

# AN INDOOR LOCALIZATION SYSTEM USING ACTIVE RFID TECHNOLOGY

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## Zusammenfassung

Im Jahr 2009 wurde das „iCampus Wildau“ Projekt an der Technischen Hochschule Wildau [FH] initiiert, ein Projekt, das vorrangig durch die Mitarbeit von Studierenden des Studiengangs Telematik geprägt ist und der Leitung von Frau Prof. Dr. Mohnke unterliegt. Das große Ziel liegt in der Schaffung eines mobilen und multilingualen Campus-Informationssystems, das es Besuchern, Studierenden und Mitarbeitern der TH Wildau [FH] ermöglicht, einen schnellen und übersichtlichen Einblick in alle Domänen des Campus zu erhalten.

Neben Höhepunkten in der Softwareentwicklung, darunter die Programmierung von Smartphone- und „Rich Internet“-Applikationen, beschäftigen sich die Projektmitarbeiter auch mit der Entwicklung und Evaluation eines Indoor-Ortungssystems in der Hochschulbibliothek, das seitens der Hardware auf aktiver RFID-Technik, die im lizenzfreien 2,4Ghz ISM-Band arbeitet, aufbaut und seitens der Software auf einem Open-Source Projekt mit dem Namen „OpenBeacon“ basiert. iCampus' Ziel ist es, das System durch Anpassung der Firmware der OpenBeacon-RFID-Tags und (Weiter-)Entwicklung von Ortungsalgorithmen so zu stabilisieren, dass es auch in kritischen baulichen Gegebenheiten zuverlässige Ergebnisse liefert und universell einsetzbar wird.

iCampus Wildau (2012)

## Abstract

In 2009 the „iCampus Wildau“ project started at the Technical University of Applied Sciences in Wildau. It is a project mainly driven by students of the Telematics course under the guidance of Prof. Dr. Janett Mohnke. The main goal is to set up a mobile and multilingual on-campus-information system, providing visitors, students and employees a quick and clear overview of the facilities of the different university domains as well as information about special events.

Besides highlights in the field of software development such as programming smartphone and rich internet applications, the iCampus project team develops and evaluates an indoor localization system in the university's library that is based on active RFID technology, working in the 2.4GHz ISM-Band and OpenSource software, namely „OpenBeacon“. Reaching the main target, which is stabilization of localization results and universal usage in almost every critical constructional area, is achieved by the adaptation of the RFID tag's firmware and the further development of localization algorithms. Detailed descriptions from the hardware and software side as well as a discussion of the perspective of this technology will be made in this paper.

iCampus Wildau (2012)

## » I. INTRODUCTION

At the University of Applied Sciences in Wildau (Germany) students establish a multi-platform and multi-lingual on-campus-information system. With the help of simplified maps, professional audio tracks, and high resolution panorama pictures a user is guided across the campus and provided with current information about visible and invisible services and options.

A content management system allows adding any multimedia content, which will be useful for a visitor. In this way, the system can be used to deliver permanent information about the facilities of different university institutions as well as temporary information about or for certain events. The content can be provided in different languages,

which again is of great value to international students and visitors.

There are several possibilities to use iCampus Wildau: On mobile devices, like Apple's iPhone/iPod Touch or Android based smartphones and in any modern web browser. The application acts like a virtual guide for its users. Because of its modular and general approach, the guide has been used for several, quite different purposes. There is a multimedia guide introducing new users to available services of the university's library, there are two virtual campus explorations, one for new students and one for visitors of the university and there is a guide giving insights into the campus architecture. (iCampus Wildau (2012))

iCampus Wildau is an active-minded project where new ideas and approaches are investigated and tried out. One of these ideas involves the improvement of the guide's usability by involving the user's location, so a location based service can be provided in this virtual exploration. By automatically providing the „Here I am“-information, the system can be more convenient for the user.

As long as the guide is used outside, technology such as GPS can be used to automatically determine the position of the user, presuming that the user has a device supporting GPS. However, this approach does not work inside of buildings because of the high signal loss. Therefore we want to use the RFID technology built by the



Fig. 1) iCampus iPod Application

Bitmanufaktur GmbH (Bitmanufaktur GmbH (2012)) and the software provided by the OpenBeacon project (OpenBeacon (2012)).

