gps*One*™: A hybrid position location system

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Abstract

The cellular geo-location problem can be solved using either network-based methods or handset-based methods. gps*One*™ is a hybrid position location technology that combines measurements from GPS and forward and reverse links of a CDMA system to improve position service availability. The CDMA wireless device's knowledge of time is used to enhance the sensitivity and time to fix of the location system. Tight integration between the CDMA and GPS parts of the wireless device result in a low-cost implementation. This paper describes the principles and benefits of integrating GPS in a CDMA system using the gps*One*™ approach. Field test results are presented to demonstrate the high availability and accuracy of the positioning service.

1 Introduction

Wireless carriers have become increasingly interested in location services. One driving force is a regulation promulgated by the Federal Communications Commission (FCC) [1], which requires wireless carriers to be able to determine the position of a wireless device (WD) making an emergency call. Other applications include value-added features such as navigation, fleet management, real-time traffic updates, location sensitive billing etc. Different approaches to providing position location include terrestrial (network) based methods and Global Positioning System (GPS) [2] methods. The coverage areas of the network solution and the GPS solution complement each other. For example, in rural and suburban areas not too many base stations can hear the WD, but a GPS receiver can see four or more satellites because of unobstructed view of the sky. Conversely, in dense urban areas and inside buildings, GPS receivers do not detect enough number of satellites, but the WD can see two or more base stations. QUALCOMM has developed a hybrid position location solution called gps*One*™ that combines measurements from the terrestrial and GPS systems to take advantage of the complimentary coverage areas of the two solutions. gps*One*™ technology provides benefits such as improved sensitivity, high availability, high accuracy, and low cost. Section 2 describes how the gps*One*™ technology works. Section 3 provides results from field trials of gps*One*™ technology. Section 4 presents the conclusions.

2 gpsOne™ principle of operation

The cellular geo-location problem can be solved using either terrestrial location methods or using GPS-based methods. Terrestrial position location methods include techniques that utilize measurements made by the WD on the forward link, or measurements made by the base stations on the reverse link, or both. Two general methods for terrestrial position location are Angle of Arrival (AOA) and Time of Arrival (TOA) or Time Difference of Arrival (TDOA). Locating a WD using network measurements requires:

1. Measuring TOA.
2. Triangulating the TOA from a minimum of three sources.
3. Strong signals and clear line of sight.

Recent developments in GPS and terrestrial mobile communications make it possible to integrate GPS functionality into WDs to solve the mobile location problem. The space segment of GPS [2] consists of a constellation of 24 satellites (plus one or more in-orbit spares) circling the earth every 12 hours. The satellites are at an altitude of about 26,000 km. Each satellite transmits two signals: L1 (1575.42 MHz) and L2 (1227.60 MHz). The L1 signal is modulated with two pseudo-noise (PN) codes–the protected (P) code and the coarse/acquisition

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(C/A) code. The L2 signal carries only the P code. Each satellite transmits a unique code, allowing the GPS receiver to identify the signals. Civilian navigation receivers use only the C/A code on the L1 frequency. A conventional GPS receiver requires pseudo-range measurements from at least four satellites to compute a 3-dimensional (3-D) position because it has to solve for four unknowns: x, y, z in position, and the time bias of the receiver.

gps*One*™ is a hybrid solution that takes advantage of terrestrial measurements that is already available to both the WD and the network along with GPS measurements to improve the accuracy, availability, and the speed of the positioning service. Among the terrestrial measurements that the gps*One*™ solution uses are:

1. Round Trip Delay (RTD) measurements made by the base station, and
2. Pilot phase measurements made by the WD.

2.1 Round Trip Delay (RTD)

In a Code Division Multiple Access (CDMA) system, the timing of the pilot signal on the forward link of each sector in the base station is synchronized with GPS system time. The WD time reference is the time of occurrence, as measured at the WD antenna connector; of the earliest arriving usable multipath component being used for demodulation. The WD time reference is used as the transmit time of the reverse link channels. As shown in Figure 1, the WD uses the received time reference from the serving base station as its own time reference. Accounting for its own hardware and software delays, the WD transmits its signal such that it is received back at the serving base station delayed by a total of 2τ , assuming reciprocity of forward and reverse links. The Measured at the base station, the RTD corresponds to twice the geometric distance between the WD and base station. RTDs to other base stations can be measured too, but they do not correspond to twice the distance between the WD and other base stations as shown in Figure 2.

