

In-building location using Bluetooth

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Abstract— This paper presents a new system for indoor location of a mobile device based on bluetooth technology. Bluetooth access points of a network are used for the location system and to access the network. Location is made by means of the signal strength received from those access points. The signal energy will be measured by the mobile device and it will be transmitted to a central server that calculates its location. Since location is made in a central server, it is possible to consider any kind of algorithm to estimate it. The location system also uses a previous scene analysis by considering a map of received signal strengths.

I. INTRODUCTION

Location systems is one of the most promising fields in mobile computing. Location systems allow to develop a new kind of location-aware mobile applications [25]. The most common location systems as global positioning systems (GPS or Galileo) [1],[3],[2] or positioning provided by mobile telephony operators [4] are suitable for *outside* environments where clear line-of-sight respect to the satellites or base stations is available. However, they suffer from multi-path effects within buildings, and therefore, in indoor they show poor performances.

To obtain good results in indoor environments it is necessary to have many indoor stations. In particular, ad hoc networks, provide a fine-grained sensor system by using small and inexpensive stations (nodes). There exist many references of ad hoc networks to provide location, based on different technologies and techniques [5] (and references therein).

In this paper it is introduced a new location system for indoors environments. This system uses radio-frequency technology provide by a Bluetooth network [18]. Since the transmitted signal energy decreases almost proportionally with the distance between stations and mobile terminals, we can consider this relation to determine the distance from a particular node. In the mobile terminal, when we have the signal levels from different nodes, we can apply different algorithms to estimate its location. Algorithm computation is made in central (powerful) servers. In order to communicate with servers, the Bluetooth network is used. This approach allows us to consider complex algorithms, since algorithm is not evaluated in the mobile device that, usually, shows limited computational capabilities.

This paper is structured as follows: section II shows the related work that will allow us to classify our system according some usual features in location systems. Section III describes the system and its operative. Section IV will describe the structure of the system. Tests of the system are shown in

section V and practical applications in VI. Finally, section VII is devoted to the conclusions.

II. RELATED WORK

Location systems estimate a mobile terminal position by using different physical phenomena and technologies [5].

Depending on the physical phenomenon used to make the estimation, we obtain the following classification:

- **Triangulation:** This technique uses geometric properties of access points location to compute mobile locations. Triangulation can be obtained by considering:
 - Propagation time, where it is considered the time that needs the signal to travel from the node to the mobile terminal. [1],[7],[8] are examples of systems using this technique.
 - Received Signal Strength (RSS), where it is considered the attenuation produced when a signal travels a distance between transmitter and receiver. [9],[13],[4] are examples of using RSS.
 - Angulation, where the signal arrival angle to different nodes is used to determine position. In a 2D environment with two nodes we could determine this position. VOR aircraft navigation system is a classical example using angulation technique [14].
- **Scene Analysis:** Uses features of a scene, previously observed, to obtain conclusions about the location of the objects. Examples of systems using this technique are [9],[11],[10].
- **Proximity:** The object's presence is sensed using a physical phenomenon with limited range. Some approaches to sensing proximity are: detecting physical contact, monitoring wireless cellular access points and observing automatic ID systems. [6],[12] are systems using this technique.

Any of the above techniques can be combined with different technologies as: radio-frequency ([8],[13],[4]), ultrasound ([7]), optical ([6],[11]), proximity sensors ([6],[12], ...).

A. Our Approach

This paper introduces a new technique with the following features:

- Radio-frequency is the technology considered. In our case the nodes are the base stations of a Bluetooth network [18].

- For the location technique we use lateration by means of the Received Signal Strength Indicator (RSSI). With the RSSI we build a RSS map of the environment. Therefore, the system is an example of scene analysis and received signal strength.
- The system gives a physical location, since the position is made thanks to nodes whose position is well known. Moreover, these nodes allows us to provide symbolic location, since we know which node is closer to the mobile device.
- Test section shows the accuracy and precision obtained. As we will see, we achieve an error from 2 to 4 meters (90 percent of the time). This precision is achieved in a 120 square meters room with 3 access points (nodes).
- Cost: Bluetooth network installation and 45 euros per access point.
- Limitations: Bluetooth devices required.

III. SYSTEM OPERATION

Our system considers three kind of components: clients, bluetooth access points and servers. Clients are the mobile devices that want to be located. Bluetooth access points are the nodes to be used as references in the location algorithm and they are also used for communication. Servers will store the maps of signal strengths and they will run the location algorithms.

