A Hierarchical Power-saving Method of WUSB over WBAN

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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). Due to portable and wearable nature, the WUSB over IEEE 802.15.6 hierarchical medium access control (MAC) protocol has to support the power saving operation and integrate WUSB transactions with WBAN traffic efficiently. In this paper, we propose a Hierarchical Power-saving Method (HPM) for WUSB over IEEE 802.15.6 hierarchical MAC to improve its energy efficiency. Simulation results show that the HPM also integrate WUSB transactions and WBAN traffic efficiently while it achieves high energy efficiency.

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

1. Introduction

Wearable systems for health monitoring may comprise various types of miniature sensors, wearable or even implantable. These biosensors are capable of measuring significant physiological parameters like heart rate, blood pressure, body and skin temperature, oxygen saturation, respiration rate, electrocardiogram, etc. The obtained measurements are communicated either via a wireless or a wired link to a central node, for example, a Personal Digital Assistant (PDA) or a microcontroller board, which may then in turn display the according information on a user interface or transmit the aggregated vital signs to a medical center [1].

USB has been using an enormous number of USB devices as the universal interface [2]. As USB technology has been advanced in succession, it has been used in various applications, such as PCs, PC peripheral devices, home appliances and mobile devices. Also it has been supported the standardization and several particulars by USB-IF (USB Implementers-Forum).

WiMedia Alliance is developing the specifications of the PHY, MAC, and convergence layers for UWB (Ultra Wide Band) systems with participation from more than 170 companies. Also, it has been promoting the standardization and adaptation of UWB for HR-WPAN (High Rate-Wireless Personal Area Netowork) that enables the multimedia and high speed data communication [2]. Recently, WiMedia Alliance has completed the specification of WiMedia D-MAC (Distributed-MAC), and this enables that various applications, such as WUSB (Wireless USB), Wireless 1394, Wireless IP, operates on WiMedia D-MAC. The WiMedia D-MAC supports a distributed MAC approach. In contrast to IEEE 802.15.3, D-MAC makes all devices have the same functionality, and networks are self-organized and provide devices with functions such as access to the medium, channel allocation to devices, data transmission, quality of service, synchronization in a distributed manner. The WiMedia D-MAC removes the Simultaneous Operating Piconet (SOP) of 2-hop range packet collision problems of the centralized IEEE 802.15.3 MAC by adopting the distributed architecture. Figure 1 shows the relationship between WiMedia protocol and various applications based on UWB [2-6].

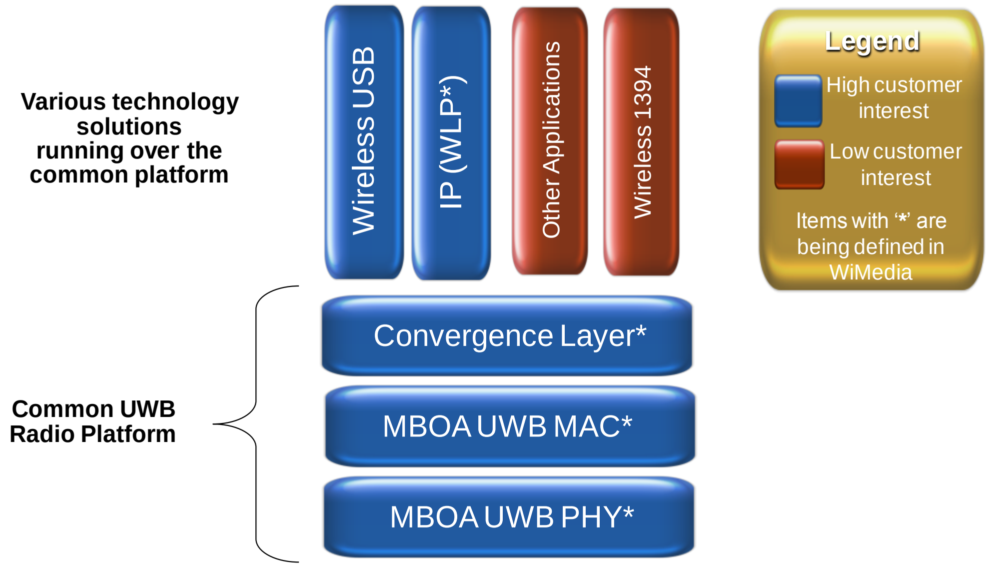


Figure 1. UWB Protocol Relationships

The advent of miniaturized sensors and actuators for monitoring, diagnostic, and therapeutic functions, and advances in wireless technology have opened up new frontiers in the race to conquer healthcare challenges. Ultra-low-power wireless connectivity among devices placed in, on, and around the human body is seen as a key technology enabling unprecedented portability for monitoring physiological signs in the hospital, at home, and on the move. Strategically placed wearable or implanted (in the body) wireless sensor nodes sample, process, and transmit vital signs (*e.g.*, heart rate, blood pressure, temperature, pH, respiration, oxygen saturation) without constraining the activities of the wearer. The gathered data can be forwarded in real time to a hospital, clinic, or central repository over a local area network (LAN), wide area network (WAN), cellular network, and the like. Physicians and caregivers can remotely access this data to assess the state of the health of the patient. Additionally, the patient can be alerted using SMS, alarm, or reminder messages [7].

