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An Application-Agnostic Quality of Service Framework For Wireless Body Area Networks

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***Abstract*— This paper presents an application-agnostic Quality of service (QoS) framework for Wireless Body Area Networks (WBAN). The applications of WBAN includes several areas such as smart health care, assisted elderly living and emergency response. In the WBAN, obtaining an acceptable QoS performance is extremely important due to its relation with human health and emergency situation. The QoS requirements of a sensor in WBAN is tightly related to the context of its application. Therefore, successful design of a QoS frameworks needs to be application context-aware. In this paper, we propose a context-aware framework to guarantee the QoS requirements of the sensor nodes in the WBAN. Our framework is implemented as a separate module which is independent of the application layer and can be utilized for different medical applications. Additionally, our framework enables the medical application to dynamically adapt to the QoS changes due to the nature of application and patient's health status.**

I. INTRODUCTION

Recent technological advancements in the low-power systems and medical sensors have witnessed the appearance of the sensor network in the field of healthcare known as "Wireless Body Area Network(WBAN)". As shown in the Fig. 1, multiple sensor nodes deployed on, in or around the body collect vital signs such as patient activity, body temperature, heart beat, blood pressure, ECG, oxygen saturation, etc. and send their data to a medical center to be processed by medical staff . WBAN has the potential to significantly improve and expand the quality of health-care across various medical applications. For instance, [1] utilizes WBAN to study the effect of specific treatment on Parkinson disease by using a body sensor network composed of accelerometer sensor nodes. Telemedicine, remote health monitoring and human behavioral studies are among the perfect examples of healthcare applications in WBAN. Meeting the potential of WBAN applications requires considering a multitude of technical challenges. Some of these challenges such as limited processing, memory constraints and scarce energy capacity are shared between WBAN and industrial wireless sensor networks(WSN). Nevertheless, WBAN brings other performance design issues into the perspective. One of the most important challenges in WBAN is the Quality of Service(QoS) assurance for sensor nodes. Each sensor node in a specific WBAN application have stringent Quality of Service(QoS) requirements which directly related to the health status of the patient and the nature of medical application. Most work in literature studied the issue of QoS in WBAN applications only in the context of Media Access Control (MAC) layer [2],[3] ignoring the fact that the QoS performance of WBAN is tightly related to the application layer. Specifically, QoS requirements of sensors in WBAN are tightly related to the medical application as well as the patient condition. For example, the rising body temperature of an infant is a critical data, that needs to be transmitted immediately. Nevertheless, high body temperature might not be critical when an athlete is performing intense exercise. Therefore, a QoS design needs to consider the context of application in higher layers as well. There are only a few work in the literature which studied the QoS design of WBAN by using the context of medical application[4].

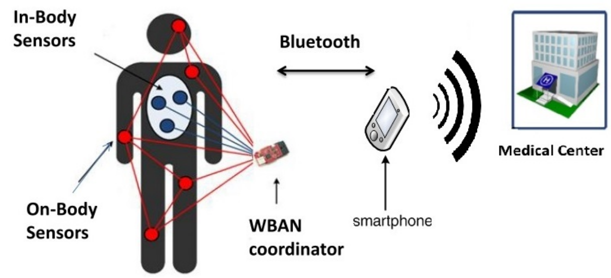

Fig. 1. WBAN scenario

In this paper, we propose a generic QoS framework for WBAN which guarantees the QoS performance of sensor nodes, independent of the medical applications. Our goal is to deploy a separate module which enables the application designer to focus on the application development itself rather than the QoS design. Therefore, applications can rely on the proposed framework for QoS assurance. Fig. 2 shows a layered view of our framework.

II. QoS Challenges and Metrics in Healthcare

A successful QoS design in WBAN dynamically allocates the network resource to the sensor nodes and guarantees the reliable data delivery for sensors with high-priority data. QoS assurance is one of the main challenges in the design of WBAN applications due to (i) human body interference and signal fading (ii) scarce resources(energy, memory, processing, data rate). Specifically, WBAN has some specific QoS challenges which distinguish it from wireless sensor networks:

A. QoS Challenges

1) Correlated Critical data: The WBAN sensor nodes collect the vital signs of the patient such as blood pressure and temperature. These signs directly determines the overall health condition of the patient. An unexpected deviation or sudden change in the value of such medical data is critical and may have a serious impact on the health condition of the patient. Hence, sensor data in WBAN have unpredictable priority nature relevant to the health condition of the patient. Furthermore, in WBAN the critical data of different sensor nodes are mostly correlated. For example, an irregular fast heart beat will probably increase the temperature of patients as well. Therefore, the system is required to serve multiple priority packets instantly and simultaneously.

2) Human Body Effect: In WBAN, sensor nodes are placed on different locations on the body or inside the body (pacemaker, glucose sensor). The wireless transmission between these nodes must propagate around or through the human body to reach the destination. The path loss exponent for the human body varies from four to seven [2], a value relatively much higher than the condition in free space. Therefore, the variations of the transmitted signal which move around the body have higher possibility of being successful. Nevertheless, human body becomes an extremely lossy environment due to the reflection and fading caused by various postures of human being in different situations (ex: walk, sleep, etc.). Hence, meeting the QoS performance of a sensor node with lossy channel requires extra consideration.

