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A Comparative Analysis of BLE and 6LoWPAN For U-HealthCare Applications

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Abstract— **For decades, there exist a variety of low-power wireless technologies deployed for healthcare applications such as Zigbee/IEEE802.15.4, Bluetooth, ANT, NFC, IrDA. However, the recently announced Bluetooth Low Energy (BLE) technology claims to offer many new compelling features and is expected to get wide adoption by many mobile manufacturers around the world and hence be included in daily life mobile devices. Therefore, it is important to provide future adopters with a thorough yet insightful evaluation of this technology as contrasted to competing ones in the market today. In this paper, we present such evaluation from an experimental point of view as well as referring to technical specifications from manufacturers. The discussion is geared toward assessing the extent to which theses technologies can meet the stringent requirements for u-healthcare applicability. BLE and 6LoWPAN showed greater potentials for such applicability in terms of power demand, bit rate and latency. Nevertheless, BLE was found to be most robust to obstacles and was operable using single coin cell.**

Keywords—U-healthcare system, BLE, Zigbee, IEEE 802.15.4, 6LoWPAN.

I. INTRODUCTION

U-Healthcare systems require key technologies for handling the challenges of the growing population around the world suffering from chronic diseases. This is due to the fact that these diseases require continuous monitoring rather than episodic assessment. A typical architecture of the ubiquitous healthcare system is shown in the Fig. 1 below.

From Fig. 1, it is evident that there exist various challenges that range from the design of Low power wireless sensor nodes for the acquisition of sensed data to the design of an energy efficient gateway and finally to the design of database applications at remote servers that will make the real-time remote monitoring possible while saving patients' data to medical records for future diagnostics and processing. The overall picture is even wider than what Fig. 1 shows if we dive into the details of data channeling from the collecting base station to the remote server.

A brief summary of the requirements in hardware and software related to design of wireless body area network (WBAN) nodes is presented in Table I [1,2]:

TABLE I: HARDWARE AND NETWORK REQUIREMENTS FOR WBAN

Hardware Requirements	Description
Ultra-low power consumption	• The hardware designed should dissipate less heat to the body. • Sensors with very less power consumption can harvest the body power such as heat, motion etc.
Wearability	Sensors shall be comfortable from wear-ability point of view. Should not hinder or encumber the person's daily life activity
Lifetime	long battery longevity (strict requirement especially for implantable sensors).
Low cost	to allow widespread usage.
Network Requirements	**Description**
Data Rate	WBAN data rate requirements range from 10kbps to 10Mbps.
Number of sensors per network	BAN standardization states a maximum of 256 devices per network.
Network density	BAN standard: 2-4 networks per meter square, assuming people can wear sensors that have 2 different networks.
Interference	Interference suppression required.
Range	A range of 2-10 m is expected since BAN sensors are found around the body and may be required to a nearby collection device.
Latency/Quality of Service	Latency must be inferior to 125 ms for medical and 250 ms for the non-medical application.
Compatibility with other PAN	The signal in WBAN has to propagate through human tissue so wireless transmission must be designed while taking into account properties of such a medium (e.g., specific absorption rate (SAR), path loss and propagation properties).
Security/Encryption/Data integrity	Transmitted data needs to be protected and integrity of received signal should be maintained.
Mobility	Must be able to handle mobility in case patient is moving outside his home or inside hospital/home environment.

There exists a variety of low-power wireless technologies available in the market (e.g, BLE, Zigbee, IEEE802.15.4, IrDA, NFC and ANT) that at first glance look obvious solutions. Several reviews covering the state-of-the art and current challenges facing these technologies when applied to u-healthcare systems can be found in the literature [3-6].

In this paper, we are presenting a systematic comparison between traditional and emerging technologies oriented to the support of low-power, low-energy devices in the context of u-health applications. In coming sections, we will compare the

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main technologies (i.e., BLE, IEEE802.15.4, IrDA, NFC and ANT, etc) according to three performance metrics (from Table I), namely, power requirement, throughput, and latency. We have found these to be most critical, and the remaining like security, compression and wearability revolve around these 3 main pillars.

