A Resource Management Mechanism of WBAN for Wireless USB Support

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Abstract

In this paper, an IEEE 802.15.6 wireless body area networks (WBAN) medium access control protocol is developed to support a wireless USB (WUSB) application as a protocol adaptation layer (PAL). However, current WBAN protocol still does not have well-defined QoS mapping and resource allocation mechanisms to support multimedia streams with requested QoS parameters. To solve this problem, we propose a novel Resource Management Mechanism (RMM). The proposed method provides fair and adaptive QoS provisioning to isochronous streams according to current traffic loads and their requested QoS parameters through executing a satisfaction of QoS algorithm at WUSB/WBAN host. From simulation results, it is shown that the proposed RMM method improves the efficiency of time-slot utilization while it maximizes QoS provisioning.

Keywords: *Hierarchical MAC, Wireless USB, Wireless Body Area Networks (WBAN)*

1. Introduction

Wearable computing can describe a broad range of devices and concepts. At the time of this writing, *wearables* are generally equated with head-up, wearable displays; one-handed keyboards; and custom computers worn in satchels or belt packs. Ideally, wearable computing can be described as the pursuit of a style of interface as opposed to a manifestation in hardware. Several authors have defined wearable computers by desirable characteristics [1]. For example, Rhodes states that wearables provide portability during operation; enable handsfree or hands-limited use; can attract the user’s attention, even when not in active use; can run continuously; and attempt to sense the user’s current context**.** Kortuem, *et al.*, employ similar criteria but use the term *augmented reality* to describe “the user interface technique that allows focusing the user’s attention and presenting information in an unobtrusive, context- dependent manner.” Meanwhile, Mann describes ‘wearables’ as constant and always ready, unrestrictive, not monopolizing of user attention, observable and controllable by the user, attentive to the environment, useful as a communication tool, and personal [1].

Growing requirement of the high quality multimedia service in wireless home network environment has made Ultra Wide Band (UWB) take a great role in the areas of Wireless Personal Area Networks (WPANs) and home networks. WiMedia Alliance has developed the specifications of the PHY, MAC, and convergence layers for UWB systems with participation of more than 170 companies. Also, it has been promoting the standardization and adaptation of UWB for HR-WPAN (High Rate-Wireless Personal Area Network) that enables the high speed multimedia communications [2-3].

WUSB is the USB technology merged with WiMedia PHY /MAC, and it can be applied to WPAN applications as well as PAN applications like wired USB. Because WUSB specification has defined high speed connection between WUSB host and WUSB devices for the compatibility with USB 2.0 specification, the wired USB applications are serviced directly. Unlikely wired USB that physically separates the USB host and USB device, WUSB allows a device to separately in time function as both a WUSB host and WUSB device on a single transceiver, referred to as the Dual Role Devices (DRD) [4].

WUSB connects WUSB devices with the WUSB host using a ‘hub and spoke’ model [4]. The WUSB host is the ‘hub’ at the center, and each WUSB device sits at the end of a ‘spoke’. Each spoke is a point-to-point connection between the host and device. Like this, the network formed by one host and several devices is referred to as a WUSB cluster [4-6]. WUSB hosts can support up to 127. Only one host in any WUSB cluster performs to transmit/receive a data with devices in the WUSB cluster. Also, it schedules the exchange of data between WUSB host and WUSB devices and allocates time slots to WUSB devices in its own cluster. Because each WUSB cluster can be overlapped with minimum interference, it can coexist with several WUSB clusters in the same communication environment.

The aging population in many developed countries and the rising costs of health care have triggered the introduction of novel technology-driven enhancements to current health care practices. For example, recent advances in electronics have enabled the development of small and intelligent (bio-) medical sensors which can be worn on or implanted in the human body. These sensors need to send their data to an external medical server where it can be analyzed and stored. Using a wired connection for this purpose turns out to be too cumbersome and involves a high cost for deployment and maintenance. However, the use of a wireless interface enables an easier application and is more cost efficient [7]. The patient experiences a greater physical mobility and is no longer compelled to stay in a hospital. This process can be considered as the next step in enhancing the personal health care and in coping with the costs of the health care system. Where eHealth is defined as the health care practice supported by electronic processes and communication, the health care is now going a step further by becoming mobile. This is referred to as mHealth [7]. In order to fully exploit the benefits of wireless technologies in telemedicine and mHealth, a new type of wireless network emerges: a wireless on-body network or a Wireless Body Area Network (WBAN). This term was first coined by Van Dam, *et al.*, in 2001 and received the interest of several researchers [7].

