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Localization and behaviour examination of mobile node of wireless sensor network

***Abstract**. The ability to locate the mobile clients moving on the large area site can be very important for the emergency services, as well as those involved in marketing. The paper presents possibility of using the wireless sensor network (WSN) to track the mobile client moving along that facility and determining its place of residence.*

***Streszczenie.** Zdolność do lokalizacji osób poruszających się po obiekcie wielkopowierzchniowym może okazać się bardzo istotna zarówno dla służb ratowniczych, jak i osób zajmujących się marketingiem. W artykule przedstawiono możliwości zastosowania bezprzewodowych sieci sensorowych do śledzenia miejsca przebywania klientów mobilnych poruszającego się po wyznaczonym terenie. (**Lokalizacja i badanie zachowania węzła mobilnego w bezprzewodowej sieci sensorowej**).*

Keywords: localization, wireless sensor networks, IEEE 802.15.4, NS-2.
Słowa kluczowe: lokalizacja, bezprzewodowe sieci sensorowe, IEEE 802.15.4, NS-2.

Introduction

Recent advances in miniaturization allow production of multifunctional devices with negligible power consumption. Cheap and "smart" nodes connected into a network via wireless links, spread over a large area, can provide services, which were previously unavailable for traditional communications systems. The ability of localization wireless nodes is undoubtedly one of the features desired by the emergency or security companies, and also for those involved in marketing and customer behaviour analysis. The possibility of estimating the time residence in a particular place can provide information, e.g. the impact of promotion on the customer. The process of localization of the mobile node in combination with the ability of receiving data from it, can provide additional information for analysis applications.

The article presents the basic techniques of localization and communication protocols used in wireless networks to verify the possibility of tracking mobile customer behaviour. As an example the object of size 100x100m with 9 stationary nodes was chosen (fig. 5). The article is an expanded version of the work presented at the conference MKM 2015 [1].

Localization techniques

The research on the methods of localization of the mobile node in a wireless sensor network are carried out almost all over the world by many research centres [2, 3, 4]. Generally localization techniques can be divided into three basic types: detecting the presence within the base station called proximity detection, triangulation and scene analysis (Fig. 1) [2].

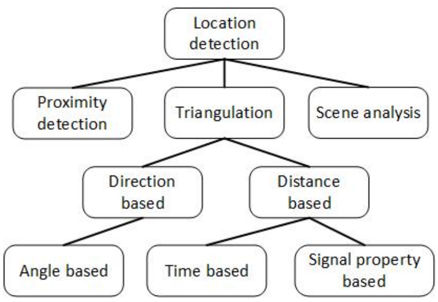

Fig. 1. Classification of mobile node localization techniques [2]

- **Proximity detection** is one of the simplest and oldest techniques. It is based on determining whether the mobile node is in within the base station at a known position. Location of mobile client is then limited to the operation area of the base station called cells (Fig. 2). When more than one base station detects presence of a mobile client in its operating area, it is possible to apply additional techniques for more accurate localization, e.g. triangulation. In the article proximity detection for the localization technique of a moving wireless client was chosen.

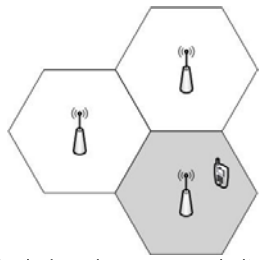

Fig. 2. Localization technique base on proximity detection [2]

- **Triangulation** is a technique used for determining the position of the mobile node based on geometric properties. It can be divided into two basic method: direction based and distance based. Direction based method involves searching of the largest radio signal value from the mobile node received by the base station of known location and defining an angle by using a rotary directional antenna or group of antennas between the base station and the detected mobile node. Having the information about the angle from multiple base stations, it is possible to estimate the position of mobile node (Fig. 3a).

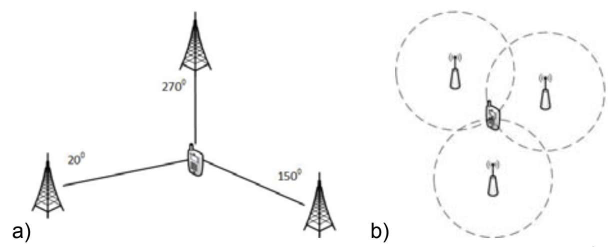

Fig. 3. Localization technique base on: a) direction (angle) of an incoming signal b) the distance of neighboring nodes [2].

