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Interoperable and Diligent Body Area Networks over IEEE802.15.6 for Real-time Monitoring

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Abstract - **Currently, there are no standardization efforts to define interfaces and verify interoperability among implementations for body area networks (BANs) on IEEE802.15.6. A BAN consists of small and lightweight sensors, such as the ring-type SpO2 sensor, and a coordinator that collects vital data from the sensors and transfers them to a backend system for real-time monitoring and analysis. It is important for sensors to be easy-to-use, light for wearing and that they are long-lived using a small rechargeable battery. IEEE802.15.6 provides basic features for these sensors. We establish an industry-driven standardization association for healthcare/medical services on IEEE802.15.6. Industry standardization targets current and emerging small sensors, not those for fixed medical devices in hospitals, such as those in the ISO/IEEE11073 family, and deals with time-driven data. We propose a combination of various layers of power-saving functions for a sensor that satisfies the interfaces. We discuss these functions and evaluate them. As a feasibility study, we then test a false-alert system using a BAN configuration following the standard interfaces, though the standardizations and evaluations are still in progress along with the IEEE802.15.6 standardization activity.**

I. INTRODUCTION

The rapidly aging population and increasing costs of the social health insurance system are changing the direction of health services in Japan. Electronic health record (EHR) systems, which make patients' medical records a meaningful component of care-giving services, increase the efficiency of treatment at medical facilities. The system, however, lacks functions for preventive healthcare, such as easily operable remote vital data monitoring.

For health monitoring, it is important to compare remotely received data with individual base measured data. Many studies have reported that resting heart rate (HR), which is analyzed via base measured data, strongly correlates to prognosis of cardiovascular disease [1]. HR in the working state is influenced by psychological and physical activity and has less reproducibility. Health monitoring systems receive working-state data, compare them with the patient's base data, and analyze them.

These systems require sensors to be noninvasive and convenient for home use, day and night. Wireless sensors, such as Bluetooth with ISO/IEEE11073 [2] data format, have een introduced, but they are intended for hospitals and nursing care homes and do not offer continuous data retrieval with lightweight, easy-to-use interfaces with security.

A BAN is a short-range wireless network of vital sign sensors wearable on the human body. A sensor is imposed extreme limitations in computation, communication, security, and weight. IEEE802.15.6 is a candidate for BANs to provide interoperability, lower power consumption, and security. A modulation in the physical layer (PHY) deployable to a sensor is simpler than that of the coordinator side. We design infrequent radio frequency (RF)-active media access control (MAC) and less-computation security.

This paper first introduces the newly formed industry-driven standardization association, which defines the BAN network interface following the IEEE802.15.6 specification [3] and BAN application interfaces. The association checks interoperability by evaluating healthcare/medical monitoring systems in addition to defining the interfaces. We propose power-efficient functions in all the layers from PHY/MAC to the security sub-layer and discuss each power-saving mechanism. We then analyze data targeted for false-alert systems on users using a BAN consisting of different noninvasive sensors following the association standards. We conclude by discussing the future direction of this work.

II. QOL SENSING NETWORK ASSOCIATION

The Quality-of-Life Sensing Network (QoL-SN) association [4] was established in July 2010 by 29 companies and two national institutes, supported by four medical/healthcare institutes to define two industry-standard interfaces. One is BAN interfaces between vital/biosensors and their coordinator based on IEEE802.15.6. The other is backend platform interfaces, called Platform-as-a-Service for Personal Health Records (PHR-PaaS), as shown in Fig. 1. The standard also defines a simple and flexible data format to allow emerging sensors to join a BAN. We have defined the first version of the interfaces and are currently evaluating them by real implementation.

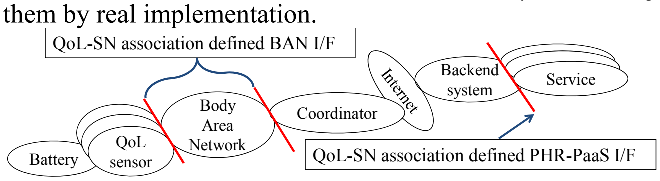

Fig. 1. QoL-SN components and standard interfaces

The applications on PHR-PaaS analyze and synthesize sensed data stored under the platform and provide individual services to the BAN wearer and healthcare professionals who remotely monitor the user. The application can securely upload the result to a backend EHR system. PHR-PaaS is defined not only on legacy database systems, but also on open

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source-based file systems. An open-sourced distributed file system, such as Hadoop [5] would be a candidate and can take advantage of read-only data characteristics.

