Can GPS Be Used for Location Based Services at Schiphol Airport, the Netherlands?

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***Abstract*—Schiphol Airport in the Netherlands is one of the main airports of Europe. To improve the airport's procedures reliable and accurate positioning information is required. This paper investigates whether GPS (or in general) GNSS can provide such positioning information. Schiphol Airport is a challenging environment for satellite-based positioning, because the area is densely built, and GNSS signals should be received inside the buildings as well, enabling indoor Location Based Services. Several experiments using a low-cost receiver have been carried out to investigate the performance of GPS. Outdoors near the piers the position availability is very good: even at locations under passing the piers sufficient satellites are tracked to compute positions. Indoors the availability of GPS really depends on the characteristics of the building. Multipath errors can degrade the position accuracy significantly. The main conclusion reads that due to a lack of availability indoors, Location Based Services at Schiphol Airport should not rely on GNSS only as source of their positioning information.**

***Index Terms*—Global Positioning System, Location Based Services, High Sensitivity GPS, personal navigation**

I. Introduction

Location Based Services (LBS) at Schiphol (or Amsterdam) Airport in The Netherlands may enhance if they are provided with reliable and accurate positioning information. For example, the navigation of rescue/emergency teams, fire fighters and security personnel may improve using accurate positioning information. In addition, the navigation of passengers is not only beneficial for airline companies in order to anticipate on their time of arrival (tracking), but also for the passengers themselves (navigation). Tracking of luggage, both inside the terminal and on the platform, is important for logistic reasons, whereas tracking and tracing of airplane materials is especially important because of their high value. Registration of incidents is important to improve safety and environmental control. Summarizing, positioning at Schiphol Airport can be done for (personal and or vehicle) navigation, tracking and tracing (of persons or material), or just for recording coordinates.

For many of the above given Location Based Services a positional accuracy of 10 m is sufficient. In principle this requirement can be met using Global Navigation Satellite Systems (GNSS), such as GPS, or in the future, Galileo, provided signals with direct lines-of-sight to at least four satellites can be tracked. Since Schiphol Airport is densely built, especially near the terminal, this is not always and everywhere possible. In this context the presence of multipath may prevent to obtain sufficient positional accuracy [1]. In addition, some Location Based Services are indoors, which means that beside multipath GPS signals are strongly attenuated and depending on the characteristics of the building, GPS positioning may be even impossible. Although this is recognized, the unaided use of GPS is investigated here, to get insight for which parts of Schiphol the technique is still able to deliver positioning information. For some (not all) Location Based Services this may still be sufficient.

The use of GPS is potentially very attractive for Schiphol Airport since no additional infrastructure is required and GPS receivers are cheap, small and widely available. To test the performance of GPS in this paper we describe the results of some experiments, conducted both indoors and outdoors at the airport. In all experiments we used a low-cost high-sensitive GPS (HSGPS) receiver of the Swiss manufacturer u-blox, known to be able to receive signals indoors. The results of these experiments are described in Section III. Before that, in Section II we briefly describe the characteristics of High-Sensitivity GPS and of the u-blox receiver we used in the experiments. In Section IV conclusions are given.

II. High sensitivity GPS

A. Characteristics of HSGPS

A conventional GPS receiver is designed for outdoor applications where sufficient (at least four) and unblocked LOS signals are available. In addition, the carrier-to-noise ratio (C/N_0) of these signals should be high enough in order to be acquired and tracked by conventional receivers. Conventional GPS receivers acquire and track signals with a C/N_0 above 33-35 dBHz [2], with a rather long acquisition time (this can be up to few minutes). A High Sensitivity GPS

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(HSGPS) receiver uses large computing power and sophisticated signal processing in order to acquire and track very weak signals [3]-[4]. It is possible to acquire and track signals with a C/N_0 as low as 10 dBHz. This means that GPS signals can be received even in an indoor environment. HSGPS results showing this have previously been presented, e.g. [5] and [6]. The noise of HSGPS measurements can be large, dependent on the signal attenuation [2]. In addition, the signals may get contaminated by large errors as due to reflections to walls, glass, concrete and obstacles (multipath). This may severely affect the positional accuracy.

