On the use of Bluetooth in Body Sensor Networks

Mitko Petrov Shopov, Galidiya Ivanova Petrova, Grisha Valentinov Spasov

Abstract – **The paper presents an analysis of Bluetooth wireless technology and the new features around Bluetooth Health Device Profile (HDP) and low power operation mode. The advantage of introducing HDP and different optimization techniques in Body Sensor Networks are also discussed in the paper. The focal point of the analysis is the achievement of high interoperability and low power consumption. Finally, a use case scenario with Bluetooth-enabled medical sensors and mobile platform for patient monitoring is presented.**

Keywords – **BSN, Bluetooth, Health Device Profile**

I. Introduction

Recent advances in Information and Communication Technologies (ICT) and more specifically in wireless networks and mobile computing have driven new directions in the development of e-Health sector. New and emerging concepts like mobile health (m-Health) and Personal Health Systems (PHS) has become even more popular. Wireless body sensor networks (BSN) are one of the key components of these systems. They provide the means to sense, collect and communicate personal health data. A BSN consists of a set of wireless intelligent sensor nodes and a coordinating device. Several application areas can benefit from BSN networks – professional athletes, military, fitness and wellness, monitoring hospital, elderly, and chronic diseases' patients. At the moment, most of the research on BSN is concentrated on health-care applications because of the increased market demand and demonstrated need. Health-care costs are continuously increasing with respect to the rising percentage of aging population and people suffering from chronic diseases. Health-care quality is also not adequate to the current stage of technology development.

To achieve a wider adoption of BSN several research challenges has to be addressed first. Among the most important of them are the ease of use, interoperability, value, privacy and security considerations. Most of these challenges are directly or indirectly related to the wireless technology of choice for the communications within BSN. These include physical parameters, media access mechanisms, protocol stacks and application level protocols. In many research papers Bluetooth and ZigBee technologies are evaluated as the most prospective candidates [1], [2], [3].

M. Shopov is with the Department of Electronics, Faculty of Electronics and Automation, Technical University – Sofia, Plovdiv branch, 61 St. Petersburg Blvd., 4000 Plovdiv, Bulgaria, e-mail: mshopov@tu-plovdiv.bg

G. Petrova is with the Department of Electronics, Faculty of Electronics and Automation, Technical University - Sofia, Plovdiv branch, 61 St. Petersburg Blvd., 4000 Plovdiv, Bulgaria, e-mail: gip@tu-plovdiv.bg

G. Spasov is with Department of Computer Systems and Technologies, Faculty of Electronics and Automatics, Technical University – Sofia, branch Plovdiv, 61 Sankt Petersburg Blvd., 4000 Plovdiv, e-mail: gvs@tu-plovdiv.bg

Many health device manufacturers already use Bluetooth wireless technology in their product implementations. The most serious problem in the majority of these solutions is the lack of interoperability. Bluetooth technology provides only the wireless link, but the underlying data protocols and formats are proprietary. Different implementations even use different Bluetooth profiles: Serial port profile (SPP), Dial-up networking (DUN), Personal area network (PAN) and even Human device interface (HID) [4], [5], [6], [7], [8].

In an attempt to solve these interoperability issues Bluetooth Health Device Profile (HDP) [13] and ISO/IEEE 11073-20601 Personal health data exchange protocols has been proposed. HDP defines the underlying wireless connection and protocol and IEEE 11073-20601 defines application level protocol and data format.

In the paper an analysis of Bluetooth technology and its applicability in BSN networks is suggested. The accent is put on interoperability and power-save operation. HDP profile and different optimization techniques are discussed. Finally, a use case scenario with Bluetooth-enabled medical sensors is presented.

II. Body Sensor Networks

BSN is a network of wireless medical sensors around of or implanted in patient's body. While sensor data is often analyzed off-line, wireless sensors are essential for the ability to perform live queries and continuous monitoring of sensor output. BSN offers a platform to establish such health monitoring system. While BSNs share many of the challenges of wireless sensor networks, they also introduce some specific requirements and challenges that need further analysis and research such as: low power consumption, small form-factor, short range communications, data privacy requirements [2], [10].

BSNs often utilize hierarchical topologies with clearly separated master/slave functions. Master node is a dedicated device characterized with higher processing and communication capabilities that plays the role of a network coordinator. Wireless medical sensors are the slave nodes in the topology. They have a reduced functionality and therefore reduced size and power consumption.

