A Heterogeneous IoT-Based Architecture for Remote Monitoring of Physiological and Environmental Parameters

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Abstract. A heterogeneous Internet of Things (IoT) architecture for remote health monitoring (RHM) is proposed, that employs Bluetooth and IEEE 802.15.4 wireless connectivity. The RHM system encompasses Shimmer physiological sensors with Bluetooth radio, and OpenMote environmental sensors with IEEE 802.15.4 radio. This system architecture collects measurements in a relational database in a local server to implement a Fog node for fast data analysis as well as in a remote server in the Cloud.

Keywords: Internet of Things · Remote health monitoring · WSN IEEE 802.15.4e · TSCH · 6TiSCH · OpenMote · OpenWSN Shimmer

1 Introduction

Wireless Sensors Networks (WSNs) are considered as one of the key Internet of Things (IoT) technologies, and are widely used in various application areas such as environmental and structural monitoring systems, industrial automation, healthcare systems, traffic management and logistics, and public safety. An efficient IoT healthcare system aims to provide a remote health monitoring (RHM) of a patient health status in real-time, the prevention of critical patient conditions, life quality improvement of the elderly through the smart environment, medical and drugs' database administration, and wellbeing services. The IoT smart sensors for healthcare enable accurately measuring, monitoring and analyzing a variety of vital health status indicators, such as heart rate, ECG, blood pressure, blood glucose levels and oxygen saturation. These sensors are being assigned a unique IPv6 address and integrated in the IPv6 IoT environment. Sensor readings are then collected and transferred to the IP end-devices or to the Cloud [1].

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Recently, the IEEE 802.15.4e standard has been proposed as a MAC amendment to the existing IEEE 802.15.4-2011 standard [2]. The specific mode, called Time Synchronized Channel Hopping (TSCH), significantly increases robustness against external interference and multipath fading while running on IEEE 802.15.4 hardware. TSCH is particularly efficient in providing ultra low-power operation. Defining IPv6 over the TSCH mode of IEEE 802.15.4e (6TiSCH) is a key to enable further adoption of IPv6 in industrial and healthcare IoT domains [3]. Therefore, we propose the use of IoT platform based on OpenMote hardware devices and OpenWSN operating system, both rooted in the new 6TiSCH standard. We believe that the use of this IoT platform in healthcare field can bring many benefits, particularly in terms of reliability and security.

Previously, Archip et al. [4] have investigated the integration of Medlab's physiological sensor boards [5] with Zolteria Z1 [6] board featuring IEEE 802.15.4. However, Mathur et al. [7] employed OpenMote with Contiki in their proposed IoT solution, but neglecting physiological sensors. In our recent work [8] we have investigated the inclusion of relational databases in the architecture for RHM and assumed only Bluetooth connection to physiological sensors. Here we extend that architectural concept by including IEEE 802.15.4 radio, environmental parameters from OpenMote devices running OpenWSN, as well as considering the concept of Fog and Cloud as local and remote storage units.

The structure of the paper is as follows. Section 2 gives an overview on the OpenWSN protocol stack implementation based on 6TiSCH architecture. The details on the system's architecture and components are provided in Sect. 3. Finally, we conclude the paper with indicating future directions in Sect. 4.

2 OpenWSN Protocol Stack

The OpenWSN is a recently released open-source implementation of a fully standard-based protocol stack for IoT capillary networks, rooted in the TSCH standard – see Fig. 1 [9]. The IEEE 802.15.4e TSCH standard replaces the traditional MAC protocol without changing the underlying IEEE 802.15.4 physical layer. Due to its time synchronization and channel hopping, TSCH enables ultra-low power and highly reliable mesh networks. The logical link layer (uRES) is the partial implementation of the IETF 6TiSCH standard. The 6LoWPAN layer enables the integration of IPv6 protocol in low data rate WPANs. The RPL is the routing protocol responsible for packet forwarding between nodes in multi-hop networks. At the transport layer, UDP protocol is used due to its lightweight implementation. CoAP application layer simplifies Web integration and interactive communication between application end-points. The OpenVisualizer (OV) is a Python-based debugging and visualization program in OpenWSN.

