Location Management of Mobile Nodes in Low-Power Wireless Sensor Network Using Link Quality Metric

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Abstract

In the article a new method for relative location estimation of mobile nodes in wireless sensor networks based on IEEE 802.15.4 standard has been proposed. This approach uses link quality indicator (LQI) provided by transceiver chip. Proving experimental measurements shows applicability of proposed method. The result is the interpolation formula for the measured relationship between LQI value and the distance between nodes.

1 Introduction

Wireless sensor networks (WSN) based on the IEEE 802.15.4 standard [1] (low-speed personal area networks) are widely used to measure and transmit parameter values in a number of technical areas (natural habitat monitoring, human environment, military tasks, etc.). This standard provides physical and link layer protocols for common industrial bands (2.4 GHz). At recent time, Recently, WSNs are uses for data aggregation in a field where sensor nodes are deployed in random manner. Such network forms a route tree structure with one gathering node (sink) and a number of sensor nodes (end nodes). One of high level protocols in this case is ZigBee specification that provides network deployment for devices of simplified functionality of automation (IoT, smart home, etc.) [2]. The ability of nodes to move autonomously in a field significantly extends the functionality of WSN. Mobile sensor networks are used for tasks of static and dynamic coverage, or for more complex, coupled with the movement, algorithms (perimeter patrol, sweeping coverage, etc.). A review of possible applications and the most typical algorithms has been shown in the work [3]. The initial location of nodes may be unknown (if nodes were deployed in random manner, for example, by dropping from an airplane). Thereafter, the most common task for mobile WSN performance analysis is the problem of optimal nodes deployment for a given field. Each point in a field must be covered at least one sensor, and the total number of involved nodes must be minimal [3]. Two examples of different deployments are shown in the Figure.1 (a – non-optimal deployment; b – optimal).

Effective location management allows to increase network performance parameters: node lifetime, robustness of the coverage, energy of nodes. For proper control, node coordinates must be estimated or calculated using one of the positioning technic. Currently, there are many approaches to determining the node coordinates: from quite expensive and accurate (GPS) to cheap, but low accurate that based on RSSI signal. Also, the RFID-based solutions of localization are uses for indoor conditions. However, it should be noted, that most of the works prove proposed approaches by network simulations only. On the other hand, the experimental deployment of such networks are described significantly rarely.

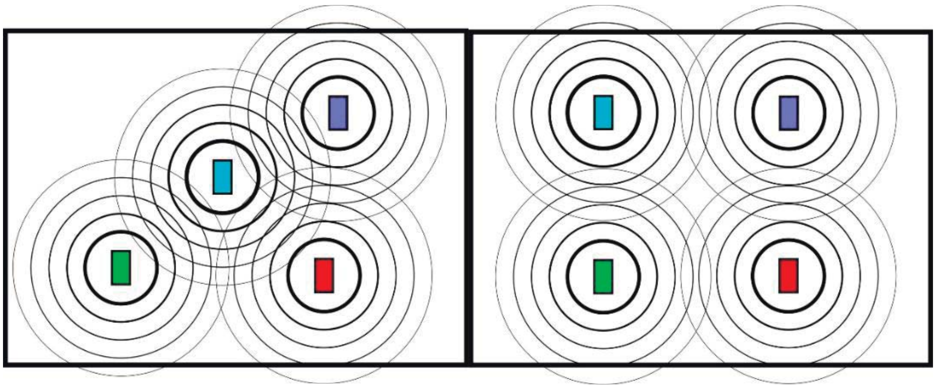

Fig.1. Examples of sensor nodes deployment in closed field (a – non-optimal deployment, b – optimal deployment)

