Managing Quality of Service in Wireless Body Area Networks using CoAP

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***Abstract*—This paper examines techniques to embark upon the Quality of Service (QoS) issues in Wireless Body Area Network (WBAN) using the Constraint Application Protocol (CoAP) framework. The design of QoS in WBAN is a challenging task due to several reasons such as lossy channel, resource-constraint nodes and priority-based services. The QoS provisioning mechanisms mostly focus on the MAC layer and do not extend easily across all platforms. We propose to integrate the QoS design into the application layer using the standard CoAP framework. CoAP architecture is a platform independent standard intended to be used in simple electronics devices such as Internet of Things (IoT). We introduce three CoAP features such as *Caching, Confirmability* and *Multicast addressing*. We examine these options to deploy the QoS mechanism in the WBAN composed of sensors with heterogeneous priorities. The proposed solutions are universal and can be deployed on any sensor platform which supports the standard CoAP software protocol.**

***Keywords*— Wireless Body Area Networks, Quality of Service, CoAP, Health Monitoring**

I. Introduction

The Wireless Body Area Network (WBAN) technology has recently witnessed an increase in the number of monitoring applications in the health-care sector. The use of low-cost, low-power and small-form-factor sensor nodes deployed on, in or around the body allows doctors and nurses to remotely monitor the health condition of the patient. Furthermore, WBAN technology has also been utilized in other medical applications such as cancer detection, Asthma, study the effect of specific treatment, etc. [1], [2]. There are several challenges involved in the design of WBAN systems. Some of these challenges such as limited processing, memory constraints and scarce energy capacity are shared between WBAN and other types of sensor networks. However, WBANs contribute to additional performance issues, specifically in the subject of medical health monitoring applications.

One of the main issues in the design of WBAN is the provision of Quality of Service (QoS) to the sensor nodes. The QoS is defined as a set of performance criteria which ensures that the sensor nodes receive a sufficient resource in a data communication network to operate properly. Delay, bit error rate, energy consumption and data rate are among the well-known QoS parameters in the literature [3]. In particular, the QoS provision becomes even more challenging when sensor nodes have different priority levels based on the application context. This is typical in medical applications when different patients have separate emergency levels. The heterogeneous WBAN priority levels are mainly stems from the health condition of patients as well as medical application requirements. Furthermore, the study of QoS in medical WBAN is paramount since if not addressed properly could lead to catastrophic consequences due to its relation with human health. Most of the solution in the literature such as the optimal power allocation [4] and fair time scheduling discipline [5] focus on the lower layers of the network such as MAC layer. These approaches are restricted to a set of specific MAC protocols and do not extend across all platforms. Some works [6] addressed the interoperability issue by proposing unified QoS mechanism which permits to be implemented on different MAC layers such as IEEE 802.15.1 [7], and IEEE 802.15.4 [8]. Nevertheless, these approaches need to be hard coded inside the sensor node operating system and not flexible to be edited for dynamic environment such as health monitoring.

In this paper, we propose the concept of shifting the QoS design in WBAN to a higher layer in the protocol stack. Specifically, the QoS module will be implemented into the QoS application layer where other medical applications co-exist. In order for QoS to be usable on any platform, we deploy the QoS module over a platform independent software standard for sensor networks called "Constrained Application Protocol" (CoAP). Recently, IETF [10] has proposed such software protocol known as CoAP which is intended to be used in simple electronics devices. We will describe different features of the CoAP software. Particularly, we explain three important CoAP features, which could be utilized to design a suitable QoS mechanism in WBANs and improve latency and throughput. It is to be noted that the proposed technique can be used on any sensor network system since CoAP is a standard protocol already deployed in numerous platforms.

II. QoS Challenges in WBAN

The QoS design in medical applications is a challenging task. There exist two main aspects which distinguish it from other conventional mechanisms. First, the priority of packets for different sensor nodes in a WBAN is tightly related to the applied medical application and the patient situation [9]. For instance, the high body temperature does not necessarily mean that the patient has a fever but maybe he/she is undergoing an intense physical exercise. This is in contrast with conventional designs where QoS parameters are related to MAC layer.

