

Cooperative Positioning with MagicMap

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Abstract—We present MagicMap, a cooperative, hybrid positioning system developed at the Humboldt-University in Berlin. While most other positioning systems are limited to specific scenarios and technologies our system provides means to incorporate any available wireless networking technology. Currently, MagicMap supports WLAN, RFID, and ZigBee as wireless technologies for positioning and Linux, Windows, and Windows CE as platforms. Position calculation and exchange is based on a cooperative approach allowing an open internet community to share the required data.

Index Terms—cooperative, hybrid, indoor, positioning

I. INTRODUCTION

THE service landscape of tomorrow will differ from the one we know today. Instead of a world where the user is required to find the service he needs, services will be tailored to the exact requirements of the user in his current situation. Personalized services are already widespread and accepted. Internet shops try to offer interesting products to the customer depending on what he bought and looked at before. Location Based Services (LBS) are the next step. These services are provided in relation to the current position of the user. In future, there will be context aware services that react on the user's situation.

Position information is the key to location based services. Many systems today are offering position information. The best known one is the Global Positioning System (GPS) [1] using satellite signals to determine the position. The achievable average accuracy lies within a few meters. The coming European system Galileo [2] promises an even better accuracy. A major problem of satellite based positioning systems is the bad reception in downtown areas where tall houses shield the signals. This shadowing of signals causes the complete failure of these systems in indoor environments.

Operators of mobile phone networks (GSM) provide positioning of mobile phones. They determine the phone's position using the associated base station and the timing advance (TA) parameter. However, accuracy based on this technology significantly depends on the density of base

stations. In urban areas with a cell size of around 200 meters positioning accuracy of 100m is achievable, whereas in rural areas position estimation may result in several kilometers of deviation. Such degree of inaccuracy does not satisfy the requirements of most indoor positioning applications.

There are several systems that provide more accurate indoor positioning using proprietary technologies. These systems require additional hardware installed in the area of interest but once set up they provide average accuracy of a few centimeters. Examples are [3] and [4].

There are many attempts to realize positioning using standard wireless networking technologies (see section II). These systems are based on WLAN, Bluetooth, RFID (Radio Frequency IDentification), or ZigBee (a standard for communication in low-power ad hoc sensor networks based on IEEE 802.15.4). Most of these solutions, however, are usually limited to one kind of technology. They are focused on pre-installed environments equipped with their senders and receivers. Typically they have been tested in research laboratory conditions only.

The reason for this is that such systems often require information about their position sensing environment which is available only at their testing site. Outside the laboratory this information is missing and positioning is not possible.

One key aspect of providing reliable position sensing with little infrastructural overhead lies in the integration of all these different technologies and information sources. Not all technologies will be available everywhere. Some points of interest may need higher accuracy than others and therefore may be equipped with additional senders or sensors. These senders are useless unless their position and transmission behavior is known to the positioning client.

Here, we propose MagicMap (www.magicmap.org) as solution approach to these problems. MagicMap is a cooperative positioning system that uses a combination of various wireless networking technologies to determine the client's position.

This paper is structured as follows: The next section presents other positioning systems that use wireless networking technology as well. Section III comprises a summary description of the entire system while section IV focuses on the technologies and algorithms used. Section V focuses on the cooperative aspect of MagicMap and the MagicMap community. A description of how the MagicMap system incorporates various wireless networking technologies is given in section VI. Our client for Windows Mobile is described in section VII. The last two sections give an

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overview of our test results and experiences with MagicMap as well as a conclusion and future plans for further development.

II. RELATED WORK

Some other research projects and commercial products are offering positioning using WLAN or other wireless technologies. Depending on the system and used technology different accuracies can be reached. Accuracy in the context of this paper means the maximum distance between measured and actual position.

The Horus system developed at the University of Maryland [5] and the RADAR system by Microsoft Research [6] are using a WLAN signal strength map for positioning. In laboratories they reach accuracy of less than three meters but are requiring huge initial effort to set up the signal strength map. A similar system is being developed and offered by Ekahau [7]. These systems work only in areas where enough WLAN access point signals are received (at least three) and need to be recalibrated in case the infrastructure is changed.

The Place Lab system by Intel Research [8] is pursuing an opposite approach minimizing the needed initial effort. The system provides WLAN positioning in a whole city. The needed data is gathered by “war driving” (driving around in a car and collect WLAN access point signals). The achieved accuracy is much less but the system is less susceptible to changing infrastructure.

