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Survey of Popular Networks Used for Biosensors

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Abstract

Miniaturized electronic components, improvements in Micro-Electro-Mechanical Systems (MEMS), have made realization of biosensors possible. Providing interconnectivity to these devices has made even more applications possible. Today biosensors are being used in many applications ranging from detection of biological agents to soil monitoring. Among others, health applications are likely to benefit most from networked biosensors. Since standalone sensors like biosensors have certain limitations, the network providing interconnectivity to these devices needs to be selected carefully. In this paper we would like to review different networks used for connecting biosensors pointing out popular applications for each one.

Keywords: Biosensors Network, Communication system standards

Introduction

Biosensors are physiological devices that sense biological & chemical events.Currently biosensors are being used for applications like environmental monitoring, biological/chemical agent detection, soil monitoring, food and water analysis, and medical parameter monitoring. A typical biosensor converts one or more chemical or biological parameters into electrical form which can be read by a tiny microcontroller onboard the sensor. Once the information provided by the sensor is understood, the next step is sharing this information with others. Typical biosensor applications need to transfer small amount of data where thedata transfer rate ranges from low to medium speed. Since in most cases biosensors operate as stand-alone units, power is typically supplied through batteries. Having limited battery life, power consumption is regarded as a very critical issue in such applications [1]. Being so critical, power budget aspect of stand-alone sensors is studied extensively by many researchers. Previous studies indicated that most of the power consumption is due to the transceiver part of the unit which provides connectivity. One such study indicates that almost 50% of the power consumption is done by the transceiver. Out of this 50%, 80% of it is consumed by the receiver section [2]. This indicates how critical it is to select a suitable network with suitable protocol to minimize power consumption for biosensor applications.

A typical biosensor is made up of transducers and electronic systems. Transducers are converters that change desired biological parameter into electrically readable form and they may be optical, electrochemical, thermometric, piezoelectric, or magnetic [3]. Other electronic systemsinside a biosensor typically include a signal amplifier to strengthen the power of the transducer signal, a processor to perform required operations and a display to present the measured value [4].

Among all other possible applications, medical applications are expected to be the most popular applications for biosensors in the near future. Going wireless may increase usage and number of applications significantly. Non-tethered nature of wireless biosensors simplifies data collection from subjects. Going wireless not only simplifies data collection from subjects but also makes it physically practical to “wear” these sensors. Practicality of the usage is a significant factor considering the aging population.The vital signals and health status of a person can be monitored by using biosensors [5]. It not only provides ability to monitor health status remotely, but also opportunity to improve the quality of life by delivering medicine on time when needed.Because of that, it is likely that popularity and applications of biosensors is expected to increase over time.This paper intends to concentrate on medical applicationsof biosensors and gives examples of existing applications.

Communication systems used for biosensor networks

As it was mentioned in the previous section, the selection of network standard is an important decision when setting upa biosensor network. In this section we will be reviewing different network standards suitable for setting up biosensor networks while presenting application examples of each one.

Zigbee protocol (IEEE 802.15.4)

The IEEE 802.15.4 standard is developed for Low-Rate Wireless Personal Area Networks (LR-WPANs) that defines physical and MAC layer protocols of lower layers of OSI reference model.The basic features of this standard are: low-throughput, low energy consumption, low cost and reliable data transfer [6].

The standard works in designated frequency bands of 2.4 GHz, 868 MHz and 915 MHz with threedifferent types of data rates ranging from 250 kbps, 40 kbps, 20 kbps. It also has multi-channel based infrastructure and has transmission distances ranging from 10 to 100 meters. Contention-based medium access and contention-free access is available for standard. TDMA and CSMA-CA or ALOHA mechanisms can be used [7]. Figure 1 shows the superframe structure of standard.

