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M-BRIDGE: Wireless Portable OnBody Aggregator and Visualizer System for Wireless Body Sensor Network

Aung Aung Phyo Wai, Yu Ge

***Abstract*— Advances made in electronics, intelligent and wireless technologies enable individuals to self-observe their health states anywhere anytime. The shift in self care becomes a promising paradigm to alleviate burdens on centralized institutional care. As a result, Wireless Body Sensor Network (WBSN) personal health solutions can be seen increasingly although medical community still has concerns on their usability and applicability. Especially, there is still lacking in portable wireless wearable gateway to integrate WBSN into existing healthcare solutions. To fulfill this gap, we design and develop MobilE on-Body aGgregator and vIsualizer Device (M-BRIDGE) system using Android smart phone. Our proposed solution fully supports the needs of flexible device interfacing, data aggregation, efficient data distribution and user-friendly visualization. We also explain how M-BRIDGE's unique features and operation can complement with and fulfill the deficiency of existing WBSN healthcare solutions. We finally present the details of implementation and technical evaluation as well as discussion on the potential issues and future works.**

I. INTRODUCTION

Advances in low-power sensing, embedded computing and wireless telephony drive innovations in revolutionizing today healthcare [1]. There are growing interests and demands from users on real-time health monitoring for personalized proactive care [2]. Various healthcare applications powered by WBSN can be seen from research prototypes to commercial products [1, 2]. WBSN solution brings benefits of real-time continuous monitoring; thus enabling a personalized and user-centric care [3]. In order to tap these potentials, IEEE 802.15.6 taskforce was setup to design interoperability standards for medical WBSN [4]. But it still faces several challenges in real-world deployment such as reliability, usability and efficiency, etc. as user is required to directly interact in operating WBSN. To fulfill unique needs of user-centric usage, it is utmost important to provide easy-to-carry and friendly-to-use WBSN system to capture real-time health information from body-worn sensors [6].

Besides wearing miniature WBSN nodes on the body [3], users usually do not desire to wear an extra and bulky device during the course of operation [7]. On the other hand, it is not reasonable to expect connecting to the dedicated gateway deployed in the environment all the times. This infrastructure only solution is not portable; thus limits the coverage and effectiveness [8]. So the main issue is the lack of wireless portable onbody wearable device that bridges between low-power WBSN and backend servers on Internet. There are existing portable solutions available [9, 10, 11] using mobile phones to resolve this issue. But those solutions are still tightly integrated with applications without providing general data aggregation, in-node processing and dissemination system. It is also important to provide user-friendly visualization for examining different states of WBSN and for controlling its operations via portable onbody device dynamically.

In this paper, we present the design, implementation and evaluation of M-BRIDGE that can be used as portable wireless onbody gateway in several wearable applications. The details of the proposed solution ranging from design, architecture, operations and implementation can be found from section II to IV. Finally, evaluations results with discussion will be presented in section V before summarizing the contributions made in this paper.

II. WIRELESS BODY SENSOR NETWORK

In order to provide generic, scalable and extensible health monitoring system, it is important to design complete eco-system with WBSN to meet different user needs. So we first adopted a modular layered architecture as shown in Fig 1 [9]; Intra-body connectivity among heterogeneous WBSN nodes on the body, Inter-body multi-radio communication support from onbody device to bridge from personal space to outside world, and Inter-device connectivity with cloud back-end server for intelligent data analysis and diagnosis. Most of existing solutions mainly focus on areas I and III [1, 2] but only a few works have been done on developing the onbody bridging system [7, 8, 9, 10]. Still these solutions did not completely meet the general usability and operation needs demanded from WBSN practical usage [10, 11].

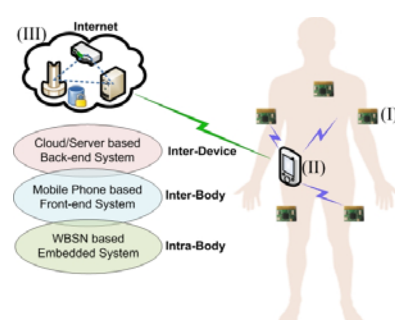

Figure 1. Proposed generic WBSN framework and functionality

As shown in Fig 1, onbody wearable system play critical role to collect user's data and to act as mediator between

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Aung Aung Phyo Wai is with Neural and Biomedical Technology Dept, I[2]R, 1 Fusionopolis Way #21-01 Connexis, Singapore 138631. (e-mail: apwaung@i2r.a-star.edu.sg).

