REAL LIFE DATA ACQUISITION IN WIRELESS SENSOR NETWORK LOCALIZATION SYSTEM

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KEYWORDS

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ABSTRACT

The paper treats the problem of localization in Wireless Sensor Network (WSN). In our work, we present and evaluate *Wireless Sensor Network Localization System*, which supports sensor node localization from data gathering from real-life deployments through modelling and applying different localization methods up to distributed computing in HPC environment. The paper describes extension of *WSN Localization System* with modules supporting real-life sensor data acquisition. A provided case study demonstrates the localization accuracy obtained for a few example networks generated by simulation models and based on acquired sensor data.

INTRODUCTION TO WSN LOCALIZATION

The aim of localization is to assign geographic coordinates to each node in the sensor network in the deployment area. Wireless sensor network localization is a complex problem that can be solved in different ways, [Karl and Willig, 2005]. A number of research and commercial location systems for WSNs have been developed. They differ in their assumptions about the network configuration, distribution of calculation processes, mobility and finally the hardware's capabilities, [Mao et al., 2007], [Awad et al., 2007], [Zhang et al., 2010].

Recently proposed localization techniques consist in identification of approximate location of nodes based on merely partial information on the location of the set of nodes in a sensor network. An anchor is defined as a node that is aware of its own location, either through GPS or manual pre-programming during deployment. Identification of the location of other nodes is up to an algorithm locating non-anchors. Considering hardware's capabilities of network nodes we can distinguish two classes of methods: range based (distance-based) methods and range free (connectivity based) methods.

The former is defined by protocols that use absolute point to point distance estimates (ranges) or angle estimates in location calculation. The latter makes no assumption about the availability or validity of such information, and use only connectivity information to locate the entire sensor network. The popular range free solutions are hop-counting techniques. Distance-based methods require the additional equipment but through that much better resolution can be reached than in case of connectivity based ones. In our works we concentrate on range based methods.

The paper is structured as follows: at the beginning we shortly describe the distance-based localization problem. Next, we provide an overview of our software environment for WSN localization and an extension applied to our software in order to acquire data from real-life deployments. Finally, we provide a case study results and conclusions.

DISTANCE BASED LOCALIZATION

Let us consider a network formed by M sensor devices (anchor nodes) that are aware of their location, either through GPS or manual recording and entering position during deployment, and N sensor devices (non-anchor nodes) that are not aware of their location in a network system. The goal of a localization system is to estimate coordinate vectors of all N non-anchor nodes. In general, distance based localization schemes operate in two stages:

- *Inter-node distances estimation stage* – estimation of true inter-node distances based on inter-node transmissions and measurements.
- *Position calculation stage* – transformation of calculated distances into geographic coordinates of nodes forming the network.

Inter-node Distances Estimation Stage

In spite of the available hardware, distance based localization systems exploit the following techniques

