A WBAN Beacon Structure for Wireless USB Protocol Adaptation

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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). To successfully set up wireless communication links, the WUSB channel should be encapsulated privately within a WBAN superframe. However, in the current IEEE 802.15.6 WBAN standard there is no available periods allocated for other heterogeneous networks. In this paper, we propose a WBAN Beacon Structure (WBS) of IEEE 802.15.6 WBAN to set up WUSB channel efficiently. Simulation results show that the WBS integrates WUSB transactions and WBAN traffic efficiently in a hierarchical WUSB/WBAN medium access control (MAC) protocol.

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

1. Introduction

The role of personal health management systems (PHMSs) is to establish the connection between the individuals and such health information networks, making the citizen-centered health system a reality. The direct benefits include not only facilitation of timely provision of telemedicine services at the point of need but also better informed and more responsible patients. PHMSs enable continuous monitoring of various bio-signals and empower citizens to have a greater role in managing their own health status. They can also optimize the communication and interface between patients and doctors. Countries in the developed world are already spending a considerable amount of their gross domestic product on healthcare, and this expenditure is rising continuously [at an annual rate of 3.8% in Organisation for Economic Cooperation and Development (OECD) countries]. PHMSs can provide the means to balance these rising costs by allowing early diagnosis and more costeffective patient monitoring and consulting beyond the ordinary hospital environment [1].

PHMSs may be in the form of wearable, implantable, or portable systems, as well as in-vitro point-of-care diagnostic devices for home use. Wearable eHealth systems, in particular, are convenient platforms for monitoring an individual’s health-related parameters, even on a continuous basis, and for processing and feeding relevant information to their users and/or medical professionals. They achieve this by integrating sensing, processing, and communicating devices in body-worn systems (e.g., wrist-worn devices, patches, or even clothes [1]), which are also linked to health information systems and electronic health records. Portable systems can be in the form of small handheld devices that can operate at any location. They may even be temporarily attached to the human body as peripheral devices/accessories. To a certain extent, portable systems can be similar to wearable systems in terms of their monitoring capability, the functionality they provide, and the services they can be combined with [1].

According to the Federal Communications Commission (FCC), UWB refers to any radio technology having a transmission bandwidth exceeding the lesser of 500 MHz or 20% of the arithmetic center frequency. FCC also regulates license-free use of UWB in the 3.1−10.6 GHz band to have a relatively low power spectral density emission. This leads to the suitability of UWB applications in short-range and indoor environments, and in environments sensitive to RF emissions, e.g., in a hospital. Commercial products based on UWB provide extremely high data rates, *e.g.*, “Certified Wireless USB” devices work at up to 480 Mbps, enabling short-range wireless multimedia applications, such as wireless monitors, wireless digital audio and video players [2-6]. These multimedia devices can be either wirelessly connected with BANs, or are themselves portable as part of a BAN. UWB is also an ideal technology for precise localization, which complements Global Positioning System (GPS) indoors for BAN tracking. At the same time, concerns with electronic and magnetic energy absorbed by human tissue from RF circuits placed in close proximity means that BAN devices need to employ low transmission power and low transmission duty cycles. In this regard UWB outperforms conventional transmission methods and thus attracts much attention. An emerging BAN standard, IEEE 802.15.6—Body Area Networks (BANs), will likely employ UWB, according to recent proposals and meeting minutes. The standard intends to endow future generation electronics in close proximity to, or inside human body.

Recently, there has been increasing interest from researchers, system designers, and application developers on a new type of network architecture generally known as body sensor networks (BSNs) or body area networks (BANs), made feasible by novel advances on lightweight, small-size, ultra-low-power, and intelligent monitoring wearable sensors [7]. In BANs, sensors continuously monitor human’s physiological activities and actions, such as health status and motion pattern. Non-invasive sensors can be used to automatically monitor physiological readings, which can be forwarded to nearby devices, such as a cell phone, a wrist watch, a headset, a PDA, a laptop, or a robot, based on the application needs.