Ge Yu is with Sense and Sense-Abilities Prog., I[2]R, 1 Fusionopolis Way #21-01 Connexis, Singapore 138631. (e-mail: geyu@i2r.a-star.edu.sg).

WBSN and outside world. The design goal is to have better energy efficiency, safety and wearability while wearing M-BRIDGE on the body. From hardware perspective, this portable device should support different wireless platforms (ZigBee, ANT+, etc) and allow easily extensible to future functional needs. In order to have flexible accessibility, such functions should be integrated into everyday wearable device like mobile phone without much hardware and software modifications. Although mobile phone has different radios (WiFi/Bluetooth/3G), extra low-power radio like Zigbee is generally not built into it. With advances in Universal Serial Bus (USB) interface support in Android OS, micro-USB port can be used to integrate WBSN basestation directly into the phone with USB On-The-Go (OTG) cable.

The onbody gateway software needs to support general functions such as device interfacing, message encoding and decoding, data aggregation, buffering, bi-directional wireless transmission, in-node processing, visualization and user interfaces (UI). Its software sub-system involves two levels; WBSN basestation application using TinyOS/nesC and Android application using Java and JavaScript. It can further be classified into asynchronous unattended and user control operations according to their functions.

III. M-BRIDGE: ONBODY AGGREGATOR AND VISUALIZER

The role and operation of M-BRIDGE that mediates between WBSN and intelligent cloud servers can be seen in Fig. 2. Its hardware consists of WBSN basestation and Android phone. The basestation is in-house built miniature platform that consists of microcontroller, CC2420 radio with Printed Circuit Board (PCB) antenna and USB to Universal Asynchronous Receiver/Transmitter (UART) circuitry.

Figure 2. Overview of M-BRIDGE's role and operation

A. System Architecture

Decoupling of visualization with UI and other core gateway functions of M-BRIDGE meets scalability, extensibility and usability requirements as shown in Fig 3. Also, modular device interfacing, message parsing and wireless communication system enables extensible and reusable components to further develop and integrate with other applications. Instead of directly handling different levels of interoperability, our focus is mainly on building basic general framework supporting the requirements from different applications. This layered design leads to easy integration of different low-power wireless devices through generic device interfacing and intelligent servers through flexible data encoding layers.

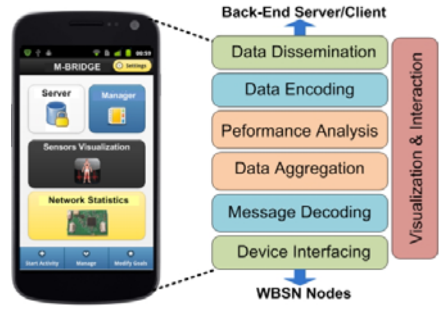

Figure 3. Layered modular software design of M-BRIDGE

B. Operation and Functionalities

Initially, "*Device Interface*" service runs automatically to check the connection status and, listens events from USB bus when phone is power-on. Upon connecting the integrated gateway, that service acquires and interprets the received messages in background. User can examine the status of services and manage their operations as well as WBSN nodes through respective UI similar to Fig. 6 (b). Depending on initial settings, decoded sensing data will be fused and processed in "*data aggregation*" service before uploading to cloud server or disseminating to connected clients. This bi-directional connectivity can be initiated from either M-BRIDGE or external applications via "*data disseminator*" service. After successful connectivity, data can be transferred as well as control can be issued to either M-BRIDGE or WBSN nodes. At every point of time, user can view either network or sensor statistics and, control any service or connection operation through respective UI.

As shown in Fig. 3, "*device interfacing and encoding*" module interact with WBSN basestation for parsing data and sending the serial data through UART interface. It is also responsible for bi-directional communication between WBSN and the rest of the system. "*Data aggregation*" transforms continuous small size data traffic received from multiple sensors to condensed large size data packet and encodes them into JSON format for exchanging contents with servers and other applications. Moreover, basic performance statistics of WBSN and wireless transmission profiles can also be computed. Then, "*data dissemination*" distributes encoded data to dedicated server(s) through available wireless connections such as WiFi/3G/LTE etc. As explained earlier, we adopt a minimalist approach of solving interoperability instead of using data standard like HL7, ISO/IEEE11073, etc. But such features can later be added as separate data encoding module. Finally, "*data visualization*" displays network performance statistics as well as sensor states and user's health information obtained from different sensors. This can be visualized inside single application or another application from the same phone or another application from another phone due to its flexible design.