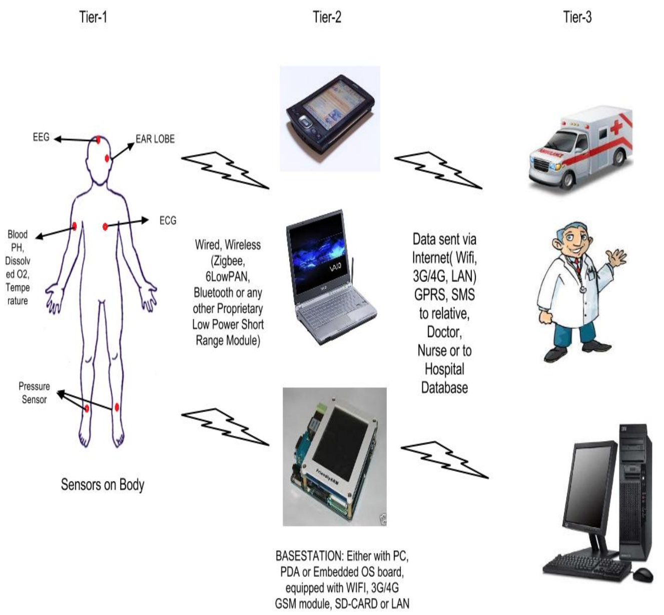

Fig. 1. Block diagram of U-Healthcare system [3]

II. Criteria for Coin Cell Battery (Peak Power Current)

The peak power current determines whether the technology is operable using a coin cell or not. The most commonly used coin cell that exists in the market is the CR2302 by Texas Instruments which is capable of providing the peak current of 15mA. Table II summarizes the peak currents of traditional and emerging technologies.

TABLE II COMPARISON OF PEAK POWER REQUIREMENTS FOR VARIOUS TECHNOLOGIES

Technology	Maximum Peak Current	Operable Using CR2302 Coin Cell
BLE	12-15mA [7]	Yes
ANT	17mA [9]	Yes
IrDA	10mA [10]	Yes
NFC	50mA [11]	Operable but demand is too High will drain battery instantly
Zigbee (IEEE802.15.4 based) Peak Current	30-40mA [12]	Operable but demand is too High will drain battery instantly
IEEE802.15.4 based mote (CC2420 Radio)	Tx/Rx = 18.8 mA/17.6mA [13-14]	Usually requires an external Controller so peak current may rise.

From above table BLE, IEEE802.15.4 based motes, ANT and IrDA technologies seem to be less power consuming when compared to Zigbee, and NFC.

III. Air Data Rate and Actual Throughput

The air data rate that is usually specified with the available technology is different from the actual throughput. Table III depicts the air data rate and throughput of each technology.

TABLE III COMPARISON OF AIR DATA RATE AND ACTUAL APPLICATION THROUGHPUT

Technology	Air Data Rate	Application Throughput
BLE	1Mbps[7,8]	305Kbps
ANT	1Mbps [9]	20Kbps
IrDA	1Gbps [10]	100-200Kbps
NFC	424Kbps [11]	424
Zigbee	250Kbps[15]	100Kbps
IEEE802.15.4 based motes	250Kbps [14]	Ranges from 10Kbps-200Kbps depending upon configuration

From above table it's obvious that IrDA and NFC offer more air data rate when compared to BLE, ANT, Zigbee and IEEE802.15.4. However IrDA and NFC require line of sight.

IV. Latency

Latency can be defined as the difference between the time at which the data was sent to the time when it was received by the end user. Latency is a very critical issue for healthcare applications and must be inferior to 125ms as suggested in the literature [1, 2]. A comparison of the latency for each of the above mentioned technologies is presented in Table IV.

TABLE IV COMPARISON ON LATENCY REQUIREMENTS OF SHORT RANGE TECHNOLOGIES

Technology	Latency Offered	Meets Desired Latency Requirements of Less than 125ms
BLE	2.5ms [8]	Yes
ANT	Zero [16]	Yes
IrDA	25ms [10]	Yes
NFC	Its manufacturer Specific	Yes
Zigbee	20-30ms [15]	Yes
IEEE802.15.4 based motes [13-14]	Depends Upon mode of device can range from 2-50ms	Yes

From the performance metrics data of peak current, latency and throughput presented in Tables [III-IV] above, it seems like each of the technologies is adequate to u-healthcare applications which is misleading. For instance, IrDA requires line of sight conditions along with a target within less than 1m. The same applies to NFC, hence both are eliminated. BLE, ANT and ZigBee (IEEE 802.15.4 based) standards are considered suitable for sensor networks, since they possess many flexible parameters that can be adapted to suit many low-power applications. BLE and ZigBee provide a better coexistence with other wireless standards (such as WiFi) in their vicinity than ANT since BLE uses Frequency hopping

(FHSS) while ZigBee uses Direct Sequence Spread Spectrum (DSSS), which both minimize interferences, with nearby RF services. ANT has interference problem it uses TDMA with very small time slots and monitors channel interference, using a technique called adaptive isochronous networking. This scheme works well within ANT enabled network devices, but can cause fails in the presence of other technologies, since it offers weak coexistence features. Nevertheless, frequency agility feature may help ANT devices to hop to a different carrier frequency which can cater for interference.

