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Performance analysis of positioning in wireless sensor networks

***Abstract**. Devices positioning plays an important role in Wireless sensor networks (WSNs) networks. The paper deals with performance evaluation of positioning in WSNs. The performance is compared with basic DV based positioning methods and proximity based location methods. They do not belong to the most accurate methods, but on the other hand they are low cost alternative to more expensive methods. The basic methods are improved by optimized algorithms proposed in our previous papers. The objective of the paper is to perform a performance analysis of these improved methods and try to find optimal method for investigated conditions. We analyze the influence of various conditions on the accuracy of localization methods.*

***Streszczenie.** Pozycjonowanie odgrywa ważną role w bezprzewodowych sieciach czujników. Artykuł przedstawia metodę DV (distance vecor) i porównuje ją z innymi (niekiedy prostszy mi i tańszymi) metodami. W metodzie podstawowej zastosowano ulepszony algorytm. Przeanalizowano wpływ różnych warunków pracy na dokładność lokalizacji. (**Analiza metod pozycjonowania w bezprzewodowych sieciach czujników**).*

Keywords: wireless sensor networks, DV based methods, proximity based method, Weighted proximity method.
Słowa kluczowe: bezprzewodowe sieci czujników, pozycjonowanie.

Introduction

At present, Wireless Sensor Network (WSN) technology does not have potential only in army infrastructure. The emerging field of wireless sensor networks combines sensing, computation, and communication into a single tiny device (node). The power of wireless sensor networks lies in the ability to deploy large numbers of tiny nodes that assemble and configure themselves. Usage scenarios for these devices range from real-time tracking, to monitoring of environmental conditions, to ubiquitous computing environments, to in situ monitoring of the health of structures or equipment. The most straightforward application of wireless sensor technology is to monitor remote environments for low data rate. In addition to drastically reducing the installation costs, wireless sensor networks have the ability to dynamically adapt to changing environments. Adaptation mechanisms can respond to changes in network topologies or can cause the network to shift between drastically different modes of operation.

The ability to change of network topology is crucial task for proper function of routing and multicasting protocols. New more efficient geographic aware routing should be implemented and information about actual positions of devices is needed. Therefore, positioning in wireless sensor networks plays a very important role in this case.

The positioning in these networks is specific. It is primarily given by network properties and hardware limitations of network devices. Most of proposed positioning methods for sensor networks are based on actual capabilities of devices; therefore the positioning accuracy is not excellent [1-4].

The positioning methods used for estimating location are possible to divide into two categories: range-based and range-free [3]. The range-based mechanisms are based on the indirect measurements of distance or angle between sensors. Examples of the mechanism are the following methods: received signal strength indicator (RSSI), time of arrival (ToA), time difference of arrival (TDoA), ultra wide-band (UWB), ultrasound or the angle of arrival (AoA) of a radio signal. The important thing to note is that these mentioned measurements always have errors and individual measurements are not independent of each other and are strongly influenced by the surrounding environment and the used transmission system. Because of the hardware limitations of WSN devices, solutions in range-free localization are being pursued as a cost-effective alternative to more expensive range-based approaches.

A great quantity of methods have been proposed to estimate the sensor nodes geographical positions based on range free methods, such as Distance Vector based algorithms [5, 6], Approximate Point-in Triangulation Test (APIT) algorithm [7], Multidimensional Scaling (MDS) algorithm [8] and Azimuthally Defined Area Localization algorithm (ADAL) [9].

Many researchers have paid an attention on the issue of improving of original positioning methods from positioning accuracy point of view. We are interested in improving of fundamental positioning methods usable in WSN: proximity and DV based methods. New modified algorithms were proposed in our previous research [10, 11]. The principles of algorithms are completely different, but we would like to compare their properties because of their low implementation requirements WSN.

The rest of the paper is structured as follows. Section 2 introduces theoretical principles of observed method. In Section 3, simulation model of the wireless sensor network is presented. In Section 4, the simulation results are presented and discussed. Section 5 concludes the paper.

Positioning methods

Firstly, principles of investigated methods are explained. Each group of methods is based on a different positioning principle, therefore they will be explained separately. We assume that given sensor network consists of mobile nodes. Reference Node (RN) is a node with known coordinates. Otherwise, node which does know own position is referred as Blindfolded Node (BN).

