GPS navigation applications and is widely used in embedded architectures [11]. An external active patch antenna was connected to the Hamlet GPS receiver which was used to collect a number of data sets through a Bluetooth connection. The National Marine Electronics Association (NMEA) files at the receiver output were stored

and analyzed in post processing. NMEA files [12] record the latitude, longitude and altitude measured by the receiver as well as other important parameters (e.g.:(a) the number of satellites in view, (b) the HDOP, (c) the elevation of the tracked satellites, (d) the Carrier-to-Noise power density ratio used in navigation as a strength measure of the received signals).

V. ANALYSIS DESCRIPTION

This section describes the method used to evaluate the error on position in the collected measurements. In all the tests presented in this paper no inertial sensors have been used in the experimental setup. The use of inertial sensors would have led to a complex system, and has not been considered for this initial set of experiments.

In order to evaluate the receiver's positioning performance a reference mark has to be determined. Since the receiver is tested along a known path, the idea is to consider the center of the carriageway as reference. Simplifying the analysis, it is possible to assume that if the estimated error is lower than the width of the carriageway, the estimated error can be completely removed. Thus, the width of the carriageway may also be viewed as a confidence interval in which a position error can be recovered, for example, through map-matching techniques. If instead the difference between the measured positions and the reference path is higher than the threshold, we proceed statistically analyzing this error.

For all the collected data sets, the estimated positioning error has been obtained by projecting the measured way points onto the carriageway center. Without the use of inertial sensors, it is not always straightforward to identify the correspondence between the measured way-points and the reference path. In order to clarify this concept, with the help of Fig. 1, let us here briefly describe the post processing analysis steps:

- **Definition of the reference points**. Through an orthogonal projection, the measured positions (light round markers in Fig. 1) are reported on the reference line (light squared markers in Fig. 1).
- **Estimation of the positioning error**. Once the measured position has been reported on the reference path, it is possible to measure its distance with respect to the original way point and indicate such a value as the estimated positioning error (ε_i).

It must be observed that ε_i represents a reliable estimation only if the true error (which is indicated in Fig. 1 as μ_i)

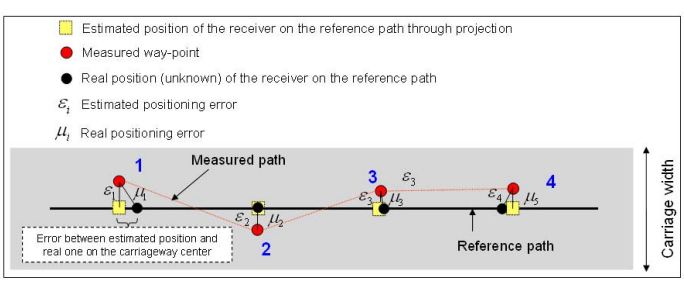

Fig. 1. Difference between the measured way-points and the reference points, when the positioning error is within few meters ($\varepsilon_i \approx \mu_i$.)

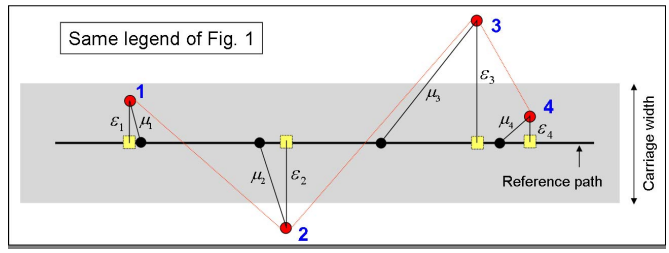

Fig. 2. Difference between the measured way-points and the reference points, in case of significant positioning errors ($\varepsilon_i \gg \mu_i$).

assumes small values. In fact, after the first step of the algorithm, a residual error between the estimated positions on the reference path (light squared markers in Fig. 1) and the real unknown positions of the receiver at the time of measurements (dark round markers in Fig. 1) still exist. However, if ε_i is only a few meters (thus, within the threshold), the difference between the estimated and the real errors is negligible and it is possible to assume $\varepsilon_i \approx \mu_i$.

This is not the case in Fig. 2, which shows the situation corresponding to an increase in error on the position's estimation. In such case the hypothesis of a negligible difference between the estimated and the true position is no longer true. When the position's estimation error is on the order of tens meters or more (thus, above the threshold), the absolute value of ε_i isn't significant and doesn't indicate the true error in position. In such case, the metric considered to evaluate the receiver's performance is the fraction of time, over the whole set of collected way points, that the difference between the measured position and the reference path is higher than the threshold.

VI. POST PROCESSING RESULTS

The performance of a single frequency, stand alone GPS receiver has been evaluated considering the measured positions extracted from the NMEA output files. The positioning errors have been obtained comparing the measured longitude and latitude to the reference path. The threshold, in meters, used to compare the difference between the collected way points and the reference path has been set equal to 20 m. This value is approximately the freeway's width. Note that in downtown Los Angeles the carriage-way width might be narrower than the freeway's and in such case this threshold value is conservative.

