Development of Low-Power Wireless Sensor Network for Improving the Energy Efficiency in Buildings

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*Abstract –**In t**his paper has been described the development of low-cost and low-powered wireless sensor network, that can be implemented for improving the energy efficiency in buildings. The sensor network uses Low Energy Bluetooth technology for connecting the sensor nodes to the central device. Asa central device and gateway has been used Raspberry Pi 2, and as sensor nodes have been used SimpleLinkSensorTags CC2650 from Texas Instruments.The functionality of the WSN has been demonstrated by logging and comparing measured temperatures, collected from different locations of a building during various times of the day.**

*Keywords –***Wireless Sensor Network, Bluetooth Low Energy, Energy Efficiency of Buildings, SensorTag CC2650, Raspberry Pi.**

I. Introduction

With the rapidly increasing development of smart devices, smart homes, smart building and even smart cities, the request of wireless sensor networks with low energy consumption is enormous. The wireless sensor networks (WSNs) with low energy consumption also should be low cost to produce, and to maintain. WSNs can be constructed using different wireless technologies including: Bluetooth Low Energy [7], ZigBee [11], and 6LoWPAN [3].

One of the areas where the WSNs have been widely used is the Civic engineering, especially with the development of the “smart buildings”. One application of the WSNs would be the monitoring of the air temperature inside and outside the building. Additionally, the collected data will be used for constructing the air conditioning systems of the building.

The Bluetooth Low Energy (BLE) technology has been usedas awireless technology for developing the WSN, characterized with ultra-low energy consumption and low cost. Usually BLE WSNs have been powered by one coin-cell battery than can last for more than a year. The low power consumption allows integration of energy harvesting technology, as solar energy.

The WSN defined in this research, implements few sensor nodes, model SimpleLink©SensorTag CC2650. As a central device is used Raspberry PI 2, that collects the data from the sensor nodes and allows the BLE WSN to connect to different networks and the Internet.

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The WSN has been tested in real environment and the results were presented to determine the helpfulness of the system in improving the energy efficiency in buildings.

II. Background

A. Wireless Sensor Networks

A wireless sensor network (WSN) combine sensor nodes, central devices and data processing, using wireless technologies and web or mobile applications in order to monitor environmental changes or physical conditions [1]. The sensor node, as a main component of the WSN, is a smart device that contains one or more sensors, processor, memory, power supply, wireless antenna and other additional elements [1]. With the development of the new technologies the cost and energy consumption of the sensor nodes and the other components of the WSNs decrease, while their performances and functionalities have increased.

A WSN can connect from few nodes up to thousands of nodes, depending on the geographic are that needs to be covered and the required accuracy. WSN usually is constructed to do one specific task as flow monitoring, control and automatization of devices in smart buildings, hear rate monitoring and monitoring of the environmental changes, like air temperature, the research subject in this paper.

B. Wireless Technologies used in WSNs

In the sensor industry, there are many differentsensors from different producers that measure all kinds of physical parameters. To have effective integration of these sensors into the wireless networks, these sensors should be standardized. Additionally, standardized data formats and standardized commination protocols are necessary, so sensors from different manufactures can be combined in same WSNs without any prior adjustments.The standardized technologies ensure that one technology will not depend just from one manufacturer, but the whole industry.

The SimpleLink© solutions from Texas Instruments have been designed to simplify the development of the WSNs allowing the sensor nodes to connect through multiple wireless technologies. The SimpleLink©CC2650SensorTag (used as sensor node in the WSN that this paper describes)supports Bluetooth Low Energy, ZigBee and 6LoWPAN as standardized wireless connection technologies [2]. The specifications of each technology are given in Table I.

TABLE I
SPECIFICATIONS OF THE WIRELESS TECHNOLOGIES[3][7][11]

	Bluetooth Low Energy	6LoWPAN	ZigBee
Max. Nodes per Master	7+	200+	200+
Range	100+m	100m	100m
Data Transfer	1Mb/s	200kb/s	250kb/s
Peak current consumption	15mA	25mA	30mA
Topology	Star/Mesh/ Scatternet	Star/Mesh	Star/Mesh

C. Bluetooth Low Power

Bluetooth [8] is global wireless technology that has been built in billions of devices as smartphones, computers, headsets, printers, speakers, and smartwatches. This wireless technology allows exchanging data over short distance using radio waves in the band from 2.4 to 2.485 GHz.

