An E911 Location Method using Arbitrary Transmission Signals

Described herein is a new technology capable of locating a cell phone or other mobile communication device byway of already existing infrastructure. Although a technology (GPS) has already been implemented in order to locate cellular handsets, propagation delay variance, transmitter Doppler error, and the combination of limited RF power and lack of proximity limit the effectiveness of the system, particularly with regard to indoor reception. With the introduction of voice over internet protocol (VOIP), reliable indoor reception is also critical. Moreover, because the same GPS system can also be utilized by those with ill intent, the system may very well need to be disabled when it is needed most.

The new technology instead utilizes primarily standard television, FM, and emergency vehicle transmitters in order to locate a cellular handset, although virtually any transmission with a bandwidth greater than zero can be used. Due to the proximity and power level of the transmitters and inherent system design advantages, multipath, variance in propagation, and Doppler errors are virtually nonexistent and propagation to areas unreachable with GPS systems is possible. Use of the technology is also limited to authorized use, so that it can remain functional in times of need.

The system utilizes four basic components: Two or more transmitters of unknown location, three or more receivers of known location, a modified cell handset, and a remote processor. The first step to the process is the locating of the transmitters, primarily comprised of television and FM radio transmitters of unknown origin. By attaching a receiver at each of the existing cell towers, each signal of these unknown transmitters can be received. By measuring the differential of time of arrival (DTOA), each transmitter can then be located. DTOA is a simple and well known method of location, but for clarity, is described byway of example in the following paragraphs.

If a signal is transmitted and the time of arrival of that signal from the transmitter to two receivers is identical, then the transmitter must logically lie on a line equidistant from the two receivers as shown in figure #1. On the other hand, if the same signal arrives at one receiver prior to arriving at the second receiver, the transmitter, by mathematical definition, must lie at some point on a hyperbolic curve encompassing the receiver at which the signal arrives earliest. Figure two shows the hyperbolic curve of possible transmission locations if the signal arrives at receiver (A) before arriving at receiver (B). Figure three shows a greater difference in the time of arrival than figure two. If a third receiver is utilized, along with either of the first two, the transmitter can then be pinpointed in location by finding the point of intersection as shown in figure 4.

Figure 1

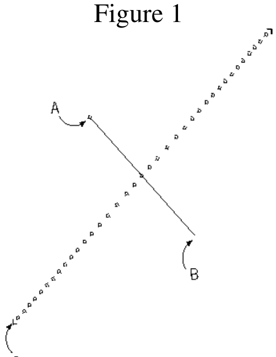


Figure 2

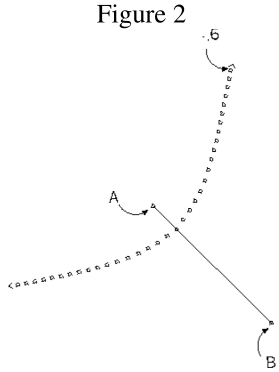


Figure 3

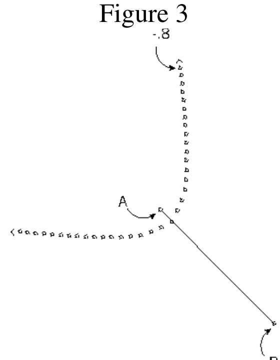
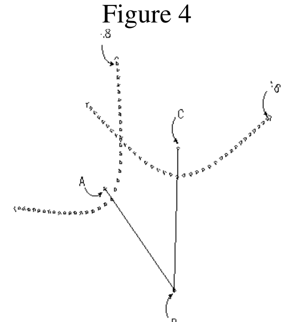


Figure 4



All frequencies travel at substantially the same velocity, so the phase change of a higher frequency is greater for the same amount of time delay. In other words, if a signal is monitored at a specific distance from the point of transmission and then compared to the signal at the point of transmission, there will be a greater difference in phase between the two points of the higher frequencies within the signal than at the lower frequencies within the signal, see figure 5. The use of two frequencies greatly reduces the ambiguity of correlation, in that, while the “correct” time offset with a single frequency repeats for every cycle, the use of two frequencies eliminates, for all practical purposes, the cyclic alias correlations. As an example, if two frequencies of 54 MHz and 58.5 MHz are utilized, with respective periods of 18.52 nS and 17.09 nS, the cycle of “correct” answers will repeat at a period inversely proportional to the difference frequency of 4.5 MHz or every 222 nS. If a third frequency, such as a stereo audio pilot signal is also utilized, the ambiguity is reduced to substantially zero.