Any of these functions can be run in either one or more phones due to its modular and extensible design and support from Android software design. Also, intelligent processing can partially be done at M-BRIDGE [14] instead of sending all data to remote servers or clients reducing amount of data traffic; thus enhancing energy efficiency and data reliability.

IV. System Design And Implementation

We develop M-BRIDGE prototype on Galaxy Nexus phone with Android OS ICS 4.0.3 installed using Java SDK and additional software libraries. Visualization and UI modules are developed in PhoneGap (http://phonegap. com/) and JQuery Mobile (http://jquerymobile.com) frameworks with Javascript/CSS programming. All developed software modules will be run as user-level applications and services.

A. WBSN Hardware Interfacing

Additional hardware interface is required to integrate WBSN system into target computing platform using USB interface. Initially, Gumstix (https://www.gumstix.com) platform was used with I/O extension but its form factor is bulky and it is not suitable to operate with battery. Secondly, IOIO (https://github.com/ytai/ioio/wiki) board was used to integrate with WBSN basestation. But additional hardware and external battery requirements affect the wearability and portability issues. Finally, WBSN basestation is directly connected to Android phone with USB Host enabled hardware interface. Comparison of important technical parameters among above options can be found in Table I.

TABLE I. Comparison among different Gateway Hardware

Parameter	***Gumstix***	***IOIO (Android)***	***USB Host (Android)***
Existing device	NO	YES	YES
Battery	Exteneral	External	Internal
I/O ports	Extensible	Extensible	Limited
Requires SDK	Yes	Yes	No
Complexity	High	Low	Medium

From this comparison, USB Host interfacing will be the best option as only miniature WBSN basestation is attaching to Android phone using USB OTG cable through micro USB port as shown in Fig 4(b). For both Gumstix and IOIO setup, additional hardware and bulky form-factor (7 cm x 3 cm) renders difficult to wear or attach them on the body over a long period of time. As WBSN basestation only draws current of 15mA in full operation, it does not affect much on obtaining power from the phone's battery via USB Host interface. Still, the major challenge faced here is to ensure energy efficiency as well as enhancing data reliability and quality relying on the personal smart phone.

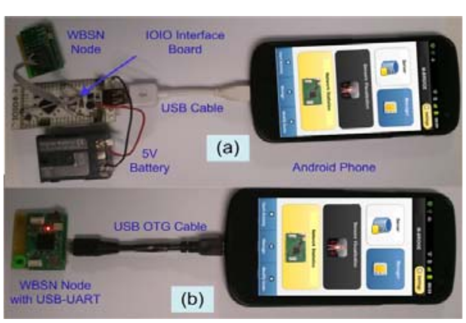

Figure 4. Different implementations of M-BRIDGE. (a) Android with IOIO using USB Slave (b) Android using USB Host

B. Data Acquisition, Aggregation and Dissemination

These functions are major software module of M-BRIDGE that communicates with WBSN and Cloud-based intelligent systems. Depending on application settings and user preference, it can be used from simple message relaying to data aggregation and complex data fusion tasks. The tradeoffs among energy efficiency, performance and reliability of these services can be easily configured through available service configuration and manager UI.

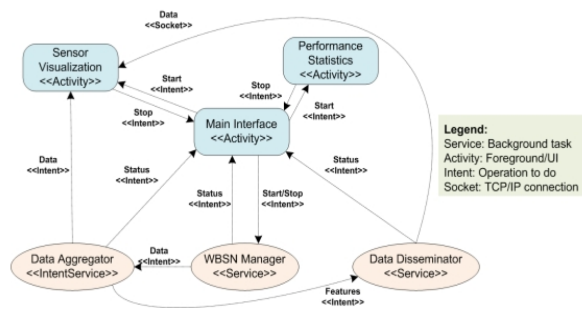

Figure 5. M-BRIDGE software components on Android

As shown in Fig. 5, time consuming and long running tasks are implemented as "Service" whereas the UI and visualization works as "Activity" according to Android platform terminology. So acquiring sensor data, data parsing or fusion and dissemination can continuously run without interrupting to user. But our design still allows users to manage such background services to activate or deactivate from their UI. As these exchanges can be specified using "Intent", other applications still can obtain data from background services enhancing extensibility and expandability of M-BRIDGE.