Systems based on RFID technologies for positioning are offering slightly better accuracy [9] but cannot be built on existing infrastructure. Additional RFID tags and readers have to be installed in the area of interest.

Bluetooth positioning systems need additional hardware to be installed as well. Depending on cell size these systems reach accuracy of up to two meters [10, 11].

III. MAGICMAP SYSTEM

While most positioning systems are specialized for certain positioning scenarios within a specific environment, MagicMap follows a broader approach. It is targeting on the utilization of any available radio signals in order to provide a



Fig. 1. MagicMap system architecture

comprehensive positioning platform – independent from a specific radio technology. Therefore, generic support for different radio technologies is provided and it is possible to

use more than one radio technology for positioning at the same time. This leads to a better spatial positioning coverage, higher dependability, and an increased accuracy at places where multiple radio signals are available.

MagicMap incorporates client-server architecture (Fig. 1.), with a distributed approach of position data propagation [12]. An open web service interface on the server side allows easy server access within most infrastructures.

The MagicMap server is the system component which is responsible for data distribution, persistency and user

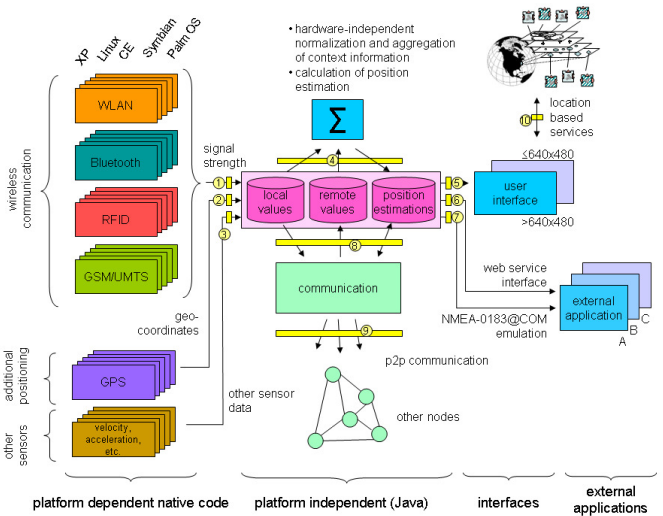


Fig. 2. Architecture of the MagicMap client

authentication. Map administration and sharing is also located on the server. An additional HTML / KML (Keyhole Markup Language, an XML-based language for managing three-dimensional geospatial data) interface allows easy Google Earth integration of the positioning data. We are currently hosting an open research server, where everybody can register, add new maps and join existing maps. However, there are scenarios where it is not reasonable to use a dedicated server but to distribute the server duties among the clients. For such purposes, we currently work on the integration of a peer-to-peer shared memory system we developed in MagicMap. Here, certain clients overtake the server’s functionality – and thus make it possible to run the system without a server.

The key functionality of the MagicMap system is implemented in the client software. It contains all the features which form MagicMap’s advanced positioning capabilities.

While MagicMap generally is platform-independent (both client and server are implemented in Java), drivers of radio adaptors are generally not. Hence, the actual position calculation (Fig. 2. center) is independent of the proprietary components (Fig. 2. left). It is possible to attach any radio technology (which is able to measure signal strengths) – like WLAN, RFID and ZigBee – to MagicMap (Fig. 2. (1)). Additionally, pre-calculated location data (e.g. GPS positions, Fig. 2. (2)) and other sensor data – like e.g. acceleration or velocity – can be included (Fig. 2. (3)) to gain increased accuracy. For position calculation, all signal strengths are

normalized and aggregated with potential context information. In case different radio technologies are plugged in, their information is aggregated regarding the expected accuracy (see section VI for details).

Being part of a distributed system, every MagicMap client is able to calculate its own position as well as the position of any other client (Fig. 2. (4)) within the MagicMap environment. Thus it is possible that clients with higher computing power calculate the positions of clients with little computing capabilities. Signal strength and position data are thereby communicated (Fig. 2. (8)) over a communication interface, which transmits these data to the MagicMap server (or to other MagicMap peers, in a future peer-to-peer environment).