A Wireless Body Area Network consists of small, intelligent devices attached on or implanted in the body which are capable of establishing a wireless communication link. These devices provide continuous health monitoring and real-time feedback to the user or medical personnel. Furthermore, the measurements can be recorded over a longer period of time, improving the quality of the measured data [7]. Generally speaking, two types of devices can be distinguished: sensors and actuators. The sensors are used to measure certain parameters of the human body, either externally or internally. Examples include measuring the heartbeat, body temperature or recording a prolonged electrocardiogram (ECG). The actuators (or actors) on the other hand take some specifications according to the data they receive from the sensors or through interaction with the user, *e.g.*, an actuator equipped with a built-in reservoir and pump administers the correct dose of insulin to give to diabetics based on the glucose level measurements. Interaction with the user or other persons is usually handled by a personal device, *e.g.*, a PDA or a smart phone which acts as a sink for data of the wireless devices.

In our study, we integrate the wireless body area networks (WBAN) with the wireless USB (WUSB) system to develop wireless communication technologies for wireless wearable computer systems. However, current WBAN MAC still does not have well-defined QoS mapping and resource allocation mechanisms to support multimedia streams with requested QoS parameters. To solve this problem, we propose a novel Resource Management Mechanism (RMM). The proposed RMM method provides fair and adaptive QoS provisioning to isochronous streams according to current traffic loads and their requested QoS parameters through executing a satisfaction of QoS algorithm at WUSB/WBAN host. From simulation results, it is shown that the proposed RMM method improves the efficiency of time-slot utilization while it maximizes QoS provisioning.

2. Features of WBAN Protocol

In WBAN, two types of devices can be distinguished: sensors and actuators. The sensors are used to measure certain parameters of the human body, either externally or internally. Examples include measuring the heartbeat, body temperature or recording a prolonged electrocardiogram (ECG). The actuators (or actors) on the other hand take some specifications according to the data they receive from the sensors or through interaction with the user, *e.g.*, an actuator equipped with a built-in reservoir and pump administers the correct dose of insulin to give to diabetics based on the glucose level measurements. Interaction with the user or other persons is usually handled by a personal device, *e.g.*, a PDA or a smart phone which acts as a sink for data of the wireless devices as in Figure 1 [1].

To date, development has been mainly focused on building the system architecture and service platform for extra-body communication. Much of these implementations focus on the repackaging of traditional sensors (*e.g.*, ECG, heart rate) with existing wireless devices. They consider a very limited WBAN consisting of only a few sensors that are directly and wirelessly connected to a personal device. Further they use transceivers with a large form factor and large antennas that are not adapted for use on a body. A WBAN can be compared with other types of wireless networks, such as Wireless Personal (WPAN), Wireless Local (WLAN), Wireless Metropolitan (WMAN) and Wide Area Networks (WAN) [1]. A WBAN is operated close to the human body and its communication range will be restricted to a few meters, with typical values around 1-2 meters. While a WBAN is devoted to interconnection of one person's wearable devices, a WPAN is a network in the environment around the person as in Figure 2 [1]. The communication range can reach up to 10meters for high data rate applications and up to several dozens of meters for low data rate applications. A WLAN has a typical communication range up to hundreds of meters. Each type of network has its typical enabling technology, designed by the IEEE. A WPAN uses IEEE 802.15.1 (Bluetooth), WUSB or IEEE 802.15.4 (Zig-Bee), a WLAN uses IEEE 802.11 (WiFi) and a WMAN IEEE 802.16 (WiMax). The communication in a WAN can be established via satellite links.