The method based on the distances (Fig. 3b) uses two basic phenomena. The first phenomenon is the relationship of propagation time to the distance between the base station and the mobile node (1),

(1) $$R = \frac{v}{t}$$

where R is the distance between the mobile node and base station, v is the transmission speed (usually the speed of light) and t is the propagation time. The second phenomenon is the dependence of the signal strength loss on the distance e.g. based on Friis equation (2)

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R} \right)^2 \quad (2)$$

where: P_T – the power of the signal emitted by the transmitting node, P_R – the power of the signal received by the receiving node, G_T – gain of the transmitting antenna, G_R – gain of the receiving antenna, λ – wavelength.

With the information about the distance between the mobile node and at least 4 base stations, there is a possibility to estimate position of the mobile node (3).

$$\begin{aligned} d_1 &= \sqrt{(x_1 - X)^2 + (y_1 - Y)^2 + (z_1 - Z)^2} \\ d_2 &= \sqrt{(x_2 - X)^2 + (y_2 - Y)^2 + (z_2 - Z)^2} \\ d_3 &= \sqrt{(x_3 - X)^2 + (y_3 - Y)^2 + (z_3 - Z)^2} \\ d_4 &= \sqrt{(x_4 - X)^2 + (y_4 - Y)^2 + (z_4 - Z)^2} \end{aligned} \quad (3)$$

where: d – distance from the base station, (x,y,z) – position of base stations, (X, Y, Z) – estimated mobile node position.

- **Scene analysis** - this method is based on dividing the surrounding area into the smaller areas. In the particular points, the basic parameters of the radio signal (e.g. a radio signal strange - RSS) are measured and stored into the database. Based on created maps, a mobile node may estimate its position by comparing the RSS with the information stored in the database. An example of this technique is the Map Matching [4] used in the technique called Fingerprinting [5].

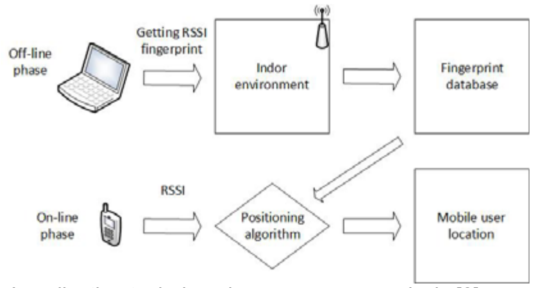

Fig. 4. Localization technique base on scene analysis [2].

Of course there are much more Localization techniques dedicated for mobile nodes. The techniques described in this article are fundamental algorithms that are still developed. There are also hybrid algorithms that combine the properties of a few basic techniques or allow the introduction of additional algorithms to those already known. An example of this approach is the ArrayTrack [6], which uses the MIMO technology (Multiple Input Multiple Output) to determine the angular value of the strongest signal.

Regardless of the localization algorithms, a common factor in estimating the position of the mobile node is the information about the localization of at least one node or base station located in immediate neighbourhood. Only when the localization of the reference node is known, the mobile node may itself determine its own position, or the information about the position may be sent to him. To make it possible it is necessary to exchange data and communicate with all the nodes in respect of which the position is calculated. Consequently, the following section describes the basic routing algorithms used in wireless sensor networks.

Routing protocols used In wireless sensor networks

The main purpose of routing protocols is to determine the best path for data transmitted from the source node to the destination. In computer networks, there are many different routing protocols, but not all of them can be used in wireless sensor networks. In the most general manner the routing protocols can be divided into [7]:

- **Proactive** protocols also known as table-driven, where information about the network topology is stored in routing tables periodically updated. Rout paths are defined "rigidly" so the data between the nodes is transmitted almost instantly. This feature allows wireless networks, in which proactive protocols are applied, to work with real-time systems, and are not recommended for environments with high dynamic changes. An example of such protocol is DSDV (Highly Dynamic Destination-Sequenced Distance Vector routing protocol) [8].
- **Reactive** protocols (On-demand or Source-initialled) in which route path is searched only if the source node needs to send packets to the destination node. When one of the nodes needs to send a message to another node that is not in its neighbour, it broadcasts a special message (Route Request). Every node keeps only a track of next hop for a route instead of the entire route. The route path is maintained by the node until the end of its use. With this solution, duration of data transmission is longer, but there is no need to send control data on the state of the network. As a result, the energy consumption is significantly lower compared with the proactive protocols. An example of a reactive protocol is the AODV protocol (Ad hoc On-Demand Distance Vector routing protocol) [9]. Reactive protocols perform definitely better in environments with high dynamic changes in the position of mobile nodes.
- **Hybrid** protocols - protocols that combine the features of a reactive and proactive protocols. In most cases, their function consists in dividing the large network into smaller fragments called clusters. Routes between clusters are determined in an active way (on-demand), but inside clusters the proactive method was used. Updates on the status of the network are sent only when it goes beyond a proper quantum of time or a significant change in the network structure configuration was occurred. An example of such a protocol is ZRP (Zone Routing Protocol) [10] or FSR (Fisheye State Routing) [11].