Wireless Body area networking (WBAN) technology has the potential to revolutionize healthcare delivery in ambulances, emergency rooms, operation theaters, postoperative recovery rooms, clinics, and homes. The benefits of unobtrusive, and continuous monitoring/treatment include long-term trend analysis, detection of transient abnormalities, prompt alerting of a caregiver to intervene in case of an emergency, regulation of treatment regimes, reduction of errors, reduction of hospital stays, extending independent living for seniors, and improved patient comfort. BAN offers a paradigm shift from managing illness to proactively managing wellness by focusing on prevention and early detection/treatment of diseases [7].

In this paper, we integrate the IEEE 802.15.6 wireless body area networks (WBAN) with the wireless USB (WUSB) system to develop wireless communication technologies for wireless wearable computer systems. Due to portable and wearable nature of the wearable computer systems, the WUSB over IEEE 802.15.6 hierarchical medium access control (MAC) protocol has to support the power saving operation and integrate WUSB transactions with WBAN traffic efficiently. In this paper, we propose a Hierarchical Power-saving Method (HPM) for WUSB over IEEE 802.15.6 hierarchical MAC to improve its energy efficiency. Simulation results show that the HPM also integrate WUSB transactions and WBAN traffic efficiently while it achieves high energy efficiency.

2. Data Flow in WUSB Protocol

As shown Figure 2, WUSB is the technology merged USB with UWB based on success of wired USB, and it can apply to WPAN applications as well as PAN applications like wired USB. Because WUSB specification has defined high speed connection between host and device for the compatibility with USB 2.0 specification, it can be adapted easily for wired USB applications. 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 device sit 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 the WUSB cluster.

WUSB hosts can support up to 127 devices and because WUSB does not have physical ports there is no need, nor any definition provided, for hub devices to provide port expansion. There is only one host in any WUSB cluster and 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 and channel bandwidths to WUSB devices in its own cluster. Because each WUSB cluster can be overlapped each other with minimum interference, it can coexist with several WUSB clusters within the same communication environment. The distributed nature of D-MAC protocol can provide full mobility support, and achieves scalable, fault tolerant medium access method [4]. Thus WUSB protocol based on WiMedia D-MAC can provide full mobility support.

WUSB defines a WUSB Channel which is encapsulated within a WiMedia MAC superframe via private DRP reservation blocks. The WUSB Channel is a continuous sequence of linked application-specific control packets, called MMCs (Micro-scheduled Management Commands), which are transmitted by the host within the private DRP reservation blocks. Figure 2 shows the relationship between WiMedia MAC and WUSB.

The Micro-scheduled Management Command (MMC) is the fundamental element of the Wireless USB protocol. MMCs are used to help devices discover information about a WUSB cluster, notify their intentions, manage power, and schedule data transmissions efficiently to attain very high throughputs. The general structure of an MMC Control packet is showed in Figure 3 and detailed in Table 1.

A WUSB Channel consists of a continuous sequence of MMC transmissions from the host. The linked stream of MMCs is used primarily to dynamically schedule channel time for data communications between host applications and WUSB Endpoints. An MMC specifies the sequence of micro-scheduled channel time allocations (MS-CTAs) up to the next MMC within a reservation instance or to the end of a reservation instance. It may be followed by another MMC without the existence of MS-CTAs between the two MMCs. In this case, the MMC is only used to convey command and control information. The channel time between two MMCs may also be idle time, where no MS-CTAs are scheduled.

The MS-CTAs within a reservation instance can only be used by the devices that are members of the associated WUSB Cluster. The direction of transmission and the use of each MS-CTA is fully declared in each MMC instance. An MMC can declare an MS-CTA during any channel time following the MMC.

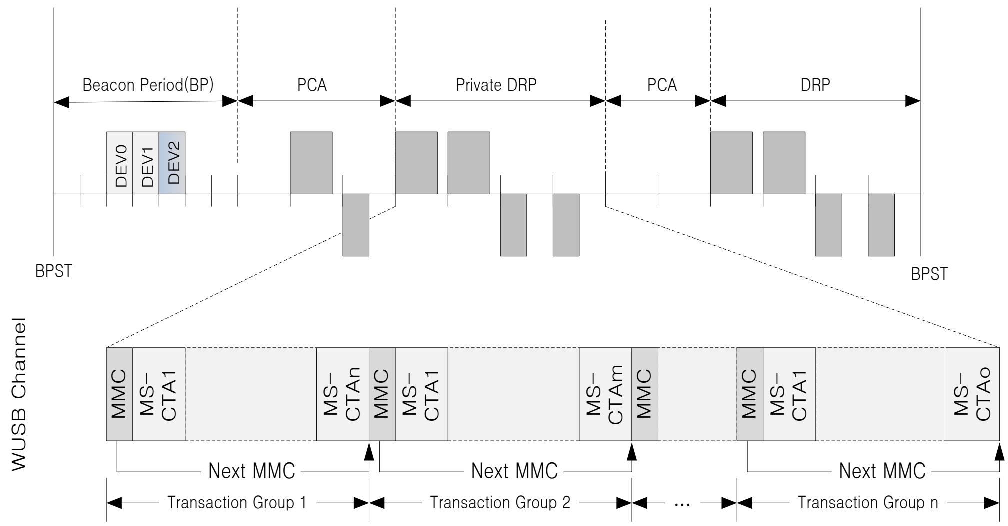


Figure 2. The example of the data exchange between WUSB devices through WiMedia D-MAC