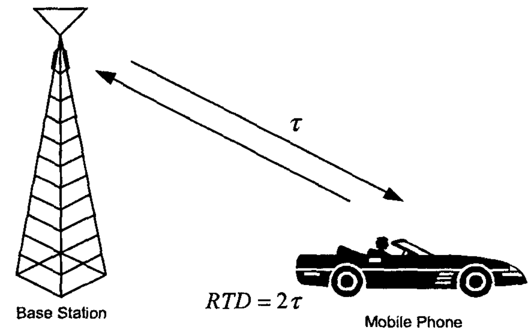

Figure 1: RTD measurements at serving base station

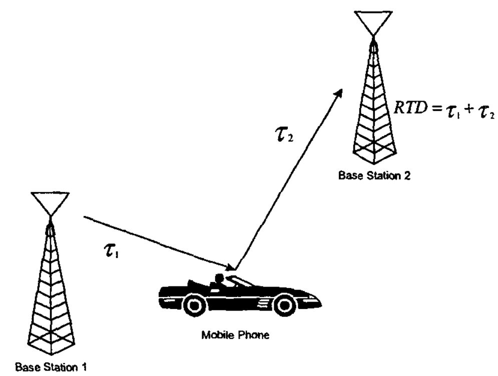

Figure 2: RTD to other base stations

2.2 Pilot phase offsets

In a CDMA system, the WD is continuously searching active and neighboring pilots to find candidates for handoff. In the process it measures the pilot phase difference (delay) between each pilot and the reference (earliest arrival) pilot. The pilot PN phase difference is the same as TDOA of the two pilots from the two base stations as shown in Figure 3.

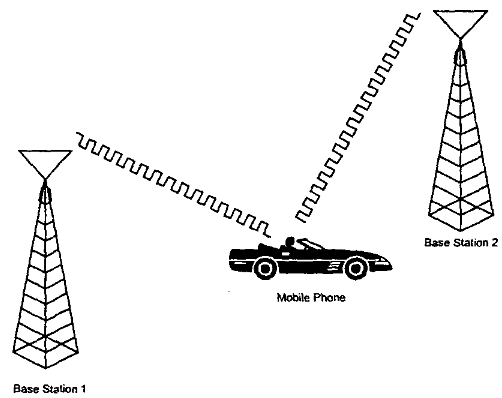

Figure 3: Pilot phase difference

2.3 Hybrid approach

The gps*One*™ hybrid approach merges GPS and network solutions. In one mode of operation, the WD collects measurements from the GPS constellation and the terrestrial network and sends the information back to a location server in the network. The server also receives RTD measurements made by the base stations. The location server fuses the measurements together to produce an accurate position. Alternatively, the WD may compute the location itself instead of sending the measurements to a location server. The WD may perform multiple GPS measurements (typically 5) per satellite to generate each position fix.

2.3.1 3-D positioning with three satellites

As shown in Figure 4, since the WD is receiving CDMA signals from at least one base station, it will acquire system time. The WD time reference is delayed with respect to true system time at the serving base station by the propagation delay τ between the WD and base station. Once the WD tries to access the system, or is on the traffic channel, the propagation delay τ is estimated as $\frac{RTD}{2}$. This estimate can be used to adjust the WD time reference to correspond to "true" GPS time. Now the WD clock is synchronized with GPS time. If this clock is used as a reference to measure the GPS pseudo-ranges, only three measurements from three satellites are needed. Thus, using the WD's time reference as a reference to measure the GPS pseudo-ranges reduces the number of satellites required to compute a 3-D location fix. Note that multipath on the link between the base station and the WD does not impact the performance of the system given reciprocity of propagation times on the forward and reverse links. This is because the WD time reference is shifted from GPS time by τ regardless of whether the signal took a direct path or a reflected path.

If RTD measurements are not available, the time of occurrence of the reference PN can be used instead to compute a 3D location with only 3 satellites in view. This method will be however, be affected by multipath on the link between the base station and the WD. This technique requires that the GPS measurements and the pilot phase measurement be made with respect to a common time reference. This technique allows the use of the base station as a pseudolite.

