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A Hierarchical MAC Protocol for QoS Support in Wireless Wearable Computer Systems

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Abstract

A recent major development in computer technology is the advent of wearable computer systems. Wearable computer systems employ a wireless universal serial bus (WUSB), which refers to a combination of USB with the WiMedia wireless technical specifications. In this study, we focus on an integrated system of WUSB over wireless body area networks (WBANs) for wireless wearable computer systems. However, current WBAN MACs do not have well-defined quality of service (QoS) mapping and resource allocation mechanisms to support multimedia streams with the requested QoS parameters. To solve this problem, we propose a novel QoS-aware time slot allocation method. The proposed method provides fair and adaptive QoS provisioning to isochronous streams according to current traffic loads and their requested QoS parameters by executing a QoS satisfaction algorithm at the WUSB/WBAN host. The simulation results show that the proposed method improves the efficiency of time slot utilization while maximizing QoS provisioning.

Index Terms: Hierarchical MAC, Wearable computer, Wireless body area networks, Wireless USB

I. INTRODUCTION

A recent major development in computer technology is the advent of wearable computer systems, which are based on human-centric interface technology trends and ubiquitous computing environments [1, 2]. Wearable computer systems use a wireless universal serial bus (WUSB), which refers to a combination of USB technology with the WiMedia physical layer and medium access control layer (PHY/MAC) technical specifications. WUSB can be applied to wireless personal area network (WPAN) applications, as well as wired USB applications such as PAN. WUSB specifications include high-speed connections between a WUSB host and WUSB devices for compatibility with USB 2.0 specifications [3, 4].

A wireless body area network (WBAN), which describes the application of wearable computing devices, allows for the integration of intelligent, miniaturized, low-power, and invasive/non-invasive sensor nodes that monitor body functions and the surroundings. Each intelligent node is adequately capable of processing information and forwarding it to a base station for diagnosis and prescription [5].

The WUSB channel is a continuous sequence of linked application-specific control packets called micro-scheduled management commands (MMCs). As shown in Fig. 1, WUSB maps the USB 2.0 transaction protocol onto the TDMA micro-scheduling feature. MMCs are used to advertise channel time allocations for enabling point-to-point data communications between the host and the endpoints of the devices in the WUSB cluster. As shown in Fig. 1, an MMC specifies the linked stream of the WUSB channel time allocation blocks up to the next MMC [3]. The

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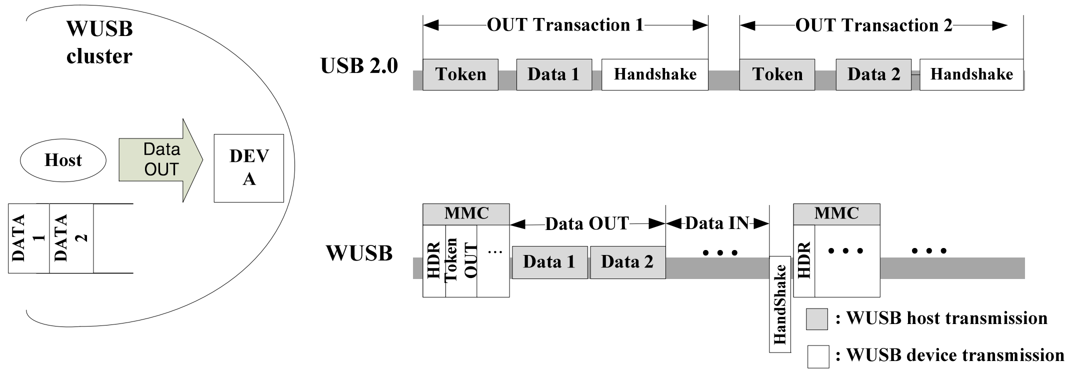

Fig. 1. Relationship between USB and WUSB transactions. USB: universal serial bus, WUSB: wireless USB, MMC: micro-scheduled management command.