By comparing these sets of signals between two receivers, and finding the correct amount of time to align both the lower and upper frequencies with regard to phase, the correct difference in time of arrival can be found, which will simply be the difference between T1 and T2. See figure 6. Alternatively, the difference in frequency ($d\phi / d\omega$) can be used to determine the difference in time of arrival when the results are compared between the two receivers. As an example, by comparing snapshots of the picture and primary sound carriers within a television frequency band at two receivers, the difference in arrival of time between two receivers can be found. Once this is accomplished, the distance from any of the receivers to the transmitter is known, and, by subtracting out the time delay from the transmitter to that receiver, the exact timing of the signal at the transmitter is also known.

Figure 5

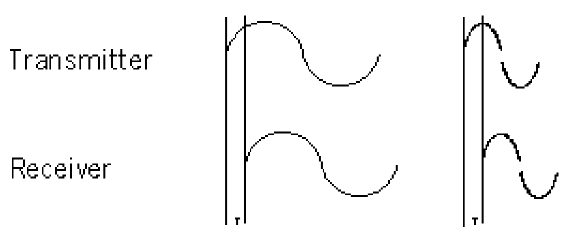
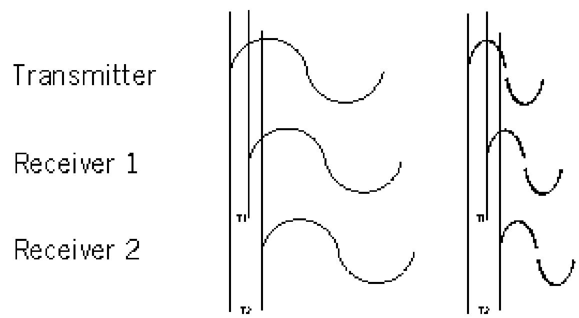


Figure 6



What is particularly convenient in this method is that the receivers are on the same network, so the timing of the snapshot of the frequency spectrum is virtually perfect, and errors such as propagation delay and multipath reception are substantially eliminated since they effect both receivers similarly as they do the third receiver.

Once the location of the transmitter and the timing of the signal is known, an unknown location receiver proximal to the known location receivers can receive the same set of signals. By using the same method to find the delay of transmission from each transmitter to the unknown receiver, the distance from each transmitter to the unknown receiver can be found. The delay from the communicating cell site to the handset can also easily be found in the same manner. Figure 7 shows concentric circles in which the delay to each point on a specific circle is constant. Figure 8 shows two transmitters, along with the cell site from which the cell handset is communicating with utilized to find the handset. Only one correlation of intersection is possible and indicates the location of the previously unknown location receiver.

Figure 7

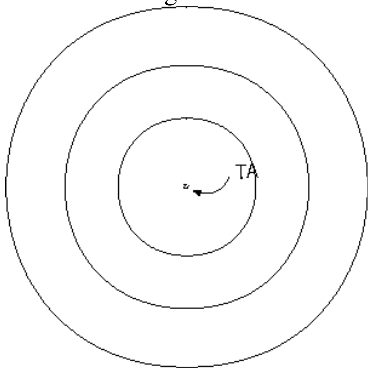
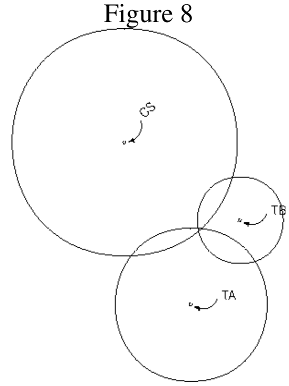


Figure 8



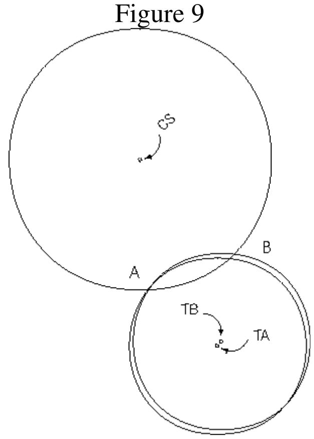
What is important to realize , is that errors in measuring the previously mentioned difference in delay and difference in frequency result in small location errors since the final calculation is based on the distance between the known location receivers and the unknown location receiver, not the distance from the transmitter to the receivers. In other words, a one part per thousand error in the measurement of phase difference or frequency difference results in an error which is proportional to the distance between the known location and unknown location receivers, not in proportion to the distance from the transmitter to the receivers. Moreover, any error from multipath, variance in propagation velocity, or other factors are entirely eliminated outside of the area encompassed by the known location receivers. What is actually being measured in the end is the differential between the known location receivers and the unknown location receiver, so although actual location of the transmitter makes for a convenient mathematical and conceptual placeholder, accuracy of the calculation with regard to the location of the transmitter is not entirely necessary. Additionally, the location signal and reference signal are correlated from the same source.