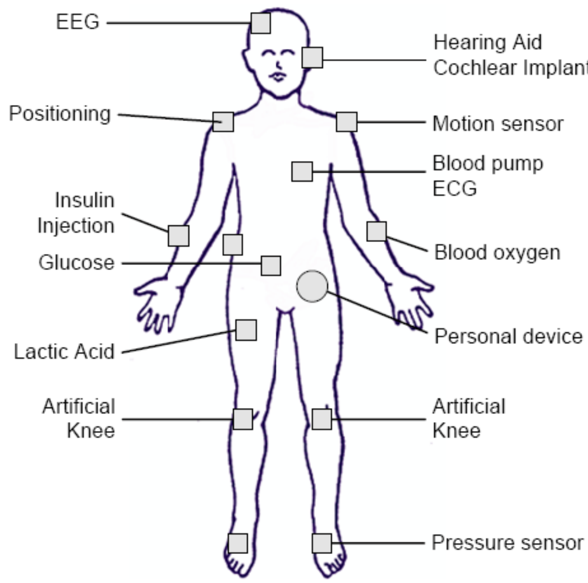

Figure 1. Example of patient monitoring in a Wireless Body Area Network

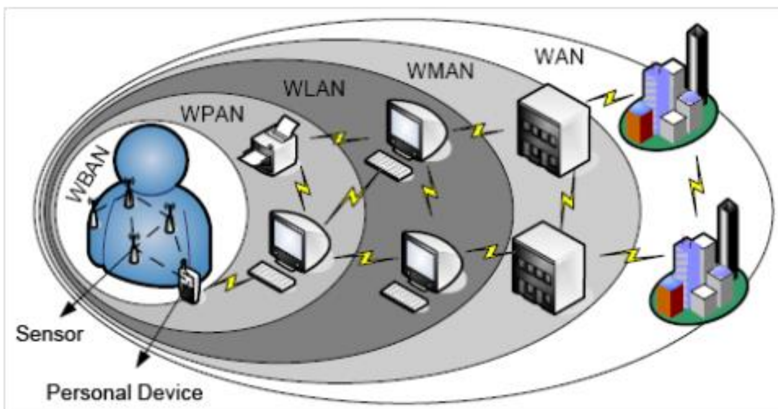

Figure 2. Wireless Body Area Network in the realm of wireless networks

IEEE 802.15.6 started as a Study Group in 2006 and motivated by the increasing research and industry interest in WBANs, the IEEE Standards Association decided to form the IEEE 802.15 Task Group 6 in November 2007. It describes itself as follows: The IEEE 802.15 Task Group 6 (BAN) is developing a communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics / personal entertainment and other [7]. Project Authorization Request (PAR) 07-0575 presents an extended description of the task group [1]. It stresses the fact that current WPANs do not meet medical communication guidelines, because of the proximity to human tissue. Moreover, WPAN technology is said not to support Quality of Service, low power operation and noninterference, all required to support WBAN applications. Based on the responses to the Call for Applications [1], the PAR also outlines a large number of applications that can be served by the proposed stan-dard, going from classical medical usage, *e.g.*, EEG and ECG monitoring, to personal entertainment systems. In 2008, a Call for Proposals on physical layer and MAC layer protocols was issued [1]. The large number of responses, 64 in total, confirmed the industry interest. Currently, the responses are being evaluated at monthly meetings, while some proposals are merged. The creation of the IEEE 802.15 Task Group 6 and the work on an IEEE 802.15.6 standard stresses the importance of the research with respect to WBANs [7].

3. WUSB over WBAN Protocol

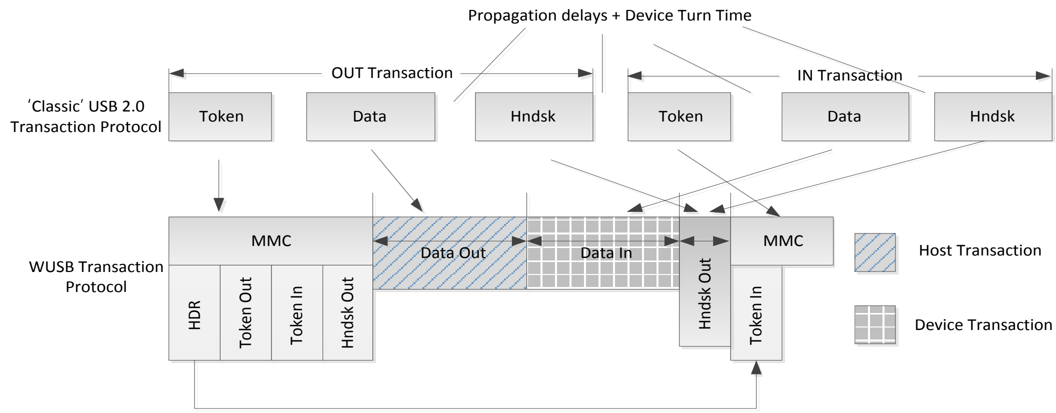

Figure 3. Relationship between wired USB and WUSB protocol

A Wireless USB Channel consists of a continuous sequence of MMC transmissions from the host as in Figure 3 [4]. The linked stream of MMCs is used primarily to dynamically schedule channel time for data communications between host applications and Wireless USB Endpoints. An MMC contains WCTA(wireless USB channel time allocation) IE to indicate the information of WUSB Channel utilization in WUSB Transaction. Figure 4 shows the general structure of WCTA IE.

LSB					MSB
bLength	IE Identifier (WCTA_IE)	W_XCTA[0]	W_XCTA[1]	···	W_XCTA[n]
1 octet	1 octet	variable	variable	···	variable

Figure 4. The format of WCTA IE

bLength field indicates the total length of the WCTA IE, including bLength field. A WCTA IE consists of one or more W_XCTA blocks. The W_XCTA block describes a time slot allocation relative to the MMC frame. There are several types of W_XCTA blocks and all W_XCTA blocks have a common header that includes an attribute field and time slot information for Transaction Group. The type of W_XCTA blocks is as follow: W_{DR}CTA (Device Receive), W_{DT}CTA (Device Transmit), W_{DNTS}CTA (Device Notification Time Slot) [4].

Figure 5 shows the format of W_XCTA block common header. In Figure 5, bits [7:6] of the bmAttributes field are WXCTA Block Type Code and indicate the type of W_XCTA block. The value in bits [5:0] of the bmAttributes field is variable according to W_XCTA Block Type Code. Table 1 shows the interpretation of the W_XCTA according to the W_XCTA Block Type Code [4].