User interface (Fig. 2. (5)) and external interfaces are well-defined to make an easy adaptation for different use cases possible. MagicMap currently features a web service interface for data exchange (Fig. 2. (6)), and we have planned to integrate a NMEA interface (defined by the National Marine Electronics Association used by marine instruments and most GPS receivers) (Fig. 2. (7)) in future.

Due to this modular architecture, MagicMap can be used for a broad range of location based services. Because of the simple integration possibility of any available radio technology, it can provide an economical solution in areas where the buildup of special positioning infrastructure is beyond budget. Furthermore, MagicMap can perfectly cope with radio transition problems – a domain where many other positioning systems fail.

IV. POSITION ESTIMATION CONCEPTS

MagicMap features positioning using the received signal strengths of the participating access points (APs). To be able to do this, the conversion of signal strengths values to distance values is of the essence.

Modern wireless adapters are able to gather information about available access points and their signal properties. These can be measured as Received Signal Strength Indication (RSSI) and Signal-to-Noise Ratio (SNR). Dependent on the wireless adapter and manufacturer, values between 0 and $maxRSSI$ (typical values are 60 to 100 value steps) are possible.

Let $RSSI_{i,j}$ be the signal strength of sender j , measured at receiver i . $RSSI_{i,j}$ is dependent on the distance $d_{i,j}$, on $maxRSSI_i$ of node i , on transmitting power P_j of node j and stochastic sources of irritation. Manufacturers are to calibrate the RSSI value in relation to certain decibel – but naturally they only approximate this requirement. Additionally, physical obstacles and directivities of antennas disturb the RSSI-distance-correlation considerably. To compensate these stochastic influences, we assign $RSSI_{i,j}$ as average over several measurements. With a simple approximation we received quite good distance estimation:

$$d_{i,j} = \maxRSSI_i - RSSI_{i,j} / P_j$$

We have measured the values $maxRSSI$ and P_j for different WLAN hardware and our RFID and ZigBee equipment. For deviating equipment, reference measurements must be performed, in order to determine these values. Through a mapping of these distances to a map, position estimations are possible, even without a radio map. Our tests on the university campus in Berlin Adlershof showed a typical deviation between 5 to 10 m.

For mapping of distances to a map, a planar projection of the distance edges must be performed. During that operation, the edges lengths have to be aligned – some edges need be elongated, some shortened. Not fixated points move to their most probable position. Overall, a quite good concordance with the real positions is the outcome of this process.

Because of the mobility of some nodes, perpetually updates of signal strengths lead to permanent new projection and optimization. For this, we use the spring layout of a modified version of the JUNG framework, which tries to represent the graph as distortion-free as possible.

In the spring layout, access points, reference points, and clients are each represented as node. The measured signal strength between access point and client or reference point is represented as an edge. The length of this edge has been described above. The distance between clients and reference points is computed by summing up the differences between the seen signal strengths. A normalization factor is computed when access points are fixated, i.e. their position is considered to be known. The average ratio of all edges between clients and access points to distances is taken as scaling factor for the map and client positioning. Currently, map matching is not done but it is a planned feature for future releases.

Drawback of this algorithm is that it leads to unwanted averaging if less than three nodes are around. This is caused by the fact that reference measurements around a single point with no receivable neighbors will converge at the center, since this is the center of all likely positions. This is a general problem for all positioning systems. With our support for potentially any radio technology, this will eventually only be a theoretical problem – there will almost always be more than one radio signal at a place.

Still, we have also integrated another strategy to cope with this problem – our modified version of the Jung framework allows dragging of nodes, in case of position inaccuracy. A stronger emphasis on short edges ensures the convergence of the graph to a local maximum. If the peer movements are not too dynamic, the graph stabilizes after a short while and the map shows an overview of the clients' positions.

V. COOPERATIVE POSITIONING

Cooperative positioning facilitates positioning for every user of the system by sharing infrastructure data among all users.

Positioning systems need information to determine the client's position. GPS, for example, provides knowledge of

the movement and position of the satellites in orbit to the clients. Similarly, positioning systems based on wireless networking technologies such as WLAN, Bluetooth, RFID, or ZigBee, use information about signal origins, e.g., positions of WLAN access points or RFID tag readers and signal propagation, e.g. given by an a priori created signal strength map.

