QoS Provisioning in Wireless Body Area Networks: A Review on MAC Aspects

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Abstract

Wireless Body Area Networks (WBANs) deal with variety of healthcare services with diverse Quality of Service (QoS) requirements. However, QoS handling is a challenging problem in such networks. In general, QoS related problems can be addressed from different layers in the networking protocol suite. Design of an efficient QoS aware Medium Access Control (MAC) protocol can address this problem in MAC layer. This paper analyzes the QoS requirements of WBAN, identifies the requisites of QoS handling system, and outlines the trends that are being followed for its advancement with focus on QoS issues at MAC layer. We review some prior works, compare them, and analyze the current research concerned with problem of providing QoS in WBAN. We also explore some open issues and discuss them.

Keywords: WBAN, QoS aware MAC, IEEE 802.15.4, IEEE 802.15.6

A preliminary short version of this paper appeared in JCICT & YES-ICuC 2011, Aug 17-20, Weihai, China. This version includes a concrete analysis and comparision and discussion of additional novel MAC protocols along with detailed discussion of relevant standards, requisities, and open issues .

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1. Introduction

Wireless Body Area Network (WBAN) is a key technological breakthrough in healthcare. WBAN consisting of autonomous portable sensor nodes with intercommunicating radio interface is meant to monitor the patient's physiological parameters such as Electrocardiography (ECG), blood pressure, blood glucose level, etc., and feedback the updates to the physician or the authorized agents like family members and care givers via the means of powerful external computing devices such as Personal Digital Assistant (PDA) or cell phones [1][2]. The external computing devices also serve as incharge of resource management.

WBAN offers two main advantages over conventional healthcare [3]. First, it is cable-less so that people are not confined in a small region any more. Second, multiple information can be collected autonomously by employing variety of sensor nodes without need of human intervention. Such new paradigm brings a number of unique advantages on healthcare [4][5]. For instance, it can play considerable role on Ubiquitous Healthcare (U-Health), i.e. on sensing and monitoring of the patient's health round the clock and automatically update the status to the physician or the authorized agents irrespective of the location. Apart from that, WBAN can also be used on interactive gaming, military services, and entertainment [6].

WBAN operates in close vicinity to, on, or inside a human body by employing various sensor nodes. As such, WBAN is also often referred to as a subset of Wireless Sensor Network (WSN). However, in spite of some common characteristics, there exist considerable differences between them. The main differences reside in the type and requirements of applications. In particular, energy efficiency and Quality of Service[1] (QoS) requirements are much more important concerns in WBAN.

Sensor nodes used in implantable or wearable form in WBAN demand more energy efficient and miniaturized design in comparison to spatially scattered nodes in WSN. This requirement is more strict in case of in-body sensor nodes. As such nodes are used in implantable form, replacing the batteries, recharging them, or using higher weight batteries become inefficient approaches. In some cases, it may even require complex surgery.

WSN is generally used for event-based monitoring and deals with same type of traffic. Once any event happens, all the nodes in close proximity monitoring the environment sense that event and prompt for transmission. On the other hand, WBAN generally deals with heterogeneous traffic. Wide variations exist in the data generated by different healthcare applications. In essence, urgency, data transmission frequency, and delay-and-loss tolerances vary from application to application in WBAN. But, for right diagnosis and right prescription, medical personnel may need all the updates correctly and timely. A failure in timely delivery of the updates or a delivery with an error can impact severely and sometimes may even risk the patient's life. Therefore, prioritize data transmission with QoS guarantee is a primary requirement of WBAN.

Energy efficiency in WBAN is commonly practised by two different ways: efficient low power hardware design and efficient optimized network protocol design. Low power hardware design is a sensor design issue such as low-power sensor circuitry design, low-power transceiver design, signal processing, etc., [7]. Whereas, optimized network protocol design is

[1]Certain technical characteristics of data transmission such as guaranteed bandwidth, delay, jitter, and error rate.

an efficient communication protocol design issue such as efficient Medium Access Control (MAC) protocol design, efficient transport protocol design, and so on. More importantly, as coordinated and controlled channel access not only ensures reliability but also minimizes energy consumption, efficient QoS aware MAC protocol can address both the requirements of WBAN: energy and QoS. As such, recently, efficient QoS aware MAC protocol design is increasingly attracting the interest of researchers both from academia and industries [8-9].

In spite of high importance of QoS aware MAC protocol in WBAN, regarding the standardized MAC protocol, yet no specific standard is currently in run for WBAN. Although IEEE 802.15.6 work group has been formed in 2007 with an aim to come up with new standard with QoS inclusion [10], it has not been published yet. As of March 2012, it has only approved a draft version of the standard (detail in section 3). Even if we assume it to be released soon, it is obvious that it takes time to build up a ready module, ratify it, penetrate the market, replace the widely deployed previous networks, and then wind up in the end user's side. Regarding the present concern, basically IEEE 802.15.4 MAC protocol has been in use. IEEE 802.15.4 standard was originally devised for the Wireless Personal Area Network (WPAN), also known as zigbee [11]. However, this conventional MAC assumes that latency and data bit rate are not so critical and hence does not support the QoS directly [12][13]. All the incoming services in this protocol are treated in a same way and are served on First-Come-First-Served (FCFS) basis.

A multitude of protocols have been proposed to address energy efficiency in WBAN [14][15][16][17]. A review of some of these protocols can be found in [6][7]. Also there has been some prior works advising the QoS based MAC protocol for WBAN [18][19][20][21][22][23][24][25]. In addition, some QoS based MAC protocols were also proposed for IEEE 802.15.6 [26]. In this paper, we summarize these works and analyze the current research trends concerned with the problem of providing QoS in WBAN MAC layer. The primary objective of this paper are to:

- Introduce the QoS requirements of WBAN,
- Introduce the requisites of QoS handling system in WBAN MAC layer,
- Review prior works concerned with problem of providing QoS in WBAN MAC layer,
- Describe and study the new IEEE 802.15.6 WBAN standard and its QoS provision,
- Explore and discuss some open issuess.