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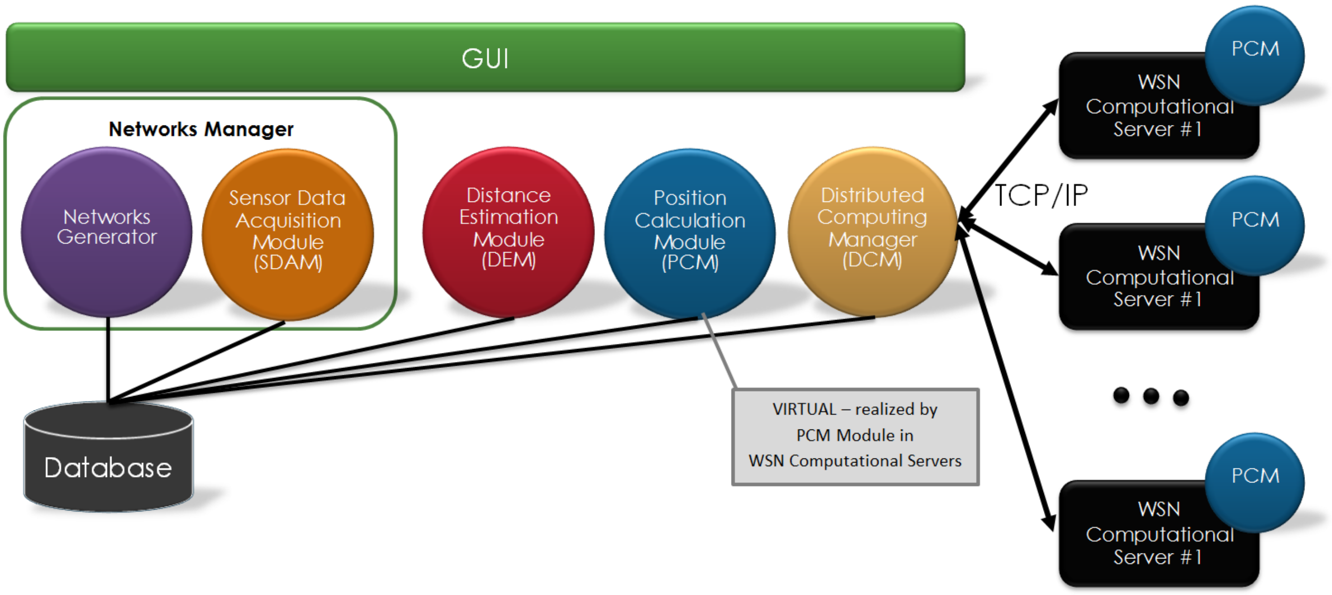

Fig. 1. The components of the WSNLS

widely described in literature [Benkic et al., 2008], [Karl and Willig, 2005], [Mao et al., 2007]:

- Angle of Arrival (AoA),
- Time of Arrival (ToA),
- Time Difference of Arrival (TDoA),
- Received Signal Strength Indicator (RSSI).

AoA, ToA and TDoA methods need an additional equipment such as antennas or accurately synchronized clocks. The most popular technique is the RSSI method because of easy configuration, deployment and no additional hardware needed (low cost). The disadvantage of this solution is low quality of measurement accuracy due to high variability of RSSI value [Benkic et al., 2008], [Ramadurai and Sichitiu, 2003]. Nevertheless some authors indicate that new radio transceivers can give RSSI measurements good enough to be a reasonable distance estimator [Barsocchi et al., 2009], [Srinivasan and Levis, 2006].

Position Calculation Stage

In the position calculation stage the computed internode distances are used to estimate the geographic coordinates of all non-anchor nodes in a considered network. Position estimation can be done by using different techniques. There are many widely used techniques such as: triangulation, trilateration, multitrilateration and multidimensional scaling. The common idea of other methods is formulating the localization problem as the linear, quadratic or nonconvex nonlinear optimization problem solved by linear, quadratic or nonlinear (often heuristic) solvers.

Recently, a popular group consists of *hybrid systems* that combines more than one technique to estimate location, i.e., results of initial localization are refined using another localization method. All mentioned methods are described and evaluated in literature, see [Akyildiz and Vuran, 2010], [Biswas and Ye, 2004], [Kannan et al., 2005], [Kannan et al., 2006], [Mao and Fidan, 2009], [Mao et al., 2007], [Niewiadomska-Szynkiewicz, 2012], [Niewiadomska-Szynkiewicz et al., 2011].

WIRELESS SENSOR NETWORK LOCALIZATION SYSTEM OVERVIEW

The Wireless Sensor Network Localization System (WSNLS) is an integrated software environment for testing various localization schemes on parallel computers or computer clusters. It provides not only a set of solvers for localization WSN nodes but supports the whole localization process from test network defining, radio signal modelling and processing, real-life data acquisition up to parallel execution of localization schemes.

An open architecture and object-oriented programming make the software easily extendable with implementations of new approaches for calculating locations of nodes in a network. WSNLS can be used to estimate the geographic coordinates of all devices forming the real life sensor network. Moreover, it can be used for tuning and performance evaluation of various localization solvers that are integrated with the framework before their practical application to a real life network.