B. Used HSGPS receiver in the experiments

In the experiments described in this paper the u-blox AEK-4T Evaluation Kit has been used, containing the ANTARIS 4 Positioning Engine and the SuperSense Indoor option enabled [7]. This HSGPS receiver (tracking sensitivity: -158 dBm) has 16 channels and its measurement frequency can be up to 4 Hz. Although it is possible to extract raw pseudo-range data using this receiver, in this paper the positions as computed by the receiver itself are used. These positions are extracted from the NMEA messages, which besides positioning information also contain status information.

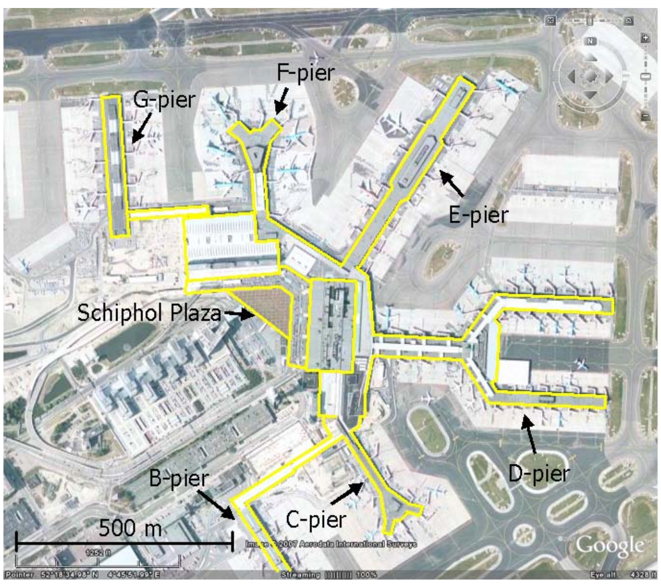

Fig. 1. Google Earth image of Schiphol Center.

III. Performance of GPS at Schiphol Airport

Practical insight into the availability of GPS positions in relation to their accuracy at Schiphol Airport has been obtained by conducting a number of experiments. These experiments have been carried out both inside the terminal building and piers as well as outside (at airside) along the ring-road connecting all piers (see Fig. 1).

First the results of the indoor experiments will be described.

A. GPS experiments indoors

For the indoor experiments the u-blox receiver kit was connected to a laptop (to store the NMEA messages) and carried on a luggage trolley. This trolley was pushed forward with more or less constant walking speed, while an external (patch) antenna was held in hand, see Fig. 2. All measurements were collected with a frequency of 1 Hz on 9 May 2007, in the following areas of Schiphol Center (see Fig. 1):

- inside and outside Schiphol Plaza at the ground floor;
- inside the D-pier.

Fig. 2. Luggage trolley with u-blox receiver connected to a laptop, while the external (patch) antenna is held in hand.

Because a ground truth is lacking, the quality of the GPS positions cannot be assessed in an absolute sense. However, the (relative) precision of the positions that are kinematically obtained is assessed by plotting the positions on Google Earth background images. Unfortunately the absolute accuracy of Google Earth images is not very high and we cannot use these images in an absolute sense as ground truth for the GPS positions. However, they are used here for the purpose of visualization, since it can be immediately seen where the positioning has been done, and where for example certain obstructions have been passed.

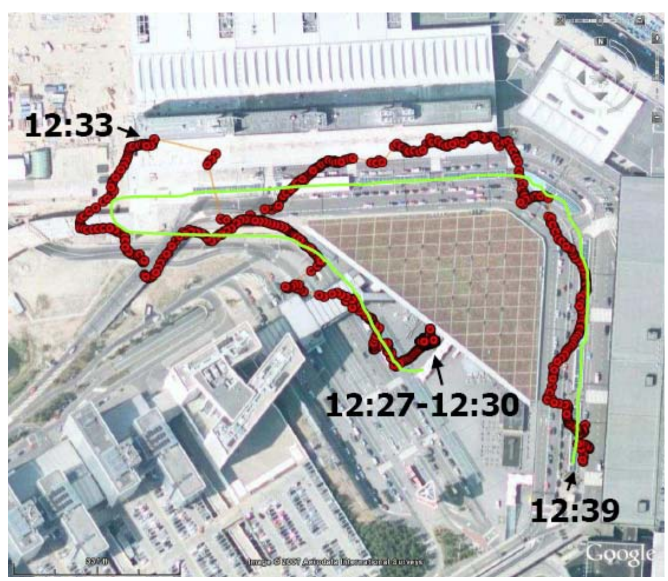

Fig. 3. Position fixes (red dots) plotted on Google Earth image for Schiphol Plaza experiment. The green line depicts the walked trajectory.