The rest of the paper is organized as follows. In section 2, we discuss about the QoS demand in WBAN. Section 3 presents the QoS handling in WBAN from MAC layer. This section discusses about requisites of the QoS handling system in WBAN MAC layer, briefly discusses relevant standards and the limitation, summarizes the prior works, and compares them. Section 4 discusses the open issues. Finally, section 5 concludes the paper.

2. QoS Demand in WBAN

To enable WBAN services to be as smooth as possible, a number of design considerations needs to be met. WBAN should be designed on a practical way so that it can fit into people's lives in an unobtrusive manner. Biocompatibility between the sensor nodes and human body also should be fully tested to ensure no adverse effects or reactions to occur. Moreover, great emphasis should be placed on the data availability and the QoS.

Despite significant technological advances in wireless technology, QoS handling in WBAN is still a challenging job. Throughput, delay, jitter, and loss/error rate are the main QoS parameters in traditional networks. While, data criticality comes as an additional parameter in

WBAN. Loss, delay, or an error in life critical data can be highly problematic in WBAN. In addition, available energy level is another substantiating parameter. Aside from that, human body also presents various adverse fading effects to the WBAN channels. Channel characteristics can also vary with body size and posture [22]. At a same time, as WBAN employ low power sensor nodes with less computational capacity and buffer size, there exist risk of data drop and data error.

In traditional wireless networks, QoS is generally supported by prioritized QoS [27][28]. Prioritized QoS first categorizes the services into different Access Classes (ACs), like real time, non real time, best effort, etc., and then assigns different priority level to each of them such that channel access becomes the function of priority. Higher the priority is, higher will be the chance to access the channel and vice versa. However, once the priority is set, it remains unchanged on this approach. All the applications belonging to the specific AC always get the same access probability irrespective of any other constraints.

There is significant gap between traditional networks and WBAN. Since each of them deals with different applications, consumer electronics related applications and medical applications, respectively, great diversities in terms of traffic profile and QoS requirements exist there. QoS parameters, specially the level of criticality, vary from application to application in WBAN. Even a single application could have different QoS demand depending upon the patient's clinical condition. For example, ECG reading is often considered more important than body temperature reading in normal case and is assigned higher priority. However, during abnormal case when body temperature reaches very high, the priority is interchanged. Similarly, some of the applications are even correlated and attempt to send the updates simultaneously. For example, with the rise in body temperature, blood pressure and the heart beat rate also rise. However, if not managed properly during abnormal case when body temperature reaches extremely high, data redundancy and collision may occur. Similarly, even the real time traffic like multimedia traffic could be of different importance in WBAN. For example, multimedia traffic during surgery is highly important than the multimedia traffic during consulting and prescription. In addition, most of the non-real time traffic, like periodic blood glucose level update, do not have high delay constraint in normal situation. However, the delay constrain can be changed abruptly in abnormal situations.

Although WBAN also inherit almost all the QoS requirements of traditional networks, direct adoption of traditional QoS provisioning schemes do not fit well in WBAN. Data criticality and the condition dependent QoS requirements demand new QoS solution in WBAN. Most importantly, supporting critical data (emergency traffic) should always be considered as main issue in WBAN. Hence, as a whole, all these requirements and characteristics demand clear methodology and approach on design of an efficient QoS framework that can satisfy high degrees of data transmission reliability with specific latency requirements by assigning high priority to the critical data but without endangering the energy consumption and resource utilization in WBAN.

3. QoS Handling in WBAN from MAC Layer

In broad sense, QoS requirements for particular applications over Open System Interconnection (OSI) layered architecture network can be addressed from any of the layers of the networking protocol suite. For example, one of the important QoS issues like reliability can be addressed from three different layers: transport, MAC, and Physical (PHY). In transport, use of efficient congestion control mechanism could enhance the reliability. In

MAC, using efficient error correction mechanism could enhance the reliability. Similarly, in PHY, using efficient modulation and coding technique could address the reliability. Similarly, another important QoS metric energy efficiency can also be addressed from multiple layers, for example network layer and MAC layer. In network layer, using efficient routing protocol and route discovery algorithm could save energy. Whereas, in MAC layer, collision resolution and duty cycle adjustment mechanisms could save energy. Apart form the single layer technique, QoS requirements can also be addressed from a cross layer technique as well. For example, the QoS requirements at the application layer can be informed to the MAC layer for efficient scheduling and the channel quality in PHY layer can be informed to the network layer for selecting a path with good channel state.

As common to all existing networking technologies, WBAN also follows the OSI layered architecture to maintain end-to-end connection between two entities in the network. Hence, QoS requirements of WBAN can also be addressed from various layers and cross layer techniques. For example, [29][30] have proposed QoS aware routing protocols for WBAN. [29] has proposed a protocol called Data-Centric Multiobjective QoS Aware routing (DMQoS) to address delay, reliability, and energy requirements. DMQoS facilitates to achieve QoS for each traffic differentiated according to the generated data types. It exploits geographic locations and QoS performance of the neighbor nodes to implement localized hop-by-hop routing. [30] has proposed new QoS and geographical routing to address energy requirement. This protocol classifies the data traffic into several categories according to the required QoS metrics and then attempts to fulfill the required QoS in a power aware way, by selecting the best candidate for routing. Similarly, [31] has proposed the cross layer designed QoS-aware routing. In this protocol routes are determined by user specific QoS metrics, channel status, packet priority level, and sensor node's willing ness to be a router. The layer design also facilitates routing service to send feedback on network conditions to the user application in order to adjust medical application service level.

