An Introduction to Radio Locationing with Signals of Opportunity

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Abstract

In this paper radio positioning techniques using "Signals of Opportunity (SOP)" are discussed. In some applications of navigation and positioning, Global Navigation Satellite Systems (GNSS), in general, and the Global Positioning System (GPS), in particular, do not work well and therefore researchers are interested in using other sources of radio signals (which are intended for other purposes) for the navigation and radio positioning applications. In this contribution first we mention some drawbacks of GPS. Then several types of signals of opportunity for positioning are enlisted and the advantages and disadvantages of these signals as well as methods of measurements are presented. The most crucial challenges of SOP for radio positioning are explained. Finally, a brief conclusion on the usage of signals of opportunity is presented.

1 Introduction

Positioning & navigation is defined as "determining a user's position and orientation with respect to its environment". The Global Positioning System or GPS is known as a good system for positioning and navigation, but it has some challenges and limitations [1]:

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- GPS is highly susceptible to jamming,
- GPS does not work well in indoor environments and urban canyons,
- GPS does not work well under dense foliage,
- GPS is a quite complicated system requiring sophisticated technology specially for phase measurements.

Navigation via Signals of Opportunity is the concept of using signals from an established transmitter infrastructure intended for other purposes, to be used for the localization of a platform [2]. The key idea is that any measurable signature that changes as a function of position has the potential for determining position. The solution characterizes the correlation between signature and navigation state, measures the salient features, and exploits it for the navigational purposes.

Signals of opportunity is a hot and attractive research topic because of following needs:

- Positioning in urban and indoor environments
  - Emergency regulation: telecommunication operators to report subscriber location in emergency
- Accuracy-addictive
  - Desire & expectation of similar accuracies for personal navigation inurban and indoor environments as those in open-sky areas
- Enabler for location-based services
  - Lucrative applications for mass markets concentrated in metropolitan regions and urban canyon
- Law enforcement, fire fighters, first Responders/rescuers

Signals of opportunity have two major specifications: first, they are freely available all the time and second, they have sources (Transmitters) at known locations with recognizable characteristics for identification and timing. In some references the usage of signals of opportunity for positioning is known as "signal hacking" [3].

There are various types of signals that can be used for navigation as alternatives for the GPS:

- Broadcast analog/digital signals
  - Radio station (AM/FM, DAB) transmission towers
  - Analog/digital television (DVB) transmission towers
- Communication network signals
  - WiMax/WiFi base stations (access points)

  - Cellular/mobile phone network base stations
  - Tactical communications (SDR/JTRS, JTIDS)
  - Satellite communication signals
- Other signals (such as Radar sites/RF beacons/transponders/UWB/RFID tags, ...)

Because of space limit, in this paper we limit our study to Broadcast signals and Communication (cellular, Wimax and WiFi) signals.

2 Methods, Measurements and Requirements for Positioning with SOP

Basically, methods for positioning with Signals of Opportunity are divided into 2 categories: The parametric/geometric methods and the non-parametric/non geometric methods. In the following these methods are summarized. Each method has its own measurements and requirements.

- Parametric/geometric methods
  - Measurements: AOA (angle of arrival), TOA (time of arrival), TDOA (time difference of arrival), DF (direction finding) [3] and RSS (Received Signal Strength) DOA (direction of arrival) and Doppler [4]
  - Methods: intersection of Lines of Position (LOP), circular, hyperbolic, multilateration, triangulation
  - Requirements: transmitter location, signal characteristics, terrain model (3D), data link, auxiliary sensors
- Non-parametric/non-geometric methods
  - Measurements: location-dependent signatures (fingerprints)
  - Methods: matching (pattern recognition, classification)
  - Requirements: database of location-dependent signatures, Point signatures, Cell/MAC ID, power spectrum, RSSI, Spatial correlation/decorrelation, temporal variability, Building up & maintaining up-to-date wide coverage database, location-differentiable.

3 Signals of Opportunity: Advantages, Disadvantages and Methods

In the following the advantages and disadvantages of SOP for positioning using various signals are discussed:

3.1 Television Signals

Both analog and digital TV signals can be used in the TV-based positioning since they both include synchronization features such as horizontal and vertical synchronization pulses in the Analog TV and the frame synchronization field in the digital TV. However, analog TV transmitters have been mostly replaced by digital ones, and they might turn off in near future. The advantages of the TV-based navigation approach include low RF frequency, wide bandwidth, high transmission power, low path loss, and broad coverage of TV transmitters. The disadvantages of TV-based navigation approach include the lack of included transmission time information and the instability of clocks in the TV transmitters. Moreover, like satellite geometries that are crucial in the GPS transmitter, geometryis also a significant issue in the TV-based positioning. For a proper positioning by TV signals, at least three spatially separated TV transmitters are required. Utilizing more transmitters should result in a more accurate positioning. Because TV signals are supposed to be used in urban/indoor areas, and they mostly pass through ground obstacles, multipath has a strong effect on the signal. Thus, TV Positioning systems require the capability of multipath mitigation. Since TV signals have synchronization features, utilizing TV signals as a ranging signal using a TDOA approach is often employed [4].

