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Design and implementation of a new quality of service-aware cross-layer medium access protocol for wireless body area networks☆

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ABSTRACT

Wireless body area networks (WBANs) consist of tiny sensors that enable monitoring the health status of a person. quality of service (QoS) is a major challenge for WBANs due to the importance of vital sign information. Therefore, many QoS-based medium access control (MAC) protocols and technologies have been developed to overcome this problem. Standardization of various technologies and protocols must be addressed. ISO/IEEE 11073 personal health data standards aim to provide interoperability between healthcare devices and technologies. This paper presents a new QoS-aware cross-layer MAC protocol based on the ISO/IEEE 11073 standards that employs a slot allocation scheme, multichannel architecture, priority mechanism, admission control, and cross-layer solution. The proposed MAC protocol has been modeled and simulated by OPNET Modeler. In addition, the proposed MAC protocol is compared with standard technologies and recent protocols in the literature, and it achieves better results for end-to-end delay, packet loss ratio, and throughput parameters.

1. Introduction

Health monitoring services are evolving to remote monitoring systems because of the freedom and mobility advantages. Remote monitoring increases the quality of life, improves usability, and decreases cost. Recently, WBANs are being used extensively for remote health monitoring applications. QoS and standardization are two of the major aspects of healthcare systems. Quality of health services should be considered based on the importance of human life. The term “QoS” has different definitions from various communities, but the International Telecommunication Union (ITU) interprets [1] it as “Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service”. In other words, the definition of QoS depends on the application requirements. The MAC layer is the most appropriate layer to provide QoS support for the application requirements in WBANs because the MAC layer regulates medium access and determines the performance of the system [2]. In addition, several problems, such as interoperability and subjectivity, are encountered due to the lack of common standards. Consequently, a communication protocol that provides QoS support and employs a public standard has become necessary.

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Table 1
Medical application classes in ISO/IEEE 11073.

Class: data type	Tolerable latency	Bandwidth
A: Alarms/alerts/positional alerts (real-time)	A1: <200 ms and A2: <3 s	Per alarm : 64 bytes
B: Person state	<3 s	Per alarm : 64 bytes
C: Sensor watchdog/heartbeat	<60 s	Per hour : 64 bytes
D: Remainder	<3 s	Per alarm: 1632 bytes
E : Physiologic parameters (real-time)	<3 s	E1: 10 bytes, E2: 100 bytes
F: Telemetry waveforms (real-time)	<300 ms	ECG: [F1: 3-lead 2.4 kbps, F2: 5-lead 10 kbps, F3: 12-lead 72 kbps], F4: ventilator : 50–60 bps, F5: SpO_2: 50–120 bps

In order to provide requirements of ISO/IEEE 11073 standards, we present a new QoS-aware MAC protocol based on ISO/IEEE 11073 [3] (also known as X73) standards. We approve the ISO/IEEE 11073 standards for implementation, as the standard is defined by two large standardization associations. The ISO/IEEE 11073 standards describe the required QoS for medical applications that enable interoperability in medical devices and focus on parameters, such as latency and bandwidth, to ensure QoS [4]. Medical application classes are specified explicitly in ISO/IEEE 11073. Table 1 shows the medical application classes, required bandwidth, and latency parameters in ISO/IEEE 11073.

The proposed MAC protocol guarantees QoS requirements of all subscribers as described in the ISO/IEEE 11073 standards. The developed slot allocation scheme allocates the number of required time slots for each node with reference to the data type class in the network. Therefore, the tolerable latency fulfilled by means of our scheme according to latency values at Table 1 and make a major contribution to delay performance which is about up to six times lower than other protocols. Also the proposed MAC protocol shows better throughput performance about up to twice as that of the other protocols for high traffic load due to robust scheduling scheme. A new priority classification contributes to improved network performance, such as throughput and latency, and provides heterogeneous traffic loads and different reliabilities. Channel allocation and bit error rate (BER) reduction mechanisms help maintain stability for reliability and that is about 0.0001% of the packet loss ratio. Admission control mechanisms balance the capacity of network. The details of the developed mechanisms are described in the next sections. In addition, the proposed MAC protocol leads to other ISO/IEEE 11073 standards-based MAC protocols.

The remainder of the paper is organized as follows. Section 2 provides an overview of the QoS-based MAC protocols for WBANs. Section 3 details the proposed QoS-aware cross-layer MAC protocol. In Section 4, a performance analysis of the network system using the proposed MAC protocol is clarified, and a conclusion is presented in the final section.

2. QoS-based MAC protocols for WBANs

Provisioning QoS is a very important issue in WBANs to improve healthcare facilities. Efficient MAC protocol design overcomes QoS support issue. Therefore, many MAC protocols have been proposed to support QoS. Several methods have been developed to provide QoS support with traffic differentiation mechanisms, priority mechanisms, and scheduling schemes. Time division multiple access (TDMA), carrier sense multiple access with collision avoidance (CSMA/CA), and improvised access mechanisms have been utilized for WBANs in the literature. In addition, latency, reliability, throughput, and energy consumption parameters are considered to support QoS requirements. We summarize the QoS-aware MAC protocols for WBANs in the literature as follows.

Two types of traffic, critical and non-critical, are defined in urgency-based medium access control (U-MAC) protocols. A priority mechanism assigns a priority to critical data that organize the data stream. Re-transmission of the packet after collision is prevented in non-critical traffic modes, which increases the capacity of the critical data stream [5].

Cao et al. present a superframe structure based on IEEE 802.15.4 that provides QoS. Guaranteed time slots (GTSs) are used for periodical traffics, and a contention access period (CAP) is utilized for channel access for critical traffics. Four types of parameters are defined in the protocol, and these parameters, namely priority, latency, arrival time, and burst size parameter, describe the QoS requirements. The proposed protocol is able to maintain a high traffic ratio percentage for time constraint compliance [6].

PNP-MAC (preemptive slot allocation and non-preemptive transmission medium access control) focuses on delay and throughput requirements to support QoS. The superframe structure consists of five phases: advertisement, CAP, beacon, data transmit slot (DTS), emergency data transmit slot (ETS), and an inactive period. Admission control is performed in the advertisement phase. Emergency data and command frames, as slot allocation requests, are transmitted during the CAP, and a short back-off time is allocated for high priority nodes. The nodes send their data during the allocated time slots in the DTS phase. The ETS phase is an extra period for emergency data [7].

Garcia and Falck define eight diverse priority classes and four access categories to send packets that provide QoS. The proposed protocol is based on IEEE 802.15.4 enhanced with a priority mechanism. A distributed access function (DAF) organizes the transmission queues with a priority-based CSMA/CA mechanism. The proposed protocol is implemented on the Philips AquisGrain platform, and the performance evaluation is compared to IEEE 802.15.4. The results show that the protocol is more efficient when compared with Zigbee [8].

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