Prima Research LLC

Mobile Wireless Terminal Location in a Defined Local Space

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INTRODUCTION

The mobile location services market is growing rapidly. Current estimates for the value and scale of the Indoor Location Services market alone range in the tens of billions of dollars. There remains significant challenges and opportunities for accurately and precisely locating mobile wireless devices, both in three dimensions and in real-time. Current approaches do not offer adequate precision (e.g., less than one foot) and most involve gathering data via a hybrid of multiple systems, from multiple signals and data gleaned separately from multiple technologies including GPS, WiFi, Bluetooth, RFID, sound, light, magnetic force, time, cameras, compass, accelerometers and gyroscopes.

Prima Research LLC has developed new, patented technology that can locate in real time, with accuracy and very high precision, any digitally modulated radio-frequency-emitting device within a defined local space (DLS). A DLS can be an indoor or outdoor space, or even a hybrid of the two. Shopping Malls, large retail stores, airports, sports arenas, train and bus stations, college and corporate campuses, commercial and industrial buildings, and virtually any space designed specifically for gathering, are examples of a DLS.

THE CHALLENGE

There are significant challenges associated with various methods of locating mobile wireless terminal (WT) devices in three-dimensional (3D) space using known two-dimensional (2D) radiolocation methods. There are significant benefits of employing an alternative 3D method that greatly improves both accuracy and precision in both two and three dimensions, with the added benefit of providing a deterministic, mathematically defined set of absolute boundaries. The three-dimensional Defined Local Space (DLS) method was developed and patented by Prima Research LLC. Technical implementation requirements and typical deployment architectures of the proposed 3D method proposed herein are also briefly discussed.

Significant accuracy and precision errors and uncertainties in locating and reporting the position of WTs in 3D space can result when employing only traditional 2D radiolocation methods. Such 2D methods typically employ one or more of traditional RF signal strength, carrier phase and time-of-arrival radiolocation techniques, when synchronized radiolocation receivers are arranged only in a 2D planar array. Physical arrangements of only three non-collocated RF receivers absolutely define only a two-dimensional plane. Any number of non-collocated receivers three or greater arranged in a physical plane will present the set of challenges described in the following sections. The three traditional 2D radiolocation techniques of relative signal strength (RSS), relative carrier phase (RCP) and relative-time-of-arrival (RTOA) measurements taken from such a synchronized array are described, followed by brief examination of the 3D method proposed herein.

SPECIFIC PROBLEMS

Simple examples can be used to demonstrate the potential for 3D accuracy errors and poor precision, starting with the 2D RTOA radiolocation technique. As one example, consider that two different points along the Z-axis perpendicular to the area at the exact center of the 2D plane, equidistant both above and below the plane, will yield the same single RTOA data set. Only one of the points is the actual location of the distant WT, and there is no reliable way to resolve the ambiguity using only RTOA data. Such opposite location errors may be usefully described by the word “aliasing.” From the same beginning example, problems of poor precision can also be described. Since there is no relative difference of signal arrival time from a WT moving anywhere in a straight line along the centered Z-axis to all three receivers in the example, calculated incremental distances above (or below) the plane can be any absolute value of the line segment within the extremes of the originating point on the plane, to a very distant point at the minimum threshold of receivers’ ability to detect a usable signal. For the RTOA technique, any number of receivers numbered three or greater arranged only in a plane will present the same problems of aliasing and poor precision.

The use of relative signal strength (RSS) by itself or in combination with either (or both) RTOA and RCP to help resolve radiolocation accuracy and precision problems presents additional challenges. RF signal levels propagating in free space do not attenuate in linear fashion with distance, but rather according to inverse-square-law as distance increases, resulting in an asymptotic signal level curve that never reaches zero. Virtually all present-day WTs in service are not calibrated emitters. Wireless terminals instead vary dynamically over a rather large signal output range according to designed output management and control features, making RSS a relatively poor choice for any radiolocation method that seeks both accuracy and high precision. More fundamentally, practical WTs of all types are not true RF “point sources.” The idealized point source radiating antenna is described in reference technical literature as an “isotropic radiator,” a device that does not exist in practice, but is instead used as a reference model for describing the gain value and signal level patterns of actual physical antennas. The signal level from a distant WT arriving at a planar array of receivers will vary dramatically with changes in actual antenna polarization as the WT device is rotated through different random orientations. Uncorrelated signal level changes during such random rotation will be different and unpredictable at each receiver in a planar array. As a practical matter, comparing independently changing relative values of received signal strength at multiple receivers for a mobile WT in motion is essentially no additional help toward resolving the aliasing and precision ambiguities attendant to any number of three or more receivers arranged in a two-dimensional plane.

