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A Hybrid Mobile-based Patient Location Tracking System for Personal Healthcare Applications

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Abstract: **In the next generation of Infocommunications, mobile Internet-enabled devices and third generation mobile communication networks have become reality, Location Based Services (LBS) are expected to be a major area of growth. Providing information, content and services through positioning technologies forms the platform for new services for users and developers, as well as creating new revenue channels for service providers. These crucial advances in location based services have opened up new opportunities in real time patient tracking for personal healthcare applications. In this paper, a hybrid mobile-based location technique using the Global Positioning System (GPS) and cellular mobile network infrastructure is employed to provide the location tracking capability. This function will be integrated into the Patient Location Tracking System (PLTS) to assist caregivers or family members in locating patients such as elderly or dependents when required, especially in emergencies. The capability of this PLTS is demonstrated through a series of location detection tests conducted over different operating conditions. Although the model is at its initial stage of development, it has shown relatively good accuracy for position tracking and potential of using integrated wireless technology to enhance the existing personal healthcare communication system through location based services.**

I. INTRODUCTION

In recent years, the growth and popularity of mobile telephony turns out to be much more significant than forecasted. However, beyond this growth phase, it has been foreseen that conventional (i.e. voice and data) services may reach a saturation point soon. In response to the current situation, mobile operators are looking for new mobile services or applications that will increase data traffic of the existing network [1].

In the new growth phase, location is a key service. It is offered as a standalone service and at the same time serves as a lower layer for other services and applications. This demand can be seen from a recent survey conducted in United States by Harris Interactive [2]. The survey has indicated that consumers are more interested in location tracking capabilities than other new mobile phone features, with safety and security issues as the primary concerns.

In addition, the presence of mandatory regulators such as the United States FCC mandate for E911 services as well as the equivalent European Union requirements for E112 requires wireless network operator to supply public emergency services with the caller's location and callback phone number. These have further motivated the blooming interest around the development of location based technologies and services.

An example is the location-based service supported by a dynamic portal to provide real-time monitoring capability. This service could be incorporated with a personal health monitoring solution as part of the Distributed Diagnosis and Home Healthcare (D2H2) concept. D2H2 is a paradigm shift to resolve current issues in healthcare by transforming the delivery of healthcare from a central, hospital-based system into a patient-centered, distributed and home-based system through integration of appropriate technologies. The incorporation of location tracking capabilities to assist the process of locating mobile patient in the time of emergency is crucial in ensuring that emergency personnel will be able to estimate the caller's location even if the caller is unable to identify or describe the location.

II. METHODOLOGY

The architecture adopted in this paper is based upon the mobile information server (MIS) that is used to isolate the location determination techniques from the applications as illustrated in Figure 1. This interface is essential as in most cases, the users, developers and service providers are not concerned with the particular positioning techniques employed. Instead they are focused on understanding and making use of their capabilities.

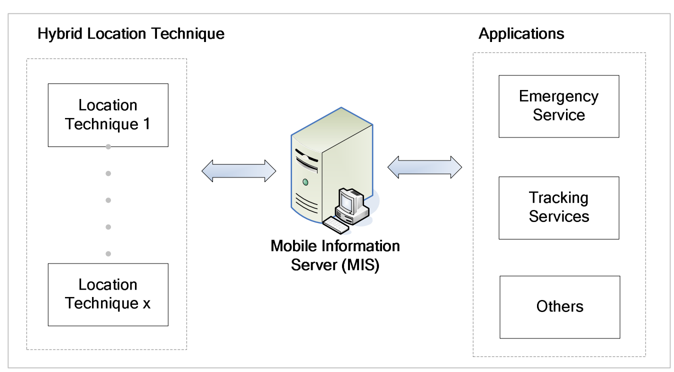

Fig. 1. Overview of patient location tracking system architecture.

The location technique is isolated from the various applications in order to provide flexibility to the overall

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system architecture. This feature increases the interoperability of the system by enabling it to be interfaced with different applications, which also allows for reusability of software when location technology advances and further development is required. The Patient Location Tracking System (PLTS) focuses on the integration of the hybrid location technique based on "GPS + Cell-ID" technique as illustrated in Figure 2.

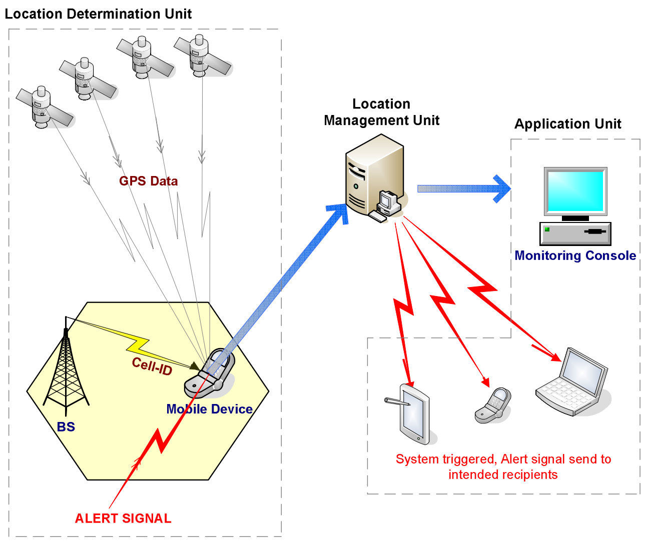

Fig. 2. Integrated system architecture for Patient Location Tracking System.