In addition to the above, BANs may interface with other wireless technologies, such as WSNs, radio frequency identification (RFID) technology, Zigbee, Bluetooth, Bluetooth Low Energy (previously called WiBree), video surveillance systems, wireless personal area network (WPAN), wireless local area networks (WLAN), internet, and cellular networks. In this case, the marketing opportunities for advanced consumer electronics and services will expand extensively, and more autonomous and intelligent applications that can be deemed essential to improving people’s quality of life will be generated [7].

Several design issues must be addressed in order to enable the deployment and adoption of BANs. At the hardware level, body sensors must be small, thin, non-invasive, wireless-enabled, and must be able to operate at a very low power level. From the communications perspective, it is imperative to design appropriate medium access control (MAC) protocols to ensure higher network capacity, energy efficiency, and adequate quality of service (QoS). At the application level, innovative architectures should be implemented for the corresponding applications [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. To successfully set up wireless communication links for wearable computer systems, the WUSB channel should be encapsulated privately within a WBAN superframe. However, in the current IEEE 802.15.6 WBAN standard there is no available periods allocated for other heterogeneous networks. In this paper, we propose a WBAN Beacon Structure (WBS) of IEEE 802.15.6 WBAN to set up WUSB channel efficiently. Simulation results show that the WBS integrates WUSB transactions and WBAN traffic efficiently in a hierarchical WUSB/WBAN MAC protocol.

2. WBAN Communication Architecture

Compared with existing technologies such as WLANs, BANs enable wireless communications in or around a human body by means sophisticated pervasive wireless computing devices. Figure 1 illustrates a general architecture of a BAN-based health monitoring system [7]. ECG, (electroencephalography) EEG, (electromyography) EMG, motion sensors, and blood pressure sensors send data to nearby personal server (PS) devices. Then, through a Bluetooth/WLAN connection, these data are streamed remotely to a medical doctor’s site for real time diagnosis, to a medical database for record keeping, or to the corresponding equipment that issues an emergency alert.

In this article, we separate the BAN communications architecture into three components: Tier-1-Comm design (*i.e.*, intra-BAN communications), Tier-2-Comm design (*i.e.*, inter-BAN communications), and Tier-3-Comm design (*i.e.*, beyond-BAN communications), as shown in Figure 1 [7]. These components cover multiple aspects that range from low-level to high-level design issues, and facilitates the creation of a component-based, efficient BAN system for a wide range of applications. By customizing each design component, *e.g.*, cost, coverage, efficiency, bandwidth, QoS, *etc.*, specific requirements can be achieved according to specific application contexts and market demands.

Unlike WSNs that normally operate as autonomous systems, a BAN seldom works alone. In this section, we define “inter-BAN communications” as the communications between the PS and one or more access points (APs). The APs can be deployed as part of the infrastructure, or be strategically placed in a dynamic environment for handling emergency situations. Similarly, the functionality of a tier-2-network (as shown in Figure 1) is used to interconnect BANs with various networks that are easy to access in daily life, such as the Internet and cellular networks. We divide the paradigms of inter-BAN communications into two categories, infrastructure-based architecture shown and ad hoc-based architecture shown in Figure 2 [7]. While the infrastructure-based architecture provides larger bandwidth with centralized control and flexibility, the ad hoc-based architecture facilitates fast deployment when encountering a dynamic environment, such as medical emergency care response, or at a disaster site.