MAC layer also plays vital role both on energy saving and QoS handling in WBAN and is becoming an important field of research. In what follows we describe the desirable properties of QoS handling system in MAC layer and review some prior works.

3.1 Desirable Properties of QoS Handling System in MAC Layer

QoS does not mean to prioritize the traffic only, it is also an act of managing available resources in an efficient manner. In MAC layer, QoS refers to resource reservation and error control mechanism. Therefore, in general, following are the major requisites that the QoS framework needs to prescribe in WBAN MAC layer.

3.1.1 Priority Mapping

Priority mapping in MAC layer is an act of classifying the services into different service classes according to their service parameters in order to facilitate them during medium access. Higher priority data are assigned higher chance to access the medium and vice versa. For instance, on the top of these concepts priority mapping for the WBAN services can be performed as exemplified below in **Table 1**.

Table 1. Priority Mapping, An Example

Service Type	Access Class	Priority	Priority Level
Emergency Alarm	AC 1	Highest	5
Real Time Periodic	AC 2	High	4
On Demand	AC 3	Medium	3
Non Real Time Periodic	AC 4	Low	2
Best Effort	AC 5	Lowest	1

Emergency service class can include the services that are critical and have highest delay sensitivity. It can represent the services like alarm triggered by sensor nodes on detecting the abnormal or the life threatening conditions. For example, alarm signal at detecting extremely high blood pressure beyond the threshold or extremely high body temperature.

Real time periodic[2] service class can include the services which need an end-to-end delay satisfaction. Reception of data with latency or out of order can be meaningless in many cases such as multimedia related traffic during diagnosis or surgery. This type of service needs to be communicated in real time and are often periodic in nature.

On demand service class can include the services like receiving feedback from sensory nodes or the database in response to the command initiated from higher layer. Command can be initiated by the coordinator or the physician.

Non real time periodic service class can include the services that need to provide the updates in a gap of some time interval either to the coordinator or the physician just for sake of update or for record keeping purposes. For example, insulin sensor set to send the data 4 times a day in the interval of 6 hours, and so on. Loss of such data momentarily or received with delay by small amount of time can be adjusted and will not be highly problematic.

Best effort service class can include all other non detrimental services. This class can include the services such as patients record file transfer, physician's note transfer, etc.

Note that, although **Table 1** exemplifies the priority mapping in terms of service parameters, each service classes can be further re-classified and re-prioritized with respect to energy level and subset of service parameters within themselves.

3.1.2 Resource Allocation

Resource allocation determines the amount of resources, bandwidth and time, to be assigned to the traffic. QoS framework should take into account the QoS parameters and available network resources during resource allocation. When it comes to WBAN applications, as different sensors aim at different service goals and therefore have different QoS requirements, they might face entirely different resource allocation problems. For example, one can be severely energy sensitive, whilst the other can be bandwidth limited or throughput hungry. Different sensors at different time and locations may also suffer with different channel condition and different services may also demand different capability. Fixing and allocating resources without considering such characteristics, like in traditional networks, can waste system resources and degrade the performance. Therefore, during resource allocation, care should be given for dynamic allocation and optimized utilization of the available resources.

3.1.3 Admission Control

Admission control regulates the traffic volume in the system. Whilst, QoS admission control is responsible to determine the amount and the types of traffic to be admitted into a system on such a way that QoS of the existing as well as newly admitted traffic will not be degraded.

WBAN QoS admission control should admit the request based on the level of QoS parameters, energy availability, and resources utilization. Furthermore, it should possess both the capacity based admission control and the QoS based admission control strategies. Until the capacity is exhausted, it can involve the capacity based admission control by indiscriminately admitting new request. While, after exhaustion of capacity, it should allow more prioritized flows to preempt less prioritized flow.

[2] Periodic in the sense that most of the services in WBAN are periodic in nature.

3.1.4 Error Control
The main role of the error control mechanism is to assist on reliable and fast delivery of the data. As wireless channels are highly affected by unpredictable factors such as interference, path loss, fading, etc., the transmitted signal undergoes transmission impairment. In such cases, complementary error control mechanism is essential to recover the data correctly. The error control schemes transmit some redundant data with the original one such that consistency of the delivered data can be checked or corrected. Rather than saving from error, these phenomenons save from lost that could occur from error. For example, Forward Error Correction (FEC) and Cyclic Redundancy Check (CRC) are widely used error control mechanism in wireless networks. In WBAN, as it is low power network and channel characteristics varies frequently, care should be given to adaptive error control that can work as a function of the channel characteristics and desired level of QoS.

3.1.5 Transmission Reliability
Even though the error control mechanism is applied to recover the data from loss, in many cases transmitted data can be lost due to poor channel quality and collision. To realize reliability of data delivery, the lost packet should be retrieved. Lost detection and automatic retransmission scheme is one of the solutions to this problem. For example, retransmission mechanism like Automatic Repeat reQuest (ARQ) is the commonly used retransmission scheme in wireless networks. However, when it is concerned to the retransmission of QoS constraint packets in WBAN, care should be taken. The delay associated with retransmission might not be able to sustain the delay constraints in many healthcare applications. Therefore, to tackle this problem, adaptive retransmission scheme that work as a function of the channel characteristics and the level of QoS should be provisioned in WBAN.

3.1.6 Energy Awareness
The MAC layer is not only responsible for coordinating channel access mechanism and scheduling the data transmission for addressing reliability and latency. Instead it is also responsible for minimizing the energy consumption. Prolonging network life time of the sensor nodes is a critical issue in WBAN. Therefore, it is also desirable that the MAC protocol in WBAN should also take into account the available energy level when assigning the priority on transmission. Energy critical nodes should be given high priority with minimum collision probability.