A. Open Sky condition

In Fig. 3 we see the travelled path on the Los Angeles freeway. The red line represents the path estimated by the GPS receiver, while the blue curve represents the center of the carriage-way. In this scenario only very small differences between the two paths are visible. Considering the positioning accuracy reported on the receiver's manufacturer datasheet (i.e. 10 m, assuming open sky condition), the result we observe in Fig. 3 clearly shows that the error is within few meters and can be easily recovered by any simple map-matching algorithm. In Fig. 4 the measured position is plotted as a function of both the longitude and latitude. The different colors represent

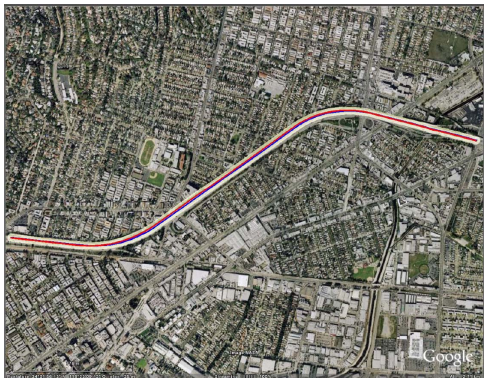

Fig. 3. View of covered path in Los Angeles freeway 10 using a COTS receiver. Blue curve: ideal covered path. Red curve: real path.

the estimated error ε_i with respect to the reference line. The estimated error values show that the measure is biased (less than 20 m). NMEA samples in the output file are periodic and there are no evident discontinuities between the sampled points during this measure.

B. Urban Canyon condition

The second scenario where the tests took place was in downtown Los Angeles. In Fig. 5 we show the path measured with the COTS receiver, superimposed to the reference path, which again corresponds to the center of the carriage-way. This is a harsh area for navigation receivers. In particular the two highlighted zones in Fig. 6, emphasized as *subzone 1* and *subzone 2*, can be considered typical urban canyons where a greater positioning error is expected. *Sub-zone 1* is characterized by narrow streets, surrounded by moderately high buildings. The second sub-zone is an urban canyon with wider streets and high skyscrapers. High buildings might shadow (or even block) the signal coming from the satellites in view, with a corresponding decrement of the C/N_0 ratio, which becomes too low to correctly estimate the receiver's position. Furthermore, in such environment, multipath can heavily degrade the measurement's accuracy.

It is clear that in downtown Los Angeles, the measured path is not always superimposed to the reference line, as

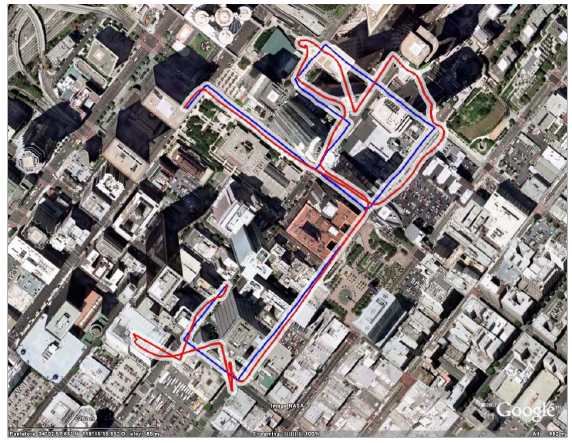

Fig. 5. Overview of the covered and reference path for the downtown selected area. Blue curve: ideal covered path. Red curve: real path.

in the freeway scenario. In particular, when passing through severe urban canyons, discontinuities appear on the measured path and the rate of NMEA samples decreases. In critical areas, the receiver is not always able to compute the user's position which results in a decreased rate of the NMEA output messages with a consequent loss of information.

As expected, Fig. 6 shows a worse receiver performance with respect to the freeway case. In *sub-zone 1* the difference between the measured position and the reference line can reach 100 m, which represents the worst case in this test. In the other critical environment, *sub-zone 2*, the difference between the measurements and the reference path is approximately 50 m. It is interesting to observe how the error introduced by the receiver in urban canyons can be very difficult to mitigate, even using map-matching techniques. In *sub-zone 2* the receiver positions itself on another street, perpendicular the street where the receiver was tested (see Fig. 7). Note that this error is detected with a low number of available NMEA samples. In such type of case, because of the environment (i.e. few satellites in view, signal shadowed or blocked by obstacles, multipath), the receiver is unable to provide a reliable estimation of the user's positions.