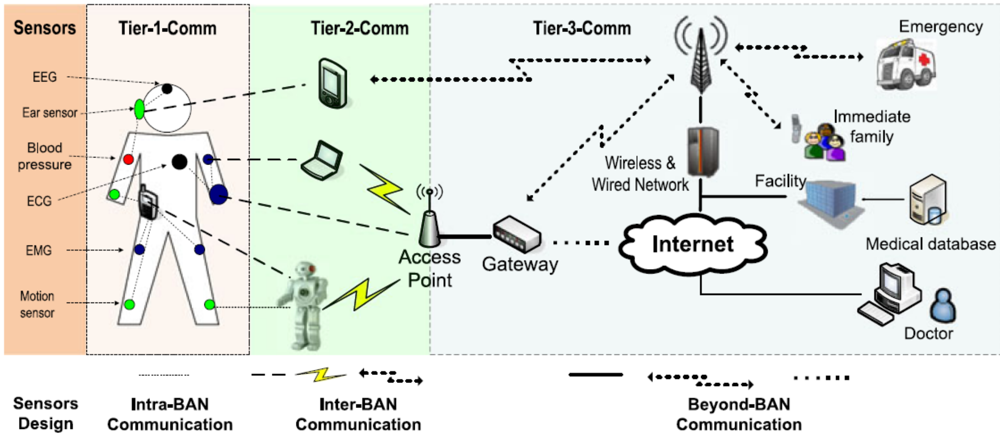

Figure 1. WBAN Communication Architecture

Figure 2. Ad-hoc based Inter-WBAN Communication Architecture

Wireless technologies for inter-BAN communication are mature, and include: WLAN, Bluetooth, Zigbee, cellular, and 3G, *etc.* The more technologies that a personal server supports, the easier for a BAN to be integrated with other applications. Bluetooth is a popular wireless protocol for short range communications, but BANs need protocols that support low energy consumption and the self-organizing feature seen in ad-hoc networks. Even though Bluetooth has a very good communications mechanism over a short range, it is not a very feasible solution for BANs. To overcome these problems, most of the BAN applications use the ZigBee protocol. A key component of the ZigBee protocol is the ability to support mesh networks. ZigBee is used nowadays for communications between sensors in a network. There are many reasons why it has become as popular. Some of them are: (1) it incurs low energy consumption for communications between the nodes, (2) it has a low duty cycle that enables it to provide longer battery life, (3) its communications primitives enable low-latency communications, (4) and it supports 128-bit security [7]. In addition, it has all the basic features required for communications between the sensors in wireless nodes. ZigBee also enables broadbased deployment of these types of sensor networks in a costeffective manner. Most of these applications use WLAN to communicate to the AP because it is much faster than cellular networks. By comparison, cellular network has a unique advantage in that many people carry cellphones using this technology, which provides a friendly user-interface, and communicates with peripheral devices conveniently.

UWB refers to any radio technology having a transmission bandwidth exceeding the lesser of 500 MHz or 20% of the arithmetic center frequency. FCC also regulates license-free use of UWB in the 3.1−10.6 GHz band to have a relatively low power spectral density emission. This leads to the suitability of UWB applications in short-range and indoor environments, and in environments sensitive to RF emissions, *e.g.*, in a hospital. Commercial products based on UWB provide extremely high data rates, *e.g.*, “Certified Wireless USB” devices work at up to 480 Mbps, enabling short-range wireless multimedia applications, such as wireless monitors, wireless digital audio and video players. These multimedia devices can be either wirelessly connected with BANs, or are themselves portable as part of a BAN. UWB is also an ideal technology for precise localization, which complements Global Positioning System (GPS) indoors for BAN tracking. At the same time, concerns with electronic and magnetic energy absorbed by human tissue from RF circuits placed in close proximity means that BAN devices need to employ low transmission power and low transmission duty cycles. In this regard UWB outperforms conventional transmission methods and thus attracts much attention. An emerging BAN standard, IEEE 802.15.6—Body Area Networks (BANs), will likely employ UWB, according to recent proposals and meeting minutes. The standard intends to endow future generation electronics in close proximity to, or inside human body.

On-going work within the IEEE 802.15.6 Task Group aims at supporting applications with various data rates, where QoS guarantees are crucial in case of life-threatening conditions. User experience with audio/video streaming is also important when designing such kind of networks, although it is much less critical. Some proposals tune the existing IEEE 802.15.4 protocols to better accommodate BANs traffic, while others advance a completely new strategy to utilize new radio technologies, such as Ultra-Wideband (UWB), to deal with new problems (*e.g.*, inter-BAN interference).

3. WUSB Communication Protocol

WUSB defines a WUSB Channel which is encapsulated within a WiMedia MAC superframe via private DRP (Distributed Reservation Protocol) reservation blocks that enables devices to reserve medium without contention. 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 3 shows the relationship between WiMedia MAC and WUSB protocol. Since the WUSB Channel is encapsulated by the WiMedia MAC channel, it is possible that WUSB devices that don’t know about the WiMedia MAC channel can be implemented. There are three kinds of WUSB devices. A device that implements the full WiMedia MAC protocol is called a Self Beaconing device. A device that implements partial features of the WiMedia MAC protocol and instead relies on the host to utilize the WiMedia MAC channel is called a Directed Beaconing device. Devices that have restricted transmission/reception capabilities without the implementation of WiMedia MAC protocol are called Non Beaconing device.

