Location-based Systems - Two New Implementations - MobiSys 2004

[Christopher Intemann]
Zentrum for Informatics
University of Goettingen
Email: [intemann@math.uni-goettingen.de]

December 20, 2004

Abstract

This article gives an overview about two new implementations of technologies for locating moving mobile devices, one in form of a case study, implemented in a real usage scenario and evaluated in a field trial for mobile advertising (Bluetooth and WAP Push Based Location-Aware Mobile Advertising System[1]), the other as a test setup to measure possible advantages and disadvantage of location systems working in an active, passive or hybrid mode (Tracking Moving Devices with the Cricket Location System[2]).

While the first effort is based on Bluetooth technologies and location relies on cell identity positioning, in the second effort distance estimates are undertaken in the receiving device, taking the RF signal into account.

Even though the second effort divides into active and passive mode based positioning, the technologies used for the mobile advertising system must be considered to be more a mixture of both technologies. The field study proved that Bluetooth positioning generally works, but still needs some improvement to enhance the rate of successful localizing operations. It also turned out that the advertising server connected to the location system lacks some functionality in profiling possibilities. Security questions were not the focus of the study, but it is obvious that the system is not capable to solve this issue satisfying

The hybrid system developed and introduced with the Cricket location system shows significant improvement in position accuracy, compared to the passive system, and clear benefits in privacy and security concerns, compared to the active system. However, it cannot reach the accuracy of an active system.

1 Introduction

Determining the location of a mobile device is a fundamental problem in mobile computing. Being aware of the location of a device could either improve the performance of a communication network, it could also be used to implement services relying on location information, e.g. mobile advertising systems and other location-based services. As a basic definition, a location-aware or location-based service is mostly driven by location information.
The need for location systems led to the development of different systems for providing location information, particularly in indoor and urban environments, where the Global Positioning System (GPS) does not work well. It must be considered, that, as it is easier to filter out errors if a device is not moving during the averaging process, the accuracy of a moving device is less compared to a device at rest.
Apart from the aim to reduce network traffic, further motivations to implement location systems are

- human navigation - direct users to their desired locations
- robotic navigation - provide location information to a moving robot
- multiplayer games - players can move in the real world and have their moves represented in a game like Quake or Doom

In the B-MAD system introduced in this article, the devices are being tracked in real time, while in the Cricket Location System an Extended Kalman Filter(EKF)is being used, to project ahead.
Mobile advertising can be defined as

- advertising moving from place to place
- advertisements delivered to mobile devices

The Bluetooth Mobile Advertising (B-MAD) system is following the second definition, in form of permission based advertising, using a special form of notifications. Notifications are usually requested by the end user, while in this case the notifications are pushed onto the mobile device. After he has been detected via Bluetooth based cell identity positioning, the user receives a WAP (Wireless Application Protocol)-Push message via GPRS (General Pocket Radio Service) containing the URL(Universal Resource Locator) to download the advertisement.
Locating systems can be divided in active, passive and hybrid mobile architectures.
In the active mobile architecture (figure 1), an active transmitter on the mobile device periodically broadcasts messages, which are destinated to receivers deployed in the environment. The measured values are stored in a central database, were the location can be calculated.

