AGPCS - An Automatic GSM-based Positioning and Communication System

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Abstract

A novel approach to automatic positioning and communication is presented in this paper. The approach is using single GSM (Global System for Mobile Communication) technology to achieve both positioning of the mobile station and communication with the other parties in a system containing a number of mobile stations. The paper deals with the overall system architecture, and briefly describes the aspects of positioning, communication and application of the system, without describing the low-level details applied in system operation. It also describes implementation of two experimental versions of the mobile stations, self-positioning and remote positioning, that integrate positioning information in the platform ready to use for different purposes. The approach is applicable to GSM and its other more recent derivatives.

1. Introduction

Automatic positioning (estimating location) and data communication is of great importance for many areas and applications, such as automatic vehicle locating and tracking, remote equipment and property locating and monitoring, boat, yachts, and cargo tracking and monitoring, remote patient tracking and monitoring, various types of dispatching and distribution systems, etc. Integration of positioning and communication into a single system is a goal not achieved in the contemporary positioning systems. Hence, it is the aim of our AGPCS (Automatic GSM-based Positioning and Communication System) project to integrate both positioning and communication based on the single GSM technology.

1.1 Global Positioning System

The most accurate positioning today is achieved using satellite-based global positioning system (GPS) (Kapplan 1996). However, the GPS has two important disadvantages. First, the information on position usually has to be transmitted to some other party requiring that the mobile station provides data communication facilities. Most often, it is provided using some sort of radio system based data transfers such as radio modems which communicate with specialised radio system infrastructure (such as trunked radio), or using an existing public cellular system. In the former case, this introduces the problem of radio coverage, and requires investment into radio transmission systems. Further costs are incurred by data communication devices. In the latter case, the positioning and communication facilities are at present implemented by two separate devices. The second disadvantage of GPS is that it is usable only for the case of "clear sky", which makes it hardly usable in urban areas, mountainous terrain, and in closed/covered space.

1.2 Radio Signal Propagation Models

Other methods for mobile station positioning are based on radio signal propagation such as signposts, dead reckoning, circular or hyperbolic trilateration systems, etc. Many methods and systems have been proposed based on radio signal strength measurement (Figel 1969, Ott 1977, Hata

1980) of a mobile object's transmitter by a set of base stations. Recently, adaptive schemes based on the use of cellular systems and on fuzzy logic (Song 1994), hidden Markov models, and pattern recognition methods (Kennemann 1994) have been used to estimate the position of mobiles. The most recent one (Hellebrandt 1997) is based on a multidimensional scaling technique. A mobile's position is determined in a such way that the measured signal strength of a certain base station in the GSM system is best fitted to the known average signal strength at this point. The performance of the method was tested by simulation for different simulated scenarios (Hellebrandt 1997).

1.3 Personal Communication Systems

The personal communications industry is one of the fastest growing industries in this decade (Feher 1995). The cellular market, as a part of this industry, is growing at the rate of almost 50 percent a year. The market offers a huge opportunity for many industries, including network service providers, software and hardware developers, and those who will upgrade the services offered by the basic network service providers. GSM, or other technologies derived from it, has become one of the prevailing cellular technologies worldwide.

1.4 GSM

GSM (Scourias 1995, Redl 1995) initially handled basic voice services and some emergency calling features, but has already added improvements in subscriber identity module (SIM) cards, which contain a microchip with the information on the caller. From the user point of view, the obvious difference between GSM and other cellular technologies is that GSM cellular phones operate only digitally, enabling both voice and data to be transferred directly digitally, without using modems, providing the backbone of the mobile communication network.

A variety of data services are offered in GSM. GSM users can send and receive data, at rates up to 9600 baud, to users on POTS, ISDN, Packet Switched PDN, and Circuit Switched PDN using variety of access methods and protocols. Other data services include G3 facsimile, and Short Message Services (SMS) which is a bi-directional service for short alphanumeric (up to 160 bytes) messages. Messages are transported in a store-and-forward fashion. For point-to-point SMS, a message can be sent to another subscriber, and an acknowledgment of receipt is provided to the sender. SMS can be used in a cell-broadcast mode, for sending messages such as updates of different sorts. Messages can also be stored in the SIM card for later retrieval. The SMS service provides a basic means to transfer data used to estimate position or coordinates of the mobile station.