C. Visualization and User Interface

The status of the generic network statistics and sensor readings can be viewed through UI as shown in Fig. 6. Visualizing WBSN statistics such as message loss, active sensors, etc enable users to locally or remotely view and manage WBSN operations. Displays of user's health states according to sensing outputs allow users examining their health states in real-time. With flexible message exchange through Android-specific *Intents* and *events*, *Services* and *Activities* implemented in M-BRIDGE can communicate efficiently through either explicit user control or implicit detected events/situations as shown in Fig. 5.

Figure 6. Visualization screen shots: (a) Main user interface (b) Network statistics (c) Sensor listing.

Fig. 6 (a) shows main application screen that allows user to view different application states and to have full control of managing interfacing, aggregation and dissemination services. Users then examine status of available sensors, WBSN network performance and connectivity with server or client applications. Screenshots from Figs 6(b) and (c) show different sensors' states (active: green, inactive: red), data reliability as well as sensed user's physiological states extracted from respective sensors.

V. Evaluation And Discussion

A set of experiments were conducted to compare the performance among different gateways in a lab setting. In our setup, ECG, EMG, Galvanic Skin Response (GSR), Inertial Measurement Unit (IMU) sensors were continuously sampled data in 10-25Hz. The amounts of data transmitted in one packet vary according to individual sensors; e.g. 2 and 20 bytes data for GSR and IMU respectively. In this evaluation, we used worst case scenario of directly sending raw readings received from different nodes to Internet server through M-BRIDGE without any data aggregation or manipulation. The power consumption of Android is not taken amount to measure current consumption and all resultant current draw is only meant for integrated gateway expect for Gumstix. But the battery lifetime is measured for total operation time of M-BRIDGE inclusive of all hardware components. All tests use the same type of battery for powering Gumstix and IOIO boards.

TABLE II. Energy Efficiency and Performance Comparison

Measured Parameters	***Gumstix***	***IOIO***	***USB Host***
Current consumed (mAh)	200-240	75 – 90	20 - 30
Battery Lifetime (hours)	1.5	3.0	4.5

Another evaluation of how data fusion or aggregation at either WBSN or M-BRIDGE helps to reduce data traffic and enhance energy efficiency is working in-progress. In general, in-node processing that consumes less power than wireless transmission definitely improves its reliability, efficiency and lifetime. But the improvements achieved highly depend on sensor types, data transmission rate and application's criteria, etc that needs further validation with application specific scenarios.

Although multi-radio is natively supported, the pressing issue with Android phone is any active wireless transmission (WiFi/3G/LTE) draws at least 50-60% of total energy [13]. By selecting appropriate network connection automatically for energy efficiency [12] or offloading traffic to low-power network [11] can also improve energy efficiency. Currently, all service activation and control must be explicitly initiated by user. Besides these limitations, M-BRIDGE design has benefits of porting easily to any low-power custom hardware platform that can support Android. That makes our solution extensible and expandable to different usages without relying much on specific hardware platform [7, 8]. Another area is harnessing sensors from smart phone fused with physiological profiles detected from WBSN to identify reliable and accurate user health profiles. With growing interests of using smart phone as personal sensing platform [14], our solution can attract better attentions to further develop and evaluate its effectiveness in specific applications through clinical trials.

VI. Conclusion

The advantages of WBSN technologies in healthcare can be seen as one of the driving factors to shift from institution-centric reactive care to user-centric proactive care. This shift in personalized self-care paradigm brings benefits to users enabling continuous monitoring of their health and well-being. But there are still practical challenges to use WBSN solutions in day to day basis. So we proposed a portable and wearable onbody aggregator and visualizer system called M-BRIDGE to fully integrate WBSN into existing healthcare solutions. We believe the proposed WBSN framework with portable onbody gateway will play an important role in developing future innovative personal heathcare solutions.

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