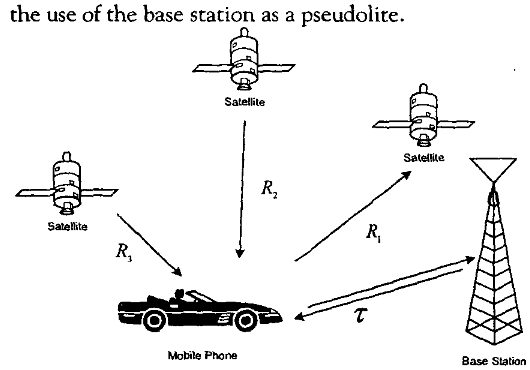

Figure 4: 3-D positioning with three satellites

2.3.2 3-D positioning with two satellites

In addition to using the RTD to the serving base station for timing, it can also be used for ranging as shown in Figure 5. The distance to the serving base station is given by $R_3 = c\tau$ where c is the speed of light. Multipath here will impact positioning accuracy. Note that under certain geometry scenarios, we may get two ambiguous solutions. The ambiguity can be resolved by using either sectorization or forward link information. For example, pilot PN phase difference of a neighboring pilot can be used to resolve the resulting ambiguity.

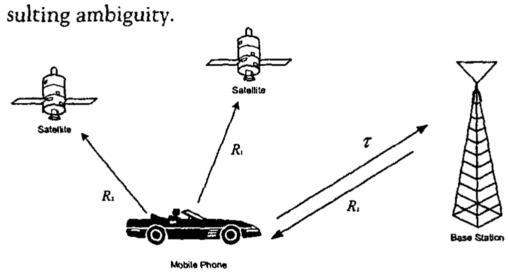

Figure 5: 3-D positioning with two satellites

2.3.3 3-D positioning with one satellite

In this scenario, the proposed approach requires one additional measurement from the cellular/PCS network. This additional measurement could be either a second RTD measurement, or a pilot phase offset on the forward link as shown in Figure 6. To reduce the impact of multipath on the calculated position, the WD is asked to report the pilot phase of the earliest arriving path.

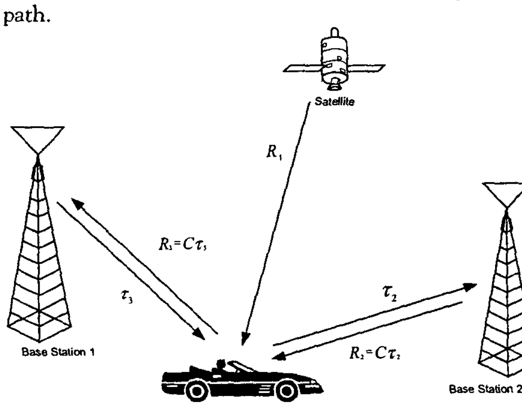

Figure 6: 3-D positioning with one satellite

2.4 Position update using only infrastructure information

Infrastructure information alone can be used to update the location of the WD. This "free wheeling" concept is useful in tracking modes because it reduces the amount of time the WD is away from the cellular/PCS channel while measuring the signal from the GPS channel. This way, there is no degradation to call delivery rate or voice quality. An initial and accurate position is determined using information from both the GPS constellation and the terrestrial network as discussed earlier. Afterwards, and until it is decided that the "free wheeling" solution is no longer reliable, the WD uses only terrestrial measurements to update its position. It can be shown that forward or reverse link information from two base stations is enough to update the 2-D position of the WD. Because of the inherent channel impairments, the update will degrade with time and eventually a fresh GPS-based solution will be needed.

2.5 GPS receiver sensitivity enhancement

The specification for the GPS signal level under clear view of the sky is –130 dBm. Building penetration, shadowing, and foliage could degrade the signal by more than 20 dB. Conventional GPS receivers typically integrate the received GPS signal coherently over one millisecond (one GPS C/A code period) and non-coherently for six milliseconds. A conventional GPS receiver can only acquire signals above –136 dBm (C/No = 34 dB-Hz assuming a receiver noise figure of 4 dB). Weaker signals require more processing gain (longer integration) for successful acquisition. Knowing "true" GPS time at the WD and the approximate range to the satellite will enable the WD to integrate the GPS signal coherently over 20 milliseconds (one GPS navigation bit period). Furthermore, if the base station can predict the bit sequence for some parts of the navigation message, the bit polarity can be sent to the WD to help with integrating coherently over multiple bits. Alternately, the bit prediction can also be performed at the WD. The bit prediction algorithm developed at QUALCOMM achieves an accuracy of about 99.5%.

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2.6 GPS signal acquisition time reduction

In addition to the sensitivity enhancement, knowing true GPS time at the WD reduces the time required to acquire the GPS signal for a given satellite. The base station can predict with some uncertainty the GPS signal C/A code phase that will be received at the WD at some time in the future. The base station sends this information in the form of search window center and the search window size to the WD. Therefore, the WD needs only to search a small window in the time domain rather than the whole code space. For a WD at four miles distance from the base station, the search window size for a satellite with a 60° elevation angle is only 20 GPS chips. This would reduce search time per satellite by a factor of 50. Similarly, the base station can also predict the Doppler frequency offset and send this information to the WD to speed up search in the frequency domain. Besides speeding up the acquisition time, reduction in the search space also allows reduction in WD complexity.

