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An Overview of Wireless Indoor Positioning Systems

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***Abstract*-In this paper an overview of some of the existing wireless indoor positioning systems is introduced. The *TOA* (*Time of Arrival*), *TDOA* (*Time Difference of Arrival*), *AOA* (*Angle of Arrival*) and *RSSI* (*Received Signal Strength Indicator*) positioning methods are described. Also, performances metrics of the indoor positioning systems are provided. A brief survey of systems is presented, and their advantages and disadvantages are summarized and discussed.**

Keywords-wireless systems, indoor positioning, TOA, TDOA, AOA, RSSI

I. Introduction

In recent years an increasing interest in positioning systems can be noticed. This increase is caused by the customers' need to have information about their position at any time and at any place. Another factor which facilitated the development of a positioning system is a very rapid development of wireless systems.

Due to mentioned facts a lot of research has been devoted to development of various positioning systems, and a lot of different systems have been developed, but just some of them are implemented in practice, because some of developed systems are too complex, some are too expensive, while some are not adequate by multiple criteria.

The positioning system can be defined as a mechanism for determining the exact location of the object/person. According to the type of the information that a positioning system provides, positioning systems can be divided into two categories, systems that provide *2D* information and systems that provide *3D* information. Also, according to the covering area size, positioning systems can be divided into the global and the local systems. The global positioning systems, *GPS* (*GPS - Global Positioning Systems*) provide information about location of the object/person on the Earth surface, by determining the longitude and latitude where the object/person is located [1]. Theoretically, global positioning systems cover the entire area of the Earth, so someone could have the impression that their existence is enough to determine any location, and that, systems for local positioning *LPS* (*LPS - Local Positioning Systems*) are unnecessary. However, in practice this is not always the case. Specifically, in highly urban areas, it is impossible to determine the position of the object/person with sufficient accuracy. Also, at places that are below the Earth's surface, even indoors, especially the ones located in the center of the building, it is absolutely impossible to determine the location using the *GPS*. At these places signal is blocked that disables positioning, so, it is obvious that systems for local positioning are more than necessary. It can be concluded that global and local positioning systems do not represent a competitive systems, but should be used in combination.

The local positioning systems provide positioning in the area which is covered by a local area network. This area is defined by the network, and its size can vary.

As already mentioned, a lot of positioning systems are developed, and some of the indoor positioning systems are presented in [2]. However, describing each of the developed systems will be time consuming, so, in this paper an overview of some of the most important indoor positioning systems will be presented.

In Section II the positioning methods used in wireless indoor positioning systems are described. In Section III the criteria for positioning system estimation are listed and explained. Section IV provides an overview of some of the wireless indoor positioning systems. In Section V major conclusions and directions for future research are given.

II. Positioning Methods

The *LPS* systems are realized by wireless networks, and the positioning in these systems is based on the measurement of certain parameter of the received signals. The measured parameter is used for the determination of the receiver location [3]. Depending on the positioning system, positioning can be provided through the measurement of: propagation time - *TOA* (*Time of Arrival*), angle of propagation - *AOA* (*Angle of Arrival*), differences between propagation times - *TDOA* (*Time Difference of Arrival*) or *RSSI* values (*Received Signal Strength Indicator*).

The *TOA* method is based on the measurement of the signal propagation time between the transmitter and receiver and the physical fact that the speed of light multiplied by the time equals the distance. Both, the emitting time t_0 and the propagation time are necessary for position calculation. The propagation time defines the distance between the transmitter and receiver, so one *TOA* measurement defines sphere or circle as possible receiver position, Fig. 1. Since a single *TOA* measurement localizes the receiver on a sphere, for accurate localization at least three transmitters are needed.

The *TDOA* method is similar to the *TOA* method. However, in *TDOA* method localization is obtained by calculation of the difference between two or more *TOA* measurements. The emitting time is not required. Therefore, transmitters must be paired to get *TDOA* measurements. The *TDOA* positioning is sometimes called hyperbolic positioning, because measurements localize the receiver on a hyperboloid or a hyperbola with the two transmitters as foci, Fig.1. The *TDOA* method is one of the most accurate positioning methods, but it requires complex infrastructure to achieve high performances.

