Physically-Secure Low-Power Human State Measurement using EQS-HBC and Edge-Analytics

Invited Paper

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***Abstract*—This paper discusses recent advancements in smart connected biophysical signal sensing technology focusing on the development of wearable biosensors and the use of Electro-Quasistatic Human Body Communication and Edge-Analytics in the human state measurement systems for lower power consumption and physical layer security.**

***Index Terms*—Electroquasistatic (EQS), Human Body Communication (HBC), Internet of Bodies (IoB), Human State Measurement, BioSensors**

I. Human State Measurement - An Overview

Devices in and around the human body have become ubiquitous and their applications in defense and healthcare have come up leaps and bounds in the last few years. Smart watches and fitness trackers have also taken the consumer market by a storm and are equipped with various sensors like accelerometers, hearth sensors and ECG sensors. The development and increase in use of wearable biosensors form a complex network of sensors on, around and even in the human body, forming a distinct subset of Internet of Things (IoT), starting to be known as the Internet of Bodies (IoB).

This advancement in biosensor technologies [1], [2] has allowed us to capture and evaluate the physiological signals of the human body as depicted in Fig. 1. Cognitive signals like Electroencephalogram (EEG) and Electromyography (EMG) or Local Field Potentials (LFP) have been captured to detect stress and fatigue. Wearable sensors like accelerometers, gyroscopes and positioning sensors have been used in tracking daily exertions. Daily health monitoring has been performed using pulse oxymetry sensors, blood pressure and temperature sensors. A combination of all these sensors create a flood of data arriving at the on-body hub to be further communicated to the remote data acquisition unit. The on-body hub employs basic data analytics to provide an immediate diagnosis where as the deeper machine learning algorithms are performed in cloud servers to further train the models to enhance the accuracy of the diagnosis and human expert analyst supervision and augmentation. The development of smart and connected biosensing has also been essential in the advent of remote monitoring of biophysical data allowing early detection of diseases and enhancing human performance levels.

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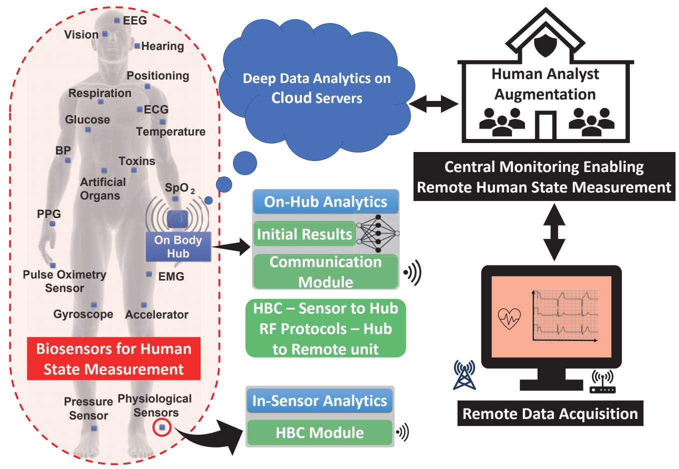

Fig. 1. Development of connected biopotential sensors forming the Body Area Network (BAN) contributing to the advancement in human state measurement.

II. Biopotential Sensor Systems

Biopotential sensor systems are developed on the basis of the specific signal characteristics. Typical biopotential signals and their amplitude and frequency values are shown in Fig. 2 (a). Based on the type of signal and the part of the body the sensor is to be placed on, the actuator and the front end of the system is designed. The data captured is then processed into a suitable format before being communicated to the hub. An example of such a system is demonstrated by Kim M.K. et al. where a wearable EMG sensor patch connected to a custom-built portable control unit was developed which allowed remote data transmission and powering. [3] The sensor system developed was wearable and cost effective having the potential to replace expensive biofeedback devices which have traditionally been used to treat dysphagia.

It has been shown in multiple studies that communication power consumed is a bottleneck in the low power size constrained wearable and implantable devices. In comparison, computation power is typically orders of magnitude lower than the power required for data communication [4]. Thus, low power methods for communication in size constrained devices is essential in improving their battery life span.

A. Communication protocols in WBAN

Traditionally, Bluetooth has been the gold standard in WBAN communication and has been extensively used in data transmission for on-the-body nodes and implantable devices.

