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Self-localization System for Wireless Sensor Network

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Introduction

Wireless sensor network (abbrev. WSN) consists of many small independent battery powered nodes with wireless communication and sensing capabilities. This type of network became popular because of its applicability, which includes many areas such as environmental, industrial, military etc. Despite the fact that the main goal of the WSN is to monitor an area of interest, several secondary objectives have to be achieved. The definition of self-localization system is one of these prerequisites required to make functional many of WSN applications that rely on location information.

Large scale of the WSN makes it infeasible to precisely place every node in the network. Therefore, some localization algorithms for the WSN were developed. Centralized algorithms are designed to run on a base station with a lot of computational power. Sensor nodes gather data and send it to the base station for analysis, while the computed positions are returned to the nodes. These algorithms circumvent computational limitations problem of the node by accepting the communication cost of moving data to the base station.

Distributed algorithms are designed to use parallelism and inter-node communication to compensate the lack of centralized computing power. Two approaches for distributed localization exist. The first one is beacon based algorithms. Nodes obtain a distance measurement to a few beacons and use this information to determine their own location. In some algorithms, newly localized nodes become beacons to improve further localization of the nodes.

Second approach uses global metric optimization over the network in a distributed fashion. This group consists of two different approaches. The first one is relaxation-based distributed algorithms [6], which use a refinement step, as each node adjust its position to optimize a local error metric. Coordinate system stitching is the second group of algorithms [4], where network is divided into small overlapping areas. In each area, an optimal local map is created. Eventually, all these local maps are merged into a single global map.

In this paper we propose adaptive self-localization system for wireless sensor network. To achieve this goal, the coordinate system stitching approach was adjusted to compute the center and direction of the relative network coordinate system. Also, a method of network center group selection and alternation was provided. Finally, we simulated and evaluated self-localization system in MATLAB environment.

Self-localization system

The problem of self-localization is important topic of research in wireless sensor network. Self-localization involves consolidating the nodes into an easily controllable network infrastructure. That is the ability of the nodes to self-conFig. among themselves to form a global or relative coordinate system.

Sensor networks have limited resources, because nodes are equipped with weak processors that cannot perform large computations. Since individual sensor nodes use small battery as a power source, communication and data processing significantly reduce the lifespan of the node. Thus, self-localization system must be operative in the WSN as long as possible. Therefore, we propose an energy-efficient method to select and maintain a relative coordinate system in the WSN.

We explore a uniform and non-static wireless sensor network, when all nodes have the same computing, sensing and battery resources. Possible random node movement that could be caused by an external impact is also considered. Therefore, a specific approach is used to establish a relative coordinate system of the entire network. A center of the relative network coordinate system is a particular group of nodes that is stable and less likely to disappear. This center group is selected using a special method that we propose in the next section.

Each node in the center group creates its local coordinate system using the localized positioning algorithm [5]. One-hop center group with local coordinate systems of the simulated wireless sensor network is depicted in Fig. 1. Every node is central in respect of its local coordinate system and all neighboring nodes are localized in it. As a result, we have a number of coordinate

systems with different directions. Later, these coordinate systems are transformed into one relative coordinate system. To achieve this goal, we need to compute a translation vector, a scale factor and an orthonormal rotation matrix, that define the transformation from one coordinate system to another. This process can be performed when at least three nodes have known locations in both coordinate systems.
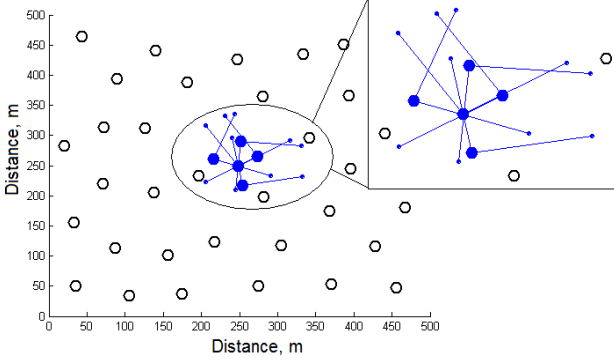

Fig. 1. One-hop center group with local coordinate systems

Our self-localization approach is based on Horn et al. method [2] that performs coordinate system translation using squared error. It is preeminent over the similar methods, because of several reasons. First, it has provable optimality over the canonical least-square error metric as depicted in formula 1. Second, it uses all the available data, though it can calculate a correct result with only a three points. Third, it can be quickly computed, because of running time that is proportional to the number of common points.