The unit of wStart field is expressed in *ms*. The value in this field is expressed as an offset from the beginning of the MMC. The WUSB host always construct the IE so that they are ordered in time. Also, the IE is always constructed with any W_{DR}CTAs followed by a W_{DNTS}CTA and then by any W_{DT}CTAs for better channel utilization. Fig. 6 shows the data flow in WUSB transaction.

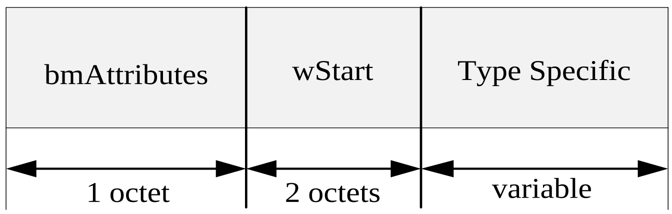

Figure 5. The format of WXCTA block common header

Table 1. The example for the interpretation of the W_XCTA according to the W_XCTA

W_XCTA Block Type Code	Interpretation of Bits [5:0]
W_{DR}CTA (00B) or W_{DT}CTA (01B)	Bits [3:0] are the WUSB device endpoint number Bit [4] is dependent on WXCTA type Bit [5] is a flag indicating that the time slot is associated with a SETUP stage of a control
W_{DNTS}CTA (10B)	Bits [5:0] are set to zero by the host and is ignored by devices
Reserved (11B)	N/A

Figure 6 shows the WUSB over WBAN architecture. Here, the IEEE 802.15.6 WBAN superframe begins with a beacon period (BP) in which the WBAN hub performing the WUSB host's role sends the beacon. This beacon mode of the WBAN is operated in both non-medical and medical traffic environments. The data transmission period in each superframe is divided into the exclusive access phase 1 (EAP1), random access phase 1 (RAP1), Type-I/II access phase, EAP2, RAP2, Type-I/II access phase, and contention access phase (CAP) periods. The EAP1 and EAP2 periods are assigned through contention to data traffic with higher priorities. Further, the RAP1, RAP2, and CAP periods are assigned through contention to data traffic with lower priorities. In the Type-I/II access phase periods, the WBAN hub reserves time slots without contention to exchange data with its input-sensor nodes.

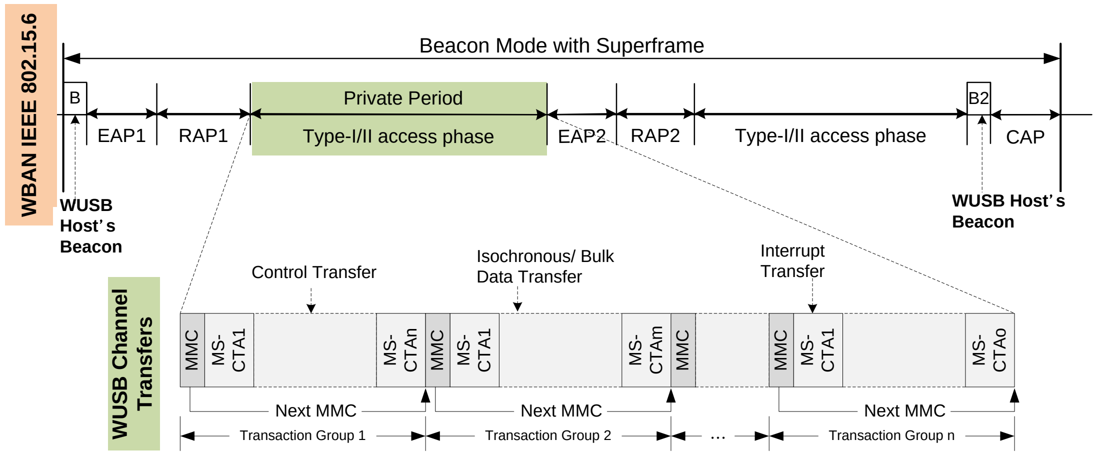

Figure 6. WUSB over WBAN architecture

In the WUSB over WBAN Architecture, in order to set up a wireless communication link to wearable computer systems, the WUSB channel is encapsulated within a WBAN superframe via Type-I/II access phase periods that enables the WUSB host and the input-sensor nodes to reserve time slots without contention through MMC scheduling. In the user scenario of a wearable computer system with the WUSB over WBAN architecture, the user carries a portable or wearable computing host device. This host device performs roles of the WUSB host and the WBAN hub simultaneously. Therefore, a “wearable” WUSB cluster and a WBAN cluster are formed. The attached input-sensor nodes perform the functions of localization-based input interfaces for wearable computer systems and healthcare monitoring. Furthermore, the attached wireless nodes comprise the peripherals of a wearable computer system, and the central WUSB host exchanges data with the outer peripherals of the WUSB slave devices [4].

