High precision location estimation for mobile devices

Abstract

A number of different methods and technologies exist for determining the location of mobile devices. Depending on the desired usage, a different subset of these may be suitable for a given project. One of the key issues in location detection is the degree of precision to which these tools remain accurate and additionally the reliability of that data. For some usages, such as markerless augmented reality, requiring accuracy to within a few meters, typical solutions such as GPS may not be sufficient and alternatives must be considered.

This paper will evaluate and compare technologies and tools for mobile devices, such as smartphones and tablets, to accurately determine their location to within 5 meters or less with consideration for different environments and conditions in which they may need to operate given different use cases. Techniques for ensuring operability in challenging environments will be discussed.

Introduction

An increasing number of applications make use of mobile location data to enrich user experience or provide additional functionality and many other applications are being developed to analyse this data providing useful information to users, city planners and businesses. The goals of such systems range from monitoring footfall and traffic flow to more accurate and efficient augmented reality and computer vision applications, to aiding navigation within sites for both users and autonomous systems, in addition to the growing number of user-facing application taking advantage of this localisation data.

A consistent trend concerning this area is the increase in potential uses from having more precise location data and better, more consistent coverage. A number of technologies have developed to meet this need ranging from global scale GNSS (such as GPS) to indoor positioning systems (such as WPS), with newer technologies giving room level accuracy in a variety of conditions. However, such systems still struggle with particular types of locations, as outlined below, and new techniques may be required to provide suitable coverage to such areas in a cost-effective manner; one such method is detailed and evidenced later in this document.

Problem Statement

A common shortfall of existing techniques for location detection is the ability to give a precise value in remote or shielded indoor areas, such as basements or out-buildings (sheds, garages, etc.). Shielding, typically in the form of thick walls, urban canyon effects or other line of sight obstructions reduce the effectiveness of GNSS, such as GPS (EGNOS Open Service (OS) Service Definition Document, 2015, p. 29) and may limit the number of visible Wi-Fi access points, potentially removing WPS as an option or otherwise significantly reducing accuracy. Expansions of these systems can potentially be costly, so a new approach is required, using existing or common hardware to extend service to such areas.

Current solutions

It is well established that GNSS (such as GPS and GLONASS) have significantly reduced accuracy in urban areas, due to the urban canyon effect (refection of signals off of man-made structures) (EGNOS Open Service (OS) Service Definition Document, 2015, p. 29) and (at least concerning non-military applications) typically lack the level of precision that can be achieved with indoor positioning systems (such as WPS). SBAS (Satellite-based augmentation systems), such as EGNOS in the EU and WAAS in North America have been developed to significantly increase the precision of GNSS by providing correction information to GNSS satellites about ionospheric distortion and clock or orbital variations, resulting in locations reliably accurate to within 3 meters, compared to 17 meters for un-assisted GPS (egnos-portal.gsa.europa.eu, 2015). However, these systems only operate over particular areas (see **Figure 1**) and still cannot address the issue of urban canyons.

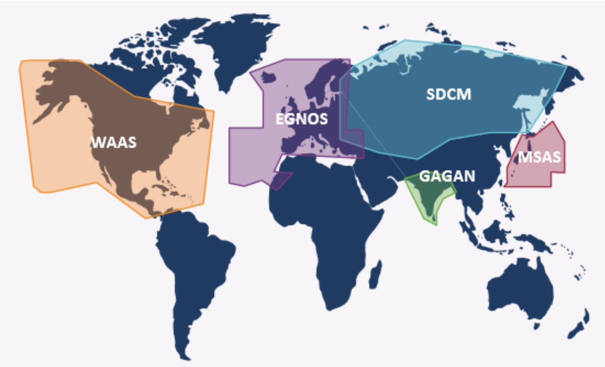


Figure 1: (EGNOS Open Service (OS) Service Definition Document, 2015, p. 14) Existing and planned SBAS coverage

Another advance in GNSS will soon come in the form of ESAs Galileo system, which is scheduled to begin first operation in 2016, reaching full operation in 2020 and is anticipated to give values accurate to within one meter (European Space Agency, 2015), potentially rivalling WPS in terms of accuracy in less dense urban areas.