In the *AOA* method the angle of arrival for two or more transmitters is measured, and then the geometry calculations are employed for the receiver position determination, Fig.2.

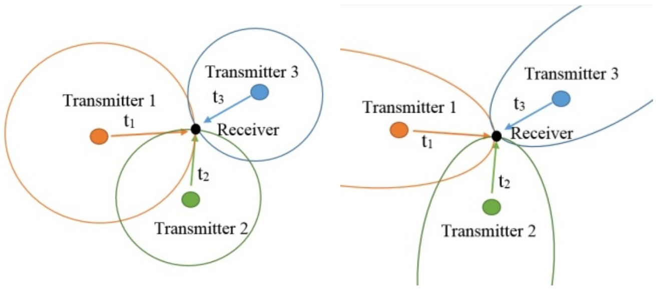

Figure 1. The *TOA* positioning method (left) and the *TDOA* positioning method (right)

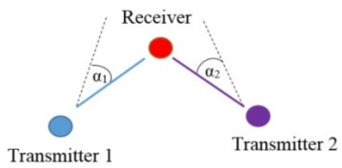

Figure 2. The *AOA* positioning method

The *RSSI* method is based on the determination of a *RSSI* value. The *RSSI* value is directly dependent on the *RF* signal strength, but it is not equal to the *RF* signal strength. However, in *RSSI* positioning method the signal strength is measured, and the *RSSI* value is obtained from the measured signal strength value. The accuracy of the signal strength measurement and receiver sensitivity (the range of signal strength, in *dBm,* which receiver is able to detect), depend on the equipment, therefore the mapping between the signal strength and the *RSSI* is different for different equipment.

The *RSSI* method has two variations; the first one is based on the *RSS* map composed of the *RSSI* vectors, while the second one is based on the calculation of the signal propagation losses.

The first variation consists of two phases, *offline* phase and *online* phase. During the *offline* phase, the received signal strength at a certain number of predefined positions within the covering area is measured. From the measured values, *RSSI* vectors are formed, whereby each *RSSI* vector is associated with one position. The elements of the *RSSI* vector represent the *RSSI* values formed from measured signal strength from each transmitter, and the dimension of the vector is equal to the number of transmitters used in the positioning system. The selection of the positions and the number of positions at which the measurement will be done is an important factor in the measurement process. The chosen positions should not be too far or too close to each other, because if they are too far the system accuracy decreases, and if they are too close the system scalability decreases.

During the *online* phase the receiver position is determined. The first step in the determination of the receiver location is to measure the received signal strength. The second step is to determine the corresponding *RSSI* value, and the third step is to compare the *RSSI* value with the *RSSI* values from the *RSS* map formed during the *offline* phase. The comparison of the *RSSI* values can be provided by different methods, the most often used are: the "*k* nearest neighbors" [4], Bayesian classification [5] and the artificial neural networks [6]. Regardless of the method used for *RSSI* vectors comparison, the location of the receiver is equaled to the location of the *RSSI* vector which is the most similar to receiver's *RSSI* vector.

The second *RSSI* variation does not contain the *offline* phase, and the receiver location is determined directly from the signal strength measurement. The location is determined using propagation model, wherein the distance *R* between the receiver and transmitter is calculated. Considering that all transmitters' locations are known, after the calculation of the distance *R*, the receiver location can be determined easily. The disadvantage of this method is that at least three transmitters are needed for the location determination. The most frequently used method in this *RSSI* variation is the Kalman filter [7].

All of described positioning methods have theirs advantages and disadvantages. The most important advantage of the *TOA*, *TDOA* and *AOA* methods is high accuracy of positioning, while their main drawback is that the line of sight between the transmitter and the receiver is required. Additional shortcoming of the *TOA* and *TDOA* methods is that the time synchronization of transmitters and receiver is necessary. On the other hand, the *AOA* does not require time synchronization, but in comparison with the *TOA* method it requires a lot more equipment (smart antennas, at least two receivers ...). The *RSSI* method has lower accuracy than other methods, but does not require line of sight between the transmitter and the receiver, which is the main reason why the majority of the indoor positioning systems are based on the *RSSI* method.

