A WiFi Assisted GPS Positioning Concept

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Abstract

The need for context aware services will raise during the next years. Ubiquitous global navigation is still not feasible in urban and indoor environments. Since more and more places are covered by WiFi access points, we can use WiFi localisation to create a new sort of Assisted-GPS. This WiFi-Assisted-GPS can reduce a number of disadvantages of GPS, such as the long Time To First Fix and positioning when not enough satellites are visible. To minimize the initialisation and the training of the WiFi-positioning a self mapping system is needed. With an accuracy of 50 meters, the WiFi system should be sufficient to integrate it to a WiFi-A-GPS system and to use the WiFi positioning system for other context-aware applications.
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1 Introduction

The need for context aware services will raise during the next years. Positioning information will become as indispensable as time information. Many research on location based systems has already been done, but there is still a gap between satellite-based outdoor navigation (Global Navigation Satellite System - GNSS) and wireless network based (cellular phone networks, WiFi or UWB) indoor systems.

Suppose a person needs to locate his favourite shop, but has no idea where exactly he is. He wants to know in a very short time, where he is located and how he can get to his shop in an easy way. He wants to know this regardless of his environment (an open square, a street surrounded by large buildings, or inside a shopping mall). With the current operational systems this is not always feasible.

Satellite-based navigation is the leading technology for outdoor navigation. GPS has already exhaustively proven itself and with the introduction of its European counterpart Galileo, GNSS services will only be extended and improved. Nevertheless GNSS cannot be used as the only positioning technology to cover all requirements on all terrains. GNSS signals cannot penetrate enough to most indoor environments to be used by a normal receiver. In urban environments and other RF-shadowed environments, satellite navigation is not always obvious. On top of this the Time to First Fix (TTFF) of a cold start of a GPS device can take up to a few minutes, which is far too long for many applications

Assisted-GPS (A-GPS) can overcome some downsides of the conventional GPS technology. Mobile phones which are equipped with a GPS receiver can receive information, such as satellite ephemeris[1], through the cellular network to augment the accuracy and reduce the TTFF of the mobile station (MS). Of course, to be used, this service needs to be offered by the mobile network.

For indoor location determination, nowadays WiFi positioning techniques are most commonly used based on Wireless Local Area Network (WLAN). Tests indicate that WiFi positioning can achieve an accuracy of 1 to 4m for indoor and 10 m to 40 m for outdoor environments[1]. A downside of WiFi positioning is the relative small range of the access points (indoor 30 m to 50 m) which makes WiFi positioning a local localization technology. Due the inexpensive deployment cost and ease of installation of the WiFi infrastructure, the use of WiFi users has been increasing. Since the drastic increase of access points, overlapping WiFi cells are not an exception anymore in urban environments. Since we can assume to have constant coverage of WiFi access points we can use this to calculate the estimate location of a device.

In this paper we will try to combine WiFi localisation with satellite-based navigation to form a WiFi-Assisted-GPS ubiquitous solution to make GNSS useful in urban and indoor environments. In section 2 of this paper we will discuss some basic principles of A-GPS and section 3 elaborates on some WiFi positioning basics. In section 4 we integrate WiFi localisation with A-GPS and tackle some practical problems.

2 Assisted GPS

A-GPS is widely used in the USA since the requirement of the Federal Communications Commission that, starting from October 1 2001, all wireless carries should be able to provide to position of a 911 emergency caller

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[1] Set of parameters used by the receiver to calculate the current position of the satellite and its clock behaviour.

to the appropriate Public Safety Answering Point [2]. The integration of GPS in mobile phones was an obvious choice, but the GPS receiver needs to be in line of sight with at least 4 satellites and TTFF of a GPS receiver can take up to several minutes.

GPS satellites transmit at a frequency of 1,57542 GHz with a Doppler shift of ±4,2kHz. Movement of the MS adds 3,7 Hz/kmh and the uncertainty in the GPS receivers local frequency reference adds an error of 1,574 kHz/1ppm of oscillator error. So the total uncertainty of the observed GPS signal is greater than ±4,2 kHz[3]. Because the MS does not know exactly on which frequency the satellite's signal can be received, its GPS receiver is compelled to scan all possible frequencies.