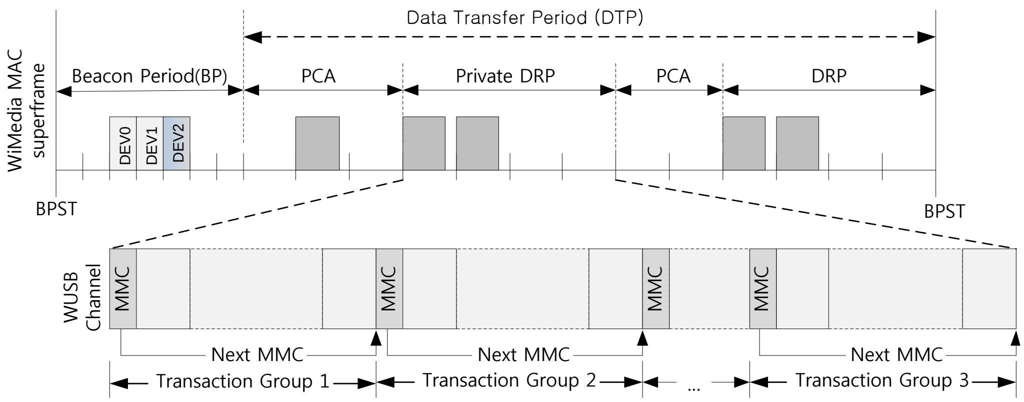

Figure 3. The Relationship between WiMedia MAC and WUSB Protocol

3.1 Self Beaconing Device

A device that implements the full WiMedia MAC protocol is called a Self Beaconing device and it knows how to manage the WiMedia MAC channel including synchronization and maintenance of Beacon Period in the WiMedia MAC. Self Beaconing devices must be able to determine which MASs (Medium Access Slot) are available for communication with the host. All DRP reservations seen by the device, except the reservations that comprise its own WUSB channel reservation, must be excluded from the device's MAS availability information.

WUSB host uses the GetStatus (MASAvailability) request to retrieve a device's MAS availability information. A WUSB device that has received the GetStatus (MAS Availability) request from the WUSB host accumulates the information from its neighbors' beacons about available MASs. Then, the WUSB device responds to the GetStatus (MAS Availability) request through the bmMASAvailability field.

After the WUSB host that has received WUSB device's response selects available MASs, it transmits a SetWUSBData(DRPIE Info) request. The SetWUSBData(DRPIE Info) is used to construct the DRP IE (Information Element) that the WUSB device transmits in its beacon. Otherwise the WUSB device does not have an existing DRP IE for this Wireless USB Channel, it simply adds the received DRP IE to its beacon. If the device has an existing DRP IE for this Wireless USB Channel, then it must replace the existing DRP IE with the new DRP IE provided in this SetWUSBData command payload.

If the WUSB host transmits the SetFeature(TX DRP IE) request to the WUSB device, the WUSB device starts the transmission of its beacon including the DRP IE set according to SetWUSBData command. To terminate the DRP reservation, WUSB host transmits a ClearFeature(TX DRP IE) request. It instructs a WUSB device to cease transmitting the corresponding DRP IE in its beacon. Figure 4 shows the current operation flow of DRP reservation for WUSB channel setup/release.

All WUSB devices can receive data frames from its WUSB host at the reserved private DRPs in WiMedia MAC, according to private DRP reservation information in the received beacon from its WUSB host. All WUSB command frames such as GetStatus request/response, SetWUSBData request, SetFeature request, and ClreaFeature request are conveyed into WiMedia beacons.