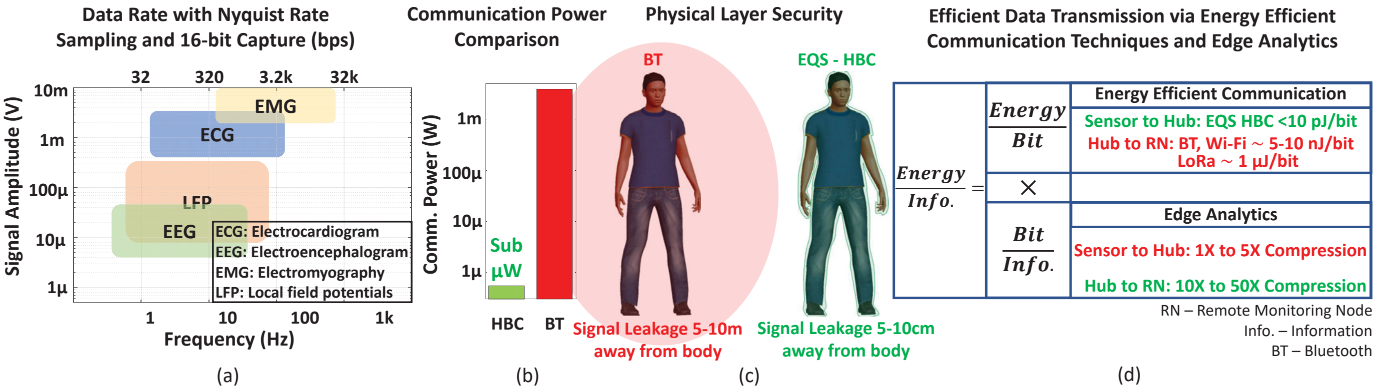

Fig. 2. (a) Typical physiological human body signals with their amplitude and frequency depicted. (b) Comparison between Bluetooth and EQS-HBC in terms of (b) Communication power and (c) Physical layer security. (d) Efficient data transmission using edge analytics and energy efficient communication

However, as shown in Fig. 2 (b), communication power required for Bluetooth is of the order of a few mW. RF based communication technologies like Bluetooth operate in a frequency range of hundreds of MHz to a few GHz. Such high frequency communication paradigms are power hungry as well as physically insecure. Devices based on Bluetooth are radiative in nature and the transmitted signals are available 5-10 m away from the body making the signal available for attackers with the required know how to tap into the system. To tackle the physical layer security issues as well as to reduce communication power, a ultra-low-power, low frequency alternative to the RF based communication technology is essential.

Human Body Communication (HBC) [5]–[13] has fast come up as a viable alternative to RF based protocols where communication channel is created using the conductive properties of body tissues. Recently, it has been demonstrated that EQS-HBC is capable of $Sub - \mu W$ communication [14] resulting in orders of magnitude improvement in power consumption as compared to Bluetooth. Further, the use of low frequencies enhances physical layer security [15] as illustrated in Fig. 2 (c) where the body acts like an inefficient radiator at the Electroquasistatic (EQS) region of less than 10 MHz. The signal leakage in such a system is limited to 5-10 cm around the body.

Low power biopotential signal recording systems using EQS HBC have been demonstrated in literature which has been shown to be physically secure along with lower power consumption than the previous state-of-the-art devices. Such a system has been demonstrated by Sriram S. et al. [16] where continuous biopotential signal monitoring has been performed in animal bodies. A small sensor node was built to capture EKG signals from a rat body and was communicated through the rat body using EQS HBC.

Transmission of raw data from the sensors around the body area network, may not be optimal which can lead to unnecessary use of communication power thus depleting the batteries of these size and power constrained sensor nodes. Edge-Analytics (Fig. 2 (d)) both at the sensor and on the hub also allows for information-extraction near the source of the data thus reducing the bits/information allowing efficient data communication. The sensors being small devices only allow lightweight computation on the senor node and limited data compression (In-Sensor Analytics). A higher computation power on the hub (On-Hub Analytics) is exploited to get higher data compression thus increasing total system efficiency (i.e. best energy/information).

A combination of ultra-low power communication methods like EQS-HBC in tandem with multi-level edge-analytics provides an architecture for connected biopotential sensor networks for energy-efficient human state measurements.

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