A common form of indoor positioning systems are WPS (Wi-Fi-based positioning systems), which typically use the RSS (received signal strength), angle of arrival or time of flight of signals from nearby Wi-Fi sources to calculate precise locations. While these systems are mostly only suitable for urban areas (due to abundance of Wi-Fi access points), they can often provide locations of much greater precision than GNSS in such environments, particularly due to avoiding most issues with urban canyons and signal blockage from terrain. They do however, experience similar issues in the form of multipath induced fading, where a signal may reflect off objects or surfaces causing it to interfere with itself, which is often difficult to predict in frequently changing indoor environments.

Working WPS using only a single AP has been demonstrated by systems such as SAIL (Mariakakis et al., 2014), however such techniques yield lower accuracy locations (mean error of 2.3m in the case of SAIL) and may require additional hardware to employ techniques such as dead-reckoning to provide sufficient accuracy, making performance device dependent and the approach potentially unsuitable for devices such as laptops.

Other WPS solutions, such as SpotFi (Kotaru et al., 2015) utilise the Wi-Fi signals of multiple sources to provide an accurate location without need of mapping or dead-reckoning and are less sensitive to distance from a particular source, with greater improvement from using more sources (Kotaru et al., 2015, p. 13). The issue with such systems however, is the strict requirement of at least two visible Wi-Fi signals (SpotFi being capable of achieving median error of 1.6 m with line of sight of two APs (Kotaru et al., 2015, p. 10)), which is often unavailable in more remote or shielded areas of a site, such as basements or out-buildings.

Proposed solution

As outlined above, across the various current implementations of WPS, a consistent issue is the ability to precisely determine the location of devices in range of only one sufficient RSS source (or otherwise a number of weak sources), without requiring previous mapping of the area or device dependent dead-reckoning. In medium density urban or industrial areas, this is a common use case that can potentially effect various out-buildings (sheds, storage-yards/warehouses, etc.) and shielded environments such as basements.

Where complex surfaces in the surroundings (such as urban canyons or mountains) may inhibit accuracy of GNSS and frequent changes in local environment (such as rearrangement of furniture, relocation of items within a warehouse or movement of other devices or access points within a site) rule out the possibility of maintaining an accurate mapping of the area, another approach is required.

While the ideal solution would be to setup more wireless access points in such areas, this is often not cost effective, especially in large areas with many line of sight obstructions where multipath interference may reduce the effective coverage of each AP and normal wireless services may not be required.

A more cost effective and portable solution would be to take advantage of systems such as SpotFi, which maintain reasonable accuracy with only two visible APs (Kotaru et al., 2015, p. 10), to obtain the location of a device placed just outside the target area, but still within range of at least two APs, then have this device act as a relay by broadcasting its own 802.11 wireless signal (a feature supported by most modern smart phones and tablets, commonly referred to as a "mobile hotspot") and use the much stronger signal from this device (due to proximity) combined with any (most likely weaker) signals from other APs which may be visible from the target area to calculate the position of the target device. This should enable location detection within the target area where it may not have been possible previously.

Testing and experimental evidence regarding the viability of this approach is documented below, however it is possible to outline a few likely issues and make some predictions beforehand.

Firstly, a clear limitation is the requirement of at least one AP with sufficient RSS in the target area, and at least one other visible to the relay device, making this solution potentially unsuitable for isolated facilities where these (minimum of) two access points may be unavailable.

There are a number of issues which could potentially adversely affect the accuracy of locations determined within the target area, the most prominent of which are likely to be compound error and the reliability of RSS from a mobile device as, while mobile hotspots are a common feature of such devices, they typically provide less stable connections than dedicated wireless access points due to having fewer and smaller antennas, hence the hardware in the device used as the relay may impact accuracy and reliability.