Table I compares the receiver's performance in downtown

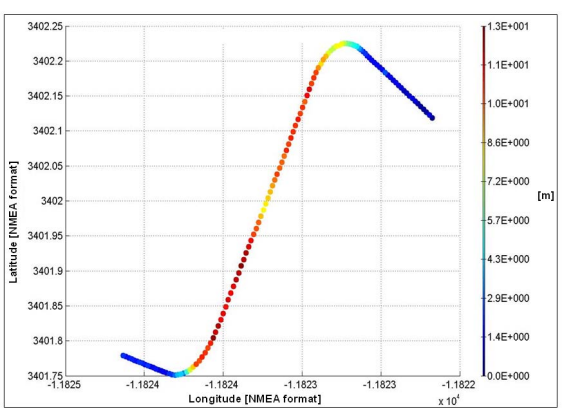

Fig. 4. Latitude and Longitude with estimated error from center of carriageway for the freeway. Negative values stand for *West Longitude*

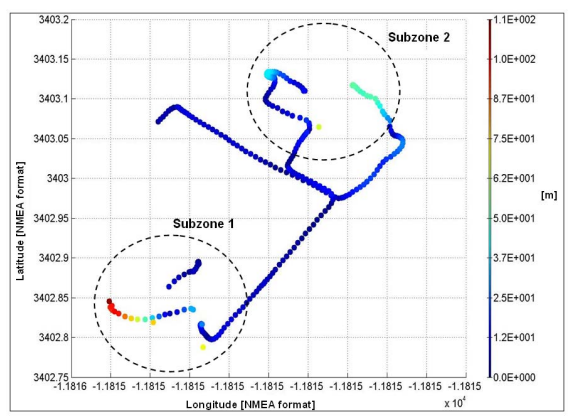

Fig. 6. Latitude vs Ovest Longitude with estimated error from center of carriageway for the downtown area.

TABLE I

FRACTION OF ERRORS ON THE CONSIDERED SCENARIOS

Range Error $[m]$	Fraction of Collected Positions	
	Freeway	Downtown
$0-10$	63.636%	50.673%
$10-20$	36.364%	22.642%
>20	0%	26.685%
Number of Snapshots	121	371

Los Angeles with the performance observed on the freeway, as the fraction of time the difference between the waypoint and the reference line is higher than the predefined threshold. The most significative errors are over 20 m, which corresponds to the assumed threshold. While on a freeway, the estimated error never exceeds the 20 m threshold, in downtown Los Angeles approximately 27% of the 371 collected measurements are considered unreliable, which means that the estimated positioning error was above 20 m.

C. Discussion

The results presented in Subsection VI-C show that in an urban canyon scenario, such as downtown Los Angeles, the commercial GPS receiver under investigation becomes unreliable. Almost one third of the collected estimates show an absolute error that heavily affects the positioning of the receiver in the urban area. We should especially observe those cases where the receiver positions the user on a parallel street. We feel that it is important to investigate the impact of such cases on vehicular networks.

Lets now suppose that a receiver positions a car on the other side of a building. Such mistake might clearly have consequences on the navigation system of the car, which may have difficulties in leading a driver to his destination. This mistake may also create problems to a vehicular network. Suppose that, say, car A, positions itself on the wrong side of a building. Car A will give this information to a geo-location service, which will then publish this information to all those hosts which wish to contact car A. If car B at some point sends a packet to car A, sending the packet to the address erroneously advertised by car A, this packet will get lost on the other side of the building. The only hope may be that the network routing protocol employs Last Encounter Routing (LER) [13] techniques and that some car on the other side of the building recently met car A.

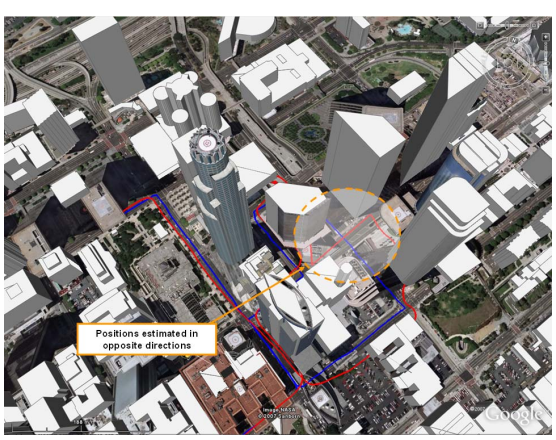

Fig. 7. Zoom on the deepest encountered urban canyon. The covered path is represented by a red line and reference path by a blue line.

From the above example we understand that the equipment we use in this paper may be unsuited for the implementation of a VANET based on geo-routing algorithms. In particular, downtown areas of American cities, where urban canyons are particularly severe, may currently represent an enormous obstacle to an efficient implementation such type of networks.

VII. CONCLUSION

This paper is a first step in understanding the performance of GPS receivers for VANET applications. In case VANETs will heavily rely on positioning systems, as it is widely believed, we wish to understand how their performance will affect the delivery of information flows.

As we have seen in this paper, more than locally affecting the planarization algorithm, as analyzed in [9], a positioning error can place a car on the other side of a block. While traveling downtown an American city, many packets may be lost because of an inaccurate estimation of a car's position. In a small downtown scenario such as in Los Angeles the impact of such problem may be limited, but in New York, for example, we may expect a much worst situation.

The next steps are to better understand the behavior of GPS receivers in such scenario by: (a) analyzing the performance of a number of different devices with different chipsets; (b) quantify how performance is expected to vary in an urban scenario. Such steps are then necessary to design a vehicular network geo-routing strategy that is capable of tolerating positioning errors without a visible degradation of performance.

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