Besides voice and data services, GSM system provides data that might be used for radio signal strength measurements and positioning. The GSM mobile station receives each 0.48 seconds the downlink signal levels from the serving and up to six neighbouring base stations in a discrete scale. The GSM mobile station applies a complex signal processing algorithms to determine the signal strengths. This information is a part of GSM system and is used in our system to estimate position of the mobile station.

1.5 New Approach - the AGPCS

By using, combining and integrating two inherent features of the GSM system (measurements of radio signal levels and ability to communicate directly digitally), we propose a novel Automatic GSM-based Positioning and Communication System (AGPCS) technology. The AGPCS is a real-time system built on top of the GSM system, and can be considered as an application layer to standard GSM. The first working versions of systems using AGPCS technology have been developed and tested. The AGPCS technology can be used for various applications, including control, as it may be easily incorporated into the standard hardware/software environments or used in the embedded form.

Our first goal was to obtain technology to estimate mobile station position with the accuracy that can be considered sufficient for a number of applications. The current model provides accuracy, which is almost always below

270m, and usually around 200m. Integration of position estimation and communication between mobile objects, or between mobile and stationary objects, has become feasible now. An integrated positioning and communication system, which can incorporate control features as well, is being obtained and used in a number of pilot applications. The AGPCS, including a brief overview of key technologies that take part in its implementation, is described in this paper.

2. The AGPCS Framework

In this section the AGPCS framework is described. First, we introduce some features of the GSM that are relevant for AGPCS. Then, the architecture and main features of the AGPCS are described.

2.1 Brief Overview of Relevant GSM Features

A GSM network is composed of several functional entities. It is illustrated in Figure 1., which shows the layout of a generic GSM network. The network is divided into three major parts:

1. The GSM mobile station subsystem.
2. The base station subsystem that controls the radio link with the mobile station
3. The network subsystem performs the switching of users and mobility management in the mobile services switching center.

The mobile station and base station subsystem communicate across the Um, or radio link, interface. The base station subsystem communicates with the network subsystem across the A interface. The International Telecommunication Union allocated the bands 890-915 MHz for the uplink (mobile station to base station) and 935-960 MHz for downlink (base station to mobile station). GSM is using a combination of Time- and Frequency-Division Multiple Access (TDMA/FDMA) method. At the 900 MHz range, radio waves bounce off everything - buildings, hills, cars, airplanes, etc. Thus, many reflected signals, each with a different phase, can reach an antenna. Equalization is used to extract the desired signal from the unwanted reflections. It works by finding out how a known transmitted signal is modified by multipath fading, and constructing an inverse filter to extract the rest of the desired signal. To minimize co-channel interference and to conserve power, both the mobile and the base transceiver station operate at the lowest power level that will maintain an acceptable signal

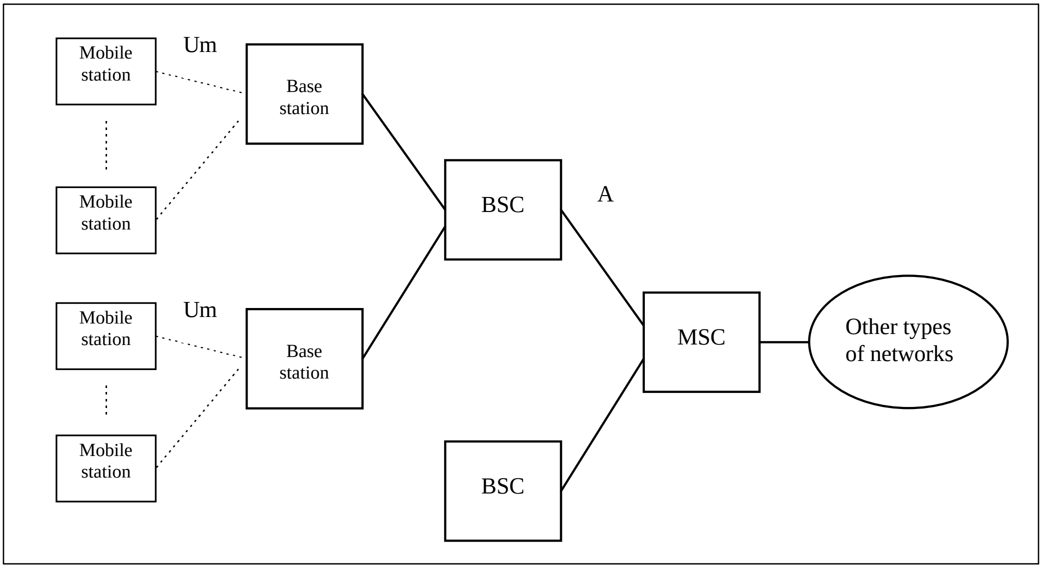

Figure 1. General architecture of a GSM network

quality. The mobile station measures the signal strength or signal quality (based on the Bit Error Ratio), and passes the information to the base station controller (BSC), which decides if and when the power level should be changed. Besides ensuring the transmission of voice and data of a given quality over radio link, the functions of mobile cellular network are the implementation of a handover mechanism, registration, authentication, call routing and location updating functions.