Since its first realization, described in [Marks, 2012], WSNLS architecture has been improved in many aspects and extended by adding Sensor Data Acquisition Module (SDAM). The system is still composed of a runtime platform (formed by two components, i.e., *Distributed Computing Manager* and *Computational Server*) responsible for calculation management and interprocess communication. However in second version of the system, *Networks Manager* has been reorganized and contains *Networks Generator* – a component for modeling a network to be simulated and *Sensor Data*

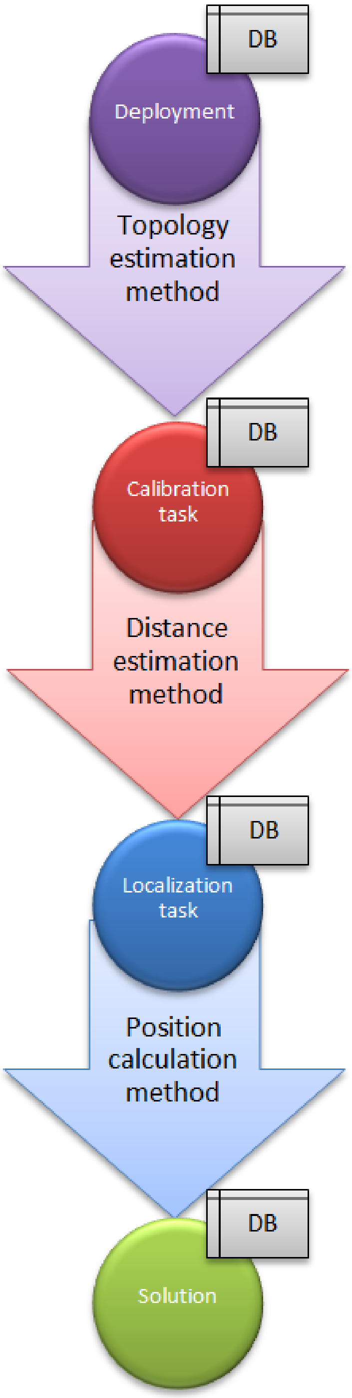

Fig. 2. Dataflow in WSNL system

Acquisition Module – component responsible for data gathering from real-life deployments. There are still two components responsible for location calculations, i.e., *Distance Estimation Module* and *Position Calculation Module*, database for recording data of all examined networks and results of calculations, and a set of tools to support the interaction with a user (GUI), but all the features of *Position Calculation Module* are realized by computational servers. The architecture of WSNLS is presented in Fig. 1.

DATA FLOW IN WSNLS

Since the aim of WSNLS is providing support for the whole localization process – from test network defining up to nodes location estimation – the data processing requires applying specialized methods on three stages as it is shown in Fig. 2. Computational method used on two stages i.e. distance estimation methods and position calculation methods are described in more details in [Marks, 2012], [Marks and Niewiadomska-Szynkiewicz, 2011]. However the first stage in presented dataflow relies on topology estimation methods, which were partially unavailable in first version of Wireless Sensor Network Localization System.

Topology estimation methods

Topology estimation methods provide a means for gathering information about network topology. This information can be obtained by using appropriate modelling or by data acquisition from real-life deployments. In general the proper modeling of low-power links is very difficult since the links characterization depends on radio chips (e.g., TR1000, CC1000, CC2420, etc), operational environments (indoor, outdoor) and many other parameters such as traffic load or radio channel – [Baccour et al., 2012]. In our software we decided to provide models based on *Link Layer Model for MATLAB* provided by [Zuniga and Krishnamachari, 2004], where we focus on wireless channel modeling and no radio modulation and encoding are considered. Much better solution, of course applicable only for institution which have at least laboratory WSN deployments, is to acquire data directly from real Wireless Sensor Networks. More information about real-life data acquisition is provided in section *Sensor Data Acquisition Module*.