III. PERFORMANCE METRICS

The positioning systems can be implemented in different ways and by using different technologies, which hinders their comparison on a structural level. Therefore, a few criteria for the positioning system's quality description are defined [3]: accuracy, precision, complexity, scalability, stability, security and cost. The listed criteria allow the comparison of performances of the positioning systems which can be structurally absolutely different.

A. *Accuracy*

The accuracy of the positioning system represents the Euclidean distance between the estimated position and the actual position of the receiver. The accuracy of the system is expressed in meters (m). The accuracy of the system is related to the positioning error, and it represents the mean value of that error. The accuracy of the system should be as high as it is possible, in order to maintain the accurate positioning.

B. *Precision*

The precision of the positioning system presents the probability of accurate positioning. However, although the accuracy and the precision are closely related, they cannot be equalized. Also, for the description of the positioning system it is not enough to know only the accuracy or only the precision of the system, the both criteria must me known in order to achieve correct estimation of the positioning system. Sometimes the precision is defined as the standard deviation of positioning error, although in general case, the precision is the cumulative distribution function of positioning error. The precision is defined for a specified distance (for example, 2m, 5m, etc.) and it is expressed as a percentage. For instance, if the accuracy is 85% to 2m, that means that 85% of the errors are less than 2m.

C. *Complexity*

The complexity of the system is related to the complexity of the hardware and software necessary for the proper functioning of the system. While it might be assumed that the increase of components and algorithms achieves better performance of the system, this rule is valid only until the certain limit. Very complex systems have only apparently good performances, because although in such systems high accuracy and precision can be achieved, increasing of the hardware and software causes destruction of other system performances (e.g., speed of response, energy efficiency, etc.).

D. *Scalability*

The scalability of the system shows how and how much the estimated position of the receiver changes with the change of receiver's actual position. While it is desirable that scalability is as small as possible, i.e. to detect the position of the receiver as accurately as possible, it is not good that scalability is very small, because it would cause system's redundancies. If the scalability is very small, even the slightest change of receiver's position will be detected, which practically means that if You are sitting at Your desk, and move a little to answer on the phone, system will detect change of Your position, which is absolutely unnecessary.

E. *Stability*

The stability of the positioning system is defined as the ability of the system to continue to function normally in the case of signal absence or in the case that determined *RSSI* values cannot be found in the *RSS* map; which can be caused by the existence of obstacles or failures of a certain part of the positioning system. In that case, either the *RSSI* values cannot be determined, or the determined *RSSI* values might be "false", in both cases, the positioning will be wrong. Due to mentioned, it can be concluded that the stability of the system is one of the most important characteristics of the system, so sometimes it is better to "sacrifice" the accuracy in order to improve the system stability.

F. *Security*

The security of the positioning system is also an important characteristic. The security of the system defines a resistance to interference signals and other types of attacks to the system. This feature is especially important in positioning systems that have military purpose, but it is also required in other positioning systems.

G. *Cost*

The cost of the positioning system is defined by the sum of the equipment price and the price of the operation and maintenance of the system. The price of operation and maintenance include the ongoing costs, such as power consumption. Therefore, it is desirable to keep the cost as low as it is possible. However, the cost is directly proportional to some other system characteristics, so it is necessary to find a compromise.

IV. SURVEY OF LPS SISTEMS

As already mentioned a lot of wireless indoor positioning systems with different performance are developed [2], [8] - [23]. While some systems are realized as independent systems, another are only integrated to existing wireless systems. Each of them has its advantages and disadvantages. The advantage of the first kind of systems is that their performances are better, because wireless systems are developed just for positioning purpose, but they cost more and the implementation time is longer, while second ones do not have first rate performances, but their implementation is much cheaper and faster.