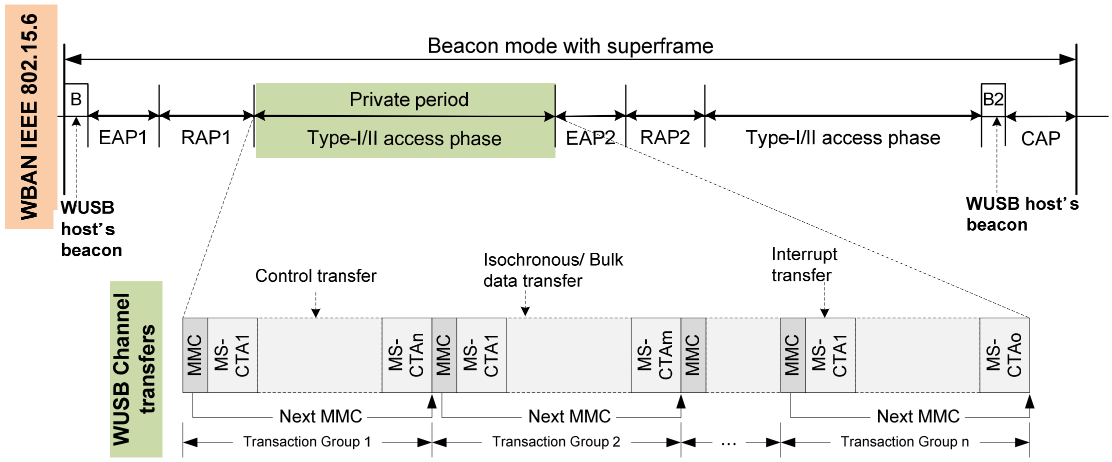

Fig. 2. WUSB over WBAN architecture. WBAN: wireless body area network, EAP: exclusive access phase, RAP: random access phase, MMC: micro-scheduled management command, MS-CTA: micro-scheduled channel time allocation.

information element (IE) fields in an MMC are called WUSB channel IEs, and they include device notification time slots (DNTS), protocol time slot allocations (device receive [DR], device transmit [DT]), and host information.

Fig. 2 shows the WUSB over WBAN architecture. Here, the IEEE 802.15.6 WBAN superframe begins with a beacon period in which the WBAN hub performing the WUSB host's role sends a beacon. 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) [5]. EAP1 and EAP2 are assigned through contention to data traffic with higher priorities. In contrast, RAP1, RAP2, and CAP are assigned through contention to data traffic with lower priorities. In the Type-I/II access phases, the WBAN hub reserves time slots without contention for WUSB data exchange transactions with its WUSB devices [3]. In this paper, we propose a QoS-aware time slot allocation method for the WUSB over WBAN protocol.

II. QoS-AWARE TIME SLOT ALLOCATION METHOD FOR WUSB OVER WBAN

A WUSB/WBAN host forms a beacon group around WUSB/WBAN slave devices, and this group consists of the WUSB/WBAN host and its one-hop neighbors. All devices in a beacon group can interfere with each other. Table 1 lists certain parameters of the proposed method.

A scheme for allocating time slots in the $(n+1)^{th}$ superframe is determined on the basis of the DNTS information received in the n^{th} superframe. These lower and upper bounds of the service rate (SR) for a traffic stream $(TS)_j$ are mapped to RR_j and DR_j, respectively ($RR_j < DR_j$). $SR_{j,n}$ denotes the number of time slots allocated to TS_j in the n^{th} superframe. RE_j denotes the data rate or the number of time slots relinquished from TS_j. Satisfaction ratio of QoS ($SoQ_{j,n}$) denotes the QoS satisfaction ratio of TS_j in the n^{th} superframe. $SoQ_{j,n}$ is calculated as follows:

Table 1. Parameters of proposed method

Symbol	Description
K	Number of traffic streams registered in a beacon group
BW	Total bandwidth or time slots of data periods in a superframe
N	Superframe sequence
$SR_{j,n}$	Service rate of traffic stream j at the n^{th} superframe
RR_j	Required data rate or time slots of traffic stream j
DR_j	Desired data rate or time slots of traffic stream j
RE_j	Relinquished bandwidth or time slots from traffic stream j
$SoQ_{j,n}$	Satisfaction ratio of QoS of 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

$$SoQ_{j,n} = \frac{SR_{j,n} - RR_j}{DR_j - RR_j} \begin{cases} SoQ_{j,n} = 1, & \text{if } SR_{j,n} = DR_j \\ SoQ_{j,n} = 0, & \text{if } SR_{j,n} = RR_j \\ SoQ_{j,n} < 0, & \text{if } SR_{j,n} < RR_j \end{cases} . \quad (1)$$

The SoQ value is smaller than or equal to 1. The closer the SoQ is to 1, the higher is the QoS satisfaction ratio of a TS. The proposed method provides fair SoQs ($SoQ_{F,n}$) for all TSs, including the existing TSs and the new TSs, whenever the number of TSs in a beacon group or the current available time slots (CATs) in a superframe varies. $SoQ_{F,n}$ shows the calculated fair SoQ at the WUSB/WBAN host for all TSs, including new TSs in the n^{th} superframe.

