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Fog Computing in Healthcare Internet of Things: A Case Study on ECG Feature Extraction

Tuan Nguyen Gia[1], Mingzhe Jiang[1] Amir-Mohammad Rahmani[1,2], Tomi Westerlund[1], Pasi Liljeberg[1], and Hannu Tenhunen[1,2]
[1]Department of Information Technology, University of Turku, Turku, Finland
[2] Department of Industrial and Medical Electronics, KTH Royal Institute of Technology, Stockholm, Sweden
Email: {tunggi, mizhji, amirah, tovewe, pakrli}@utu.fi, hannu@kth.se

***Abstract*—Internet of Things technology provides a competent and structured approach to improve health and wellbeing of mankind. One of the feasible ways to offer healthcare services based on IoT is to monitor humans health in real-time using ubiquitous health monitoring systems which have the ability to acquire bio-signals from sensor nodes and send the data to the gateway via a particular wireless communication protocol. The real-time data is then transmitted to a remote cloud server for real-time processing, visualization, and diagnosis. In this paper, we enhance such a health monitoring system by exploiting the concept of fog computing at smart gateways providing advanced techniques and services such as embedded data mining, distributed storage, and notification service at the edge of network. Particularly, we choose Electrocardiogram (ECG) feature extraction as the case study as it plays an important role in diagnosis of many cardiac diseases. ECG signals are analyzed in smart gateways with features extracted including heart rate, P wave and T wave via a flexible template based on a lightweight wavelet transform mechanism. Our experimental results reveal that fog computing helps achieving more than 90% bandwidth efficiency and offering low-latency real time response at the edge of the network.**

***Keywords*—Internet of Things, Healthcare, Smart Gateway, Sensor Network, Heart Rate, ECG feature extraction, Fog Computing.**

I. Introduction

Internet of Things (IoT) can be considered as a dynamic global network infrastructure where objects with unique identities are interconnected for enabling advanced services. Wireless Body Area Networks (WBAN), which is one of the fundamental technologies in healthcare IoT, is ubiquitous used for acquiring different vital signs such as Electrocardiogram (ECG), Electromyography (EMG), body temperature, blood pressure in a real-time, unobtrusive and efficient way. WBAN can be established from a multitude of implantable or wearable sensor nodes to sense and transmit the data over a wireless network via communication protocols such as Wi-Fi or IEEE.802.15.4 to end users for visualization and diagnosis. Low-cost and power efficient WBAN-based systems play important roles in various areas of healthcare environments from monitoring, clinical care to chronic disease management and disease prevention. For example, these systems are used for monitoring and treating many cardiovascular diseases.

In many health monitoring systems, remote cloud servers have been used for storing and processing big data collected from a large number of sensor nodes due to cloud computing benefits such as low-cost services, capability of large data storage volume and superfluous maintenance cost. However, there exists many challenges in these systems regarding latency-sensitive issues, location awareness and large data transmission. Undoubtedly, the more data is transmitted over a network, the higher possibility of error occurs because bit error, data transmission latency and packet dropping possibility are proportional with the volume of transmitted data. Especially, in case of emergency, a single error in analyzed data causes inaccurate treatment decisions and affect crucially to a human life. Therefore, there is a need of reducing the number of transmitted data over a network, on the other hand, quality of service (QoS) is still guaranteed.

A proper solution for fulfilling the requirement is the provision of an extra layer in between a conventional gateway and a remote cloud server. The extra layer denoted as fog layer helps diminishing the volume of transmitted data for guaranteeing QoS, and saving network bandwidth by preprocessing data. In addition, fog computing offers advanced services at the edge of the network and reduces the burden of cloud [1]. Fog computing not only brings the cloud computing paradigm to the edge of the network but also addresses unsupported or unfit fundamentals in the cloud computing paradigm. For instance, edge location, low latency, location awareness, geographical distribution, interoperability, and support for on-line analytics are some of fundamental characteristics of fog computing. Due to these characteristics, fog computing can be suitable for supporting human health monitoring WBAN-based systems which have features of low energy, low bandwidth, low processing power and include hardware constrained nodes. To this end, a combination of WBAN-based system, cloud computing and fog computing can be a sustainable solution for challenges in the current IoT healthcare systems.

In this paper, we present an efficient IoT-enabled healthcare system architecture which benefits from the concept of fog computing. Using this architecture, we demonstrate the effectiveness of fog computing in IoT-based healthcare systems in terms of bandwidth utilization, QoS assurance, and emergency notification. In addition, we utilize ECG feature extraction at the edge of the network in our implementation as a case study. In summary, the key contributions of this work are as follows:

- Low-latency data processing and low bandwidth utilization at smart gateways (i.e., edge of the network)

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- Support various sensor node types, communication protocols, operating systems at smart gateways (i.e., heterogeneity, and interoperability)
- Real-time rapid interaction at smart gateways in case of emergency (i.e., real-time push notification)
- Real-time and on-line analytic at the fog layer even in case of poor connection with the cloud (i.e., geographical distribution, location awareness, graphical user interface)

The rest of the paper is organized as follows: In Section II, the related work and the motivation of the paper are discussed. The concept of an e-health IoT-based system and a smart e-health gateway are presented in section III. Section IV presents an implementation of the smart IoT-based gateway. Demonstrations and experimental results are provided in section V. Finally, section VI concludes the paper and present discussion for further researching.