3.2 Overview of Relevant Standard

3.2.1 IEEE 802.15.4 MAC

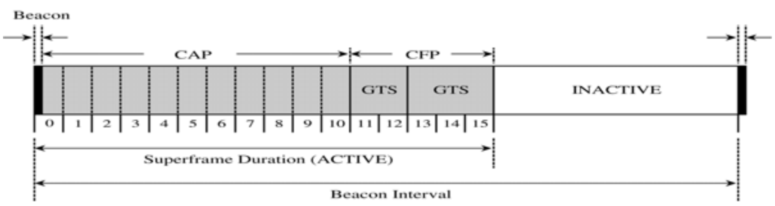

Fig. 1. IEEE 802.15.4 superframe

IEEE 802.15.4 is a low-power protocol designed for low data rate applications in small area network. It allows two types of channel access mechanisms: beacon enabled and non-beacon enabled (beacon-free). In beacon enabled mode, coordinator starts the superframe that consists of a beacon, an active period, and an inactive period, as shown in **Fig. 1**. Superframe starts with a beacon signal and the nodes need to be synchronized with it. Beacon signal carries an information about the superframe format, identity information, etc.

Superframe is divided into 16 equally sized slots and the coordinator defines an active and inactive period out of them. Active period is further divided into Collision Access Period (CAP) and Collision Free Slots (CFS). Nodes access CAP with slotted CSMA/CA. While, the CFP contains Guaranteed Time Slots (GTSs). GTSs are assigned by the coordinator in response to GTS request. There could be seven GTSs at maximum in one superframe. Advantage of this mode is that the coordinator can communicate at its will with all nodes. Disadvantage is that the nodes must wake up to receive a beacon even though they have nothing to send.

In non-beacon enabled mode, a coordinator does not transmit any beacon and nodes do not need to be synchronized. GTS is not permitted in this mode. All the transmissions use un-slotted CSMA/CA to access the channel. Advantage of the non-beacon mode is that the node does not have to regularly power-up to receive a beacon. Disadvantage is that the coordinator cannot communicate at its will with the nodes but must wait to be polled by them.

• IEEE 802.15.4 Limitation: The first and foremost problem with the current IEEE 802.15.4 is on its GTS allocation. Using it in WBAN, the current GTS allocation sometimes may rise the problem of bandwidth under utilization and sometimes the problem of bandwidth scarcity. If nodes use only a small portion of the allocated GTSs, the major portion will remain unused. On the other hand, as the protocol explicitly supports seven GTSs at maximum, different applications may face bandwidth scarcity problem. Even one application in WBAN can involve tens of sensor nodes, e.g. ECG. In addition, as a single node can request for all seven GTSs, such unbalanced slot distribution can block other needful nodes. Apart from that, the current IEEE 802.15.4 superframe structure contains a constant size CAP. While, for most urgent scenarios, WBAN may need flexible size CAP.

In non-beacon enabled mode only random access is adopted for medium sharing without the consideration of any of the QoS requirements and hence it is always prone to collision and delay.

3.2.2 IEEE 802.15.6 MAC

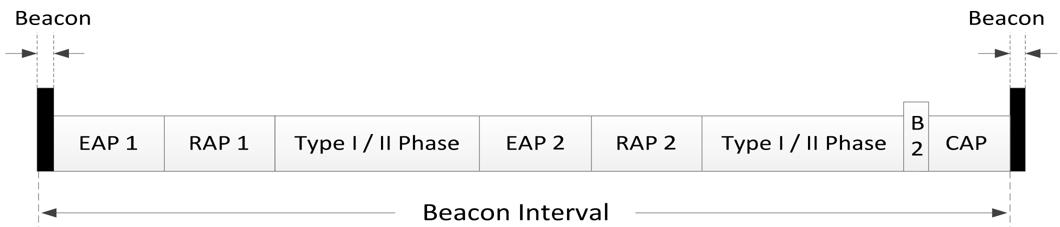

Fig. 2. IEEE 802.15.6 superframe

The purpose of the IEEE 802.15.6 task group was to define new PHY and MAC layer specifications for WBAN. As of March 2012, it has only approved a draft version of the standard. The draft version has defined three transmission modes: beacon mode with superframe boundaries, non-beacon mode with superframe boundaries, and non-beacon mode without superframe boundaries. In first, as shown in Fig. 2, superframe is divided into Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), type-I/II Access Phase, Exclusive Access Phase 2 (EAP2), Random Access Phase 2 (RAP2), type-I/II Access Phase, Beacon 2 (B2), and CAP. EAP1 and EAP2 are dedicated for highest priority traffic, e.g.

emergency traffic. While, RAP1, RAP2, and CAP are for other traffic. The Type I/II phases are for scheduling uplink allocation intervals, downlink allocation intervals, bilink allocation intervals (both directions), and delay bilink allocation intervals. Whereas, B2 frame is to indicate the begin of the CAP phase. In non-beacon mode with superframe boundaries, there is no beacon. However, superframe and allocation slots are established as channel access involves time referencing. The start of the current superframe is indicated by the timed frame called T-Poll. In this mode, entire superframe is consist of either Type I or Type II phase. In non-beacon mode without superframe boundaries, on the other hand, there is no superframe boundary and time referencing information; hence only unscheduled Type II polled access is supported.

For the channel access, three mechanisms have been provisioned in IEEE 802.15.6: random access mechanism, which uses either CSMA/CA or a slotted aloha procedure, improvised and unscheduled access, which uses unscheduled polling/posting for resource allocation, and scheduled access and variants, which schedules the allocation of slots in one or multiple superframes.

For QoS provisioning, eight access categories has been defined in IEEE 802.15.6: background, best effort, excellent effort, controlled load, video, voice, media data or network control, and emergency or medical event report. Their priority is in ascending order, respectively. The priority is assigned via contention window alteration, e.g. high priority emergency data has minimum contention window of 1 and maximum contention window of 4, whilst low priority background data has minimum contention window of 16 and maximum contention window of 64. **Table 2** shows the difference between IEEE 802.15.4 and IEEE 802.15.6 briefly.

