Distance estimation in a ZigBee wireless mesh network for disaster situations

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***Abstract*—Wireless sensor networks (WSN) have gained importance through applications in the Internet of Things (IoT) and Industry 4.0. Especially the mesh topology has been integrated in wireless standards. These wireless mesh networks (WMN) offer a wide range of deployment possibilities. The usage in disaster situations without Global Position Satellite System (GPSS) support is investigated. While a WMN usually requires a thorough planning of positioning of the nodes this is not possible in case of a disaster. Starting from a destroyed infrastructure the challenge is to spread the wireless network nodes. Therefore the focus is on the optimal distribution of the nodes with regard to navigation and positioning rather than on the optimal coverage and range of the network. The WMN is piecemeal build up for basic navigation and sensor communication. In a 7.4-hectare park a wireless ZigBee mesh consisting of six nodes was deployed and basic navigation and communication was tested under urban conditions. All nodes are battery operated and can be used in a destroyed infrastructure. The combination of WMNs and Inertial Measurement Units (IMU) provides first promising results for position determination and estimation.**

***Index Terms*—Disaster network, Navigation, Positioning, Wireless sensor network, ZigBee**

I. Introduction

The basic idea for this study is using WSNs to support navigation and positioning in a disaster or crisis situation. Disasters and crises are categorised in two parts such as man-made and natural disasters. Examples for man-made disasters are nuclear accidents, accidents in production facilities, terrorist attacks and so forth. The second category are natural disasters like earthquakes, floods, volcanic eruptions, avalanches or giant waves. Disasters are causing damage to the infrastructure dependent on location and magnitude. Critical infrastructure is among others power supply, central water supply and telecommunication networks. The disaster management is composed of four disaster phases: mitigation, preparedness, response and reconstruction [1]. After a disaster took place the most important phase is the response phase [2] focusing on the protection of the local population, the environment and saving lives by providing proper resources. Based on the destroyed infrastructure localisation and navigation are limited to the GPSS. The localisation of survivors of, for example, an earthquake or rescuers like fire fighters is severly restricted. The use of IoT devices is also critical in the context of a disaster scenario due to the destroyed communication and energy networks. Furthermore it is of great interest to provide different location-based services managing critical resources or supporting optimal routing to geographical areas instead of IDs. Reliable localisation of IoT devices must be available even in absence of GPSS to ensure its viability in this kind of scenarios. The same applies to the use of WSNs. GPSS is an ubiquitous technology and is used as state-of-the art navigation in many sectors. The origin of GPSS lies in the military field. There are four main GPSS in the world: NAVSTAR-GPS, GLONASS, Galileo and Beidou. All of them support the civilian sector but can be limited to a purely military use in serious cases. Even the European project Galileo which was not meant to be for military use only can be switched to a purely military use nowadays. This history makes it obvious that Outdoor Positioning Systems (OPS) need to operate independently from position and location systems controlled by military decisions. Even current discussion show that GPSS is a highly coveted and easily shut off resource [3]. However, GPSS is only a solution in outdoor scenarios. It is not available for indoor location systems.

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II. Proposed Solution

We propose a solution moving a mobile node in a battery powered mesh network for localisation and navigation. First a ZigBee/IEEE 802.15.4 network with is dpoloyed. Then a mobile ZigBee node is used to navigate through a chosen terrain. To get the best distance estimation a predictor / corrector algorithm based on the Kalman filter [4] is used.

III. ZigBee

For the application scenarion the IEEE 802.15.4 standard and the ZigBee protocol, which is built upon this standard, are alternatives to the coomunication standards WiFi (IEEE 802.11) and Bluetooth (IEEE 802.15.1). In WSN and in the application field of IoT low-cost communication networks a reasonable battery life and the ability to transfer data over long distances is often required. In a disaster case with destroyed infrastructure low-cost communication and low-power-consumption are imported properties [5]. ZigBee supports two frequency bandwidths 2450 MHz and 868 MHz and a Peer-to-Peer architecture [6].