3) Context-aware QoS: In a WBAN environment, the priority of the packet depends on the nature of medical application and patient situation. For instance, consider a situation where body temperature has risen above the threshold which does not necessarily mean that the patient has a fever but maybe he/she is doing a tense physical exercise. This is in contrast with traditional QoS designs in other wireless systems where QoS parameters are related to network or MAC layer [5], [6], [7]. Most of the work in the literature have proposed QoS for MAC layer without considering the context of the application.

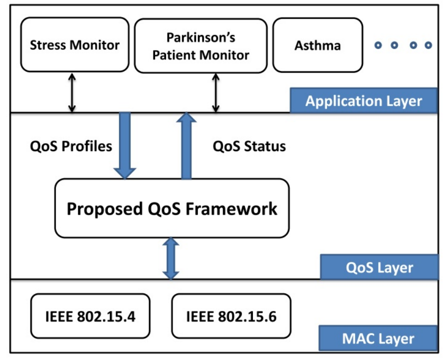

Fig. 2. Framework Layer

B. QoS Metrics in WBAN

Any successful design of WBAN is required to address four main performance criteria:

- **Timeliness(Delay):** Critical data packets are real-time in nature and meeting their delay threshold is crucial to the performance of the WBAN system. For instance, most of the sensor node need to have a point to point latency less than 250ms to have a reliable communication [8].
- **Reliability(Bit Error Rate):** Reliability of sensor data is measured by Bit Error Rate (BER) which represents the ratio of the number of error bits received at the receiver to the number of bits generated by the sender. Higher BER could result in waste of valuable energy since the packet needs to be re-transmitted. Furthermore, the occurrence of error in the received packet without detection caused false alarm and make diagnosis difficult for the doctors.
- **Energy Consumption:** The on-body sensor design must be noninvasive for human body which leads to smaller energy capacity. Also, since the in-body sensors cannot be replaced for long time, their energy must be carefully utilized.
- **Throughput(Data Rate):** Applications are composed of several heterogeneous sensor nodes with different sampling rates. The data rate of sensors may vary from a few b/s to a few kb/s across various applications. The current standard (IEEE 802.15.4) support data rates up to 250kbps.

III. Proposed Framework

Most of the WBAN implementations are designed for specific medical applications[1][9]. Unfortunately, current WBAN standards(IEEE 802.15.4, IEEE 802.15.6) do not support any QoS technique. Hence, most WBAN applications develop their own QoS mechanism. Two main issues arise when the QoS is integrated into the application layer: (i) it increases the size and complexity of the WBAN application and (ii) it prevents the system designer to reuse the QoS module for other applications with same characteristics. This motivates the design of a new QoS framework which is independent of application layer as shown in Fig. 2. In the next section, we propose an application-agnostic framework which guarantees the QoS performance for any type of WBAN application.

A. System Model

The system is composed of three main entities: sensor nodes, coordinator and the cellphone as shown in Fig. 3. The sensor nodes deployed on, in or around the body (ex: ECG, temperature, heart beat, etc.) collect vital signs from patient and send their data to a central node called "coordinator". The coordinator has several duties such as time scheduling, sensor data aggregation and communication with cellphone to transfer the data. The patient cellphone receives all data from the coordinator and transfers them to the medical center where doctors and nurses can analyze the data. Each WBAN application utilizes several sensors and defines different QoS requirements for them based on the nature of application and the patient's health condition. For instance, packet delay of ECG sensors must not exceed 3ms or the precision of heart beat shall not be worse than 10^{-5}. Based on our discussion in the Section I, QoS performance of WBAN applications could be defined with four main parameters: Delay(D), throughput(ω), BER(B) and residual energy (E). In our system, each sensor node i is identified by a "QoS profile" which is represented by two vectors:

1) Threshold: $Q^i_{th} = (Q^i_D, Q^i_\omega, Q^i_B, Q^i_E)$
2) Weight: $\Phi_i = (\phi^i_D, \phi^i_\omega, \phi^i_B, \phi^i_E)$

The threshold vector specifies the valid range for QoS parameters. The QoS parameter is expected to meet the thresholds during the lifetime of the network. The weight vector shows how disastrous the patient's health condition would be if the sensors deviate from their threshold values. In other words, the weight vector represents the priority of QoS parameters which depends on the application constraints. The weight vector is the essence of flexibility of our system. The value of weights could be customized based on the medical application and can vary across patients and sensors. The QoS profiles of sensors are set up by the application at the initial stage of the system. The value of QoS profiles for sensors can be customized by medical staff depending on the medical application and the patient's health condition. These parameters could dynamically be updated based on the system status. The system time is divided into several time slots and each time slot has several intervals. At the beginning of each time slot, patient's cellphone sends the configured QoS profiles to the coordinator. The coordinator's job is to schedule the sensor nodes based