Table 2. Difference between IEEE 802.15.4 and IEEE 802.15.6

	IEEE 802.15.4	IEEE 802.15.6
Frequency	868/915 MHz, ISM	Medical authorities approved band for in-body and other for out-body
Channel	Air	Body and Air
Application	Small home/office	Medical, entertainment, gaming
Range	10-100m	2-5m
Data rate	up to 250 Kbps	up to 10 Mbps
QoS	Not defined	Six ACs with QoS prioritization for random access, scheduled access, unscheduled and improvised access
Energy	Low power	Extremely low power

3.3 QoS Handling Protocols in MAC

3.3.1 U-MAC

Urgency based MAC protocol for WBAN, U-MAC, is a priority access mechanism to allow sensor nodes with urgent health information contend for the channel more than the nodes with non urgent information [18]. The traffic are classified into two classes: critical and non critical. According to the associated traffic types, nodes are labeled critical and non critical nodes, respectively. Then the QoS is supported through differentiated nodal access, i.e. by cutting-off the number of packet retransmissions for non critical nodes to increase the access probability of critical nodes. It has considered aloha based channel access scheme in IEEE 802.15.4. The main consideration of the protocol is on the system design. Based on the performance results, this protocol can help on adjusting the critical node's packet retransmission times for supporting a certain number of critical nodes with desired traffic arrival rate, or achieve certain arrival rate for a given number of critical nodes.

3.3.2 Employing IEEE 802.15.4 for QoS in WBAN

Employing IEEE 8025.15.4 for QoS in WBAN [19], proposes a QoS provisioning framework by employing IEEE 802.15.4 superframe structure in beacon enabled mode. It defines four QoS parameters to specify the QoS requirements. Priority of the applications, delay constraint, arrival rate, and the available burst size are considered. According to the parameters, traffic are differentiated into three service classes: Alarm/Control (AC), Command/Data (CD), and Routine Traffic (RT). Their priority level is in descending order, respectively. Furthermore, with in their own class the traffic are re-prioritized again with respect to their urgency.

The framework utilizes both the CAP and CFP. AC and CD class traffic are transmitted in CAP employing slotted CSMA/CA scheme. As AC class traffic holds higher priority than CD, it is assigned smaller backoff value than the CD. For example, backoff value equal to 2 is assigned for CD traffic and 0 for AC traffic. The RT class traffic are assumed to arrive in larger volume on periodic fashion and are provisioned to transmit on CFPs.

Admission request is processed with respect to corresponding traffic's priority. For example, on receiving the admission request, AC or CD traffic is determined immediately and is handled by admission controller itself. While for the RT class traffic, admission controller handover it to the scheduler to make a decision. Scheduler determines whether to accept or reject the request based on network parameters and current CFPs status.

3.3.3 QoS for IEEE 802.15.4 based WBAN

QoS for IEEE 802.15.4 based WBAN [20] also defines QoS provisioning scheme in IEEE 802.15.4 with service differentiation and prioritization. It differentiates the traffic into different service classes and prioritizes them. Application layer classifies the traffic into 8 different classes at first. While, at second, those 8 classes are mapped into four different classes by MAC layer. According to access class types priority is assigned at scheduling. Higher priority class has higher chance to be selected and vice versa. In addition, to enhance reliability, different MAC layer parameters are also altered during prioritization. Along with the change in contention window size, maximum retry value and maximum/minimum backoff value are also changed.

3.3.4 Secure and QoS Assurance Scheduling Scheme

Additionally with the scheme for secure and authenticated data transfer, secure and QoS assurance scheduling scheme [21] classifies the traffic broadly into real time and non real time at first. Again the real time traffic are further classified into different subclasses based on the weighting factor in terms of QoS parameters. Classified traffic are stored into high and low priority queues. The scheduling solution is applied then to minimize the mean waiting time of the high priority traffic. High priority queue is served in higher rate than low priority queue. Furthermore, it selects the packet from the queue for the next servicing only after ensuring that the running process will finish its task first.

3.3.5 BodyQoS

BodyQoS [22] is an asymmetric architecture adapted radio-agnostic QoS MAC and is able to provide adaptive resource scheduling. Mainly it consists of three components: admission control, QoS scheduler, and virtual MAC. Admission control and scheduler components are implemented as a master and slave module both on the aggregator and the sensor nodes.

Admission control module has two main functions. First, to accept or reject new QoS reservations. Second, run time estimate of the effective bandwidth. Admission control decision is made based on the requested bandwidth, delay constraint, and priority. It also considers the available wireless resources, previous reservations, and the estimated effective channel bandwidth.

BodyQoS defines three types of traffic: aggregator to mote, mote to aggregator, and best effort. In each transmission period the bandwidth is first assigned to the aggregator to mode traffic. The aggregator generates the polling packets for the mote to aggregator transmission. Polling packet consists of the information about the number of data packets to be sent and the granted time interval. In response to the polling packet, the scheduled nodes send the data packets. After every cycle, aggregator measures the effective bandwidth considering the assigned number of data packets, received number of data packets, and the assigned time interval. The fundamental information required here is how to determine the number of data packets and time interval. For these requirements, there are two solutions: Resource Reservation-Light (RSVP-Light) QoS scheduling and adaptive QoS scheduling.

In RSVP-Light QoS scheduling, it assumes the traffic as the audio/video stream that needs fixed bandwidth and time for data transmission without retransmission provision[3]. This scheme ignores the current channel condition. However, adaptive QoS copes up with this situation. As it can know the idle case scenario, best case scenario, maximum and minimum number of packets that could be transmitted, and the average effective bandwidth shift from earlier knowledge, adaptive QoS calculates the required data packets and time interval dynamically.