The use of relative carrier phase (RCP) is also of limited value. Phase angles repeat every wavelength, and are not “tagged” or otherwise identified as to the number of wavelengths between any fixed or moving WT and an ultimate receiver. Wavelengths for most current WTs range between approximately two feet and a few inches. Additionally, the phase of radio signals can add both constructively and destructively, due to reflections from a variety of physical objects and flat surfaces, resulting in peaking and fading of received signals. Such peaking and fading at a receiver is the result of additional unintended paths for the signal, termed “multipath” distortion. Many people have experienced the severe audio distortion of an otherwise strong local FM radio station after momentarily stopping at a red traffic signal, fully restored by moving a few feet forward after a moment. That is an example of destructive interference from a reflected (and delayed) signal that arrives at the receiving antenna 180 degrees out of phase, severely distorting the main signal. Although such FM signals have a wavelength of approximately 10 feet, well below frequencies used for most WTs, the same potential multipath distortion effect applies to all frequencies. Relative carrier phase techniques are used for electrically maneuverable antennas and other special applications, but such techniques by themselves do not anticipate and prevent known radiolocation problems that can lead to aliasing and poor precision with commonly deployed planar two-dimensional receiver arrays.

The attached example drawing (Fig. 1) illustrates the high potential for aliasing when RCP is selected as the primary radiolocation method. The simplest example of such RCP method employs two phase-synchronized receivers in a physical plane separated by one-half wavelength. The top of the simplified drawing shows two receivers spaced at a distance of one-half wavelength for the frequency of 500 MHz. The free-space physical distance separation for a half-wavelength at 500 MHz is 11.8 inches. At the top of Figure 1, there are three additional example frequencies listed, also used for WTs of various types. Note that half-wavelength physical distances for the other frequencies are much different. As frequency increases, physical wavelength decreases. At the highest example frequency of 1500 MHz, the half-wavelength physical distance decreases to 3.9 inches. Since the receiver half-wavelength physical spacing remains fixed at 11.8 inches to accommodate the lowest frequency of 500 MHz, the two receivers electrically become three half-wave sections apart when the new frequency of interest is 1500 MHz. Since carrier phase angles repeat every 360 degrees of rotation, this immediately creates a minimum of two possible aliases that militate against accurate WT radiolocation at the higher frequency, when radiolocation is based only on carrier phase in this simple example. As illustrated in the Case 2 section of the drawing in Figure 1, a 1500 MHz WT could be at any of three possible locations, and not even the additional use of RSS can reliably help to resolve the actual location.

THE SOLUTION

The method developed by Prima Research LLC virtually eliminates the possibility that a WT signal from any other point outside a mathematically Defined Local Space (DLS) will produce the same three-dimensional RTOA data set corresponding to a point within predetermined DLS coordinate values.

A simple example can be used to demonstrate how aliasing and other problems common to 2D radiolocation methods are obviated by 3D DLS deterministic radiolocation in the present Prima Research LLC invention. The example, shown in Fig. 2, shows a WT previously located at the exact center of the three-dimensional space within a tetrahedron (with no signal RTOA difference among all four synchronized receivers) that is instead relocated to a physical point outside one of its four plane faces. The example outside point is selected at the same physical distance outward from the plane face that exactly mirrors the original distance from the plane face inward to the exact center of the space within the tetrahedron. The modulated signal from the example outside-relocated WT will now arrive at three of the four synchronized receivers located at three corners of the plane face with no relative time difference of signal arrival, and at a later signal arrival time at the fourth synchronized receiver located at the tetrahedron vertex opposite the plane face in the example. The resulting four-receiver non-zero RTOA data set for the example now falls outside the range of RTOA defined possible coordinate values for the example DLS within the tetrahedron. The external potential alias point is thus properly excluded from further consideration by the common processor, and in reciprocal fashion, there is no internal DLS alias possible for any wireless terminal that happens to be external to the DLS.