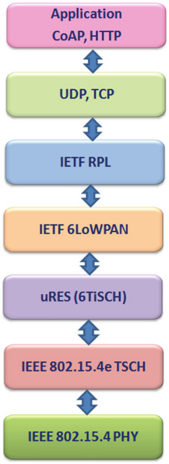

Fig. 1. OpenWSN protocol stack.

3 IoT Healthcare Architecture

We propose the initial framework for IoT platform based on Bluetooth and IEEE 802.15.4 wireless connectivity as illustrated in Fig. 2. The implementation of 6TiSCH protocol stack in RHM field brings many benefits, and is also foreseen as a possible reference for Healthcare 4.0 initiative. Sensors attached to the patients' body sample raw data, and send it to the final destination (local server in the Fog or remote server in the Cloud). A PC acts as a Gateway by supporting both Bluetooth and IEEE 802.15.4 radios. To provide the reliable and secure transmission, the OpenMote device selects the best data path based on the link quality metrics (e.g., LQI, RSSI and ETX) or network metrics (e.g., remaining energy, end-to-end delay, throughput, and traffic level). This prevents packet collisions and/or battery depletion that leads to data losses. Due to scheduled and synchronized transmission, 6TiSCH network provides end-to-end resource reservations and trafic flow isolation, thus enabling a secure acquisition of heterogeneous data.

3.1 System Components

The proposed platform for IoT RHM is the modification of the system architecture presented in [8]. The modified architecture enables data collection from multiple sensors (both on-body and environmental) in order to process and extract useful information about current state of the patient, and also about environment in which a patients resides. We use the OpenMote devices for environmental parameter monitoring, whereas Shimmers provide physiological parameters. Web-based real-time monitoring makes it very easy to identify each device and to obtain sensor values – see Fig. 3.

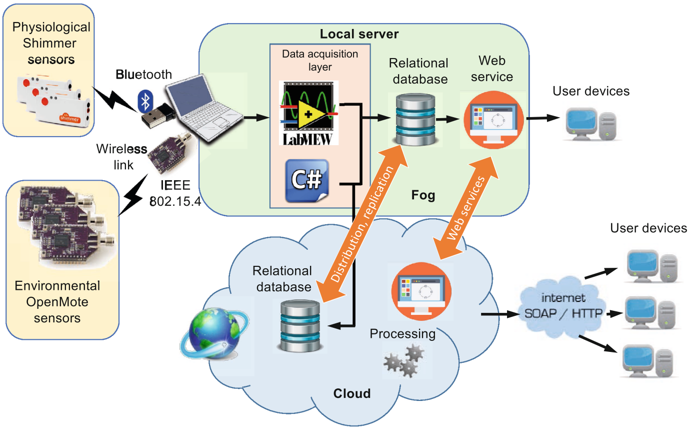

Fig. 2. The system architecture.

Wireless sensors. Shimmer is a wireless sensor platform for RHM applications [10]. Each Shimmer3 ECG/EMG unit provides an inertial measurement unit (IMU) including accelerometer, gyroscope, and magnetometer, as well as ECG unit, which additionally provides 3 ECG leads (limb leads plus one precordial lead). The acquired signals can be stored locally on the device or streamed via Bluetooth. The maximal sampling frequency of the Shimmer3 is 8 kHz. With respect to energy consumption, according to measurements presented in [11], Shimmer sensor with ECG module runs for almost 10 h on its built-in battery, while sending ECG data continuously on the Bluetooth wireless link.