DV Based Positioning

DV-Hop and DV-Distance positioning methods belongs to this group. These methods utilize a ranging between RN and BN. Position is estimated by trilateration from information of three RNs. Optimizing algorithm for RNs selection for positioning is used. Principle of the optimizing algorithm is detailed described in [11].

DV-Hop method

This method was proposed in [5]. It is the most basic algorithm. First, it employs a classic distance vector exchange so that all nodes in the network determine distances to the reference nodes (in hops). Next, the hop counts are converted into distances. The average hop distance between them is derived. The average hop distance is flooded into the network. When an arbitrary BN received the correction, it may then have estimate distances to three or more RNs, in meters, which can be used to perform the trilateration to estimate its own location.

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$$c_i = \sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} . (\sum h_i)^{-1} \quad (1)$$

where [x_i; y_i], [x_j; y_j] – coordinates of RNs i and j; h_i – amount of hops. The average hop distance as correction c_i is flooded into the network. When an arbitrary blindfolded node received the correction, it may then have estimate distances to three or more reference nodes, in meters, which can be used to perform the trilateration to estimate its own location. The principle of the method is depicted in Figure 1.

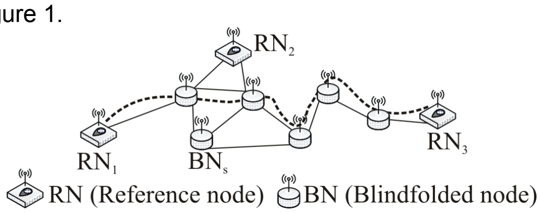

Fig.1. DV-Hop method

DV-Hop works well in dense and regular topologies, but for sparse or irregular networks the accuracy degrades to the radio range.

DV-Distance method

It is similar to previous method with the difference that distance between nodes is presented in meters instead of hops. The simplest solution for determining the distance to the reference node is simply adding the ranges encountered at each hop during the network flood. As a metric, the distance vector algorithm is now using the cumulative traveling distance (in meters). Each receiving node adds the measured range to the path length and forwards the message. The propagation range may be measured either by means of received signal strength or by time of arrival. The final result is that each node will have stored the position and minimum path length to at least flood limit RNs.

Described method is more precise than DV-Hop, because not all hops have the same size, but, on the other hand it is sensitive to errors caused by measuring of particular distances between nodes [6].

Proximity Based Positioning

Proximity based positioning belongs to the group of range-free localization. Localization using proximity measurements is popular, when low cost takes precedence in priority over accuracy. Since, messages necessarily pass between neighbors, there is no additional bandwidth required to proximity. Proximity measurements simply report whether or not two devices are 'connected' or 'in-range'. The proximity based localization has been used by numerous researchers for localization in ad hoc and wireless sensor networks [4-7].

A fixed number of RNs in the network with overlapping regions of coverage transmit periodic beacon signals. The nodes use a simple connectivity metric that is more robust to environmental vagaries, to infer proximity to a given subset of these reference points. Devices localize themselves to the centroid of their proximate reference points. The accuracy of localization is then especially dependent on the separation distance between two or more adjacent RNs. In [10] weighted proximity algorithm was proposed. The utilized influence of particular nodes for location estimation is increased, and on the other side the impact of other nodes is reduced. This simple enhancement leads to increasing of positioning accuracy without significant innovation.

Proximity measurement S is determined based on the measured signal. $S_{i,j}$ is obtained from $RSS_{i,j}$ (Received Signal Strength) and it is equal to 1 if devices i and j are in range, and it is 0 if not. It is necessary to clearly define transition from status "in range" to "out of range". Therefore, we define a threshold. If the RSSi,j at j node transmitted by i node is higher as defined threshold then i node is assumed to be in range of the j node.

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$$S_{i,j} = \begin{cases} 1, & RSS_{i,j} \geq RSS_T \\ 0, & RSS_{i,j} < RSS_T \end{cases} . \quad (2)$$

The location coordinates of blindfolded device are determinated based on the RNs which fulfil the threshold condition. Following proximity based methods are investigated in this paper:

- Common proximity (CMP) - the estimated location is determined on the basis of the closest RN location, i.e. the BN has same coordinates as the closest RN.

$$[x\_cmp_{est}; y\_cmp_{est}] = [x_{closest\_node}; y_{closest\_node}] \quad (3)$$

- Weighted proximity (WEP) - the principle of this algorithm results from centroid proximity [10], but the each input part (particular coordinates of nodes) is individually weighted. The fundamental of WEP is the increasing of influence of closer RNs at the expense of further nodes. The mean value of coordinates obtained after the weighting gives the WEP estimate. The main benefit of the WEP algorithm is the accuracy gain by combining information contributed from multiple part inputs.