II. Related Work and Motivation

There have been many efforts in designing smart gateways for healthcare applications. For instance, Chen *et al*. [2] introduce a smart gateway for health care system using wireless sensor network. The proposed gateway acting as a bridge between wireless sensor network and public communication networks has a data decision system, a lightweight database and an ability to notify caregivers in case of emergency. In addition, the gateway provides a way of diminishing a remote server's burden by applying the request and response message method.

Mohapatra *et al*. discuss a hybrid framework for remote patient monitoring via a sensor cloud [3]. Advantages of using a sensor cloud for patient health status monitoring is demonstrated in their proposed system. In [4], authors present a cloud computing solution for patient's data collection in health care institutions. The proposed system uses sensors attached to medical equipments to collect patient data and sends the data to cloud for providing ubiquitous access. Yang *et al*. present a personal health monitoring gateway based on smart phone [5]. The proposed gateway uses a Bluetooth interface to upload gathered data to remote servers. In a work presented in [6], the sensor network system uses sensing servers as gateways in the system. However, the proposal is expensive, poor scalable, and inefficient for the number of IoT-based applications. In [7], authors discuss a prototype of a smart IPv6 Low power personal area network (6LoWPAN) border router based on Hidden Markov Model for making decisions of health states. In [8], authors propose a mobile gateway for ubiquitous health care system using ZigBee and Bluetooth. The gateway tenders various services such as alarms and analysis of medical data. However, the proposed gateway is inefficient in term of power consumption and it cannot be considered as a novel gateway for several IoT-based applications. Zhong *et al*. present a gateway based on a mobile phone for connecting sensor network nodes and devices supporting CDMA or Bluetooth [9]. In another work [10], the proposed architecture acquire data via multiple personal health devices via USB, ZigBee or Bluetooth.

The topic of body area sensor network systems has attracted a lot of research efforts in recent years. Especially, the number of works in the healthcare domain has dramatically increased to explore several undiscovered aspects or overcome existing drawbacks in health monitoring systems. With the purpose of novel health monitoring systems provision, some of works try to expand current systems with more services and functions while others attempt to propose new platforms or methods. However, as described in the aforementioned examples, a large number of systems focus on ZigBee whereas it is a challenge to assure the quality of service in ZigBee when monitoring streaming bio-signals such as ECG, EMG and Electroencephalography (EEG) as the maximum data rate of ZigBee is 250 kbps. Inversely, Bluetooth technology can overcome problems of low data rate in ZigBee and other short range communication protocols. Nevertheless, it might be more difficult to design a gateway based on Bluetooth technology for supporting mobility and acquiring data from multiple targets [8]. The discussed systems basically dispense conventional gateways for collecting data from nodes and sending these data to remote servers. More precisely, none of these works have considered to fully take advantage of the fog computing paradigm and bring intelligence to the gateways.

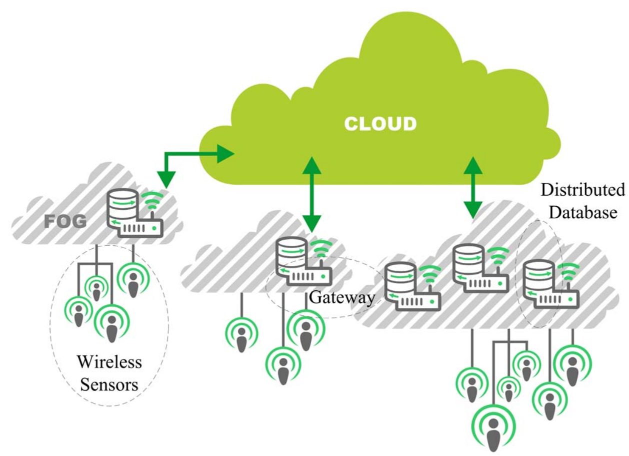

Fig. 1. Fog computing concept

The main motivation of this paper is to enhance a health monitoring IoT-based systems used in diversified environments such as home and hospital by providing a smart gateway [11] with the fog layer having quantities of advanced services. The role of fog computing is illustrated in Fig. 1. It is a middle computing layer between sensors and cloud computing which consists of gateways and distributed databases. Fog computing concept is the extension of the cloud computing paradigm in a view of pointing applications and domains which the paradigm of the cloud does not fully support. Some of them consist of i) real-time applications including video conference applications, and Voice over Internet Protocol (VoIP) require very low latency because substantial delays may cause diminishing QoS. ii) large data applications collecting a ton of data from numerous sensors and transmitting the data over networks stand in need of very high bandwidth [12]. iii) monitoring applications, which operate unremittingly, require uninterrupted data in case of losing connectivity between monitoring systems and the cloud [13]. Characteristics of these aforementioned applications are similar to characteristics of real-time health monitoring systems. In such systems, a large amount data are acquired from a multitude of bio and environmental sensors. Then, the large data is transmitted for networks for being ultimately remote monitoring by end users such as care-givers or medical doctors. Therefore, fog computing fits these systems marvellously. It is acknowledgeable that instead of replacing or lessening the role of the cloud in IoT applications, fog computing is completely cooperated and compatible with the cloud to enhance existing IoT applications from the aspects of location awareness, low latency, scalability, real-time interactions, heterogeneity and interoperability [14].