In the literature also another group of routing protocols is mentioned. These protocols made the decision about the choice of the route path on the basis of the location of the receiving node. These are the so-called **location-aware** or position-based protocols [7]. Wireless nodes where this type of routing protocol is used mostly do not store the information about the structure of the whole network. The decision on the next hop is taken on the basis of the information about the physical location of the neighbours, and information about the physical location of the destination node. The node information about the position of its own and neighbours in the network are obtained through sending queries to the location services e.g. GPS services. Using the information of geolocation, the search of a route path in a whole network is avoided. Data packets are sent only to the nodes of which the position is in line with the direction of the destination node coordinates. This feature makes the location-aware protocols to adapt more quickly to the changes in the network structure and are more scalable than proactive and reactive protocols. An example of location-aware protocol is LAR (Location Aided

Routing) [12] or GPSR (Greedy Perimeter Stateless Routing) [13].

Examples of routing protocols used for wireless sensor networks are shown in Figure 5.

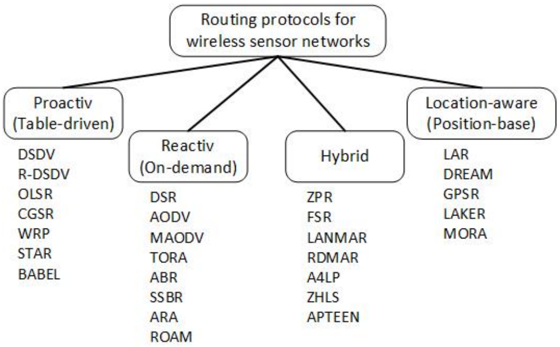

Fig. 5. Routing protocols for wireless sensor networks [7].

The examination of the sojourn time of the wireless mobile node using the proximity detection technique.

The main aim of the research was to examine whether the wireless sensor networks and simple localization technique can be used for motion track of a mobile node over large area site. The proximity detection was selected as a localization technique, due to the simplicity of its operation. In addition, as mentioned in [14], the trilateration technique based on a radio signal strength can be very difficult due to its random variation in time (Fig. 6).

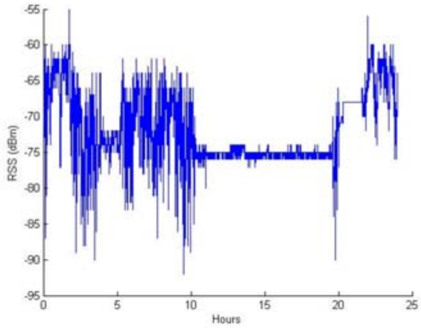

Fig. 6. RSS measurements for one day period in a laboratory environment [10].

The study was to estimate the residence time of a mobile client on area covered by single base station. Also the possibility of detecting the direction of motion of mobile node and the frequency of visits of the stationary nodes were analysed. The simulations were performed in an NS-2 simulator. The position scheme of the stationary nodes and mobile node was shown in fig. 7.

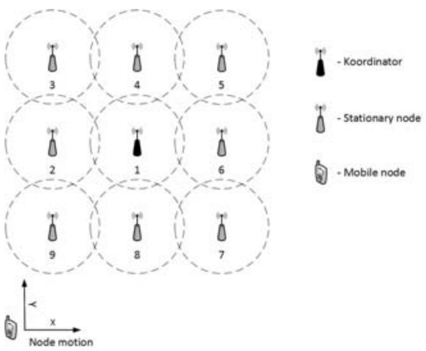

Fig. 7. Position scheme of the stationary nodes (SN) and mobile node (MN) modelled in the NS-2 simulator.

Stationary nodes have been set at 19 m. This arrangement allowed to cover the area close to 6000 m^2. The remaining area has been deliberately left as free to be able to observe the output of the mobile client from the operation area of the wireless network and re-connect it.

On the mobile node any restrictions for the direction and speed of movement were not imposed. These parameters were set as random. The movement speed was in a range of 0.1 to 3.0 m/s. This was done to simulate the behaviour of the average consumer doing shopping in a store. Table 1 presents the parameters for the NS-2 simulator.