Wireless communication plays essential role in BSN. Both standard and non-standard communication protocols exist. Standard protocols are preferred because of the interoperability and integration issues within products of different vendors. Among standard communication protocols Personal Area Networks (IEEE 802.15) more closely cover the specific requirements of BSN. Many research efforts are concentrated on Zigbee (IEEE 802.15.4) as a communication technology to base BSN on [9]. This is understandable since BSNs share many of the characteristics of sensor networks that Zigbee is designed for. Bluetooth (IEEE 802.15.1) on the other side, is still preferred in many commercial and research projects for several reasons. The first is that Bluetooth is a mature technology, meaning that both developers and consumers are familiar with and it is also integrated in most modern mobile devices. Secondly, Bluetooth offers higher data rates than Zigbee and for some applications with heavy bandwidth demands like ECG it could consume lower energy per bit [11].

II. Bluetooth and BSN

Started as a cable replacement technology Bluetooth has gone a long way to achieve its current state of supporting applications. The interoperability has been achieved through specification of profiles for particular application. The most used profile for integration of sensor nodes within BSN is Serial port profile (SPP), used to create a virtual serial port between two devices. Other general purpose profiles are also used – DUN, PAN and HID. These profiles do not address specifics of BSN, nor they define the needed for interoperability unified protocols and data formats. In an attempt to solve this, Bluetooth HDP and associate protocols and specifications have been proposed. They will be presented in the next lines. Another issue of high concern in BSN design is the power consumption. This has been addressed by the Ultra Low Power (ULP) Bluetooth standard, adopted from Wibree – a standard initially started from Nokia.

A. Multi-channel adaptation protocol (MCAP)

MCAP [12] is a simple communication protocol working on the top of Logical link control and adaptation protocol (L2CAP) from the Bluetooth protocols stack. The main features of MCAP are:

- It provides structured management of a group of related channels between a given pair of devices. These include one *control channel* and zero or more *data channels*.
- Permits multiple simultaneous data channels. Data channels can work in either of enhanced retransmission mode or streaming mode and are called *streaming data channel* and *reliable data channel* respectively.
- Defines standardized Clock synchronization protocol (CSP) to coordinate local clocks. Precise timing synchronization is necessary for applications such as correlated high speed medical sensors.
- Associates context identifier with connections permitting reconnection of the link to the previous state if required memory to preserve state is available on both devices.

MCAP is designed to be used together with Bluetooth HDP.

B. Health device profile (HDP)

The health device profile (HDP) is an application profile that defines the requirements for qualified Bluetooth healthcare and fitness device implementations. This profile is used for connecting application data *Source* devices (pulse oximeters, blood pressure monitors, glucose meters, etc.) to application data *Sink* devices (mobile phones, laptops, desktop and dedicated health appliances). HDP provides a number of advantages over other more general profiles [13]:

- Defines interoperability requirements for health-related applications.
- Provides provisions for application level interoperability by operating with ISO/IEEE standards for personal health data exchange protocol and device data specialization.
- Integration with Bluetooth service discovery protocol (SDP).
- Connection-oriented to ensure reliable detection of out-of range and disconnect conditions.
- Permits multiple simultaneous Data Channels.

The HDP is based on MCAP communication protocol and uses new L2CAP features – enhanced retransmission mode, streaming mode, frame-check sequence (FCS). The full dependency model of the HDP is presented on figure 1.

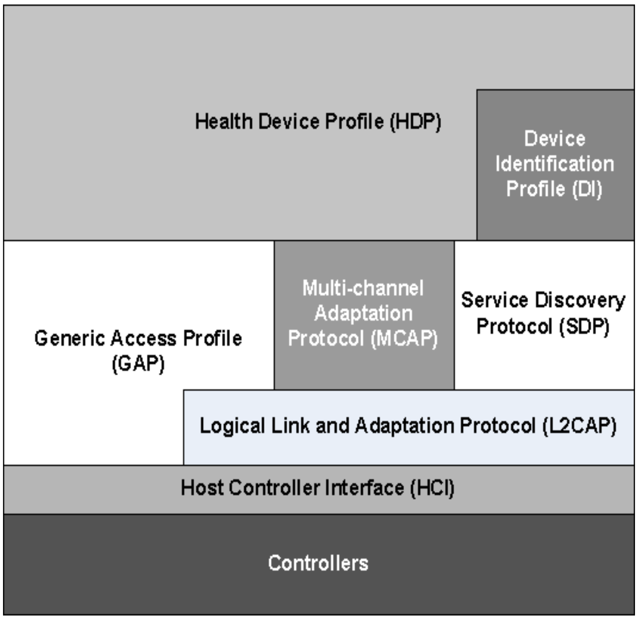

Figure 1: HDP dependency model [13]