A. *RFID systems*

The *RFID* (*Radio Frequency Identification*) positioning systems determine the position of the receiver using *RFID* tags. The basic components of a *RFID* system are *RFID* readers and *RFID* tags, whereby the communication between the *RFID* readers and *RFID* tags is provided through a certain protocols. The *RFID* tags, and therefore the *RFID* systems, can be active [8] or passive [9]. The passive tags are smaller than active ones, and contain no power supply (battery). Actually, the passive tags are reflectors; they reflect signal wherein some information about their position is added through the signal modulation. Disadvantage of the passive *RFID* systems is short range, only 1-2 m, and very high cost. One of the most famous passive *RFID* systems is Bewator [10].

Unlike the passive tags, active tags are transceivers which emit the signal received from the *RFID* reader, with adding some information in it (for example their ID). The active tags have a much bigger range than passive ones (up to 10 m). Some of the most popular active *RFID* systems are: SpotOn [11] Landmark [12], Vire [13] and LEMT [14]. The accuracy of Landmark positioning system is less than 2m, while the precision is about 50% on 1m.

The main advantages of the *RFID* positioning systems are high accuracy and high precision, but the main disadvantage is high complexity (a lot of *RFID* devices are required).

B. The positioning systems based on the mobile communication systems

As noted before, some of the positioning systems are implemented in the existing wireless systems. The positioning system based on the mobile communication systems are one of them. The positioning in these systems is achieved through the information about the cell in which the mobile user is located [15]. The cell is defined as an area that is covered by a particular base station. Each cell has its own ID, and this is the most commonly used parameter for positioning. The receiver's location is determined according to the ID of the cell in which receiver is located.

The benefit of this method is the simplicity, but the weakness is low accuracy. Namely, the accuracy is not uniform, and it is directly dependent on the cell's size. In highly urban areas, which are covered by pico cells, the positioning accuracy is satisfactory. However, in rural areas, where the cells are larger, such positioning method is not convenient because the cells have big diameter, and therefore the big positioning error is possible. The average accuracy of this type of positioning systems is about 5m, while the precision is about 80% on 10m.

C. Bluetooth systems

The *Bluetooth* positioning systems are based on application of *Bluetooth* communication standard for the location determination [16]. The *Bluetooth* transmitters communicate with the *Bluetooth* receivers or users who possess a *Bluetooth* application, and through the communication receiver get the information about its location. The location of the receiver is in fact location of the transmitter in whose coverage area receiver is. If the receiver detects more than one signal, there are two possible scenarios. The first scenario is that receiver takes information about location from the transmitter which sends the strongest signal, while the second scenario is that the location of the receiver is determined through the geometric calculation applied on the information gotten from all detected transmitters. Theoretically, second scenario provides more accurate positioning, but in practice some problems can occur, because the calculating can give more than one solution, which increases the possibility of errors.

The main advantage of *Bluetooth* systems is quite high positioning accuracy, while their main drawback is relatively high cost, caused by a small range of *Bluetooth* devices (1-10 m), so a lot of devices are needed to cover entire area of interest. Due to that, positioning systems are rarely based only on the *Bluetooth* technology. The most common is to combine *Bluetooth* technology with another one, and on that way the positioning accuracy is preserved, while the cost is reduced. One of the hybrid *Bluetooth* systems is system Topaz [17], which represents a combination of *Bluetooth* and *infra red* technology. Since the *Bluetooth* technology is combined with the *infra red* technology, the distance between transmitters can be more than 10 m (max 15 m). The increasing of that distance reduces the system complexity, while the precision and the accuracy are still high, 95% on 2m and 2m, respectively.

Another hybrid *Bluetooth* positioning system is given in [18]. In this system, *Bluetooth* technology is combined with *Wi-Fi* technology, wherein the benefits of each technology are preserved, high precision of *Bluetooth* and a large range of *Wi-Fi*. In the pre-positioning stage *RSS* map is formed and stored in each of the *Wi-Fi* transmitters. The positioning stage has a few scenarios, in first one the receiver detects *Bluetooth* transmitter, and from detected *Bluetooth* transmitter receiver gets information about transmitter's location which receiver equalizes to its location; if receiver does not detect any of the *Bluetooth* transmitters, then receiver scans area looking for the *Wi-Fi* transmitters and when it finds one or more *Wi-Fi* transmitters it takes the information about location from *Wi-Fi* transmitters (information is based on the previously recorded *RSS* map). It is important to say that if the receiver is in the coverage area of a *Bluetooth* transmitter, that information is recorded and stored in the positioning system, and when receiver left that area, ant try to locate itself again, if it does not detect new *Bluetooth* transmitter, positioning is performed at the level of *Wi-Fi* transmitters, but *Wi-Fi* transmitter will not compare receiver's *RSSI* whit entire *RSS* map, just with the parts of the *RSS* map, which are located next to coverage area of the previously detected *Bluetooth* transmitter. In this way, the positioning time is significantly reduced.