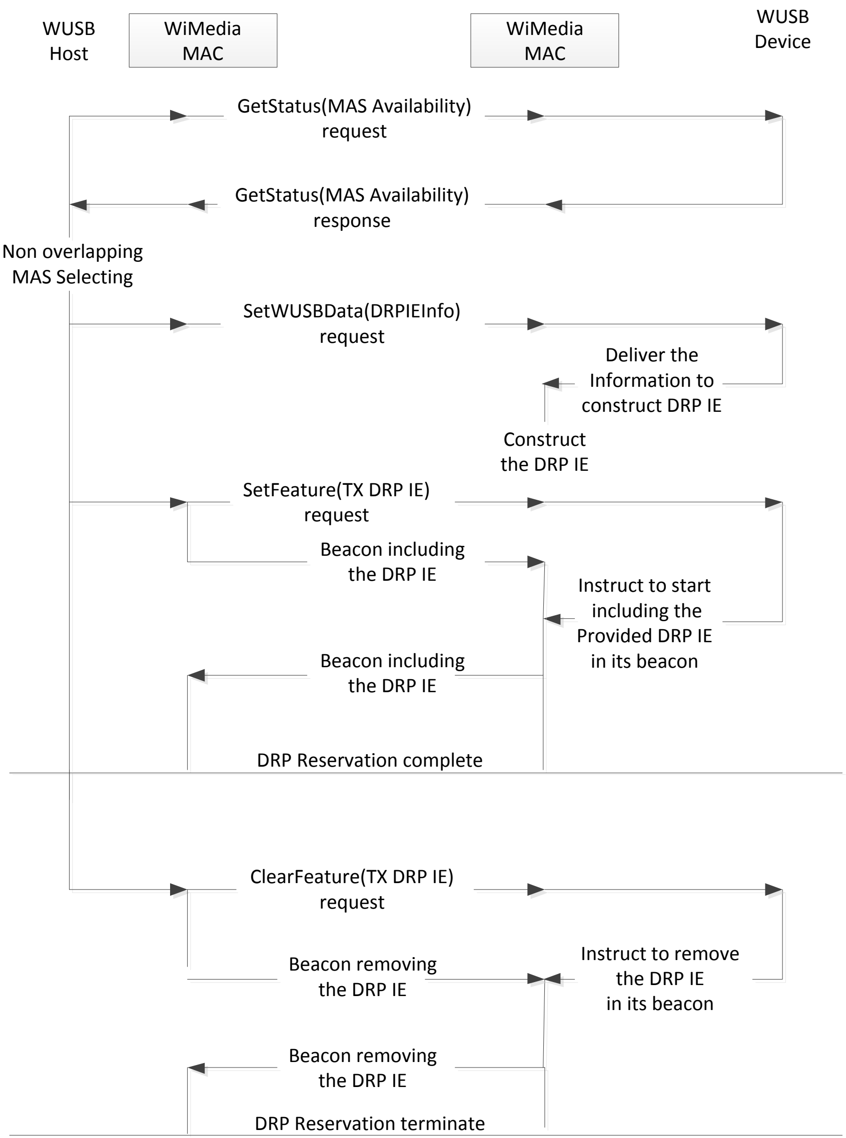

Figure 4. The Current Operation Flow of DRP Reservation in WUSB Channel setup/release

3.2 Directed Beaconing Device

A WUSB device that implements only the WUSB protocol must support device capabilities defined by WUSB specifications that allow its host to learn about hidden devices that locate out of range from the WUSB host, but in range of the WUSB device. And Directed Beaconing device should be able to transmit beacons defined by its WUSB host. These capabilities are required to guarantee that the private DRP reservations for Wireless USB channels in WiMedia MAC layer are transparently observed by hidden devices so the DRP reservations by the WUSB host for those WUSB channels can be protected. WUSB devices that support these capabilities are called as Directed Beaconing devices. Directed Beaconing devices must support three functions: Transmit Packet, Count Packet, Capture Packet. And it performs one of these functions at a time.

3.2.1 Transmit Packet Function

A WUSB device that implements only the WUSB protocol must support device capabilities defined by WUSB specifications that allow its host to learn about hidden devices that locate out of range from the WUSB host, but in range of the WUSB device. And Directed Beaconing device should be able to transmit beacons defined by its WUSB host. These capabilities are required to guarantee that the private DRP reservations for Wireless USB channels in WiMedia MAC layer are transparently observed by hidden devices so the DRP reservations by the WUSB host for those WUSB channels can be protected. WUSB devices that support these capabilities are called as Directed Beaconing devices. Directed Beaconing devices must support three functions: Transmit Packet, Count Packet, Capture Packet. And it performs one of these functions at a time.

