Indoor GPS Positioning

Challenges and Opportunities

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Abstract— *This paper provides an overview of the challenges encountered in the acquisition and tracking of weak GPS signals present in indoor environments. Successful acquisition and tracking of weak GPS signals requires longer integration times, effective strong/weak signal decoupling, and correct multipath detection and rejection. The weak signal acquisition and tracking can be improved substantially with aiding information provided by cellular networks.*

Keywords- GPS, Weak, Strong, Signals, tracking, coherent, non-coherent, multipath, A-GPS, transition bits, Galileo.

I. INTRODUCTION

In 1996, the Federal Communications Committee (FCC) mandated that wireless carriers provide Public Safety Answering Points (PSAPs) with precise location for all emergency calls from mobile phones. This system is known as Enhanced 911 (E911) system. The agency divided the implementation in two phases and set December 31, 2005 as the deadline to reach this goal.

Phase I requires that with each 911 call the carriers provide PSAPs with the caller's phone number and the location of the cell tower answering the call.

Phase II requires that the carriers provide for each E911 call an Automatic Location Identification (ALI) from a networked based solution that calculates the caller location from the wireless signal reception at several cell towers. The accuracy requirements for the ALI were originally set at the 100-meter level 67 percent of the time, and at 300-meter level 95 percent of the time. In 1999 the FCC modified the Phase II mandate to include handset-based ALI services using Assisted GPS (A-GPS) with a 50-meter accuracy 67 percent of the time, and 150-meter accuracy 95 percent of the time [1].

The number of cell phones sales is expected to reach approximately 800 million units in 2005, and all these units will most likely be GPS enabled. This market opportunity represents one of the primary drivers behind the search for a GPS solution that will meet the new demands for indoor positioning, near-instantaneous time to first fix, and very low power consumption. These demands have challenged the GPS community to rethink the GPS design from the RF front end to the computation of the navigation solutions [2, 3].

According to the latest version of the IS-GPS-200 specification [4], the GPS coarse acquisition code (C/A) code signal at L1 is designed to arrive on the ground at not less than -158.5 dBW (i.e. -128.5dBm) power level. For indoor positioning the GPS signal are further attenuated as they propagate through the buildings.

Conservative models suggest that the attenuation in buildings can reach levels of 2.9 dB per meter of structure [5]. Experiments indicate that attenuation of the GPS signal through the buildings is typically higher than 1 dB per meter of structure [6]. Therefore, to track the GPS signals indoors inside high buildings and elevators the GPS receiver needs to be able to track signals with power levels ranging from approximately -160dBW to -200dBW. This requirement represents a major challenge as the noise floor of a typical receiver at room temperature is at the -131 dBW level [7].

II. WEAK SIGNAL PROCESSING

A. Acquisition

A typical strong-signal GPS receiver will "search" the incoming signal in two dimensions: Doppler frequency, and code delay. The search process involves down-converting by a particular trial value of Doppler, and multiplying by a locally generated version of the satellites CDMA code, with a given trial delay. This latter process is colloquially known as "correlating" because as the delay is varied, the cross-correlation with the incoming signal is formed and the delay is detected which closely matches the autocorrelation of the satellite's code, plus "noise". The search is performed on chunks of the incoming signal known as "integration periods". For strong signals, an integration period of 1ms (i.e. the C/A code repetition time) is sufficient, since the correlation peak values appear above the noise level of the incoming signals. For weak signals, however, the correlation period must be extended to improve the signal-to-noise ratio at the correlator output. Effectively, if the integration is "coherent" (see below), the noise bandwidth (and hence the noise power) is reduced in inverse proportion to this integration time.

Several problems arise when the integration period is extended. The first problem is associated with the acquisition time, which increases with the square of the integration period.

This is because the search for the signal occurs in two "dimensions" – code delay, and Doppler frequency (i.e. a search occurs for each individual code delay/ Doppler frequency pair). If the integration time doubles, then the time to search at a given Doppler frequency also doubles, because the same number of code delays are tried. In addition,, the number of Doppler frequencies also doubles (giving an overall factor of 4 time increase), since the steps between the trial Doppler frequencies is set such that the carrier will drift no more than a quarter period during the integration period. Therefore, doubling the integration period halves the step size, thereby doubling the number of trials required. If the carrier drifts too far, it will eventually become negative, "flipping" the code, causing subtraction where addition (integration) is required.