D. WLAN Systems

The fast development of *WLAN* systems (*Wireless Local Area Network*) facilitated the development of a *WLAN* positioning system. The main advantage of the *WLAN* positioning systems is low cost, and simple and fast implementation. However, the positioning in *WLAN* systems is based on the *RSSI* method, which is characterized by a certain degree of instability, caused by instability of the signal strength due to multiple path, therefore WLAN positioning systems do not have high precision and accuracy, the majority of *WLAN* systems have precision about 50% to 2m, while the accuracy is 2-5m [2].

The *WLAN* positioning systems can be divided into two categories: deterministic systems and probabilistic systems. In deterministic systems signal strength at certain location is presents as scalar value (usually its mean value) and deterministic methods are used to determine the location of the receiver. The best-known system in this category is RADAR [19], which uses the "*k* nearest neighbors" method to determine the location of the receiver. The "*k* nearest neighbors" method compares the *RSSI* vector with the *k* most similar *RSSI* vectors from the *RSS* map, and the location of the receiver is equalized with the position of the most similar *RSSI* vector. In [19] for the *RSS* map formation the two models are proposed, the first model is empirical model, while the second model is signal propagation model based on the *WAF* (*Wall Attenuation Factor*) and *FAF* (*Floor Attenuation Factor*) values. In the empirical model, the *RSS* map is formed of the measured data, while in the signal propagation model the *RSS* map is formed from calculated data. Through experiments presented in [19], it has been shown that empirical model provides higher accuracy, while the propagation model significantly reduces the time required for the system implementation. The average accuracy of the RADAR system is 2-3m, while the precision is about 50% on 2.5m.

Unlike the deterministic, the probabilistic systems determine the location of the receiver by probabilistic methods, of which the most commonly-used is Bayesian classification. The probabilistic positioning system which employs the Bayesian classification is Horus system, described in [20]. The procedure for the location determination in Horus system is shown in Fig.3. The experiments presented in [20] have shown that the accuracy of the Horus system is directly proportional to the number of samples used to form the *RSS* map, and that accuracy of system is 2m, and the precision is 90% to 2.1m. In addition to these features, the advantages of the Horus system are high stability and low cost.

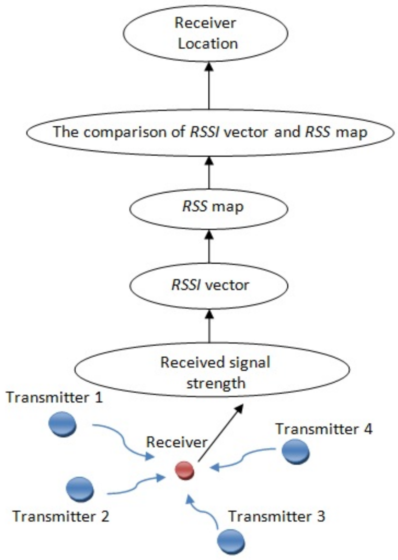

Figure 3. The Horus system

In [21] two modification of the original Horus system are presented. In both modifications the *offline* phase is the same as in the original Horus system, while the *online* phase is different. In the first modification, in *online* phase *the center of mass* technique is used to determine the receiver position. Namely, each measurement position from the *offline* phase is identified as an object whose mass is equal to the probability that receiver is at that position. According to that, if the receiver is between the *N* positions, its position will be equalized with the position of the object whose weight is the heaviest. The second modification of the Horus system is directed to the implementation of *the time averaging* technique. According to this technique, the *N* previous positions are compared and their mean value is adopted as the current receiver position. The experiments presented in [21] have shown that *the center of mass* technique improves the accuracy for 13% compared to the original Horus system, while the *time averaging* technique improves accuracy for 15-24% depending on the number of previous positions (*N*). The experiments have also shown that the increase of the number of previous positions (*N*) significantly increases the positioning time.

