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A GSM Signals Based Positioning Technique for Mobile Applications

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A mobile positioning system based on GSM signals analysis and on a cooperative stochastic optimization algorithm is presented. The proposed technique is intended as a backup solution in those applicative scenarios where the GPS system fails to work (e.g., urban canyons). The hardware architecture of the system and the positioning algorithm are described and validated by means of a numerical assessment.

Introduction: Global System for Mobile communications (GSM) [1] is the most widespread mobile phone standard. It operates in the 900 MHz and 1800 MHz frequency bands. Each assigned band is subdivided into 200kHz radio channels by using the FDMA (Frequency Division Multiple Access). Every GSM Base Transceiver Station (BTS) has a special Broadcast Control Channel (BCCH) used to transmit its own identification data and the identities of neighbouring cells, which are monitored by the mobile stations to guarantee a suitable quality-of-service (QoS) of the communication link. Since the propagation properties of the BCCH depend on the spatial positions of the mobile stations, they can be profitably exploited to develop a positioning system. As a matter of fact, the use of the GSM system for location services has been analyzed in several studies [2] [3] [4]. In general, it has been mainly used to determine the position of the mobiles with respect to the infrastructure. In this letter, a GSM-based technique is proposed for the development of a location system for mobile devices able to calculate their positions without any intervention and additional components in the network infrastructure. The underlying idea is to measure the Time Differences of Arrival (TDOAs) concerned with the propagation of BCCH bursts from N base stations to the mobile and then to estimate the node position by solving an optimization problem through a cooperative stochastic method.

Description of the positioning system: The GSM-based positioning system is composed by a hardware module devoted to the reception/analysis of the GSM signal and a software module aimed at estimating the mobile node position starting from the knowledge of the propagation times as well as of the positions of the base stations. With reference of Fig. 1, the architecture of the hardware system is composed by three units besides the antenna. The first unit is a GSM modem to analyze the GSM signals transmitted by the neighbouring BTSs and to detect their Cell Global Identity (CGI) codes. Moreover, a Location Measurement Unit (LMU) is used to estimate the TDOAs between the bursts transmitted by every couple of base stations. Finally, a Time Reference Unit (TRU) provides the system with a stable clock for a precise time difference detection. The whole system is driven by an external computer through an I/O interface. As regards to the SW part, the positioning algorithm starts by setting a communication with the GSM modem to detect and identify the N neighbouring base stations by means of their CGI codes. The locations of the base stations are then stored in a database. Successively, the TDOAs are acquired from LMU. More in detail, the LMU continuously checks the BTSs and stores the TDOAs from every couple of detected BTSs. Starting from the coordinates of the BTSs and the TDOAs, the algorithm determines the locus of unknown positions (i.e., a hyperbolic curve) in correspondence with each BTS couple. In an error-free scenario, the intersection of the hyperbola defines a unique location that exactly identifies the unknown node position. On the other hand, several error sources are present in a real scenario (e.g., multi-path, scattering from objects, etc...) and the TDOAs are different from those of an ideal line-of-sight configuration. In such a case, the hyperbolas do not intersect in a unique point and the unknown position cannot be easily/uniquely identified. For such a reason, the algorithm addresses the localization problem in terms of an optimization one by minimizing a cost function defined as the sum of the distances between the unknown position and each hyperbola (see Fig. 2 where N = 3 BTSs). Towards this end, a customized version of the Particle Swarm Optimizer (PSO) [5] [6] [7] has been adopted.

Numerical and experimental results: In order to assess the effectiveness of the proposed architecture, two different 2D synthetic scenarios have been considered. The first one is concerned with a noiseless case, while, in the second one, the TDOA values have been blurred with an additive noise. The descriptive data, related to a reference position (x = - 1200 m, y = - 500 m), of the two scenarios are summarized in Tab. 1. In Figs. 3(*a*) and 3(*b*), the positions estimated in correspondence with the noiseless scenario and for N = 4 and N = 5 BTSs are shown. As expected, the PSO algorithm is able to exactly locate the actual node position whatever the BTS configurations. Starting from a random initial position, the iterative procedure updates the estimated position (denoted by an asterisk in Fig. 3) until the convergence (i.e., the minimum of the cost function). In the second experiment, the same scenario has been taken into account, but an error (maximum 10%) has been added to the TDOAs (Tab. 1). The reconstructed positions are shown in Figs. 4(*c*) and 4(*d*). As it can be observed, the algorithm is still able to quite accurately estimate the actual positions of the node with error values equal to 49,63 m (N = 4) and 25,87 m (N = 5), respectively.