A. Sensors and BAN

A wearable sensor typically needs to be small and light for wearing (less than 20 grams so as not to hurt the skin) and easy-to-use (operable by simply pressing a button), because the user wears it continually. It also provides individually protected privacy for the user to not be identified in association with the illness.

An accessory-type bipolar-lead ECG [6], an SpO2 sensor (pulse oximeter), vitality measurement sensors, sphygmomanometers, spirographs, 3-D acceleration sensors (posture sensors) and various near-infrared spectrophotometric (NIRS) sensors are components for a BAN system to help prevent targeted diseases, such as high blood pressure-related diseases and heart disease.

The BAN system is used for self-performed home checkups and is expected to operate continuously for over 24 hours with a small rechargeable battery such as CLB2032 from Hitachi Maxell Energy, Ltd. Other radio communications, such as ZigBee and low-power Bluetooth, can also be deployed in a BAN, but they consume much more power and are more complex to securely setup than the IEEE802.15.6 solution, especially on the sensor side. They also provide no resource-constraint security with an easy-setup mechanism.

B. PHR Service and Interface

PHR services execute on three interfaces, PHR-PaaS, PaaS-IaaS, and SN-IaaS, as shown in Fig. 2. Various types of data storage, such as DB and distributed file systems, taking advantage of non-modifiable data retrieval, are deployed under the interface as long as the interface is satisfied.

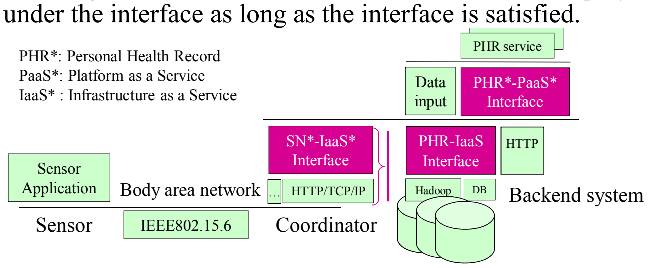

Fig. 2. QoL-SN components and interfaces

We have not fully evaluated the interfaces, but confirmed their function by way of a huge amount of data, such as ECG/breath data gathered daily.

III. Diligent Body Area network

BANs require less power consumption in computation. There are two methods depending on CPU functions. One is to use the deep sleep mode during idle, if such a function is available. The other is to execute slowly by slowing the clock to prevent an idle state. We can estimate the sleep time or execution time as long as a time slot is predefined for the sensor with some accuracy by the real-time clock (RTC). An accessory-type ECG retrieves data every 8 ms and sends them to the coordinator when the assigned time slot is ready. An SpO2 sensor, on the other hand, detects a bottom peak by 15 ms sampling and sends the data every pulse wave duration of the user. A BAN based on IEEE802.15.6 supports both cases in a power-efficient way.

The communication between a sensor and the coordinator requires a high data rate for less power consumption in data transfer and keeps data ordering among sensors involved in a BAN. It also expects less traffic from the coordinator to sensors, such as timing beacons, to reduce the receive-wait state on the sensor side.

The privacy protection of a BAN is also important since eavesdroppers may predict the user's symptom by data traffic analysis. Currently available short-range wireless communication, such as Bluetooth, is used for peer-to-peer services like hands-free voice communication and does not presume security as a primary function.

Finally, lightweight and long battery durability characteristics are important for wearable sensors. We focus on the diligent BAN functions assuming a rechargeable 2.9 g coin battery and total sensor weight of less than 20 g.

A. MAC and PHY Selection in IEEE802.15.6

BAN provides data ordering among vital data that are received from sensors. Vital sign sensors such as ECG and SpO2 usually keep sending data to the coordinator; so a guaranteed time slot (GTS) is assigned for each sensor to synchronize between a vital sign sensor and the coordinator.