However, the measurements used to calculate coordinates of the nodes are likely to have errors. Therefore, a minimization of the misalignment between the two coordinate systems is performed. If $x_{l,i}$ and $x_{r,i}$ are known locations of the node $i = 1…n$ in two neighboring coordinate systems then the goal is to find a translation t, scale s, and rotation R which transform a location of the node from one coordinate system into another using such formula

$$x' = sRx + t . \qquad (1)$$

According to the Horn et al. [2], t, s and R are expressed via following condition

$$(t, s, R) = \underset{t,s,R}{argmin} \sum_{i=1}^{n} \| e_i \|^2 , \qquad (2)$$

where error term is evaluated as follows

$$e_i = x_{r,i} - sRx_{l,i} - t . \qquad (3)$$

Network center and its stability are critical factors for the entire network. Therefore, we do not choose a local coordinate system of a single node as a network coordinate system. If for some reasons, that particular node disappear, all network infrastructure would be lost. Thus, it is ensured that group of center nodes is the most stable in the entire network. Furthermore, center movement is less compared to individual node mobility. Therefore, the larger group of

nodes composes center, the more stable it is, but more difficult it becomes to maintain.

According to likely network mobility, group size should be chosen. In almost static networks, one-hop neighborhood is acceptable, while highly mobile networks require two or even three-hop neighborhood.

In general, Fig. 2 presents how the proposed self-localization system operates. As center group is identified, all nodes in this group construct their local coordinate systems. Later, these local coordinate systems are transformed into one relative coordinate system. Finally, remaining network nodes compute their positions in this coordinate system.
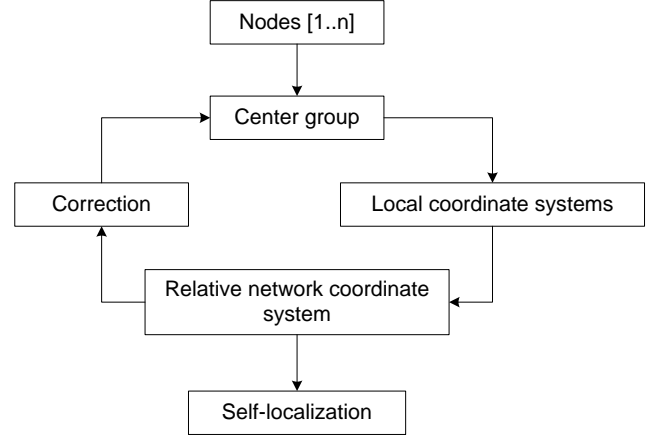

Fig. 2. Control flow in the self-localization system

Because of node mobility and energy depletion, network center and direction vary in time and must be regularly updated at a fixed time intervals using correction procedure. If the total energy of the nodes in the center group decreases below the critical threshold, then new center group is selected. In general, new center is chosen according to the total residual battery power and internal communication costs of the group.

Center group selection method

As described in previous section, center group definition depends on network mobility and energy consumption. If the total remaining energy of the center group reaches predefined threshold level, then a new center group is identified on the particular set of nodes that are healthier. We propose a destination group selection method that is designed to find the most suitable group of nodes for the network center in respect of total remaining energy and internal communication costs in the group.

According to the authors of [3], energy loss in the path d_i is evaluated as follows

$$E(d_i) = p_i \left(\alpha + \beta d_i^{\eta} \right), \qquad (4)$$

where d_i – transmission distance on edge e_i, $i = 1…n$, as n is the number of hops in the group G; p_i – total bits transmitted on edge e_i; η – path loss exponent; α and β – distance independent and dependent energy components for one bit communication. This method is

platform independent, because values of α, β and η are to be measured for the WSN platform in use.

Thus, total energy consumption for communication in the group we evaluate as follows

$$C_G = \sum_{e_i \in G} E(d_i) = \sum_{e_i \in G} p_i \left(\alpha + \beta d_i^{\eta} \right). \qquad (5)$$

Subsequently, for all the groups of the network, energy balance is calculated

$$E_{B,j} = E_j - C_{G,j}, \qquad (6)$$

where E_j – total remaining energy of nodes in the group, $j = 1 \ldots m$, as m is the number of groups in the wireless sensor network. Thus, $E_{B,j}$ indicates suitability of each group in the network to be selected as a center group. Suitability of every group is evaluated according to the total residual battery power and energy costs required for communication in the group.