OpenBeacon provides an active 2.4 GHz RFID system which is based on Open Source software and Open Source hardware. All components are available under the GPL license and can be programmed and adapted using the C language. In the following, we first want to introduce some special knowledge that you need to understand the rest of the paper. Then we will describe the system, how it works, what the results are and what kind of other use cases are imaginable. Our results are based on field tests inside the library of the University of Applied Sciences in Wildau.

## » II. COMMUNICATION METHODS

### 2.1. Radio frequency identification

Radio frequency identification (RFID) means the clear marking of objects through electronically saved data. The objects identification data is transmitted via radio, where the used frequency bands are low frequency (LF, 100-135 kHz), high frequency (HF, 13.56 MHz) and ultra-high frequency (UHF, 868 MHz and 2.45 GHz). An RFID system consists of different types of components that will be explained below. (Finkenzeller 2012: 15ff.)

The first part to mention is the so-called “tag” which is the carrier containing the identification data of the

object. These tags usually have a very small construction form as they include an integrated circuit for storing and processing data and a modulation component as well as an (in some cases noticeable huge) antenna for data transmissions. The energy for running a tag can be supplied actively by connecting a battery or passively through the usage of the physical phenomenon of induction. When using passive RFID tags, the energy will be passed by electromagnetic waves emitted by the so-called “readers”.

Readers are important to RFID tags because it is their task to write data to and read information from the tags via contactless transmission. Generally, readers have an interface to talk to a computer or network so that the received data can be processed. The distance between tag and reader can vary from about 1cm up to many meters. There are also bulk readers which have the ability to read the information of multiple tags in the surroundings very fast.

RFID technology already had its hype in the years after 2000 (Finkenzeller 2012: preface), but is still present in many industrial and especially logistical fields. There are many uses: The university’s library uses RFID to lend books and for security reasons so that nobody leaves the building with an unprocessed book. Warehouses put personal clip tags onto clothing to avoid thievery, logistic companies want to track the way the containers go and we want to use RFID to localize people and maybe later books in our university’s library, too.

### 2.2. (Wireless) Local area network

Almost everyone has heard of the terms “LAN”, “WLAN” or “Wi-Fi” and knows that it describes some kind of connection between computers and mobile devices. In detail, local area networks enable the connection between two or more devices so that they can communicate. WLAN is the further development of LAN and received its detailed description in IEEE 802.11, an international communication standard. It works in the license-free 2.4GHz ISM-Band and is restricted in its transmission power to a maximum of 100mW. Dependent on the in-built radio unit and the surroundings, communication distances can be up to 100m. In most cases of usage the data packet exchange happens via an access point which mostly has an integrated DHCP-Server, distributing the network settings (IP, DNS-Server and Gateway) to new devices. The transfer rates in WLANs are between 11Mbit/s and 600Mbit/s, while the wired LANs reach rates in the gigabit range.

The largest advantage of Wi-Fi is that it is extremely easy to install and allows its users a certain mobility and flexibility in choosing the right place for their computer and device, respectively, whereas LANs always need fixed installed network sockets to get access.

## » III. HARDWARE COMPONENTS

### 3.1. OpenBeacon tag

The OpenBeacon tag, internally also called “reference tag” or “sputnik tag”, is next to the other devices one of higher importance. The core features are a PIC16F688 microcontroller built by the Microchip Company, the NRF24L01 RFID chip made by Nordic Semiconductors and of course the ceramic antenna. On its baseplate you can also find a touch interface, consisting of golden rings, providing the possibility of simple user inputs.

The tag is pasted into a plastic case so that it is resistant to external influences and easier to install on shelves and lockers. The OpenBeacon tag is an active tag because its energy supplier is a 3.6V AA battery that has to be changed after 1-2 years, depending on the usage. Although the implemented



Fig. 2) An OpenBeacon tag pasted in a case

firmware supports many functions for saving energy, changing the battery always means a lot of work. That is why there are plans to support the energy delivery by installing solar cells on the tags case in the near future.