3.2.2 Count Packet Function

The Count Packet function causes the Directed Beaconing device to receive for a period of time. And it makes the device record how many frames were received, store some basic packet information, and record when the packets were received. WUSB host can use this functionality to make the device scan other WiMedia PHY channels to check whether the device observes any activity during that time period, or scan during a beacon period to check whether the device listens any beacon frame that the WUSB host can't listen.

The WUSB host transmits a SetWUSBData(Receive Params) request to provide the device with the USB channel time window during which the device should receive WUSB data. The WUSB host is responsible for initializing the Directed Beaconing device by transmitting a SetWUSBData(Receive Params) request before enabling a device to do directed packet transmissions. Directed Beaconing device disables the Count Packet function, when it receives a ClearFeature(COUNT PACKETS) request from its WUSB host.

3.2.3 Capture Packet Function

The Capture Packet function causes the Directed Beaconing device to receive and store a single packet during a specified period of time. The WUSB host utilizes Capture Packet function to make the device receive and store beacon frames during the Beacon Period in WiMedia MAC layer so that the WUSB host can see all the beacons.

The WUSB host transmits the SetWUSBData(Receive Params) request to provide the device with the USB channel time window during which the device should receive WUSB data. The WUSB host enables a Directed Beaconing device to capture frame by sending a SetFeature(CAPTURE PACKET) request. WUSB host is responsible for initializing the device by transmitting a SetWUSBData(Receive Params) request before enabling a device to capture a packet. Directed Beaconing device disables the Capture Packet function, when it receives a ClearFeature(CAPTURE PACKET) request from its WUSB host.

3.3 Non Beaconing Device

WUSB also defines what is called a Non Beaconing device. Due to the reduced transmit power and receiver sensitivity, that device can only exist close to its host. Any neighbor of this device must be in range of the WUSB host and thus is able to observe the WUSB host's beacon. Therefore, data transmission between the Non Beaconing device and its WUSB host don't interfere with its neighbor's traffic. The Non Beaconing device never transmits a WiMedia MAC beacon. This device communicates only with its WUSB host according to scheduling information in the received beacon from its WUSB host.

4. WBAN Beacon Structure for WUSB over WBAN Architecture

In this subsection, we analyzed the beacon frame structure of IEEE 802.15.6 WBAN MAC and designed the WBS structure for WUSB MMC Scheduling. WBAN slave devices which have received beacon from WBAN host schedule their receiving and transmitting operations according to information delivered by the beacon.

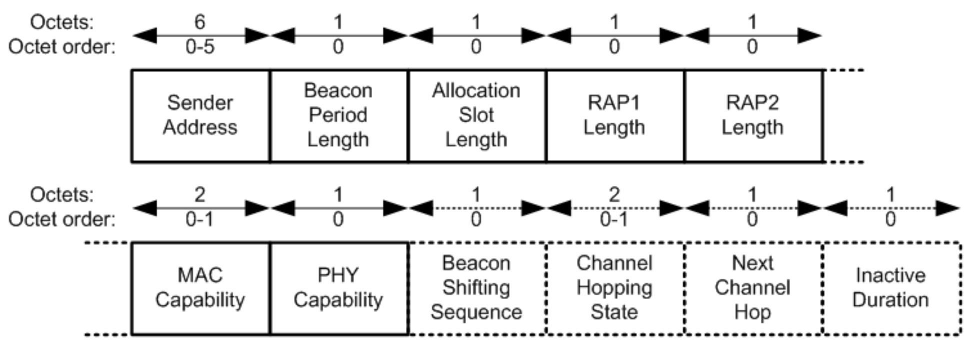

Figure 5. WBAN Beacon Frame Format

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 WBAN beacon frame of Figure 5, 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 6 shows current WBAN MAC Capability format standard. To successfully set up wireless communication links for wearable computer systems, secure WUSB channels should be encapsulated privately within a WBAN superframe. Furthermore, the WUSB channel allocated privately in the IEEE 802.15.6 WBAN MAC enables the MMC scheduling between WUSB host and its several peripheral devices. In the current IEEE 802.15.6 WBAN standard, there is no available periods allocated for other heterogeneous networks. In this paper, we propose a WBAN beacon structure (WBS) of IEEE 802.15.6 WBAN to set up WUSB channel efficiently.

