Web-Enabled Intelligent Gateways for eHealth Internet-of-Things

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Web-Enabled Intelligent Gateways for eHealth Internet-of-Things

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Abstract. The currently unfolding Internet of Things (IoT) technologies will enable health services that have higher quality and lower cost than those available today. However, the large majority of the current IoT research and development expects that the IoT "things" communicate wirelessly, leaving the question of their energy supply and communication reliability more-or-less open. The obvious alternative, wire line, has gained much less attention, perhaps since it is too well known. In this paper, we present an energy-efficient IoT architecture for healthcare applications that leverages clinical and home care scenarios, given their typically fixed, stationary nature, as the mobility of patients is in many cases confined to a room or a building. The architecture is based on intelligent, wired gateways that are power-efficient and low-cost. The gateways link wired/wireless medical sensors and hospital appliances to web services, enabling hospital automation and widespread data collection and aggregation of vital signs in a convenient, and cost-effective approach.

Keywords: Internet of Things · Web of things · WebSocket · Gateway · HTML5 · Healthcare · Smart Hospital · Home care

1 Introduction

The Internet of Things (IoT) refers to the extension of the current Internet services where the mundane everyday things are connected to the Internet, in addition to the already connected computers and smart phones [1]. This paradigm enables Electronic Health (eHealth), Mobile Health (mHealth) and Ambient Assisted Living (AAL) technologies that allow remote monitoring and tracking of patients living alone at home or treated in hospitals. These technologies provide health workers with the ability to check vital signs of patients from anywhere at any time [2].

In wireline, wireless, and hybrid situations, an IoT gateway could play an important role in health-related IoT applications. Initially, such a gateway may securely and reliably bridge legacy sensors and other medical equipment to traditional Internet Protocol (IP) based networks, such as a hospital intranet. In the longer run, such gateways may connect the devices to a (private) cloud-based service, allowing data

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aggregation and sensor fusion across multiple sensors and all patients, both in hospitals and home care environments.

The IoT gateway may also be made responsible for intelligent processing and partial data aggregation of the vital signs signals, along with protocol conversion from the proprietary or primitive sensor data formats to those used IP based networks. When real-time asynchronous communication capabilities are desired, the WebSocket protocol [3] proves being useful by providing socket like capabilities for the Web.

Another potential benefit of the proposed approach is that sensors and actuators for both building automation and clinical appliances may be powered and networked by PoE (Power over Ethernet) [4] enabled technology. This allows building a Smart Hospital system where the medical devices and building automation, including safety and security, may become integrated. Furthermore, in the future even patients' own devices, such as cell phones, may be integrated to the system, increasing their awareness and self-responsibility of their situation.

In this paper, we propose an IoT architecture for healthcare applications based on energy-efficient web-enabled gateway design customized for health related data processing and transmission. The proposed architecture focuses on enabling wide-spread data collection from both wireless and wireline sensors, not only from the medical world but also from e.g. the building safety and security systems, in a unified way. The combination of this two realms of healthcare services and smart hospital realizations by taking advantage of PoE and web of things technologies represent a convenient, and cost-effective approach to healthcare services.

2 Related Work

In [5], a WebSocket based monitoring system for sensor activity over a 6loWPAN (IPv6 over Low power Wireless Personal Area Networks) network is proposed for feedback on building energy consumption, the WebSocket client is implemented in the sensor gateway and a web user interface based on HTML5 is used. The gateway however, does not serve as an energy source for the sensor nodes, leaving them to depend on batteries or third party power sources to work. In [6], authors present design and optimizations of a low power wireless gateway node that bridges data from wireless sensor networks to Wi-Fi networks on an on-demand basis. These works do not consider the use of intelligent processing of health related data on gateways. Ultimately the gateways in these works are used as connection points to external web servers instead of embedding the web connectivity on the gateway itself as proposed in this paper.

3 Motivation

IoT applications are based on the extension of Internet to resource-constrained network nodes that cannot take advantage of existing web services due to their high overhead and intricacy. Resources are accessed through RESTful interfaces in synchronous request/response fashion using methods such as GET, PUT, POST and DELETE and are identified by Universal Resource Identifiers (URIs) which allow for short lived transmissions only [7]. However, monitoring bio-signals required to estimate the overall user's health condition necessitates a constant connection for the non-stop transmission of live data from continuous and pulsed signals such as Electrocardiography (ECG), Electromyography (EMG), Electroencephalography (EEG), respiratory and heart rate. Each signal has a different bandwidth as shown in Table 1. Electrical activity often requires band-pass and notch filtering to remove baseline wandering, electric hum noise and motion artifacts. Depending on the need, the signal could be processed for feature extraction. In addition, classification of normal, deviant, risk and high risk conditions are performed in order to send notification to caregivers in order to take appropriate actions before a catastrophic event occurs. Many of these functions could be performed on the gateway in order to alleviate the burden that the sensor can carry.