Electrooculography (EOG), EMG, EEG, ECG are important signals gathered by monitoring systems for diagnosing human health in both daily activities and medical abnormalities. However, in this paper, only a case study of ECG is addressed to present the concept of fog computing and its benefits in health monitoring IoT applications. In order to efficiently utilize network bandwidth between a health monitoring system's gateway and a cloud server, we present a flexible template with light-weight algorithms for extracting heart rate, P and T waves which can be presented at an end-user's browser. The extracted heart rate is presented at a secure graphical user interface and fed to our warning service for real-time notification in cases of emergency. In addition, a secure graphical user interface at the smart gateway is used for representing result of P, T waves after preprocessing and raw ECG data in graphical waveforms for real-time visualization and analytics. Furthermore, we introduce a method of providing gateway interoperability in the interest of supporting Ethernet, Wi-Fi, Bluetooth, ZigBee and 6LoWPAN.

III. System and Gateway Architecture

A health monitoring system often comprises of several devices to collect bio-data from a human body and transmit the data to a processing or visualization device via wires and cables for monitoring and diagnosis. Several drawbacks exist in such system such as unsupported mobility and remote monitoring which cause many inconveniences for both patients and doctors. For example, health of diabetes and cardiovaculus needs to be continuously monitored 24/7. When the conventional system is applied for this procedure, these patients must carry many devices and cables during long period of monitoring hours and incorrect data is acquired due to movement activities of these patients. A health monitoring system based on WBAN can handle these drawbacks effectively through its characteristics of mobility and wireless transmission. Although there are different types of health monitoring WBAN-based systems designed for particular bio-data and diseases, they have three main parts including sensor nodes, a gateway and a back-end part. The detailed description of these components is presented in the following.

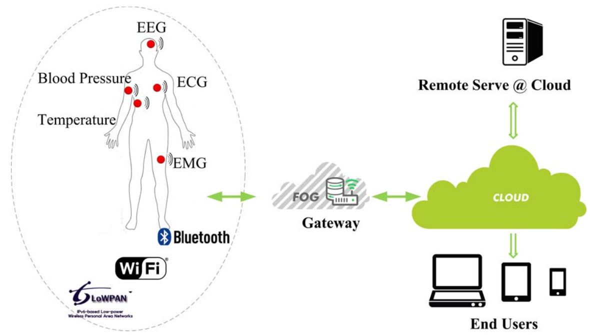

Fig. 2. The IoT-based health monitoring system architecture

1) Medical sensor node: is a composition of several physical devices including implantable or wearable sensors which are integrated to a tiny wireless module for gathering contextual and medical data such as temperature, location, humidity, SpO2, ECG, EMG, and EEG and then transmitting the data to a gateway via a specific communication protocol such as Wi-Fi, Bluetooth, ZigBee or 6LoWPAN. Depending on treatment methods for different diseases, particular bio-data and the contextual data are intentionally focused in various health monitoring WBAN-based systems.

2) Gateway: plays an important role in such a WBAN-based system because it connects a profusion of sensor nodes with a remote cloud server. When a gateway does not function properly or bottle-neck occurs at a gateway, the whole system will be affected. As a result, real-time bio-data cannot be appropriately accessed at a cloud server.

3) Back-end part: consists of a cloud server and back-services which can be different from systems to systems depending on technologies and services offered. A cloud server is used for storing, processing and broadcasting data while back-end services are responsible for representing real-time data for analysis and visualization.

The current human health monitoring WBAN-based systems containing several existing challenges can be augmented for shortening the gap towards the novelty level. In order to achieve this target, smart gateways with fog computing substituting for gateways in conventional IoT-based health monitoring systems are introduced. Our proposed IoT-based health monitoring system architecture is shown in Fig. 2.

A. Smart gateway architecture

In addition to perform functionalities of conventional gateways, the smart gateway should have abilities to offer a high level of advanced services in the fog computing platform. The smart gateway architecture including physical and operational structures is elaborately designed and described in the following.

The physical gateway structure shown in Fig. 3 includes several embedded devices which are an embedded router and one or several sink nodes. The embedded router supports some communication protocols such as Bluetooth Low Power (BLE), Wi-Fi and Ethernet but it cannot offer any possibility to connect with sensor nodes via low power wireless communication protocols. With the purpose of handling this challenge and achieving interoperability, sink nodes, which offers 6LoWPAN and other low power communication protocols are integrated into the gateway. The number of sink nodes does not limit within one or several ones but it can reach to dozens or even a hundred depending on specifications of the USB extension, SPI, I2C connections and the Internet service provider. For example, the maximum tier for USB extension is tier 7 and the gogo6 service [15] provider allows a maximum of 256 sink nodes per a network.

