GRIPS Generic Radio based Indoor Positioning System

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Abstract: GRIPS (Generic Radio based Indoor Positioning System) is an indoor radio signal strength based positioning system. In order to track, locate and inform mobile users, GRIPS' devices participate in WLAN/Bluetooth ad-hoc or access-point based wireless networks. Apart from its ability to track passive devices, it is possible to deploy the system in a spontaneous ad-hoc manner. With the help of cheap, active UHF RFIDs, the overall accuracy of GRIPS becomes an adjustable parameter. Location based information can be triggered, independently, simply by reading data, stored on RFIDs, but also by providing extended services via the WLAN/Bluetooth network link. In order to realize both, proximity measurements as well as continuous tracking we explored the feasibility of three light weight positioning algorithms, namely the mass spring model, atomic multilateration as well as Kalman-filter enhanced atomic multilateration.

1 Introduction

Indoor localization has been an active area of research for several years. Especially as an enabling technology for location based services (LBS), indoor location support is of high interest for many business cases as well as for emergency/security scenarios. Location sensing represents a core component of ambient computing architectures, smart-environments and ubiquitous/pervasive computing architectures.

The main reasons, why indoor LBS are yet not commonly deployed in a broad scale are high cost, complexity, administrative difficulties, security issues and weak accuracy. Most solutions are neither affordable for LBS providers, nor for their possible clients or customers. Therefore, in order to deliver a *cheap and broadly applicable* LBS-enabling solution we concentrate on commonly integrated wireless communication technologies (i.e. Bluetooth, WLAN) and on cheap RFID beacons.

Concerning reliability, robustness and accuracy, it shows that a *combination of different wireless interfaces*, promises to yield best results. Especially the combination of a far-range network enabled wireless transmission technology (WLAN, Bluetooth Class III) for continuous tracking, and a short-range beaconing methodology with cheap tags / beacons (Bluetooth Class I, RFID) delivers promising results. This is not only true in terms of cheapness of components, but also in terms of accuracy, since far-range indoor tracking methodologies deliver fair granularity of room-size resolution, whereas short-range beacons deliver fine granularities (i.e. high localization resolutions). Moreover, being connected to a network, beacons need only store and transmit a short unique amount of data, which is mapped to arbitrarily big amounts of data (stored on entities on the network, e.g. on the Internet).

The next section describes GRIPS' relation to current indoor positioning strategies, highlighting differences and similarities. In *chapter three* we shortly discuss the sensor layer, where different radio based technologies gather different information about the quality of their radio link quality to their neighbours. Subsequently, *chapter four* elucidates measurement and conversion of these metrics into meaningful values that can be related to distances (with the help of appropriate radio propagation models). Thereafter in *chapter five*, these measurements are collected at the fusion layer, where they are weighted, filtered and refined, in order to determine the best fitting position. Finally, in *chapter six*, the paper is concluded.

2 Related research and Innovations

In contrast to existing indoor localization systems, GRIPS *does neither depend on expensive positioning hardware* (like Video, UWB or Ultrasound like in [1],[2]*) nor on time-consuming, non-reusable environmental profiling* (extensive radio signal strength measurements at many different locations in the building like in [3],[4]). Therefore, GRIPS is both: quickly deployable, as well as cheaply utilizable; hence GRIPS is applicable in many indoor scenarios, enabling location based services in various different situations (emergency-scenarios as well as standard office/museum/shopping mall environments). Not only its generic design (which makes GRIPS applicable to (m)any radio based technologies), but also GRIPSs capability to locate passive (non-cooperative) devices (like Bluetooth/WLAN based handhelds/mobile phones) permits GRIPS to be deployed in a quite universal manner.

Apart from highly expensive positioning hardware solutions [1] [2], existing positioning systems like RADAR [3] or EKAHAU [4] solve this uncertainty, by extensively profiling the environment during an offline phase. This is not only time consuming, but also not reusable if anchor devices change their position or if simply the environment changes. Apart from that, these systems require a minimum of three access-points, which are not available in many scenarios. Furthermore, these systems are not capable of tracking devices that are not actively participating in the network.

Whereas a great amount of scientific research efforts concentrated on simulations (e.g. with OMNET), investigating many different algorithms in order to improve positioning accuracy, many other investigations concentrate on the integration of special positioning hardware, also in pursue of accuracy enhancements. However, market surveys have shown that vendors, as well as customers would only utilize location-sensing technologies, if these enabling technologies were *low cost*, *easily installable* and would *support a large scale of wireless technologies*.