3 Compexity and overhead

When developing a position location solution, one of the most important aspects to consider, besides accuracy, availability and time to first fix, is the additional complexity and messaging overhead associated with the system. A network based solution represents no additional complexity in the WD but it requires additional functionality at the base station (BS) side. A GPS based solution or a hybrid solution requires comparable additional complexity in the BS and it also adds some complexity to the WD. The additional hardware complexity in the WD will not be significant because much of CDMA and GPS hardware can be shared. The additional software complexity greatly depends on the selected operating mode, i.e. whether the mobile does standalone position location calculation or it merely acts as a GPS sensor and sends the obtained pseudorange measurements back to the BS for further processing.

The position location related messaging and data traffic over the air interface between the BS and the WD will introduce an overhead. In an emergency situation (911 call), when the time to first fix is critical, most traffic associated with the position location function will be point to point and will cause a significant overhead. However, when the time to first fix is not critical, which is expected in most of the cases, the traffic can be directed through broadcast or other non-dedicated channels, which represents little cost in overhead.

4 Field Trial Results

This section presents results from a gps*One*™ technology field trial. Performance of the gps*One*™ position determination technology was tested with different number of satellites in view. For each scenario, the location reported by the gps*One*™ system was compared to the surveyed reference location of the GPS antenna. The WD performed five GPS measurements per visible satellite (Note that the WD did not track the GPS signal). The GPS measurements were combined with forward link measurements from two base stations in situations where the number of satellites visible was not enough to compute a location based on GPS measurements. Forward link measurements were also used in cases where the inclusion of forward link measurements reduced the Horizontal Dilution of Precision (HDOP) significantly. Coherent integration over multiple GPS bits was performed to enhance the sensitivity of the GPS receiver. The WD time reference was transferred to the GPS sensor to allow the use of small search windows. The following sections present results from each scenario. The 67 % and 95 % points on the cumulative distribution function of the horizontal error are presented along with the yield. The yield is defined as the ratio of the number of successful location fixes to the number of location fix attempts.

4.1 All satellites in view

Scenario	All satellites in view
Yield	100%
Horizontal error	67% = 11 meter
	95% = 18 meter

4.2 Three satellites in view

Scenario	All satellites in view
Yield	99.3 %
Horizontal error	67% = 19 meter
	95% = 35 meter

4.3 Two satellites in view

Scenario	All satellites in view
Yield	100 %
Horizontal error	67% = 88 meter
	95% = 253 meter

4.4 One satellite in view

Scenario	All satellites in view
Yield	95.5 %
Horizontal error	67% = 139 meter
	95% = 345 meter

5 Conclusion

gps*One*™ location determination technology uses measurements from the terrestrial network and the GPS constellation. gps*One*™ position determination technology provides the following advantages:

- Provides better location service availability, since it merges the coverage areas of network-based and GPS-based approaches. This allows computation of WD position when fewer than four satellites are visible, thus enhancing the availability of the location service to areas where less than four GPS satellites may be visible (such as urban canyons and indoors).
- Enhances the sensitivity of the GPS receiver by enabling long coherent integration times. This permits operation in urban canyons and inside buildings. In addition, it may result in lower antenna sub-system cost.
- Enables the use of search windows to reduce the time to acquire the GPS signal by reducing the search space in the code phase domain. (The GPS receiver has to search less number of hypotheses). This leads to fast time to fix.
- Reduces the cost and complexity of implementing a GPS receiver in the WD by reducing the number of GPS correlators that must be implemented in the WD, and by reducing antenna sub-system cost.
- Allows the use existing hardware correlators and software searchers already implemented in a CDMA WD.
- Reduces the impact on battery drain because the GPS signal can be acquired very quickly (because of small search space).
- Reduces the interruption to the CDMA channel, thus minimizing the impact on voice quality, call drop rate and call delivery rate.
- Narrows the search window in the frequency domain since the CDMA WD is continuously tracking the base station frequency.
- Allows continuous tracking after initial position is obtained using a hybrid technique. During tracking only a few and infrequent GPS measurements are needed.

References

[1] FCC Report and Order, Docket No. 94-102, adopted June 12, 1996.
[2] Global Positioning System: Theory and Applications, Edited by B.W. Parkinson and J.J. Spilker, Jr., American Institute of Aeronautics and Astronautics