The OpenMote device is a representative of new generation open-hardware platforms [12]. The OpenMote-CC2538 is based on TI CC2538 SoC functionalities, thus combining the 32-bit ARM Cortex-M3 MCU with the IEEE 802.15.4 transceiver. The OpenMote platform has 32 KB of RAM and 512 KB of flash memory, and supports several peripherals, such as GPIOs, ADC, I2C, SPI, UART, timer modules, and AES/RSA Encryption Engine. OpenMote has 3 digital sensors (temperature/humidity, light, accelerometer). The accelerometer may be used to track the movements (activity/inactivity sensing, free fall detection). The OpenMote has a battery supply, so it can be displaced easily within the monitored area. By careful separation of Bluetooth and OpenMote devices, the coexistence without interference can be achieved. The OpenMote indoor transmission range is around 50 m, and in outdoor environments is around 200 m. In this way, the OpenMote can extend current Shimmer capabilities (Bluetooth radio), and thus providing monitoring for bigger area.

Data acquisition layer. The data acquisition layer involves gathering signals from sensor nodes and preparing them for storage, analysis and presentation. Shimmer platform includes three interfaces for data acquisition implemented in MATLAB, LabView and C#.NET, whereas for the OpenMote, OpenWSN has integrated data acquisition and makes the data available on the local web server

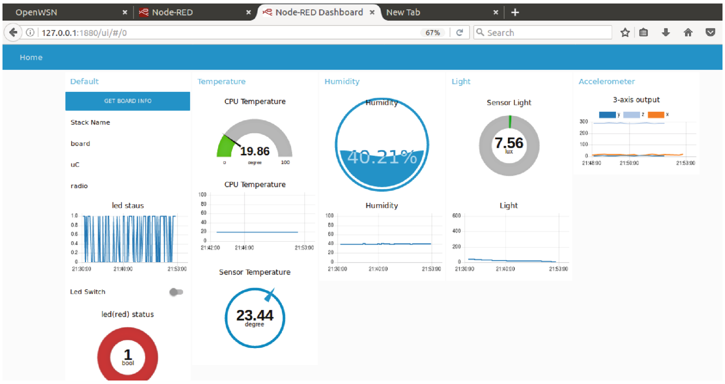

Fig. 3. Web-interface for environmental monitoring.

or Cloud. The data can be inserted in the database immediately upon arrival, either by taking values from the web service (applicable for both sensors) or using the interfaces (Shimmer only).

Database. In our previous work, we presented a relational database structure for RHM [8], which can handle physiological, movement and environmental data, the data about questionnaires and related answers, as well as the general data about patients and system users. In general, any custom relational database can be used. Alternatively to using relational databases it is also possible to store the data in files only or to use NoSQL databases that can, in the same way as relational database, reside on the local server (Fog node) and/or in the Cloud.

Web service and web interface. Local or remote web services can provide data to multiple web interfaces (clients) at a time. The interface is organized as a number of configurable and adjustable graphs that present the data continuously – see Fig. 3. A historical view has also been implemented. This web structure was chosen for the presentational layer instead of a desktop application as in this way the presentational layer is platform independent and easily accessible.

Cloud. The Cloud is a very useful platform for RHM since it can store the acquired measurements, apply already available processing abilities to the data (e.g. [13,14]), and make the data available to the clients. The data can be fed to the database in a Cloud directly from the data acquisition layer, or the databases in the Cloud can be an automatic replica of the local database. An additional interesting possibility is to use distributed relational databases in which case a part of the database can be kept locally, whereas another part can reside in the Cloud – see Fig. 2. Similarly, the web service in the Cloud can expose the data from the Cloud database, but it can also communicate through web protocols (REST, SOAP, MQTT) to the web service on the local server.

4 Conclusion

This paper presents the preliminary design of a heterogeneous RHM system by considering both physiological and environmental sensors empowered with Bluetooth and IEEE 802.15.4 radios. The hardware and software heterogeneity brings many challenges that incorporates with reliable and secure wireless data communication, while providing smart data analysis at different levels. In the future, we will perform extensive experiments to evaluate the quality of service of the system in various environmental and network conditions.

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