Whereas we clearly forbear from integrating highly expensive positioning hardware, we adopt the benefits of sophisticated radio propagation models as well as the advantages of light weight positioning algorithms. By means of extensive environmental radio scans, we first integrate all available radio enabled devices in the target zone (Access Points, WLAN-, Bluetooth-, RFID-devices) and if this is not enough, we cover the environment with inexpensive beacons (Bluetooth, RFID tags). This strategy allows a quick setup, especially interesting for emergency scenarios.

3 System Design

Generally spoken, it is possible to estimate the position of any radio device, as soon as three non-collinear anchor devices are able to sense the current radio signal strength of the device. This is not only true for 802.11a/b/g-enabled devices, but also for Bluetooth, RFID, ZigBee or WiMax systems. It therefore makes sense to design a system, which is capable of sensing radio-enabled devices, no matter which specific transmission/reception technology is used.

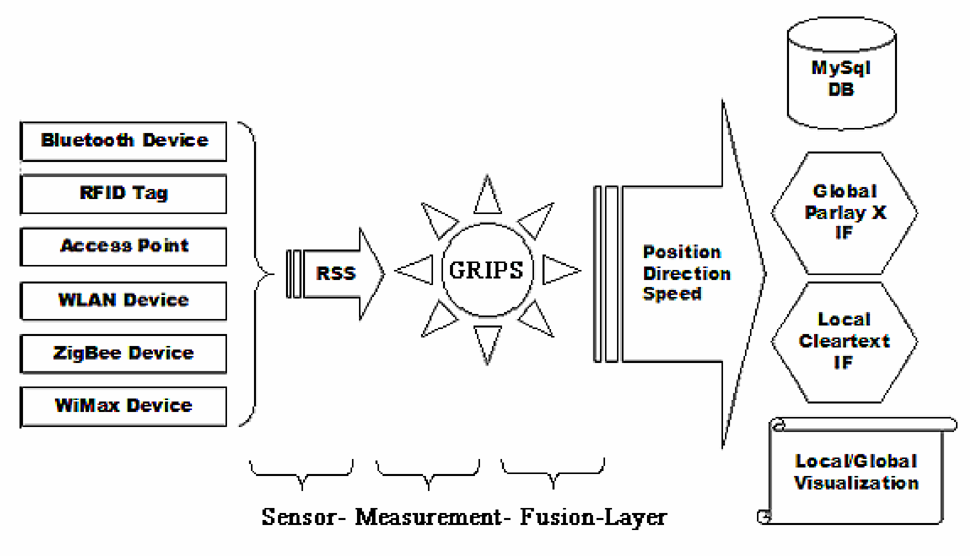

Figure 1 GRIPS data processing schema

Figure 1 shows the different RSS measuring interfaces, as well as GRIPS different interfaces for position propagation. The following figure 2 outlines GRIPS basic procedures in order to independently locate and position scanned devices. We chose the local strategy not only to increase robustness, but also in order to improve scalability.