The MagicMap system is based on knowing the positions of as many senders and reference measurements as possible. This information is often difficult and time consuming to collect. WLAN access points and other network components have to be accurately placed on a map to achieve sound results. The more technologies are involved in the positioning calculations the more complex and error-prone this procedure gets.

MagicMap is reducing this effort for every user by sharing existing information among the community. Every user may create new maps, drag access points to their place and save this information on the central server. Other users can download this information and use it for positioning. By adding more information to a map or revising existing information the accuracy of the position calculation is improved for all users.

We have started to create a community that shares information about position information at different locations on our server. The aim is to have not only a system developed as open source but to have the data also as property of the community as kind of “open data”.

Another form of cooperative positioning currently developed in the MagicMap project is to share the measured signal strengths in real time among the clients. This will allow clients to adjust easily to changing environments. A second current research topic is the sensing of signal strength among the clients themselves, not only among clients and fixed hardware which will lead to further improvement of accuracy. Most existing communities for WLAN based positioning allow cell based accuracy only [14, 15]. MagicMap is currently the only cooperative positioning system based on multiple wireless networking technologies which allows signal strength based hybrid position sensing.

VI. HYBRID CONCEPT

A major drawback of many positioning systems is their limited operational area. GPS does not work indoors, and GSM – which has probably the widest coverage – is way too inaccurate. Many concepts have evolved to bring positioning techniques to places uncovered by satellite positioning systems – but yet not with a real generic approach for a comprehensive solution. Additionally, many new radio technologies will be entering the market in the close future. The mass circulation of RFID is just at the beginning, ZigBee has just entered a mature state, and with Ultra Wideband (UWB) a new radio technology will enter the area of home and office periphery. Thus, it can be assumed, that all these technologies will provide additional radio information, which

can also be used for positioning.

This diversity is another reason why MagicMap allows the integration of any radio technology, as long as it provides signal strength information. Due to the increasing number of available radio technologies, this broadens the possible applications for MagicMap. Though, the crucial benefit of this ability is that it is possible to use several radio technologies *simultaneously*. This increases both accuracy and reliability of the position calculation.

For optimal results, our hybrid concept does not just build the average of the measured positions per technology. Instead, the distances are calculated separately for every node independently – no matter of which technology it belongs to. In addition it is still possible to supply the different technologies with varying weightings to address differing accuracies of radio technologies. In figure 3 nodes with technology 1 have more weight than those with technology 2 during position calculation.

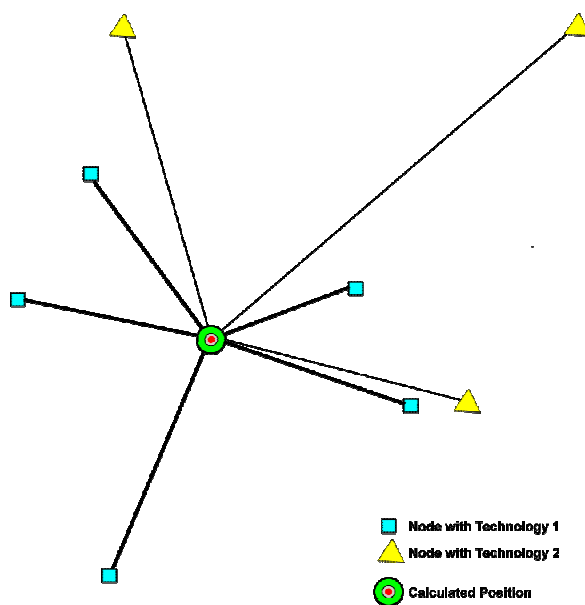


Fig. 3. Hybrid aggregation method

Using this technique, we have measured an accuracy improvement of 33% in average. In areas, where one significantly more accurate radio system is present (in our case an RFID reader with an average positioning accuracy of 0.5 m) we measured an improvement of 60%.

In addition to the increased accuracy, our hybrid technique makes the positioning system much more reliable. Assuming a reliability of 0.9 for each participating radio system leads to a reliability improvement of factor ten, when using two instead of one radio technology simultaneously (Fig. 4.).

Of course, positioning costs in terms of needed hardware and energy double in the worst case. However, the future will most likely show that each additional technology adds only little additional costs – even today it is common for smart phones to incorporate GPS, WLAN, Bluetooth and GSM at a time. A system which is able to use all these technologies will

just take advantage of the devices' capabilities.

