White Paper

ANDREW
A CommScope Company

MREL

(Multiple Range Estimation Location)

Andrew Solutions
Mobile Device Location Technology

Abstract

Andrew LLC has developed a novel technique for locating mobile devices using signals transmitted from a mobile device and wireless network measurements. This technique has inherent advantages that make it more effective in locating mobile devices in low site count as well as noisy environments. The technique was rigorously laboratory tested with archived field data collected from several wireless networks. The test results, compared to conventional network-centric location techniques, show that this technique provides location solutions where established techniques fail, improved accuracy for sparse sensor cases, and good overall accuracy for higher site count cases.

Introduction

Location of mobile devices for E911 and Location-Based Services (LBS) is an essential component of services provided by mobile network operators. Location of mobile devices during an emergency call is a requirement that has been imposed on network providers by the FCC mandate. Demand for LBS is increasing due to the proliferation of PDAs and smart mobile phone devices. To meet these location requirements, various techniques have been developed and deployed by network providers.

Beginning in the early 1990's military applications for locating transmitters were utilized by location providers for developing location systems for mobile telephones. At the time, AMPS was the predominant wireless interface protocol used in the United States. In AMPS, the mobile phone transmissions are random in time, and thus the time of transmission of the mobile phone is not known. This feature of AMPS eliminates the practical use of any range estimation based location systems. However, two popular military system techniques were used for locating AMPS mobile phones. The techniques used were time difference of arrival (TDOA) and angle of arrival (AOA). Both techniques can be used without any knowledge of when the mobile signal is transmitted. The TDOA method is a location technique in which a signal transmitted by the mobile is received at two sensors and the difference in the time of arrival between the two sensors is calculated. The TDOA calculation provides a hyperbola curve along which the mobile is located. TDOA information from 3 or more sensors can provide an intersection of two TDOA hyperbolas which provides an estimate for the location of the mobile. AOA systems use a phase calibrated antenna array to determine the angle from which a mobile signal is received. A line of bearing is calculated from that angle, and its intersection with a line of bearing from another sensor or with a TDOA hyperbola can be used to estimate the mobile location.

TDOA hyperbolic-based location systems are among the most commonly used techniques for today's network-centric location methods. These are techniques that use a network of sensors to detect signals transmitted by the mobile to be located. However, as wireless network operators continue to expand their coverage area, deploying sensors at every site becomes more challenging and costly. Thus, wireless operators' need for location with emphasis on sparse and poorly configured sensor geometry is increasing. At the same time, location services are expected to deliver higher yield and accuracy. Therefore, to address these needs, Andrew LLC developed Multiple Range Estimation Location (MREL), a novel technique for locating mobile devices.

Currently, most of the mobile air interface protocols in the United States require that the mobile be synchronized to the base station. MREL exploits the synchronized relationship between the mobile and the base station in order to derive the time of transmission of the signal from the mobile. Knowing the time of transmission of a signal from a mobile, MREL can determine a circular range estimate from each sensor, based on the time of arrival (TOA) of the signal at the sensor. Deriving the time of transmission of a signal from a mobile obviates the need to calculate TDOA hyperbolas. Thus, this technique, relies on TOA circular range rings rather than TDOA hyperbolas as the basic measurement to provide better accuracy and yield performance in low site count cases as well as cases where the measurements are noisy.