Finally, the center group G_{center} is selected as follows

$$G_{center} = \max_j \left\{ E_{B,j} \right\}. \qquad (7)$$

This methodology is intended to select and maintain a relative coordinate system in the WSN. As a result, it significantly increases longevity of the self-localization system.

Results

Proposed self-localization system is simulated and its functionality is explored in MATLAB environment. Firstly, network mobility impact to the center group of the relative network coordinate system is examined.

Network nodes are non-static and their movement is random. Therefore, our simulation is performed in a way, when destination points for a number of nodes are randomly selected in the network area. Also, motion of mobile node is determined from the predefined range of speed. Range of speed and a number of mobile nodes are specified before simulation. As node arrives to the destination point, a new one is randomly selected with particular speed and destination point parameters.

Self-localization system uses a special method to select and maintain a center group of the network. However, group size should be chosen based on probable network mobility. The main problem is to find optimal center group size in order to restrict center motion. In the highly mobile network, only a large center can ensure stability. Otherwise, large center significantly increases energy consumption. Network center motion is compared in Fig. 3 as different sizes of center group are used.

Thus, when node speed is from range 1 to 8 m/s, simulation results indicate, that three-hop center group produces stable network center with only 0.03 m/s average speed. Using two-hop group size, center motion becomes approximately stable when average node speed exceeds 2 m/s. One-hop center is not stable with selected simulation parameters.
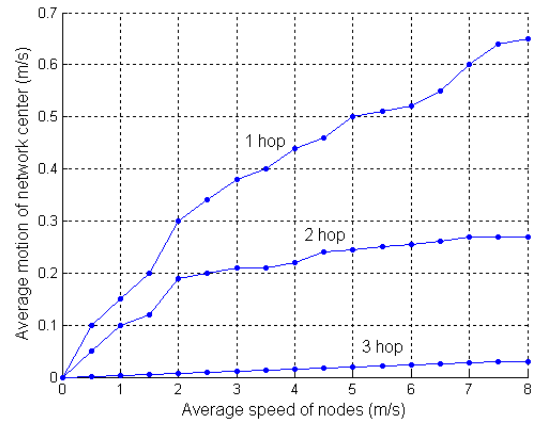

Fig. 3. Motion of network center

Further we explore a functionality of the method that is intended to maintain a center group. Thus, sensor network of 500 square meters was simulated with randomly deployed nodes and two-hop center group. Initially, network center was assigned to the first group. Nodes in this group go out of battery power quicker than other nodes in the network, because of creation and maintenance of the relative network coordinate system. New identification process was initiated when the residual energy of the center group has reached a predefined critical threshold that was set to 15%.

Therefore, at 1029 minute was determined that center group must be redefined on the other set of nodes before its energy is entirely depleted. Thus, center alternated from 1 through 2, 3, 4 and 5 groups with the aim to extend longevity of the self-localization system (Fig. 4).
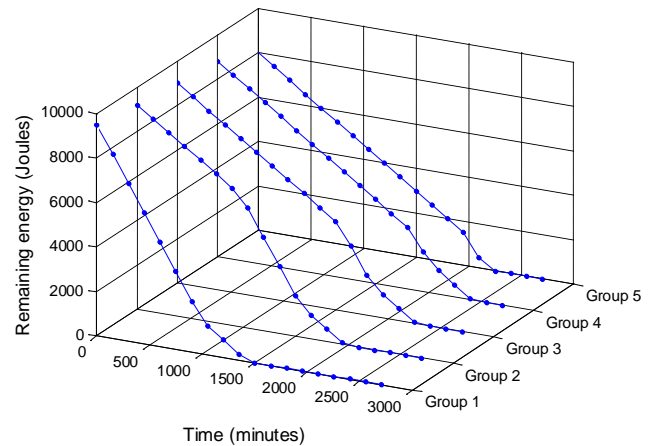

Fig. 4. Energy depletion

Energy depletion of each center group in the entire network center alternation process is shown in Fig. 4. Because of alternation capability, self-localization system operated until 2247 minute and that is 87% longer time compared to the case without center alternation feature. Here, a linear battery model [7] was used, as it allows evaluate the efficiency of center group alternation by providing a simple metric of energy consumption for computation and communication. Also, the ideas of battery management in the WSN [8] and energy savings of a node [1] were considered.

