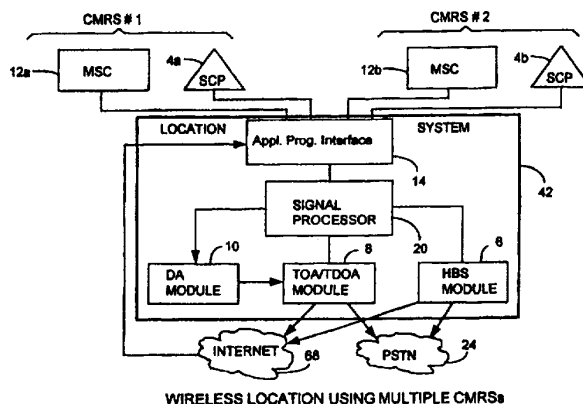




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(54) Title: LOCATION OF A MOBILE STATION USING A PLURALITY OF COMMERCIAL WIRELESS INFRASTRUCTURES



## (57) Abstract

A location system for commercial wireless telecommunication infrastructures (CMRRs). The system is an end-to-end solution having one or more location systems (42) for outputting requested locations of commercially available hand sets or mobile stations (not shown) based on, e.g. AMPS, NAMPS, CDMA or TDMA communication standards, for processing both local mobile station location requests and more global mobile station location requests via, e.g., Internet communication between a distributed network of location systems. The system uses a plurality of mobile station locating technologies including those based on: two-way TOA and TDOA; home base stations and distributed antenna provisioning. Further, the system can be modularly configured for use in location signaling environments ranging from urban, dense urban, suburban, rural, mountain to low traffic or isolated roadways. Accordingly, the system is useful for 911 emergency calls, tracking, routing, people and animal location including applications for confinement to and from certain areas.

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## LOCATION OF A MOBILE STATION USING A PLURALITY OF COMMERCIAL WIRELESS INFRASTRUCTURES

### 5 RELATED FIELD OF THE INVENTION

The present invention is directed generally to a system and method for locating people or objects, and in particular to a system and method for locating a wireless mobile radio station in a macro base station, distributed antenna, or home base station environment.

### BACKGROUND OF THE INVENTION

10 Wireless communications systems are becoming increasingly important worldwide. Wireless cellular telecommunications systems are rapidly replacing conventional wire-based telecommunications systems in many applications. Commercial mobile radio service provider networks, and specialized mobile radio and mobile data radio networks are examples. The general principles of wireless cellular telephony have been described variously, for example in U. S. Patent 5,295,180 to Vendetti, et al, which is incorporated herein by reference. There is great interest in using existing infrastructures for wireless communication systems for  
15 locating people and/or objects in a cost-effective manner. Such a capability would be invaluable in a variety of situations, especially in emergency or crime situations. Due to the substantial benefits of such a location system, several attempts have been made to design and implement such a system. Systems have been proposed that rely upon signal strength and trilateralization techniques to permit location include those disclosed in U.S. Patents 4,818,998 and 4,908,629 to Apsell et al. ("the Apsell patents") and 4,891,650 to Sheffer ("the Sheffer patent"). The Apsell patents disclose a system employing a "homing-in" scheme  
20 using radio signal strength, wherein the scheme detects radio signal strength transmitted from an unknown location. This signal strength is detected by nearby tracking vehicles, such as police cruisers using receivers with directional antennas. Alternatively, the Sheffer patent discloses a system using the FM analog cellular network. This system includes a mobile transmitter located on a vehicle to be located. The transmitter transmits an alarm signal upon activation to detectors located at base stations of the cellular network. These detectors receive the transmitted signal and transmit, to a central station, data indicating the signal strength of the received signal and the identity of the base stations receiving the signal. This data is processed to determine the distance between  
25 the vehicle and each of the base stations and, through trilateralization, the vehicle's position. However, these systems have drawbacks that include high expense in that special purpose electronics are required. Furthermore, the systems are generally only effective in line-of-sight conditions, such as rural settings. Radio wave surface reflections, refractions and ground clutter cause significant distortion, in determining the location of a signal source in most geographical areas that are more than sparsely  
30 populated. Moreover, these drawbacks are particularly exacerbated in dense urban canyon (city) areas, where errors and/or conflicts in location measurements can result in substantial inaccuracies.

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Another example of a location system using time of arrival and triangulation for location are satellite-based systems, such as the military and commercial versions of the Global Positioning Satellite system (GPS). GPS can provide accurate position determination (i.e., about 100 meters error for the commercial version of GPS) from a time-based signal received simultaneously from at least three satellites. A ground-based GPS receiver at or near the object to be located determines the difference between the time at which each satellite transmits a time signal and the time at which the signal is received and, based on the time differentials, determines the object's location. However, the GPS is impractical in many applications. The signal power levels from the satellites are low and the GPS receiver requires a clear, line-of-sight path to at least three satellites above a horizon of about 60 degrees for effective operation. Accordingly, inclement weather conditions, such as clouds, terrain features, such as hills and trees, and buildings restrict the ability of the GPS receiver to determine its position. Furthermore, the initial GPS signal detection process for a GPS receiver is relatively long (i.e., several minutes) for determining the receiver's position. Such delays are unacceptable in many applications such as, for example, emergency response and vehicle tracking.