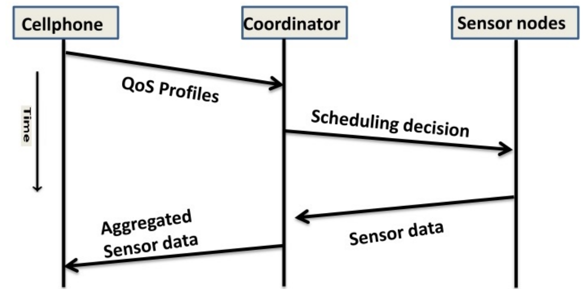

Fig. 3. Proposed framework interactions

on their QoS profiles. The coordinator sends a broadcast packet to all sensors which contains information about itinerary of the next time slot. The broadcast packet describes the number of time intervals assigned to each sensor node in following time slot. Sensors with higher priority get more chances (number of intervals) to send their data. Afterwards, sensors send their data to the coordinator in their respected time intervals. Finally, the coordinator aggregates all collected data and send them to the cellphone via point to point protocols such as serial cable or Bluetooth technology. The medical staff can change the weight vector of an application, given current status of the system. For example, suppose the doctor needs more accuracy for ECG sensor data on patient i. Then, the administrator can easily achieve that by adjusting the value of ω^i_{th} and Q^i_ω respectively. Next, we will discuss how the coordinator utilizes the weight vector of sensors to satisfy all four QoS requirements of each sensor in a network.

B. Coordinator Scheduler

After the receipt of the QoS profiles from the cellphone, the coordinator is required to enforce those profiles by scheduling the sensors data transmission. Similar to the IEEE 802.15.4 standard, the coordinator in this paper utilizes the Time Division Multiple Access (TDMA) scheduling to assign the sensor nodes to different time intervals. The time slot is divided into several intervals. Only a single sensor is allowed to send data during each time interval. The sensor with critical data receives more time intervals. The coordinator continuously monitors the QoS status of each sensor node by comparing the value of its QoS parameters with the threshold vector. If a deviation occurs, the coordinator immediately recalculates the number of time intervals allocated to each sensor for next time slot using their weight vectors. Next, we explain how the scheduler in our proposed framework responds to the deviation of each QoS parameter and recalculate the assigned number of intervals for the next time slot.

1) Throughput: We consider the throughput weight of any sensor i denoted by ϕ^i_ω equal to the average data rates of the sensor node. During initial time slots, the system uses the data rates to partition the first few time slots and schedule the sensors. Usually, the data rates of sensors are constant bit rate with only a few kilobit/sec. Therefore, the coordinator needs to only assign a fixed number of interval(proportional to data rate) in each time slot to achieve the required bit rate. Nevertheless, the sensor data rate may vary due to noise and fading factors. Thus, we use the notion of moving average of data rate as the weight of sensors for a long period. This approach has also been utilized in [5].

2) Reliability: Existence of lossy channel between a sensor node and the coordinator due to body fading effect is the main cause for high BER in WBAN. Therefore, while some sensors occasionally do not have a good channel quality, others can efficiently transmit their data to the coordinator. In multi-hop routing approach, the sensor with lossy channel forwards its traffic to other sensor which has clear channel to to the coordinator. If the sensor node a have exceeded its threshold for BER due to its lossy channel with coordinator, then the coordinator performs the following steps:

1) Select another sensor node b that is near the sensor a which does not have lossy channel to the coordinator.
2) Request sensor a to redirect its data to sensor b by using next broadcast packet.
3) The sensor node a will be assigned multiple intervals proportional to its weight factor ϕ_B to send its data. Meanwhile, since the sensor b is responsible to route the sensor a data to the coordinator, it will be given extra time to send both its data as well as sensor a data.

Using multihop technique for WBAN has been proven to be a very effective technique to improve the performance of the system (for more information refer to survey [10],[11].

3) Delay: Packet delay is due to several factors such as processing, queuing and re-transmission delay associate with each packet. If a sensor is not successful to meet its delay threshold , we propose to increase the number of allocated time intervals in next time slot in proportion to its delay weight. Therefore, there is more time to send the data and this eventually decreases the delay.

4) Energy Consumption: The residual energy of a sensor is the most crucial aspect of a sensor QoS performance. We define the residual energy weight of sensor i denoted by ϕ_E^i as an increasing(exponential) function of residual energy. Therefore, as the residual energy of the sensor i declines and approaches the threshold, the coordinator increases the weight ϕ_E^i of that sensor. Thus, the sensors with scarce energy resource will have higher priority to send their data with respect to other sensors.

IV. CONCLUSION

The unreliable nature of wireless communication and heterogeneous sensor data in WBAN applications urges the need to design a QoS framework to enhance the overall performance of the sensor nodes. Specifically, the QoS requirements of sensor nodes are tightly related to the nature of medical application. As the patient's health condition may evolve from a regular status to a critical situation, a context-aware QoS design is essential to adapt the network performance to the new situation. In this paper, we propose a generic framework which guarantees the QoS performance of sensor nodes in WBAN for different medical applications. Our framework is designed as a separate module and is independent of the application layer. Furthermore, our framework allows the application to dynamically adapt to the changes in QoS requirements of sensor nodes which vary based on the health condition of the patient.

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