The BAN interface is defined on IEEE802.15.6, which will be finalized in 2011. IEEE802.15.6 defines three PHYs and two types of MACs to accommodate different types of applications. The QoL-SN association selects the narrowband PHY with 2.36/2.4GHz PHY and non-beacon mode MAC with sensor-driven data synchronization to satisfy a maximum data rate, which is usually required by ECGs, and to reduce power consumption on the sensor side.

B. Low Power for Sensor RF Modulations

IEEE802.15.6 has adopted $\pi/2$-shift Differential Binary Phase Shift Keying (DBPSK) as the mandatory RF modulation. Differential detection is generally applied to receive signals modulated by $\pi/2$-shift DBPSK. However, the use of differential detection increases the receiver's complexity since it requires both I- and Q-phase components of the received signal. One possibility for realizing low-power wireless communication is to apply the FM demodulator instead of differential detection. This scheme is based on interoperability between $\pi/2$-shift DBPSK and frequency shift keying (FSK). A popular form of FSK modulation is Gaussian-filtered minimum shift keying (GMSK), which has been applied in the Global System for Mobile Communications (GSM) and other legacy wireless devices. Since plenty of mature technologies for GMSK modulation are available now, the use of the GMSK module provides a way to realize low-power operation on a RF transceiver in a sensor module.

C. Quiet BAN Synchronization

Communication is synchronized by the GTS. Each sensor knows how often and when to adjust the data transfer timing based on the information exchanged during its association with a coordinator. Once an association is established, the sensor requests that the coordinator readjusts the RTC with data sent by a QoL-SN defined data subtype DATA-PACKET-WITH-SYNC in the slot shown in Fig. 3, receives the response, and restarts the RTC for the next synchronization. The protocol reduces the RF receive-wait duration and reduces the power consumption.

A sensor may not have an accurate RTC. A small sensor may use the GMSK modulation with a CPU that does not satisfy the clock resolution of 20 ppm specified in IEEE802.15.6. To allow these sensors to join a BAN, we adopt a sensor-driven synchronization method that has an advantage over beacon-type synchronization because each sensor can synchronize with the coordinator by its timer resolution. Each sensor knows its own timing with the coordinator.

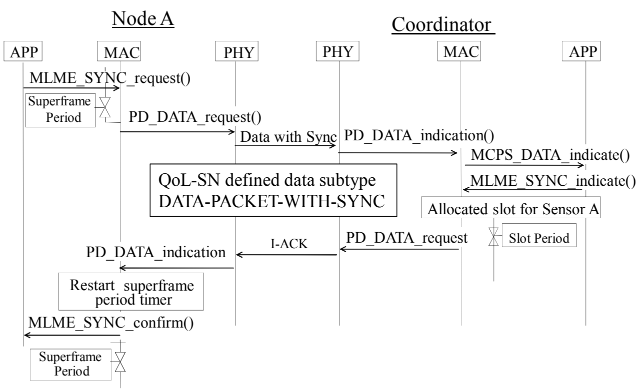

Fig. 3. Sensor-driven BAN synchronization

A coordinator is sophisticated enough in a BAN because it manages sensors securely by its accurate RTC. The coordinator is usually a smartphone or tablet that can transfer data received from sensors remotely.

D. *Low-computation and Low-communication Key Sharing*

Effective security requires simple key pre-distribution with re-keying to maintain strong security and less traffic mutual authentication between each sensor and the coordinator in addition to popular block cipher integration and protection from unintentional attacks.