To detect the signal, the GPS receiver multiplies a locally generated replica of the code it should receive from the particular satellite, with the received signal to obtain a peak correlation signal. Only when the frequency and the local generated code delay is correct the receiver will find the correlated signal. So to find this correct combination the receiver has to search for all possible frequency offsets and code delays. A typical GPS receiver dwells at least one millisecond in each bin (range of frequency and code-delay) and will need 40 seconds to search the entire frequency/code delay space for each satellite. Once the satellite signal is acquired, the receiver will switch from acquisition mode to tracking mode. Every time the lock is lost the acquisition must be repeated.

The TTFF can be substantially reduced by providing the receiver with information, such as the satellite ephemeris, from which the MS can calculate the Doppler shift of the satellite and thereby reducing the search space by a factor of ten[3]. Since the elevation of a satellite changes by 1 degree every 100 kilometres and the A-GPS servers can obtain an estimate of the MS's position (through the cell and sector of the MS), the server knows which satellites the MS should be able to view and can send this info to the MS.

The A-GPS server can also be combined with differential GPS (DPGS) and send this information to the GPS receiver. Using this data, measurement errors introduced by for example ionosphere delays can be reduced.

Furthermore the A-GPS system can also help the MS by computing the handset's position (MS assisted localisation). In this mode the MS sends the GPS measurements to a server, which computes its location and sends the position back to the MS. In MS based localisation the GPS measurements are processed in the GPS receiver itself.

Table 1: Fingerprint dataformat

Type	**Value**
Position coordinate (X)	Horizontal (x-value, latitude)
Position coordinate (Y)	Vertical (y-value, longitude)
Position coordinate (Z)	Elevation (z-value, floor, altitude)
Timestamp	Date and time
Access Point ID	MAC Address
Signal Strength	RSSI Value

3 WiFi localisation

In the training phase a radio map of signal strengths is created which will be used in the positioning phase. For indoor positioning the fingerprints are normally created on well-known spots with a distance of 1 m to 3 m. For outdoor positioning a less dense reference network will be used, since it is not convenient to create fingerprints every 3 meter. In this way a database is constructed with data similar to table 1. In most systems the origin of the measurement data will also be recorded.

Two simple positioning algorithms will be explained as possible solutions to be implemented later in this paper.

A popular algorithm for indoor positioning - and also the algorithm proposed by RADAR is RF-fingerprinting. The combination of all RF signals radiated from the access points generate a unique pattern which can be mapped to a floor plan. If we know the exact location of all the access points we could use a signal propagation model to estimate the signal strength of every specific access point on all places. We could assume that the signal strength attenuates exponential with the distance. This model works only in free space, but since the access points are used in indoor and urban environments we cannot predict the exact signal propagation. Furthermore we need to know the exact location of the access point.

A more useful way is to measure the signal strengths on specific training points instead of using the attenuation. A downside of this technique is that far more training data has to be gathered to create a reliable RF map. If we have constructed the database with fingerprints and the training phase is finished, we can compute the position of a client by finding the closed match of the received signal strengths and the entries in the database. A possible algorithm makes use of the k-nearest-neighbour algorithm.

3.1 K-nearest-neighbour algorithm

Suppose we receive three access points (AP_1, AP_2, AP_3) with signal strengths $RSSI_1$, $RSSI_2$ and $RSSI_3$. We can calculate the difference between every possible entry ($RSSI_1$', $RSSI_2$' and $RSSI_3$') from the database and the observed signal strengths.

$$\Delta RSSI = \sqrt{(RSSI_1 - RSSI_1')^2 + (RSSI_2 - RSSI_2')^2 + (RSSI_3 - RSSI_3')^2}$$

We have now calculated the differences between all possible locations, to determine the user's position, we use the k nearest fingerprints (the k smallest differences) and compute the average of its coordinates. Cheng et al.[5] found, using preliminary experiments, that $k = 4$ provides a good accuracy. If an access point was discovered during the positioning phase but was recorded during the training phase, it was discarded. At the other hand if no corresponding set in the database was found (if an access point was removed after the training phase), the set was expanded to find entries with different access points. Using their test, Cheng et al. concluded that using sets with 2 unknown access points still produce satisfying results. The matching rate for fingerprints raised from 70% to 99% using this extended sets.

A problem using fingerprints is that most devices record different signal strengths from the same access points.