Range Computation in MREL

The MREL technique estimates range from the mobile to the serving and neighboring sites by first estimating the time of transmission of a known marker at the mobile device. A measurement of TOA of the uplink marker signal at the serving site can be made by a receiver placed at or near the serving site. A TOA range ring centered on the receiver can be determined from the estimated time of transmission of the signal from the mobile and the TOA of the signal at the receiver. The TOA range ring is computed by exploiting several aspects of the synchronization of a mobile to the downlink transmission of a base station in a digital wireless network. Specifically, in a TDMA network, such as GSM or LTE, the mobile's uplink timing advance (TA) is adjusted through a feedback loop between a base station and the mobile as a function of the distance between the mobile and the serving site. TA represents multiples of symbol times by which the mobile is advancing its uplink transmission relative to what it measures as the downlink time. While the TA alone provides a coarse approximation of propagation delay time from the mobile to the serving site, range rings based on TA alone do not provide sufficient accuracy for FCC E911 requirements. However, if the serving site's downlink marker time of transmission is detected by a receiver placed at, or near, the serving site, a refinement of the coarse propagation delay can be achieved. This refinement in propagation delay would be a perfect measurement in the absence of noise and multipath on the signals in contrast to the coarse measurement obtained using only the TA and serves as the fundamental building block of the novel MREL technique; it permits the computation of the mobile transmit time even when only a single sensor (site) is available.

Now having established the exact propagation delay from the mobile to the serving site, an estimate can be made of the time of transmission of a signal from the mobile, and the exact range rings from the mobile to all of the available sites can be computed by measuring the TOA of the signal at each of the sites.

Location Determination Using Range Rings

The intersection of TOA range rings described above provides an approximate location of the mobile. An understanding of the process applied here can be obtained by considering some fundamental issues associated with Line of Sight (LOS) propagation and TOA range ring accuracy. First, it is important to note that the TOA range rings obtained as described in the previous section could have some uncertainty associated with them due to even a small error in estimating the transmission time at the mobile. The MREL technology incorporates a novel method of error correction in order to increase the accuracy of the location estimation. The parameter α is used to permit correction of timing errors, to possibly correct any error in the mobile's implementation of the TA, and also to compensate for multipath in the serving base station to mobile path. Second, once these measurement inaccuracies have been addressed, the remaining error on the range rings is assumed to be Gaussian noise as in the ideal case of LOS signals. This noise is statistically limited by other quantities such as the power level of the signal, and is generally small. For example in the GSM protocol the associated error is of the order of a few tens of meters.

In addition, the TOA range rings may be weighted to increase the accuracy of the location estimation. An example of such a weight is the inverse of the variance of the TOA range ring measurements that were used to generate that particular range ring. Another example may be a measure of the overall quality of the measurements that generated this range ring. For example in GSM, these weights are the inverse variances of a set of range rings measurements, with one such set of measurements for each mobile-site pair.

MREL Performance

Andrew has completed preliminary performance testing of the MREL technology in the laboratory setting. The test results showed that MREL's accuracy and yield was as good as or better than UTDOA. While the MREL performance could have been compared with any other available location techniques, Andrew has compared the MREL results with results from using UTDOA technology, due to Andrew's extensive experience with UTDOA technology, and the availability of archived field test data.

Advantages of the MREL Technique

In order to understand the advantages of MREL, it is useful to compare it with existing hyperbolic location schemes like UTDOA. There are several major differences that may be noted:

- In UTDOA location, there is no attempt made to determine the time of transmission from the mobile. MREL on the other hand requires a determination of the mobile transmit time so that it can function appropriately. This knowledge of a 'feedback' loop as explained in earlier sections is a clear differentiator from the UTDOA scheme.

- In UTDOA location, since the mobile transmit time is unknown, there is no option but to subtract individual arrival times at sensors to produce a single hyperbola for a pair of sites. In contrast, in MREL, the propagation time of the signal from the mobile to the sensor is known, and allows the calculation of two range rings for a pair of sites.

- If the location problem involves *n* sensors, the MREL technique generates *n* surfaces. Each of these surfaces is a circle. UTDOA location, on the other hand, generates $n - 1$ surfaces, each of which defines a hyperbola.