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Moreover, the heterogeneity in sensor nodes' data rates makes the design cumbersome. Generally, the sensor node data rates in WBAN are either very low (a few Kbps) or high (>50Kbps). Table 1 presents a better examination on the data rates of different senor nodes. This significant variation in the data rates makes the resource allocation mechanism unfair in WBAN since high-rate sensor nodes may flood the channel with their packets and as a consequence degrades the performance of low data rate devices due to resource starvation. To tackle these QoS problems, we propose to use existing CoAP software standard features which have potential to address above issues. Following section, gives a brief introduction to CoAP software protocol and illustrates how it contributes to the implementation of QoS in the application layer.

TABLE I. DATA RATES OF DIFFERENT SENSORS

Body Sensors	Description	Data Rates (Kbps)
Blood Pressure	Maximum and mininum of the blood pressure	0.01 – 10
Pulse Rate	Heart beat rate	0.01 – 10
Temperature	Temperature	0.01 – 10
Respiration	Chest expansion/contraction	0.01 – 10
Glucose	Sugar level in the blood	0.01 – 10
SpO2	Blood oxygen saturation level	0.01 – 10
EEG	Brain wave activities	10 – 200
ECG	Electrical activity of heart beats	10 – 200
EMG	Electrical activity of the skeletal muscles	10 – 500

III. CoAP ARCHITECTURE

The implementation of Web Service framework in sensor networks needs to adapt to existing protocols and avoids the interoperability issues. CoAP is a software protocol proposed by IETF [10] to connect to Internet through application layers for simple electronic devices with constraint resources. In particular, CoAP is used for small low power sensor which needs to be manipulated by a remote coordinator. This protocol has been implemented to connect with low power sensors through Internet and is designed to translate the HTTP model into senor network to include more requirements such as multicast, low overhead and simplicity, which are important for the Internet of Things (IoT) [11] and machine to machine (M2M) protocols. Packets in CoAP framework are designed to be smaller than HTTP packets and their structure is simpler which leads to reduce the use of RAM in constrained devices. CoAP is also designed to interoperate with other RESTful [12] Web Services via methods such as GET, PUT, POST through simple proxies. Furthermore, CoAP is built to run over UDP and not TCP since it implements the reliability feature by itself. This removes the extra overhead of TCP headers while allows full IP networking in small microcontrollers. Also, the multicast addressing is allowed in the UDP.