Whenever the number of isochronous TSs or CATs varies, the WUSB/WBAN host calculates $SoQ_{F,n}$ and announces it by sending a beacon. Therefore, it sets the $SoQ_{F,n}$ of WUSB/WBAN slave devices, which then decide upon a method for relinquishing time slots to new TSs. By using the proposed method, we ensure that all TSs always have the same $SoQ_{j,n}$. On the basis of $SoQ_{F,n}$, each TS can relinquish a calculated number of time slots or can request for the reservation of a greater number of time slots by sending DNTS messages to the WUSB/WBAN host. If there is a new WUSB/WBAN slave device that wants to reserve a few time slots due to a transmission request of its new TS in the $(n\text{-}1)^{th}$ superframe, the device sends a DNTS message. After receiving all devices' DNTS messages in the n^{th} superframe, the WUSB/WBAN host calculates $SoQ_{F,n+1}$ to guarantee fair QoS provisioning for the existing WUSB TSs as well as the new WUSB TSs.

$$SoQ_{F,n+1} = \min\left[\frac{BW - \sum_{j=1}^{K} RR_j}{\sum_{j=1}^{K} (DR_j - RR_j)}, \quad 1 \right]. \quad (2)$$

$$\begin{aligned} SR_{j,n+1} &= SoQ_{F,n+1} \times (DR_j - RR_j) + RR_j , \\ RE_j &= SR_{j,n} - SR_{j,n+1} . \end{aligned} \quad (3)$$

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

III. RESULTS AND DISCUSSION

A. Case of Single WUSB Traffic Characteristics

For the sake of simplicity, we assume that all TSs have the same QoS parameters (RR_j = 4.13 Mbps, DR_j = 14.8 Mbps, maximum allowed queuing delay = 150 ms). The magnitude of BW in every superframe is 360 Mbps [6-8]. In our NS2 simulation, we considered two time slot allocation methods in the WUSB over WBAN MAC: the minimum QoS (Min_QoS) method and the proposed SoQ method. The Min_QoS method provisions all TSs with the minimum service rate equal to RR_j. Because a time slot allocation method that considers the QoS parameters of TSs is not available for the current WUSB/WBAN MACs, the WUSB/WBAN host determines their service rates as its minimum service rate (Min_QoS).

In Figs. 3 and 4, the throughput and delay performances of a TS are compared. In both figures, the SoQ method yields better throughput than the Min_QoS method. Furthermore, the delay performance shows a trend similar to that of the throughput performance. In Fig. 3, the throughput (%) is given as the ratio of the service rate $SR_{j,n}$ to the maximum service rate DR_j. From these results, it can be inferred that the Min_QoS method may waste time slots, because they are static and, thus, be inefficient at resource allocation. However, the SoQ method, which has been proposed for the WUSB/WBAN MAC protocol, adaptively provides fair and maximized QoSs to all TSs on the basis of the current traffic load condition.

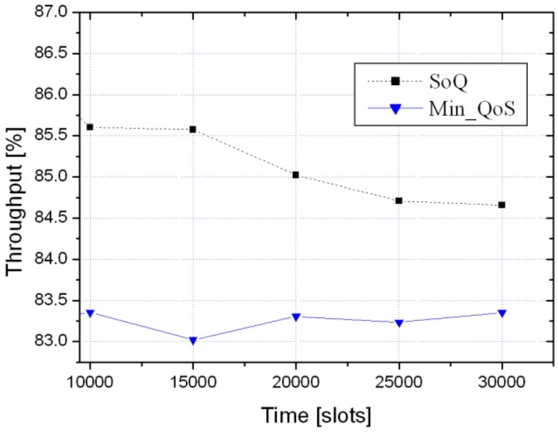

Fig. 3. Throughputs of SoQ and Min_QoS methods.