- One of the main advantages of using TOA ranging-based location systems is that such methods confine the mobile to a finite set of points that form a circle. In contrast, hyperbolic-based location systems confine the mobile to an infinite set of points that form a hyperbola. As show in figure **1** below, the MREL surfaces, being one more in number than the UTDOA surfaces have reduced ambiguity. This can clearly be seen in Figure **1** which is derived from archived field data. Here we have a case where there are three sensors, denoted 420, 422 and 431. In this case, the three circles constituting MREL surfaces intersect in a single point A which is the correct location, whereas the hyperbolae generated as UTDOA surfaces have two points of intersection indicated as A and B. Note that with three sensors there are only two independent hyperbolic surfaces, whereas we have plotted all three hyperbolic surfaces to show that the intersections common to the first two independent hyperbolae are unaltered when the third dependent hyperbola is introduced. The main observation is that there is no ambiguity when MREL surfaces are used, whereas there is ambiguity (*i.e.*, is the solution A or B?) when UTDOA location is applied.

- The MREL surfaces (circles) are much better constrained geometrically than UTDOA surfaces (hyperbolae which extend to infinity at their tails). This can also be proven with a consideration of the Geometric Dilution of Precision (GDOP).

- The UTDOA location scheme offers no equivalent to the error correction parameter α that is used with MREL. The limitation on the range of α constrains the solution further. In a UTDOA implementation, such error correction would be masked by the fact that time differences of arrival times are obtained, and where such differencing effectively negates the possibility of excluding certain arrival time measurements.

- Since the MREL technique operates with individual TOA range rings as the building blocks, it is better suited for filtering out those range rings which may have large multipath associated with them. In a UTDOA implementation, one cannot isolate multipath to a particular mobile-site pair since all available measurements deal with two sites at a time. This fact is exploited in the MREL technique by weighting the individual TOA range rings and deleting those mobile-site range rings with large multipath. Thus in environments with large multipath, MREL performs better than traditional UTDOA.

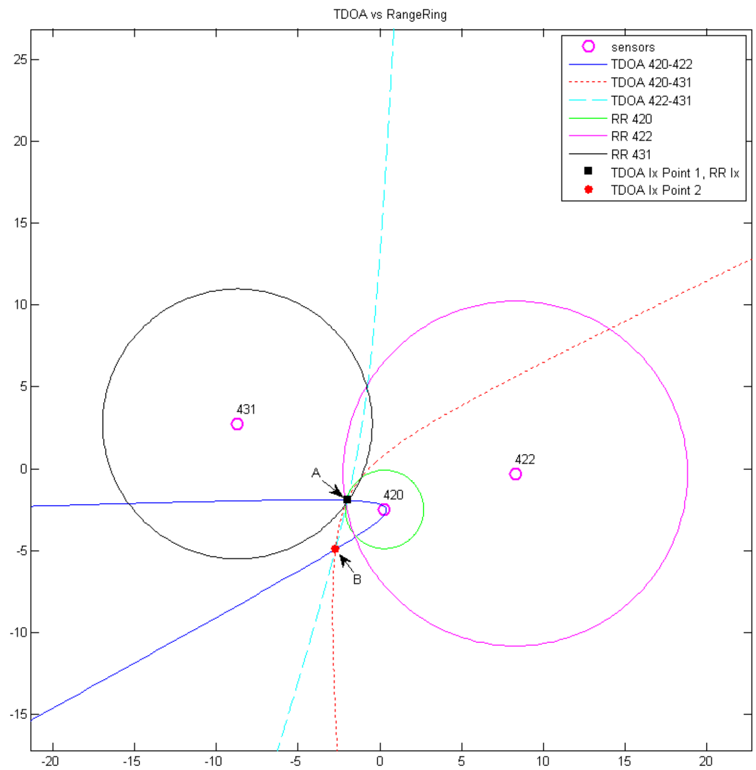

Figure 1

Conclusion

The MREL technology presents a novel method for locating wireless devices. This method has some inherent advantages that allow it to better cope with lower site count cases. Addressing such cases is becoming increasingly important as network providers continue to expand their networks, thus increasing the pressure for network-centric solution providers to sparse the deployment of location sensors. Other inherent advantages of this technique are better GDOP, multipath mitigation, and accuracy quality metrics.

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