Beyond this point, we will focus only on IEEE802.15.4 (Zigbee and 6LoWPAN), and BLE. Section V explains Zigbee and 6LoWPAN stacks, section VI gives a detailed introduction of the BLE stack, section VII presents a thorough comparison between BLE and 6LoWPAN substantiated withexperimental results by the authors, and finally section VIII concludes the paper.

V. ZIGBEE AND 6LOWPAN (IEEE802.15.4 BASED) STACKS

IEEE802.15.4 is a standard for low power personal area networking by 802.15 Working Group for wireless personal area network (WPAN) [17]. It operates in 16 channels over 2.4GHz industrial, scientific and medical (ISM) band (at 250kbps), in 10 channels over the 915MHz band (at 40kbps) and in one channel over the 868MHz band (at 20kbps). It supports features such as low-power consumption, security, auto networking, and 16-bit/64-bit addressing mode. It also provides two modes for multiple access which include CSMA/CA or synchronized channels access based on a beaconing mechanism and direct sequence spread spectrum coding (DSSS).

Various proprietary networks and application layer protocols operating on top of IEEE802.15.4 have been proposed by various vendors, where Zigbee was the most widely adopted one. Zigbee is the name of the standard which provides support at network, security and application layer on the top of IEEE802.15.4. It also makes use of AES algorithm with 128-bit keys to guarantee message integrity and privacy to perform authentication. It has been widely deployed in the automation industry, agriculture industry and also in some cases in health-related projects. However, there are many WSN research projects that are based on IEEE 802.15.4 chips that do not employ the Zigbee protocol stack either because networking capabilities are not mandatory, or because researchers are interested in devising more appropriate protocols for their application specific requirements.

In an effort to provide best and optimal design on top of the IEEE802.15.4, and researchers designed a variety of application-specific protocols. With several techniques built on the top of IEEE802.15.4, there is no single standardized solution available; hence the interoperability of the WSN remains a challenge. To address this issue, an effort to standardize the design of the network layer, using the IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) specification effort has recently started. 6LoWPAN is an International Open Standard developed by the IETF that enables building the Wireless "Internet of Things (IoT)", using IEEE802.15.4 and IP together in a simple well understood way. It enables the efficient use of IPv6 over low-power, low-rate wireless networks on simple embedded devices through an adaption layer and optimization of related protocols [16].

There are huge benefits associated with IoT. These include interoperability, the use of existing infrastructure, tools for managing, established commissioning and diagnosing IP-based networks. Also, IP technology encourages innovation and is better understood by a wider audience. Since IP technology is not optimized for PAN but can be adapted to make perfect use of WSN with internet and this is what 6LoWPAN does; denominated as IoT protocol. Key features of 6LoWPAN include efficient header compression, network auto configuration using neighborhood discovery, unicast multicast and broad cast support, fragmentation, support for IP routing using RPL [17] (Routing Protocol For Low Power Lossy Networks) and support for link layer mesh (e.g. 802.15.4). Typical Stack of 6LoWPAN is shown in Fig. 2.

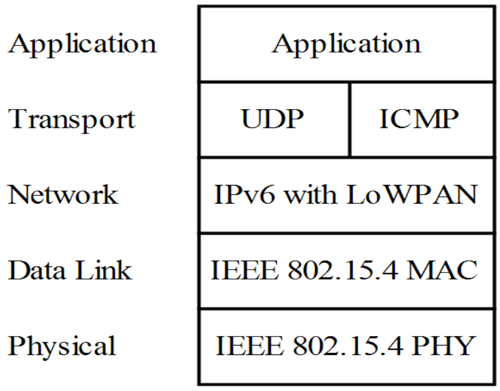

Fig. 2. A typical stack of 6LoWPAN

VI. BLUETOOTH LOW ENERGY (BLE)

Although the IEEE802.15.4 has been adopted by the various researchers and developers in a variety of their hardware device, however, still this technology has never been integrated in mobiles. BLE as mentioned before is an emerging new low power wireless technology that is developed for short-range monitoring and control applications and is expected to be included in billions of devices worldwide in next few years. Like for IEEE802.15.4 where there are tradeoffs to be considered between the amount of data to be transmitted, network latency, network size and throughput, similar tradeoffs may also be considered for BLE. BLE provides a single-hop communication which enables its applicability to various healthcare, consumer electronics, and smart energy and security applications. Moreover the IETF 6LoWPAN Working Group (WG) has realized the importance of BLE in IoT and is considering a draft regarding specification on how to transmit IPv6 packets over BLE [21].