In DVB positioning the OFDM modulation features and high code rate of DVB signals can also help synchronization modules to catch and track signals and extract the transmission delay for positioning purposes. There are various methods of estimating TOA for OFDM DVB signals without employing a reference receiver. One of the major methods uses the pilot carriers in OFDM signals to obtain a channel impulse response by calculating the correlation of the received signal with a pilot symbol-only local replica and to calculate the TOA of a signal [4]. For a mobile TV system based on the DVB-SH standard and using realistic channel sounding measurements a mean positioning error of about 40 m is reported in [5].

3.2 Radio Signals

The benefits of radio signals (AM, FM, DAB, ISDB-T) are both indoor and outdoor reception ability, low-cost low-power measurement hardware, high power, and finally the large number of transmitters that can provide a good geometry for positioning. Specially the AM band is attractive because of the following 3 reasons [1]:

1. In most parts of many countries, signals from many stations are available,
2. The long wavelengths may be more suitable for indoor and underwater navigations,
3. Low frequencies and low bandwidths may simplify receiver design.

DAB signals have some characteristics that facilitate positioning. The most important one is the synchronization channel which can determine the start of a frame. DAB systems also operate in different single frequency networks (SFNs), which consist of a set of synchronized transmitters that work in the same frequency and can be used for positioning. In DAB-based positioning, OFDM modulation helps the receiver to determine the receiver clock offsets by looking at the synchronization part of the signal at the start of each transmission frame. TDOA ranging measurements can be then applied by using the transmitter location information to estimate the position; however, timing delay between different SFNs is an important issue here to be taken into account.

Generally speaking, the most crucial problem of radio signals is that they do not carry any timing information, which is a critical factor in the range calculation. Moreover, radio transmitters are unsynchronized in time, frequency, and phase. Furthermore, navigation using radio signals would be degraded by effects of multipath and non-line-of-sight (NLOS) signals. For the DAB signals there are still some errors which need to be remedied to achieve higher accuracies- such as timing delay between different SFNs, heights of transmitters, their exact locations, and the geometry they provide. Due to the lack of timing information in radio signals, the TOA, TDOA, and AOA techniques for radio-based navigation use an additional reference receiver. In addition, in order to extract timing and direction information, a particular hardware with a multi-directional antenna is required.

Another approach is localization based on RSS, which is an economical method because it does not need any additional hardware or infrastructure. There are two general approaches to wireless localization using the RSS technique: Signal propagation modeling and Signal fingerprinting. RSS positioning technique with signal propagation approach is not suitable for use in multipath fading channels where the variations of signal strength can be up to 30 dB [6]. In signal fingerprinting the signal strength at each location is used as a signature to estimate location. Similarities between the RSS readings are essential criteria for the fingerprint-based WLAN positioning [7]. The fingerprinting approach is less sensitive to propagation errors as the method does not have to go through the process of accurate radio propagation modeling which can be quite challenging in multipath rich indoor environments [8].

3.3 GSM Signals

The GSM technology covers more than 80 percent of the world's population. The number of base stations in the urban and suburban areas is not an issue to be worried about in most countries. Since network providers require the best use of the spectrum, they are supposed to reduce the cell size i.e., increase the number of base stations. A large number of stations helps provide a good geometry and hence a lower Dilution of Precision (DOP) and a higher accuracy. Recently the location estimation of a mobile device in wireless cellular networks has gained considerable attention especially when Federal Communications Commission (FCC) demanded service providers to generate precise location of all Enhanced-911 (E-911) emergency calls. The benefits of GSM signals that make them interesting for positioning are the large number of cellular towers (base stations) across populated areas, no interference from nearby devices due to their licensed band, and making use of mobile devices that people mostly carry with them. A significant challenge in GSM-based positioning is the multipath and NLOS situations especially in the urban/indoor areas. Another issue is that the cellular network stations have a low power and a narrow bandwidth which ultimately degrade the cell identity-based position estimation up to few hundred meters. The cell identity approach is a very simple and low-cost way; however, the positioning accuracy is inversely proportional to the sector size and is not adequate for the most demanding services such as emergency situations. Generally, the positioning-related calculations can be network-based, handset-based, or a combination of both. In other words, the estimation is done at base stations or in handsets (mobile stations). Modifying all base stations in such a way that they can calculate precise location of handsets is costly. Handset-based solutions enable the use of sampled temporal measurements and motion models to enhance estimation accuracy and integrity but mobile stations need to have enough power to carry out the complex positioning algorithms, while there is limited energy of battery packs in them.