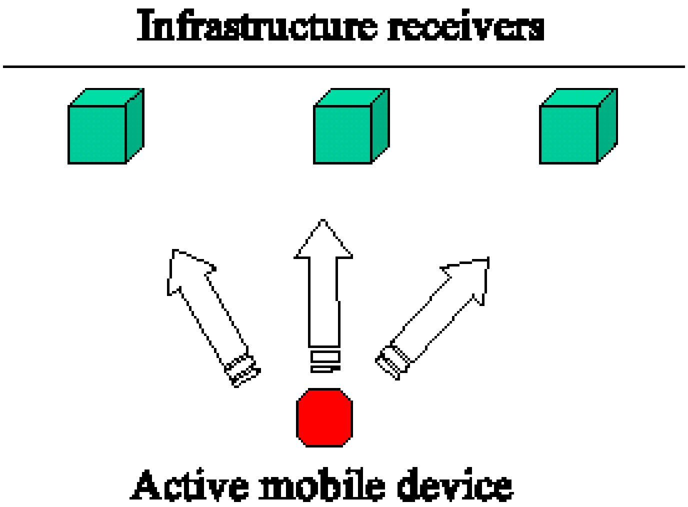

Figure 1: active architecture

In the passive mobile architecture (figure 2), beacons are deployed at known positions in the environment and are transmitting messages, which are received by passive receivers on the mobile devices. The passive mobile architecture scales better than the active mobile architecture, as the wireless traffic is independent from the number of mobile devices.
Several advantages and disadvantages can be observed in both architectures - while the passive mobile architecture allows a mobile device to estimate its location itself, and therefore can control which other entities can get this information, the active architecture raises security and privacy concerns. Another disadvantage of the active system is the need for a network infrastructure to connect to the central database. Furthermore, there is a risk for network congestion, corresponding to an increasing number of devices.
On the other hand, compared to the passive system, it solves the tracking of a moving device in a more natural fashion. In the passive system, the receiver located on the moving device can only receive one beacon at a time, resulting in less accurate estimated positions, if the device is moving.
Taking these facts into account, a hybrid architecture was developed, trying to combine the technologies in order to get the benefits out of both of them.
To measure possible benefits, the three architectures were implemented in the Cricket location system as a test setup.
The B-MAD system relays on active transmission from both the mobile device and the

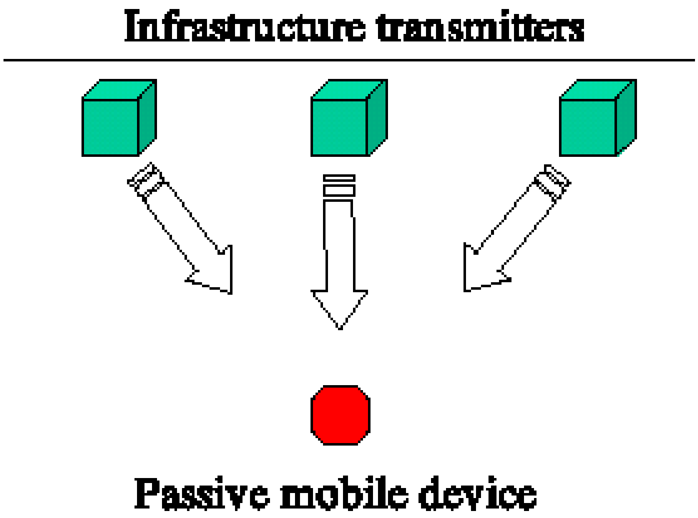

Figure 2: passive architecture

sensors, so it cannot be clearly assigned to the active nor to the passive architecture.

2 Related Work

A lot of research work has already been done regarding both the mobile advertising and the location system design topic.

- The Bat system is an implementation of an active mobile system, demonstrating its benefits as well as the disadvantages([3]).
- The HiBall head tracking system does not use an RF signal in favor to infrared LEDs([4]).
- The Whisper system is an approach to obtain precise distance estimates using spread-spectrum audio([5]).
- The Global Positioning System (GPS) is a well known, satellite based location system, with the benefits of worldwide coverage and high availability, but weak indoor coverage and expensive infrastructure.
- Some other research was done to measure and improve the Kalman filter, which is also used in the Cricket system([6]).

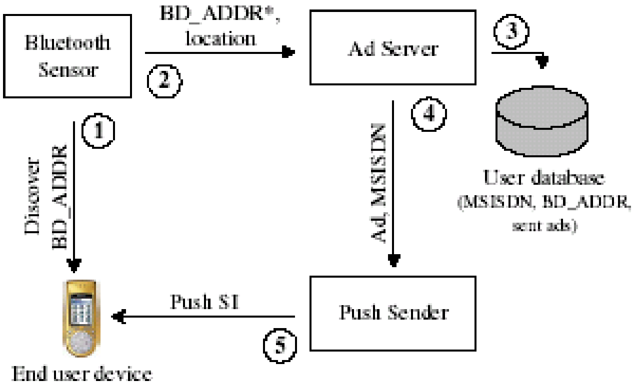

Figure 3: overview

- The mobile advertising related work spreads from SMS advertising([7]) via wireless lan based mobile advertising([8]) to a shopping jacket, which can remind the wearer of interesting shops if he walks along([9]). Some research about business models applicable to mobile advertising has also been undertaken([10]).