The signaling protocol in GSM is structured into three layers. Layer 1 is the physical layer, which uses the channel structures of GSM. Layer 2 is the data link layer. Across the Um interface, the data link layer is modified version of the LAPD protocol used in ISDN, called LAPDm. Across the A interface, the Message Transfer Part layer 2 of Signalling System Number 7 is used. Layer 3 of the GSM signaling protocol is itself divided into three sublayers:

- Radio Resource Management which controls the setup, maintenance, and termination of radio and fixed channels, including handovers. The management of radio features such as power control is performed in this sublayer.
- Mobility Management which manages the location updating and registration procedures, as well as security and authentication
- Connection Management which handles general call control, and manages supplementary services and short message service.

Obviously, from the AGPCS point of view, the most important is Layer 3, at which the AGPCS technology is hooked-up to GSM.

2.2 AGPCS Architecture and Operation

The AGPCS represents an application technology built on the top of standard GSM. It performs the positioning of the mobile station in the coverage area of the GSM network. The logical structure illustration of an AGPCS system is given in Figure 2.

The AGPCS mobile station consists of the GSM mobile station (actually handset) and a mobile computer connected

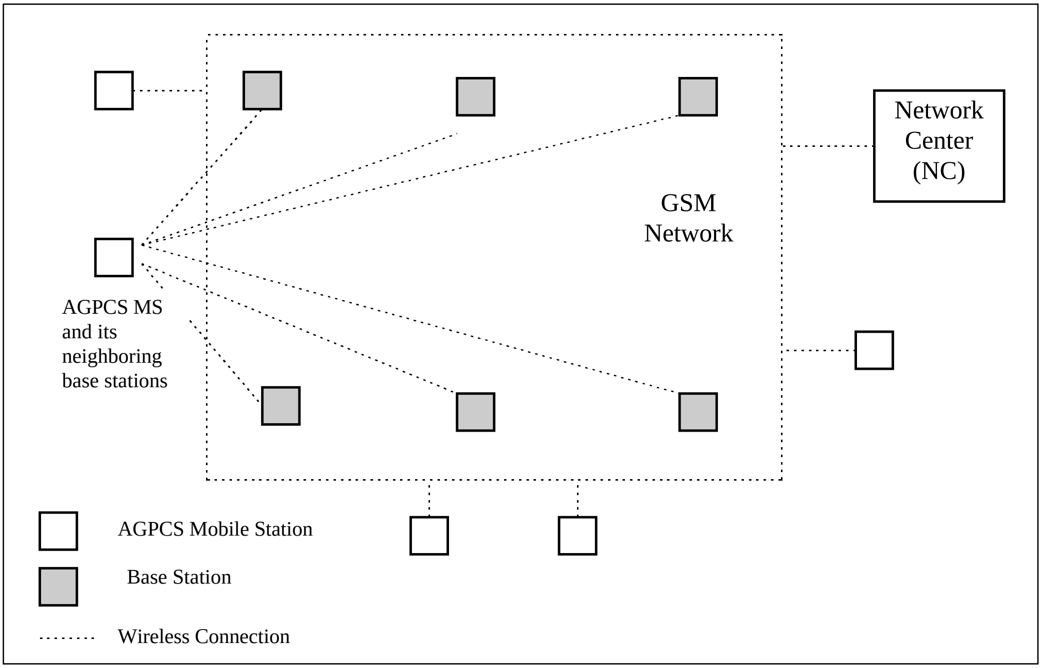

Figure 2. The AGPCS system illustration

to it. Depending on the power of the mobile computer, various degrees of intelligence and application complexity can be achieved within the AGPCS mobile station. The AGPCS mobile station performs continuous radio signal strength measurement and acquisition of measurements to estimate its position. The position is estimated by applying a combination of mathematical and statistical modeling, augmented with the use of artificial neural networks to determine position or area in which is the AGPCS mobile station. The model is based on current signal strength measurements, history of signal strength measurements, as well as some a priori knowledge of the environment. The mobile computer collects signal strength measurements from serving and up to six neighboring base stations, together with time stamps, and evaluates the distance of the mobile station from the neighbouring mobile stations. This operation is performed in real-time. Radio signal strength measurements are performed with the sampling interval between 0.5s and 1.0s. All calculated distances are used to determine an area (if there are just three distances it is a point) in which the mobile station might be. The distances of the AGPCS station from the base stations are calculated from the radio signal propagation model with parameters which are determined and subsequently changed by a training process using artificial neural networks.