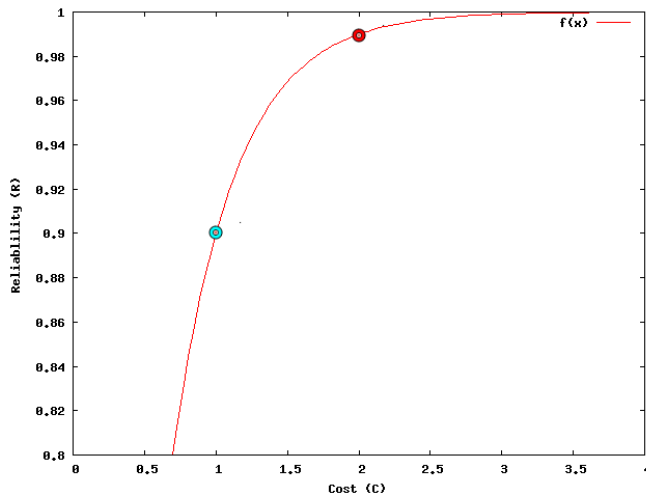


Fig. 4. Reliability improvement

VII. MAGICMAPCE

Many mobile devices developed today such as PDAs or mobile phones are running on Microsoft Windows Mobile. To provide position information for this class of mobile devices we developed a client running on MS Windows Mobile 2003/2005 with the .NET Compact Framework 2.0. To read the required data of the WLAN adapter the client uses the OpenNETCF framework (an independent repository for information and shared-source projects specifically targeting the Microsoft .NET Compact Framework). The core data model is ported from JAVA to Windows CE as many technologies used for the JAVA client are not available on Windows CE such as the SWING GUI and the JUNG framework. It has been completely rewritten in C#. All other components of the CE client are developed independently from the JAVA version.

The newly developed graphical user interface (Fig. 5.) allows scrolling of large maps, zooming, provides information on objects on the screen, and allows intuitive manipulation of positioning data. Access point and reference point positions can be altered by drag and drop, new reference points can be added, and the server communication can be adjusted.

The CE client supports some additional functionality that is not provided by the JAVA version such as filtering of access points and listing all available data. These features were implemented during testing and proved to be very useful. Therefore we decided to support them in the final version.

Besides the client/server mode the CE client supports an offline mode which allows operation while the client is not connected to a server. Maps can be locally saved and positioning data can be adjusted without the need for a communication link to the server. All necessary settings can be done on the client.

The client supports a caching mechanism that saves data collected or entered while the client is in offline mode. When a map is loaded from a server and the communication

between client and server fails, no data is lost. It is transmitted to the server the next time the connection is reestablished.

As opposed to the JAVA version the CE client architecture provides a standardized interface for algorithms. This allows easy testing of different algorithms used for position computing. They can be selected and configured during use. Therefore the optimal algorithm for each different situation (different technologies, indoor/outdoor) can be chosen and adjusted.

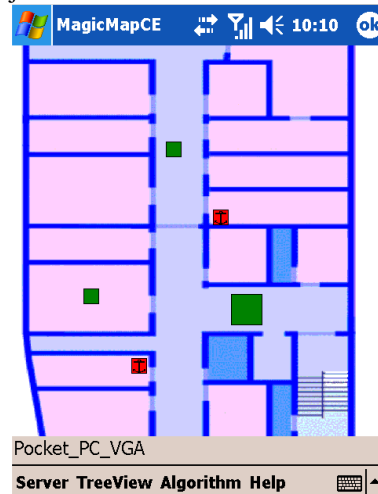


Fig. 5. MagicMapCE client – main screen

Further adaptivity is added by so called node selectors. To reduce the complexity of positioning in case too many access points, clients, or reference points are included in the map data these filters allow excluding nodes following specified criteria.

The extension of supported platforms from JAVA technologies to CE devices enables a new group of devices for positioning. CE devices are usually smaller and therefore more mobile than devices supporting standard JAVA virtual machines (J2SE).

VIII. EXPERIENCES / TEST RESULTS

Dependent on the environment we measured positioning accuracy between 5 to 10 meters when using WLAN. With reference measurements accuracy up to 2 meters is possible.