As we have seen, the location technique is based on the Received Signal Strength Indicator (RSSI) of bluetooth nodes. The system works in a similar way than the RADAR system [9], where, first, a server must store a map of the RSSI at different coordinates. To build the map of the RSSI in a closed environment (i.e. a room), a fixed number of access points ¹ will be considered. To create and conform the map, a mobile device should move through all the coordinates of interest. From each coordinate, this device will notify some parameters to store with the map: its location, information of the signal power that receives from each access point, and finally some information of interest. Mobile device notifies these parameters by sending information in one tuple similar to the shown in (1)

$$(P_1, [(AP_1, RSS_1), (AP_2, RSS_2), \dots, (AP_n, RSS_n)], I) \quad (1)$$

One tuple referring to the same coordinate can be sent several times to the server, which can adopt two options depending on its configuration: keep only the last information received from a coordinate, or make for each request a weighted average with the previous ones. This process will be repeated for each coordinate in the map. Mapping process should be repeated in case of any change in the access points positions.

Once the maps are conformed, mobile devices change its behaviour to be clients, and ask the system for location and associated information to this one. When a client wants to

¹Also known as signal reference points.

know its position, it makes a request to a server indicating the information about the signal strengths that it detects from its position. Developed system is able to locate clients in closed environments and reply to a request of location originated by the client, in form of data or voice. The client is a mobile device, part of a Bluetooth network in roaming way, that is connected to one access point. Communication with the server is made through this network.

Although system supports the use of several algorithms, we have chosen to implement an algorithm based on triangulation with the signal strength as it is shown in the figure 1. The algorithm considers the RSSI obtained from N access points to estimate the position of the mobile device.

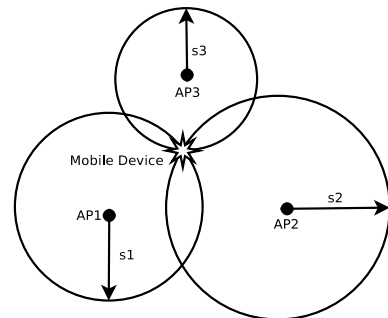


Fig. 1. Algorithm example for 3 Access points.

System also can work in *tracking* way. This way of operation allows to make a tracking of the route that mobile follows. If system enters in tracking way of operation, the mobile device will make requests of location to the server every certain time (preconfigured). Server will keep the space-time information, describing the path followed by the mobile. Tracking supposes an important improvement to the system because we can follow the mobile trajectories, avoiding some non possible paths (i.e. crossing a wall), and we have a mechanism that allows us to improve the precision of the system. To obtain a bigger precision we used Galilean physics (2) of which a moving body crosses a given distance in a given time, depending on the speed. Therefore, for a specific speed of the mobile device, we can know a radius where next position will be e :

$$e = v * t \quad (2)$$

where v is the mobile estimated speed and t is the time passed from the last location. With this mechanism we obtain a system that is tolerant to noise and avoid *absurd* locations.

IV. SYSTEM ARCHITECTURE AND USED TECHNOLOGIES

The system has been developed with premises of distribution and fault tolerance, both in the storage and the application logic. In addition, since mobile devices have a considerably inferior capacity of processing than a cluster of servers, Client/Server architecture with light clients and heavy server has been chosen for the system.

This section describes the physical and the logical architecture of the system.

A. Logical Architecture

Logical architecture describes the structure of the system in terms of software systems. As it can be observed in figure 2, logical architecture consists of three main parts: the server, composed by a database and the logic of application, middleware is the connection between network services and applications and, finally, the clients of the system.

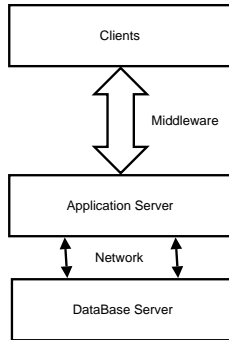


Fig. 2. Logical architecture.

- Client: Client corresponds with View in MVC [24] pattern (Model, View, Controller). An small application must be running in the clients, since they must obtain the RSSI from the Bluetooth driver at any time. For this reason, we have discarded that mobile had an access to the server of WEB type. In our case, clients have been developed in C (using GTK) and Symbian, for the development in a notebook and PDAs / *smartphones* , respectively.
- Middleware: It is the part of the system where data from mobile devices (clients) is transferred to the server. In order to make transparent clients and server implementations, we have consider a standard protocol, based on a web service: XML-RPC [19]. This protocol, encapsulates information into XML (eXtensible Markup Language) and sends it by using HTTP, providing a great diversity to the system and allowing it to be used through firewalls.
- Server: The server is compound of two main parts: The database storage and the logic of application.
 - DataBase storage: where the server stores the mapping of signal strengths corresponding to the coordinates of the environment. Our system uses a topological map [21] that is stored in Mnesia [22] (include with OTP, Open Telecommunications Platform [20]), that is a database manager that offers properties of distribution and fault tolerance. Mnesia is appropriate for telecommunication applications and other that need continuous operation and properties *soft* real time.
 - Application logic: Application logic has been programmed in Erlang [20]. Erlang is a functional, general-purpose programming language and runtime environment. Erlang has built-in support for concurrency, distribution and fault tolerance. Erlang is used by several large telecommunication systems from