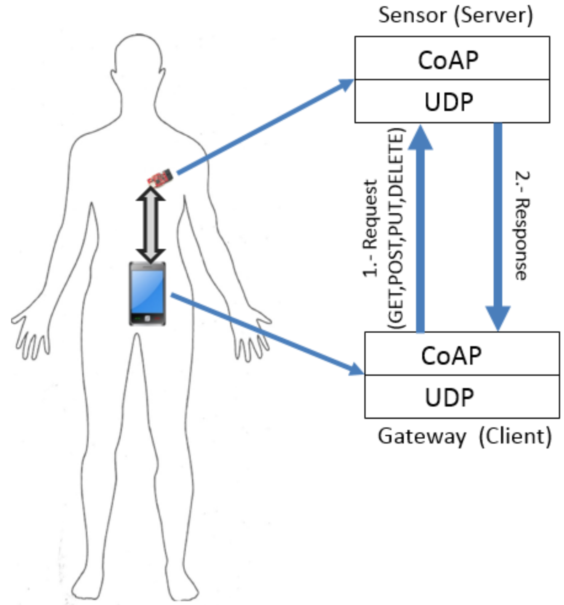

Figure 1. CoAP protocol in application layer

CoAP Request and CoAP Response can be tagged "confirmable" and "non-confirmable". The "non-confirmable" packets do not require acknowledgement while 'confirmable' packets require an ACK confirmation from the receiver which indicates the receipt of packets. This protocol, as HTTP, includes content negotiation, which permits client (coordinator) and server (sensor node) to negotiate the representation of the resources which resides in the sensor nodes. Furthermore, CoAP supports URIs (Universal Resource Identifier) similarly to HTTP, which enables the receiver to determine the authority, path and identity of the resource to be manipulated. In terms of security, the CoAP software protocol is built with DTLS (Datagram Transport Layer Security), which provides the same assurances as TLS but it works on top of UDP instead of TCP. Because of DTLS, CoAP protocol can support several security mechanisms such as RSA and AES. The standard CoAP does not require IPv6. However, CoAP operates efficiently with IPv6 where devices are directly routable in the network. Furthermore, CoAP can be integrated with data formats such as XML, CBOR, and JSON to communicate efficiently with other platforms. The Frame Structure for the CoAP message is depicted in Figure 2.

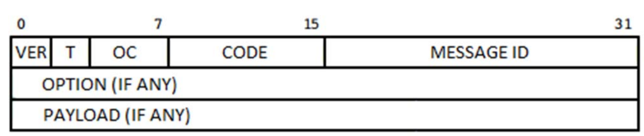

Figure 2. Option header in CoAP Request/ Response

In Figure 2, VER Indicates the CoAP version number. T is a 2-bit unsigned integer which specifies the type of transaction. OC indicates the option counts. CODE shows the type of packet. Finally, the Message ID is a unique number used for the detection of message duplication.

IV. INTEGRATION OF QOS IN COAP FRAMEWORK

The CoAP software architecture is composed of several features to model the data communication between different entities. These features are implemented as an option inside the CoAP message and are represented using the Type-Length-Value (TLV) style. CoAP software protocol supports several options such as URIs, caching, Resource Discovery, etc. In this section, we examine three main options which can be utilized in the QoS design of sensor networks where sensor nodes have different priority levels. These options are *caching*, *confirmability* and *multicast*.

A. Caching as QoS Technique

"Caching" is used to optimize the performance of data transfer by preventing an entity to send the redundant data. Two fields indicate that a packet is in caching mode namely *Max-Age* or *E-tag.* Data packets are sent from Sensor to the Coordinator. When sensor appends the *Max-Age* field to a packet, it indicates that for next *Max-Age* seconds, the sensor data is equivalent to the value of this packet. When the *E-tag* field is attached to a data packet, it gives a unique versioning number referring to a packet which was sent previously. The E-tag should be included in a request used for an already cached resource.

Both Max-Age and E-tag fields can be used to decrease the number of packet transmissions and improve the efficiency. Using the *Max-Age* feature reduces the number of packets in transmission and leads to fewer packet loss and reduces the battery life. For instance, the body temperature would barely fluctuate in a short period of time. Therefore, a single packet with *Max-Age* field can represent a sequence of packets with same value. *E-tag* field is used whenever a Sensor sends a data which was sent previously. This means, the sensor sends complete data for the first packet, and for the second packet, the sensor will only send a small packet accompanied with E-tag option which refers to the first data packet. When the second packet is received, coordinator uses the E-tag option to look up in its local memory and fetch the packet. E-tag packet is smaller in size in contrast with the original one. For instance, an ECG sensor packet size mostly ranges from 30 to 100 bytes while an E-tag packet is less than 10 bytes. This approach has two QoS advantages for high-rate sensor nodes. First, the high-priority sensor node sends fewer data which leads to higher efficiency, fewer packet loss, and lower energy consumption. Consequently, the E-tag approach helps to improve the time efficiency for low data rate sensor nodes. The CoAP transaction is shown in Figure 3. In particular, this figure (see the lower part) illustrates the use of E-tag in the data transaction between sensor and coordinator.