2 Existing approaches for the calculation of WSN node coordinates

The paper [4] gives a survey of the existing methods for calculation coordinates of a node. There are absolute and relative location management methods. As an example of absolute positioning scheme, one of the satellite navigation systems (GPS, Galileo, GLONASS) [5] can be discussed. However, the use of this localization method is applicable only for outdoor environment in places where the signal from satellites can be received. In addition, receiving equipment increases the price of a node and its power consumption. Methods for determining the relative position in field include the use of radio communication parameters (RF) for this purpose [6]. As a rule, these approaches are based on the evaluation of the received RSSI (received signal strength indicator). However, as shown in [7], the use of this method allows to estimate the distance between nodes with low accuracy due to the fact that the value of RSSI is influenced by many factors (external noise, the presence of obstacles, the antenna orientation). Thus, it can be noted that the using of RSSI requires to supplement by another measuring scheme to improve an accuracy in distance measurement. To overcome these shortcomings, a combination of radio and ultrasonic rangefinder evaluation was proposed [8]. Some authors propose the installation of an additional ultrasonic or infrared transmitter and receiver on the mobile platform. In the case that operating field is closed and can be equipped the special active labels with known coordinates it is possible to orient nodes in the field using information from this pre-deployed “anchors”. RFID-based solution are widely used in these purposes [9]. In this work, we propose the approach for estimate relative distance between nodes using existed transceiver chip for ZigBee network communications. This method uses LQI (Link Quality Indicator) that is described in IEEE 802.15.4 standard and estimates quality of communication link between the nodes.

3 Proposed method of relative distance calculation

According to ZigBee specification [2], the routing algorithm for transmission a message from end nodes to the sink calculates route metric, which depends on quality of communication link between nodes. The cost of the route is calculated as the sum of the metric values C_{ij} :

$$C_{ij} = \begin{cases} 7, \\ min\left(7, round\left(\frac{1}{{p_l}^4}\right)\right) \end{cases} \tag{1}$$

where p_l in second option is an integral estimation of link quality between nodes i and j. This value takes into account the quality of communication indirectly, and equals the probability of successful transmission throw the link. According to [2], the p_l must be estimated for each incoming packet. The simplest method of calculation is based on the value of the link quality indicator (LQI), which is proposed by IEEE 802.15.4-2003 standard at physical and channel layer. The standard proposes to estimate LQI with the help of the energy of received signal or signal/noise ratio, or as a combination of both methods. The LQI value should be between 0 and 255, where 0 is the value for the worst signal quality and 255 is for the best one. The relationship between LQI and the distance between nodes is considered only in a few works: [10] (outdoor and indoor), [11] (indoor). The main drawback in previous provided results is that the algorithm for calculation LQI depends on a chip manufacturer. Thus, the data published on this topic mainly concern Chipcon CC2420 chip and cannot be extrapolated to other chip models. However, according to [10,11], we can assume that the relationship can be interpolated by a simple piecewise linear function:

$$S_{ij} = f\left(LQI_{ij}\right) = A \cdot LQI_{ij} + B \tag{2}$$

where A and B – coefficients that depends on specific hardware platform. To prove this assumption, a number of experiments to measure the relationship between the distance and LQI has been provided. As hardware platform we chose communication module XBee S2C (Digi Inc.) with Ember's EM357 chip. This module was connected to Arduino-based platform for simulation of sensor node functionality.

4 Experimental setup

The experimental setup consists of a pair of modules (transmitter and receiver), the distance between which can vary from 0 to 85m. The tests were carried out indoor and outdoor in the absence of people at a line of sight between the modules. Packet payload consists of 100 bytes (maximum length of payload that is defined in ZigBee specification). The transmission rate is 1 packet per second. Fig.2 shows general view of the setup.

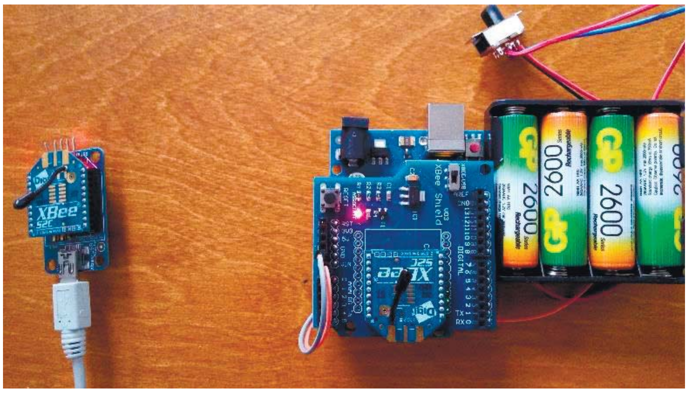

Fig.2. Experimental setup for LQI measurement

The total number of transmissions for each experiment is 1000. Measured parameters:

- average LQI, which is provided by the IEEE 802.15.4 standard and implemented in EM357 chip as the number in the range from 0 (the worst quality) to 255 (the best) (indoor and outdoor)
- average RSSI, which is measured by chip software for each incoming packet (indoor)
- packet delivery ratio (outdoor)

The LQI values are changed by changing the distance between nodes. Also for indoor case, a number of measurements was carried out for different transmission powers. This parameter in XBee modules can be changed in two ways: a) set the transmit power level directly as the number in range 0 - 4, where 0 is the lowest power (-5 dBm), 4 is the highest (+5 dBm). b) enable boost power mode, which increases the transmission power by 2 dBm. Three different power modes were selected for the simulation: mode 1 - power level (PL) set to 0 with disabled boost mode (BM = 0); mode 2 – PL = 4 with disabled boost mode (BM = 0); mode 3 – PL = 4 with enabled boost mode (BM = 1).

Outdoor measurements were carried out only for mode 3 because this is the most powerful mode, and this case must test the module in extreme long distances. For outdoor case the packet delivery ratio (PDR) was measured. This parameter must be taken into account for pointing the moment when modules lost connection and can not resume it in all observed time interval.

5 Results of the measurements

Experimental results for indoor measurments are shown at Fig. 3,4

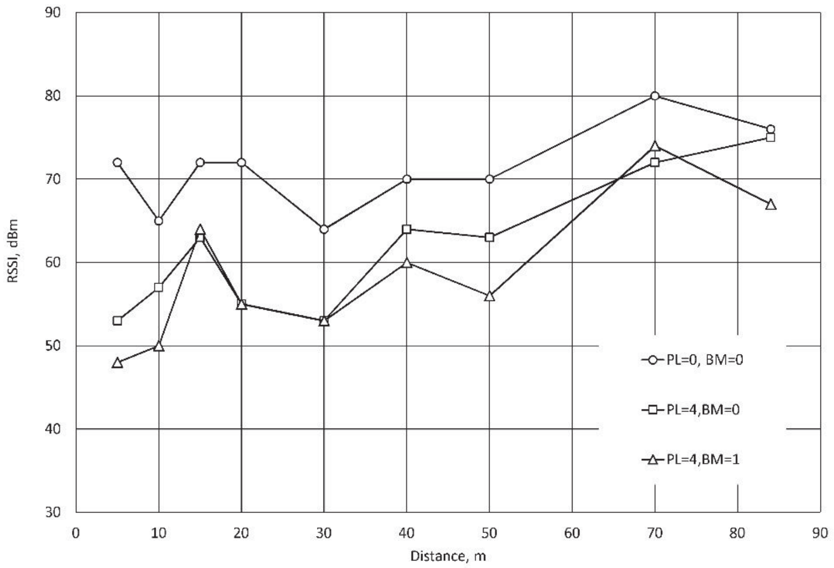

Fig.3. Influence of the distance between nodes on measured average RSSI value for indoor

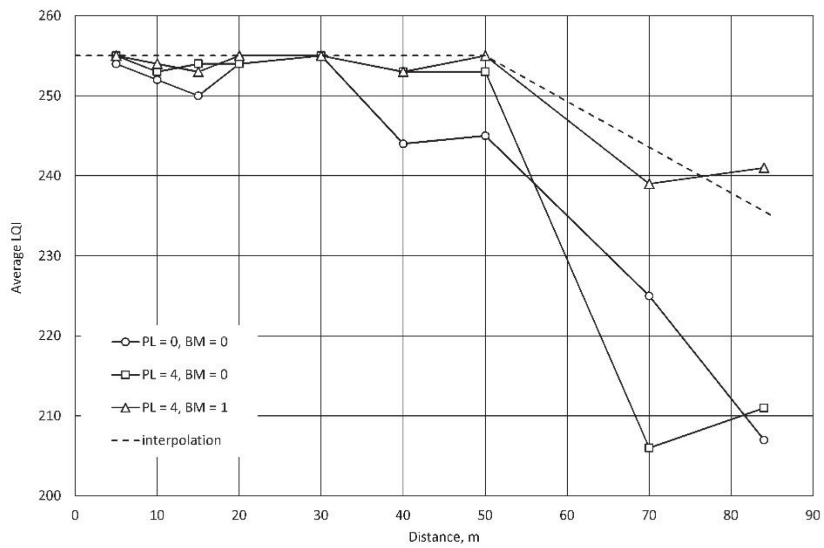

Fig.4. Influence of the distance between nodes on measured average LQI value for indoor