The first experiment (from 12:27–12:48 UTC) started near the main entrance of Schiphol Plaza, outside at street level. The first three minutes the trolley was not moved in order to collect some static measurements. During this period the carrier-to-noise ratios of the signals tracked were up to 50 dBHz (see Fig. 4), and these are typical values for outdoor measurements with (more or less) direct lines-of-sight. Next, the trolley was moved forward on the street (see the green curve in Fig. 3). Along its way it under passed several obstacles: a large pedestrian bridge and a viaduct. During these passes however the number of satellites never dropped to zero; still about 7-8 satellites were used to compute positions. However, some deviation with respect to the followed path can be seen in Fig. 3, which might be due to multipath errors. At 12:33 UTC the trolley went inside a shopping corridor in the Plaza building (see Fig. 3) and immediately after entering only signals of at most 15-20 dBHz could be tracked. Due to this weak signal tracking unfortunately for some time intervals after 12.33 UTC no positions could be output by the receiver. After 12:35 UTC, still inside the shopping corridor, the tracked signals became stronger, which is due to the presence of windows in the roof from this point onwards (see Fig. 5). As a consequence of GPS signals penetrating through these windows, positions could be fixed all the time (see Fig. 4), up to a point, at almost the end of the corridor. At this point no windows were present (from about 12.38 UTC), and positioning became problematic.

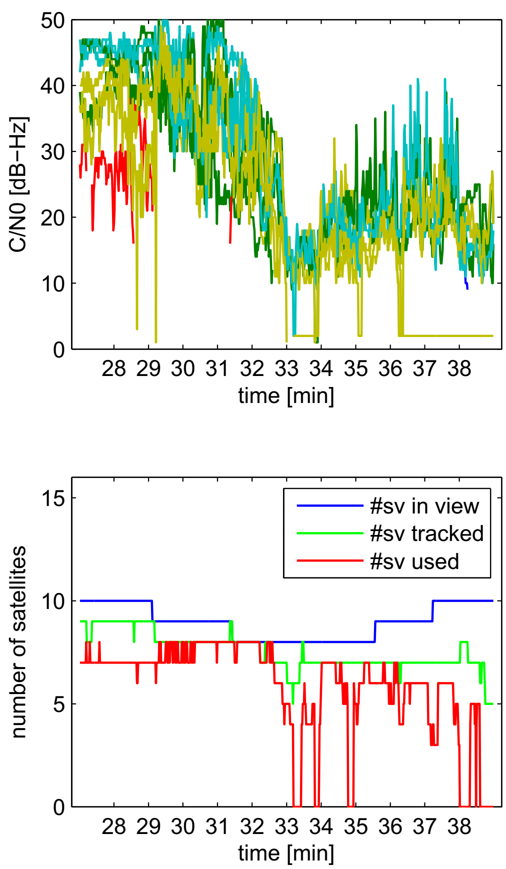

Fig. 4. Carrier-to-noise ratio C/N_0 (top) and number of satellites (bottom) as function of time for experiment at Schiphol Plaza. The number of satellites 'in view' is the theoretical number of satellites (based on almanac data) the receiver can "see", while the number of satellites 'tracked' is actually received. The number of satellites 'used' is the number that is used for the position computation.

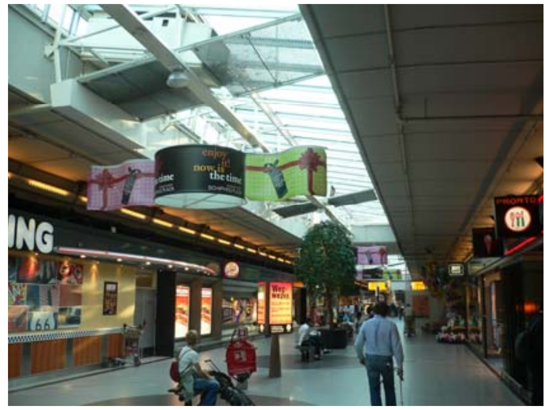

Fig. 5. Shopping corridor in Schiphol Plaza having windows in the roof.