C. ISO/IEEE 11073

ISO/IEEE 11073-20601 Data Exchange Protocol standardizes a framework of object-oriented information modeling, information access, data representation and a secure transport of medical data. The protocol addresses interoperability issues between data management devices. It includes provisions to achieve maximum benefit from HDP features like temporal disconnect/reconnect, multiple data channels and streaming, and reliable data connections. ISO/IEEE 11073-104xx Device Data Specialization is a collection of specifications that provides details on how Data Exchange Protocol is implemented for a concrete health device. Although HDP could be implemented with any data exchange protocol, the current specification includes only IEEE 11073-20601. The full HDP application model is presented on figure 2.

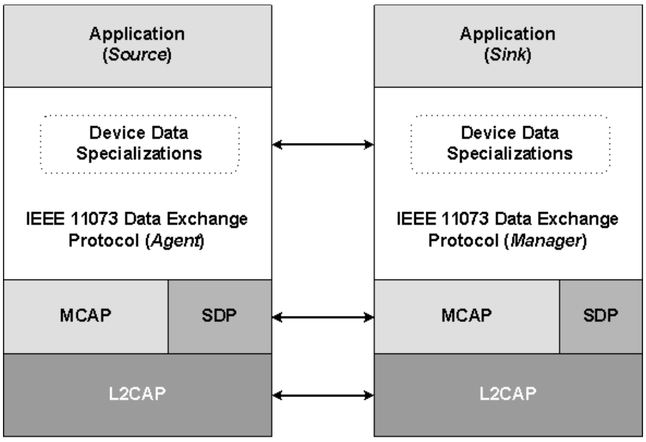

Figure 2: HDP application model [13]

D. Bluetooth and Power management

Power consumption is a critical parameter in BSN and power management techniques to reduce consumption are essential for a proper BSN design. Bluetooth offers several power-saving features that BSN nodes could benefit from.

Reconnection is a feature that allows two devices that implement HDP to reconnect previously established MCAP link, skipping redundant reconfiguration steps and thus reducing the number of bytes sent. In BSN this feature is particularly useful because of its typical operation – sensors send measurements and then disconnect and turn-off radio part until next measurement period.

Sniff mode operation is another power saving feature. It allows two devices to negotiate periods of time during which no data packets will be exchanged. This allows the receiver to turn-off its radio for the negotiated period. Sniff Subrating extends sniff mode operation by allowing dynamic alteration of time between transmissions initiated by either device.

Enhanced data rate (EDR) is a feature that could be used to reduce transmission time. It is useful for applications that require large amount of data to be transmitted. However, using EDR with small data packets could potentially increase transmission time. Since most of the data exchange in BSN is of the second type, the use of EDR is limited to few more demanding applications.

E. Continua Health Alliance

Continua Health Alliance [14] has the mission to ensure interoperability between health monitoring devices from different manufacturers. Continua *Version One Design Guidelines* recommend protocols, specifications and configuration parameters for secure transport of sensor data over wireless Bluetooth or USB links and standards for records representation. These guidelines define use cases for monitoring devices and specify compliance with Bluetooth HDP and IEEE 11073.

III. A use case scenario

This section presents a use case scenario for realization of a BSN based on Bluetooth communications. The proposed architecture is shown on figure 3 and consists of a BSN, a BSN coordinator and medical services. The BSN consists of various health sensors with Bluetooth interface and support to HDP profile. Sensor implementation could vary from stand-alone sensors (one sensor measures one physiological parameter) to combined sensors and health stations combining multiple parameters in one device. The BSN coordinator could be a mobile device – smart phone, PDA, laptop or desktop computer and custom designed health station.