Compound error will result from assuming the accuracy of the relay device's location when calculating that of the target. As the location of the relay is being determined using conventional WPS techniques, it is sensitive to the same issues as these systems, such as multipath interference and reduced accuracy when less APs are visible or lack direct line of sight (Kotaru et al., 2015, p. 13). These issues are particularly likely due to the nature of the problem attempting to be solved (see above for outlined use-cases) however may be less problematic in the case that the target area is shielded and signals may be significantly stronger just outside the target area. Any inaccuracy in the location given for the relay device will significantly affect the accuracy of locations calculated within the target area, where the signal from the relay device may be heavily relied on due to lack of other signals to act as a reference and due to the comparatively high RSS from the relay due to proximity.

Experiments and proof of concept

The following is an outline of an experiment to prove the viability of the technique proposed above:

Let R and S be devices with known locations, capable of Wi-Fi broadcasting

Let P be a device with no known location, capable of Wi-Fi broadcasting and receiving

Let G be a device whose location must be determined, capable of receiving Wi-Fi

Record the locations of R and S

Place P within range of R and S

Use the location of R and S and their observed signal strengths from P to calculate the position of P

Let Q be either S or R

Place G within range of P and Q

Use the locations of P and Q and their observed signal strengths from G to calculate the position of G

The actual implementation of the experiments conducted varied somewhat from this conceptual model due to inability to obtain working, compatible WPS algorithms for the devices available. Creation of a custom algorithm was beyond the scope of this project. As such, the experiments conducted aim to act as a proof of concept for the technique previously discussed; details of the experiments conducted are as follows:

In all following experiments, devices were arranged as shown in **Figure 2**, there were no significant changes to positions or environment during or between tests. All tests were conducted over ten minute periods to demonstrate reliability.

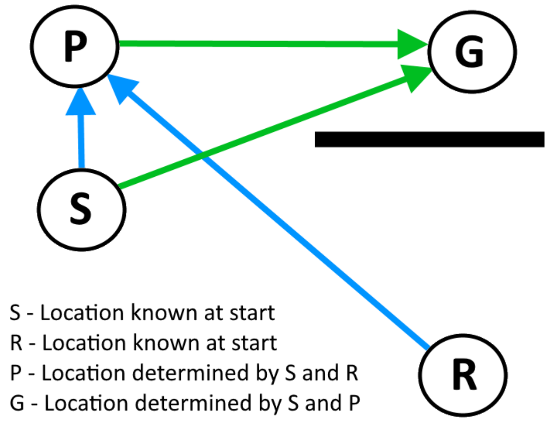


Figure 2: Positioning of test equipment and layout of environment. The thick line under G represents shielding from a thick wall with metal insulation. The arrows indicate the expected reception of signals in the experiment.

To determine the location of a device, it is assumed that the RSS from two APs with known locations is required. Hence, to determine the position of G, it is first necessary to observe the RSS from R and S at P. The results from this test are shown by **Figure 3** (overleaf).

Assuming that this data would be sufficient to calculate the location of P, it now becomes possible to use P as a location-known AP for determining the location of G by having P broadcast its own 802.11 wireless signal. Two tests were conducted for this using different mobile devices (with different wireless hardware) at location P.

In the first test, the device at P is a Moto G XT1032 smartphone. The results of this test are shown in **Figure 4** (overleaf). These results lead to a few notable observations:

- Signal R is intermittent and could not be relied upon for location calculation.
- Signal S, while weaker than as observed at P, is still reasonably consistent and should be suitable for location calculation.
- Signal P has a high average RSS (primarily due to proximity) but has poor consistency, taking an average of its value over several minutes should provide a suitable value for location calculation.

The second test replaces the device at P with an ASUS F70S laptop. The results of this test are shown in **Figure 5** (overleaf). Some observations from this test are as follows:

- Signal R continues to be unsuitable for location calculation.
- Signal S continues to be suitable.
- Signal P, from the new device, is much more consistent than in the previous test, with only occasional extreme values. It should be possible to filter out such errors using the standard deviation.