Zigbee networks are made up of coordinator, router and gateway nodes. Coordinator node transmits periodic beacons at the beginning and the end of superframe. CSMA-CA or ALOHA method is used in Contention Access Period (CAP). After that, TDMA method is used in Contention Free Period (CFP). The number of guaranteed time slots (GTSs) are limited with seven. Nodes are passive in sleep mode (inactive period). This type of network is reported to be used for connecting electroencephalography (EEG) sensors, a blood pressure sensor, electrocardiography (ECG) sensors, wireless watch, a

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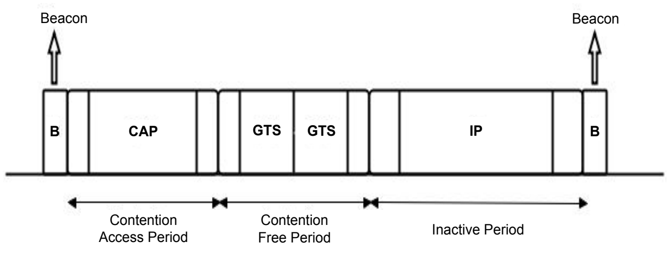

Figure 1: IEEE 802.15.4 super frame structure

glucose sensor,electromyography (EMG) sensors, and motion sensors (accelerometers/gyroscopes) on ahuman body wirelessly through a smart phone [8].

There are many Zigbee-based application instances developed such as; Code blue project [9], which is developed by Harvard University, collects patient's physiological dataand shows the status of patient. The BASUMA (Body Area System for UbiquitousMultimedia Applications) project [10] aims to real-time monitoring of thepatient's health statusat outdoor environment. BSN Earpiece [11] is also another project which implements a monitoring system for indoor environment. The Fire Informationand Rescue Equipmentproject [12] is emergency application for fire fighters which is developed by University of California at Berkeley. The Great Duck Island project [13] is about large scale habitat monitoring application. Lin and Tseng developed mobile object tracking system [14] that is an example of tracking systems.

There are currently commercial ZigBee applications using 10's of thousands interconnected nodes. The technology is quite mature and there is currently dozen of commercial manufacturers manufacturing ZigBee chips. ZigBee components can be purchased as stand-alone chips which can be interfaced into any commercial processor or can be purchased as System-on-Chip (SoC) which comes in the form of a processor with embedded ZigBee capability. SoC applications typically provide the smallest and most inexpensive route to integrating ZigBee into an application. Recently added "green power" feature to Zigbee uses so little power that, the needed power can be harvested from surrounding without really requiring battery.

Bluetooth protocol (IEEE 802.15.1)

The IEEE 802.11 (a.k.a. Bluetooth) standard is developed for medium data rates and lower energy consumption for WPANs. The Bluetooth standard is an industry specification that is suited for real-time application requirements. Wireless Interface for Sensor and Actuators (WISA) is one of the representative specification for 802.15.1-based technology [15]. The coverage distance range from few centimeters up to 100 meters by three different classes [16].The error rate is less than $10^{-9}$and cycle time of 2msis specified in WISA specifications [17].

WISA network structure has a cellular topology that communicates in 2.4 GHz frequency band at a data rate of 1 Mb/s. Each cell consist of a base station (Master node) and 120 sensors and/or actuators (Slave nodes). Time Division Multiple Access (TDMA) and Frequency Division Duplex (FDD) mechanisms are used in the WISA networks [18].

What made Bluetooth as a competitive network alternative for biosensor applications is the Bluetooth low energy standard (BLE) which is officially known as Bluetooth v4.0 Low Energy (BLE) standard. This version of the standard has sacrificed distance and transmission rate for low power capability while maintaining a convenient connection process of the original Bluetooth protocol. (Typical Figures are 0.27 Mbps speed with less than 50 meters range.) The BLE standard is specifically designed for battery operated devices where the devices are expected to operate from months to years between battery changes. BLE systems on chips (SoC) are available from several well-known manufacturers.

A novel application uses this type of network for monitoring point-of-care application by using biodegradable, bio-compatible sensors [19]. In this application MEMS sensors are utilized as "canary sensors" to respond to environmental changes. The sensors are distributed over the body of the user and information coming from these sensors is collected by a smart phone through Bluetooth network.Information is later relayed to central computer by the smart phone.