Two scenarios are used from this point on. First, if the computational power of the mobile computer is sufficient, it performs further calculations, determines the estimated position, and displays it on the geographic map. It is also able to transmit its estimated position, as well as signal strength measurements, if needed, to any party in the AGPCS system, including supervisory center. This scenario leads to self-positioning and communication system, or SPCS. The SPCS is useful in applications in which the AGPCS mobile station and its user want to know current position.

In the second scenario, the mobile computer has a minimum of intelligence and input/output devices. It is used just to collect signal strength measurements, preprocess them and transmits to a network center (NC), where they are used to estimate position. A simplified version of positioning model can run on the mobile computer, and estimate the distances to the base stations, or position, which are then sent to the NC. The NC plays supervisory role in the AGPCS system. It is connected by wireless connection to the GSM. Further refinement of position can be done and the corresponding database is updated. The NC maintains data on positions of a number of mobile stations, and provides the means for presenting positions on geographic map display, but can be used for various other purposes. The NC and a number of the AGPCS mobile station make an AGPCS system. Obviously, the number of independent AGPCS systems or their architecture is not limited, because it depends only on the application requirements. Both scenarios involve transfer of messages between the AGPCS stations or between stations and the network center. This communication is performed without employing GSM voice channels. It is based on short message service (SMS) that provides exchange of short messages without using any additional interface equipment.

3. Position Estimation

Mobile station positioning is carried out by a complex combination of three types of models:

1. Geometric model based on trilateration, which gives accurate position given the distances of mobile station from the base stations.
2. Radio signal propagation model, which is of empirical character and includes many uncertain or unknown elements changing in time randomly.
3. Artificial Neural Network (ANN) model, which is used to reduce uncertainties by learning from the previous experience gained at the training station or mobile station itself.

Although the combination of these models carries certain level of redundancy, this is desirable in order to reduce the influence of the randomness, which is very high in the area of radio signal propagation and makes its modeling a very difficult task.

The main problem affecting the estimated position accuracy is the high uncertainty and randomness of radio signal propagation process. Using ANN modeling (Braspenning 1995, Swingler 1996) proved to have some advantages such as not requiring a priori knowledge of the relationship between dependent and independent variables. First, the model is run to learn using past and current positioning data including signal strengths and actual positions determined by more accurate GPS technique, or computer-supported and generated maps. Then, the model is validated using another set of measurements. Finally, the model is used to estimate positions. At this stage, the back propagation ANN model is used in estimating AGPCS station position. It is an adaptive multilayer feedforward network modeling technique, which is often used in non-linear system modeling and time-series prediction. Two approaches have been used in estimation of AGPCS station position:

1. Signal strengths and desired AGPCS position input-output pair. In this case, ANN learns to predict the position from relationship of signal strengths and actual position determined by GPS or obtained with high accuracy from the computer generated map.
2. Trilateration. In this approach, ANN is used to model the distance between the AGPCS station and neighboring base stations from actual measurements/ positions process.

Results obtained using two described approaches are better than some other reported in literature (Song 1994). The accuracy of estimated position is better than 270m. This is still worse than those reported in (Hellebrandt 1997). However, results from this reference must be taken cautiously, because they are obtained in a fully simulated environment. All our results refer to the real system experiments with real-time estimation of position. These results have been tested on limited area of about 3 x 3 km.

The implemented model is obtained by training process on the AGPCS station itself. The AGPCS station moves in a specific area and signal strength measurements together with actual positions are recorded automatically. Then, the training process starts. It first includes analysis of various types of BP ANNs using genetic algorithm (Goldberg 1989). Genetic algorithm ranks the BP ANNs the according to values of the fitness function. Finally, the best of selected ANNs are used to implement the positioning model. In the current version of the AGPCS, the selected ANNs are implemented in software. The software implemented ANN is capable of estimating position in real-time. The whole process of signal strength measurements and measurement data preprocessing, and application of ANN's model is performed in real-time using a standard PC-compatible notebook as the mobile computer. Further details of our model will not be discussed in this paper and will be reported elsewhere.