The interesting thing about the tag's firmware is that it standardly allows transmitting with 4 different signal strengths, providing signal ranges from 5m to 25m. By setting a special pin inside the code, the output current can be limited so that the maximum range is less than 5m. This is called proximity mode and allows us to effectively use 8 different strengths. The package rate, which means the number of packets that can be sent out by a tag within a certain amount of time, is up to 50 packets/sec with a cyclic transmission of every signal strength.

### 3.2. OpenBeacon USB1

This component is very interesting for testing functions of surrounded tags by providing a view of the content of

the transmitted packets. The OpenBeacon USB1 also has a NRF24L01 on its board which is supported by a larger antenna, allowing much better reception quality. The device gets its power by plugging it into a USB port of the computer, which is done for a supported debug or for using output functions on the computer screen. The USB1 is like a sniffer in our scenario, but can be used for many other purposes as well.

### 3.3. OpenBeacon USB2

OpenBeacon USB2 is a powerful active RFID tag, having an LPC1343 ARM Cortex M3 microcontroller at its heart that allows a clock up to 72MHz. In addition we find the PAN1321 Panasonic Bluetooth module, the NRF24L01 RFID chip, a triple-axis accelerometer and a 4MB external flash storage. A rechargeable battery, with a charge of 700mAh, supplies the power for all this.

Because of its micro USB port, the tag can easily be recharged and flashed by using the computer. In addition, the firmware allows a debug output on this interface, which makes error handling quite comfortable. By using the 3 key switches at the front you can reset the tag or boot it into the flashing mode. There are also plastic cases for this which can also be used as nameplates. The disadvantage with them is that they cause problems with the emitted and received signals, so that packets can get lost.

### 3.4. OpenBeacon AC WI-FI

As the name already tells us, this has to do with Wireless LAN. The OpenBeacon AC Wi-Fi station transforms RFID signals into WLAN signals. The box needs a 230V power socket which makes it quite inflexible in positioning. On its board you can find the NRF24L01 RFID chip, an ATMEL AT91SAM7SE512 microcontroller and a 2.4 GHz WLAN module, namely RN-131 GSX by Roving Networks. The AC Wi-Fi station is fitted with an internal antenna, but can also be provided by an external antenna. Its main task is to forward the RFID packets sent by the tags into a wireless network, in our case into the iCampus network. With a server connected to the network, you can receive the data and work with it.

### 3.5. OpenBeacon Ethernet ETHERNET EasyReader

The EasyReader can be seen as a further development of the AC Wi-Fi Station, whose power supply comes via Ethernet (PoE). In addition, it receives data with 2 antennas to avoid the loss of



Fig. 3) The OpenBeacon USB1

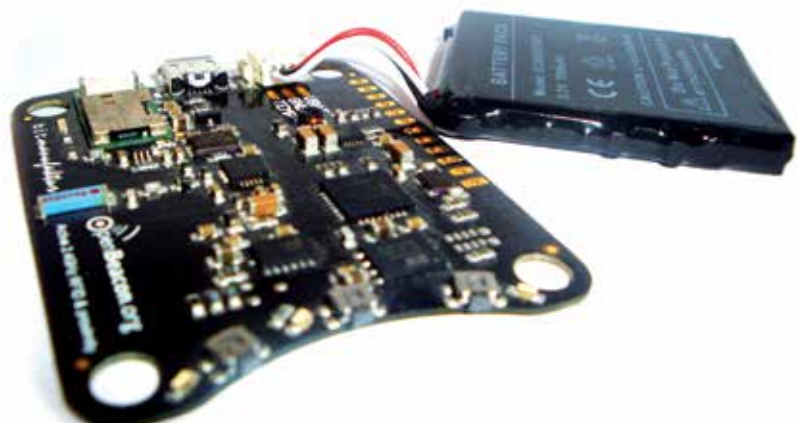


Fig. 4) OpenBeacon USB2 without case





Fig. 5) The OpenBeacon Easy Reader

packages due to local cancellations in the 2.4GHz band. Received RFID packages are forwarded across the Ethernet port of the EasyReader. Next to these hardware features the reader is configurable and flashable via a mini USB port. Furthermore, it offers a statistic mode, where users can see package transfer rates and more. Using a filtering algorithm, the implemented firmware automatically handles the double-signal reception. (OpenBeacon (2012))