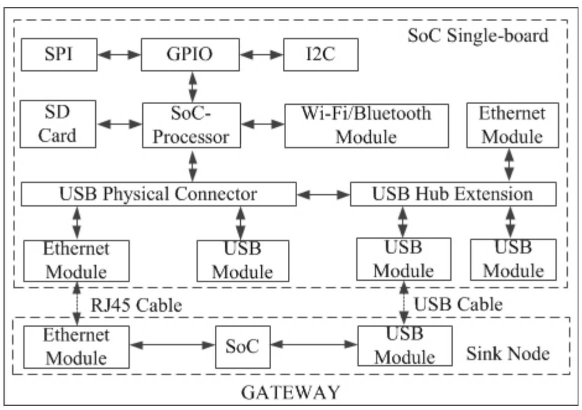

Fig. 3. Physical gateway structure

The embedded router contains different components such as processor, extendable SD card, USB connection, Ethernet, GPIO with SPI and I2C support, and a wireless connection module. Therefore, it can be able to run an operating system and process some heavy computing, which are clarified via the operational structure shown in Fig. 4. It presents the gateway operational structure comprising of a fog computing service layer, an embedded operating system and a hardware layer.

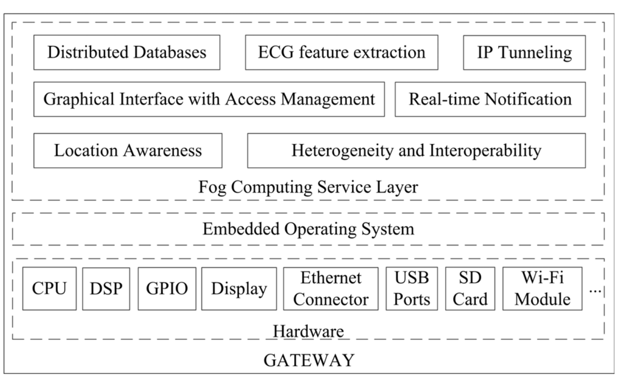

Fig. 4. Operational gateway structure

1) Hardware layer: A hardware layer operates as middleware between an embedded operating system and all physical components. Middleware receives the operating systems instructions for allocating physical hardware to gateway services. The hardware layer allows only one service to have a permission to access the component at a time. When two or more services need to access the same component, the rest must wait for its turn to acquire permission.

2) Embedded operating system: There are two types of embedded operating system used in a smart gateway including one type in the embedded router and another type in sink nodes. The embedded operating system in a sink node must be light-weight, compact, and does not require specification of powerful hardware. Inversely, the operating system in the embedded gateway does not need to be very compact because it has to provide various tools, and management mechanisms to ensure that real-time data is transmitted into a remote cloud server and all fog computing service function properly.

3) Fog computing service layer: The fog computing service layer plays the most essential role in a gateway because it contains a profusion of advanced services for not only embodying functionalities of a conventional gateway but also performing characteristics of fog computing. Details of these services are described in the following.

Distributed databases contain a static look-up storage, a general purpose storage, and a synchronized storage. The static look-up storage contains static and essential data required for several services and algorithms (e.g., security with username and password, references for data accessing and access management); therefore, the static database is kept intact for all cases except for the case of system administrators. The general purpose storage storing high data rate incoming data is used for both the fog computing service and graphical user interface. The general purpose database size can vary depending on specific applications. The synchronized storage is as an inventory of temporarily environmental data and bio-data which are sent from sensor nodes with a low data rate such as temperature, and humidity. Furthermore, it has responsibility for updating data at a remote server.

ECG feature extraction: ECG feature extraction has been processed and carried in many researches due to its important role in many applications, especially in healthcare domain. For example, in addition to help doctors monitoring and giving treatments to many diseases related to cardiovascular more efficiently, it helps to detect some abnormalities of the heart. Heart rate is one of the most concerned features extracted from ECG because it provides an overview of the heart which is necessary for emergency services and diagnosing many diseases. Furthermore, via heart rate information, some instant methods might be applied to keep the heart operating normally. For instance, a workout person can reduce the workout intensity level when heart rate is very high because heart rate is proportional with the workout intensity.