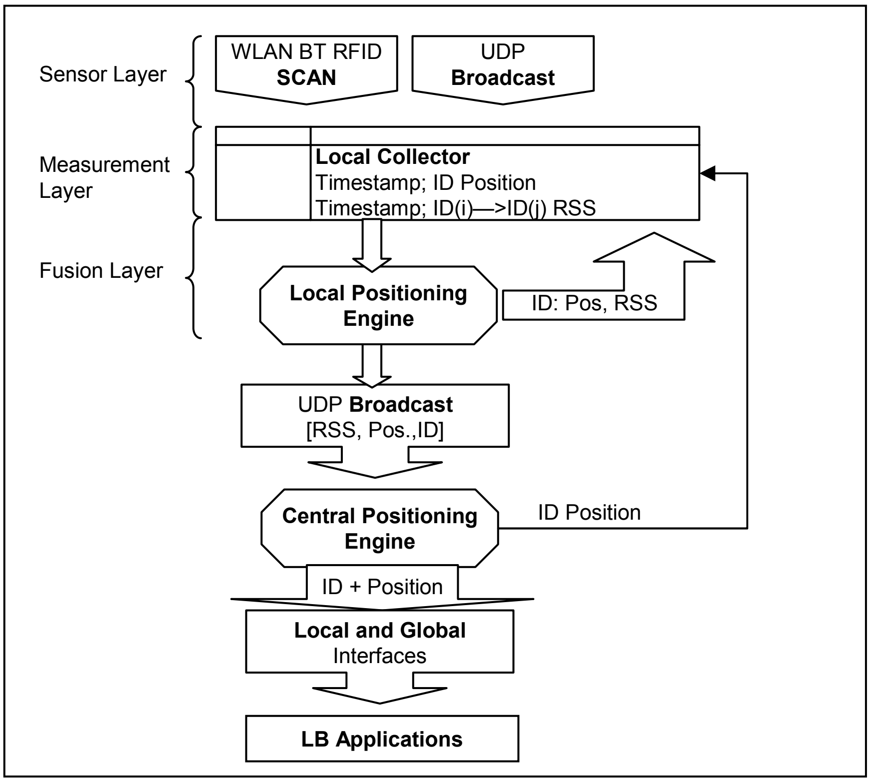

Figure 2 Local RSS retrieval and propagation

3.1 Sensor Layer

The sensor layer consists of location and/or radio signal strength sensing hardware and software drivers for detecting raw data. As recommended by currently active scientists [5] [6], a combination of many different wireless technologies improves not only location accuracy/availability, but also stabilizes the localization in case of device-/network- failures or break downs. Since our architectural premises were low cost and broad availability, we primarily focused on WLAN, Bluetooth and RFIDs.

Interface	Metrics measured	Fixed Information
WLAN	Radio Signal-Strength	Type / Position
Bluetooth	Radio Signal Strength Indicator or Link Quality	Type / Position
RFID	Radio Signal Strength or TX-Power Proximity	Type / Position

Table Fehler! Kein Text mit angegebener Formatvorlage im Dokument.**-1 Sensor layer output**

3.2 Measurement Layer

Different wireless technologies, deliver different metrics for perceived signal strength. Apart from radio signal strength (RSS), denoted in dBm or mW, the received signal strength indicator (RSSI) are commonly reported, but also perceived radio signal quality (SQ) or even the bit error rate (BER) are used. Moreover, even within one specific transmission technology, there exist big differences of transmission levels, not only due to chipset differences (e.g. Bluetooth classes I-III), but also due to differences in hardware integration (e.g. built-in vs. external). What makes conversion even more difficult is the fact that RSSI specifications differ from vendor to vendor.
Therefore, in order to derive distance from RSS measurements accurately, we integrated a generic mapping methodology. Either one provides the positioning system with a number of parameters (transmission-/reception gain, frequency) which clearly specify how to translate and convert measured RSS(I) metrics into meaningful units, or the parameters have to be specified empirically, by measuring them at fixed, known distances, with the help of already calibrated receivers and transmitters.

Position	Relative position based on specific propagation model
Uncertainty	Based on preliminary empirical results
Timestamp	Indicates the time when the measurements been taken

Table Fehler! Kein Text mit angegebener Formatvorlage im Dokument.**-2 Measurement layer output**

Also here, at the measurement layer we designed ORPS to deliver both classes of positioning strategies, i.e. mechanisms that continuously map RSS to distances (with the help of propagation models and positioning algorithms), as well as proximity measurements that only deliver information about whether or not a device is in range. It shows that by varying the RF power of the RFID reader, much better short range granularities can be achieved than by measuring continuous RFID RSS. Therefore we decided to measure the proximity of short range (0-10m) RFIDs, whereas we measure continuous RSS from all other long range signal sources (WLAN, Bluetooth and Long Range RFIDS). Figure 3 shows that especially very short ranges (1-4 meters) as well as medium ranges (7-9 meters) can be measured with accuracies up to 1 meter.