Ericsson. Three modules stand out: Database access, location module and XML-RPC server.

First has been made using a DAO [24] (Direct Access Object) pattern *variant* that defines the access to the objects of the data base.

Second has been made using the Template pattern, which allows to choose between several algorithms to carry out the positioning. These two first elements conform the Model in MVC pattern.

At last, we have a XML-RPC server module that implements the Facade [24] pattern and that is the agent that receives requests from mobiles. This element is the Controller part in this implementation of pattern MVC.

As we can see, the design of the application has been made using a suitable set of patterns and behaviours. This architecture give us the following properties:

- Concurrency: Erlang processes are very lightweight and they have memory requirements that can vary dynamically. Erlang design allows applications with a high number of concurrent processes.
- Distribution: it has been designed to be executed in distributed environments. The system allows to execute each module in a cluster of computers, communicating between them through a network. A system based on erlang is a network of nodes (typically one by processor), that behave like virtual machines. The resident processes in different nodes communicate to each other as if they were being executed in a single one.
- Robustness: primitives of error detection are used for the development of fault tolerant systems. In this way, processes executed in a distributed system can be configured to migrate to other nodes in an automatic way in case of failure of the node in which they reside.
- Real time: allows applications with *soft* realtime constraints, where the response times are in order of miliseconds.
- Updates: for environments that cannot be stopped, Erlang considers mechanisms of *hot* code change, and, therefore, any software maintenance can be made while the system continues executing itself.

B. Physical Architecture

System is composed by several hardware components that can be seen in the scheme of figure 3. The system considers the following five components:

- Database server: due to the nature of the DBMS (DataBase Management System) used, the database server can be from only one PC to a cluster of several PCs or servers.
- Location server: application that contains the location logic can run in dedicated servers or share the host with the database servers. If the demand is too high, also it is possible to create dedicated clusters for the location.
- Heterogeneous Network: The communication between the clients and the server will be made in two stages.

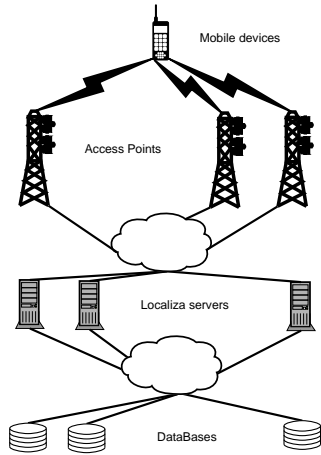


Fig. 3. Physical architecture.

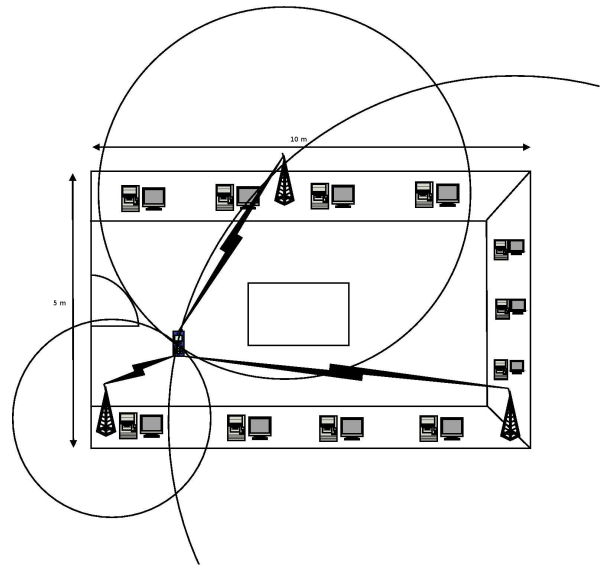


Fig. 4. Laboratory map.

First communication between clients and Bluetooth access points will be established. At this stage, communication will be wireless by means of the Bluetooth network. Second stage consists in communication between access points and servers. This stage can pass through any kind of network: WLAN, LAN, WAN, ...