There are many examples of Bluetooth based applications. Ren et. al. [20] employed a physiological signal measuring system for medical care applications. Tura et. al. [21] developed a wearable medical device to brain-injured children for home care activities. Smart Shirt [22] is smart textile systems that monitors a wearer's movement and health data in real-time. Health Gear [23] is also one of the health care system for visualizing and analyzing health status of patients that uses non-invasive sensors.

WBAN (IEEE 802.15.6)

IEEE 802.15.6 is an ongoing standardization effort for body area networks. The group is targeting development of communication standard optimized for low power communication with tiny transmitter and small size antenna in or around body. It is intended for short range communication and consideration for long term battery life applications.

IEEE 802.15.6 Task Group 6 aims to present a standard structure for physical and medium access layer that is for low frequencies, short-range communication, low-cost and reliable wireless communication. The standard provides three physical layers; Narrowband (NB), Ultra wideband (UWB) and Human Body Communications (HBC) [24]. Figure 2 shows thefrequency bands for Wireless Body Area Networks, WBANs.

There are 3 types of mechanisms for the channel access; Random Access mechanism with CSMA/CA or slotted aloha, improvised and unscheduled access with unscheduled polling/posting, scheduled access and variants with TDMA. Network is designed to operate in threedifferent types of modes as; beacon mode with superframe boundaries, Non-beacon mode with superframe boundaries and Non-beacon mode without superframe boundaries. The slots does not exceed 255 in superframe and each time slot length is equal [25]. Figure 3 shoes the communication modes for IEEE 802.15.6 standard.

There are eight priorities for access the medium. It defers from the type of traffic that aims to ensure the Quality of Service (Qos) [26]. Table 1 shows the priority mapping.

Sometimes modified versions of this network are used for wireless body area networks. A study made by Aboueiet. al. uses Raptor coded FSK to reduce the power consumption even further [27]. In another application Takizawaet. al. [28] realized a capsule endoscope for monitoring internal organs by video and images. Yuce and Ho [29] realized a multi-patient monitoring system that can measure up to four vital signals.

Although some experimental SoC's are produced for implementation of this standard, commercial multi-vendor

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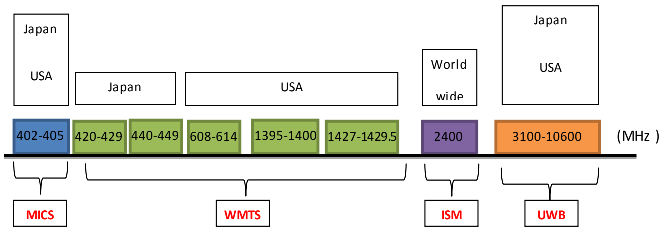

Figure 2: Frequency bands for WBANs [12].

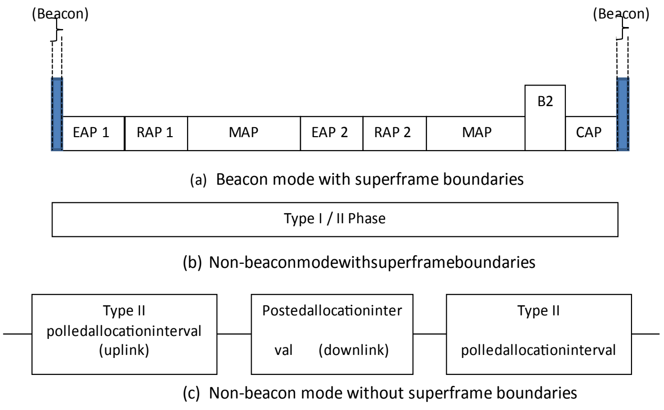

Figure 3: IEEE 802.15.6 communication modes.

User Priority	Traffic type
0	Background
1	Best Effort
2	Excellent Effort
3	Video
4	Voice
5	Medical data or Network Control
6	High priority medical data or network control
7	Emergency or medical

Table 1: IEEE 802.15.6 User priorities

manufacturing of these chips are not expected until the standard is finalised.