3 B-MAD System Description

After discovering the globally unique Bluetooth device addresses (BDADDRs) of a nearby end user device, the Bluetooth sensor sends the addresses over a WAP connection to the advertising server, together with a location identifier. Then, the advertising server maps the addresses to the user phone numbers (MSISDNs) and checks from the database if there are any undelivered advertisements associated with the location that have not been delivered. If there are some undelivered advertisements, they are sent to the Push Sender for delivery. Finally, the Push Sender delivers the advertisements as WAP Push SI (Service Indication) messages (figure 3). The requirements for the sensor and end user devices are

- commercial availability
- GPRS capability
- programming interface to the Bluetooth stack for the Sensor
- XHTML (eXtensible HyperText Markup Language) browser for the end user device

These requirements are matched by phones running Symbian Series 60.

Technical Details

The Symbian Bluetooth stack does not offer the possibility to determine the signal strength of a Bluetooth connection, but it is possible to disable the cache storing discovered devices, therefore cell identity positioning can be used for localizing. If a device is within vicinity, it can be discovered in inquiry mode. Unfortunately, the inquiry is terminating after about five seconds, which prolongs the discovery time.

It is possible to install the localizing software as well on the mobile device as on the sensors.

In the B-MAD implementation, as well for the sensors as for the mobile devices Symbian 60 phones are used and the B-MAD software is installed on the sensors, which publish the device addresses(BDADDR) of the located devices to an advertising server. The Advertising server is a collection of PHP (PHP Hypertext Preprocessor) scripts running on a LAMP (Linux, Apache, MySQL, PHP) platform. If an end user subscribes to the mobile advertisement service, an association between the phone number (MSISDN) and the Bluetooth device address (BDADDR) is stored in a database. The user accounts have several profiling capabilities, including the form of the markup language (XHTML/WML), whether the phone has a color display, and the preferred language. Furthermore, it is possible to bundle the messages with some certain sending criteria, like the order of the messages, or the time between localization and sending of the message. The advertisement is delivered using SI Push Service Indication messages via WAP/GPRS.

4 Evaluation Of The System

Theoretical Positioning Time

As the inquiry state of the device is terminated after about five seconds, there is only a 50% chance for a device to be discovered in an inquiry period X, therefore the Number of attempts needed has the geometric distribution with the parameter p = 0.5:

$$EX = \frac{1}{p} = 2$$

The standard deviation is:

$$\sigma_x = \sqrt{\frac{1-p}{p^2}} = \sqrt{2}$$

The assumed update period of the Bluetooth sensor is 10 seconds. The random value T and standard deviation are:

$$ET = 10EX = 20s$$

$$\sigma_T = 10\sigma_x = 10\sqrt{2} \approx 14.14s$$

Observed Positioning Time

The observed value is the time measured between swichting on the Bluetooth radio and processing of the detected BTADDR in the advertising server. This means, that the time measured represents not only the time needed to discover the device, but also the latency of the network and hardware involved in these operations. The measured time over all distances is 25.4s in mean, with a standard deviation of 15.86s. As the observation setting was partly interfered by a wavelan access point, also transmitting on the 2.4 GHz ISM(Industrial, Scientifical, Medical) band, and a clear improvement could be found with decreasing wavelan traffic, it can be assumed that the observed position time could come even closer to the theoretical calculated value. Taking the latency of network, hardware and manual timekeeping into account, the measured results seem to be very reasonable.

Probability of detection of walking users

Assumed a user walks through a Bluetooth cell of circle shape and 25m radius at a speed of 1.5 m/s (5.4 km/h), he will spend $\frac{2 \cdot 25m}{1.5\frac{m}{s}} = 33.3$ seconds in the cell.