Predictable accuracy and precision problems associated with radiolocation methods that use one, some, or all of RSS, RCP and RTOA techniques only in two dimensions are thus eliminated by 3D DLS deterministic radiolocation in the present invention. The DLS synchronized receiver array is designed to accept all received signal strength levels within a wide maximum-to-minimum dynamic signal range for each of the matched receivers. Within the wide receiver signal strength dynamic range, all received signals within a DLS are candidates for further RTOA examination by the central processor. Significant signal cancellation due to multipath is very unlikely below the low end of the receivers' wide dynamic range during virtually all samples of moving WTs within a DLS. The use of 3D RTOA effectively eliminates DLS location errors by the combination of accepting signals within a broad range of signal levels, not relying on RCP and RSS for any location calculations, and simply ignoring all signals that appear later in time than the first four to arrive at synchronized DLS receivers.

All internal points within a DLS have unique 3D coordinate values. If four synchronized DLS receivers are arranged to become the points of an equilateral tetrahedron (a four-sided pyramid) and they all receive and demodulate the return signal from a mobile WT at the same instant in time, the WT position reported by the DLS platform processor is at the exact center of the three-dimensional space within the DLS tetrahedron. Accordingly, there is one and only one set of coordinate values for each physical point within the tetrahedron space and any defined (and shaped) subset thereof. One method of calculating the physical location of a mobile WT within a DLS is converting WT-specific RTOA samples to points on intersecting hyperbolas in three dimensions, at the DLS processor. Because there are two real solutions for the hyperbolic function, one additional receiver is required in practical DLS platform design, to resolve the ambiguity.

Time-stamping WT return-path transmissions at the DLS synchronized receiver/processor platform involves the discernment of unique terminal identification/electronic serial number (TID/ESN) information embedded within return path transmissions from each two-way wireless terminal. Since WT TID/ESN return-path information is typically never sent “in the clear,” derivation of the embedded TID/ESN information for DLS time-stamping purposes requires demodulation of one or more modulation methods employed in WT devices at the DLS receiver platform. Such modulation methods include (and are not limited to) TDMA, CDMA, WCDMA, COFDM, GSM, G3, and other similar techniques known to those skilled in the art. Such TID/ESN demodulation at the DLS receiver platform requires intimate timely communication between the DLS receiver platform and every participating carrier’s radio access network (RAN). The fundamental reason for this requirement is due to random scheduling of RF air interface resources between specific mobile WTs and the RAN, and the initial lack of ability to uniquely identify user devices without inside information known only to the WT and the RAN. In order to enable accurate location of all mobile WTs associated with all carrier networks that have an RF “presence” within a given DLS, the DLS platform must have dedicated access to such intimate communications, for each serving carrier’s RAN. Absent such RAN communication access at the DLS, mobile WT device return-path transmissions will be indistinguishable from each other at DLS receivers due to code-spreading and intentional pseudorandom scrambling of virtually all digital transmissions. The WCDMA standard (currently deployed by 457 operators in 178 countries, to some 1.3 billion subscribers) is generally predictive of the same intimate RAN/WT communication requirements at the DLS receiver platform, for the LTE and cdma2000 environments.

In view of the general TID/ESN demodulation requirement at the DLS platform, it is envisioned that a link would be established between the DLS receiver/processor platform and each respective serving RAN resource allocation function (residing at the serving base station or some centralized location), so that resource allocation details for specific user devices can be passed to the DLS receiver platform in a timely manner to enable the DLS receivers to demodulate and time-stamp specific uplink transmissions by mobile WTs of interest. The information must include the user-specific uplink scrambling code and the resource allocation details such as frame number, timeslots, channelization code, and preamble ID used for control traffic. With this information, the DLS receiver/processor platform will be able to uniquely identify and time-stamp uplink transmission bursts, thereby enabling three-dimensional location determination of specific mobile WTs within the absolute boundaries of a mathematically defined DLS.