3.3.6 Scalable and Robust MAC in WBAN

As the channel sensing is not appropriate and accurate always due to low Signal to Noise Ratio (SNR) and probability of hidden nodes, the scalable and robust MAC protocol [23] proposes another contention based method in CAP without carrier sense. It proposes an aloha based mechanism using minislots in CAP. One slot in a superframe consists of four minislots. Minislots are used only for the command packets and lightly loaded best effort data packets transmission. When the node transmits its request command using minislot, the coordinator allocates dedicated slots to the node in the CFP. Then the node transmits data frames in the next superframe at the appropriate CFP slot. In this protocol, there is no limitation for the CFP duration. It can be flexibly adjusted. It may be zero if there is no CFP traffic. While, it may occupy whole active portion of the superframe at maximum.

3.3.7 DQBAN

DQBAN [24] uses fuzzy-logic decision technique based scheduling algorithm. The TDMA slots are divided into access subslots and those access subslots are further divided into access minislot and data subslot. Sensor nodes send the contention based access request in the access minislots and collision free data in the data subslots. Associated with these two types of transmissions, all the sensor nodes join two separate queues, namely, Collision Resolution Queue (CRQ) and Data Transmission Queue (DTQ).

The coordinator broadcast the feedback packet to update the CRQ and DTQ. If CRQ is empty and DTQ is not, then the sensor node can send the access request by randomly selecting the access minislots. If the request is sent successfully (which can be known from feedback packet), it can take its place in DTQ. If DTQ is empty, then it can directly transmit the data. Otherwise, in case of DTQ already occupied, the sensor node applies the fuzzy-logic

[3]It assumes out of order or late reception of the packets, like audio video packets, is not applicable.

algorithm in order to demand collision free data slots. The fuzzy logic algorithm determines how favorable or how critical is the specific situation is for that particular node. If the situation is favorable, it sends its decision to forward the packet, if not, it sends decision to delay. Through feedback packet the coordinator broadcasts about the specific changes made thereafter. In case of urgency, a sensor node occupying other position in DTQ except first can send an alarm message as well.

A fuzzy logic approach allows each sensor node to individually take a decision considering multiple input variables such as SNR, packet waiting time, and residual battery life to demand the data slots or to refuse it (in case of already assigned data slots are inappropriate).

3.3.8 PNP-MAC

PNP-MAC [25] provides QoS in accordance with the priority of traffic. It handles the QoS requirements through preemptive slot allocation and non preemptive transmission. In preemptive, slots already assigned for low priority applications can be used by high priority applications. Emergency data is assigned higher priority, then the continuous data, periodic data, and non periodic data, respectively.

In PNP-MAC the superframe is divided into five periods: advertisement, CAP, beacon, Data Transmit Slots (DTS), and Emergency Data Transmit Slots (ETS). Remaining part of the superframe is inactive. In advertisement period, BAN coordinator advertise the network related information to the newly adjoining nodes, e.g. BAN identifier and superframe information. CAP and ETS are contention based while DTS is TDMA based. However, priority during data transmission is applied on both the cases. During CAP nodes send the DTS allocation request on contention based access following the prioritized backoff. Higher priority data select the lower backoff value and vice versa. On receiving the request, coordinator assigns the DTS and announces the allocation status via beacon. DTS are also assigned according to the priority. Higher priority data are assigned first and vice versa. In case of insufficient DTS, higher priority data can preempt lower priority data. After a beacon TDMA starts; consisting of DTS and ETS. ETS is contention access slot reserved for urgent delivery. It assumes that emergency rarely happens, so even if DTS is not sufficient then coordinator can assign it to nodes. However, to give higher priority and collision free emergency data transmission, nodes trying to preempt the ETS need to go through Clear Channel Assignment (CCA) for certain duration of time.

3.3.9 QoS MAC Proposals in IEEE 802.15.6

As mentioned earlier, QoS based MAC protocol design for WBAN is increasingly attracting the interest of researchers both from the academia and the industries. As such, many proposals were presented for IEEE 802.15.6 from individual as well as group. For example, group of research institutes like GE Global Research, Philips, Texas Instruments, and Toumaz Technology proposed MAC called MedWin [32], National Institute of Information and Communication of Japan proposed NICT [33], IMEC-NL and Holst Centre proposed IMEC [34], Samsung Electronics proposed Samsung [35], Inha university Korea with Electronics and Telecommunication Research Institute (ETRI) proposed Inha [36], Fujitsu Laboratories of Europe Limited proposed Fujitsu [37], etc. All of these protocols have claimed to be compatible with IEEE 802.15.6 QoS requirements. However, MedWin, Inha, and IMEC have explicitly defined QoS and most of their main stream ideas have been included in the draft version. Here we present their brief discussion.

MedWin proposed three types of access mechanism: scheduled access (1-periodic, m-periodic), improvised access (polls and posts), and random access (CSMA/CA). In schedule access, node initiates the connection by sending connection request frame to the coordinator and the coordinator grants the connection by sending connection assignment frame. In improvised access, coordinator can allocate connection immediately (refereed as short distance) in the following beacon period or can allocate in later beacon period (referred as long distance). If node needs bandwidth beyond the schedule allocation, it can request poll with more data bit in header of control frame in this MAC. In random access, beacon advertises two random access phase RAP1 and RAP2. However, different to the IEEE 802.15.6 draft version, first phase starts immediately after a beacon signal while second phase starts at half of the beacon interval. Latency less than 1 second is guaranteed for urgent data via two access methods. Improvised access permits to transfer data outside of scheduled allocations to satisfy latency constraints and random access with QoS prioritization (as mentioned above in draft version) gives high transmission probability to urgent nodes.