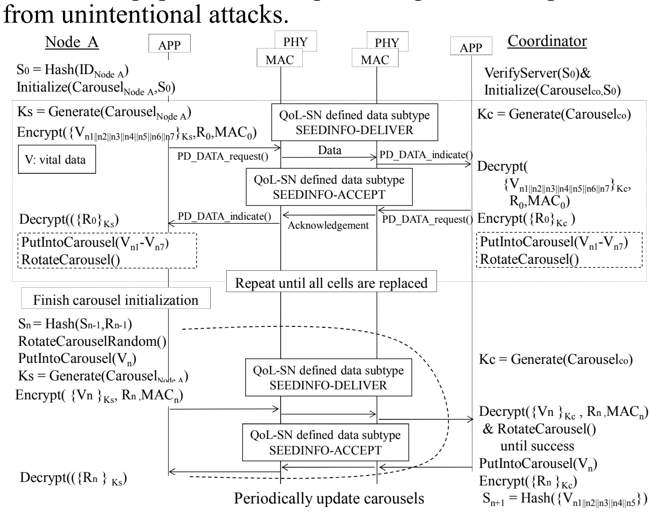

Fig. 4. Key-setup protocol

The Carousel Rotation Protocol (CRP) is a lightweight mutual authentication protocol between two entities using shared information such as time-varying data. The data used in the key generation are specific to behavior/vital data [7].

Both a sensor and the coordinator share a carousel corresponding to the varying data history. This carousel is used to establish a shared authentication key between the two entities; therefore both entities use a function to generate the same mutual authentication key from the carousels. The function produces the same key independently of each carousel, since keys are recreated when new data is entered in the carousel.

Vital data are candidates for time-varying data. Sensors have an interface to obtain a range of vital data, such as an electrocardiogram (ECG) signal and posture using 3D acceleration data. The QoL-SN association defines the data subtype of seed information delivery/accept for key setup on IEEE802.15.6. The protocol is shown in Fig. 4.

IV. BAN System Evaluation

In this section, we evaluate the power efficiency of a BAN following the standard interfaces defined by the QoL-SN association, though some features are difficult to measure because measuring itself is difficult in a small sensor. This evaluation mainly uses estimations.

A. *Efficiency of Modulation*

There is an energy-efficient way to implement the IEEE 802.15.6 PHY. The mandatory modulation scheme, $\pi/2$-shift DBPSK, has interoperability with GMSK signaling. Fig. 5 shows packet error ratio (PER) performance when using a GMSK transceiver instead of that of $\pi/2$-shift DBPSK. The result shows that the loss caused by the replacement is less than 1 dB compared with theoretical PER of BCH-coded DBPSK. The FM demodulator, which is an energy-efficient demodulator, is available to demodulate GMSK signals. The complexity of its base-band processing is reduced to half the complexity of a differential detector since the differential detector requires orthogonal detection. As a result, the use of the GMSK module provides an energy-efficient modulation with comparable PER performance.

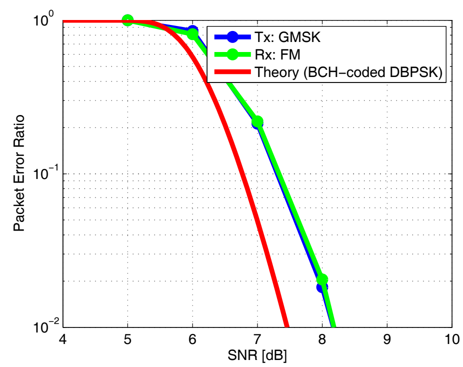

Fig. 5. PER between GMSK and differential detector

B. *Efficiency of Quiet BAN Synchronization*

We measured the current draw of send/receive in the RF chip nRF2401 for the BAN synchronization. The 8-bit CPU consumes 3.3mA. The current draw of data transfer in the RF is 11.3mA and its active time is 300 μs, whereas that of data receive is 11.8mA with active time of 9.5ms. The average current draw of data transfer is 3.3mA, whereas that of data reception is 3.7mA. The relationship between the average current draw and the number of GTSs for timer re-synchronization expresses how short of a time a sensor needs to enter the receive-wait state. The average current draw is almost the same when the interval of the re-synchronization exceeds 100 GTSs. This indicates that the reduction of the receive state in the sensor node is not so important for the reduction of power consumption, since the CPU consumes 3.3mA in data encryption and the MAC execution is considered a baseline.

We evaluated the CRP compared to TLS authentication. Evaluation is required to be conducted in a real sensor, but still, due to limitations, we evaluated the coordinator side, which consumes about 17 times (35 cells/2) more in computation compared to the sensor side. Through this comparison, CRP is negligible compared to the Transport Layer Security (TLS) authentication as shown in Fig. 6.