#### » IV. LOCALIZATION SETUP

The OpenBeacon tags are distributed in the library in a way that from each point at least 2-3 tags are visible by a moving observer and continuously transmit packets into different transmission strengths. When placing the tags, position coordinates are stored together with the tag ID in the server application. Contents of the packages sent are the ID of the tag and the corresponding transmission intensity with which the packet was sent. Moving observers wear an OpenBeacon USB2 receiver on their chest. To achieve line of sight to the observers the tags are installed preferably at a height of 2-3 meters.

The OpenBeacon USB2 receivers aggregate statistics of tag IDs versus packets received on each power level. These raw statistics are sent to the network infrastructure consisting of OpenBeacon AC Wi-Fi's that are installed permanently in the library. It is their job to re-transmit the statistics to a centralized server via Wi-Fi network using a UDP-based network protocol. As an alternative to the AC Wi-Fi

readers, EasyReaders can be used for the re-transmission. The Tracking Server Application that runs on this server receives the packets from the wireless and calculates the position of the USB2. This position is stored in a JSON file in a freely readable directory on the server. From there, applications that want to evaluate the location can fetch it any time.

#### 4.1. The localization algorithm

Tags transmit packets containing their ID 20-40 times per second - cycling through 2-8 transmit power levels. The effective transmission range of these packets depends on the power level and spans from 0.3-1.2 meters and 5 to 25 meters for the eight available levels. The concept behind the localization algorithm is to maintain packet loss statistics for each individual power level. To calculate the position of the observer, the packet loss statistics are fed into a mechanical rubber-band model of the observer position. Less packet loss means a shorter distance to a tag and thus a stronger force to the particular tag. The different distance dependent forces on the observer, as a result of the distance dependent packet loss, create a force vector on the observer model position and result in movement of the observer.

By changing the model "weight" of the observer in the algorithm the responsiveness of the position change can be influenced: A higher observer model weight results in slower response to movement of the observer and a higher precision. A lower observer model weight leads to quicker response to movement and a higher inaccuracy in the calculated observer position.

#### 4.1.1. Centralized tracking server application

Using the previously described localization algorithm the centralized server application collects incoming UDP packets, maintains packet statistics per power level and calculates observer positions based on the stored tag floor plan positions. The unit for distances can be freely chosen, but because of practical reasons, tag positions are stored in pixel positions of readers in the floor plan schematic bitmap. Choosing pixels as base units simplifies the setup phase where positions of distributed tags are determined and also simplifies web client programming as observer positions can be directly translated into pixel positions that fit displayed bitmaps for real-time update.

The updated list of observer positions, tag positions and tag state (button press etc.) is sent to a web server in JSON format (pre-compressed and plaintext) five times per second as simple files stored in a memory backed file system (tmpfs, ramdrive) for higher performance. As the supplied JSON files contain the full state of the system, the web client for visualization or other services can freely choose the frequency of polling for updates.

#### 4.2. Visualization via the Tracker Web Application

The Tracker Web Application visualizes the localization data and allows the setting of positions of the reference tags. After the reference tags are set by click, the created scenario can be saved and loaded again. The positions of the tags will be sent via AJAX to the tracking server on which the position calculation is done. When the server is running and enough packets are received, the results of the calculation can be seen live with the Tracker Web Application. Using AJAX and jQuery, the position is updated every 100ms from the position-JSON-file the server creates. It is also possible to let the application plot positions onto the map, so that the course of the calculation can be seen easily. This app is a really useful tool for logging experimental results.

## » V. EXPERIMENTAL RESULTS

Tests have shown that the range of the different signal strengths is highly dependent on water in the surroundings. That means that not just people between tags influence the position calculation, but also the weather, especially the humidity. When humidity is high, the ranges of all signals are generally limited. For example, the limited signal range caused by excessive humidity can be passed by parameters to the algorithm, so that the result is adapted. People disturb the detection much more, which makes it difficult to correct.