In order to extract the ECG feature at a smart gateway, we design a flexible template shown in Fig. 5. The template contains three main parts including ECG preprocessing, wavelet transformation, and ECG feature extraction. The ECG preprocessing part contains some filters such as notch filter or moving average filter in pursuance of movement artifact removal. The wavelet transformation part encompasses fast computation methods and wavelet algorithms. Finally, the ECG extraction part is used for applying various algorithms for extracting different data such as P-R interval, Q-T interval, S-T segment, QRS area and QRS energy. In this paper, we design a light-weight algorithm which is suitable with requirements of fast computation and low hardware resources consumption with the purpose of extracting P wave, T wave and heart rate from original ECG signals for keeping track of the heart's activities and verifying the smart gateway's warning service. The algorithm includes specifying a proper threshold value via scanning the whole ECG input signals, extracting the number of pulses via the help of the threshold value, and calculating heart rate based on the formula given as

$$\text{Heart rate} = \frac{60}{\text{R-R interval}} \quad [16]$$

The algorithm is designed in such a way that some parts of the algorithm can be reused for extracting other data besides R-R interval, P wave, T wave and heart rate. For instance, steps of scanning ECG signals and the method of calculating a threshold value are two reusable parts of the algorithm although parameters of these methods may vary depending on which parts of ECG signals, medical doctors want to diagnose.

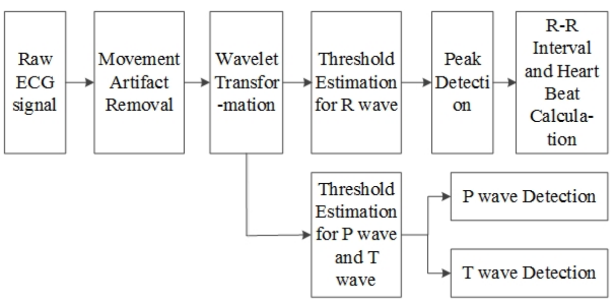

Fig. 5. The ECG feature extraction template

Graphical user interface with access management: The interface can be used by end users such as caregivers, medical doctors and system administrators for visualizing ECG and other bio-data at the smart gateway. In order to have an access to the gateway's graphical user interface, a user must login with his/her username and password which are created via the access management service. The service has a mechanism which categorizes end users into several groups depending on their responsibilities. Data available for each group will be different. For example, some sensitive data can be seen by medical doctors while the data is unavailable to patients or their relatives. The main reason for building this mechanism is to avoid some unexpected situations related to patients reaction during the disease treatment process. For example, when a patient knows his/her current status health, the patient may overreacts or has some strong emotions which may cause bad effects for disease treatment. With the intention of avoiding both the brute-force method and flooding the system's database, a user only has three chances during 10 minutes to login into the system. After three failed times, a user needs to wait for extra 10 minutes for the next login. Due to the limitation of the gateway's resources, all recorded data are stored in the database within 5 minutes. After that, the database will be purged for storing new incoming data.

Real-time notification: The notification service is a real-time notification to inform about abnormal situations. The gateway sends some real-time signals to a remote cloud which sends notification messages to an end users device when one of three following cases occurs. Firstly, the smart gateway does not receive any data from specific sensor nodes during a particular period of time. Secondly, an internal temperature of an embedded gateway or a sink node is higher than a predefined threshold. Finally, heart rate is not in the range of normal heart rate which is defined by American Heart Association. Notification messages are categorized into three groups having level 1, 2 and 3, respectively. Depending on particular situations, the push notification generates different messages with corresponding levels. For example, when the temperature of the embedded gateway is 50, 60, and 70 Celsius degrees, the push notification service sends warning messages level 1, 2, and 3 to system administrators, respectively. The higher warning level, the more urgent and critical the situation is. Similarly, this mechanism is applied for other cases.

Location awareness: Location awareness, which is used for providing information of geographical location of a device, is supported in our system via a method of tracking a physical MAC address of the systems gateway. Typically, a single gateway is setup for serving one or server rooms in the same corridor with the purpose of diminishing the complexity of the location awareness service and enhancing QoS. Through the location awareness service, the system administrators or caregivers can properly detect a patient location without any effort, which is necessary in case of emergency. In addition, the service is in conjunction with a congestion recognition mechanism which is used for monitoring an amount of incoming data of a gateway in an instant time in the direction of avoiding possibilities of exceeding a gateways bandwidth limit. When the amount of incoming data is too large, the service sends an instant signal to the real-time notification service which then notifies an administrator with real-time messages.

Heterogeneity and Interoperability: Cloud computing physical infrastructure can be described as a combination of homogeneous physical resources which are deployed and managed in a centralized manner. In contrast, fog computing physical infrastructure consist of heterogeneous resources managed in a distributed manner. Therefore, fog computing has possibilities of supporting interoperability which is an ability of serving different devices in terms of various manufactures, models, different operating systems and inconsistent communication protocols. The gateway architecture is designed in a way of supporting many operating systems and several versions of an operating system type. For instance, different versions of Linux can be installed as an operating system of a gateway. Moreover, sensor nodes produced from various producers including Texas Instrument, Zigduino, Arago Systems, and Zolertia operating under inconsistent communication protocol standards such as Wi-Fi, 6LoWPAN, and Bluetooth can connect with the gateway for establishing a complete heterogeneous wireless sensor network.

IP tunneling: IP tunneling constructed by a combination of router advertisement daemon and gogoc services is a gateway service for connecting 6LoWPAN with IPv4/IPv6. The router advertisement daemon service has two main functions including router advertisement provision and router solicitation listening while the gogoc service is responsible for querying a tunneling between a gateway and a tunnel server.