Sequential acquisition is becoming less of a concern with the advent of hardware search engines and software receivers, which perform much of the acquisition task "in parallel" [9]. However, the use of search engines accelerates weak and strong acquisition equally, so the arguments above regarding the increase in integration time for weak signals still hold. Sometimes Doppler processing is performed non-sequentially using a FFT, which will increase with the characteristic $\sqrt{N}$ rather than N so overall complexity would increase as $N\sqrt{N}$ rather than N^2.

In many applications, such as E911, there is a strict limit to how long it takes to obtain a position (16s for CDMA and 20s for GSM networks [8]). This is one important driver to A-GPS (see next section).

The second problem associated with long integration periods relates to data bit boundaries. There are twenty 1ms code epochs in each GPS BPSK data bit. So if an integration period overlaps one of these boundaries, the integration will be adversely affected (i.e. SNR can be severely diminished). One way of getting around this problem is to "strip" the data (i.e. reverse all the data transitions with only the carrier remaining) using a second receiver which tracks the strong signals and provides the required information to reverse all data transition bits [10]. This is clearly impractical in real situations. However, the GPS signal is very repetitive. Each 30 second period of data re-appears almost identically [11] and hence can be often predicted and thus stripped. Another solution is to use "non-coherent" integration by "squaring" the signal to remove the ±1 BPSK data. With this approach the noise is also squared, resulting in what is known as "squaring loss". Due to squaring loss, the integration period grows rapidly as the received power drops away (Fig. 1).

Acquisition down to -183.5 dBW has been achieved using an external receiver with integration times of 256ms [10]. Signav has achieved unassisted acquisition down to -183dBW and tracking down to -185dBW using 256ms integration periods and a patented data removal method [12].

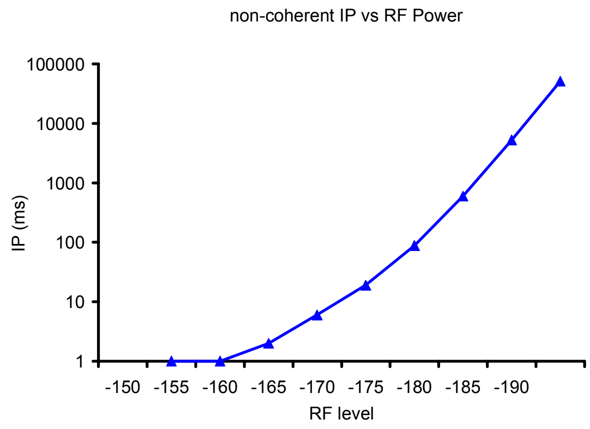

Figure 1. Non-coherent integration period for strong (-150dBW) to very weak (-190dBW) GPS signals

B. *Multipath*

Outdoor GPS applications tend to experience multipath in only its most benign form, i.e. a reflection that is weaker than the direct line-of-sight signal (Fig. 2-Top). Indoors, the situation is worse. The reflection can readily exceed the direct signal (Fig. 2-Middle), or the direct signal can disappear altogether (Fig. 2-Bottom).

The dominant direct path case (Fig. 2-Top) does not move the correlation peak from its non-multipath position. Almost all multipath mitigation schemes operate on this assumption. In indoor applications, however, the direct signal can disappear, and therefore new algorithms need to be employed for the indoor GPS acquisition and tracking in the presence of only multipath signals.