Acknowledgments

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Table captions:

Table 1: Parameters of the noiseless and noisy scenarios

Table 1

BTS	X [m]	Y [m]	TDOA ideal scenario [nsec]	TDOA real scenario [nsec]
1	-1900	-1800	4933	4933 ± 10%
2	1500	-1300	9400	9400 ± 10%
3	800	900	8060	8060 ± 10%
4	-800	1300	6100	6100 ± 10%
5	1400	400	9130	9130 ± 10%

Figure captions:

Fig. 1 Hardware architecture

Fig. 2 Representative schema of the positioning process (N = 3)

Fig. 3 GSM based positioning technique assessment – Ideal scenario: (*a*) N = 4 BSTs and (*b*) N = 5 BTSs; Real scenario: (*c*) N = 4 BSTs and (*d*) N = 5 BTSs

Figure 1

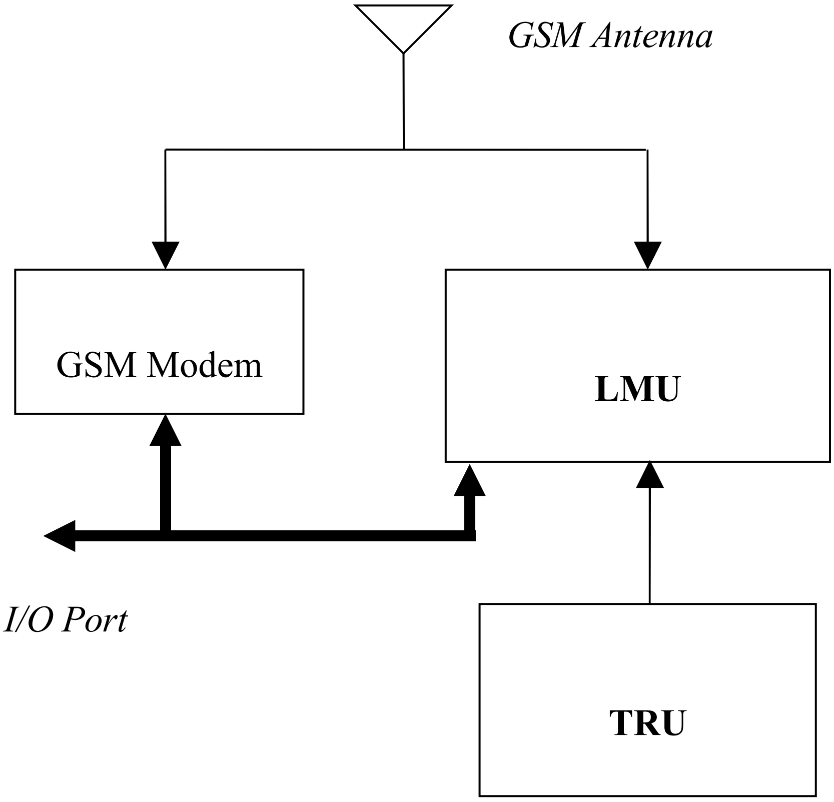


Figure 2

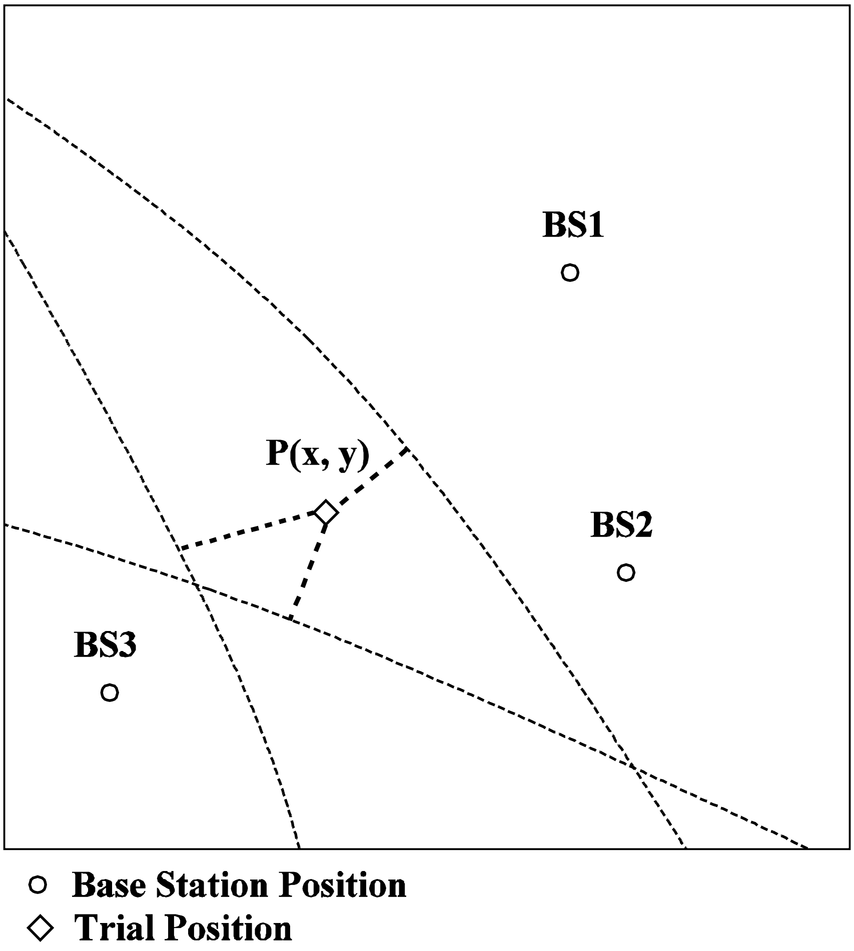
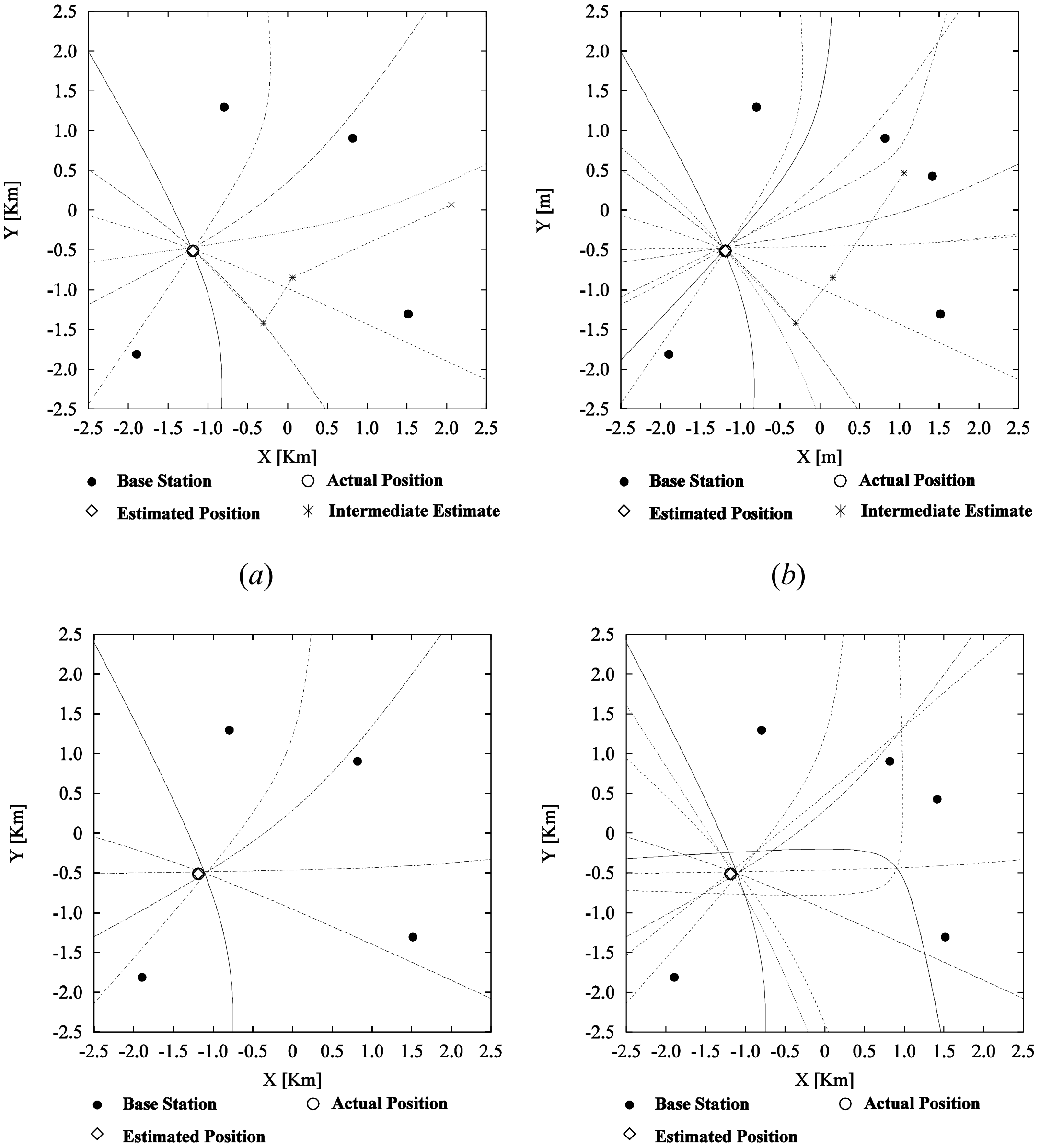


Figure 3



(*a*)

(*b*)

(*c*)

(*d*)