X73 (ISO/IEEE 11073)

ISO/IEEE 11073 standard is designed to enable communication between medical devices and computer systems. It targets giving real-time plug and play interconnection capability to medical devices so that users can make connection to an existing system with minimal effort. It focuses on interoperability in medical devices and defines the QoS for medical applications that operates on, in or around the body.The requirements (latency and bandwidth) are specified from the standard to provide the required QoS. The X73 standards define the full seven-layer ISO/OSI(International Standards Organization/ Open System Interconnect)model that includes application profiles, terminology of specification, domain information model and medical device descriptions [30].Table 2 shows the medical application classes that is defined by ISO/IEEE 11073.

The standard focuses on two topic; supply real-time interoperability for medical devices that allows to detect, conFigure, and communicate automatically. Second one is to enable the processing of vital signs and medical device data efficiently to make it possible todisplay the data in near real-time [31].The following Table indicates allowable delay time for different functionalities of medical devices using this standard.

Some application examples of this standard are as follows. Yao and Warren [32] apply the standard to wearable health monitoring systems that also display sensor data through software interface. METABO [33] project is developed for diabetic patients to monitoring their metabolic disorders and blood glucose. The RC-S380 [34] product is an USB NFC Reader that complies with ISO/IEEE 11073 that is certified by the NFC Forum Certification Program.

There are few manufacturers manufacturing SoC chips for IEEE 11073.

WLAN (IEEE 802.11e)

The standard is one of the most commonly used wireless network technologies in the world because of cost effectiveness, easy deployment, hightransmission rates of up to 54 Mbps in the 2.4 GHz band. The standard provides three physical layer specifications; Frequency Hopping Spread Spectrum (FHSS), DirectSequence Spread Spectrum (DSSS) and Infrared (IR). IEEE 802.11 MAC provides two different access mechanisms, the mandatory DistributedCoordination Function (DCF) and Point Coordination Function (PCF). DCF mechanism supports CSMA/CA method and PCF mechanism supports polling which is organized by central node. There are 2 types of architectures in the IEEE 802.11; BSS (Basic Service Set) and IBSS(Independent Basic Service Set).In BSS architecture, there is an AP (Access Point) and a lot of portable or mobile station. The data moves through the AP to other stations. In IBSS architecture, stations can communicate to each other [35].

IEEE 802.11e is an improved version of IEEE 802.11 to provideQos requirements by adding priority mechanism.There are four types of Access Categories (AC) that have been specifies different priority for data traffics. A new coordination function is added toIEEE 802.11e that is hybrid coordination function (HCF). Because of these, the IEEE 802.11e is more suitable for medical applications than other WLANs.

There are many IEEE 802.11 based application that also can be adopted to IEEE 802.11e. For example; The Scalable Medical Alert and Response Technology (SMART) system [36] monitoring vital signals of patients in waiting areas. CareNet project [37] is a remote healthcare application that regards highlyreliable and privacy-aware communication.

WirelessHART (IEC 62591)

In WirelessHART (Highway Addressable Remote Transducer Protocol) standardoperates usingwired or wireless based technology. The protocol utilizesmesh network architecture that consist of graph routes. Graphs link up to network devices. The central station updates the graphs continuously that can change the network topology. There are various types of network devices as; field devices, routers, adapters, hand-held devices, access points, gateway, network manager and security manager. The protocol supports multiple APs. In wireless communication, the standard usesTDMA mechanism and supports channel-hopping scheme. Also 15 different RF channels is available that operates in the 2.4 GHz ISM bandDSSS physical layer by using 802.15.4 standard and superframe subdivided to time slots of 10ms[38].