IV. Smart Gateway Implementation

Our smart gateway is built by combining various embedded hardware including Pandaboard [17] and a 6LoWPAN sink node, as shown in Fig. 6. Pandaboard is used in our implementation because it is constructed from the OMAP 4 platform which is a power efficiency and high performance system-on-chip. The processor of the OMAP 4 platform comprises of dual-core ARM Cortex-A9 MPCore in which the speed of each core is more than 1 GHz. The processor is suitable with our application due to its characteristics such as power efficiency, symmetric multiprocessing, hardware accelerator provision (i.e., a programmable digital signal processor). Furthermore, the platform supports non-volatile and volatile memories via high performance and comprehensive controllers. Therefore, external memory such as 64 GB SD card can be appended into Pandaboard for serving as a system storage. Additionally, Pandaboard is capable of dealing with different communication protocols such as Ethernet, Wi-Fi, and Bluetooth via various interfaces and pre-integrated hardware modules.

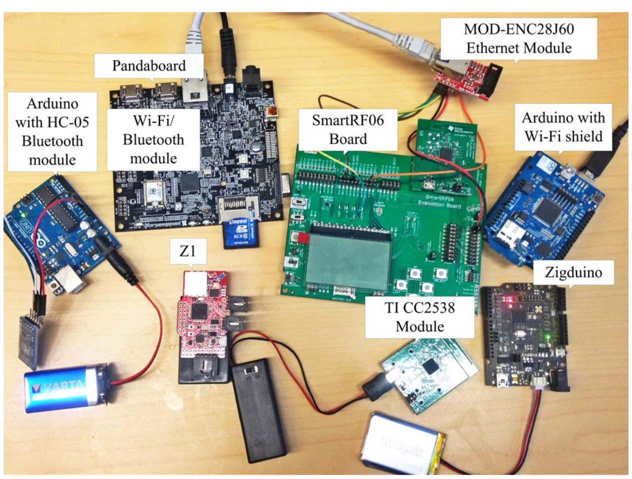

Fig. 6. Demonstration of our smart IoT-based healthcare gateway

Moreover, the OMAP4 platform supports different operating systems and applications such as Symbian, Linux (LiMo, Android, Ubuntu), and Windows Mobile. Convincingly, Ubuntu is selected as the gateway's operating system in our implementation due to its benefits including open-source operating system, various software support and high performance. In addition, Linaro operating system, which is another embedded Linux operating system, is installed in another gateway for proving the gateway's interoperability in terms of operating system support. Furthermore, we experiment heterogeneity and interoperability in our gateway by applying various hardware including Arduino with Wi-Fi shield, TI CC2538, Zigduino, Z1, and Arduino with HC-05 Bluetooth module as wireless sensor network nodes for collecting and sending data to the gateway via different communication protocols such as Wi-Fi, 6LoWPAN, ZigBee and Bluetooth.

MySQL comprising of sub-databases and tables is used as a main inventory for storing configurations of services and mechanisms, e-health and environmental data. The MySQL ensures that the data in a remote server is always updated regularly via the support of the third party tool (i.e., xSQL Lite database synchronization tool).

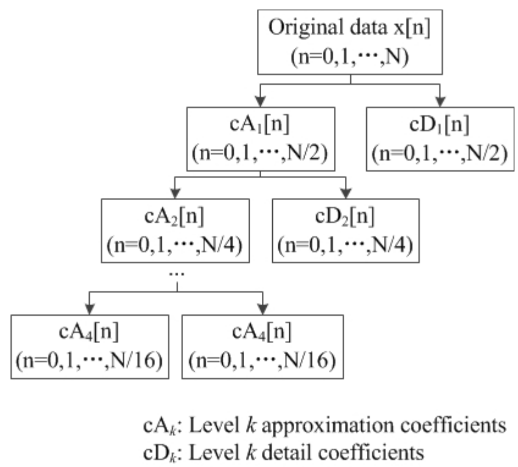

Fig. 7. Four-level Discrete Wavelet Decomposition

In a direction of implementing fog computing in the smart e-health gateway, many services and tools including gogoc, tunslip, router advertisement, socket receiver, push notification, graphical interface with access management are applied or constructed.

With a view of gateway workload reduction, a push notification service is completely implemented in a cloud server by using WebSocket. In the gateway, only a push notification mechanism is created. When the push notification service in cloud receives a desired signal from the gateway, it sends a notification to end users or system administrators.

With the interest of ECG heart rate, P wave, T wave extraction, we applied our proposed template. As mentioned above, the template has several phases including movement artifact removal, wavelet transform and ECG feature extraction. Initially, the baseline drift elimination step is implemented with a 20-points moving average filter. Then Discrete Wavelet Decomposition (DWT) with db 4 wavelet, which is in the family of Daubechies, is used as the mother wavelet. With the purpose of achieving proper results, a 4-level DWT shown in

Fig. 7, is applied. Finally, R-R interval value, P wave, T wave and heart rate can be extracted.