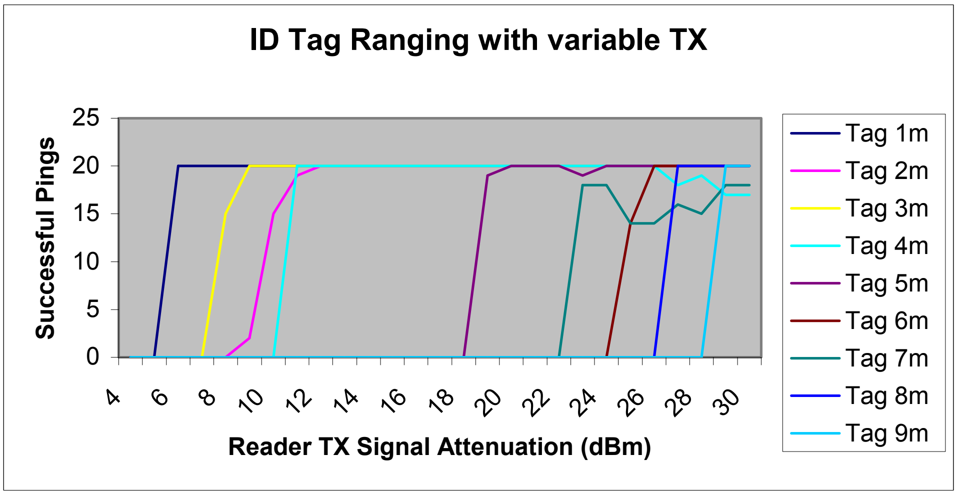

Figure 3 Room based short range RFID ranging

3.3 Fusion Layer

Collaborative nodes that run the scanning, positioning and broadcasting client software are the vitally important components of the location-enabled network (in our prototype system we use 3850 IPAQs with Bluetooth-, WLAN-Interfaces and PCMCIA RFID-Readers, running familiar Linux). Either they only localize themselves, or they also compute the position of passively tracked devices.

Position Uncertainty Timestamp	Absolute and/or relative, obtained by superimposing all available position information Derived by means of geometrical reasoning, based on empirical results Indicates the time when the measurements been taken

Table Fehler! Kein Text mit angegebener Formatvorlage im Dokument.**-3 Fusion layer output**

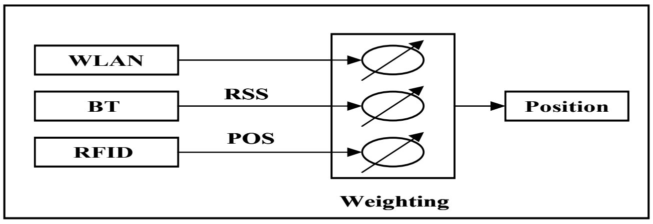

Figure 4 Fusion layer weighting mechanism

Depending on the equipment of the tracked/located device, the overall position estimation accuracy ranges from +/- 3m in case of solely WLAN equipped devices, to +/- 80cm in case of WLAN and RFID equipped devices. These measurements assume an anchor node density of 4 WLAN reference points (APs/Nodes) per 50 qm². The static WLAN based device is located at X=250cm and Y=500cm. The anchor nodes are placed at the edges of the room (5mx10m).

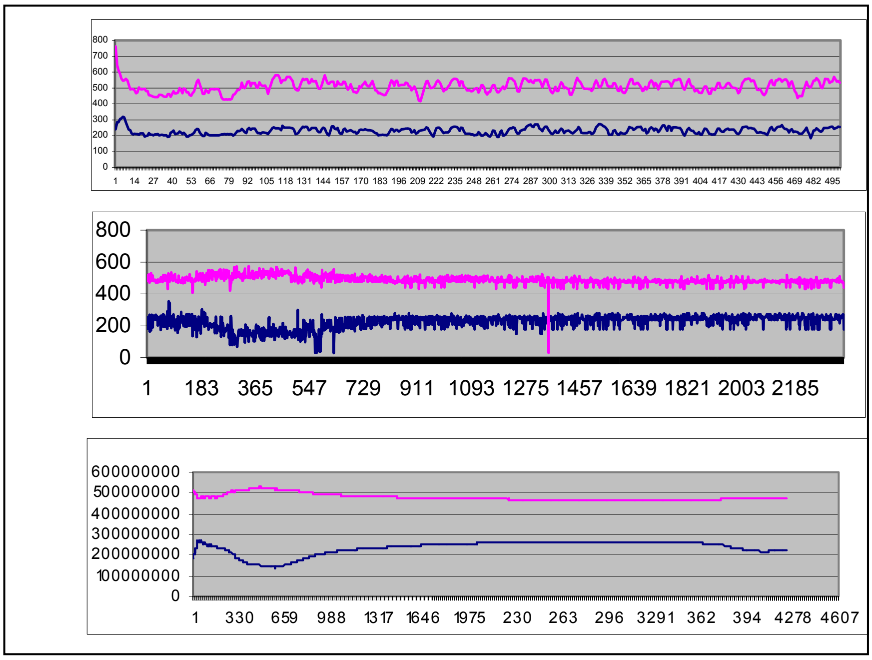

Figure 5 Mass Spring model, atomic ML, and Kalman ML

	M. Spring M.		Atomic ML		Raw ML		Ideal	
X/Y	X	Y	X	Y	X	X	X	X
medium X/Y	230	510	203	499	240	476	250	500
variance	20,20	34,67	21,93	55,66	1,67	8,65	0	0

Table 3 Positioning Algorithm statistics compared

In contrast to geometry based algorithms (like the Multilateration), the mass spring model does not depend on geometric reasoning. It simply converts RSS to "forces" like the gravity of a weight on a spring and adjustably dampens the velocity. Table 3 shows that the bare multilateration performs weak compared to the mass spring model, whereas the Kalman enhanced multilateration outperforms the others. However the mass spring model is much simpler to implement and tune.