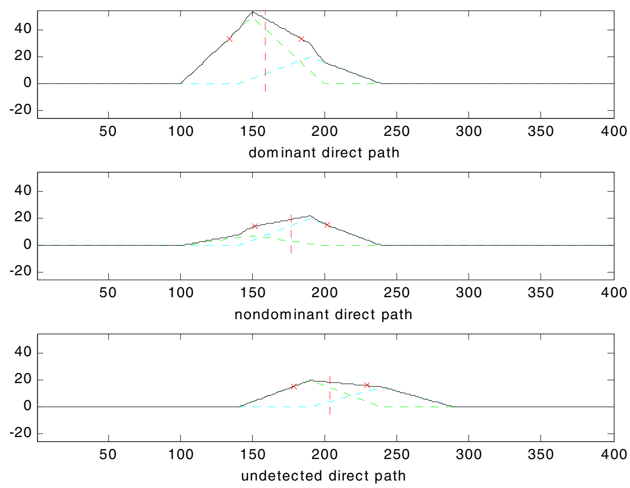

Figure 2. Multipath scenarios and their effects on the autocorrelation function: dominant direct path, non-dominant direct path, and undetected direct path. The component contributions to the overall shape are shown, as is the positions of a classic early-late correlator (x) and the peaks that it picks (vertical line) – the peak should appear at ordinate 150.

C. *Strong/Weak Signal Interaction*

The cross-correlation of the C/A codes transmitted by different satellites has peaks 24dB down from the main auto-correlation peak (Fig. 3). This means that if signal A is 24dB stronger than signal B, and the receiver is seeking signal B, the receiver may lock into the cross-correlation peak of signal A and B instead of the auto-correlation peak of the signal B. To avoid this situation, the strong signals must be acquired first and "removed" before attempting to acquire the weak signals [12]. Methods for acquiring and removing the strong signals include successive interference cancellation, parallel interference cancellation, subspace projection methods and subtractive projection [13].

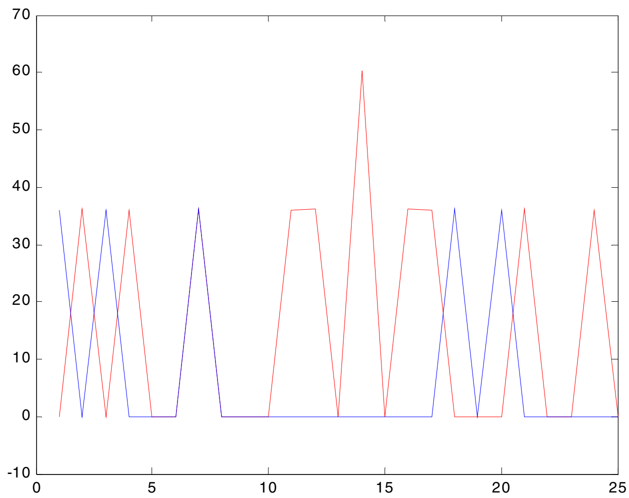

Figure 3. Autocorrelation of satellite 1 (red) and cross-correlation of satellites 1 and 19 (blue). It can be seen that the peaks in the cross-correlation are 24dB down on the autocorrelation peak.

III. ASSISTED GPS

Given the E911 requirements, and the growing demand for Location Based Services (LBS), there is significant pressure to get GPS into cellular handsets. Although this situation brings along the acknowledged difficulties of indoor GPS operation, it also means that the GPS receiver communicates with a network which can provide aiding information for acquisition and tracking. This is very beneficial, because the GPS receiver needs as much help as possible in weak-signal environments. For instance, poor SNR prevents decoding of the satellite data, which are fundamental to the calculation of a position and can be supplied by the network [14].

The satellite data that the network can provide are as follows:

- Satellite orbit parameters (ephemeris)
- Satellite clock corrections
- Other corrections (e.g. ionosphere)
- Accurate estimate of local time (CDMA networks provide a better estimate than GSM networks)

Additional network provided information that can be useful for signal acquisition and tracking is as follows:

- Initial position estimate (e.g. cell base station location – the location provided by "cell ID")
- Visible satellites
- Relative code delay offsets
- Doppler frequencies

The availability of the Doppler frequencies and the relative code delay offsets allow the receiver to acquire only one signal with the specified Doppler for each satellite, and only search in the neighborhood of the supplied code delay offsets, assuming the rover is located close to the base receiver (i.e. within 150km). This process reduces substantially the search space and consequently the acquisition time.