A. Location Determination Unit

The location determination unit (LDU) is designed to be implemented on the mobile station for acquiring raw location information. This information will then be processed into an appropriate form, and sent out on a periodic basis to the MIS using short messaging service (SMS) or via the internet using general packet radio service (GPRS) for further processing.

In addition, it is also designed to respond to emergency-event-triggered situation which requires the use of an asynchronous procedure. This procedure is triggered by the alert signal sent by a sensor device worn on the patient when an emergency situation occurs. The patient's mobile phone will respond by transmitting an alert signal.

Since LDU is only concerned with the location techniques used in obtaining the raw location information, it can be easily integrated with other application to provide location capability. Any changes in the location techniques employed will be contained within the unit and will not affect other parts of the system.

B. Location Management Unit

Raw location information sent by location determination unit is in a coded format. There must be a location management function to interprete the positioning data for location based service (LBS) applications to be relevant. This is achieved through the location management unit (LMU), which serves as an interface between positioning equipment and LBS infrastructure. The LMU processes the acquired raw location information or alert signal from the LDU into a compatible form to be used by the application. This unit is deployed in the MIS for data processing and provides flexibility to the entire system structure through isolation of the location detection techniques from the real application as stated. This architecture aims to reduce the workload for both the mobile device and the application. Subsequently, power consumption of the mobile devices is reduced by distributing the execution of computational tasks to the LMU.

The data processing involves utilization of a mapping algorithm and a database of reference mapping information. Hence, the first step is to set up a database of reference location information to ensure the relevance of these received data. The ideal technique is to connect the MIS database directly to the service providers to obtain the most complete information on their base-station locations, cell-ID allocation and the corresponding GPS parameters. Alternatively, mapping information can be created by manually mapping the GSM landscape to obtain the raw location information corresponding to each location descriptor (created to make the raw location information useful). The advantages of the manual solution are as follows: [1] Independent of the operator [2] Easy roaming across countries and [3] Low costs in implementation. However, the disadvantage is limited coverage during the initial mapping phase.

Generally, the overall mapping precision is dependent only on the resolution of the mapping information instead of the way the information is acquired. Therefore, dense location information stored in the database will improve the mapping result (i.e. a more accurate location descriptor). Similar to the LDU, LMU is also designed with the capability to address emergency-event-triggered situation that requires asynchronous processing. The MIS will respond to these events by promptly taking appropriate actions to alert the intended recipient. This can be achieved by either sending an alert via SMS directly to the corresponding recipients or translating the data into a suitable format to be processed by the next application.

C. Application Unit

The application unit makes use of the acquired location descriptors in applications that provide the relevant location information to the intended recipients. In the PLTS, the applications include providing the real-time monitoring capability anytime and anywhere for the intended recipients. Furthermore, in the event of an emergency situation, the intended recipients will be notified by an SMS alert message.

D. Location Mapping

The hybrid location technique employed in this paper is designed to use the most accurate information available for GPS or/and Cell-ID source, either individually or in combination to provide accurate and reliable positioning even when one of the sources is not available. This can be achieved by using a proper mapping algorithm that is described in the following section. Although this mapping algorithm (combination and usage procedure) does not affect the accuracy of the location estimation, it has a significant impact on the coverage result. In order to illustrate operation of the mapping algorithm, the layout of the information source via the received and decoded SMS is shown. Table 1 lists out the relevant, obtainable information.

Table 1: Obtainable and Relevant Location Parameters.

Location Techniques	Obtainable Parameters				
1. Cell-ID	country code	network code	location area	cell identity	signal strength
2. GPS	satellites in range	latitude	longitude	altitude	

A number of Cell-ID and GPS parameters are available for location mapping. Extended processing time will be required in order to make use of this huge database of information. This is resolved by dividing the mapping algorithm into two phases, each using a filtering mechanism to extract the database information to be used. The first phase makes use of the Cell-ID parameters to estimate and minimize the possible area that the mobile user is in. The second phase uses the available GPS data to fine-tune the estimated location such that accurate location estimation can be obtained.

1. Phase 1: Estimated Mobile Location Using Cell-ID

Phase one is focused on estimating the mobile user location using parameters obtained via the Cell-ID parameters. This process is started by correlating the relationship between the parameters obtained via the Cell-ID method as shown in Figure 3.