In Inha MAC, WBAN traffic is first categorized into three classes: emergency, normal, and on-demand. Normal traffic is further classified into high traffic, medium traffic, and low traffic. High traffic represents the traffic that needs frequent wake-up, e.g. wake-up per minute. Medium traffic represents average wake-up, e.g. wake-up per hour, and low traffic represents minimum wake-up, e.g. wake-up per day. Both the coordinator and nodes wake up by following the traffic pattern. For example, for normal traffic nodes send data based on the wake-up table, while in on-demand traffic it receives wake-up signal from coordinator and respond, and in emergency traffic it immediately sends the data if threshold is crossed. Beacon carries the information about the channel and GTS allocation. Coordinator knows the wake-up time of the respective nodes and transmits the beacons exactly at an appropriate time. While in emergency case, nodes triggers itself to wake up and sends a wake-up signal to the coordinator.

IMEC proposed priority guaranteed MAC in beacon enabled mode. In this MAC, active part of superframe is slotted into beacon, application specific uplink control channels AC1 and AC2 provisioned with randomized slotted aloha, and traffic specific data channels separately for periodic traffic (regular basis) and bursty traffic (per session/packet basis) provisioned with TDMA. AC1 is used for emergency traffic while AC2 is used for other traffic. Slot size is flexible in this MAC. Control channels use basic slot size that could accommodate one control packet and the acknowledgement packet. While, data slots can vary to facilitate low to high data rate. To address scalability and to enhance resource utilization, it has provisioned adaptive tuning of the size of AC1 and AC2. Nodes listen to beacon for synchronization in every frame only if clock drift is restricted, else, nodes can listen to the beacon only when it expects information from the coordinator.

3.4 Comparison and Discussion

We compare the general aspects of above discussed protocols in terms of targeted network, properties, and QoS addressing. **Table 3** presents the comparison.

Targeted network column presents the network frame structure that have been followed by the respective protocols discussed above. They have either followed IEEE 802.15.4 or IEEE 802.15.6 with beacon enabled mode or beacon free mode. However, QoS assurance scheduling protocol [21] has only discussed the scheduling solution and has not specifically defined the framework. Property column summarizes the fundamental concept of each protocol. QoS addressing column, which has been classified again into five different columns, presents what type of desirable properties the protocol satisfy. Priority mapping, represented as PM, column presents whether they have priority mapping property or not.

Table 3. Comparision of Prior Works

Protocol	Targeted Network	Property	QoS Addressing				
			PM	RA	AdC	EC*	EA
U-MAC	IEEE 802.15.4/ Beacon enabled	Nodes with urgent health information contend for the channel more	Yes	No	No	No	No
Employing IEEE 802.15.4 for QoS	IEEE 802.15.4/ Beacon enabled	High priority traffic is assigned smaller backoff value	Yes	No	Yes	No	Yes
QoS for IEEE 802.15.4	IEEE 802.15.4/ Beacon free	Priority is assigned at scheduling, higher priority class has higher chance to be selected and vice versa	Yes	No	No	No	No
QoS Assurance Scheduling	-	Traffic are stored into high and low priority queues, scheduling solution to minimize the mean waiting time of the high priority traffic, selects the packet from the queue for the next servicing only after ensuring the running process will finish its task first	Yes	Yes	No	No	No
BodyQoS	IEEE 802.15.4/ Beacon free	Run time estimate of the effective bandwidth, adaptive resource scheduling calculates the required data packets and time interval dynamically and assigns the access via polling	Yes	Yes	Yes	No	Yes
Scalable and Robust MAC	IEEE 802.15.4/ Beacon enabled	Node transmits request command using minislot, coordinator allocates dedicated slots to the node in the CFP, no limitation for the CFP duration, CFP can be flexibly adjusted	Yes	Yes	Yes	No	Yes
DQBAN	IEEE 802.15.4/ Beacon free	A fuzzy logic approach is used to allow each node to individually take a decision considering multiple input variables such as SNR, packet waiting time, and residual battery life	Yes	Yes	No	No	Yes
PNP-MAC	IEEE 802.15.4/ Beacon enabled	Slots already assigned for low priority applications can be used by high priority applications	Yes	No	No	No	No
MedWin	IEEE 802.15.6/ Beacon enabled	In schedule access, node initiates the connection by sending connection request frame to the coordinator and the coordinator grants the connection by sending connection assignment frame, improvised access permits to transfer data outside of scheduled allocations to satisfy latency constraints, and random access with QoS prioritization gives high transmission probability to urgent nodes according to the priority level	Yes	Yes	No	No	Yes
Inha	IEEE 802.15.6/ Beacon enabled	For normal traffic, nodes send data based on the wake-up table, while in on-demand traffic it receives wake-up signal from coordinator and respond, and in emergency traffic it immediately sends the data if threshold is crossed	Yes	No	No	No	Yes
IMEC	IEEE 802.15.6/ Beacon enabled	Two control channels, one is specifically dedicated to emergency traffic, adaptive tuning of control channels to address latency, utilization, and scalability, flexibility in slot size to accommodate high to low data rate	Yes	Yes	No	No	Yes

PM: Priotity Mapping, RA: Resource Allocation, AdC: Admission Control, EC: Error Control, EA: Energy Awareness
*EC except the default FEC in MAC frame

It can be observed that all the discussed protocols have adopted priority mapping to differentiate and prioritize the services during channel access. Resource allocation, represented as RA, column presents whether they satisfy the QoS aware resource allocation or not. It can be observed that BodyQoS, scalable and robust MAC, DQBAN, MedWin, and IMEC considers each incoming traffic and assign priority on run time basis, taking into consideration the QoS parameters, channel utilization, and available resources in order to allocate the resources.On the other hand, rest of the protocols assign fixed priority and do not support adaptive resource alloation. Admission control, represented as AdC, column presents whether they have facilitated QoS aware admission control or not. It can be observed that [19][22], and [23] have facilitated the QoS aware admission control while rest of the discussed protocols have not specifically mentioned the admisson control. Energy awareness, represented as EC, column presents whether they have considered supplimentary error correction method or not. Supplimentary in the sense that the extra EC method than the default FEC or CRC. Again it can be observed that none of them have addressed EC. At last, EA column shows the protocol's awareness towards energy during prioritization or access grant. For instance, IEEE 802.15.4 for QoS protocol considers the remaining energy in the node during prioritization. Similarly, BodyQoS, DQBAN, and all the proposed MAC in IEEE 802.15.6 also consider the energy parameters while prioritizing the services and have energy awareness. However PNP-MAC, and rest of the other protocols do not take energy into consideration during prioritization.