A typical BLE stack consists of 2 major parts one is called the controller part while the other is called the host part. Controller part usually consists of the Physical and Link Layer (implemented in the form of a SoC (System-On-Chip) with an integrated radio) while the host part runs on an application processor and includes upper layer functionality consisting of Logical Link Control and Adaptation Protocol (L2CAP), the Attribute control (ATT), the Generic Attribute Profile (GATT), the Security manager Protocol and Generic Access Profile (GAP). The communication between the host and the controller part is standardized as the Host Controller Interface (HCI). Fig. 3 depicts the block diagram of BLE protocol stack.

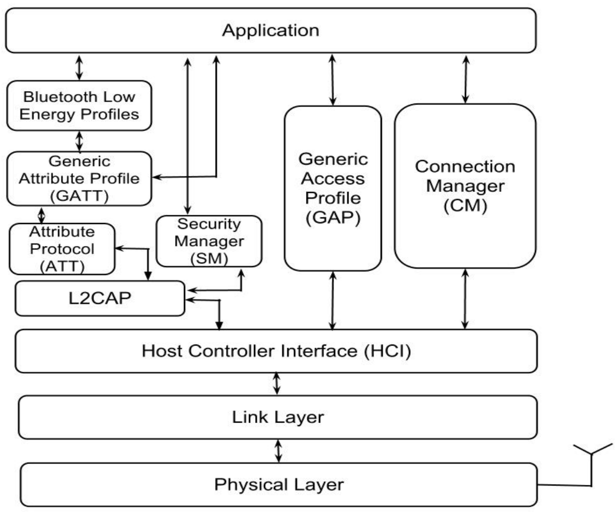

Fig. 3. A BLE protocol stack [20]

BLE stack consists of the Physical Layer that operates at the frequency of 2.4GHz and makes use of around 40 channels that are 2MHz apart. There are 2 types of channels for BLE devices: advertising channels and data channels. Advertising channels are used for advertisements related activities, device discovery, broadcast and connection establishment, while data channels are used for transferring data between devices. In BLE, there exists an 'advertiser' node that transmits advertising packets through advertising channels at a precise time intervals referred to as advertising events, and a 'scanner' node that acts to receive data using the advertising channels. BLE devices first need to connect to each other before they begin a reliable two-way data communication. The connection between the two devices is an asymmetric procedure in which the advertiser transmits advertisements packets through advertising channels, whereas the other device that is the initiator that listens for these packets. Upon receiving those packets, the initiator transmits a connection request message to the advertising device which allows a connection to be established, thus enabling a point to point link between both nodes.

The Link Layer in BLE defines the devices as either a Master or a Slave, which act as initiator and advertiser, respectively, during connection establishment. A Master can connect to as many slaves as possible, thus forming a star network. In basic routine operation, slaves get into sleep mode and turn themselves on, periodically, to listen for any packets from the Master. It is the Master, usually, who determines the sleep/wake-up periods of the slaves.

BLE uses a lighter version of the Logical link control and adaptation protocol (L2CAP) that was defined for the classic Bluetooth. The main task of the L2CAP is to take care of multiplexing data from the three higher layer protocols, Attribute Protocol (ATT), the Security Manager Protocol (SMP) and Link Layer control signaling, onto a Link Layer connection. In this context, the L2CAP offers a best-effort endeavor to get the data of these services transmitted to the next hop without using retransmission and flow control mechanisms available in earlier Bluetooth versions. Another feature that is dropped from earlier Bluetooth version in the BLE L2CAP is segmentation and reassembly under the assumption that higher layer protocols provide PDUs that fit into the maximum L2CAP payload size, which is equal to 23 bytes in BLE [20].

VII. COMPARISON BETWEEN BLE AND 6LOWPAN

Both BLE and 6LoWPAN are strong competitor technologies. Although 6LoWPAN has been widely tested in various projects, BLE offers more compelling features in some aspects also the 6LoWPAN WG is considering a draft regarding the specification for the transmission of IPv6 packets over BLE [21]. A quick comparison of the BLE with 6LoWPAN is shown in Table V.