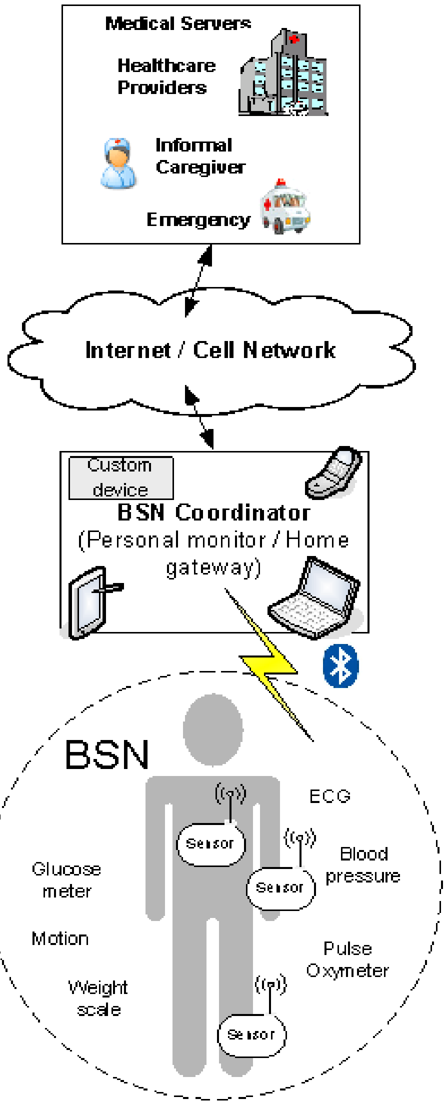

Figure 3: The use case architecture

Depending on the sensor type and particular application, different configuration of MCAP/HDP will be required. Measurements of blood pressure and weight do not need additional streaming data channel, while measurement of pulse-oximetry, ECG and combined sensors could benefit from balancing data exchange between one or more reliable data channels and one or more streaming data channels.

An example implementation for monitoring pulse and oxygen saturation is realized based on the suggested use case scenario. It consists of a Bluetooth pulse oximeter sensor Onyx II 9560 from Nonin [16] and a mobile phone that acts as a BSN coordinator. Onyx II 9560 implements Bluetooth HDP profile and IEEE 11073 standards and is Continua certified.

The implementation of the client application uses BlueZ – an open source Bluetooth protocol stack for Linux and MCAP/HDP patch provided by OpenHealth project [15]. Two programs are written – one in Java for mobile phone with Android and one in Python for iDigi Wi-9P Embedded Gateway [17] that comes with Python based framework. The sensor supports MCAP/HDP reconnection features and disconnects after sending measured data. Since coordinator application also supports reconnections and state sustentation, the unnecessary step of connection reconfiguration is omitted allowing for power efficiency and prolonging of the battery life. A test with reconnection feature disabled at the coordinator side results to reconfigurations of both MCAP connections and IEEE 11072-20601 data layer. Figure 4 presents the logs from a sample MCAP/HDP session with the pulse oximeter sensor.

```
HDP: New mdep 1
HDP: Starting up
set_sock_options: Mode 3, fcs 1
set_sock_options: Mode 0, fcs 1
MCAP: session thread -1218544752 running
HDP: handle 0xa71aa719
HDP: found 0 previous features
HDP: finally 1 features
HDP: Waiting 0 seconds
HDP: Waiting
HDP: Finally one found 0x3001
HDP: SDP Service record 0x20048
MCAP: Control Channel 3 created with 00:1C:05:00:18:EA
process_request_connected: MCAP_MD_CREATE_MDL_REQ received
HDP: Channel accepted
HDP: New channel connected
MCAP: Data Channel 4 created with 00:1C:05:00:18:EA
HDP: Waked up
HDP: Data Channel created successfully
HDP: Receive
HDP: Received 48 bytes
process_request_disconnected: MCAP_MD_DISCONNECT_MDL_REQ received
MCAP: Disconnected with 00:1C:05:00:18:EA
```

Figure 4: MCAP/HDP connection’s logs

IV. Conclusion and Future work

The paper presents an overview of Bluetooth technology and its place in the design of Body Sensor Networks. An analysis of Bluetooth Health Device Profile, its features and capabilities is also presented. Based on that analysis a use case scenario is suggested and an example implementation with a Bluetooth sensor and a mobile phone for measurement of pulse and oxygen saturation is described. These preliminary results will be used as a basis for future development of health sensors implementing HDP, both actual and emulated.

Future work includes comparable analysis of sensors implementing HDP and SPP Bluetooth profiles in terms of data transfer speed, consumed energy, supported applications and interoperability. Another area for future work includes comparative analysis of Bluetooth ULP and ZigBee, since both have theoretically similar energy consumption parameters.

V. Acknowledgments

The presented work is partially supported within the project *BG 051PO001-3.3.04/13* of the HR Development OP of the European Social Fund 2007-2013 and Technical University of Sofia, project “*102ПД078-19/2010*” – entitled “Experimental environment for analysis of protocols and processes within web-based multi-tier personal health-care systems”.

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