IV. Distance based on RSSI and LQI

The Receive Signal Strength Indicator (RSSI) represents the signal power at the receiver [6]. The signal power at a distance can be calculated by the equation of the path-loss model [7]

$$P_d = P_0 - 10 \cdot 2 \cdot \lg(f) - 10 \cdot n \cdot \lg(d) + 30 \cdot n - 32.44$$

where P_d is the received signal power in dBm at a specific distance d. P_0 is the signal power from the transceiver in dBm at distance zero at the antenna. The ZigBee nodes use the signal frequency f of 2450 MHz. n is a variable for different environments [8]. n Besides the RSSI value the link Quality Indicator (LQI) is also used. The LQI measurement gives an estimation of the received signal quality during radio traffic.

V. Execution of the Experiment

A. Hardware

The mesh network is constructed through ZigBee nodes which are 0.08 m x 0.08 m x 0.05 m small and weigh 0.15 kg. All nodes are powered by two 1.5 Volt AA Mignon batteries.

B. Test Area

The tests have been carried out in the Günthersburgpark in Frankfurt am Main, Germany. Twelve positions are determined using laser measuring equipment and GPSS. The park is 7.4-hectare in size. Besides visitors there are natural obstacles like trees and bushes as well as artificial obstacles like walls, a playground and park benches. During the testing the following weather conditions were encountered: temperature of 5-6°C, air pressure of 1032-1035 hPa, a relative humidity of 59 %, no precipitation and a wind speed of 10 km/h from the west.

C. Experimental Setup

The ZigBee nodes are mounted on tripods at a height of 1.65 m and distributed in the park. Some nodes are positioned in line of sight to each other and some are not. In addition, the line of side is randomly blocked by visitors of the park. The largest distance is between node 007 and 003 with 172.55915 m and the line of sight between them is constantly blocked.

D. Implementation

The experiment consists of four parts: First the stationary ZigBee nodes are build piece by piece. The second part consists of distance measurements between all nodes, measured 2000 times in an interval of 200 m. In the third part a mobile ZigBee node is carried through the area. At intervals of 100 m the RSSI and LQI values are queried for all nodes. At marked positions, the current position is recorded via a button while moving the ZigBee node. This marker serves as a reference to location estimation of the ZigBee network. The fourth attempt is equal to the third with the difference of a flying start.

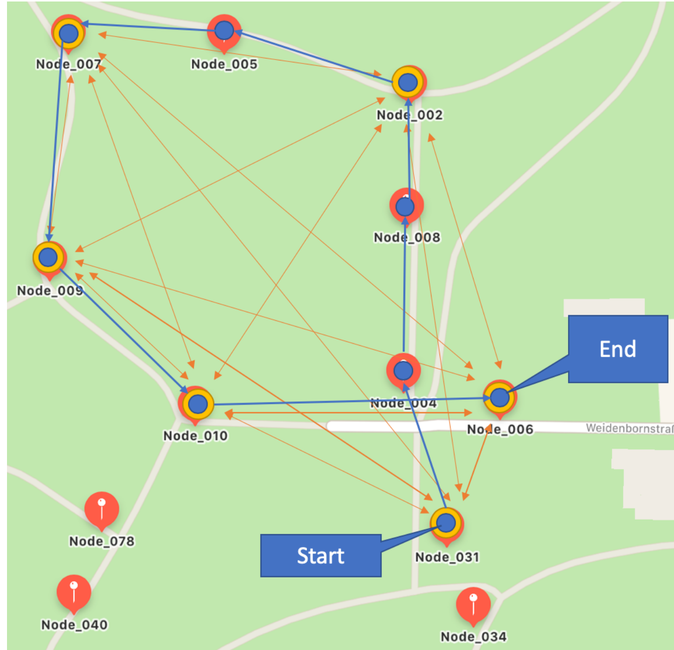

Fig. 1. The yellow dots represent the ZigBee nodes. The orange arrows indicate the direction of measurement and between which nodes the RSSI and LQI values are evaluated. The blue arrows show the movement of the mobile ZigBee node through the terrain.

VI. First Results

The results show that the distances between the nodes with regard to coverage are not a problem. Even at the largest distance the LQI value remains very good (≈ 250 LQI) despite the obstacles in the park (playground and trees). The energy consumption of the nodes is low compared to the test duration of five hours and a high communication rate of 100 1/ms.

Conclusion

The experiment demonstrates that the interim construction of a ZigBee network for navigation and localisation in a disaster area is possible in the application use case. The nodes are suitable for this type of application due to their design and cost. Further optimisations for the piecewise distribution of the nodes using correction algorithms and additional sensors should be the next step.

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