As only 73.3% of the observations are less than or equal to 33.3s, the system cannot reliable detect moving users, which in consequence means that not all users will get an advertisement.

Positioning Accuracy

If the system is not calibrated, the estimated position accuracy can roughly be considered to be around 50m to 100m.

Scalability

The Octopus WAP gateway, due to license restrictions limited to ten requests every ten seconds, turned out to be the bottleneck of the system. Therefore, the advertisements were kept as simple as possible, as all traffic, as well originating from the sensors, from the mobile device and from the advertising server, goes through the gateway. However, the server performance, tested with a shell script, could easily solve 50 sequential fake requests.

The average sending latency over 15 measurements was 11.6 seconds, which combined with the average 25.4s for positioning allows the user 37s to walk away from the location. Again assuming a walking speed of 1.5 m/s, the user could walk $37s \cdot 1.5m/s = 55.5m$ in 37s.

5 Field Trial

Nine Bluetooth sensors were placed in the display windows of eight stores in the town center of Oulu, Northern Finland, within a circumference, that a test user can walk along the shops in a distance of 600 meters. In total, 11 advertisements were applicable, 2 with delivery criteria like order or length of stay within the vicinity of a Bluetooth sensor.
It could be observed, that delivering advertisements to mobile phones with WAP push using Bluetooth positioning generally works, even though not very reliable. In average, the test user received 6 out of 11 advertisements and downloaded 4.7. Due to the latency of the system, users can walk quite far until receiving the message, an issue many users complained about. Some test users did not download all advertisements, because they considered the frequency of receiving advertisements to be too high. Other issues were that the users were not familiar with the test devices and had some difficulties to use them. A mobile advertisement system needs to be profiled and personalized, targeting the advertisements to the user is very important.

6 Cricket System Description

The test setup for the Cricket system consists of a Lego train with attached Cricket unit, illustrating the moving mobile device, and Cricket beacons/receivers, fixed on the ceiling.
The experiments are conducted with different speed. As well the train as the devices attached to the ceiling can act as a receiver or a beacon, offering the possibility to let the system operate in active, passive or hybrid mode. The Cricket Location System uses the Extended Kalman Filter (EKF) tracking algorithm to obtain distance estimates.
The Kalman Filter tracking algorithm consists of a Least Square Minimization (LSQ), an extended Kalman filter (EKF), and outlier rejection. While the outlier rejection and LSQ is explicitly named in figure 4, the Kalman filter is displayed in separate steps. The basic idea of the EKF is that the filter is aware of its state at any time. Therefore it tries to project ahead using recent measured samples and internal state. The measured position value is compared to the predicted position when reached, and the system adjusts its state. The EKF can either work in P-Filter mode, assuming the device is at rest, or in PV-Filter mode, assuming the device to move with a constant

