Classification and comparative analysis of localization approaches for Wireless Sensor Networks

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Abstract – **The aim of this paper is to investigate and study the various localization approaches, which are used in the modern wireless sensor networks (WSNs). In the Introduction we shortly describe what the WSNs are and what their main characteristics and some of their purposes are. In the second section of the paper we investigate and analyse the radio-based approaches for localization in the WSNs. Later we present the main characteristics of the satellite-based approach for localization, and its implementation for the needs of the WSNs. In chapter four we shortly present the sound-based approaches for localization. In the next chapter we conduct a short comparative analysis of the localization approaches and we highlight the main disadvantages and issues with them. The paper is then completed by the conclusion section, followed by the acknowledgment and references sections.**

Keywords – **Wireless sensor networks, localization approaches, radio-based localization, satellite-based localization, sound-based localization.**

I. Introduction

The rapid rate of development in the fields of telecommunication and computer sciences has led to the emerging of several new technologies and paradigms for networking. One of these new ideas was the development of tiny mobile devices with sensing capabilities and with the possibility for wireless data delivery. Since the initial introduction of these devices, they have been found as suitable for a variety of different purposes - from animal movement and population monitoring, trough warning systems and systems for detection of hazardous agents and radiation to the latest military purposes - as vehicle and troops tracking and monitoring systems [1, 2, 3]. Despite the variety of sensor devices and their many purposes, there are several disadvantages of the networks they form. One of the current issues is the limited sensor lifetime due to the battery capacity of the devices. Another open issue, which is a consequence of the demand for smaller and more compact sensor devices, is their limited storage and computation capabilities [4]. The sensor motes are equipped with wireless communication interface and are using the 433 MHz, 868-915 MHz and the 2.4 GHz bands [1]. There are two modulation formats available - two-tone Frequency-Shift-Keyed (FSK) at 433 and 868-915 MHz and direct sequence spread spectrum (DSSS) at 2.4 GHz supporting the 802.15.4/ZigBee standard. All radio interfaces are commonly bidirectional, and support a range of 10 to 100 meters [2, 3]. There are several different data routing approaches in the WSN. The direct routing approaches are most easy to use, but they suffer from many disadvantages and are not suitable for large scale WSNs. The flat routing approaches provide more efficient ways for energy consumption, which they achieve by retransmission of the data towards the bases station using sensor motes in close proximities and by aggregation of the information. The hierarchical routing approaches are the most widely used ones. They define that the network has to be organized into clusters, which are controlled by cluster heads. One of the largest advantages of the WSNs is the possibility to locate and track different objects. This is also a prerequisite for the efficient work of the directed and the hierarchical routing approaches, since they rely on the location of the different neighbouring sensor devices in the sensor field.

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II. Radio-based localization approaches for Wireless Sensor Networks

Some of the most widely used approaches for localization in the wireless networks are the radio-based approaches. There are two main classes, but they both use the information from the radio interfaces to calculate the range to a certain device. These approaches do not require additional hardware components and instead use the build-in radio interfaces of the devices.

Localization using the Radio Hop Count

The first of the radio-based localization approaches, which we will investigate, is the radio hop count approach. This is one of the most inaccurate approaches [5], but yet it is a usable approach in certain cases and based on the purpose of the network. As it is widely known the radio interface of every device has a limited range, let’s say *R* meters. So when sensor device *A* is communicating with device *B*, then *A* has to be no more than *R* meters away from *B*. As it is to notice by this statement there is an error margin of $0*R$ to $1*R$ meters, since in the two border conditions the nodes can be either on top of each other (error of $1*R$ meters) or they can be on R meters away from each other (error of *0*R* meters). Even though that this approach provides low level of localization accuracy it still can be used for a number of purposes like for instance in the routing processes for the WSNs. There is a number of routing approaches which rely on the radio hop count to find a shortest path to a given target device or to decide, if it is effective to transmit data between two devices [5, 6]. Similar to the routing protocols, which are used in the IP networks, there are routing protocols in the WSNs, which use the local connectivity information provided by the radio interfaces to form a connectivity graph. In this graph of the network the vertices are the sensor devices and the edges are representing the radio links between them (Fig.1).

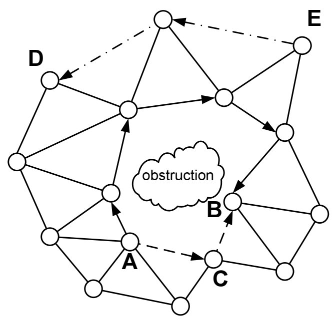

Fig.1. Examples of most common issues with the hop count localization based approach