Distance estimation methods

Distance estimation methods transform RSSI measurements into internode distances estimations. At present *Distance Estimation Module* has registered three approaches to distance estimation: Ordinary Least Square Method (OLS), Weighted Least Square Method (WLS) and Geometric Combined Least Square Method (GCLS). More information about distance estimation stage can be found in [Marks and Niewiadomska-Szynkiewicz, 2011].

Position calculation methods

Position calculation methods estimate the coordinates of non-anchor nodes in the network using internode distances. Position Calculation Module is realized in the object-oriented way and it can be easily extended with new localization algorithms. Currently Trilateration, SA (Simulated Annealing) and TSA (Trilateration & Simulated Annealing) methods are supported, in the near future TGA (Trilateration & Genetic Algorithm) method will be added. More information about position calculation methods can be found in [Niewiadomska-Szynkiewicz and Marks, 2009].

SENSOR DATA ACQUISITION MODULE

There are three types of information which are needed for distance based localization and localization quality verification in case of using RSSI readings:

- anchor nodes coordinates,
- RSSI readings between nodes in the network,
- all nodes coordinates (optional).

The anchor nodes coordinates and RSSI readings between nodes in the network are mandatory and there is no chance to localize nodes in global space without both this data. Coordinates of all the nodes in the network are optional and they are needed only for localization accuracy verification. In *WSN Localization System* we assumed two ways of providing the information.

The fist one is just the form where user is asked for providing data about number of nodes, number of anchor nodes and coordinates for anchor nodes. Filling the data about non-anchor nodes coordinates is not mandatory, but it can be done using the same form.

Second part of acquiring information is done automatically. After registration starting the *Sensor Data Acquisition Module* initiates data collection from the network through a sensor node playing a role of *Edge Router* which is connected to our system via USB connector and has the capability to communicate with other sensor nodes using IEEE 802.15.4 radio. The overview of data gathering process is depicted in Fig. 3. Of course it is possible to organize data collection only by using this automatic approach, but this approach implies then the necessity of equipping all anchor nodes with GPS modules or hardcoding information about their locations which is not the most convenient solution.

Data collection protocol is based on *BLIP 2.0* stack. BLIP 2.0 – Berkeley Low-power IP stack, is an reimplementation in *TinyOS* of a number of IP-based protocols including IPv6, RPL anc CoAP. More information can be found in [Silva et al., 2009], [Rodrigues and Neves, 2010]. Each sensor node in the network is responsible for exchanging packets with all the nodes in its neighbourhood and collection a vector of pairs *neighbour id* and *received signal strength*. After collection such vectors are transmitted using multi-hop unicast transmission to edge router and then registered in database by *Sensor Data Acquisition Module*.

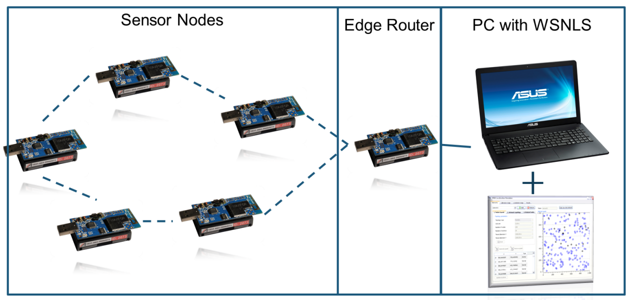

Fig. 3. Scheme of data acquisition system

EXPERIMENTAL RESULTS

Sensor platform

Wireless Sensor Network Laboratory organized in Institute of Control and Computation Engineering Warsaw University of Technology is equipped with over 130 sensors. Laboratory contain 28 MicaZ nodes produced by Memsic Company (former Crossbow) and over 100 Advantic Technology CM3000 and CM5000 sensors (clone of TelosB platform). All experiments described in this paper were realized using MicaZ sensor nodes based on ATmega128L low-power microcontrollers and Chipcon CC2420 radio transeivers (2.4GHz). One of the nodes is presented in Fig. 4.