TDOA measurements require a synchronous network but GSM base stations are not synchronized. Furthermore, the accuracy of the TDOA estimation highly depends on the relative distances between the base stations and a mobile station, channel conditions, and multipath. On the other hand, due to the complexity of the RF signal propagation, multipath, and NLOS, it is known that the signal strength method and the fingerprinting approach can achieve a better performance than other distance-based techniques. However, the fingerprinting technique needs a large amount of work to construct a database. It also requires continuous updates and recalibrations because the topology of a GSM network can be changed at any time by the network operator. Also, how best to design the grid of reference points and how to reduce the number of them become challenging issues. The AOA technique does not work well for GSM networks due to the harsh multipath near mobile stations in indoor and urban areas.

It has to mentioned that in addition to the methods mentioned above, the Assisted GPS (AGPS) can utilize the GSM network as references for the correlations and pseudo-range estimates. The assistance data transmitted by the network will help positioning and enhance the accuracy. This method, however, is not efficient for indoor positioning, where the GPS signals are not available.

3.4 Wi-Fi Signals

WLAN especially based on the IEEE 802.11x standard (also known as "Wi-Fi") is becoming increasingly popular now a days. Wi-Fi uses radio frequencies in the 2.4 GHz band. Wi-Fi signals provide low-cost best-effort connectivity and are usually deployed as an ad hoc wherever access to a wired backbone infrastructure is available. Wi-Fi networks are increasingly present in everyday life and a variety of mobile devices support them.Position location systems based on WLAN are more accurate within the service area of a network. However, its application is limited by the network coverage. Wi-Fi signals are short-range signals and accordingly they cannot be often utilized for outdoor positioning. They typically have a range of 32 m indoors and 95 m outdoor with a stock antenna.

Furthermore, some signals produce interference to Wi-Fi, such as ZigBee and Bluetooth devices, microwave ovens, 2.4 GHz wireless phones, other wireless LANs, and security cameras. Bluetooth-enabled devices, such as laptops and PDAs, may degrade the positioning performance if they are located closely to Wi-Fi access points. Microwave ovens operating within 3 meters of an access point or radio-equipped user will also decrease the Wi-Fi performance. 2.4 GHz wireless phones and access points in the same room result in disconnections, disruptions in data transmissions. Other wireless LANs can cause interference unless the selection of Wi-Fi channels is coordinated. Moreover, utilizing Wi-Fi for positioning, make battery life in mobile devices a concern[1].

Geographical situations are not significant issues to be considered when using Wi-Fi signals for location estimation. Population, however, is an influential factor because more populated areas tend to have more Wi-Fi access points and thus better Wi-Fi coverage. The geometric distribution of the access points influences the accuracy.

It has to be emphasized at this juncture that Wi-Fi-based indoor and urban canyon geolocation solutions mostly depend on the RSS technique by applying fingerprinting algorithms. Another approach is exploiting TOA for Wi-Fi positioning presented in [10]. Like other signals of opportunity, Wi-Fi was not intended for positioning purposes; therefore, using TOA positioning requires additional hardware and software in order to fulfill the cross-correlation processing, which increases the cost and decreases the generality of the Wi-Fi system. This solution, however, is highly prone to multipath produced by indoor and urban canyon environments. Thus, a TOA Wi-Fi ranging system requires novel techniques for multipath mitigation.

4 Conclusion

In this paper we reviewed signals of opportunity for navigation purposes. The most crucial challenges for all of these signals of opportunity are geometry of transmitters, multipath, and NLOS issues which significantly affect the positioning accuracy. The better geometry they provide, the less value of DOP is obtained. The SOP positioning can address various problems of GPS but not all with one SOP signal. Some signals such as AM radio signals have long wavelengths and are therefore useful for navigation in subsea and indoor applications. On the other hand, some other radio signals such as Wi-Fi signals have short wavelengths and are useful for precise indoor or urban canyon navigation. Selection of the most suitable signal depends on its application. The interaction of various SOP signals with GNSS makes it even more interesting. In general case, either a combination of GNSS (e.g., GPS) with signals of opportunity or an integration of signals of opportunity together is required for a robust and reliable positioning solution. However, how to integrate these signals remains a challenging research issue.

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[1] There are methods to solve this problem, such as Wi-Fi Multimedia (WMM) Power Save technique, in which the same amount of data can be transmitted in a shorter time, while allowing the Wi-Fi device to remain longer in a low-power, "dozing" state [9].

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Biographies

H. Nikookar received his Ph.D. in Electrical Engineering from Delft University of Technology in 1995. In the past he has led the Radio Advanced Technologies and Systems (RATS) program, and supervised a team of researchers carrying out cutting-edge research in the field of advanced radio transmission. He has received several paper awards at international conferences and symposiums. Dr Nikookar has published about 150 papers in the peer reviewed international technical journals and conferences, 12 book chapters and is author of two books: *Introduction to Ultra Wideband for Wireless Communications*, Springer, 2009 and *Wavelet Radio*, Cambridge University Press, 2013.

P. Oonincx obtained his PhD in mathematics (2000) from University of Amsterdam. He published various monographs, papers and research reports on both theory and applications of mathematical signal processing. He is also editor for the European Journal on Advances in Signal Processing and the Cambridge Journal of Navigation. Currently he is full professor in Navigation Technology and vice-dean at the Netherlands Defence Academy.