Differential GPS, or DGPS systems offer correction schemes to account for time synchronization drift. Such correction schemes include the transmission of correction signals over a two-way radio link or broadcast via FM radio station subcarriers. These systems have been found to be awkward and have met with limited success.

Additionally, GPS-based location systems have been attempted in which the received GPS signals are transmitted to a central data center for performing location calculations. Such systems have also met with limited success due, for example, to the limited reception of the satellite signals and the added expense and complexity of the electronics required for an inexpensive location mobile station or handset for detecting and receiving the GPS signals from the satellites.

The behavior of a mobile radio signal in the general environment is unique and complicated. Efforts to perform correlation between radio signals and distance between a base station and a mobile station are similarly complex. Repeated attempts to solve this problem in the past have been met with only marginal success. Factors include terrain undulations, fixed and variable clutter, atmospheric conditions, internal radio characteristics of cellular and PCS systems, such as frequencies, antenna configurations, modulation schemes, diversity methods, and the physical geometry of direct, refracted and reflected waves between the base stations and the mobile. Noise, such as man-made external sources (e.g., auto ignitions) and radio system co-channel and adjacent channel interference also affect radio reception and related performance measurements, such as the analog carrier-to-interference ratio (C/I), or digital energy-per-bit/Noise density ratio ( $E_b/N_0$ ) and are particular to various points in time and space domains.

Before discussing real world correlation between signals and distance, it is useful to review the theoretical premise, that of radio energy path loss across a pure isotropic vacuum propagation channel, and its dependencies within and among various communications channel types.

Over the last forty years various mathematical expressions have been developed to assist the radio mobile cell designer in establishing the proper balance between base station capital investment and the quality of the radio link, typically using radio energy field-strength, usually measured in microvolts/meter, or decibels.

One consequence from a location perspective is that the effective range of values for higher exponents is an increased at higher frequencies, thus providing improved granularity of ranging correlation.

Actual data collected in real-world environments uncovered huge variations with respect to the free space path loss equation, giving rise to the creation of many empirical formulas for radio signal coverage prediction. Clutter, either fixed or stationary in geometric relation to the propagation of the radio signals, causes a shadow effect of blocking that perturbs the free space loss effect. Perhaps the best known model set that characterizes the average path loss is Hata's, "Empirical Formula for Propagation Loss in Land Mobile Radio", M. Hata, *IEEE Transactions* VT-29, pp. 317-325, August 1980, three pathloss models, based on Okumura's measurements in and around Tokyo, "Field Strength and its Variability in VHF and UHF Land Mobile Service", Y. Okumura, et al, *Review of the Electrical Communications laboratory*, Vol 16, pp 825-873, Sept. - Oct. 1968.

Although the Hata model was found to be useful for generalized RF wave prediction in frequencies under 1 GHz in certain suburban and rural settings, as either the frequency and/or clutter increased, predictability decreased. In current practice, however, field technicians often have to make a guess for dense urban and suburban areas (applying whatever model seems best), then installing a base stations and begin taking manual measurements.

In 1991, U.S. Patent 5,055,851 to Sheffer taught that if three or more relationships have been established in a triangular space of three or more base stations (BSs) with a location database constructed having data related to possible mobile station (MS) locations, then arculation calculations may be performed, which use three distinct  $P_{cr}$  measurements to determine an X,Y, two dimensional location, which can then be projected onto an area map. The triangulation calculation is based on the fact that the approximate distance of the mobile station (MS) from any base station (BS) cell can be calculated based on the received signal strength. Sheffer acknowledges that terrain variations affect accuracy, although as noted above, Sheffer's disclosure does not account for a sufficient number of variables, such as fixed and variable location shadow fading, which are typical in dense urban areas with moving traffic.

Most field research before about 1988 has focused on characterizing (with the objective of RF coverage prediction) the RF propagation channel (i.e., electromagnetic radio waves) using a single-ray model, although standard fit errors in regressions proved dismal (e.g., 40-80 dB). Later, multi-ray models were proposed, and much later, certain behaviors were studied with radio and digital channels. In 1981, Vogler proposed that radio waves at higher frequencies could be modeled using optics principles. In 1988 Walfisch and Bertoni applied optical methods to develop a two-ray model, which when compared to certain highly specific, controlled field data, provided extremely good regression fit standard errors of within 1.2 dB.

In the Bertoni two ray model it was assumed that most cities would consist of a core of high-rise buildings surrounded by a much larger area having buildings of uniform height spread over regions comprising many square blocks, with street grids organizing buildings into rows that are nearly parallel. Rays penetrating buildings then emanating outside a building were neglected.

After a lengthy analysis it was concluded that path loss was a function of three factors: 1.) the path loss between antennas in free space; 2.) the reduction of rooftop wave fields due to settling; and 3.) the effect of diffraction of the rooftop fields

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