4. Open Issues

To this end, it can be known that QoS based MAC protocol design is one of the important fields of interest in WBAN. In order to address the energy efficient and reliable data transmission, there is no other general alternatives than the QoS based MAC protocol implementation. However, since QoS parameters are application specific and numerous applications with varied QoS requirements exist, globally categorizing the applications into certain classes and prioritizing each of them like in traditional networks and few of the above discussed protocols could not cover all the essential aspects. On the other hand, assigning the run time prioritization scheme could add control overhead and scheduler burden. Similarly, in some cases, applications criticality and the QoS parameters even need to be identified and defined by medical personnel according to their needs. Hence, the flexibility while tuning the MAC parameters should also be concerned.

Although the prior works discussed above have discoursed the QoS handling in some aspects, all of them have their own pros and cons, as can be seen in **Table 3**. All of these protocols have been developed considering the different applications where each of them considers different trade-off factors. Although these innovative protocols have been proposed with an objective to enhance the WBAN QoS performance, non of them can simultaneously satisfy all the desirable properties such as energy efficiency, data reliability, high throughput, low delay, and good fairness while maintaining the simplicity of implementation and operation in real WBAN scenario. Hence, QoS handling is one of the important but yet a challenging issues in WBAN.

Apart from the trends that are being followed here, there can be other numerous alternative approaches too. One of such future interest can be the implementation of Multiple Input Multiple Output (MIMO) antenna system in the coordinator side or to include cooperative virtual MIMO concept in the network. MIMO can enhance the transmission reliability employing diversity technique. Although, it is generally assumed that the high probability of a

Line-Of-Sight (LOS) and the subsequent correlation between the subchannels prevents MIMO from offering benefits in small area network like WBAN, it has been already dispelled in case of WPAN [38]. Another approach can be introduction of cross layer techniques to control the spatial range or other MAC parameters. Similarly multi-hop network solution for medium access and routing can also hold the importance. Furthermore, as the application domain of WBAN has been greatly widen and is supposed to deal with various applications with varying data length, efficient data manipulation technique, compression or aggregation, is also an emerging need in WBAN.

Apart from the different research goals mentioned above, the initiative research approach towards integration of WBAN with various existing networks with end-to-end QoS provisioning MAC can provide a landmark in the U-Health development. Since WBAN is low power personal area network, its service coverage is not wide. While, to facilitate the U-Health service, the patient's healthcare updates should be available anytime and anywhere without disruption. The corresponding agents should also be able to archive the patient's earlier healthcare history without any hinderance. To facilitate the seamless U-Health services, it becomes important to integrate WBAN with other outgoing networks, like cellular networks, Wi-Fi networks, satellite networks, etc. Not only the link connections, instead, the integrated network also has to maintain end-to-end QoS along with other substantive parameters of data transmission. As two or more than two types of network each having different protocol stacks are integrated, the end-to-end QoS support is always a challenging job. Blindly categorizing the streams and mapping the traffic with one another QoS module could not satisfy the QoS demand of WBAN (e.g emergency traffic in WBAN mapped to real time traffic in cellular networks could be problematic). Furthermore, various factors like network load and efficiency of routing in intermediate network nodes also affects the QoS performance. In addition to aforementioned, mobility management is also one of the important tasks to be considered here [39]. When it comes to WBAN case, it has to look after both the intra and inter WBAN mobility. The high host mobility of the human body and the attached sensor nodes make the mobility management task more challenging. Even a small body movement in the low power and small scale network may sometimes cause a complete change in network topology and may break the connection or degrade the channel quality in a WBAN. While, for patient movement in home, hospital, and outside environment, efficient handoff management is pivotal. Hence, for the sake of fine-grain QoS assurance newly defined QoS parameters and end-to-end QoS solution with MAC-to-MAC connection protocol is desirable.

One of the probable solutions to address the aforesaid issue could be appropriately adopting some policy layer that dynamically manages an overall operation in an intelligent way, e.g. Self Organizing Network (SON). The concept of SON has already been a main stream idea in different networks [40]. The main goal of SON in an integrated network is to provide a flexible and automated control plane so that the services even in a complex mesh of different networks could be handled in self-organized way. To achieve better service quality in an end-to-end manner and to ensure easy usage of communications services, SON can be thought of as empowered with the capabilities of intelligent traffic identification, effective service classification and prioritization, topology discovery, and error discovery and self healing. Recently, the SON concept also has been widely studied. However, when it comes to WBAN case, still there exist some challenges like complexity, stability, robustness, scalability, etc., and needs more explorations.

5. Conclusion

In this comprehensive survey, we discussed and summarized core issues required to be considered while handling QoS in WBAN MAC layer. Efficient QoS based MAC protocol for WBAN should handle the admission control, data prioritization, and the transmission assighnment in a different and more efficient way than other traditional networks. We highlighted some of the requisites of these issues in WBAN. We also summarized some prior works related to these issues and also presented the trends that are being followed to address these issues. We also highlighted the pros and cons while implementing some of these issues in one or different ways. We discussed the open issues and also presented some future research directives.

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