Application Identifier	Type	Next MMC Time	Reserved	WUSB Channel Time Stamp	IE[0]	IE[1]	...	IE[n]
2 octets	1 octet	2 octets	2 octets	3 octets	L_1 octets	L_2 octets		L_n octets

Figure 3. The general structure of an MMC Control packet

An MMC contains the information elements necessary to identify the WUSB Channel, declare any MS-CTAs, or other information elements that are used for command and control. The MMC is a broadcast control packet that is for receipt only by devices that are members of the WUSB cluster. The host must use the Broadcast Cluster ID value in the DestAddr field of an MMC packet's MAC, WiMedia MAC header. This technique identifies this packet transmission as a broadcast targeting all devices in a WUSB cluster, and avoids potential confusion at Non-WUSB devices in listening range of the host. The MMC payload must be encapsulated within a WiMedia MAC secure packet; however its data payload is transmitted in plain text, thus using the security encapsulation for authentication purpose only.

A host is required to implement the WiMedia MAC protocol, establish and maintain WUSB Channels by allocating sequences of private DRP reservation in WiMedia MAC. A device may implement the full WiMedia MAC protocol; however it is nominally only required to implement the WUSB protocol which operates within the WUSB Channel.

Table 1. Detailed Field Description of MMC Control Packet

Field	WUSB Equivalents
Application Identifier	Wireless USB: 0100H
Type	MMC Command Type: 01H
Next MMC Time	The number of microseconds from the beginning of this field indicates the value of the next MMC packet.
Reserved	This field is reserved and should be set to 'zero'
WUSB Channel Time Stamp	Timestamp provided by the host based on a free running timer in the host. The value in this field indicates the value of the host free running clock when MMC transmission starts. This timestamp is formatted into two fields as follows: - 0~6 bits: Microsecond Count. The microsecond count rolls over after 125 microseconds. Each time it rolls over the 1/8th Millisecond Count is incremented. - 7~23 bits: 1/8th Millisecond Count. This counter increments every time the Microsecond Counter wraps.
IE[0-n]	Array of information elements. There must be at least one IE.

As mentioned above, a WUSB host and WUSB devices must include a DRP IE in their beacon frames to protect the WUSB Channel. When a WUSB host becomes active, it must choose a PHY channel in which to operate the WUSB channel. Once the host is beaconing it then establishes a WUSB Channel by DRP reservation for WUSB data communications. In this case, WUSB host is the DRP reservation owner, and WUSB device is the DRP reservation Target. Thus, WUSB device must be able to determine which MASs are available for communication with the WUSB host. Since there are various devices in the WUSB cluster, the WUSB device identifies the WUSB host's DRP IE based on the following keys:

- Reservation Type field is Private
- Stream Index field has the value of the WUSB Channel's stream index.
- Owner DevAddr field set to the WUSB Channel's Broadcast Cluster ID

The WUSB device identifies a cluster member's DRP IE based on the following keys:

- Reservation Type field is Private
- Stream Index field has the value of the WUSB Channel's stream index.
- Owner DevAddr field set to the WUSB host's DevAddr

Figure 4 shows the current operation of DRP reservation in WUSB protocol. A WUSB host uses the GetStatus(MAS Availability) request to retrieve a device's MAS Availability information. A WUSB device that receives the GetStatus(MAS Availability) request from the WUSB host accumulate the information from its neighbors' beacon about available MASs. Then, the WUSB device responds to the GetStatus(MAS Availability) request through the bmMASAvailability field in GetSatus request. In the format of the GetStatus request, bmMASAvailability field is a 256-bit map, where each bit location corresponds to a MAS slot in the WiMedia D-MAC Layer superframe. A 1B in a bit location means that the device is available for a reservation in the corresponding MAS slot. A 0B indicates the device is not available.