Fig. 4. MicaZ node from ICCE WUT Laboratory

Localization technique

In this experiment a trilateration – the simplest method available in the Wireless Sensor Network Localization System was used. The *trilateration* technique requires the distance measurements between the node with unknown location and its neighbors (in 2-D space three neighbors with known locations are sufficient). The minimization problem with the performance function calculated as a difference between the measured and estimated distances is formulated and solved. Several variants of *multitrilateration* method are proposed in literature to reduce limitations of the typical trilateration scheme.

Atomic multitrilateration incorporates distance measurements from multiple neighbors. It is used to improve an accuracy of the location estimation if the distance measurements are noisy.

The idea of *iterative multitrilateration*, implemented in our software, is to repeat trilateration for increased number of anchor nodes (every iteration each node with estimated position changes its role to anchor).

Considered topologies

In this section preliminary results obtained for two real-life deployments are presented. In both cases sensor nodes where deployed in a square region. In the first scenario anchor nodes are located evenly in the whole considered area, while the second scenario describes situation where all anchor nodes are located unevenly – they are grouped in one quarter of the deployment area. All experiments where done in the interior of Main Auditorium Warsaw University of Technology. The place of experiment realization had a big impact on quality of obtained location estimates because of a big problems with signal reflections of stone elements and a high radio waves density (multiple Wifi networks operating in this area).

TABLE I: Scenario 1: Localization error for anchor nodes deployed evenly

Method	Real-life network	Simulated network
dv-hop	62.72%	55.34%
trilateration	49.87%	16.67%

TABLE II: Scenario 1: Localization error for anchor nodes deployed unevenly (1/4 of deployment area)

Method	Real-life network	Simulated network
dv-hop	87.29%	70.49%
trilateration	86.13%	49.10%

In tables I and II localization errors for two considered scenarios are presented. To compare the performance of the tested algorithms we used the mean error between the computed and the actual unknown location of the nodes in the network, defined as follows

$$LE = \frac{1}{N} \cdot \frac{\sum_{i=1}^{N}((\tilde{x}_i - \hat{x}_i)^2 + (\tilde{y}_i - \hat{y}_i)^2)}{R^2} \cdot 100\% \quad (1)$$

where $(\tilde{x}_i, \tilde{y}_i)$ is true location of sensor node i, $(\hat{x}_i, \hat{y}_i)$ estimated location of sensor node i and R radio range. The location error LE is expressed as a percentage error. It is normalized with respect to the radio range to allow comparison of results obtained for different size and range networks.

Both tables contains the comparison of localization errors for two methods – described earlier *Trilateration* and a connectivity-based method *dv-hop* [Niculescu and Nath, 2003] which is treated as a reference point as it is commonly used in practical applications. The results obtained for simulated networks shows that trilateration is capable to provide much better results – three times smaller error for scenario 1 and almost two times smaller for scenario 2. However in case of data acquired from real-life deployments the difference is almost invisible for scenario 2 and less than two for scenario 1. Conducted experiments shows how important is verification of WSN algorithms in real-life deployments. Of course the main reason of the differences in localization quality is realization of experiment in a very difficult environment. The differences between localization accuracy for reference dv-hop method, where distance estimation is not necessary, are acceptable.

CONCLUSIONS AND FUTURE WORKS

We have presented the design and evaluation of our *WSN Localization System* extended with Sensor Data Acquisition Module. The software can be used for creation and solving different WSN localization problems using various methods from *Position Calculation Module* – such as trilateration, SA or TSA methods. The software can be easily extended with another methods utilizing the same software framework. Emphasis was placed on the distributed computation modules which allows us for maximizing the methods robustness for different tasks.

Conducted experiments shows how important is verification of WSN algorithms in real-life deployments. In our future research, we would like to conduct additional experiments with much bigger numer of sensor nodes and more sophisticated localization techniques (SA and TSA) which allows to obtain much more accurate localization results.

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