We are interested in calculate location estimate from N available the closest reference devices, where $[x_j; y_j]^T$ j = 1,2,…,N is vector of their coordinates. Then, the WEP estimate $[x\_wep_{est}; y\_wep_{est}]^T$ is written as:

$$[x\_wep_{est}; y\_wep_{est}] = \left[\sum_{i=1}^{N} x_i . w_i . \left(\sum_{i=1}^{N} w_i \right)^{-1} ; \sum_{i=1}^{N} y_i . w_i . \left(\sum_{i=1}^{N} w_i \right)^{-1} \right] \quad (4)$$

where $[w_j]^T$ j = 1,2,…,N are input weights.

According [10], the weight {6-3-1} will be used in our simulations.

Simulation model

Simulation model takes into consideration a network of RNs and one BN. Signals from particular nodes are independent to each other and all nodes in the model are deployed with omni-directional antenna.

Let $[x_i; y_i]^T$ $i = 1,2\ldots,m$ are coordinates of RNs and $[x_r; y_r]^T$ are coordinates of BN. Positions of particular nodes were generated by uniform distribution on the area 100 x 100 m. The results are based on 1000 independent runs.

Radio channel is modeled as AWGN (Additive White Gaussian Noise) channel, i.e. it consists of two parts: path loss and white Gaussian noise. Path loss is modeled by following equation:

(5) $$P_d(\mathrm{dB}) = P_0(\mathrm{dB}) - 10.n_p.\log(d/d_0)$$

where P_d – the received signal strength at the distance d in dBm; P_0 – the received signal strength at the reference distance d_0. Typically d_0 = 1 meter, and P_0 is calculated by the free space path loss formula [12]. The path loss exponent n_p is a function of the environment.

The impact of channel properties is not investigated in these experiments, because it does not have impact on the methods. Therefore, SNR = 9 dB is used in all experiments. The size of radio range of the nodes depends on the particular experiment.

The positioning accuracy is compared by means of Root Mean Square Error (RMSE) [10]

(6) $$RMSE = \sqrt{(x_r - x_{est})^2 + (y_r - y_{est})^2} \quad \text{[km]},$$

where $[x_r; y_r]$ are coordinates of true location; $[x_{est}; y_{est}]$ are coordinates of estimated location.

Simulation Results

This chapter analyzes simulation results obtained by above described positioning methods, i.e. DV-Hop, DV-Distance, Common proximity and Weighted proximity in various simulations. Impact of following parameters on positioning accuracy is investigated:

- the radio range of particular nodes,
- the number of reference nodes in the network.

In the first experiment, an impact of the radio range of reference nodes in the sensor network on positioning error was investigated. The number of RNs was 20 in this case.

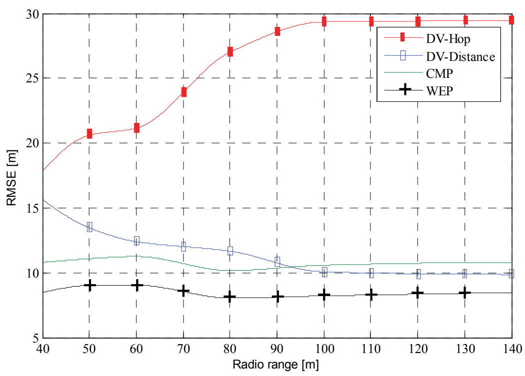

Fig.2. RMSE vs. radio range

Figure 2 depicts the dependency of RMSE particular methods on radio range of all nodes in observed sensor network. The presented results are RMSE median values of all independent trials. On the basis of simulation results, it can be concluded that radio range has different impact on the methods. In case of DV-Hop, radio range increasing means also increasing of RMSE up to 100 m. It could be caused by fact that all nodes in the observed area are mutually in the range.

In Figure 3, CDF (Cumulative Distribution Function) of RMSE for No. of RNs = 20 and radio range = 60 m is shown.