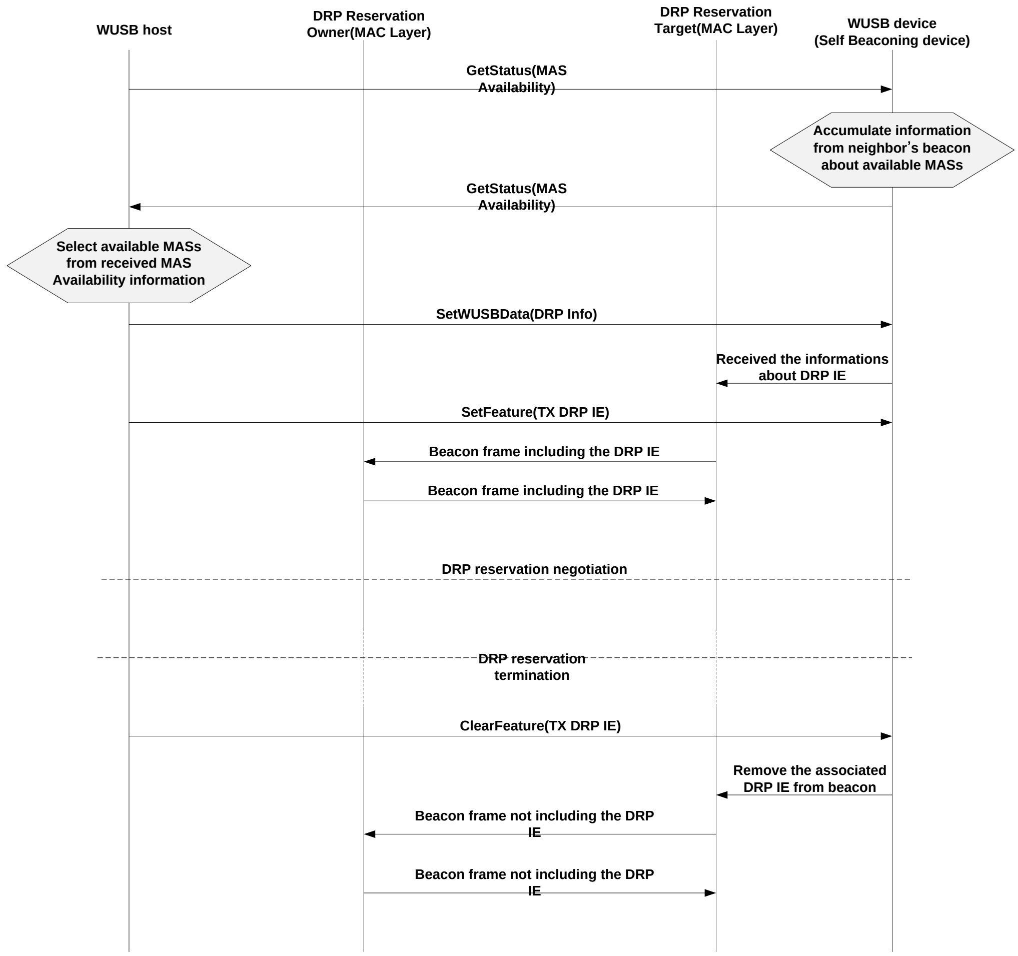


Figure 4. The Current Operation of DRP reservation in WUSB Protocol

3. Features of WBAN Protocol

WBANs are intended to support lifesaving medical applications. Hence, safety, security, QoS, and reliability are important metrics besides energy efficiency. Harmonized coexistence of multiple collocated BANs in crowded places such as hospital elevators and wards needs a robust MAC protocol. Efficient duty cycling methods have to be developed to minimize power consumption without compromising QoS. The MAC protocol should be able to cope with topology and density changes induced by nodes moving in and out of range due to body movements [7].

QoS and reliability of wireless BAN technology should be at par (if not better) with current wireline technologies to be adopted in clinical settings. The QoS framework should be flexible so that it can be dynamically configured to suit application requirements without unduly increasing complexity or decreasing system performance. Real-time life-critical applications of BANs are not only delay-sensitive but also losssensitive. Lost or corrupt alarm/alert packets due to unreliable wireless networks have serious consequences [7].

Fair bandwidth sharing among collocated BANs and graceful degradation of service are highly desirable. BAN devices have limited memory, which means there is little room to store and retry unacknowledged data. Therefore, strong error detection and correction schemes, and efficient acknowledgment and retransmission mechanisms have to be defined [7].

The full potential of BAN technologies can only be realized if the promise of anytime, anywhere, automatic, and continuous connectivity to infrastructure networks is fulfilled. Connectivity of a BAN to infrastructure networks can be realized using a gateway device (*e.g.*, a cell phone or PDA) that transfers data between the BAN and infrastructure networks such as WLAN, WPAN, or cellular networks. Low-cost limited-range high-capacity WLAN and WPAN infrastructures can be leveraged for indoor connectivity (*e.g.*, inside a hospital or at home), whereas lowercapacity longer-range cellular infrastructure can be leveraged for outdoor connectivity. This brings forward the issues of integration of heterogeneous wireless networking technologies to support seamless roaming and end-to-end QoS. In non-real-time applications the gateway may store data locally and upload it when the gateway is connected to the Internet. Real-time wireless connectivity to infrastructure enables location freedom and universal mobility while being monitored. A wireless-enabled ICD can automatically call an ambulance through a cell phone when it detects cardiac arrest. Similarly, a fall detector can automatically send an alarm or call an emergency center/caregiver upon detecting a fall. However, precise location determination technologies are needed to be able to provide quick assistance to the person in case of an emergency [7].

The success of many wireless technologies such as Wi-Fi and Bluetooth is driven by standardization. Standardization enables interoperability and seamless user experience, and drives down the cost by exploiting economies of scale. Standardization frees the consumer from vendor dependence and empowers them to buy what best suits their needs rather than what works.