A typical building automation system for hospitals is usually designed without taking into account the health data generated by biomedical sensors. Yet, a trend in modern healthcare is to go beyond the scope of traditional building management and integrate all kinds of data sources into a big data cloud repository for performing advanced analytics, improve forecasting and prioritize actions for increasing the bottom line while improving health services quality. As an example, room sensors sense the needs and preferences of staff and patients and allow to move from a traditional nurse call system based on buttons fixed to a wall to intelligent context aware nurse call system based on detecting hazardous situations (e.g. when a patient's temperature rise into fever or an abnormal heart condition is detected).

Table 1. Types of bio-signals and bandwidths.

Type of biosignal	Bandwidth	Signal nature
ECG	0.5–40 Hz	Continuous waveform
EMG	20–400 Hz	Continuous waveform
Continuous blood pressure	0–100 Hz	Continuous waveform
Systolic and diastolic blood pressure	–	Discrete measurements
Respiration rate	0.5–10 Hz	Continuous waveform
Heart rate	20–200 BPM	Pulses per minute
Blood glucose	–	Discrete measurements

4 Architecture

The intelligent gateway proposed features processing and web software components customized for the handling and transmission of healthcare related signals such as vital signs. On the sensor side, the gateway takes care of translation layers to accommodate vendor agnostic sensors using different communication protocols.

The system architecture is shown in Fig. 1. The biomedical sensors used for assessing physiological status serve as one of the data inputs to the system. These are wired or wireless sensors for biometrics such as ECG, EMG, EEG, temperature, pressure, heart rate, position, respiration rate, glucose levels, complete blood count, etc.

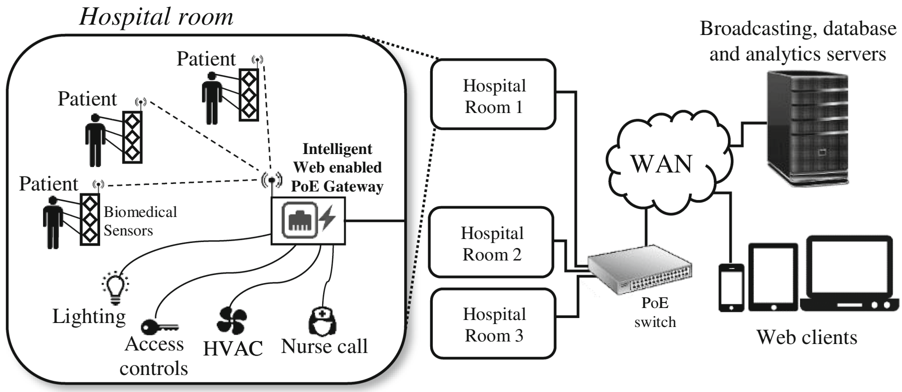


Fig. 1. Energy efficient IoT architecture for healthcare applications.

These sensors are connected to the gateway which receives the data, executes signal processing and/or feature extraction and forwards relevant information to a server, database or a directly to a web client.

In addition to remote patient monitoring, a smart building system is integrated consisting of IoT nodes used for building automation. These include traditional lighting, public address, access control and HVAC as well as hospital centric appliances namely next-to-bed controls and context aware applications such as intelligent nurse calling. The envisioned system is energy efficient by harnessing the PoE capabilities of the gateway, which allows for powering actuators and sensors directly without recurring to a different power grid or AC outlets. The back-end of the system consists of the two remaining components, the PoE enabled switch and a cloud computing platform that includes broadcasting, data warehouse and Big Data analytics servers, and finally Web clients as a graphical user interface for final visualization.