3.2 Ranking algorithm

A solution could be to use a ranking of signal strengths instead of the absolute signal strengths. An extended algorithm based on this ranking was used by Krumm et al.[6]. If we record for example the signal strengths ($RSSI_1$, $RSSI_2$ and $RSSI_3$) = (-50,-30,-45) it will be substituted by ($RSSI_1$, $RSSI_2$ and $RSSI_3$) = (3,1,2). Problems arises when access points disappear and the ranking gets unbalanced.

3.3 Arithmetic mean algorithm

An easier algorithm uses all the reported fingerprint positions to estimate the geographic location of the access points by computing the arithmetic mean, conform:

$$\bar{AP}_x = \frac{1}{n}\sum_{i=1}^{n} x_i \ , \ \bar{AP}_y = \frac{1}{n}\sum_{i=1}^{n} y_i \ , \ \bar{AP}_z = \frac{1}{n}\sum_{i=1}^{n} z_i$$

Using this estimated access point locations, the client is positioned at the centre of the access points. Cheng et al.[5] also experimented with a weighted version, where the position of each access point was weighted with the signal strength measured by the client:

$$\bar{x} = \frac{\sum_{i=1}^{n} RSSI_i.APx_i}{\sum_{i=1}^{n} RSSI_i}$$

But in their test the weighted version could only improve the accuraccy with a maximum of 4%. With the basic algorithm an accuracy up to 14 meter was received.

4 WiFi-Assisted-GPS

Suppose we have a database containing sufficient fingerprints of access points positioned in a city to locate a WiFi device up to a reasonable accuracy. For a lot of location-aware city wide applications 50 meters is enough. This applications can for example be basic navigation, neighbourhood shop or activity finding, etc. Suppose we can connect through this access points which cover the city to a central server and suppose we have a device equipped with a GPS receiver and a WiFi client. We will later discuss possible solutions if one of above requirements are not met.

When we want to start the GPS receiver, we record all received WiFi signal strengths and send them to a WiFi-A-GPS server. This server computes an estimation of our position and will send useful ephemeris data to the client. The receiver can start with the estimate position retrieved by the server and the TTFF will be reduced comparing with a normal GPS receiver.

After the GPS has 'locked' its position, it is able to record its location and all received signal strengths of surrounding access points on regular time intervals and send this information to the WiFi-A-GPS server which can use this information to update and improve its database. In this way the self-mapping system, will become more accurate and complete during existence. A form of non-intrusive war driving, which for example is used to collect the data in the PlaceLab project[7], can be used to build an initial database.

If there will be no connection between the device and the A-GPS server during operation. It should be possible to preload a partial database of the fingerprint information on the device together with almanac data[2] of

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[2] A set of parameters used by a GPS receiver to calculate the approximate location of a GPS satellite and the expected satellite clock offset.

the satellites. The simple 'arithmetic mean' algorithm can be used by the device to compute its position and use this knowledge to assist the GPS receiver with its first lock. If the device finds any access points which are not in the database on the device or any missing access points, the location can be recorded on the device and with the next connection to the server the data can be synchronised.

If the application only needs an estimated position, or the GPS signals cannot be received, the system can work using only the WiFi positioning. LaMarca, Hightower et al.[8] present a graph-based self-mapping algorithm to update the fingerprinting database with only the use of the WiFi device. With as little of 50% of the access points locations known to the system, self-mapping can produce a radio map that estimates the user's location as well as a war driving database. If a region is well covered by WiFi access points and a WiFi-A-GPS server is available, this system can easily be implemented since it makes use of all existing infrastructure and no extra services have to be implemented by any mobile operators.

5 Conclusions

Since the number of WiFi access points is rising in urban environments, which is exactly the place where GPS alone cannot always fulfil the needs because of RF shadowing, we can use this WiFi coverage to assist the GNSS system and drastically reduce the Time To First Fix. The combination of GPS and WiFi can solve some problems of GPS in a relative easy and economical way. The system should be self-mapping to avoid a big training phase. In cases where an estimate positioning with an accuracy up to 50 meter is sufficient, the use of the outdoor WiFi location system alone can be enough. A WiFi-Assisted-GPS system makes Assisted-GPS possible without the need for changes in existing infrastructure and the need for mobile operators to offer an A-GPS service.

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