The second indoor experiment was conducted at the large D-pier (see Fig. 1) from 14:13–14:20 UTC. This pier has two stories. The experiment started at the top floor at the most southern wing of the D-pier from which the trolley was moved towards the entrance of the D-pier (see Fig. 6).

Fig. 6 shows the GPS position fixes during this experiment, while Fig. 7 depicts the carrier-to-noise ratios of the signals tracked and the number of satellites as function of time. It can be seen that the signals are relatively weak, having carrier-to-noise ratios lower than 30 dBHz all the time. For some time the receiver is not able to output position fixes; this can be seen in Fig. 6 close where the pier 'splits' into a northern and southern wing. For this period without positions the receiver still tracks sufficient satellites (see Fig. 7), however, the receiver does not decide to compute any positions. In Fig. 6 one can recognize a reasonably tall building above the location where the pier splits into two parts, which is most

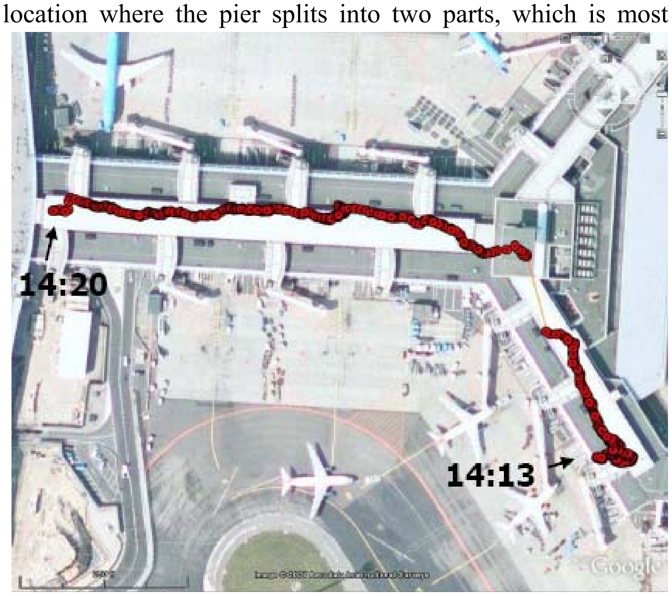

Fig. 6. Position fixes plotted on Google Earth image for D pier experiment.

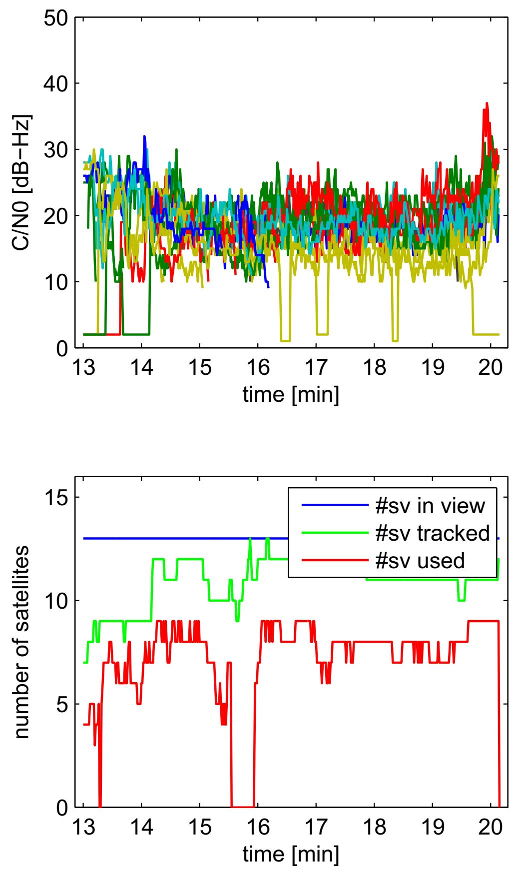

Fig. 7. Carrier-to-noise ratio C/N_0 (top) and number of satellites (bottom) as function of time for D-pier experiment.

likely responsible for this poor performance.

It was also tried to perform GPS positioning at the ground floor level of this D-pier, but unfortunately this failed; no positions could be fixed at all at this level. The cause for this failure is likely the (metal) coating applied in the windows of the D-pier. This coating is not applied to the windows at the top floor.