Table 1. Parameters of NS-2 simulator

Parameter	Value
Pt_ (Transmit power)	1 mW (0 dBm)
The height of the antennas	z = 1,5 m
Radio propagation model	TwoRay ground
The size of modelling plane	100 x 100 m
The speed of the mobile node	0,1 – 3 m/s
The distance between stationary node	19 m
Network topology	Tree
Network mode	IEEE 802.15.4 Nonbeacon-enable
Routing	AODV

The data from the mobile node to the sink node (coordinator) were sent during movement. The residence time of the mobile node in a specific area was analysed based on the number of data packets transmitted from the moving node to the first intermediate node in the data exchange. By counting the number of received packets per unit of time (1 packet - 1 sec.) the results were obtained, which are shown in fig. 8a, b. A higher value of time units means that the mobile client remained longer in the stationary node area.

During the studies two scenarios were considered. In the first scenario the ability of identifying the areas that have been visited by the mobile node were analysed, and for how long a single mobile node remained there (Fig. 8a). The second scenario analysed the possibility of obtaining information in which areas the 100 mobile nodes spent the most of time (Fig. 8b).

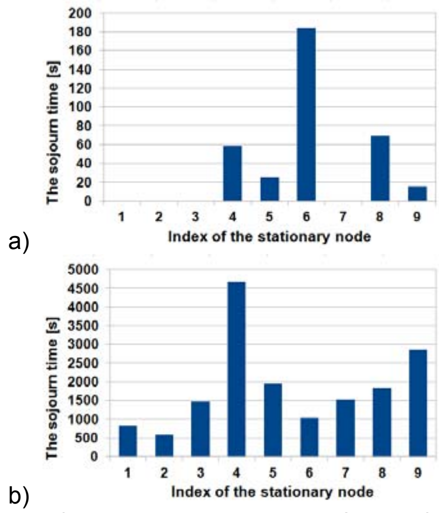

Fig. 8. Result of simulations showing which SN and for how long they have been visited by: a) 1 b) 100 MN.

The situation from the first scenario reflects the process of moving of a single customer in the store, which performs its own way of moving around the shop, the most favourable from his point of view. The second scenario may present situation of impact of the promoted product for customers moving in the store. In this case, it is possible to check whether the promotion of the product is confirmed by the statistics of the visits by customers and its purchase.

The results clearly show that it is possible to obtain information assumed at the beginning of the experiment.

Figure 8a shows that the client stayed for the longest time near the SN 6, but never visited the 1, 2, 3 and 7. A slightly different situation is when the analysis is subjected to a group of customers. Fig. 8b shows that the dominant place was around the SN 4. SN 6, which in the previous scenario was dominant, is no longer so heavily visited. Assuming that the promoted product was placed near the entrance of the store (SN 9), that in a global scale it was relatively frequently visited, almost 3000 units of time (fig. 8b). However, from the point of view of the individual customer, shown in fig. 8a, it probably did not attracted his attention.

Analysing the results, it seems that the experiment did not give answers on the movement of the client around the store. It was decided to analyse the output files and check the timestamps. This analysis gave the answer on the movement of the client around the store, which was presented in Fig. 9.

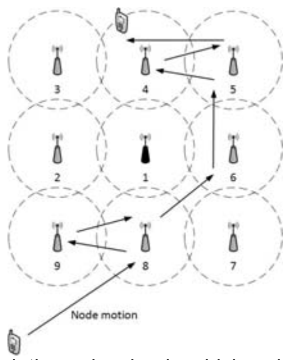

Fig. 9. Result of simulations showing in which order SN have been visited by MN.

It is clear that using the technique of proximity detection, it is impossible to assess the exact location of the customer in the store. In this case, it is only possible to obtain information about the areas in which the customer occurred.

Summary

The article presents the possibility of using wireless sensor networks to track the movement of the mobile client in the designated area. The studies provide a basis to conclude that wireless sensor networks combined with even the simplest location technique can be successfully applied to track the movement of mobile client. It is possible to investigate the direction of movement, obtaining the information about whether the mobile client stopped in a particular area and what stands he visited. The impact of promotional stands, the possibility of preparing personalized advertisement for the customer, designation of routes of moving of the customers or the methods of determining the exposure of the product in the store are only small examples of the possibilities, which gives the analysis of the obtained from the wireless sensor network data. For people working in marketing, such information may be relevant. Importantly, these information can be obtained in a way that does not violate the customer personal rights. The same information can also be used by cleaning service or rescue team in order to determine the position of the customers during the rescue action, especially in a crisis conditions.

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