SUMMARY

With the unprecedented demand and rapid growth of new location services for mobile wireless devices, the need for gathering location input data with extremely high granularity has become increasingly important. The Prima Research LLC method provides location accuracy and high precision, along with simplicity, low cost and high scale, compared to an otherwise mixed-bag approach to source data gathering about mobile wireless device location. With other methods that typically use a hybrid approach by gathering information from multiple systems such as GPS, WiFi, Bluetooth, RFID (and numerous others) the resulting source data is not only imprecise, it is also uncorrelated and therefore of limited value.

The importance of introducing a correlated-source-data capability for precisely locating mobile wireless devices in real-time, and in three dimensions within a Defined Local Space, cannot be overstated. The value of the highly granular location information produced by this method will quickly become apparent to the new location-based-services sector.

Prima Research LLC is currently soliciting and considering bids for the licensing of the patented method described above. See also U.S. Patent No. 8,315,598.

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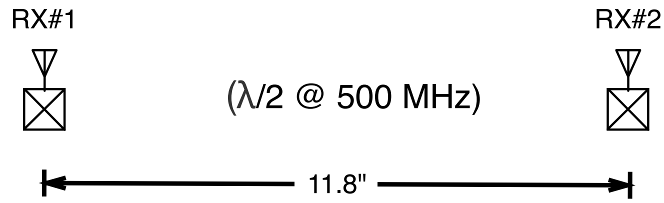
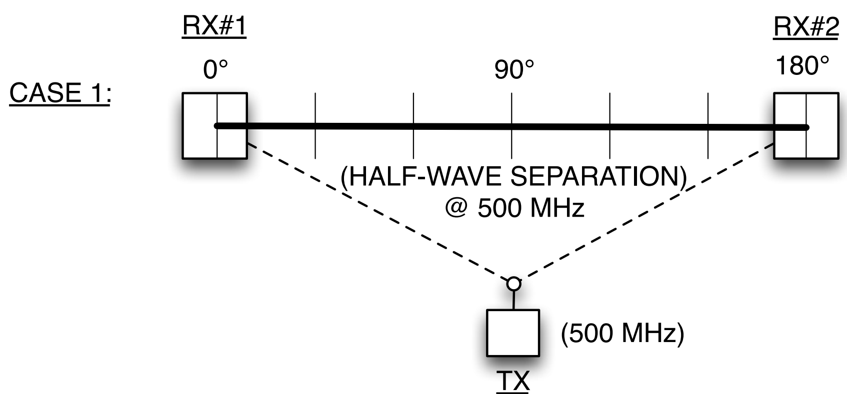


AT A FIXED RECEIVER SPACING OF 11.8 INCHES:

FREQUENCY	λ/2	λ SPACING	PHASE SHIFT
500 MHz	11.8"	HALF WAVE	180°
750	7.8	THREE QUARTER-WAVE	270°
1000	5.9	FULL-WAVE	360°
1500	3.9	THREE HALF-WAVE	540°