Whereas the above accuracy can only be achieved with a high anchor node density (4 anchors per room), the building wide positioning is enhanced by RFIDs beacon placement. With a minimum of 3 long range anchors (WLAN, Bluetooth or Long range RFIDs), and a minimum of 1 beacon every two rooms, a continuous tracking of room sized granularity is achieved. WLAN devices or short range RFIDs can be placed wherever higher resolution is desired. RFID beacons deliver spot resolutions of +/- 1 meter, whereas 4 WLAN anchors, deliver continuous room wide resolutions of 1 meter, for a 10x10 meter room.

This is GRIPs solution for indoor localization that can be setup instantaneously, without extensive a-priori environmental signal strength profiling [3][4]. The "accuracy by beacon density"-approach, surely has its disadvantages, especially when it comes to "non-off-the-shelf" hardware such as RFID readers. However, cheap WLAN and Bluetooth beacons are currently developed, that soon will replace special positioning Hardware, delivering cheap indoor location based services.

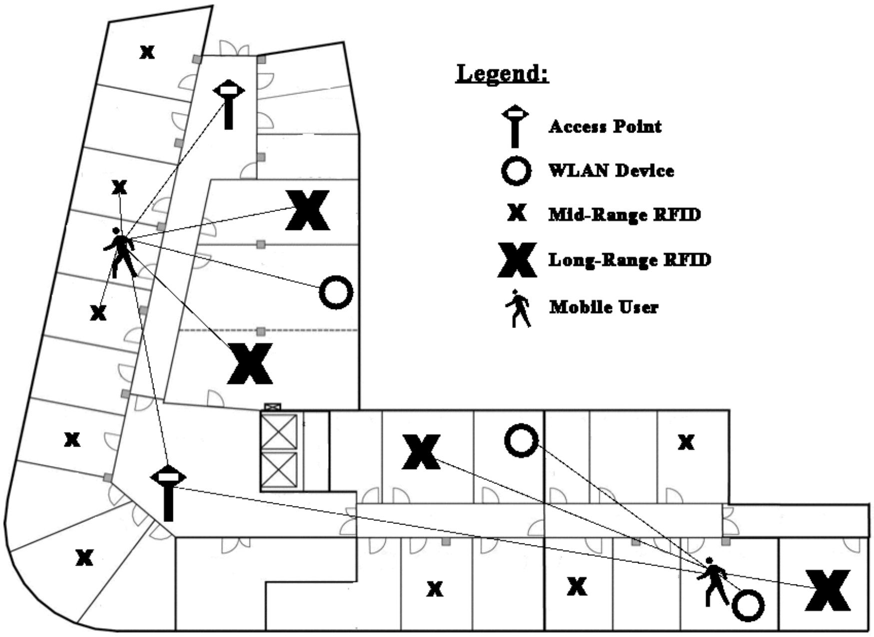

Figure 6 Floor-wide room-granularity with continuous tracking

4 Conclusions and Outlook

Although a great number of scientific research efforts intensively dealt with indoor positioning strategies and concepts, yet there is no common agreement on necessary procedures, recommended technology or data exchange standards. Therefore, from a scientific point of view, the most valuable part of the GRIPS project is the attempt to unify and classify specific procedural steps. Whereas [6] differentiates sensor-, measurement- and fusion- layer, the "location stack" proposed in [5] additionally differentiates four more "higher" layers that deal with applications that deliver derived information like orientation, position history, acceleration and speed. Whereas we did not concentrate on the higher layers of these frameworks, we studied and implemented a generic location sensing architecture, differentiating sensor-, measurement- and fusion-layer modules. Thanks to this modularity, we have implemented a test-platform enabling us to study feasibility, applicability and usability of higher layered features in the near future.

This work has been performed in the context of FOKUS 3G beyond Testbed, known as "National Host for 3Gb Applications", sponsored by the German ministry of Education and Research (BMBF). This testbed provides different kinds of fixed and wireless next generation network technologies and related service delivery platforms. [7] [8]

5 References

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