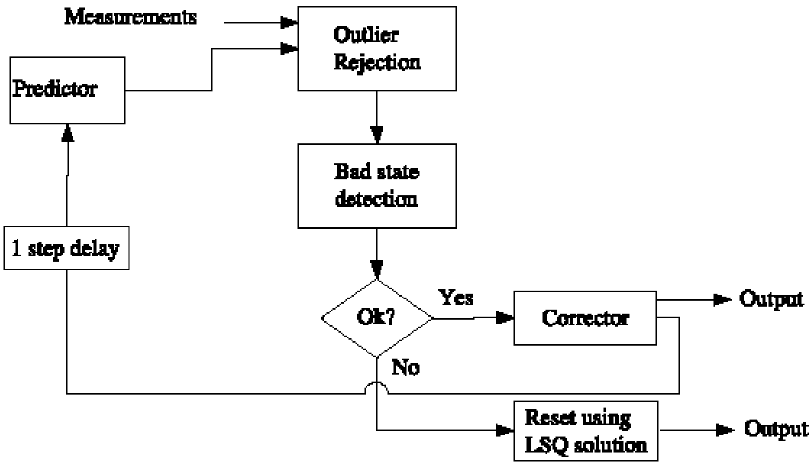

Figure 4: Cricket Location System

velocity. Compared to the PV-Filter, the P-Filter is less computationally expensive, while the PV-Filter not always assures better results, as sharp turns can affect a device moving at constant speed like strong accelerations, adulterating the calculated position predictions. The multi-modal filter combines the output states of the P and the PV Filter model in order to produce more accurate results. The Least Square Minimization(LSQ) is used to estimate the position of the moving device if no accurate position could have been acquired. It does not always produce a good estimate. Therefore, a Kalman Filter is rather used. However, LSQ is used for initializing or resetting (if in bad state) of the EKF. The Outlier Rejection receives predicted position estimates from the EKF, so it can decide whether a measured position is an outlier, and in that case, reject these values. The fraction of rejections is monitored. If it significantly exceeds the expected fraction, the EKF is assumed to be in bad state. Now the LSQ output is used and compared to the EKF output. If it is more accurate, the filter is reseted with the LSQ estimate as a new position.

7 Hybrid Architecture

In the passive architecture, the EKF will rather get in bad state, as it only hears one beacon at a time, and the measurements are serialized in time. If in bad state, in the active system the filter can be reseted estimating the position by using simultaneous distance samples to multiple beacons, while in the passive system LSQ is used. LSQ is complex and subject to large errors. This led to the development and implementation of the hybrid solution: normally working in passive mode(for increased privacy and

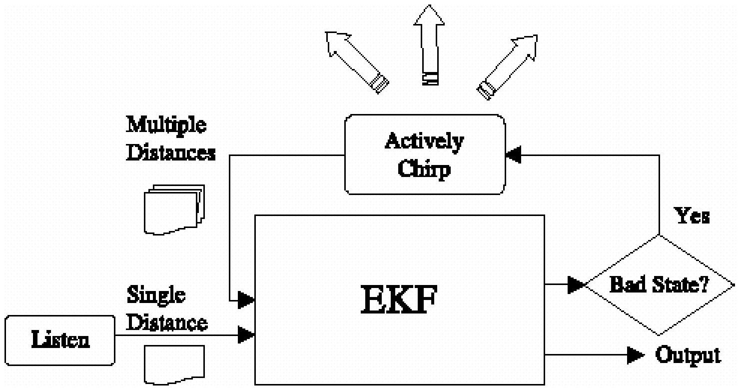

Figure 5: Hybrid Architecture

scalability), the hybrid system uses active mobile operation to determine the position on start-up and when resetting. As the transition to active mobile operations occurs only if the EKF is in a bad state, the probability of network congestion is very low, and the system therefore scales well. The privacy is granted, as random nonce could be used, and even if there is only a single user, a listener has to be aware of that. There is very few active transmission, using LSQ is also possible to totally discard it in favor of security benefits, but with losing accurancy. All calculation is being done in the mobile device, a central network architecture is not needed.

8 Conclusion and Outlook

The B-MAD system is a working effort to introduce and evaluate a system for delivering permission-based location-aware advertisements to mobile phones using Bluetooth positioning and WAP Push delivery. It is not aiming on privacy and security issues and it lacks encryption capabilities. The association of the phone number with location information can be considered to be a sensitive information, and is transmitted in plain HTTP SI-messages. It would be a better effort to map the device address to the location information locally in the client device. Furthermore, it is generally not a good idea to keep the Bluetooth device in a discoverable mode, because of exploitable firmware in the mobile devices, and the risk of bluejacking. Installing the locating software on the mobile device instead of the sensors, to make the system act in a passive locating system manner could be an option to improve privacy and security for the mobile user. While on the one hand the delivery of the advertisement via WAP SI message is more reliable than Bluetooth, as not limited to the restricted coverage of a Bluetooth cell, it is bound to the GSM network infrastructure, causing additional costs and traffic, the possibility of using the Bluetooth Object Push profile is not used.