Another *WLAN* indoor positioning system which uses the Bayesian classification is the Ekahau system, introduced in [22]. The Ekahau system is shown in Fig.3. As can be seen in Fig.4, the receiver must have the Ekahau application, which represents the interface for the communication with the Ekahau positioning engine, which is connected to Ekahau manager. The function of the Ekahau manager is to analyze the data provided by the Ekahau positioning engine, and to determine receiver location according to the previously defined model. The Ekahau positioning engine forwards the information from the Ekahau manager to the Ekahau application, which converts the information in the form understandable for the user. The performed experiments have shown that the accuracy of the Ekahau system is about 1m, and the precision is 50% on 2m.

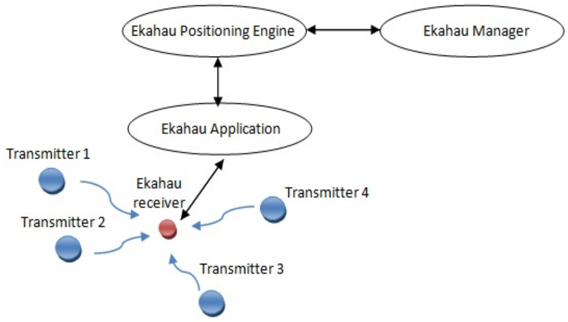

Figure 4. The Ekahau system

The Ekahau system for the Android platform is described in [23]. The Ekahau Android application is necessary on the receiver-end. The purpose of this application is to measure the signal strength, and to communicate with the Ekahau server, which determines the receiver location and sends information about location to the Ekahau application. In addition to the positioning capability, another possibility of the presented system is determination of the shortest path to the desired location. For the determination of the shortest path the *Dijkstra* algorithm is employed. The algorithm determines the trajectory according to the method that taxi driver uses to move on the streets. In fact, when the current location of the receiver and its desired location are determined, the *Dijkstra* algorithm calculates the closest "free" positions, whereby the "free" position is the position where the receiver can go directly from its current position. The direct path from one position to another is possible only if there are no obstacles between positions, such as walls. Once the set of all "free" positions between the current and desired position is defined, algorithm shows the path which receiver should follows to rich desired position.

In order to facilitate the comparative review of previously mentioned indoor positioning wireless systems, the key features of some of these systems are given in Table 1.

TABLE I. INDOOR POSITIONING SYSTEM PERFORMANCES

System	Wireless technology	Precision	Accuracy
Landmark	RFID	50% on 1m	<2m
Mobile based	GSM	80% on 10 m	5m
Topaz	Bluetooth	95% on 2m	2m
RADAR	WLAN	50% on 2.5m	2-3m
Horus	WLAN	90% on 2.1m	2m
Ekahau	WLAN	50% on 2m	1m

V. Conclusion

In this paper an overview of some of the most important wireless indoor positioning systems is presented. The most often used positioning methods are explained and the criteria for estimation of the positioning systems are listed.

Through a brief overview of already developed wireless indoor positioning systems, it can be concluded that there is no universally good technology for the positioning system realization. Therefore, the pre-defined performances are crucial for the selection of the most convenient technology for the system realization. If the high accuracy and precision are on the first place, then the most suitable technologies are the *RFID* and *Bluetooth*. On the other hand, if the low cost and the fast implementation are on the first place, then the *WLAN* systems and the systems based on the mobile communication systems represent the best solution. However, the best choice is to compromise the criteria, which can be achieved by combining few technologies and realization of the hybrid system.

Due to increasing customers' demands for accurate and precise information about their current location, the indoor positioning system will become even more important than they are now. Therefore, it is mandatory to develop some new and advanced positioning systems, and the solution might be to combine some of wireless technologies.

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