Bluetooth was invented by the telecom company Ericsson in 1994. Bluetooth is managed by the Bluetooth Special Interest Group (SIG), which includes more than 30,000c ompanies in different areas as networking, telecommunication, computing and electronics. Bluetooth SIG supervises the development of the specification, manages the qualification program, and protects the standard. Every manufacturer must meet the required Bluetooth SIG standards to market their devices as a Bluetooth device.

Bluetooth Low Power (BLE) [8], compared to the standard Bluetooth, was projected to offer significantly reduced power consumption and cost, while maintaining same or better characteristics.BLE operates at the same range (2.4–2.4835 GHz) as the standard Bluetooth, but uses a different set of channelsand frequency hopping to neutralize narrowband interference problems. This, allows BLE to send same amount of data in about 3ms compared to 100ms needed for the standard Bluetooth, which saves a lot of energy when the device is powered from a battery.

III. DEVELOPMENT OF BLUETOOTH LOW ENERGY WIRELESS SENSOR NETWORK

In this research, Bluetooth Low Energy Wireless Sensor Network has been developed to monitors the air temperature at few different locations of a building and the collected data has been stored into a database. The collected data can be used to determine the energy efficiencyof the building, based on the changes of the air temperatures inside the billing compared to the outside temperatures at the same time. In addition, has been created web application that can connect to the database, search the data by date and time and visualize the positions of the sensor nodes and air temperatures with a heat map.

A. Hardware Components

For monitoring the air temperature has been used SensorTag CC 2650, show in Fig. 1, and it will operate under the Bluetooth Low Energy mode that is the default firmware for the sensor nodes. This sensor nodehas ten low power consumption sensors: ambient light sensor, altimeter/pressure sensor, humidity sensor, 9 – axis motion sensor, IR thermophile temperature sensor, magnet sensor and microphone [2].

Fig. 1. Raspberry Pi 2 with the SensorTag CC2650 nodes

As a central device has been used Raspberry Pi 2, presented in Fig. 1, one circuit board computer with a size of a credit card, that comes with 900 MHz quad-core ARM Cortex-A7 CPU, 1 GB RAM, 4 USB 2 ports, 40 GPIO pins, full HDMI video port, Ethernet port, 3.5 mm audio jack and micro SD card slot [6]. And all these come at very low price. Raspberry Pi 2 is presented in Fig 1. The quad-core ARM Cortex-A7 CPU allows full version of GNU Linux or Windows 10 to be installed. The recommended operating system (OS) is Raspbian,even Raspberry Pi 2 is compatible with Ubuntu, Windows 10 IoT Core, OpenELECи RISC OS. In this paper is used the recommend OS, Raspbian.

To enable Bluetooth connection to the Raspberry Pi 2 has been used USB Bluetooth 4.0 Dongle, also shown in Fig. 1, plugged in one of the USB ports.

B. Software Components

First, has to be installed the OS on Raspberry Pi 2, and for that additional hardware is required. This includes monitor, HDMI cable to connect the monitor, USB keyboard and mouse and SD card, which will store all data and the OS. The SD card has to be formatted first, has to be done on a computer that runs Windows, Mac orLinux. Next, the installation file of the OS Raspbian has to be downloaded from the official web site of Raspberry Pi foundation (https://www.raspberrypi.org/downloads/) and copied to the SD card [6]. Once the SD card is inserted into Raspberry Pi and it is turned on, the installation window opens where to be has followed the steps to complete the installation. After the installation of the OS, Raspberry Pi is fully functional.