Interoperability, low cost, and user convenience are key enablers for the mass market, which is why there has been growing interest in standardizing healthcare technologies. The IEEE 802.15.6 Task Group [7] is developing the first industrial standard encompassing PHY and MAC layers for BAN. This standard is expected to fill the critical gap in the peak power vs. data rate graph. Advances in low power RF technology are likely to lower peak power consumption significantly, thereby making low-cost small disposable sensor patches a reality.

It remains to be seen whether the upcoming IEEE 802.15.6 standard outperforms other standardized technologies such as ZigBee and Bluetooth, and succeeds in penetrating the market. To enable true plug-and-play interoperability, all layers of the protocol stack, application profiles, and data exchange formats have to be standardized, which is currently underway in the following groups [7].

The ISO/IEEE 11073 Personal Health Data Working Group defines standards and protocols that facilitate exchange of health information between peripheral area network devices and application hosting devices such as cell phones, personal computers, and gateways. The group defines transport-independent applications and information profiles including data formats, exchanges, and terminology. The Continua Health Alliance has been developing interoperability guideline, testing, and certification program for the emerging personal telehealth ecosystem targeting disease management, aging independently, health, and fitness. Continua’s interoperability guideline defines profiles over existing or upcoming standards. Continua defines interoperability goals around four network interfaces [7]. The Peripheral Area Network Interface connects body area sensors and actuators to application hosting devices. For instance, Bluetooth is a candidate technology for lower-layer connectivity, and IEEE 11073 protocols are candidates for higher layers. Similarly, a LAN or WAN interface connects application hosting devices to LAN or WAN devices, respectively as show in Figure 5. The Alliance has endorsed ZigBee healthcare as Continua's low-power LAN standard.

Figure 5. Inter-WBAN communication architecture

4. Hierarchical Power-saving Method for WUSB over WBAN Architecture

In this subsection, we analyzed the IEEE 802.15.6 WBAN MAC structure and designed the HPM structure for over IEEE 802.15.6 hierarchical MAC. WBAN slave devices which have received beacon from WBAN host schedule their receiving and transmitting operations according to information delivered by the beacon.

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.

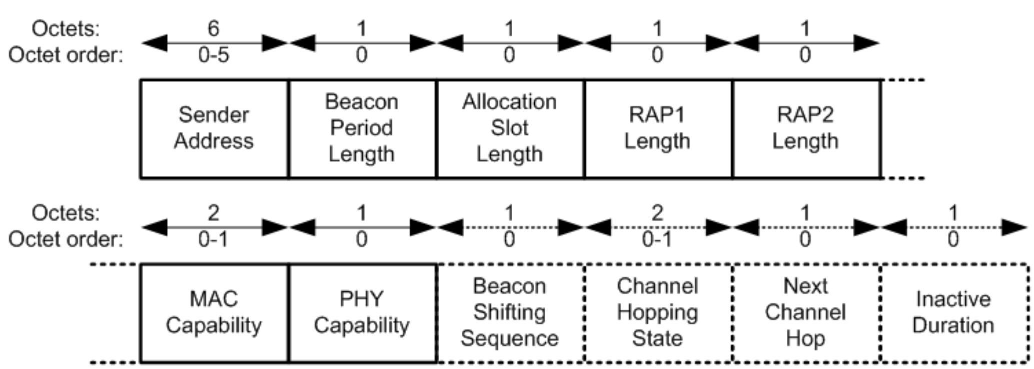


Figure 6. WBAN beacon frame format

In the WBAN beacon frame of Figure 6, the Sender Address field is set to the IEEE MAC address of the WBAN hub sending the current beacon. The Beacon Period Length field is set to the length of the current beacon period (superframe) in units of allocation slots. It is set to 0 to encode a value of 256 allocation slots. The Allocation Slot Length field is set to L such that the length of an allocation slot. The random access phase 1 (RAP1) and RAP2 Start fields are set to the number of the allocation slot that starts RAP1 and RAP2, respectively. RAP1 and RAP2 Length fields are set to the length of RAP1 and RAP2, in units of allocation slots respectively. The Beacon Shifting Sequence, Channel Hopping State, Next Channel Hop and Inactive Duration fields are used for interference avoidance in WBAN wireless channel environment.

The IEEE 802.15.6 WBAN MAC systems have several MAC Capability options. Figure 7 shows current WBAN MAC Capability format standard. We denote the WUSB slave device which also performs the WBAN slave device function as WUSB/WBAN slave device. The WUSB/WBAN slave devices keep its active mode during an entire superframe if the Always Active field is set to one in the received beacon in that superframe. Otherwise, if the Always Active field is set to zero, the WUSB/WBAN slave devices keep its active mode during only the beacon period and other allocated periods for that superframe. This operation is called as the hibernation.