4. Proposed Resource Management Mechanism

WLP (WiMedia Logical Link Protocol) specification supports the Token Bucket TSPEC (Traffic Specification) to provide a standard set of parameters to characterize a traffic source, based on which networking resources can be reserved for parameterized QoS provisioning [4]. Token Bucket TSPEC represents the characteristic of traffic source using by the theoretical model of a fluid twin token bucket. The fluid twin token bucket model provides standard terminology to describe the behavior of a network traffic source [4]. This model characterizes a traffic stream by three parameters, mean rate r, peak rate p and maximum burst size b. Figure 7 shows the arrival curve of a token bucket model for traffic source with the characteristic of $\{r, b, p\}$. The arrival curve represents the cumulative maximum number of bits the traffic source may possibly inject during any time interval t.

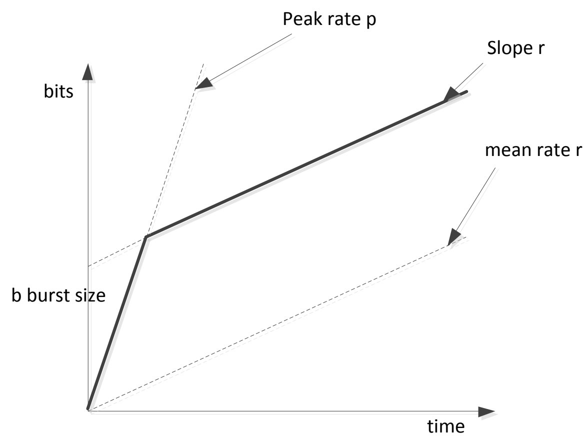

Figure 7. Arrival curve of twin token bucket model

In provisioning of Guaranteed QoS service, the requirement of maximum allowed delay is specified using the service TSPEC parameters of WUSB Transfer Service Rate (*R*) and Slack Term (*S*). For a WUSB traffic stream (TS) with traffic characteristics of {*r, b, p*}, there exists a theoretical minimum service rate for a certain delay bound constraint. Figure 8 depicts the relationship between service TSPEC and token bucket TSPEC. As seen in the Figure 8, slack term *S* signifies the difference between maximum allowed delay (shown with the green horizontal line) and the delay resulting from the requested service rate *R* (shown with the red horizontal line). The vertical grey line represents minimum buffer space necessary to avoid overflow for the TS.

In Figure 8, *d* is shown with the red horizontal line that is also the maximum horizontal distance between the arrival curve and the service rate line. In [4], the theoretical service rate *R* is derived from the fluid twin token bucket model to guarantee delay bound d for a traffic stream with characteristics of {r, b, p}. It is given by [4]:

$$R = \frac{p}{1 + d \times \frac{p-r}{b}} \tag{1}$$

From using Eq. (1), we can also calculate the delay *d* which a traffic stream experiences at service rate *R*. As mentioned above, slack term *S* means the difference between maximum allowed delay and the delay *d* resulting from the service rate *R*. Hence, the requirement of a maximum allowed delay can be expressed in terms of WUSB Tranfer service TSPEC{*R, S*} as below:

$$d_{\max} = \frac{p-R}{p-r} \times \frac{b}{R} + S \tag{2}$$

As seen in Eq. (2), WUSB Transfer service TSPEC of {*R, S*} together specifies the maximum allowed delay for the TS with the token bucket TSPEC of {*r, b, p*}. And as represented in the shaded area in the Figure 8, the specification of slack term allows using a range of service rates that are lower than *R* to satisfy the TS's maximum allowed delay d_{max}. Consequently, when a traffic stream (TS) with traffic characteristics of {*r*, *b*, *p*} has the requirement of a maximum allowed delay dmax, the upper and lower bounds of a service rate *R* can be calculated at p with 0 delay and with *c* from Eq. (1), respectively. Thus slack term *S* can take a value within the range of (0, d_{max}) according to the service rate *R*.

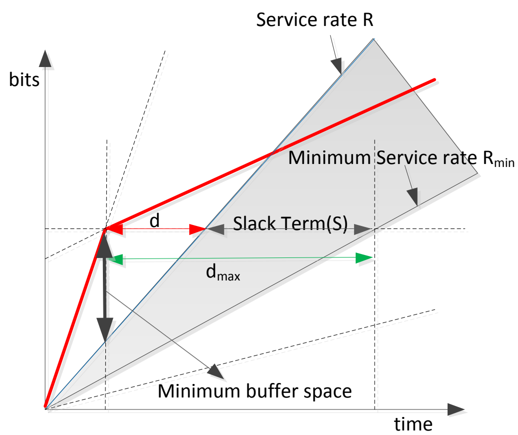

Figure 8. Minimum service rate to transport the TS according to the WUSB Transfer Service TSPEC

A beacon group is formed by a WUSB/WBAN host around WUSB/WBAN slave devices, and it consists of that WUSB/WBAN host and its one-hop neighbors. All devices in a beacon group can interfere with each other. In Table 2, there are given some parameters which are RR_j and DR_j for QoS mapping, $SoQ_{j,n}$, RE_j and $SR_{j,n}$ for fair resource allocation.