4.1 Medical Sensors

Medical sensors capture signals from the body used for treatment and diagnosing of a medical state. Examples are ECG, EMG and EEG signals for analyzing heart, muscles and brain conditions. The sensor contains transducers and electrodes for acquiring electrical signals that are converted to digital form using an analog front-end. The signal is then transmitted to the gateway via wireless or wired communication protocols such as Serial, SPI, Bluetooth, Wi-Fi or IEEE 802.15.4. The transmitted data contains information about the number of channels used and other status data such as lead-off detection.

4.2 Gateway

The gateway receives data from sensors and performs in-network processing e.g. data aggregation, filtering and dimensionality reduction. The gateway also contains a

WebSocket server for streaming data directly to web applications, or to interface to other broadcast servers. The WebSocket connection relies on TLS/SSL to provide encrypted, end-to-end secure client and server communications.

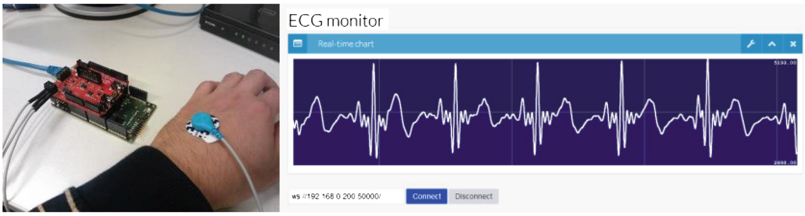
For the gateway role, we have designed a hardware platform known as *Ell-i* [8] which is an open source Arduino like development platform for fixed things that implements IEEE 802.3 at Power-over-Ethernet standard for 1–35 watts power consumption range. A DC/DC converter on board converts 48 V into 5 V and/or 3.3 V needed by the Microcontroller Unit (MCU), and an extra power supply converter is used for providing bulk power to the wired sensors and actuators of the system such as high-power LEDs, solenoids or electric motors. The gateway is designed to be low-cost in order to be massively deployed along a hospital (e.g. one gateway in every room or for every bed) so that low power wireless sensors benefit from small coverage area. The gateway receives commands over Internet to execute different tasks such as start streaming of sensor data which include processing and transmission over the WebSocket interface.

4.3 Smart Hospital Framework

The networking capabilities of the gateway can serve multiple roles in addition to monitoring patients. The same protocols used for connecting medical sensors are used in a similar way for managing building automation systems such as lighting, access control, indoor PA systems and HVAC controls and other more clinical centric as in the case of ambient-intelligent nurse calling systems. This setup enables the centralization of data acquisition not only for patient health data but also for hospital building management of an integrated Smart Hospital framework. The gateway serves not only as a managing node for the smart hospital controls but also as a smart power source by harnessing the power coming from the PoE cable. This makes the system more energy-efficient and practical compared to other architectures that use embedded solutions such as Raspberry Pi [9] as web servers.

5 Experimental Results

A test have been designed to assess the performance and practicality of the setup. We use the Ell-i platform with an e-health daughter board that includes signal conditioning circuitry to acquire ECG data from electrodes attached to a test patient (Fig. 2a). The data is digitally filtered in the gateway to remove power line noise and is streamed over Internet using the embedded WebSocket server via Ethernet. A JavaScript client plots the near real-time chart (1 s delay) of the signal (Fig. 2b). A set of commands is implemented to control transmission start-stop. Future work includes the expansion of the command set into a complete API for gateway management. The energy source comes from the PoE enabled Ethernet cable connected to the gateway which also powers the sensors.



(a) **(b)**

Fig. 2. PoE powered gateway with e-health daughter board and electrodes attached to a test patient for ECG monitoring (a). JavaScript client interface (b).

The signal is sampled at 500 SPS with 12-bit resolution. Samples are packetized into WebSocket messages of size 800 bytes and sent at an average rate of 1 KB/s. The cost of the system is estimated in $200 USD per patient.

6 Conclusions

We believe that focus on the IoT gateway design for healthcare applications represent an opportunity to solve IoT architecture challenges such as web connectivity, power efficiency and Smart Hospital integration. In this paper, an IoT architecture have been proposed that uses PoE powered gateways to serve as a bridge for medical sensors and hospital building automation appliances to IP based networks and cloud computing platforms. The proposed design of the gateway does processing and data aggregation of vital signs and includes streaming web server. In addition, the gateway harness the energy provided by the PoE enabled Ethernet cable to power sensors and actuators. The gateway is designed to be low-cost and allows massive deployment along the hospital facilities that together with PoE enabled network infrastructure result in an energy-efficient architecture for healthcare in hospitals and homes.

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