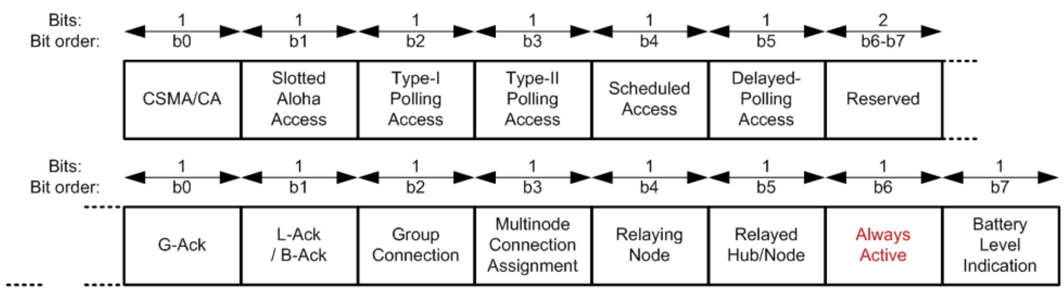


Figure 7. WBAN MAC Capability format standard

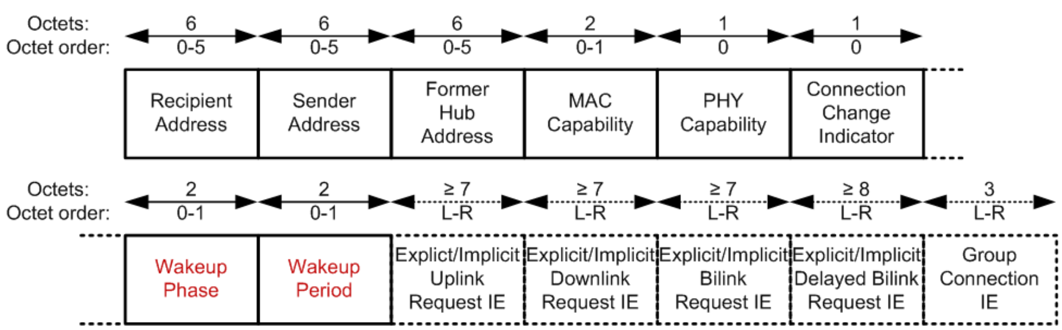


Figure 8. Connection Request control frame format

The duty cycle and length of the hibernation in the IEEE 802.15.6 WBAN systems can be varied according to the WBAN system requirements. If a WUSB/WBAN slave device wants to sleep during several superframes, it set the Wakeup Period field in the Connection Request control frame and sends the Connection Request control frame to the WUSB/WBAN host as in Figure 8. If the value of Wakeup Period field is equal to m, it means that the slave device sleeps during m-1 superframes and turns into active mode at the mth superframe. The Wakeup Phase field in the Connection Request control frame indicates the sequence number of superframe where the device turns into active mode. After receiving the Connection Request control frames from WUSB/WBAN slave devices, the WUSB/WBAN host has to store information of Wakeup Period and Wakeup Phase fields. But, values of Wakeup Period and Wakeup Phase fields in the Connection Assignment control frame which the WUSB/WBAN host sends to devices do not need to be the same with those in the Connection Request control frames. That is, this operation means that the WUSB/WBAN host can control the duty cycle and length of the hibernation according to the status of IEEE 802.15.6 WBAN networks.

If the Wakeup Period field in the Connection Assignment control frame which the WUSB/WBAN host sends is set to a non-zero value, it means that the host assigns the m-periodic allocation to its slave devices. Otherwise, the Wakeup Period field in the Connection Assignment control frame is set to one, it means that the host assign the 1-periodic allocation to make its slave devices alive every superframe. At the m-periodic allocation, WUSB/WBAN slave devices receive and transmit frames after m-1 superframes. Through the hibernation technique, the WUSB over WBAN hierarchical network turns into active mode during only predetermined superframes. At the case of m-periodic allocation, the WUSB/WBAN hierarchical network only stay in the active status during T/m time for entire T time. Therefore, the hierarchical network saves power consumption during (T-T/m) time for entire T time.

The WUSB/WBAN host should transmit WUSB data without interference with WBAN data when a request for WUSB data transmissions occurs in the WUSB cluster. For this purpose, the WUSB/WBAN host has to allocate the WUSB private channels. Basically, the IEEE 802.15.6 superframe is composed of several data transmission periods such as EAP1, RAP1, Type-I access phase, EAP2, RAP2, Type-II access phase and CAP. However, Except the RAP1 period, length of the other periods can be set to zero. By using this feature, the WBAN host which also performs the function of WUSB host allocates the WUSB private channels at the RAP2 period.

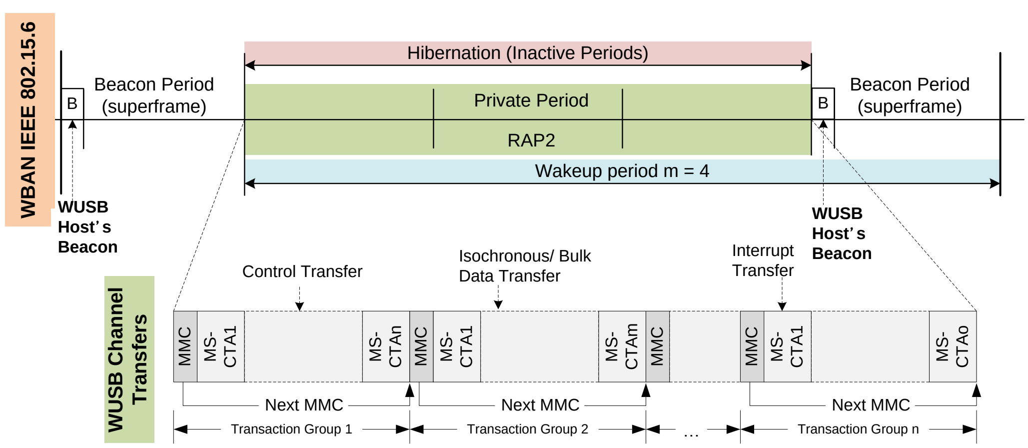


Figure 9. WUSB private channel allocation at the m-periodic allocation hibernation