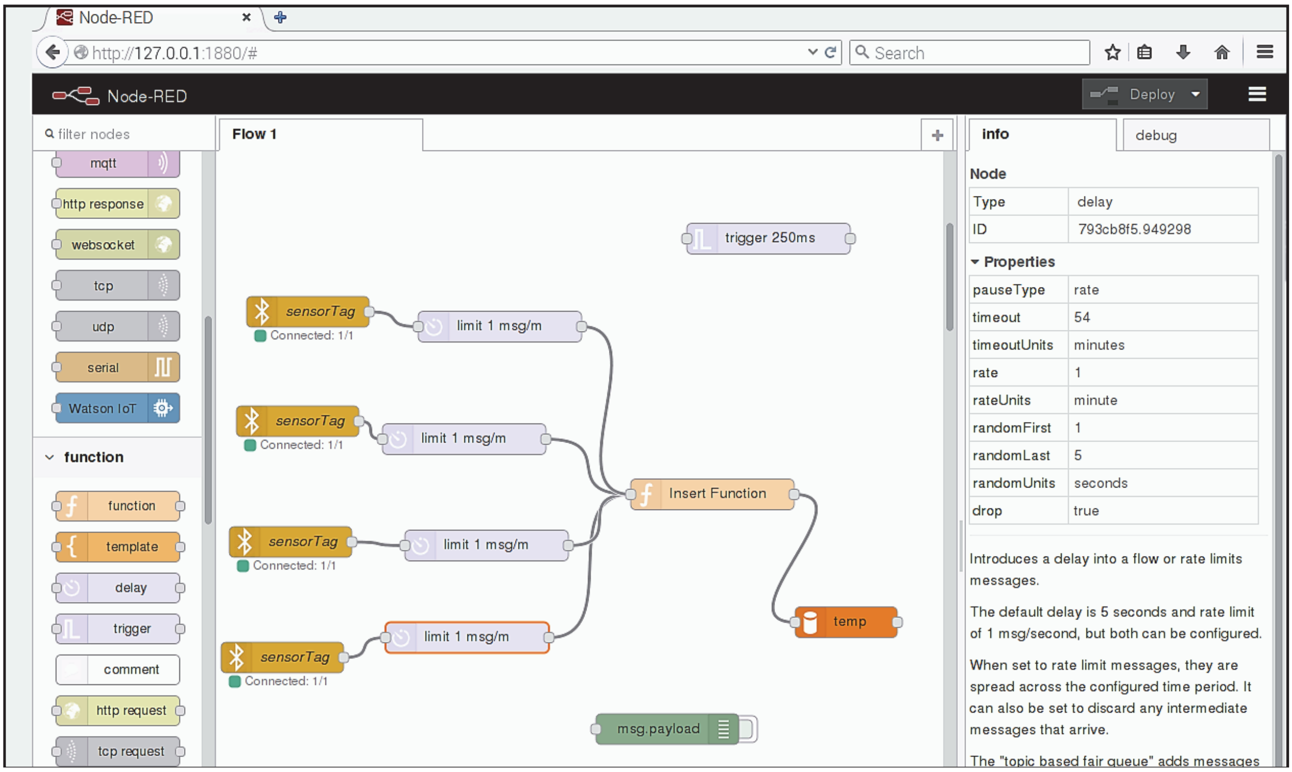

Fig. 2. Node-RED visual editor with the SensorTag nodes added and connected to MySQL node

The next step is to install the Bluetooth dongle and the Bluetooth stack and drivers, which are necessary to be established Bluetooth Low Energy connection between the Raspberry Pi and the sensor nodes. Inthis case, has been used BlueZ 5.39 [8]that can be downloaded and installed with the following commands:

sudomkdirbluez
cdbluez
sudowgetwww.kernel.org/pub/linux/bluetooth/bluez-5.39.tar.xz
sudo unxz bluez-5.39.tar.xz
sudo tar xvf bluez-5.39.tar
cd bluez-5.39
sudo ./configure—disable-systemd
sudo make
sudo make install

Once the BlueZ has been installed, the following step is to install Node-RED, visual programming tool for wiring together hardware devices, APIs and online services. Node-RED delivers a flow editor that allows wiring together flows with a use of wide range of nodes. Flows can be easily deployed to the runtime with a singleclick.With over 225,000 modules, it is easy to upgrade the range of palette nodes and add new capabilities to Node-RED [4]. The OS Raspbian comes with pre-installed Node-Red, so there is no need for any additional installations. In Fig. 2 is shown the Node-RED visual editor with the sensorTag nodes added and connected to MySQL node. The SenorTag nodes can be simply added to the work are by pilling from the palette (on the left side). Once the nodes have been added they can be configured on the settings window. Since in this project only the air temperature will be monitor, only the temperature sensor has been enabled.

After the SensorTag nodes have been configured, additional software is required for storing the temperatures, accessing them and presenting for further researching. For this, has been installed LAMP (Linux, Apache, MySQL, PHP) stack. Linux was installed already, and the other servers Apache, MySQL and PHP can be installed with the following commands respectively:

sudo apt-get install apache2
sudo apt-get install php5 libapache2-mod-php5
sudo apt-get install mysql-server php5-mysql

Apache is popular web server that can serve web pages and HTML pages with a use of programing language as PHP (installed previously). MySQL[5] is the most used system for databases owned by Oracle Corporation. There are two types of editions that can be used, Open SourceMySQL community Server andProprietaryEnterprise Server.For the research has been used the open source edition for creating database that will store the measured air temperatures. When MySQL server is installed and the database is created, MySQL node can be added into the workplace of Node-RED and connected with the SensorTag nodes as displayed in Fig. 2. Once the connections are completed all system can be run with a single click on the Deploy button.