Results show that small distances (up to 50m) do not affect on LQI, and quality of communication does not depend on the distance in this interval. At the same time, the RSSI changes significantly and unpredictably in this interval. This can be explained by the fact that RSSI value in the receiver depends on not only the signal from the transmitting module, but also the third-party transmitting devices, which usually present indoor area and work at the same frequency range (Wi-Fi access points, mobile user devices, etc.). LQI is calculated as the packet delivery ratio, and have good correlation with the distance. Small fluctuations of its values are possible due to interference from walls, floors and roof. After the distance was increased to 40m, the LQI begins to decrease linearly (see Fig.4).

For the maximum transmission power, a piecewise linear interpolation function *LQI(S)* was provided:

$$LQI(S) = \begin{cases} 255, \text{при } S < 50\text{м} \\ -0{,}57 \cdot S + 284, \quad \text{при } S \geq 50\text{м} \end{cases} \tag{3}$$

The inverse relationship *S(LQI)* can be expressed from (3) for distances that exceed 50m:

$$S_{ij} = f\left(LQI_{ij}\right) = -1{,}75 \cdot LQI_{ij} + 496{,}25 \tag{4}$$

This experimental results good agree with previous published researches. Obtained piecewise linear function (4) can be used to estimate distance between ZigBee modules. It must be noted that this relationship is true for large distances (more than 50m). Smaller distances saturates LQI values that close to maximum 255.

The outdoor case result is shown at Fig.5

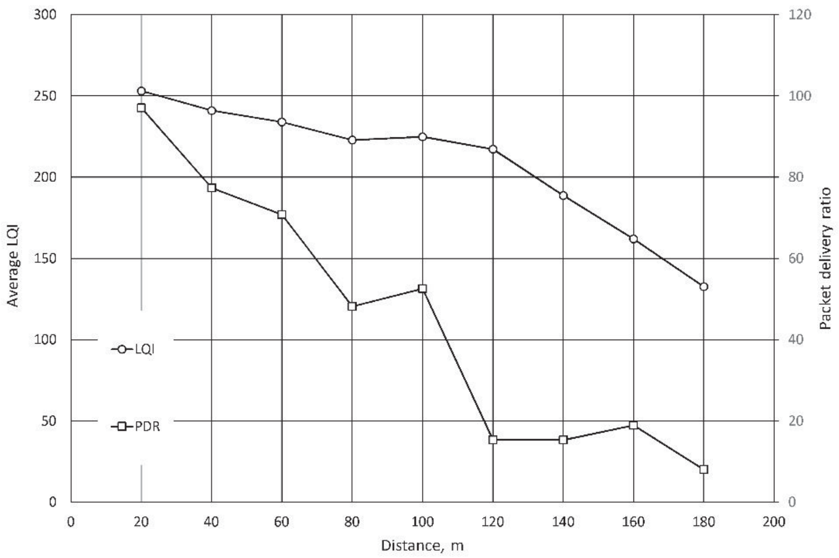

Fig.5. Influence of the distance between nodes on measured average LQI and PDR for outdoor

These results (see Fig.5) is similar the ones for indoor case: LQI decreases linearly, when the distance increase. Packet delivery ratio also decreases with the distance but the curve “jumps” more unpredictably. Therefore, PDR is less applicable for distance estimation, then LQI.

6 Conclusions

In this paper the problem of distance estimation between nodes of mobile ZigBee WSN has been considered. For this transmission stack, the distance between devices can be measured with the help of link quality indicator, which is introduced in IEEE 802.15.4 standard for LowPAN networks. LQI calculation is provided by transceiver chip for each received packet. The proposed method do not uses any additional equipment (ultrasonic or infrared transceivers, GPS-receivers, etc.). To prove the technic, a number of experiments were carried out to measure the relationship between transmission distance and RSSI signal, and between distance and LQI. The results of the experiments show that the use of LQI for distance estimation is more preferable in comparison with the RSSI and PRD value. Relationship *S(LQI)* can be interpolated with the help of piecewise linear function.

Further efforts will focus on construction of a mobile platform that allows an autonomous location management that will use proposed approach. Practical issues of interaction between several such platforms in the deployment of coverage network also remain open for research.

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