4. Communication

The short message service (SMS) is a unique service provided in GSM that allows users to send and receive point-to-point alphanumeric messages of the length of up to 160 characters. It allows two-way messaging, store-and-forward delivery, and acknowledgment of successful delivery. This service is performed within GSM control channels and does not require the use of the voice channels. This further means that no special equipment for data service, like modems or special data cards, is needed. The SMS service operates by sending a message to the service provider message center, and it is forwarded to the destination using service provider network. A problem that can arise is the delay in delivery of the message to the destination. Although delays of this type occur occasionally, most deliveries are performed within actual real-time constraints. However, delivery cannot be guaranteed within very strict time constraints. The SMS service is used to sending position information, signal strength measurements, or to exchanging other information between the AGPCS mobile station such as telemetry measurements, or control information. An application layer of the communication protocol has been developed that provides transfers of two types of messages:

1. Short messages of the length of up to 160 characters representing a computer supported version of GSM-provided SMS service. Software in the form of a dy-

namic link library supports sending and receiving of short messages, management of message buffers and GSM mobile station local memories. This software provides a number of functions that can be used from high-level programming languages.

2. Long messages of almost arbitrary length. Because of the limited data transfer speed in GSM network, the length of the long message is practically limited to the values that depend on specific application. The software layer for long message transfers provides fragmentation and defragmentation of messages, ordering, and checks for correctness of transfer, if required.

Another important feature of the AGPCS communication is ability to create own AGPCS systems (closed networks). Once the NC is created it knows which AGPCS stations are authorised to take part in the system. The AGPCS station must first register to the NC, and report to it at the agreed time intervals or at the NC request. Otherwise, the NC may unregister it from the system. This feature is important to reduce the frequency of traffic to a minimum, because sending messages is associated with the cost. Each AGPCS station can be brought in a sort of dormant state, and awakened by the NC when needed. Also, through its own intelligence it can demand communication with the NC when predefined changes in the positions or other monitored variables occur.

The AGPCS allows yet another type of message exchange. This alternative way is using point-to-point transfers that are performed after establishing connection by dialing. The transfers are done using voice channels and actual air-time. However, this option requires additional data card plugged into the notebook computer. In the current implementation of the AGPCS system, this software relies on the complex Microsoft Telephony Application Programming Interface (TAPI). Once the connection is established, it enables guaranteed data transfers between parties at the maximum data transfer speed in GSM of 9,600 baud.

5. Implementation and Application Aspects

The first implementation of the AGPCS system uses the AGPCS stations consisting of the GSM mobile station (handset) connected to the PC-compatible notebook computer. The whole software is developed to run in the MS Windows operating environment. A small real-time kernel-like application collects signal strength measurements, and prepares them to be either sent to the network supervisory center, or used to estimate position locally. The application can decide what to transfer to the NC depending on the criteria set up by the application. The other application software is used to display the current position on the geographic map. This operation is not time critical, and software reads the current position from the file that is optionally used to log (keep track of) all positions.

Maintaining the database of the AGPCS stations including position and other information can be done in the NC. In this case the AGPCS station can be reduced to the GSM mobile station and an embedded system used just to collect measurements, perform estimate of position, and send that information to the NC. The tasks performed at the level of network center become more computationally and time consuming. The communication aspect becomes very important. It is the responsibility of application developer to keep number and frequency of transferred messages low enough to avoid bottleneck at the point of connection of the NC to the GSM.

Based on GSM, the AGPCS provides and guarantees the highest level of security through the application of encryption algorithms and frequency hopping which are fully transparent to application developers. Also, the AGPCS is internationally applicable, enabling completely new global applications without using specialised equipment or investing in expensive infrastructure.

6. Conclusions

The AGPCS technology for positioning, communication and control of mobile objects is described in this paper. The AGPCS uses standard GSM to perform all functions, making simpler combination of those tasks than in other contemporary systems. New positioning method allows to position mobile stations within 270m accuracy making technology applicable for many existing needs. Current implementations of the AGPCS mobile station and network center use PC-compatible/MSWindows hardware/software platform. They have been chosen as suitable for compatibility with many other development tools and applications. However, the AGPCS mobile station can be redesigned to the form of embedded solution. The main future research directions are further improvement of positioning model accuracy, implementation of mobile station as embedded solution, and new applications of the AGPCS technology.

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