B. GPS experiments outdoors

Outdoors, the external patch antenna of the u-blox receiver was fixed to the roof of a car (see Fig. 8) and connected to a laptop inside the car. The car drove along the ring-road at the airport, which goes around Schiphol's terminal building and all piers (see Fig. 1). At several places this road underpasses the building and piers, making it a challenging environment to test the impact of these urban 'obstructions' to the performance of GPS. The test was carried out on 26 October 2007 from 9.47-10.05 UTC with a measurement frequency of 4 Hz.

Fig. 9 (top) depicts the trajectory of the car obtained using the positions logged in the NMEA messages. The car started at the G-pier and drove along all other piers to finish in the Southwestern corner. We remark that the last part of the trajectory (after the B-pier) was driven in rather open field conditions. The availability of GPS signals was very good

Fig. 8. Car used in Schiphol HSGPS outdoor test. The u-blox patch antenna is fixed to the roof of the car (see arrow).

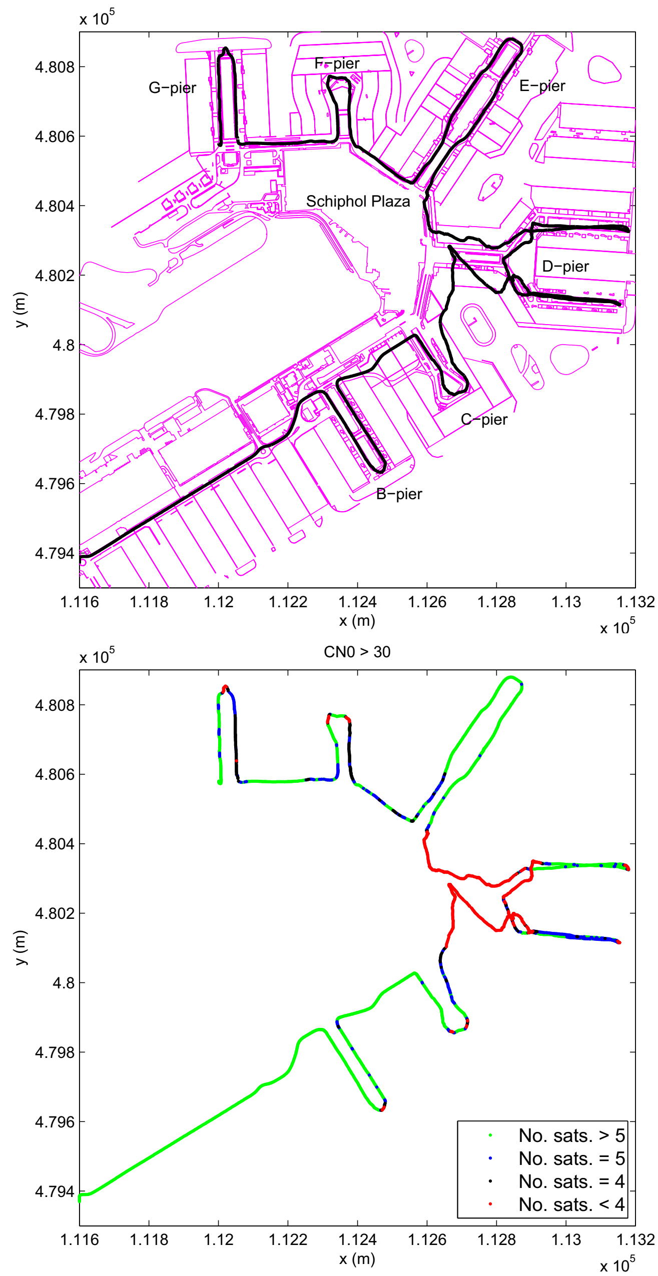

Fig. 9. GPS positions of outdoor test plotted at a Schiphol map with roads (top) and number of satellites having a carrier-to-noise ratio larger than 30 dBHz plotted on position fixes (bottom).