The tracking is in a stage of permanent development where it can already be used for some applications. It is not suited to track a motion in real time. There are still some pending actions in order to use the system in real-time mode. The main problem is the delay in getting the correct position of a moving observer. Therefore the current algorithm for determining the position is best suited for pinpointing. A real-time tracking using this algorithm is possible as well, but further improvements of the setting and the algorithm have to be done.

Figure 6 shows the map of the second floor of the library with a snapshot of tracking results and associated positions. In this picture, the top left corner of the box with the tag ID corresponds to the position calculated by the algorithm. The black dots represent the correct location of the USB2 tags. The measured values were recorded approximately 5 seconds after the tag has not changed its position.

## » VI. SUMMARY AND PERSPECTIVE

In this paper, we have introduced “OpenBeacon”, an active 2.4 GHz RFID system which is produced by Bitmanufaktur GmbH. Since the system is based on Open Source software and Open Source hardware it can be adapted to serve quite different application scenarios. Our special focus has been on its installation and adaption to the library of Technical University Wildau. Here we have created an indoor localization system for the library. This paper

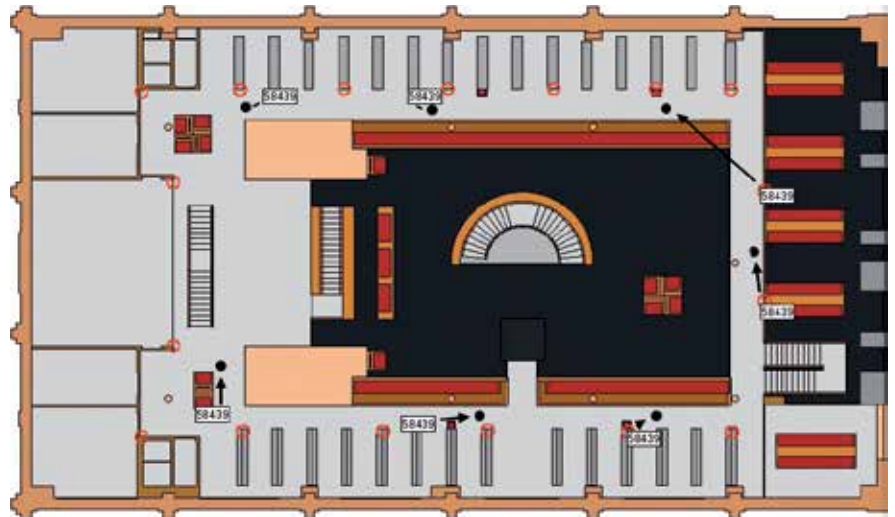


Fig. 6) Experimental results in the library

presents the current state of development of the system. It can be used for pinpointing the location of a non-moving observer with good results. So this is exactly where we are going to use it for in the near future. We have worked on applications that provide different location-based services for library users. Initially planned for the iCampus Wildau guide only, the system is mainly used for applications developed within a partner project of iCampus Wildau, called “iLibrary”, at the moment. The goal of the iLibrary project is the development of an interactive information system for the improvement of virtual library services within our library. To name a few ideas, the OpenBeacon location system will be used to develop a service that helps a library user to locate an expert helping him or her to solve a library related problem. Also, a service that guides a user through the library for collecting books along an optimal path has been implemented. Other ideas are under development. All services can be used on Android based smartphones so far. An application for Apple’s iPhone has been developed. With our growing knowledge about the system, its advantages and current disadvantages, we also focus on further improvements to be able to use the system for real-time-tracking applications as well.

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### REFERENCES

- iCampus Wildau (2012): Project information. <http://www.th-wildau.de/index.php?id=5321> (04/30/2012).
- OpenBeacon(2012): OpenBeacon Active RFID Project. <http://www.openbeacon.org/> (04/30/2012).
- Bitmanufaktur GmbH (2012): Bitmanufaktur Open Source Projects. <http://www.bitmanufaktur.de/> (04/30/2012).
- Mohnke, J., Seeliger, F. (2012): iCampus goes library. Advantages of using a Multimedia Guide in a Library, Singapore.
- Finkenzeller, K. (2012): RFID Handbuch. Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC. 6. Auflage, München.

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