The results of these experiments show that the hardware of the relay device used at P would have a significant impact to location calculation at G. Due to instability of the signal from P in the first test and the resulting need to take a long-term average, there would likely be a significant delay before obtaining an accurate location for G when using such a device. The results from the second test however are more promising and indicate that this technique may be viable, so long as the relay device has suitable hardware.

With the ongoing improvements to mobile wireless cards it may soon be viable to use more modern smartphones to achieve similar results as in the second test, however even a laptop makes for a considerably more portable alternative to installation of an additional AP. This raises the possibility that such a setup could be deployed as and when needed to provide device localisation within otherwise problematic areas such as these.

Graphs of experiment results

Figure 3: Results of test at P, showing RSS at P.

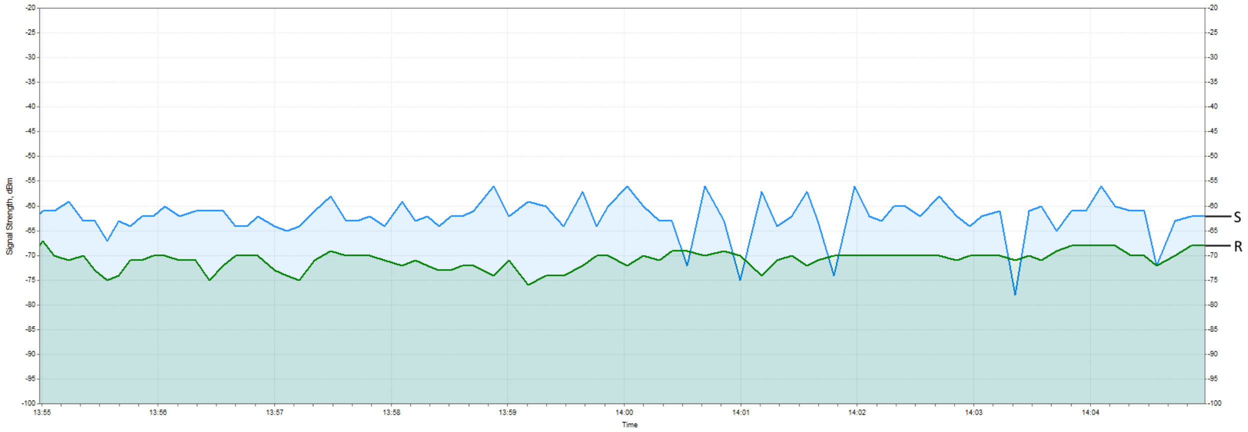


Figure 4: Results of first test at G, showing RSS at G with smartphone broadcasting from P.

