On the Track of 5G Radio Access Network for IoT Wireless Spectrum Sharing in Device Positioning Applications

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Abstract This chapter discusses equipment positioning, which has a large range of potential applications from per-user advertisement, through elderly-care until cop security. We propose a general system based on passive measurements that, in contrast to currently available solutions using one specific technology (e.g., Wi-Fi), runs in multi-technology environment. This means that it is possible to position radio equipment using any of the radio technologies: Wi-Fi, Bluethooth, RFID and other technologies based on IEEE 802.15.4 operating in the 2.4 GHz band. Thanks to that, our platform will significantly increase the number of monitored users. Service of abovementioned technologies will be implemented by means of a common hardware platform, using time multiplex in the radio space. Such a solution eliminates interference between antennas from different technologies and provides higher positioning accuracy at the same time. A second important feature is the openness and programmability of the platform, which distinguishes our solution from similar solutions on the market and is one of its competitive advantages.

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1 Introduction

The application discussed in this chapter is confined to human behavior analysis. It is based in collecting data from users in order to arrange statistical data enabling optimization of marketing activities and thereby increase revenue and improve operations efficiency. In addition to marketing, users' data collection is useful for several other applications such as security or elderly-care. Users' data collection requires monitoring systems characterized by limited (or lack of) user activity, round-the-clock operation and tools for analyzing collected data according to the customer expectations. The customer (beneficiary) of the system will be its administrator, or companies interested in having information of the behavior of potential users. It is assumed that the users, i.e., the owners of devices (e.g., smartphone), are not constrained to install any new software in their own devices.

The users' data collection in marketing may innovate/improve operations such as to control the frequency of visits to a shopping center, to differentiate users with regard to visiting purpose or purchase, to identify users from the population on the basis of technical data, to monitor staff and comparison with revenues, to make heating maps (human activity) into shopping centers, and many other potential functionalities.

From the technological point of view, the system could be based on users' hardware or be fitted with a special device that communicates with the users' devices. In this chapter we propose an implementation of a system that aims to monitor the current location of user devices located in buildings (e.g., shopping mall) without the explicit awareness from the users. This means, in turn, that the positioning process will be carried out mainly based on infrastructure held by administrator and there is no possibility to install a dedicated software on localized devices. These assumptions mean that the proposed solution should be based on measurements of the power of Received Signal Strength (RSS) radio signal under different technologies, most frequently used by the users. At the same time the measurement of RSS is performed during normal operation of monitored devices (e.g., during update of the list of active access Wi-Fi access points) and does not use additional features requiring support from the application layer. The use of location technologies which requiring support (interaction) from the localized device is inefficient in the most scenarios, since such an approach causes a significant reduction in the number of monitored devices (only belong to users who have consciously made the appropriate configuration).

At the control plane (MAC and routing layers), the proposed platform groups together the considered technologies into an open and programmable platform, which is easily adaptable to concrete requirements from the administrators of the equipment positioning system. Therefore, the full support of each radio technology will be implemented on the basis of the software without the need for dedicated hardware resources. In this way, it will be possible to use the protocol defined by the IEEE 802.15.4 standard instead of a closed expensive ZigBee solutions, which leads to reduction of the costs of the products. The undoubted benefit of using a single hardware platform and software level technology support (eliminating expensive hardware acceleration) is much lower cost of transmission and reception. In result, much more antennas can be deployed in a given area, which significantly improves the accuracy of positioning.

2 Requirements for Users' Data Collection System

The first requirement of the system is that it should allow for monitoring/locating the greatest number of people moving in the monitored areas, therefore it is desirable to use for this purpose radio solutions implemented in different technologies that can be developed into the devices owned by the users. In particular, these technologies include: Wi-Fi, Bluethooth, RFID, other systems based on IEEE 802.15.4. It should be noted that although there are solutions for locating objects inside the rooms, which use more than one technology, there are no solutions which provide support for all of the above technologies. Current solutions usually use no more than two technologies for locating the users' devices: one of which is usually Wi-Fi technology, and the second one, depending on the approach, may be one of the following: Inertial Measurement Unit (IMU) [1] bluethooth [2], ultrasound [3].

Parallel monitoring of devices implementing several technologies may, on the one hand, significantly increase the number of monitored devices (users) and, on the other hand, it increases the complexity and cost of the system. Furthermore, due to the fact that most of the abovementioned technologies operate in the same frequency range—2.4 GHz, interference between the systems results in reduced positioning accuracy.