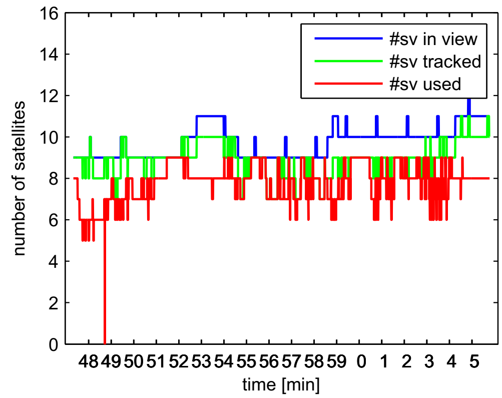

Fig. 10. Number of satellites as function of time for the ring-road experiment.

Fig. 11. Ring-road underpassing a pier at Schiphol Airport.

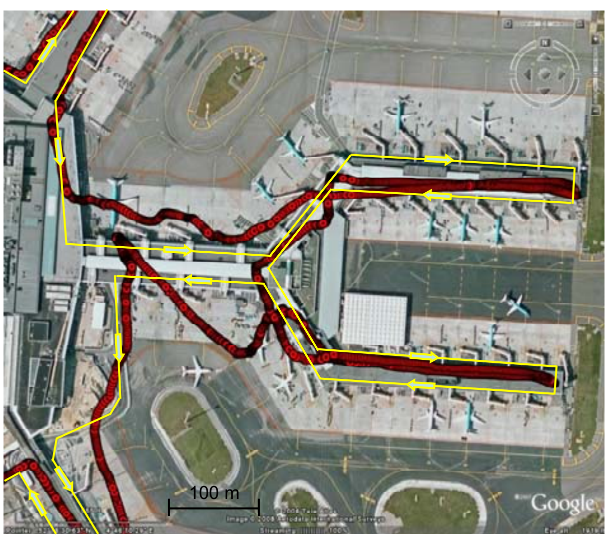

Fig. 12. Position fixes (red dots) vs. driven trajectory (yellow line) in the D-pier area.

during this experiment: for only one epoch the signals were lost and no position be fixed by the receiver. For all other epochs at least 5 satellites could be used for the positioning computation (see Fig. 10). When looking at Fig. 9 one may see that the series of position fixes reasonably well resembles the ring-road trajectory, except for the area around the D-pier, where deviations are visible. We remark here that the plotted road contours have a precision at cm level, so they can serve as ground truth to verify the quality of the GPS positions.

To check the large position errors around the D-pier, in Fig. 12 this area is zoomed in, and one may see that in this part the ring-road underpasses the terminal building and pier at frequent places (see also Fig. 11). As a consequence, multipath can be severe (at some places even no direct lines-of-sight may be received at all), and the resulting position gets biased. This bias can be up to 100 m, see Fig. 12.

Fig. 9 (bottom) shows per position fix the number of satellites tracked for which the carrier-to-noise ratio is larger than 30 dBHz. It can be seen that for the majority of the fixes this number is at least four, but for the area around the D-pier this is lower than four. This applies to the part of the trajectory that is fully under passing the pier. This shows that also for outdoor areas it is beneficial to use High Sensitivity GPS receivers; using a conventional GPS receiver not enough signals would be tracked in this area. The price to pay is of course the degraded positioning accuracy due to multipath.

IV. CONCLUSIONS

Although it was never expected that GPS as a standalone technique can provide reliable (continuous) and accurate positioning information for the broad range of Location Based Services at Schiphol Airport, we have carried out some experiments at the Airport both indoors and outdoors as to quantify the availability and accuracy of the positions obtained using a low-cost but highly sensitive GPS receiver.

The experiments revealed that reception of the signals indoors at the airport is problematic or even impossible, depending on for example whether (metal) coating has been applied in the windows. However the u-blox receiver is able to acquire and track signals in certain areas, which could not be received by conventional GPS receivers. If signals are tracked indoors, position errors can be up to 50 m. The availability of GPS signals is outdoors of course much better. Even in the dense urban environment of the terminal and piers, position availability is almost 100% in the experiments using a cheap u-blox receiver. For most of the tested outdoor locations the position accuracy is good, except for some locations underneath the piers, where due to multipath position errors up to 100 m may show up.

An additional GNSS such as the envisioned Galileo will of course improve the availability of signals. In [8] it is predicted that the position availability is enhanced significantly in the dense urban area of Schiphol Airport. Indoors one should not rely on the use of GNSS-only; in order to obtain reliable and continuous positioning information a combination of several techniques should be used, for example GNSS with INS, and/or WiFi based positioning.

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