Graphical user interface is built by MySQL database, PHP used as server-side scripting and JavaScript (JQuery) for HTML content generation such as plotting charts. All mechanisms for access management, verifying username, password and checking the number of login times are built in PHP with the assistance of MySQL database.

A 6LoWPAN sink node consists of three components such as the Olimex Ethernet module [18], the TI Smart RF06 board, and the CC2538 module [19], shown in Fig. 6. The Ethernet module is used for data communicating between the 6LoWPAN sink node and Pandaboard. The CC2538 module takes responsibility for receiving data from sensor nodes through 6LoWPAN while the TI Smart RF06 board is used for interface provision and debugging.

V. Experimental Results and Demonstration

According to MIT-BIT Arrhythmia database [20], ECG signals were recorded from 47 subjects by two-channel ambulatory ECG system and the recordings were digitized at 360 samples per second per channel with 11-bit resolution over a 10 mV range. In addition, the database recorded a large number of statistics and records related to ECG data such as a total number of normal heart beats and other types heat beats during 30 minutes recording time of each person. Due to these statistics, ECG data in the MIT-BIT Arrhythmia database is a suitable candidate for our experiments. Initially, ECG data was stored in the gateway storage and then processed with the fog computing service. Finally, ECG features (e.g., heart rate, P wave and T wave) were extracted. In order to have a closer view to our proposed template functionality, we applied the file "101" from MIT-BIT Arrhythmia database into the template. The result is shown in Fig. 8.

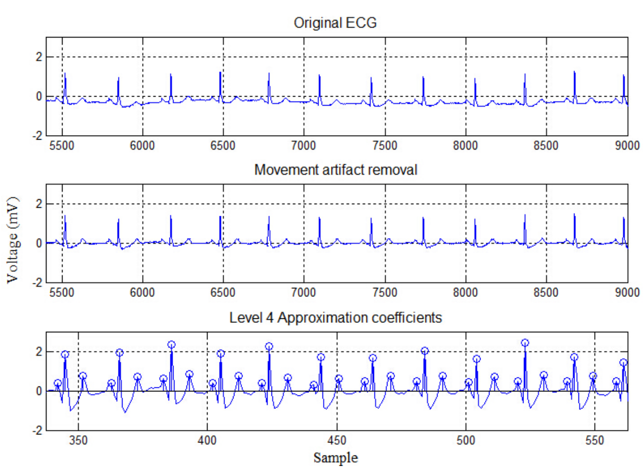

Fig. 8. ECG processing implementation

With the intention of presenting benefits of fog computing towards a healthcare IoT system, latency of transmitting various raw ECG data from the gateway to a remote cloud is compared with a total latency of processing the fog computing service and transmitting preprocessed ECG data. The comparison results shown in Table I are achieved via Wi-Fi whose information such as network condition, data rate, frequency and link quality are provided in Table II. In case of fog computing, a volume of data transmitted over Wi-Fi is small on the grounds that processed data including heart rate, P wave, and T wave is transmitted.

TABLE I
Data rate and latency comparison

Data rate (Mb/s)	Raw data		Fog computing			Improvement	
	Data size(B)	Latency (ms)	Data size(B)	Processing(ms)	Transmitting(ms)	Data size reduction(%)	Latency reduction(%)
18	240000	106.6	⩽15840	≈ 96.3	⩽6.6	⩾93	⩾3.5
12		152.2			⩽9.5		⩾30.5
9		213.3			⩽13.5		⩾48.5

TABLE II
Information of Wi-Fi network

Network condition	Data rate	Frequency	Link quality
Not busy	18Mbit/s	2.437GHz	53/70
Busy	12Mbit/s	2.412GHz	51/70
Busiest	9Mbit/s	2.402GHz	50/70

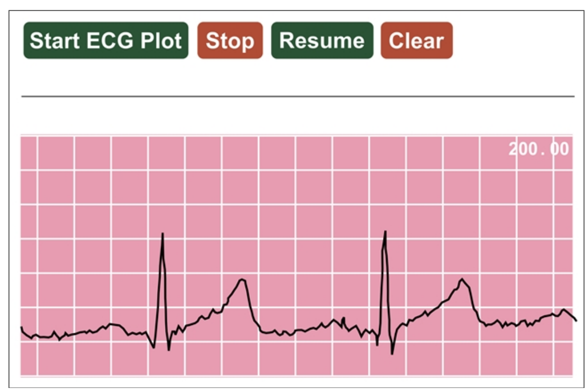

Fig. 9. ECG waveforms

Throughout these reported results, the fog computing service is efficient in terms of transmission latency minimization. In addition, the fog computing service helps to reduce the number of data transmitted over a network. As a consequence, a volume of transmitted data reduce dramatically, which leads to efficient utilization of network bandwidth.

As mentioned above, users can log in to our gateway graphical user interface by their usernames and passwords for visualizing and diagnosing real-time ECG data shown in Fig. 9, P wave, T wave and heart rate. In this experiment, instead of using ECG data from the MIT-BIT Arrhythmia database, ECG data is collected from nodes and sent to the smart gateway via Wi-Fi. In addition, the gateway user interface is designed for achieving user friendliness with several functional buttons for manipulating ECG waveforms.