Wireless HART is one of the early standards designed for connecting factory floor sensors and actuators wirelessly. Being initiated in 2004, this was a reliable and secure way of connecting industrial devices. The nodes are robust and battery can last 5-10 years. Although the network

Class: Data Type	Latency	Bandwidth
Alarms/alerts/PositionalAlerts(Real-time)	A1:< 200ms ve A2: <3 s	per alarm : 64 byte
Person state	< 3 s	per alarm : 64 byte
Sensor Watch dog/heart beat	< 60 s	per hour : 64 byte,
Remainder	< 3 s	per alarm : 1632 byte
Physiologic parameters (real time)	< 3 s	E1:0.5 and E2:5 Hz param at: 20 byte
Telemetry Waveforms (Real-time)	< 300 ms	ECG: [F1: 3-lead2.4 kbps, F2: 5-lead10 kbps, F3: 12-lead72 kbps], F4:Ventilator :50-60 bps, F5: SpO2:50-120 bps

Table 2: Medical Application Classes in IEEE 11073.

is designed to be very reliable, this is considered overkill for simple biosensor networks.

Example applications are ; Zhu et. al. [39]developed a location-determination system that uses Received Signal Strength Indication (RSSI) method. Song et. al. [40] realized prototype implementation for real-time industrial process control. Endress+Hauser A/S Inc. manufactured a monitoring system for heavy crude oil extraction [41].

ISA100.11a

This is a standard developed by the International Society of Automation (ISA) for the purpose of interconnecting field devices wirelessly. The functionality of the standard is similar to WirelessHART standard mentioned in the previous section. The protocol goals are to provide secure, flexible, reliable connectivity to field devices through multiple protocols and open standard.The data link layer based on non-compliant version of IEEE 802.15.4 standard and physical layer based on compliant Zigbee standard that communicates in 2.4 GHz with DSSS multiple access scheme. Because of using DSSS, co-existence with other network can be possible. The network and transport layer utilizes 6LoWPAN, IPv6 and UDP standards. The standard supports mesh, star-mesh and star topologies. The application protocol does not defined in ISA100.11a. There are error detection mechanism and channel hopping mechanism to ensure the reliability. There are features such as; duo-ACKs, changeable time slots and frequency hopping to provide flexibility. Also there are data integrity, privacy, authenticity, replay and delay protection mechanisms for security [38].

Although the standard has nice features for connecting field devices it may be overly complicated for connecting close proximity biosensors. Some of the applications utilizing ISA100.11a are as follows. Chen [42] has realized a monitoring system for refinery that collects pressure and temperature data from environment.Rasgascompany realized an application for Brazed Aluminum Heat Exchanger (BAHX) that monitored temperature of system [43].

CONCLUSIONSAND FUTURE TRENDS

Within the scope of the articleseveral popular standards for wirelessly connecting sensors are discussed. When implementing sensors networks, capabilities of networks as well availability of chipsets and engineering tools become important. Since standards evolve over time, what is recommended today may not necessarily be suitable tomorrow.

Based on these facts, the following recommendations can be made:

1. The nature of the application should be the first and the foremost criteria in selection of the network. Each standard focuses on certain features that separate them from others. WLANs have high transmission rate up to 54 Mbps, widespread usage. 802.11e has QoS support but has comparatively high energy consumption. Zigbee standardhas low energy consumption, low cost and reliable data transfer but low-throughput and absence of QoS support are disadvantages. The Bluetooth protocol is suitable for real-time applications that require medium data-rates and short range. WBANs use large frequency band and support QoS as well as being low-cost and reliable wireless communication. But interoperability and co-existence are the concerns of standard. The ISO/IEEE 11073 protocol focuses on interoperability and defines QoS support. WirelessHART is reliable and secure protocol and supports interoperability and suitable for industrial environments. ISA100.11a provides multiple protocols and applications, flexible architecture and includes security mechanisms such as; data integrity, privacy, authenticity, replay and delay protection.
2. The power consumption of requirement of sensor nodes is an important decision in selection of the network. Some standards clearly stand out in this respect.
3. Availability of network integrated circuits in SoC form is an important factor during implementation of the network. Availability in SoC from translates into quicker development and smaller size network nodes.
4. Availability of engineering tools, having different vendors and software support are also important factors. Having multiple vendors usually means competition for better and faster chips as well as more sources of support.

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