Based on this, the hop count H_{AB} between any two sensor devices *A* and *B* can be calculated using Dijkstras shortest-path algorithm [7]. By knowing the value of the hop count, we can define that *A* and *B* are at the most $R*H_{AB}$ meters away. As seen in Fig. 1 this statement is correct, but the value of the Euclid distance between both devices is many times smaller than $R*H_{AB}$. This is the first of the three major problems of this approach. The second one is the fact that two different in length routes can have the same value for hop counts. This can be seen in Fig.1 for the routes between devices *E* and *D* and between devices *A* and *B* ($H_{ED}=H_{AB}=2$). This problem is specifically to be taken into consideration when there are multiple equal in hop count routes between two devices. As a result of this, the inappropriate route can be selected, which will lead to a significant delay or to an ineffective energy consumption (both due to the larger distances the data will have to travel). The third and last problem with this approach is the fact that different obstacles can prevent edges from appearing in the connectivity graph. This can be demonstrated by removing device *C* (due to the obstacle) from Fig.1. This action will lead to the removal of the path between *A* and *B* trough *C*. The new path will have a hop count of *5*, but again this will not necessary mean that the devices are *5*R* meters away.

Received Signal-Strength Indication

The RSSI approach is significantly more complex than the radio hop count approach, but can provide more accurate estimation of the location of the devices [8]. The main idea behind this approach is to use the widely known fact, that the energy of the radio signals decreases with the distance travelled. The receiver can then use this statement to calculate backwards the distance to the transmitter based on the strength of the received signal. This approach would work perfectly in ideal conditions, but in the real world the propagation of the radio signals is not uniform and this leads to a certain degree of errors [9]. Additionally the environment, in which the sensor nodes are placed, can contribute significantly to the localization errors, due to the fact that many physical objects and surfaces can absorb or reflect the radio waves. In the real world, when this approach is used for localization in the network, two devices, which are centimetres away, but separated by a concrete wall, can appear to be positioned many meters away one from another.

III. SATELLITE-BASED LOCALIZATION APPROACHES FOR WIRELESS SENSOR NETWORKS

The idea behind every localization technique is to determine the coordinates of a given object. Unlike some of the localization methods (like RSSI and Radio Hop count), which determine the location of the sensor devices relatively and based on some local known coordinates, there is also an approach, which can determine the global coordinates of the devices. This means that the coordinates of every device can be compared towards already known global points, obtained by any satellite-positioning system, or even better - all of the devices in the sensor field can be equipped with a satellite-positioning sensor boards meaning that they can obtain their global coordinates by themselves [10].

In order to implement the satellite-based localization approach in a 2-D based sensor network, there must be at least 3 noncollinear sensor devices, which will act as referent points. If the localization is performed in 3-D then there must be at least 4 such noncollinear referent devices [11]. These sensor devices are regular sensor motes, but they have the means to obtain their global position (GPS/GLONASS modules) or they know their global coordinates a priori (hard copied coordinates). The consequence of using satellite-based localization approach is the decreased time for localization of the devices and increased device performance (no need to perform calculations to obtain coordinates or to store RSSI or Hop count data), since the global coordinates are directly received. However, this approach is rarely implemented since GPS receivers are very expensive, which is in direct controversy to the idea to have very cheap sensor devices (less than 1 USD). Another major issue with this approach is the fact that the GPS receivers can rarely be used indoors and their reading are sometimes influenced by environmental obstacles. Additionally the satellite receivers require huge amounts of energy to operate, which is a big problem in the energy-limited wireless sensor networks. A solution for this issue is to use predetermined data about the global coordinates of the devices. This alternative is sometimes very impractical or impossible. Placing a large number of nodes on specific coordinates is a difficult and time-consuming problem, and sometimes the nature of the environment, where the sensor networks is to be deployed does not allow it (like for instance when placing the sensor devices on the bottom of a river or when the devices have to be mobile).

IV. Sound-based localization approaches for Wireless Sensor Networks

Localization using sound is not a new paradigm and there are many animals, which use sound to locate they pray or to draw they movement plan. In the modern wireless sensor networks there are several approaches, which use sound for localization, and here we will discuss the two most used ones – Time Difference of Arrival and Angle of Arrival.

Time Difference of Arrival (TDoA)

The idea of TDoA is to have all sensors equipped with microphones and speakers. As already known, radio waves travel substantially faster than sound waves [12, 13], so the idea is for the source to transmit a radio signal and the sink to mark the time of the reception, then the source to transmit a sound pattern and the sink again to mark the time when it is received (Fig. 2). After this the sink can compute the distance to the source using the following equation:

$$d = (s_{radio} - s_{sound}) * (t_{sound} - t_{radio} - t_{delay}), \quad (1)$$

where d is the distance between the sink and the source, and t_{sound}, t_{radio} and t_{delay} are correspondingly the time interval, which determines the reception of the sound pattern, the time interval, which determines the reception of the radio signal and the time interval, which the source has waited before transmitting the sound pattern (t_{delay} can be zero).