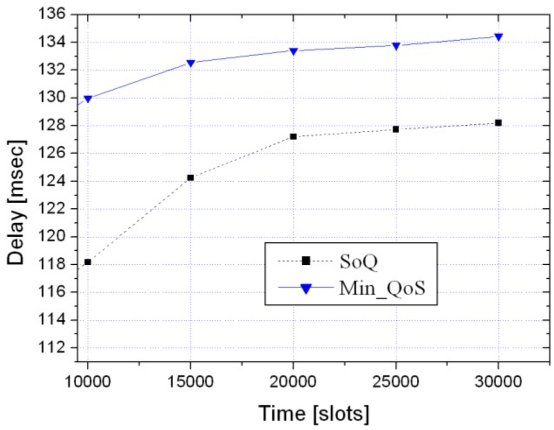

Fig. 4. Delay performances of SoQ and Min_QoS methods.

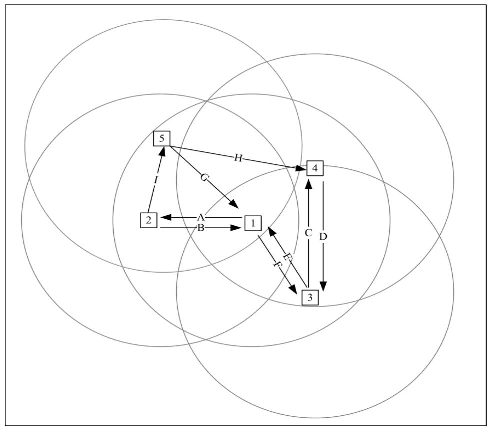

Fig. 5. Simulation topology.

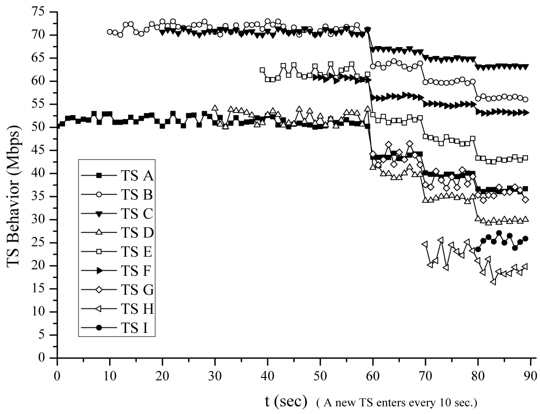

Fig. 6. Measurement of WUSB TSs' throughput behavior in SoQ. WUSB: wireless universal serial bus, TS: traffic stream.

B. Case of Multiple WUSB Traffic Characteristics

In this subsection, we simulate SoQ in a scenario comprising several TSs with different WUSB traffic characteristics. As shown in Fig. 5, there are five devices (DEV1 to 5) in the WBAN beacon group of DEV1; each arrow corresponds to a TS, and a circle around a device represents the communication range of this device. In the simulation results, nine TSs (A to I) are sequentially created, and they request guaranteed QoS to the WBAN MAC entity at 10-second intervals. Accordingly, each DEV allocates appropriate service rates to its TSs by using the SoQ. The $SoQ_{j,n}$ of each TS is calculated as 1 until the 954th superframe of 60 seconds, which indicates that all six TSs (A to F) are provided with the desired service rate of DR_j. Whenever a new TS (G to I) continuously requests its service in the 953rd, 1093th, and 1265th superframe, respectively, the service rates allocated to existing TSs are lowered for accommodating the new TSs according to $SoQ_{F,n}$. Accordingly, the $SoQ_{j,n}$ of each TS decreases from 1 to 0.3, while each TS obtains an identical and fair $SoQ_{j,n}$ value. Fig. 6 shows the simulation results that indicate the actual throughput of each TS transmitted through its reserved WUSB blocks, $SR_{j,n}$, for fair QoS provisioning according to the SoQ method under varying traffic conditions, where new TSs request its service.

IV. CONCLUSIONS

In this paper, we proposed a QoS-aware time slot allocation method. The proposed method provides fair and adaptive QoS provisioning to isochronous WUSB streams according to the current WUSB traffic loads and their requested QoS parameters by executing a QoS satisfaction algorithm at a WUSB/WBAN host. From the simulation results, it was shown that the proposed method improves the efficiency of time slot utilization while maximizing QoS provisioning. The proposed SoQ technique is compatible with the current IEEE 802.15.6 WBAN and WUSB standards.

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