Figure 9 shows WUSB private channel allocation scheme at the m-periodic allocation hibernation of a WBAN superframe. At the m-periodic allocation hibernation, there are m-1 inactive superframes. In this paper, an efficient WUSB private channel allocation method of HPM is proposed. In this method, the WUSB private channels are allocated during the inactive periods to improve channel utilization.

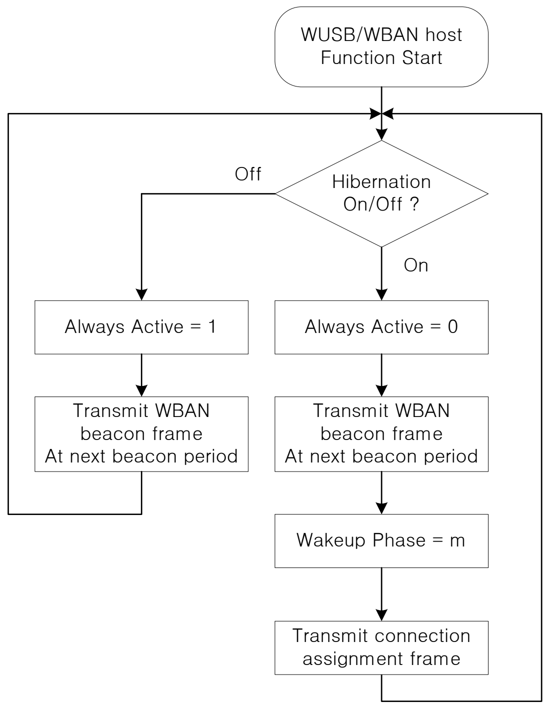
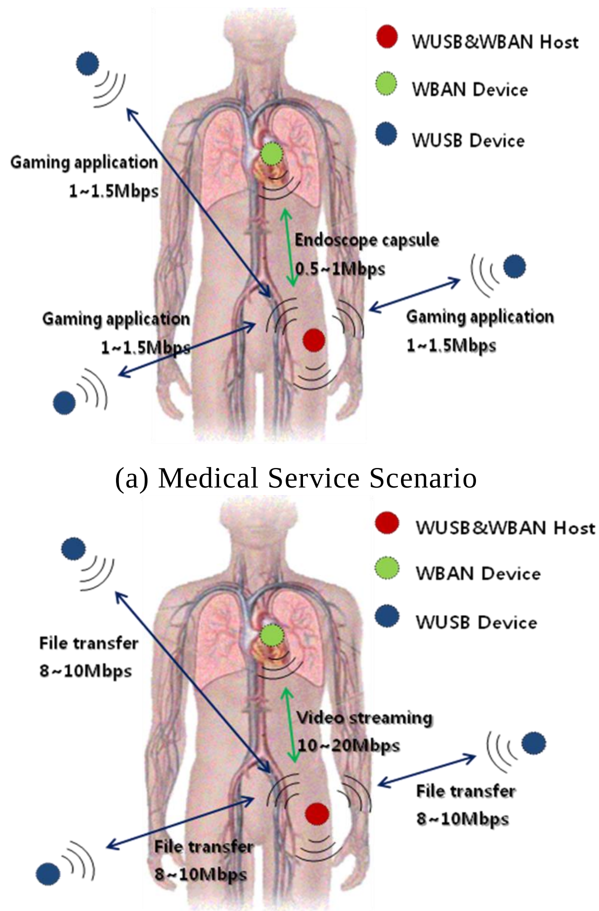


Figure 10. WUSB private channel allocation procedure at the m-periodic hibernation

Figure 10 shows the WBAN host Beacon transmission procedure for WUSB private channel allocation at the m-periodic hibernation. When a request for WUSB data transmissions occurs at the WUSB host or WUSB slave-devices in the WUSB cluster, WBAN host which also performs the function of WUSB host sets the Private Period Allocation field to one in the MAC capability field of Figure 7. And the WUSB/WBAN host also sets the WBAN beacon's RAP2 length field to the length of inactive periods required for MMC scheduling in the WUSB private channel. Then, the WUSB/WBAN host transmits its beacon frame. And the Wakeup Period field in the Connection Assignment control frame which the WUSB/WBAN host sends is set to a non-zero m value. And the Wakeup Phase field in the Connection Assignment Frame set to a sequence number of superframe increased by m. After receiving beacon and Connection Assignment control frames, non-WUSB WBAN slave devices enter into sleep mode during m superframes. On the contrary, the WUSB/WBAN host and slave devices enter into active mode at every RAP2 period during consecutive m superframes, for the WUSB transactions.