Table 2. Symbols required for the proposed Method

Symbol	Description
K	Number of traffic streams registered in a beacon group
BW	Total bandwidth or time slots of the data period in a superframe
n	sequence of a superframe
$SR_{j,n}$	Service rate of the j traffic stream at the n-th superframe
RR_j	Required data rate or time slots of the traffic stream j
DR_j	Desired data rate or time slots of the traffic stream j
RE_j	Relinquished bandwidth or time slots from the traffic stream j
$SoQ_{j,n}$	Satisfaction ratio of QoS of the traffic stream j at the n-th superframe
$SoQ_{F,n}$	Fair satisfaction ratio of QoS for all traffic streams serviced at the n-th superframe

How to allocate time slots in the (*n+1*)-th superframe is determined according to information of DNTSs received in the *n*-th superframe. These lower and upper bounds of service rate *R* for the traffic stream *j* are mapped to RR_j and DR_j, respectively ($RR_j < DR_j$). $SR_{j,n}$ is the number of time slots allocated to the traffic stream *j* at the *n*-th superframe. RE_j is a data rate or the number of time slots relinquished from the traffic stream j. $SoQ_{j,n}$ is a satisfaction ratio of QoS of the traffic stream j in the n-th superframe. $SoQ_{j,n}$ is calculated by using (3).

$$SoQ_{j,n} = \frac{SR_{j,n} - RR_j}{DR_j - RR_j} \begin{cases} SoQ_{j,n} = 1, & \text{if } SR_{j,n} = DR_j \\ SoQ_{j,n} = 0, & \text{if } SR_{j,n} = RR_j \\ SoQ_{j,n} < 0, & \text{if } SR_{j,n} < RR_j \end{cases} \tag{3}$$

The SoQ is ranged smaller than or equal to 1. The closer the SoQ is to 1, the higher is the satisfaction ratio of QoS of a traffic stream. The proposed method provides fair SoQ ($SoQ_{F,n}$) for all traffic streams including existing traffic streams and new traffic streams whenever the number of traffic streams in the beacon group or current available time slots (CATs) in a superframe varies. The $SoQ_{F,n}$ shows the calculated fair SoQ at the WUSB/WBAN host for all traffic streams including new traffic streams at the n-th superframe, and it can be also derived from (1).

Whenever the number of isochronous traffic streams or CATs varies, the WUSB/WBAN host calculates $SoQ_{F,n}$ and announce by sending its beacon. Therefore, it sets $SoQ_{F,n}$ of the WUSB/WBAN slave devices, and they decide how to relinquish time slots to new traffic streams. By using the proposed method, all traffic streams always have the same $SoQ_{F,n}$. Based on the $SoQ_{F,n}$, each traffic stream can relinquish a calculated amount of time slots, or it can request to reserve more time slots by sending DNTS messages to the WUSB/WBAN host. If there is a new WUSB/WBAN slave device that wants to reserve some time slots due to transmission request of its new traffic stream at the (n-1)-th superframe, then the device sends DNTS message. After receiving all neighbors' DNTS messages in the n-th superframe, the WUSB/WBAN host calculates $SoQ_{F,n+1}$ from (4) to guarantee fair QoS provisioning for existing traffic streams and the new traffic stream.

$$SoQ_{F,n+1} = \min\left[\frac{BW - \sum_{j=1}^{K} RR_j}{\sum_{j=1}^{K}(DR_j - RR_j)}, \quad 1\right] \tag{4}$$

$$\begin{aligned} SR_{j,n+1} &= SoQ_{F,n+1} \times (DR_j - RR_j) + RR_j \\ RE_j &= SR_{j,n} - SR_{j,n+1} \end{aligned} \tag{5}$$

If the calculated $SoQ_{F,n+1}$ is a negative value, it means that the BW at the n-th superframe cannot accommodate any new additional traffic streams. Thus, the WUSB/WBAN host denies the new request, and the $SoQ_{F,n+1}$ is set as the previous $SoQ_{F,n}$ value. Otherwise, each existing traffic stream adjusts its $SR_{j,n}$ to $SR_{j,n+1}$ according to the $SoQ_{F,n+1}$, and it relinquishes time slots as many as RE_j to the new traffic stream. $SR_{j,n+1}$ and RE_j can be calculated as in (5). If the number of traffic streams in a beacon group decreases at the n-th superframe, then the number of CATs at the $n+1$-th superframe increases. Accordingly, $SoQ_{F,n+1}$ becomes greater than $SoQ_{F,n}$. It means that the existing traffic streams can be provided with better QoS at the $n+1$-th superframe. In that case, each traffic stream recognizes that the number of CATs increases by receiving $SoQ_{F,n+1}$ from beacon. And it requests the additional time slots as many as ($SR_{j,n+1}$ -$SR_{j,n}$) using the DNTS message.