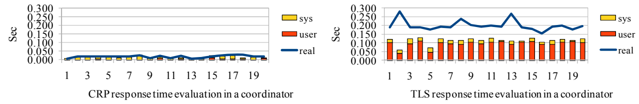

Fig. 6. CRP/TLS response time comparison

C. *BAN System consisting of SpO2 and Breath Sensor Mat*

One of the major BAN applications is health monitoring by vital sign referencing individual base-measured data. Another one is to reduce false alerts at night in hospitals and nursing homes. It is a challenge to monitor patients/users continuously with no constraints, especially at night. There are very high numbers of false alerts and, as a result, nursing staff mostly ignore alarms from the monitors [8][9]. As long as sensors follow the standard interface of the BAN, the coordinator collects data day and night. A healthcare professional or false alert system can check intended data and confirm the right vital signs.

Fig. 7. SpO2 sensor and breath sensor mat

We tested a BAN example with real-time monitoring using a SpO2 sensor (pulse oximeter) and a breath sensor mat satisfying the QoL-SN BAN interfaces, as shown in Fig. 7. A user wears an SpO2 sensor on one finger and a breath sensor is put under his/her body. During sleep, both sensors send vital data wirelessly to the coordinator.

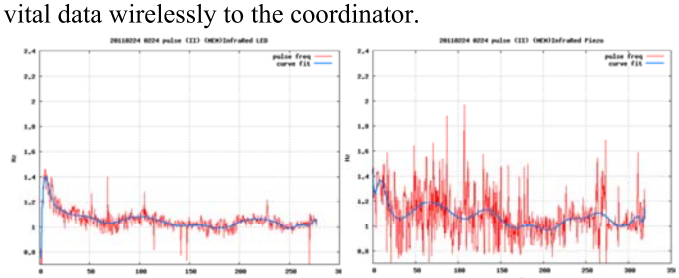

Fig. 8(a) Pulse wave SpO2 (b) Wave: Breath sensor mat

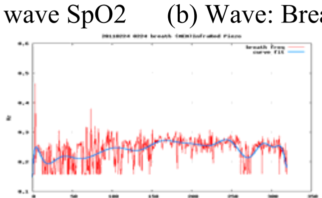

Fig. 8(c) Respiration

The SpO2 sensor samples every 15 ms, detects a bottom peak and calculates the interval of bottom peaks using a running average algorithm in addition to the oxygen saturation rate. The interval is the pulse wave. The breath sensor mat analyzes by filtering and FFT, and the base heart rate (HR) is extracted. Fig. 8 shows curve fittings of the SpO2 and breath sensor mat. The wave in Fig. 8(a) is the pulse wave extracted from SpO2 samples and Fig. 8(b) is the heartbeat separated by 1.1Hz signal separation with twice integrals from respiration, which is shown in Fig. 8(b). The pulse wave in Fig. 8(a) and heart rate in Fig. 8(b) have similar waves. The data retrieval is still in progress, but this shows the same heartbeat from different sensing devices and the BAN will become a component of easy-to-use false alert networks. The Fig. 8(b) result also shows the base heart rate at night, and this result is used as the base heart rate for individual health checks. Fig. 8(c) is used for breath reference in addition to the heart-rate analysis.

V. Conclusion and Future Work

In this paper, we introduced the Quality-of-Life Sensing Network (QoL-SN) association that defined the first version of the BAN interface following IEEE802.15.6 and BAN application interfaces for healthcare/medical monitoring systems. We discussed power-efficient functions in all layers from PHY/MAC to the security sub layer and evaluated them. We then explained a real test of a BAN consisting of a small ring-type SpO2 sensor and breath sensor mat satisfying the standards defined by the association. These sensors are easy-to-use and candidates for false-alert systems and base data measurement devices at night for heart rate analysis because of their noninvasive features.

Evaluation of power efficiency is still in progress. We will work on this and apply it to various BAN systems following the QoL-SN standard targeting real healthcare support.

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