TABLE V THOROUGH COMPARISON OF IEEE802.15.4 AND BLE

Technology	**IEEE 802.15.4/6LoWPAN**	**Bluetooth Low Energy (BLE)**
Radio Frequency	868MHz, 915MHz, 2.4GHz	2.4GHz
RF Data Rate	250Kbps	1Mbps
Distance	10-200 meters	10 to 100m (Typical)
Peak Current Consumptions	< 15mA	<15mA
Application Throughput	< 0.1Mbps	0.2Mbps
Network Topology	Star or Mesh	Star-bus
Robustness	DSSS, Uses 16 Channels ISM (2.4GHz) band only.	Adaptive Frequency Hopping
Certification Body	IETF/ Open Source	Bluetooth SIG
Security	128b AES and application layer user defined	128b AES and application layer user defined
Suitable For WBANs	Suitable for applications with low data rate and on-body sensors	Suitable For applications with Medium Data Rate and on-body sensors
Vulnerable to attacks	Less	Less

BLE and IEEE802.15.4/6LoWPAN are close competitors when considering general low power applications. BLE market is expected to expand rapidly compared to IEEE802.15.4. Although IEEE802.15.4 has been widely tested in various healthcare applications, it has not been integrated in any of the mobile or laptops so far.

The authors have developed a complete U-healthcare system using 6LoWPAN and BLE to send ECG signals at different rates using an ECG simulator [22-23]. The systems are capable of sampling the simulator data from the sensor node and forward it to the gateway. The gateway application receives the data from the sensor node wireless and forwards the data to a LabVIEW based TCP client to enable remote monitoring. For 6LoWPAN, we used the contiki stack and adjusted the channel check rate parameters such that the latency remains inferior to 125ms as defined in Table I. Moreover, the Latency in BLE depends mainly on the number of the nodes in the network. In the current work[20], we used a single node resulting in a latency of around 7.5ms and hence was in the acceptable range (< 125ms). The ECG signal was displayed using the high-resolution scope directly from the ECG simulator and remotely via 6LowPAN and BLE over LabVIEW. The results in both cases revealed no difference as shown in Fig. 4. More insights of this work can be retrieved from [22, 23].

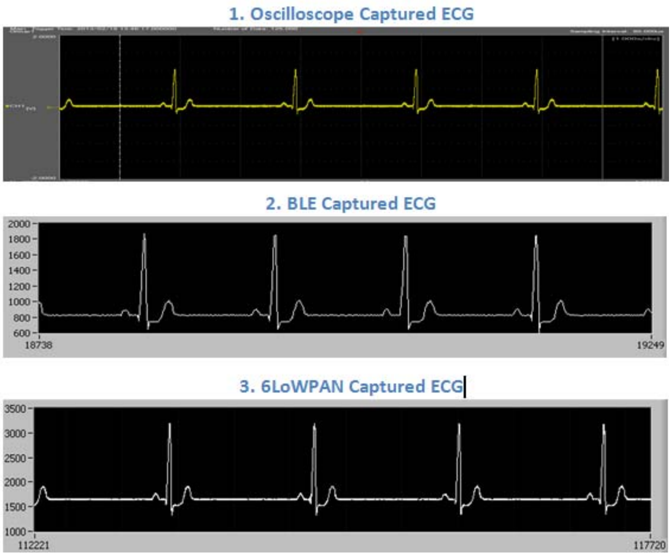

Fig. 4. Comparison of Scope Captured ECG Simulator data with remote LabVIEW captured 6LoWPAN and BLE data

The results indicate that both technologies are well suited to u-healthcare applications with differences in performance. We are currently working towards a thorough evaluation of both technologies and will describe complete analysis in our future publications. Evidently, 6LoWPAN is more efficient in interoperating with IP-based applications which are tremendous. Nevertheless, a clear drawback encountered with 6LoWPAN is that it showed more vulnerability to obstacles when compared to BLE. In contrast to BLE, our results revealed that 6LoWPAN signals faded out quickly and the connection gets lost for any obstacle obscuring transmitter and receiver. This is of paramount importance for applications such as WBAN where obstacles like clothing permanently exist. We believe the combination of BLE and 6LoWPAN that the IETF is considering will solve a lot of problems encountered with both technologies and thus produce a new technology expected to be very efficient for low-power, short-range, IP-based applications.

VIII. Conclusion

This paper discussed and compared various short-range wireless technologies targeted for low-power personal area networks for u-healthcare applicability. It was concluded that 6LoWPAN and BLE are superior in meeting the stringent requirements imposed by wireless body area network which is central to u-healthcare systems. This constitutes the basis on which the IETF is currently considering both standards in order to communicate 6LoWPAN packets over BLE protocol. This would foster solving the problem of excess vulnerability of 6LoWPAN toward obstacles that was the first time pointed out by the authors. Moreover, a thorough study of the stacks of both technologies was presented in order to help designers and engineers grasp the main differences between them.

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