(a) Medical Service Scenario

(b) Nonmedical Service Scenario

Figure 11. WUSB over WBAN Architecture

In the WUSB over WBAN Architecture, in order to set up a wireless communication link to wearable computer systems, secure WUSB channels should be encapsulated within a WBAN superframe. This enables the MMC scheduling between WUSB host and its several peripheral devices without contention. Figure 11 shows the example topologies of the WUSB over WBAN Architecture in both non-medical and medical traffic environment.

In this scenario, 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 can be 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.

5. Performance Evaluation

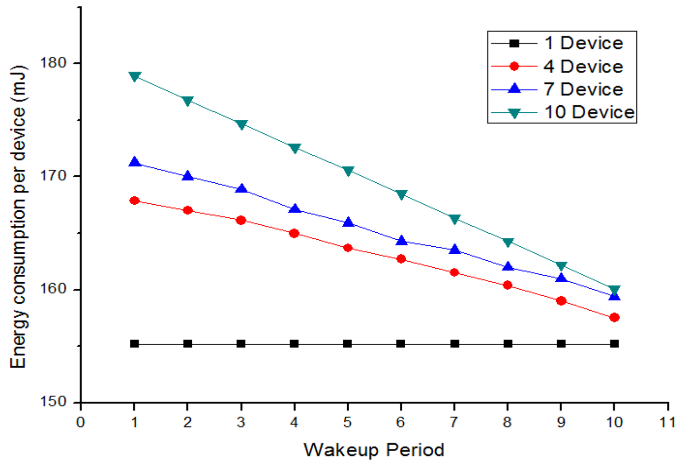


Figure 12. Energy consumption of WUSB/WBAN device according to number of wakeup periods

Performance of the proposed scheme is evaluated through OMNet++ simulations [8-13]. The simulated network size is 10m*10m and the maximum 20 devices are randomly deployed into this area. Figure 12 shows the consumed energy per superframe of a WUSB/WBAN device according to number of wakeup periods. As shown in Figure 12, the longer wakeup period reduces the consumed energy per WUSB/WBAN device except the case where the only one device exists in the WUSB/WBAN hierarchical networks. Furthermore, the larger devices increase the consumed energy per device. This result is caused by more transmissions and receptions in a device due to increased scheduling overhead.

In the simulation for Figure 13, there are four WBAN data streams between WUSB/WBAN host and its WBAN slave devices in a WBAN cluster. In that situation, each WUSB device enters into that cluster and associates with the WUSB/WBAN host, one by one, to communicate. When a request for WUSB data transmissions occurs at the WUSB host or WUSB slave-devices in the WUSB/WBAN cluster, the WBAN host which also performs the function of WUSB host allocates the RAP2 period for WUSB private channels. As the number of WUSB slave devices increases, the WUSB transactions also increase. Then, the allocated RAP2 periods to WUSB channels become longer. As a result, the data transmission period available to non-WUSB WBAN traffic becomes shorter. Therefore, this phenomenon leads non-WUSB WBAN devices to have longer scheduling delay and consume more energy. In this simulation, the Wakeup Period is set to four in the hibernation scheme. And the consumed energy do not change up to five WUSB devices. This result is caused by the mechanism that the WUSB/WBAN host allocates the inactive periods for WUSB private channels by setting the beacon's RAP2 length field to the length of inactive periods while the other non-WUSB WBAN devices enter into sleep mode during four superframes repetitively.

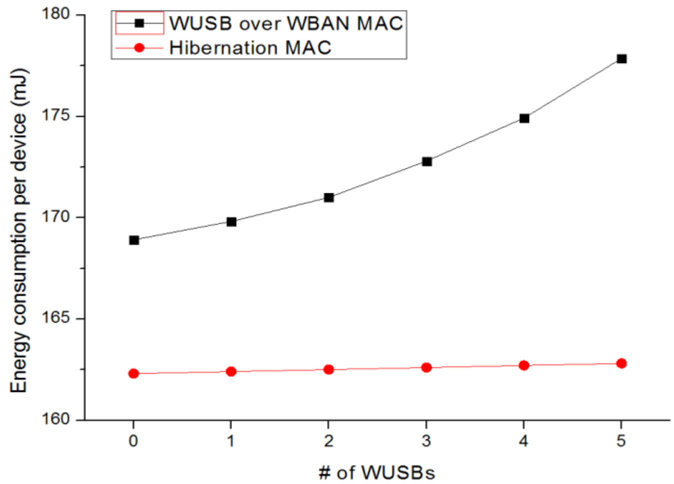


Figure 13. Energy consumption of WUSB/WBAN Hibernation MAC according to number of WUSB slave devices

6. 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). In this paper, we proposed a Hierarchical Power-saving Method (HPM) for WUSB over IEEE 802.15.6 hierarchical MAC to improve its energy efficiency. Simulation results show that the HPM also integrate WUSB transactions and WBAN traffic efficiently while it achieves high energy efficiency. Proposed HPM technique has compatibility with current IEEE 802.15.6 WBAN and Wireless USB standards.

Acknowledgements

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