- Access point: Access points are the devices to serve as reference to mobile devices.
- Mobile devices: The client is the device that makes requests, either for the creation of maps, or consultants of location. This device can be of diverse nature: mobile phone, PDA, notebook, ... The only restriction for this device is that it must incorporate a Bluetooth adapter.

In the physical architecture design details have been also taken into account, causing the system to conserve the inherited characteristics of the logical architecture.

V. TESTS RESULTS

System has been proved in rooms with sizes between fifteen and forty square meters, using devices of class 1 and 2 (rank of coverage of ten and one hundred meters respectively). Obtained results were satisfactory with errors between one and three square meters in better cases and six meters in worst cases. In addition, if the room is small, it has been probed that even with two access points would be enough, due to the physical limitation that supposes crossing walls.

In particular we have made thorough tests in the laboratory we work (figure 4). This is a fifty square meters room (10m x 5m) with different affluence of people depending on the hour of the day.

For the tests we have divided the room in a small cells with an 1.2m x 1.2m area. One of this regions in the room was inserted in the map as point to be located by the system. After finishing maps, we began location tests. Results are shown in tables I and II.

Conclusions and remarks:

TABLE I
TESTS MADE WITH TWO ACCESS POINTS

Percentage	Error in meters	Error in square meters
30%	≤ 1,2 meters	≤ 4,52 square meters
60%	≤ 2,4 meters	≤ 18,09 square meters
10%	≥ 2,4 meters	≥ 18,09 square meters

- System improves its accuracy when we try to locate in a position near an access point.
- Measurements are affected with people presence. As solution we propose making several maps per room and use the most suitable for environmental conditions. This can be made manually or using reference points, where system knows signal values and choses automatically the most appropriate map.
- Another issue is the time response that bluetooth provides. In order to search bluetooth devices in the room, a standard time between seven and eight seconds is necessary. If we reduce the inquiring time, it can affect to the visibility of the access points from the mobile devices. Other solution is to assign several access points to a map when we create it. Instead of making a scan each time we want to locate, client asks the server what access points belong to this map. After it tries to connect directly to the above mentioned access points. If no connection can be

TABLE II
TESTS MADE WITH THREE ACCESS POINTS

Percentage	Error in meters	Error in square meters
79%	≤ 1,2 meters	≤ 4,52 square meters
16.8%	≤ 2,4 meters	≤ 18,09 square meters
4,2%	≥ 2,4 meters	≥ 18,09 square meters

established signal value will be minimum (zero in most cases).

We are making tests about precision with system in tracking mode. We think that result will be far better, but not comparisons can be made at the moment. Note that using tracking mode in combination with the environment map, some nonsense locations, can be detected and therefore they can be avoided.

VI. PRACTICAL APPLICATIONS

There exists a lot of practical applications of location systems. However, since many mobile devices (mobile phones, PDAs, notebooks, ...) includes bluetooth capabilities, the system is specially useful. Those applications can be group in two categories.

On the one hand, it can be very useful for contextual information systems. When a user demand an information from its mobile device, the response will be configured depending on the origin of this request. For example, in a museum, exhibition or trade show, in which the user can ask where is the exit or the toilets. In this case, the user would make a request through the application in the mobile device to the location system. Through this system, the pertinent information is sent to him depending on his own location. One of the main advantages of our system is the use of the same technology for communication and location. Thanks to it, the mobile device only need to have a bluetooth adapter.

Another application would be a system that locates a device in a transparent way. That is, a mobile device will be located without user request. Suppose the case of a fair, in which each visitor receives a terminal susceptible to be located; in this way the organisation could take a control of the visits 'stands', adapt the quality of the contents for future editions, ...

VII. CONCLUSIONS

In this article we have introduced a new system that allows the location of mobile devices in indoor environments. This system uses radio-frequency technology provided by a bluetooth network used to communicate mobile devices. The system is based on the signal strength received at mobile devices from the network access points. A device can obtain its position by request it to a server indicating the signal strengths received from several access point of the network. Servers have a signal strength map (previously computed) that will be used to determine mobile device location.

Since an existing bluetooth network is used to estimate location of mobile devices, the system is low cost and very useful since it uses a technology adopted by most of the mobile devices (mobile phones, PDAs, notebooks, ...). Moreover, tests show that the system provide a high precision.