In order to avoid cross-technology interferences, we propose to use common part of the radio (antenna system) for all of these technologies. This is possible by the fact that the abovementioned technologies operate in the same frequency band, and moreover the system will be used only for the purpose of location of users (no other data will be sent that require high bandwidth). Common radio access is achieved by separating the functions, which are responsible for the transmission on the radio channel and the control functions (including higher layers). As a result, the control functions (including MAC and network layers) may be fully programmable on software-based platform, as well as it is possible to use virtualization technologies taking profit of its benefits (e.g., modularity).

Figure 1 shows the architecture of the proposed system where the technology controller will be developed on virtualization software platform.

The proposed solution involves that the radio part will alternately serve each one of the abovementioned technologies (time division will be applied). In accordance with [4], the coexistence of multiple wireless device depends on three factors: frequency, location in space and time. The individual radio networks will be able to function if it differs in at least one of the above factors. In our case, since we use the same antennas (which means the same frequency and position), the coexistence of multiple technologies can be implemented only with time division. The two main

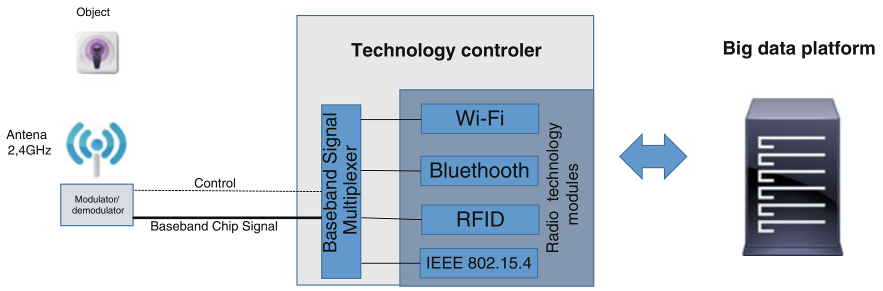

Fig. 1 General diagram of the proposed system architecture

advantages of this solution is the lack of interference between devices from different technologies (because at the particular time, antenna set performs the functions of only one technology) and significantly lower cost of implementation compared with parallel installations for each of the technologies tackled. From the point of view of the developing system, the most important advantage of the proposed solution is the possibility of providing more accurate measurements of the objects. This is due to two factors: firstly, greater accuracy is the result of a lack of distortions resulting from the coexistence of radio technologies in the community, which are operating in the same frequency band. Secondly, a much lower cost of radio network components allows for deployment of much more antennas in the area, which significantly increases the accuracy of positioning.

It is worth to pay attention to the legitimacy of the use of RFID technology. For the majority of applications, this technology is used to identify objects based on RFID Tag for short distances (up to tens of centimeters). Obviously, these solutions, due to the small range and the different range of frequencies used are not suitable from the point of view of our proposed localization system. Nonetheless, advanced RFID systems operating in the unlicensed frequency band and using Active Tags (with their own power supply) achieve several meters range, which is suitable for the purpose of the system in some fields as, e.g., employees monitoring.

3 Big Data Platform and Computational Algorithms

One of the cheapest systems to monitor the current location of user devices located in buildings may be achieved by utilizing networks in 802.11 standard (Wi-Fi). The main advantage of Wi-Fi networks is that in many locations the Wi-Fi network already exists as part of the communications infrastructure. In this case we may avoid costly and time-consuming process of infrastructure development. Although Wi-Fi does not include a positioning function at the preparation stage, its radio signals can be used to assess the location based on the RSS if localized business is seen from at least three access points. Such a positioning system can be relatively easily implemented to any devices that support Wi-Fi.

Basically, there are two types of indoor positioning systems based on the measurement of the signal strength of Wi-Fi devices. The first is the proximity type (proximity detection), which uses measurement of the RSS to identify the exact location and radio signal propagation models [5–7]. It is extremely difficult to develop an accurate propagation model for each of Wi-Fi access points (AP) in the room in the real environment. Therefore, the most attempts to measure this method are burdened with relatively high positioning accuracy error [7, 8]. The second common type of location based on the measured RSS is the location using the Fingerprinting method [8–13]. It is based largely on the use of empirical data. Under this method, the location is usually carried out in two stages: a calibration stage and the positioning stage. In the calibration phase, the mobile device is used to measure the RSS value (in dBm) in a number of APs located in the selected calibration points. Each of n measurements becomes the point of radio maps in which individual locations are defined by geographical coordinates and the specific RSS values for each AP. As a reference value of RSS, the average of several measurements is usually used. During positioning, the mobile device measures the value of RSS in an unknown location and uses an algorithm to estimate location using previously created radio maps. Because the rooms have unique signal propagation characteristics, it can be assumed that each location can be determined by a unique combination of RSS value. This approach provides a fairly accurate positioning, even in very complex environments, where modeling of signal propagation is very complicated.