B. Using Transaction Field for Reliability

The CoAP architecture operates on top of the UDP protocol. The UDP protocol is a light-weight and stateless transport protocol which does not provide reliability similar to TCP protocol. Reliability is critical in the QoS performance of sensor nodes by assuring that their packet will reach the destination. The message header in CoAP includes T field (see Figure 2) which denote the transaction type of the packet. This field has two bits and is used to compensate the lack of reliability of the UDP protocol. T field indicates if this message is Confirmable (0) or Non-confirmable (1) type. Whenever the Coordinator receives a Confirmable data, it must acknowledge the receipt of the packet to the Sensor. This acknowledgement assures the Sensor that its transmitted packet has been received successfully. Therefore, if the number of packet loss increases, that Sensor can dynamically set the transaction value to Confirmable type in order to request an acknowledgment and improve its data reliability. Note that, this approach is suitable for only low data rate sensor nodes since the use of Confirmable packets for high data rate sensors would increase the traffic and degrade the network performance. Figure 3 depicts (top part) the Confirmable (CON) feature. As shown in the figure, due to packet loss in the first transmission, sender will send the packet repeatedly until the acknowledgment (ACK) packet is received.

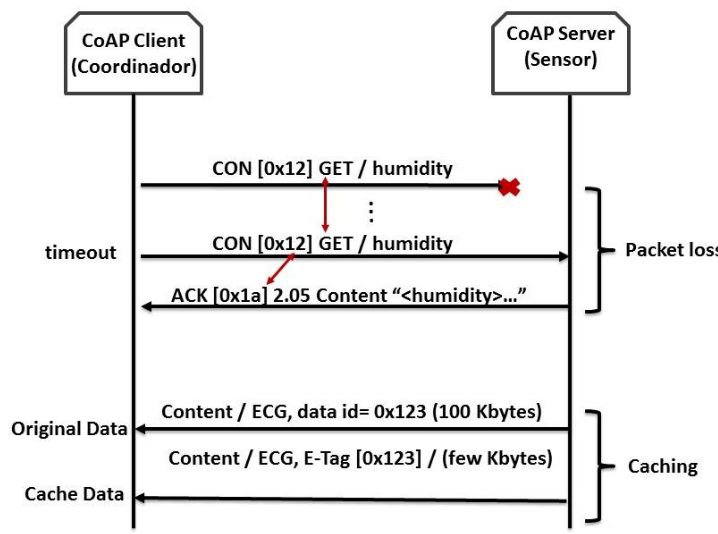

Figure 3. CoAP option in transaction

C. Modeling Priority Groups using Multicast

The addressing scheme for sensor networks only support the unicast and broadcast addresses and do not support multicast. Basically, the addressing of sensors in WBAN is according to the MAC layer addresses. Each sensor nodes will be assigned a unique address to communicate with others. There exist three types of addressing in the network: *unicast*, *multicast* and *broadcast*. The unicast packet is destined for a single destination while broadcast packet will be received at all nodes. The multicast address is a group-based addressing mechanism which specifies a subset of sensor nodes to receive the packet. To address the multicast issue, CoAP software protocol implements the multicast addressing in the application layer for sensor devices to overcome this issue. As discussed in the previous section, the sensor nodes in a medical WBAN could be divided into several different priority levels depending on their QoS status. For instance, the IEEE 802.15.6 [13] standard defines 7 priority levels to categorize the criticality of sensor data. Multicast addressing is a suitable approach for the coordinator to communicate with a group of sensor nodes with equivalent priority using fewer messages. This enables the coordinator to simultaneously enforce the QoS restriction on a group of sensor nodes with same priority. For example, suppose that there exist two groups of sensor nodes in a WBAN (i) *critical* and (ii) *non-critical* where each comprises a distinct subset of sensors. Since the critical group which have serious QoS performance degradation (e.g. packet loss and throughput), the coordinator needs to inform the other non-critical group to reduce their sampling rate. A single multicast packet from coordinator to all sensors of non-critical group could accomplish the job. This will save the battery lifetime and reduces the number of packets and consequently packet loss collisions in the network.

V. Conclusion

In this paper, we discussed the issue of QoS in the WBAN. We distinguished several challenges in the QoS design of WBAN. Specifically, the QoS design needs to support interoperability between different platforms. To this extend, we propose to use CoAP architecture. In particular, the application of CoAP software protocol on the design of QoS in WBAN is examined. The CoAP framework includes several options such as caching, multicast and transaction field which have the potential to address the reliability and efficiency. Each option is examined in the context of QoS. The CoAP protocol is a promising future of sensor development and therefore, it is a suitable software to deploy as a universal and platform independent QoS technique.

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