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REFERENCES

- [1] Hoffmann-Wellenhof, B. H. Lichtenegger, and J. Collins, *GPS: Theory and Practice*, 3rd ed. New York: Springer-Verlag, 1994.
- [2] P. J. Dana, "Global Positioning System Overview, <http://www.colorado.edu/geography/gcraft/notes/gps/gps.html>, website last visited on April 29th, 2005.
- [3] Galileo website, European Commission: http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm, website last visited on April 29th, 2005.
- [4] US Federal Communications Commission's E911, <http://www.fcc.gov/e911/enhanced/>, website last visited on April 29th, 2005.
- [5] Jeffrey Hightower and Gaetano Borriello, *Location Systems for Ubiquitous Computing*, an article appearing on pp. 57-66 of the August 2001 issue of IEEE Computer Magazine.
- [6] R. Want et al., "The Active Badge Location System", *ACM Transaction Information Systems*, January 1992, pp. 91-102.
- [7] A. Harter, A. Hopper, P. Steggle, A. Ward, P. Webster, "The Anatomy of a Context-Aware Application", *Proceedings 5th Annual International Conference on Mobile Computing and Networking (Mobicom99)*, ACM Press, New York 1999, pp. 59-68.
- [8] N. B. Priyantha, A. Chakraborty and H. Balakrishnan, "The Cricket Location-Support Systems", *Proceedings 6th Annual International Conference on Mobile Computing and Networking (Mobicom00)*, ACM Press, New York 2000, pp. 32-43.
- [9] Paramvir Bahl and Venkata N. Padamanabhan, "RADAR: An In-Building RF-based User Location and Tracking System", *Microsoft Research*, 1999
- [10] R. Raab et al., "Magnetic Position and Orientation Tracking System", *IEEE Transactions Aerospace and Electronic Systems*, September 1979, pp. 709-717.
- [11] J. Krumm et al., "Multi-Camera Multi-Person Tracking for Easy Living", *Proceedings 3rd IEEE International Workshop Visual Surveillance*, IEEE Press, Piscataway, N.J. 2000, pp. 3-10
- [12] R. J. Orr and G. D. Abowd, "The Smart Floor: A Mechanism for Natural User Identification and Tracking", *Proceedings Conference Human Factors in Computing Systems*, ACM Press, New York 2000.
- [13] Jeffrey Hightower, Chris Vakili, Gaetano Borriello, and Roy Want, "Design and Calibration of the SpotON Ad-Hoc Location Sensing System", *University of Washington*, Seattle, WA, August 2001.
- [14] VHF Omnidirectional Ranging: <http://www.navfltsm.addr.com/vor-nav.htm>, website last visited on April, 29th, 2005.
- [15] Stefano Basagni, Marco Conti, Silvia Giordano and Ivan Stojmenovic, "Mobile Ad-Hoc Networking", *IEEE Press*, United States: Wiley-Interscience, 2004.
- [16] Vijay Abhijit, Carla Ellis and Xiaobo Fan, "Experiences with an In-building Location Tracking System: Uhuru", *Department of Computer Science Duke University*
- [17] J. Armstrong, R. Virding, C. Wikstrm, Mike Williams, *Concurrent Programming in ERLANG*, Prentice Hall, 1995
- [18] Official Bluetooth page, <http://www.bluetooth.com/>, website last visited on March 31th, 2005
- [19] Official XML-RPC page, <http://www.xmlrpc.com/>, website last visited on March 31th, 2005
- [20] Erlang OTP page, <http://www.erlang.se/>, website last visited on March 31th, 2005
- [21] E. Remolina and B. Kuipers, "Towards a General Theory of Topological Maps", *Artificial Intelligence*, 152(1):47-104, January 2004.
- [22] Mnesia documentation, <http://www.erlang.se/doc/doc-5.4.3/lib/mnesia-4.2/doc/html/index.html>, website last visited on March 31th, 2005
- [23] Official BlueZ page, <http://www.bluez.org/>, website last visited on March 31th, 2005
- [24] Core J2EE patterns, <http://java.sun.com/blueprints/corej2eepatterns/>, website last visited on March 31th, 2005
- [25] G. Chen, D. Kotz, "A Survey of Context-Aware Mobile Computing Research", *Technical Report TR 2000-381*, Dept. of Computer Science, Dartmouth College, 2000
- [26] L. M. Ni, R. Liu, Y. Cho Lau, A. P. Patil, "LANDMARC: Indoor Location Sensing Using Active RFID", *PerCom03*, March 2003, Fort Worth, Texas, USA.
- [27] O. Serrano, J. M. Caas, V. Matelln, L. Rodero, "Robot localization using WIFI signal without intensity map", *WAF04*, March 2004, Girona, Spain.