The actual information fields provided by the networks are defined in several standards (TIA/EIA/IS-801-1, 3GPP2 C.S0022-0-1, 3GPP TS 25.331). Minimum operational performance of A-GPS handsets are also defined (TIA 916, 3GPP2 C.P9004-0, 3GPP TS 25.171 V6.0.0). The standards cover both Mobile Station (MS) – based A-GPS (i.e. the MS performs positioning) and MS-assisted A-GPS (i.e. the MS is assisted to acquire satellites and reports information so position is calculated at the base).

In indoor environments special problems arise from not being able to decode the satellite data. Since there is no accurate measure of local time, there is an ambiguity in the code phase with period of 1ms that must be resolved. Not knowing exactly where the bit boundaries in the received signal are, there is lack of knowledge of the satellite transmission time resulting in significant pseudorange (distance to the satellite affected by clock errors) measurement errors.

Experiments conducted at the University of New South Wales using Nortel Networks servers and Signav receivers have shown that the acquisition of the satellite signals could be accelerated by 200 times within a 100km radius [15].

Regardless of the weak signal advantages, A-GPS provides useful assistance even to receivers with strong signals available. An outdoor receiver took less than 30 seconds (from turn-on to position, without ephemeris) for 65% of fixes using A-GPS whereas 92% took longer than 30 seconds without aiding [14]. This is because the receiver does not need to wait for the 50bps data from the satellite.

IV. SYSTEM IMPROVEMENTS

For 30 years, GPS has had a single signal available to civilians, on the L1 (1.57542 GHz) frequency. In the next two years there will be two new signals available, L2C (1.2276 GHz) and L5 (1.17645 GHz). Also, in similar frequency bands, the European Galileo system will commence broadcasts. These new signals will assist weak-signal operation in several ways:

- Signal levels. Although the L2C signal will be the same level as L1 [11], L5 will be 6dB stronger [16]. The Galileo signals are also stronger: L1 (+5dB), E5 (+8dB) and E6 (+5dB) [17].
- "Dataless" channels. For L5 and Galileo, there will be channels with no data bits (i.e. just a carrier) which will mean the data transition problems will be avoided [16, 17].
- Longer codes. Because all of the new signals will use longer codes, the cross-correlation problem will be significantly reduced. [11, 16, 17].
- Non-BPSK signals. Because Galileo will use binary-offset carrier signals, it will have a stronger resilience in the presence of multipath, and easier separation of the multipath components[17].

In other words, when the new systems become available, indoor and weak signal operation will be much easier. Either that, or current methods will simply be used to drive operation into ever more attenuated environments.

V. COLCLUSIONS

Effective indoor GPS positioning requires signal acquisition and tracking at power levels in the range of -180dBW to -200 dBW. Successful acquisition and signal tracking techniques for indoor GPS positioning rely on long "Integration Periods", decoupling of the weak/strong signal interaction, proper identification, tracking and/or rejection of multipath only signals.

Signal acquisition at these low levels requires integration periods longer than 20 ms with proper reversing of the data transition bits. Furthermore, the acquisition time increases by the square of the integration period which poses significant processing requirements for successful signal acquisition and tracking. This problem is alleviated with the use of an external receiver which tracks the satellites in an open environment and sends to the Mobile Station (i.e. rover receiver) the Doppler frequencies and the relative code delay offsets of the tracked satellites (i.e. A-GPS). With this information available only a small search space around the transmitted relative delay offsets is required for successful signal acquisition and tracking, which in turn makes it possible to track GPS signals indoors with the processing power available in cellular handsets.

Decoupling of the weak/strong signal interaction is achieved by acquiring and removing the strong signals using such methods as successive interference cancellation, parallel interference cancellation, subspace projections, and subtractive projections [13].

The availability of the stronger (+ 6dB) new GPS L5 "dataless" signal, and the stronger Galileo signals at the "dataless" channels will alleviate all the problems related to the data transition bits for long integration periods. Furthermore, the Non-BPSK Galileo signals will provide stronger resilience in the presence of multipath, and easier separation of the multipath components.

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