Using a signal generated from the same source as a means of detection is by far more accurate than an oscillator based receiver in that, regardless of the quality of the oscillator, there will be some drift in frequency, a certain amount of noise generated, and phase and frequency jitter. The drift of the oscillator can be compensated for by phase locking to a carrier signal if available, or by integrating the transmitted modulated signal and phase locking to it, but the remainder of the problems can not be resolved. Utilizing the original signal removes any modulation information from that signal, but the modulation isn't needed for detection. Using the same signal for detection also cancels any noise, frequency jitter, or phase jitter, in that they are entirely cancelled out in the detection process. Any noise, in fact, will theoretically add to the detection process in that it is treated in the same way as an additional carrier. This is significantly more accurate than utilizing separate transmitter and receiver oscillators in that the final detection can be done with essentially zero bandwidth since oscillator noise and drift over time is entirely cancelled in the detection process.

There is an apparent stumbling block to the proposed system. Most television and FM radios, for obvious reasons, are located in approximately the same location. Figure 7 shows two transmitters at substantially the same physical location. From figure 9 it can be seen that the Second unknown transmitter is not actually needed for the resolution of location, but rather to discriminate between two ambiguous location possibilities. In other words, providing that point A correlates in location to a higher degree than point B, point A can be determined to be the correct and accurate location. The placement of the second transmitter does not effect the resolution of the system. Moreover, the ability to receive non specific transmissions allows the use of sources of location other than that of television and radio receivers. Again, the use of the same signal for both the reference and detection allows a higher accuracy and also the ability to integrate the signal over an essentially infinite period of time.

Emergency radio transmitters, which typically lie within the band of television transmission could just as easily be utilized. This includes not only the transmission at the central police, fire, and other emergency stations, but also the mobile radios within emergency vehicles. The use of radios within emergency vehicles is particularly useful in that it provides an increase in accuracy of the system as emergency vehicles approach the area of need, this serves a particular convenience in a critical emergency because, generally, the more lives at stake, the greater number of emergency vehicles that are present at the scene and generally the more accurate the system becomes byway of the additional transmitters contained within those vehicles. Finally, the system is virtually worthless to unauthorized users as the data can not be made useful without the fixed location receivers and central processor, it is because of this that the system can remain functional in time of any emergency caused byway of a terrorist act.

Figure 9



Implementation of the system is simple and practical. A wide band receiver is contained in the cell handset that will receive television, FM radio, and emergency band transmissions. Television and FM signals are particularly useful due to the fact that a large portion of the transmitted power is contained within multiple frequency carriers, making reception of usable signals an easier task. Although emergency band transmission is not at this point standardized, the flexibility of the system allows reception and use of those frequencies as well. An identical receiver is placed at each cell tower.

Well before an emergency call is made, FM radio, television, and emergency bands are scanned at specific time intervals by the receivers fixed to the cell towers so that frequencies of regular transmission can be noted and stored at the central processor. When a caller initiates an emergency call, the central processor instructs the fixed location receivers and the handset to receive what has been determined to be the most useful of the frequencies known to have transmitted power. Because the fixed receivers and cell handset are on the same network, and the distance from the cell site to the handset is known, the timing of these frequency band snapshots can be nearly exact. The bandwidth of transmission from the handset and from the fixed location receivers can also be limited to the specific areas of the band which are allocated for carrier transmission within the transmitted signal. Once areas of known, regular transmission have been scanned, the processor instructs the fixed receivers and handset to search for other frequency bands to be utilized for further location accuracy. In a critical emergency, there is likely to be multiple emergency vehicles on the scene. The trunked radio systems within these vehicles can also be utilized for location.

Moreover, the carried police radios themselves can be located with the same system, and although the particulars of that radio will remain unknown, this can be very powerful tool in certain situations such as a burning building where the lives of emergency personnel are at risk. Consider the situation of a burning building containing an injured fire fighter. Any transmissions emitted from his radio can be found in the same manner as with the television transmitter. A second, able fighter can also be located, and most important, the distance and direction that the able fire fighter needs to travel in order to arrive at the injured fire fighter's location can be determined. Implementing this second, useful feature of the system is simply a matter of additional software, as no added hardware is needed.

The current GPS system is clearly and well known to be grossly ineffective with regard to our present and future needs for emergency location services. What is presented herein is an effective, cost efficient system that will meet both current and future needs for these location services, US patent application 10/686/122 is cleared for issue, has been filed with the PTO for international patent coverage, and is available for license.