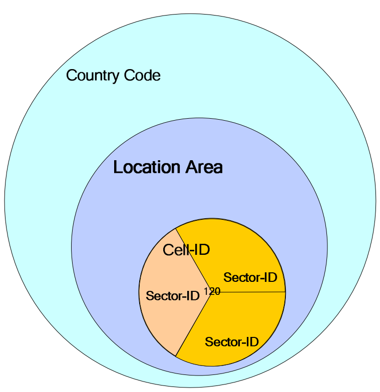

Figure 3. Location Parameters Obtained via Cell-ID Techniques.

Through the use of Cell-ID technique, the Country Code (MCC), Network Identity Code (MNC), Location Area Code (LAC) and Cell Identity can be obtained. The addition of each set of information can further reduce the possible area where the mobile user is located. This is achieved by first using the MCC to sort out the corresponding country where the mobile user is currently located and to load the corresponding database of information to be used. The presence of the network code is used to further filter the database to obtain information only for the local service provider. Subsequently, the area ID can be used to reduce the possible area where the mobile user could be located. Finally, this area can be further filtered using the cell-ID or sector-ID. Using this divide-and-conquer method, the mobile user location can be successfully estimated.

2. Phase 2: Fine-Tuned Mobile Location Using GPS

Although the first mapping phase is able to locate the cell sector where the mobile user resides, the accuracy needs to be improved. This will be done in the second phase. The improvement of accuracy is achieved by mapping the GPS data to the corresponding Cell-ID filtered mapping table obtained previously. Subsequently, the exact location (location descriptor) of the mobile user can be computed. However, GPS has lower yield and limited availability. In order to ensure that the system operates even when GPS connectivity is not available, an additional switching mechanism has been set up. The key function of the switching mechanism is to monitor the status of the GPS technique. In the case when the GPS data is not available, the system will automatically load the previous GPS data for analysis. If this previous GPS data matches with the current detected cell information, the system will assume that the current and previous locations of the mobile patient are close to each other. As a result, the system will display the location using the previous location descriptor. When the GPS signal is not available and a mismatch between the previous GPS and the current cell information is detected, the system will display an approximate location based on the current Cell-ID.

The mapping algorithm employed has utilised the complementary nature of hybrid location detection techniques to effectively combine both the GPS and cell data when both location techniques are available. But in the case that one of them is not available; the system is still able to operate with the switching mechanism employed.

III. RESULTS

The performance of the hybrid mobile-based location tracking system is verified through a comparison between the predicted location and the real user location in different test scenarios. In order to analyze the characteristics of the system under different operating conditions, a series of test scenarios are required. Six different test scenarios are conducted to verify the tracking accuracy in deducing the actual location of the user. The scenarios are chosen with and without the GPS line-of-sight (LOS) establishment. The mobile user is assumed to be moving at low speed or remain stationary. Table 2 lists the test scenario description and the accuracy of the location prediction.

Table 2: Test scenarios description and accuracy.

Test 1	Description: GPS LOS Established. Open area. Clear sky.
No. of satellite visible: 6	Predicted location: correct (~90%)
Test 2	Description: GPS LOS Established. Open area. Cloudy.
No. of satellite visible: 6	Predicted location: correct (~80%)
Test 3	Description: GPS LOS Established. Outdoor near buildings.
No. of satellite visible: 5	Predicted location: correct (~70%)
Test 4	Description: GPS LOS Established. Partial covered area.
No. of satellite visible: 4	Predicted location: correct (~70%)
Test 5	Description: No GPS LOS Established. Enclosed area. Last known GPS location available.
No. of satellite visible: Nil	Predicted location: correct (~60% based on Cell-ID and last known GPS data)
Test 6	Description: No GPS LOS Established. Enclosed area. Last known GPS location unavailable.
No. of satellite visible: Nil	Predicted location: correct (~60% based on Cell-ID data)

IV. DISCUSSION

The test results show that Cell-ID is a less accurate location detection technique as compared to GPS. But unlike GPS whose performance degrades with geographical impediment and has low yield, Cell-ID has higher yield coverage and is available in most cases. Hence, the hybrid combination of both techniques allows the cell-ID technique to fill in the gaps in coverage for the GPS, which results in significant improvement in the system yield and facilitates a continues operation even when GPS signal is not available. The accuracy of this system can be further improved by increasing the resolution of the mapping information.

V. CONCLUSION

The hybrid mobile-based PLTS has demonstrated the essential features for LBS. Its location tracking capabilities have been proven in retrieving both GPS data and Cell-ID from the network concurrently and to send out the information in the form of SMS. The verification results of the location detection capabilities under different test situations have also shown good potential in making relatively accurate information from the obtained location parameters for use in the application with relatively short computation time. Further analysis will be required to reinforce this possibility.

In addition, the accuracy of this system can be further enhanced by increasing the resolution of the mapping information. This requires dense location information that can be obtained in real-time via the service provider. The potential for this refinement can be seen from the phenomenal growth of LBS which has prompted many service providers to roll out LBS products into the mobile market. The development of this hybrid system has key advantages in using wireless technology at a low cost to improve the existing communication systems in the healthcare environment; as well as offering good potential in line with the development of new location based services.

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