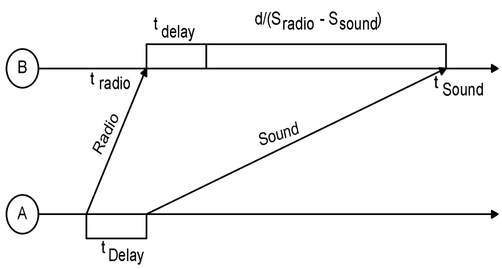

Fig.2. TDoA example, where node A is sending a radio signal and a sound pattern to node B and it is using the difference in the reception times to determine the distance to the signals source

There are several disadvantages of the TDoA approach. In order to implement TDoA localization in a WSN, all motes need to have a speaker and a microphone, which will increase the price of the devices [12]. Additionally the approach requires allocation of extra computational and storage resources. TDoA systems may require also special calibration, since speakers and microphones have different characteristics [13]. Finally there are some environmental requirements for the TDoA to be functioning correctly - line-of-sight between the source and the sink, constant humidity and air temperature and etc. This all has proven to be a holdback for the further development of this approach for its use in the wireless sensor networks.

Angle of Arrival (AoA)

The AoA approach is an amendment to the TDoA approach [14]. The idea is to have not one, but several spatially distributed microphones, which are to hear a single transmitted signal and by analyzing the phase or time difference between the signal's arrival at the different microphones to determine the AoA of the signal [15].

This method has proven to provide accuracy down to a few degrees, but unfortunately suffers from the same disadvantages as the TDoA.

V. Open issues with the localization approaches in the WSNs

Since the wireless sensor networks are a special type of telecommunication networks there are some additional factors (compared to the traditional communication networks), which have performance impact on the localization approaches. There are three major categories of issues with the localization approaches for wireless sensor networks – environmental-based, device-based and network-based issues.

Environmental-based localization issues in the WSNs

The environmental obstacles are something, that the designers of the WSNs are rarely taking into consideration, but can be something that can have a huge impact on the performance of the localization approaches [16]. Large obstacles can interfere with radio interfaces and signals, introducing errors when the RSSI or the Radio hop-count approaches are used. Additionally they can shadow the GPS receivers and prevent the direct line of sight for many of the localization approaches. The deployment of the devices on various surfaces and in various atmospheric conditions can affect the radio-based and sound-based localization approaches as well. Placing the devices indoors and outdoors can also have a huge impact on the localization processes. As a overall conclusion the environmental-based localization issues are not something that the networks can have a impact on, but the sensor devices have to be designed or configured in such a way, so that the effects of the environment on the localization performance has to be reduced to a minimum.

Device-based localization issues in the WSNs

The idea about sensor networks is to have thousands of tiny inexpensive devices which are to detect certain events or to monitor environmental parameters and to transmit the sensed data using a wireless network. This means that due to the restrictions for the size of the devices they will have to be equipped with low size processors, memory chips and other components, which makes extensive computation and data storage impossible [17]. Moreover, sensor nodes are typically battery powered. This means that the wireless communication is to be performed on short ranges in order to conserve power. Since the localization is often not the primary task of a WSN, but is nevertheless used so that the network can perform its normal operations, it should be performed at the lowest possible power cost, hardware cost and deployment cost.

Network-based localization issues in the WSNs

There are several parameters of the networks which are having an impact on the localization approaches and their accuracy. One of those parameters is the density of the nodes. The radio hop count and sometimes the satellite based approach (when a given number of devices have GPS receivers they have to be in communication range so that multilateration can be used) require high node density for their normal operations. Other approaches can be affected negatively by the increased density of the devices, since interference (both radio and sound) can occur.

An additional problem, which is defined by the network topology, is the unequal distribution of the nodes. This can lead to uneven levels of localization accuracy for certain areas of the network compared to the localization accuracy in areas with denser sensor mote population. Another issue is how to obtain the accurate coordinates of the edge nodes in the network. These devices are the last of the nodes in the sensor field and can be observed only from the inside of the network, which means that they are localized using partial information.

The data delivery and processing mechanisms of the wireless sensor networks can also affect the localization processes. Based on the network topologies or organization methods there are couple of approaches for localization. In the hierarchical cluster based WSNs the cluster heads can obtain their coordinates using the data sent from the base station. After that the cluster heads are being used by the sensors in the clusters, so that they can obtain their coordinates [17].

Different approach is to use an algorithm to roughly determine the coordinates of the nodes in the network. After that the location data can be improved either by the use of a different localization approaches or by a second run of the same approach, but with a different filters and settings.

There is also an approach in which the localization of the sensors is performed locally for a given group of sensors (like in a cluster). Finally the data for all of the sensor groups is merged together to form a map with the coordinates of all of the devices in the network.

VI. CONCLUSION

As seen by the analysis in this paper there are a number of localization techniques available for implementation in the WSNs. All of these approaches have their advantages and disadvantages and are suitable for specific network applications. Typically the sound based localization approaches achieve better accuracy than the radio-based localization approaches. The highest localization accuracy is provided by the satellite-based localization approaches, but nevertheless, this accuracy is achieved at the expense of higher equipment cost. The general conclusion is that when designing a wireless sensor network, one has to take into consideration all of the factors that will impact on the accuracy of the localization approaches - the characteristics of the environment, the hardware constrains of the devices and the particular specifics and features of the network itself. After that the appropriate approach can be selected based on the purpose and the requirements of the network.

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