The structure of the environment and the number and positions of access points play a major role for successful positioning. Generally, accuracy improves with increased number of access points. On the other hand, MagicMap relies on communication between server and clients, which is typically working wirelessly as well. Too many WLAN access points lead to communication problems (since there are only 13 radio channels (11 in the US), from which only three can be used without overlapping). We experienced these problems at CeBit 2006, where more than 50 access points where within reach simultaneously.

Additionally, the number and quality of reference measurements has a significant influence on positioning results. Tests suggested an optimal relation of reference

measurements to area of one to four (1 RP per 4m²).

Our hybrid method using WLAN, RFID and ZigBee lead to an average 33% improve of accuracy in areas where at least two technologies were available. The results in figure 6 show the first test environment comparing WLAN, ZigBee and our hybrid approach (with 14 WLAN reference points). WLAN showed an average accuracy of 1.82 m, ZigBee showed an average accuracy of 1.94 m, our hybrid approach showed an average accuracy of 1.20 m.

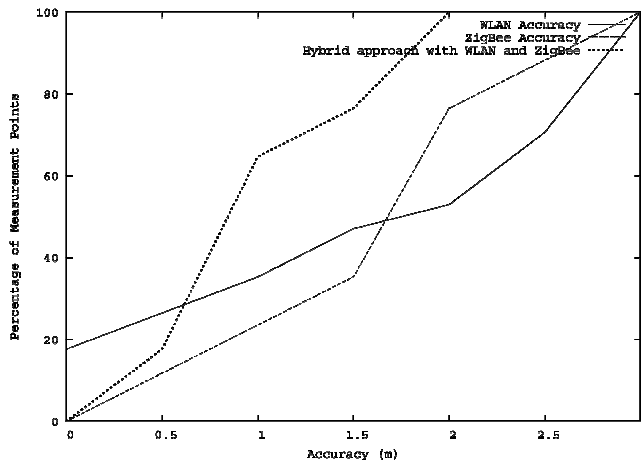


Fig. 6. Accuracy comparison of WLAN, ZigBee and hybrid approach.

In figure 7 WLAN, ZigBee, RFID and our hybrid approach are compared. WLAN showed an average accuracy of 1.4 m, ZigBee 1.45 m, RFID 0.7 m. Our hybrid approach reached an average accuracy of 0.4 m in areas covered by RFID and 1 m in areas without RFID.

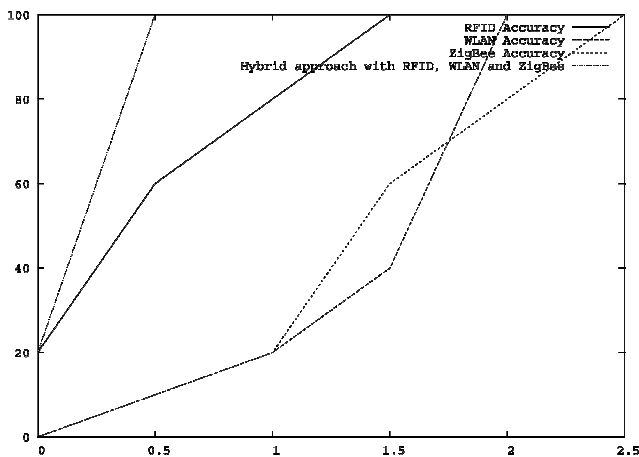


Fig. 7. Comparison of accuracies using WLAN, ZigBee, RFID and our hybrid approach.

We also measured differences between the use of standard laptops and PDAs. The smaller size of the PDAs, requiring smaller antennas lead to a greater sensitivity to signal absorption.

IX. CONCLUSIONS AND OUTLOOK

Our experiments showed that hybrid positioning leads to a significant improvement of accuracy. Coverage for positioning is improved as well. MagicMap's standardized

interfaces make it open to support any wireless networking technology. This integration of standard technologies is a major strength of the MagicMap system and we aim towards the incorporation of more standards. To make positioning available to a wide community of users we think that our concept of open source and open data provides a feasible solution to create and distribute the needed infrastructure information.

We currently work on 3D positioning as a major step for increased accuracy as in normal office environments there are access points on every floor. Another current task is the integration of info objects that allow to link information to places and devices in order to provide additional value to the users. This information can be created and maintained by the community similar to the infrastructure information. The next technology we want to integrate is Bluetooth since it is widely supported by devices available today.

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