Importantly, the fingerprinting techniques usually do not require a precise knowledge of the location of access points. Consequently, in practice fingerprinting method is the most commonly method used for determining the position of objects in buildings.

Bearing in mind the accuracy of the fingerprinting method, a key element is the correlation between the RSS measurement and individual points of radio maps. In practice, it comes down to determine the distance between the two abovementioned issues, which in terms of statistical maps, shows the contributions of individual components and uses the correlation between them. In this context, it is essential to choose an appropriate measure of distance, since it is closely related to positioning accuracy [14]. In [15], the authors evaluated the different measurements of distance in terms of their application to fingerprinting type positioning using Wi-Fi networks. Among these measures were distances of: Euclidean, Manhattan, Chi-Squared, Bray-Curtis and Mahalanobis. The tests carried out showed that the highest accuracy can be achieved using Mahalanobis distance. The confirmation of this thesis is the use of Mahalanobis distances by several other solutions (e.g., [16–19]). In the mentioned solutions, a number of enhancements designed to increase accuracy were proposed. These enhancements basically take into account the volatility of RSS value in the algorithms for the same location, which is very common in real environment. For example, a number of positioning solutions use the fingerprinting method in order to improve the accuracy of the measurement called Inertial Measurement Unit (IMU) [1]. The advantage of the use of this module is a compensation of measurement inaccuracy associated with the movement of the user during the measurement procedure. Measurement data indicating strength of RSS signal are linked to the IMU module data and sent to an application which calculates the final location based on specific algorithms. It should be noted that in this approach the final measurement data is obtained from the positioning device, which excludes the possibility of applying this method in localization systems based on passive measurements.

In case of Bluetooth technology, construction of locating platform can be based on various measuring metrics which provide input data for further use of destination algorithms. There are 4 major metrics: RSS, LQ (Link Quality), TPL (Transmission Power Level) and IRR (Inquiry Response Rate).

Similarly to the WI-FI case, RSS used in the fingerprinting method described above is the most popular measurement. Bluetooth technology in LQ connection status defines the status of the link and maps it into a value from 0 to 255 (255 represents a perfect link status). Tests have shown that LQ parameter depends on the distance between the transmitter and Bluetooth receiver, which enables the use of a method based on the above parameter in determining the location. It should be noted that the LQ parameter is possible to measure when localized device has an active connection with the master device, which represents a significant reduction in the application.

It is also possible to measure the power of Transmission Power Level (TPL) transmission signal in Bluetooth. This parameter is possible to determine only in the connected state, as in the case of LQ. However, preliminary tests [20] have shown weak dependence of this parameter on the distance, which virtually eliminates any location method based on TPL. The last parameter used to locate in Bluetooth technology is IRR (Inquiry Response Rate), which indicates the number of responses received in the time interval to inquiries generated by the master in the process of collating connection. This parameter is mainly used in fingerprinting method. However, tests showed low accuracy of location measurement based on this parameter.

Of course, beyond the methods of determining the location based on the measurement of the power of radio signal, one can find in the literature a number of alternative solutions based on active measurements. These methods may include, among others: Time of Arrival (ToA) [21], which consists of measuring the radio wave propagation time between transmitter for which location is determined and receivers installed in Wi-Fi hotspots. The time measurements obtained from many access points are further processed by an algorithm for distance approximation of the localized device. The main disadvantage of this method is the location accuracy, which is limited to 3 m due to the time measurement accuracy. Furthermore, it should be emphasized that the method requires a precise time synchronization of the transmitting and receiving device, and, because of this, this method requires active measurements.

Despite the use of advanced algorithms, in practice there are a number of restrictions that significantly affect the accuracy of positioning. Studies in [19] showed that the RSS value, and thus the positioning accuracy, significantly depends on the orientation (rotation) of the measuring device. This is due to the radio signal irregularities, which causes that the measured power depends on the direction of orientation of the antenna, components of the reflected radio signal and the proximity of the user's body, which due to the high water content in the human body absorbs a part of radio signals [19, 22, 23]. The abovementioned correlations mean that the measurements of positioning phase in practical applications almost always take place in an environment different from the measurements of calibration phase. It should also be noted that usually apparatus with totally different characteristics are used in calibration and positioning phases. Finally, in a number of practical applications, there are varying propagation conditions (e.g., client standing next to another person or a pallet with goods can substantially suppress the signal from the specific AP), and there may be interference with other systems operating in the same frequency band. This all results in mistakes in specifying location in enclose spaces. Therefore, we emphasize the importance of using multi-technology multi-antenna environment for limiting positioning error. In our system, multi-technology multi-antenna system combined with fingerprinting method gives a chance to get sufficiently accurate results. For developing optimal positioning algorithms we propose to take advantage of best practices, including [17–19, 22, 24, 25].