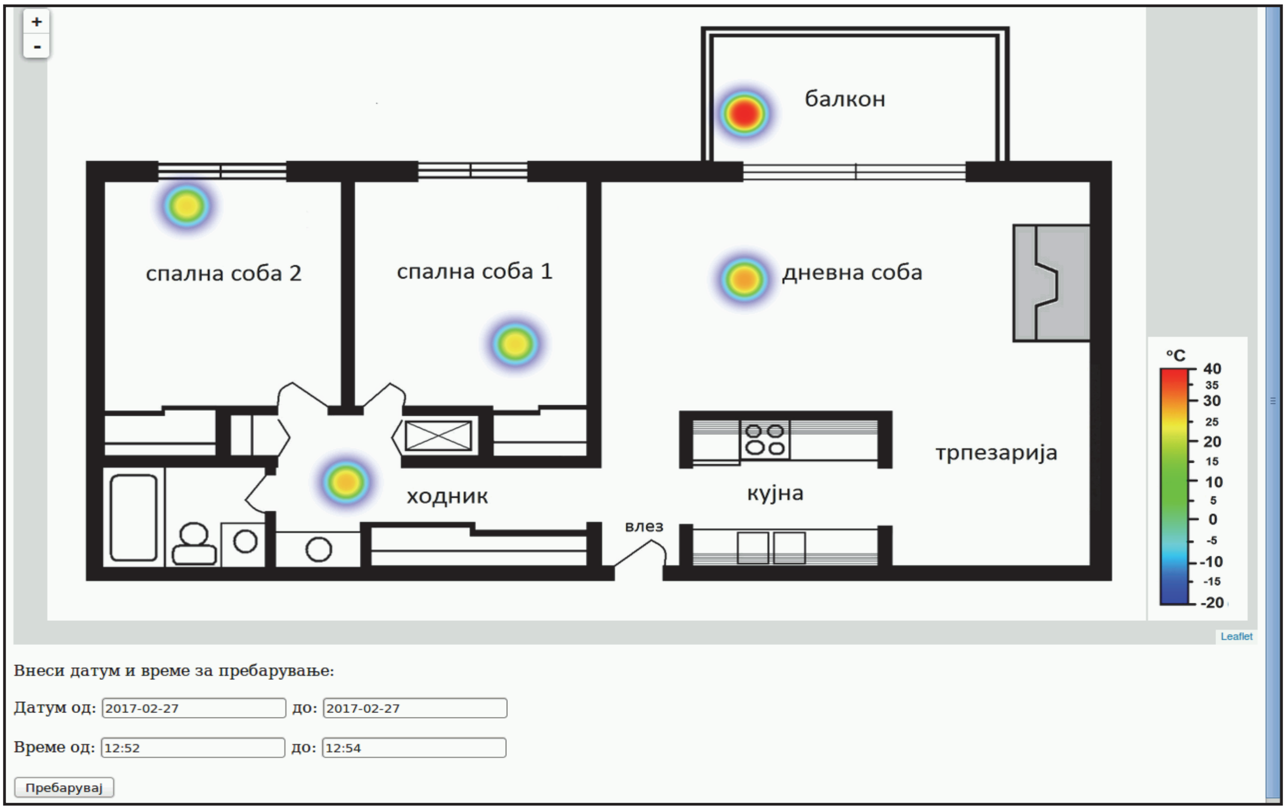

Fig. 3. Instance of measured air temperatures in a given date and time

IV. Testing of the System

To test the entire system, five sensor nodes were placed on different location of a building, 4 inside the building and one outside to monitor the outside temperature. For accessing and visualization of the collected data has been created web application that will connect to the MySQL database with a PHP script [9], search the database by previously entered parameters and display the results on the web page. In addition, after the results are returned, on the page will be displayed a heat-map of the locations of the sensors and the measured temperatures on the given date and time. For the heat-map has been used Leaflet heat map. Leaflet [10] is leading opensource JavaScript library for mobile and web interactive maps. In Fig. 3 has been shown one sample of the result from the testing on a given date.

V. Conclusion

In this research paper was presented Bluetooth Low Energy Wireless Sensor Network for improving the energy efficiency of buildings. It has been designed with SensorTag CC2650 nodes and Raspberry Pi 2, and a number of open-source software programs. Based on the research, we can conclud that this system has ultra-low energy consumption and very low cost to implement and maintain. Also, it is compact, customizable, scalable, easy to deploy, and easy to maintain. The application of this system will helpto improve the energy efficiency and energy management in the buildings. This will provide preservation of the energy resources and economic advance, while in a same time the effectiveness will increase.

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