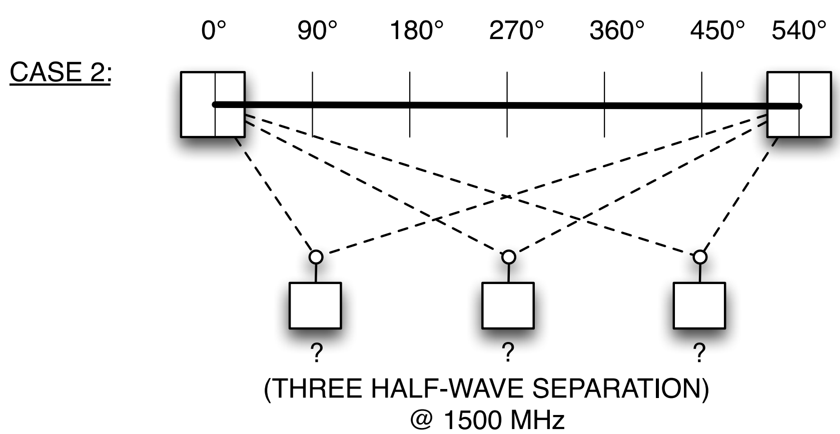


FIGURE 1

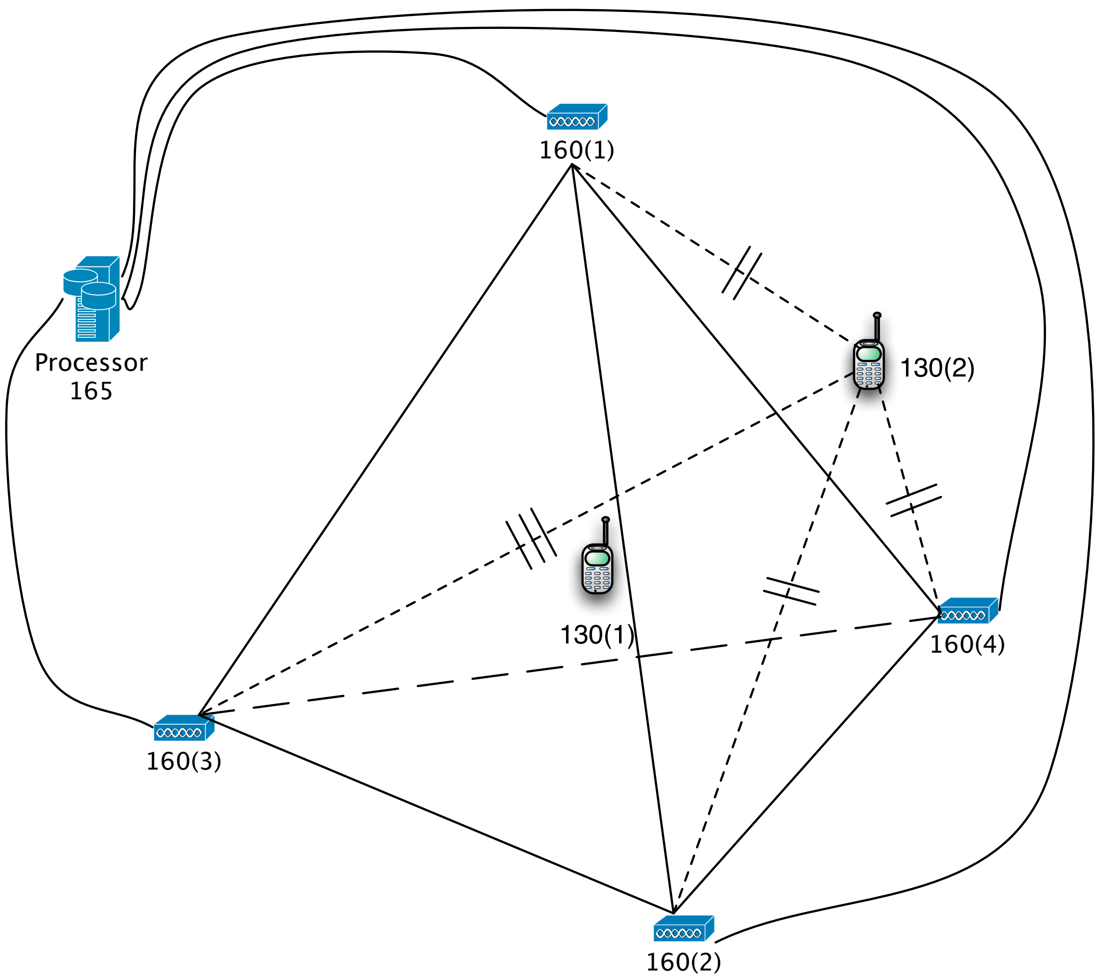


Figure 2