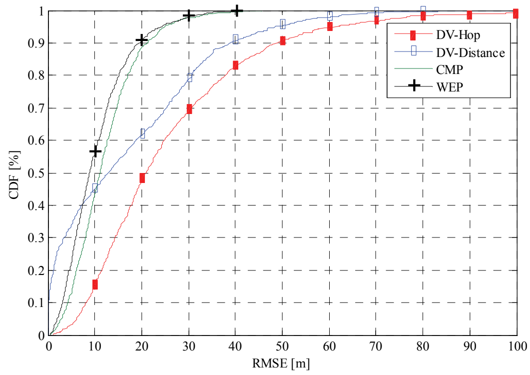

Fig.3. Performance comparison of the methods

On the basis of simulation results, it can be seen that DV-Distance method is more accurate up to CDF is 0.4. Nevertheless, the values more than 0.5 is more valuable. Proximity based methods achieved more accurate results in general. The WEP (black line with +) is the most accurate method of all investigated methods. On the other hand, DV-Hop (red line with fill square) is the less accurate method.

In the following simulation, impact of the number of all RNs in the modeled sensor network on positioning accuracy is compared. Radio range = 60 m in this simulation.

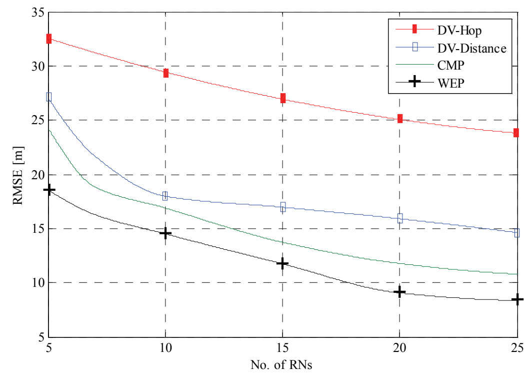

Fig.4. RMSE vs. No. of RNs

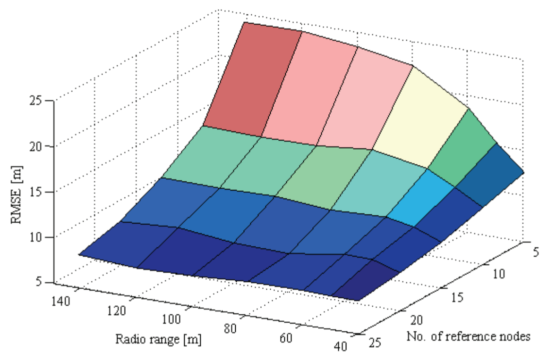

Fig.5. Performance of WEP method

According Figure 4, ascending value of RNs involved in observed area means decreased RMSE in case all observed methods. It causes the fact that the density of

RNs is higher in the area. This fact is usable in wireless sensor networks where the big amount of RNs is assumed.

In the final experiment the performance of Weighted proximity method is analyzed.

On the basis of simulation results, it can be seen complex view on WEP positioning. Radio range does not play role in case that network of RNs is dense. It is important in case of 10 and less. The shorter radio range means the smaller RMSE. It result from used the nearest RNs for final position estimation. This fact is also confirmed by number of reference nodes in the networks. On the other hand, the successful positioning is lower, i.e. the method is not able to estimate position if enough RNs is not in range.

Conclusion

We discussed methods for the location determination based on the DV protocol and proximity technology for wireless sensor networks. The distinguished advantage of these positioning techniques is its simplicity and the easy implementation. We analyzed the impact of following parameters, i.e. the number of all present reference nodes in the observed area and their radio range. The mentioned parameters were tested by means of extensive simulations. It is necessary to note that particular basic methods were improved by optimization algorithms proposed in our previews research [10,11].

According to the results, the performance of the weighted proximity technique is better in comparison with the other methods. The common proximity achieved better results compare to DV based methods and its advantage is that it does not need any calculation capacity for the localization procedure. DV based methods could be better implemented in no very dense sensor networks. There will be more successful.

From this study, the proximity based methods is not accurate in comparison with the sophisticated localization methods, but it is sufficient for certain non-critical applications in huge WSNs.

This work has been partially supported by the Slovak VEGA grant agency, Project No. 1/0392/10 "The research of mobile nodes in wireless sensor networks" and the Slovak Research and Development Agency under the contract No. LPP-0126-09.

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