VI. Conclusion and Discussion

In this paper, we present fog computing at a gateway for augmenting health monitoring systems. We have implemented fog computing services including interoperability, distributed database, real-time notification mechanism, location awareness and graphical user interface with access management. In addition, we introduce a flexible, light-weight template for ECG feature (e.g. heart rate, P wave, and T wave) extraction. The demonstration and results show the achievements provided by the smart gateway. The template based on wavelet transform can be used for extracting various ECG features by detecting different parts of ECG waveforms (e.g. PR interval, and QT interval), or extracting EMG, EEG features.

References

[1] J. Burt, "Fog computing aims to reduce processing burden of cloud systems," http://www.eweek.com/networking/fog-computing-aims-to-reduce-processing-burden-of-cloud-systems.html, 2010.

[2] Y. Chen, W. Shen, H. Huo, and Y. Xu, "A smart gateway for health care system using wireless sensor network," in *2010 Fourth International Conference on Sensor Technologies and Applications (SENSORCOMM)*, July 2010, pp. 545–550.

[3] S. Mohapatra and K. S. Rekha, "Sensor-cloud: a hybrid framework for remote patient monitoring," *Int. J. Comput. Appl*, vol. 55, no. 2, pp. 1–11, 2012.

[4] C. O. Rolim, F. L. Koch, C. B. Westphall, J. Werner, A. Fracalossi, and G. S. Salvador, "A cloud computing solution for patient's data collection in health care institutions," in *ETELEMED'10. Second International Conference on eHealth, Telemedicine, and Social Medicine, 2010.* IEEE, 2010, pp. 95–99.

[5] S. Yang and M. Gerla, "Personal gateway in mobile health monitoring," in *2011 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops)*, March 2011, pp. 636–641.

[6] J. W. Yoon, Y. K. Ku, C. S. Nam, and D. R. Shin, "Sensor network middleware for distributed and heterogeneous environments," in *NISS'09. International Conference on New Trends in Information and Service Science, 2009.* IEEE, 2009, pp. 979–982.

[7] W. Shen, Y. Xu, D. Xie, T. Zhang, and A. Johansson, "Smart border routers for ehealthcare wireless sensor networks," in *2011 7th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM)*, Sept 2011, pp. 1–4.

[8] T. H. Laine, C. Lee, and H. Suk, "Mobile gateway for ubiquitous health care system using zigbee and bluetooth," in *2014 Eighth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS).* IEEE, 2014, pp. 139–145.

[9] *A Phone-centered body sensor network platform: Cost, energy efficiency & user interface.* Institute of Electrical and Electronics Engineers, Inc., April 2006. [Online]. Available: http://research.microsoft.com/apps/pubs/default.aspx?id=103003

[10] K. Park and J. Pak, "An integrated gateway for various phds in u-healthcare environments," *BioMed Research International*, vol. 2012, 2012.

[11] A. M. Rahmani, N. K. Thanigaivelan, T. N. Gia, J. Granados, B. Negash, P. Liljeberg, and H. Tenhunen, "Smart e-health gateway: Bringing intelligence to internet-of-things based ubiquitous healthcare systems," in *Annual IEEE Consumer Communications and Networking Conference.* IEEE, 2015, pp. 826–834.

[12] F. Bonomi, R. Milito, P. Natarajan, and J. Zhu, "Fog computing: A platform for internet of things and analytics," in *Big Data and Internet of Things: A Roadmap for Smart Environments.* Springer, 2014, pp. 169–186.

[13] N. Bessis and C. Dobre, *Big data and internet of things: a roadmap for smart environments.* Springer, 2014.

[14] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli, "Fog computing and its role in the internet of things," in *Proceedings of the first edition of the MCC workshop on Mobile cloud computing.* ACM, 2012, pp. 13–16.

[15] J. Whitby, "Systemd for gogoc," http://www.gogo6.com/forum/topics/systemd-for-gogoc, jun 2012.

[16] K. Goh, J. Lavanya, Y. Kim, E. Tan, and C. Soh, "A pda-based ecg beat detector for home cardiac care," in *IEEE-EMBS 2005. 27th Annual International Conference of the Engineering in Medicine and Biology Society, 2005.* IEEE, 2006, pp. 375–378.

[17] "Resources, pandaboard.org." http://pandaboard.org/content/resources/references.

[18] "Olimex. mod-enc28j60 development board, users manual." https://www.olimex.com/Products/Modules/Ethernet-/MOD-ENC28J60/resources/MOD-ENC28J60.pdf.

[19] "Smartrf06 evaluation board users guide (rev.a)." http://www.ti.com/lit/pdf/swru321.

[20] G. B. Moody and R. G. Mark, "The impact of the mit-bih arrhythmia database," *Engineering in Medicine and Biology Magazine, IEEE*, vol. 20, no. 3, pp. 45–50, 2001.