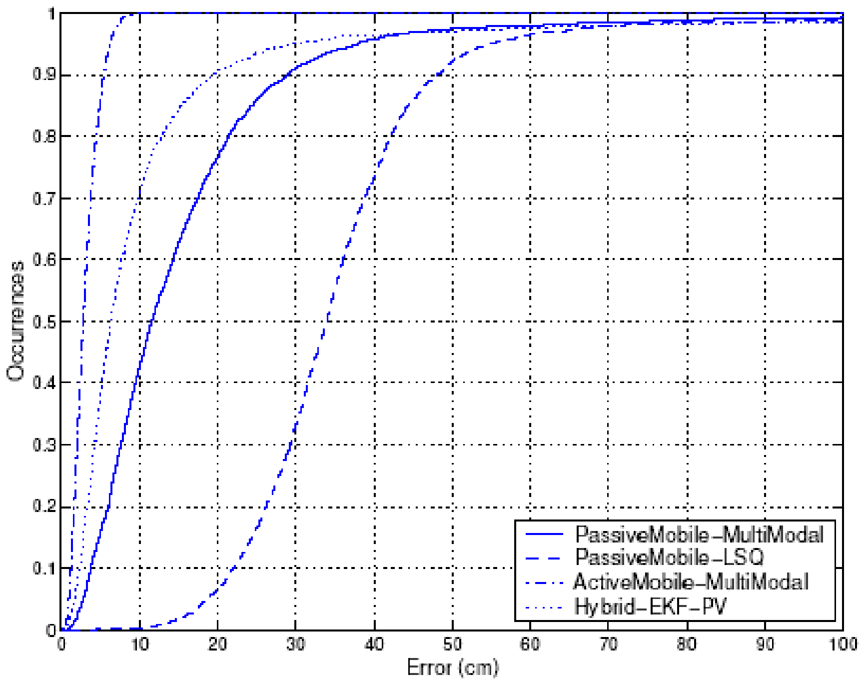

Figure 6: Cricket System Tracking Performance

However, the current mobile phones cannot receive URLs via Bluetooth yet. Another possible option would be to send the mobile advertisements as MMS(multimedia Message System), even though the costs might be the limiting factor in this scenario.
The chart 6 compares the measured position accuracy of the activemobile system, the hybrid system, and the passive mobile system, using Multimodal and LSQ algorithms for position estimations.
As expected, the active system performs best. For the passive systems, the multi modal effort performs much better than LSQ.
It turns out that the newly implemented hybrid architectures shows a significant improvement in position accuracy.

References

[1] L. Aalto, N. Gthlin, J.Korhonen, and T. Ojala, "Bluetooth and wap push based location-aware mobile advertising system," *MobiSys*.

[2] A. Smith, H. Balakrishnan, M. Goraczko, and N.Priyantha, "Tracking moving devices with the cricket location system," *MobiSys*.

[3] A. HARTER, A. HOPPER, P. Steggles, A. Ward, and P. Webster, "The anatomy of a context-aware application. in," *Proc. 5th ACM MOBICOM Conf.*

[4] G. Welch and G. Bishop, "Incremental tracking with incomplete information," *Computer Graphics*, vol. 31.

[5] N. M. Vallidis, "A spread spectrum approach to occlusion in acoustic tracking," *PhD thesis*.

[6] I. R. Petersen and A. V. Savkin, "Robust kalman filtering for signals and systems with large uncertainties."

[7] P. Barwise and C. Strong, "Permission-based mobile advertising," *Journal of Interactive Marketing*, vol. 16, no. 1, pp. 14–24, 2002.

[8] T. Ojala, J. Korhonen, M. Aittola, T. K. M. Ollila AND, J. Thtinen, and H. Karjaluoto, "Smartrotuaari-context-aware mobile multimedia services," *2nd International Conference on Mobile and Ubiquitous Multimedia*.

[9] C. Randell and H. Muller), "The shopping jacket:wearable computing for the consumer. personal and ubiquitous computing."

[10] H. Yunos, J. Gao, and S. Shim, "Wireless advertising's challenges and opportunities," *IEEE Computer*, vol. 36, no. 1, pp. 30–37, 2004.