19

Conclusions

The requirement of different solutions for different applications and also the high number of possible applications of the WSN inspired the study and proposal of new solution to the localization problem. Based on the ideas of the coordinate system stitching approach, adaptive self-localization system was provided. It is dedicated for infrastructure free network deployments with probable motion of nodes.

Using results from the simulation, it is verified that growth of network mobility causes additional energy costs required to maintain relative coordinate system. In almost static network, one-hop center group is enough to maintain a relative coordinate system with sufficient stability. However, as the average mobility of nodes approximate to 8 m/s, three-hop center group is required.

Furthermore, a method that is intended to maintain a center group significantly increases the lifetime of relative coordinate system and therefore extends application longevity. As a result, proposed self-localization system is adaptive in respect of changeable distribution of energy in the WSN.

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V. Martusevičius, E. Kazanavičius. Self-localization System for Wireless Sensor Network // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 7(103). – P. 17–20.

Wireless sensor networks (WSNs) consist of many small battery powered nodes with wireless communication and sensing capabilities. This type of network has many possible applications in the scientific, military and commercial domains. Examples of these applications include environmental monitoring, surveillance and many others. Despite the fact that the main goal of the WSN is to monitor an area of interest, several primary objectives have to be achieved. The definition of self-localization system is one of these prerequisites required to make functional many of WSN applications that rely on location information. Therefore, we propose a self-localization system that is the ability of the nodes to self-conFig. among themselves to form a relative coordinate system. This system includes a special method that increases the longevity of the self-localization system according to changing energy situation in a dynamic WSN. Ill. 4, bibl. 8 (in English; abstracts in English, Russian and Lithuanian).

В. Мартусевичюс, Е. Казанавичюс. Система автолокализации для беспроводных сенсорных сетей // Электроника и электротехника. – Каунас: Технология, 2010. – № 7(103). – С. 17–20.

Беспроводные сенсорные сети (англ. WSNs) состоят из множества мелких узлов на батарейках с беспроводной связью и сенсорными возможностями. Этот тип сети имеет много возможных применений в научных, военных и коммерческих областях. К таким приложениям относятся мониторинг окружающей среды, наблюдение и многое другое. Несмотря на тот факт, что основной целью WSN является наблюдение за сферой интересов, некоторые первичные цели должны быть достигнуты. Определение автолокализации системы является одной из предпосылок необходимых для многофункциональных приложений WSN, которые основаны на информации местоположения. Поэтому предлагается автолокализация системы, которая предоставляет возможность узлам сформировать относительную систему координат. Эта система включает в себя специальный метод, который увеличивает долговечность автолокализации системы учитывая динамическое изменение энергии на WSN. Ил. 4, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Martusevičius, E. Kazanavičius. Bevielio sensorinio tinklo autolokacijos sistema // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 7(103). – P. 17–20.

Bevieliai sensoriniai tinklai (angl. WSNs) susideda iš daugelio mažų baterijomis maitinamų įrenginių, vadinamų mazgais, kuriems būdingos bevielio ryšio ir jutimo galimybės. Tokio tipo tinklai plačiai naudojami mokslo, karo ir komercijos srityse. Dažniausiai jie taikomi diegiant aplinkos stebėjimo, objekto sekimo ir kitas sistemas. Nors pagrindinis WSN tikslas yra stebėti įvairius aplinkos reiškinius, tačiau prieš tai turi būti išspręsti tam tikri pradiniai uždaviniai. Autolokacijos sistemos sudarymas yra vienas iš tikslų, kurį reikia įgyvendinti, kad būtų galima sėkmingai įvykdyti pagrindinius uždavinius, kuriems reikalinga buvimo vietos informacija. Tam sudaryta autolokacijos sistema, kuri leidžia mazgams suformuoti santykinę tinklo koordinačių sistemą ir pagal ją apskaičiuoti savo koordinates. Be to, pateiktoje autolokacijos sistemoje taikomas specialus metodas, kuris pailgina jos egzistavimo trukmę, atsižvelgiant į kintamą energijos pasiskirstymą bevieliame sensoriniame tinkle. Il. 4, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).