5. Four Performance Measures

5.1. TS capacity

c_{TS} is the ratio of the number of currently serviced TSs equal to K_{cur} to the number of total MASs allocated for transmitting all those K_{cur} TSs equal to the sum of $SR_{j,n}$. Therefore, this TS capacity means the average number of TSs for the total serviced BW for them at a superframe. In other words, it indicates the degree of resource allocation efficiency in utilizing the given BW. c_{TS} is given by Eq. (6).

$$c_{TS} = \frac{K_{cur}}{\sum_{j=1}^{K_{cur}} SR_{j,n}} \qquad ({}^{\mathrm{TS}}\!/\!{}_{\mathrm{MAS}}) \tag{6}$$

5.2. An average queuing delay during the n-th superframe

$E(d_n)$ is an expected queuing delay time experienced by K_{total} TSs at the n-th superframe. If a TS j is transmitted with a proper QoS at a $SR_{j,n}$ in n-th superframe, its queuing delay $d_{j,n}$ is calculated by setting S to 0 and R to $SR_{j,n}$ from Eq. (2). Otherwise, it waits for MASs to be released in a transmission queue. Therefore, in this case its $d_{j,n}$ is equal to the $T_{superframe}$ length per each superframe until CAMs (Current Available MASs) become enough to be released to guarantee its QoS. According to our method, if a TS j is serviced with a guaranteed QoS, the corresponding $SR_{j,n}$ has a positive value. That is, if $SR_{j,n}$ is larger than 0, it means that the TS j is now being transmitted at the n-th superframe. If $SR_{j,n}$ is equal to 0, it means that the TS j is in a state of waiting in a transmission queue during the n-th superframe $d_{j,n}$ and $E(d_n)$ at the n-th superframe can be explained by Eq. (7).

$$d_{j,n} = \begin{cases} \dfrac{p - SR_{j,n}}{p - r} \times \dfrac{b}{SR_{j,n}}, & \text{if } SR_{j,n} > 0 \\ T_{Superframe}, & \text{if } SR_{j,n} = 0 \end{cases}$$
$$\therefore E(d_n) = \sum_{j=1}^{K_{total}} \frac{d_{j,n}}{K_{total}} \tag{7}$$

5.3. QoS fairness

σ_{SoQ} is the standard deviation of $SoQ_{j,n}$ of all TSs registered in a beacon group at the n-th superframe. This σ_{SoQ} shows the degree of fairness in QoS provisioning for all TSs. If a TS j is serviced with a fair QoS, its $SoQ_{j,n}$ is equal to $SoQ_{F,n}$. Otherwise, its $SR_{j,n}$ is equal to 0, and its $SoQ_{j,n}$ has a negative value according to Eq. (3). In Eq. (8), E(SoQ_n) means the average SoQ of all K_{total} TSs at the n-th superframe.

$$E(SoQ_n) = \sum_{j=1}^{K_{total}} \frac{SR_{j,n} - RR_j}{K_{total} \cdot (DR_j - RR_j)}$$

$$\sigma_{SoQ} = \sqrt{\sum_{j=1}^{K_{total}} \frac{(SoQ_{j,n} - E(SoQ_n))^2}{K_{total}}} \tag{8}$$

5.4. delay tolerance

$t_{j,n}$ is the ratio of a tolerable delay time of a TS j to a maximum allowed delay $d_{j,max}$ at the n-th superframe. As mentioned in previous Sections, each TS has a QoS requirement of $d_{j,max}$. And a minimum service rate is calculated from Eq. (1) in order not to violate $d_{j,max}$. To offer the only minimum service rate to the TS does not mean that the required QoS of the TS is guaranteed. Fundamentally, the wireless link is unstable due to its relatively high bit error rate (BER) and high sensitivity to changes in radio circumstances. Also, mobile devices may cause conflicts between TSs in the timeslot blocks. In case that some parts of a TS are corrupted due to link errors or collisions, it is required to retransmit the parts of the TS. Accordingly, it makes the TS experience additional and unexpected delay, which causes encroachments on the QoS guarantee of the TS. Therefore, a TS should be provided with a data rate higher than the minimum service rate on the given BW. In Eq. (9), $E(t_n)$ means the average delay tolerance of all K_{cur} TSs at the n-th superframe.