4 Wireless Access

We propose a radio access that separates physical layer from MAC and network layers, similarly as it occurs in Radio Access Networks in 5G networks. The main difference is that our platform requires different modulation for different wireless technologies.

To reach this objective, the antenna should develop multi-modulator that cyclically sends frames of each one of the technologies. Thus, the antenna deploys technology multiplex in time. The transmission and the reception from the users' devices should be synchronized. This means that when a given technology sends beacons and waits responses in one or more channels, the other technologies are disabled (in the radio access).

802.15.4 standard modulates the signal with offset quadrature phase-shift keying (O-QPSK). Also Bluetooth technology bases on 802.15.4 for the physical layer implementation,

Wi-Fi technology modulates the signal by means of Differential Binary PSK (DBPSK) for 1 megabit per second data rate signal, and Differential Quadrature PSK (DQPSK) for 2 mbps data rate signal. However, other extensions of 802.11 standard make use of other modulations and coding mechanisms (e.g., 802.11b added Complementary Code Keying for 5.5 and 11 Mbps rates).

For higher rates (standard 802.11 g), Wi-Fi deployed orthogonal frequency division multiplexing (OFDM), where the available radio band is divided into a number of sub-channels and the final chip sequence is divided and encoded between the radio sub-channels. The transmitter encodes the bit streams on the 64 subcarriers using Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), or one of two levels of Quadrature Amplitude Modulation (16, or 64-QAM). Since the modulation as well as the frequency range (2.4, 5 or 60 GHz) are different for different Wi-Fi standards, the Controller should implement different Wi-Fi nodes for different standards in the case when devices using different standards are thought to be used in the scanned place.

At last, active RFID uses dual sideband modulation.

The antenna should implement all these modulators and receive information about which modulator must transmit the bit stream received from the controller. Each node of the Technology Controller (see Fig. 1) maps the frame into a stream of bits that will be directly modulated by the antenna. As an example, the 802.15.4 technology creates the so-called baseband chip sequence, which is the result of the conversion from symbol to chip as shown in Table 1 (source: Standard IEEE Std 802.15.4™-2011). Each four bits of the raw data stream are converted in 32 chips, so the baseband chip sequence is eight times longer than the 802.15.4 frame created by the controller. Therefore, the link between the controller and the antenna should ensure high capacity (at least 1 Gbps). Moreover, problems with synchronization may appear for high bitrates and long bit streams. Thus, simple coax cable between controller and antenna cannot be enough if the number of users located in the antenna scanning area is high.

The nodes into the Controller send information about the necessary modulation for each bitstream in parallel to the baseband chip sequence by using the control link between antenna and controller. The antenna is not aware about higher layers functionalities (e.g., MAC) which remains under the control of the technology nodes into the controller.

Table 1 Symbol-to-chip mapping for the 2450 MHz band (*source* IEEE Std 802.15.4™-2011)

Data symbol	Chip values (c0 c1 … c30 c31)
0	1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0
1	1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0
2	0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0
3	0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1
4	0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1
5	0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0
6	1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1
7	1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1
8	1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1
9	1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1
10	0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1
11	0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0
12	0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0
13	0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1
14	1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0

In the opposite direction (i.e., for the communication between users' devices and controller), the antenna should be able to specify the demodulation used for obtaining the bit stream and pass this information to the controller (once again by using the control link). This information is used at the host of the controller in order to address the bit stream to the corresponding node.

The antenna performs operations in a cyclical way, so when it sends beacons from one technology, the antenna waits until receiving the responses form the devices. After finishing sending and receiving operations, the antenna changes to another technology and asks for a new bit stream from another technology node. All the communication for synchronizing antenna and controller should be sent by the control link.

5 Summary and Conclusions

This chapter provides a discussion about indoor positioning systems. We proposed a system directed to make the monitoring system simpler and, concretely, we faced up the possibility of bringing the 5G Radio Access Network approach to position monitoring devices. 5G Radio Access Network separates radio from control plane, which simplifies the hardware development. In a similar way, we presented a system for separating radio from control in monitoring antennas, which allows for a cost-efficient antenna deployment and, thanks to that, increases the measurement accuracy by increasing the number of antennas in given indoor location.

We analyzed the different algorithms used in indoor location systems (presented in the literature) and gave some guidelines about the best algorithms that could be developed in multi-antenna environments.

At last, we presented details of radio access for four different radio technologies: Wi-Fi, RFID, Bluetooth and other technologies using 802.15.4. We analyzed the requirements for assuring radio and control separation and introduced some implementation guidelines.

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