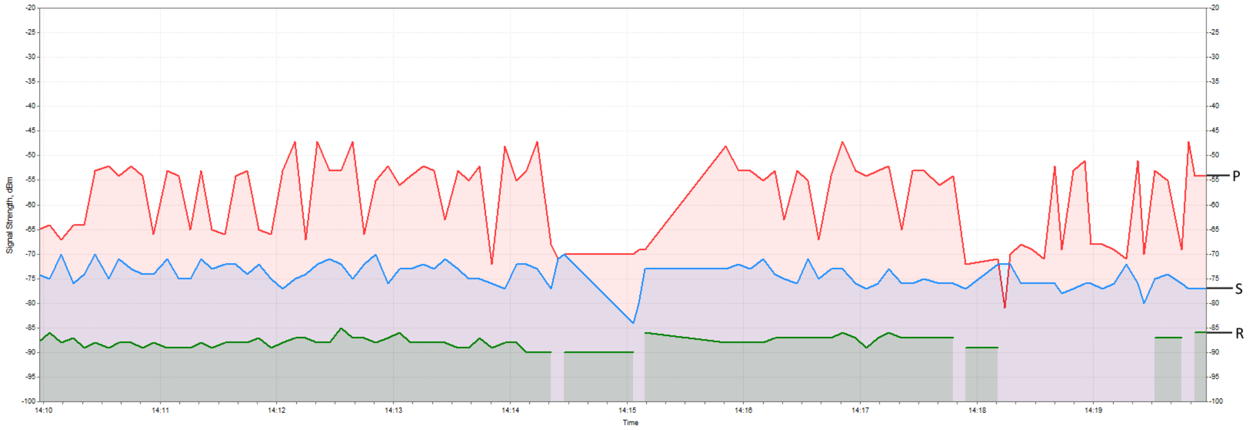
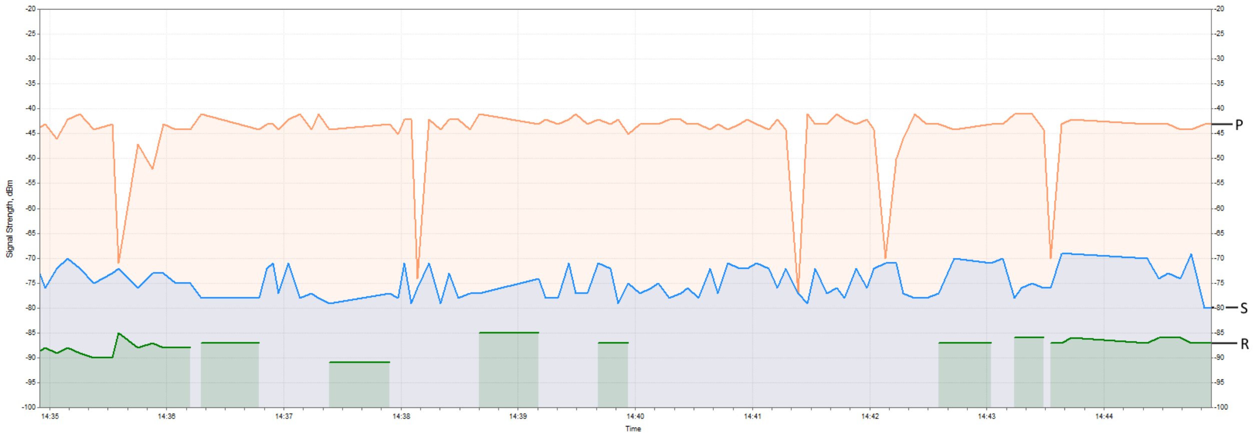


Figure 5: Results of second test at G, showing RSS at G with laptop broadcasting from P.



Conclusion

Advances in WPS technologies now facilitate accurate location detection for mobile devices in most indoor urban environments with high AP density, where current GNSS can have poor performance due to terrain and line of sight obstructions, even with SBAS augmentation. In future, when the EU Galileo GNSS is made available for public use, more precise locations may be possible in low density urban areas, potentially rivalling WPS when few APs are available.

Experiments have shown that use of existing techniques for WPS positioning using two APs can potentially be applied to resolve positions in otherwise difficult environments by use of a relay device, but that the performance of such a technique is highly dependent on the Wi-Fi broadcasting capabilities of the relay device. This presents the possibility of inexpensive, portable coverage extension to a WPS as needed using only commonly available mobile devices.

The limitations of experiments conducted here result in this acting as a proof of concept and raise the opportunity for further research in developing a working system following this method to demonstrate possibility of real world application. Further experimentation could also be conducted using greater variety in relay device hardware (particularly looking at the capabilities of more modern smartphones and tablets) and in other difficult environments such as basements.

Abbreviations and acronyms

ESA	European Space Agency
GNSS	Global Navigation Satellite System
GPS	Global Positioning System (United States implementation of GNSS)
GLONASS	GLObal NAvigation Satellite System (Russian implementation of GNSS)
SBAS	Satellite-Based Augmentation System
EGNOS	European Geostationary Navigation Overlay Service (European implementation of SBAS)
WAAS	Wide Area Augmentation System (United States implementation of SBAS)
WPS	Wi-Fi based Positioning System
RSS	Received Signal Strength
AP	802.11 wireless Access Point

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