$$d_{j,\max} = \frac{p - SR_{j,n}}{p - r} \times \frac{b}{SR_{j,n}} + S, \quad \text{if } SR_{j,n} > 0$$

$$t_{j,n} = \frac{S}{d_{j,\max}} = 1 - \frac{b \cdot (p - SR_{j,n})}{d_{j,\max} \cdot SR_{j,n} \cdot (p - r)} \tag{9}$$

$$\therefore E(t_n) = \sum_{j=1}^{K_{cur}} \frac{t_{j,n}}{K_{cur}}$$

6. Performance Evaluation

We For simplicity, we assume that all Traffic Streams (TS) have the same QoS parameters as shown in Table 3. The lengths of *BW* in every superframe are fixed, equal to 210 time slots and 360Mbps [8-13]. To evaluate the performance of the proposed method, we have considered two cases of time slot allocation methods in the WUSB over WBAN MAC. They are Minimum QoS (Min_QoS), and the proposed SoQ methods, where Min_QoS method provides a TS with the minimum service rate equal to the RR_j. Since the current WUSB/WBAN MAC has no time slot allocation method considering the QoS parameters of TSs, the WUSB/WBAN host determines their service rates as its minimum service rate (Min_QoS). Min_QoS method can waste time slots since they are static and inefficient in the resource allocation process. However, the proposed SoQ method provides TSs with maximum allowable service rates under the current available time slots.

Table 3. Simulation Parameters

Symbol	Description
Mean Data Rate (RR_j)	4.13Mbps
Peak Data Rate (DR_j)	14.8Mbps
Maximum Burst Size (b)	131359 Bytes
Maximum allowed queuing delay	150ms
Minimum service rate	8.97Mbps
Maximum service rate	14.8Mbps

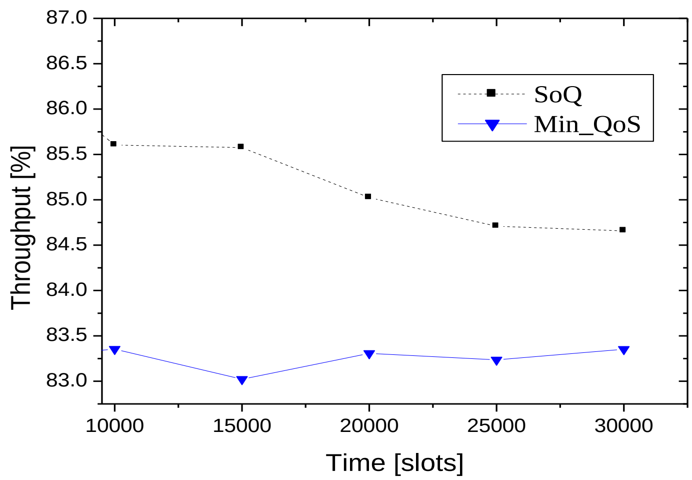

Figure 9. Throughput performance of SoQ, Min_QoS

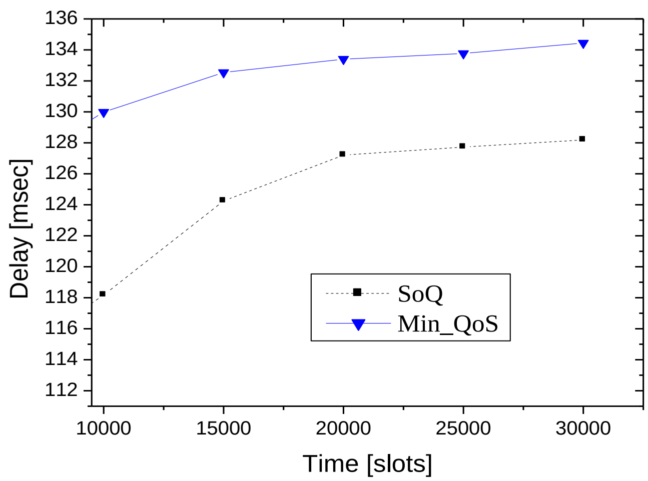

Figure 10. Delay performance of of SoQ, Min_QoS

In Figure 9 and Figure 10, throughput and delay performances of a TS are compared. In both Figures, the SoQ method shows better throughput than Min_QoS method. And delay performance exhibits similar behavior to throughput performance. In Figure 9, the throughput(%) means the value equal to the ratio of service rate $SR_{j,n}$ to Maximum service rate. From these results, it can be concluded that the SoQ method, proposed for the WUSB/WBAN MAC protocol, provides fair and maximized QoS for all TSs adaptively according to the current traffic load condition.

7. Conclusion

In this paper, an IEEE 802.15.6 wireless body area networks (WBAN) medium access control protocol is developed to support a wireless USB (WUSB) application as a protocol adaptation layer (PAL). Further, we propose a novel Resource Management Mechanism (RMM) which provides adaptive QoS provisioning to isochronous streams according to current traffic loads and their requested QoS parameters through executing a satisfaction of QoS algorithm at WUSB/WBAN host. From simulation results, it is shown that the proposed RMM method improves the efficiency of time-slot utilization while it maximizes QoS provisioning.

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