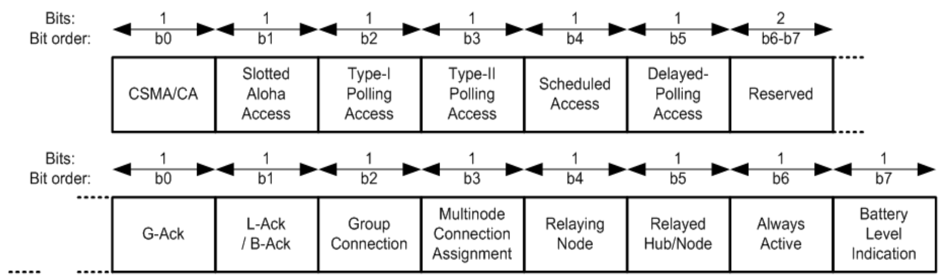

Figure 6. Current WBAN MAC Capability Format Standard

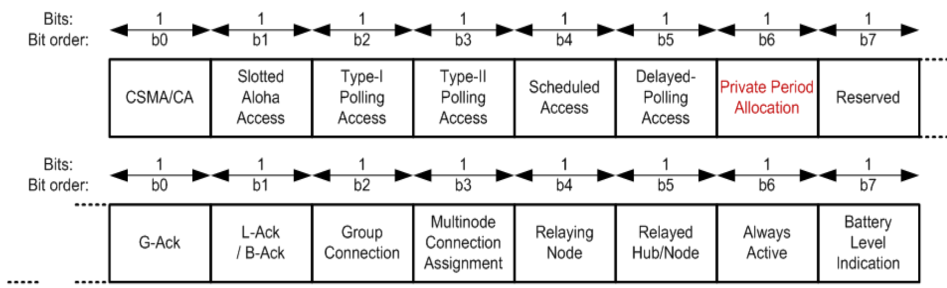

Figure 7. A New WBAN MAC Capability Format for WUSB Private Channel Allocation

In Figure 7 for a new WBAN MAC Capability format, a Private Period Allocation field is made by using one bit in the reserved bits in Figure 6. The Private Period Allocation field is set to one if the WBAN MAC supports private WUSB channel allocations, or set to 0 otherwise. If the Private Period Allocation field is set to 1, the RAP2 length field indicates the private WUSB channel length. Therefore, after receiving beacon from the WBAN host non-WUSB devices never use the RAP2 periods during the WBAN superframe.

Figure 8 shows a new IEEE 802.15.6 superframe structure supporting the WUSB private channel allocation. 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.

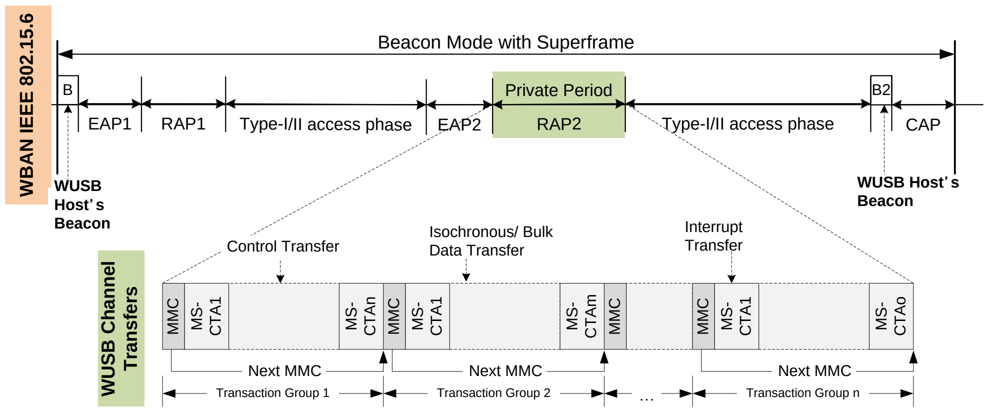

Figure 8. IEEE 802.15.6 Superframe Structure for WUSB Private Channel Allocation

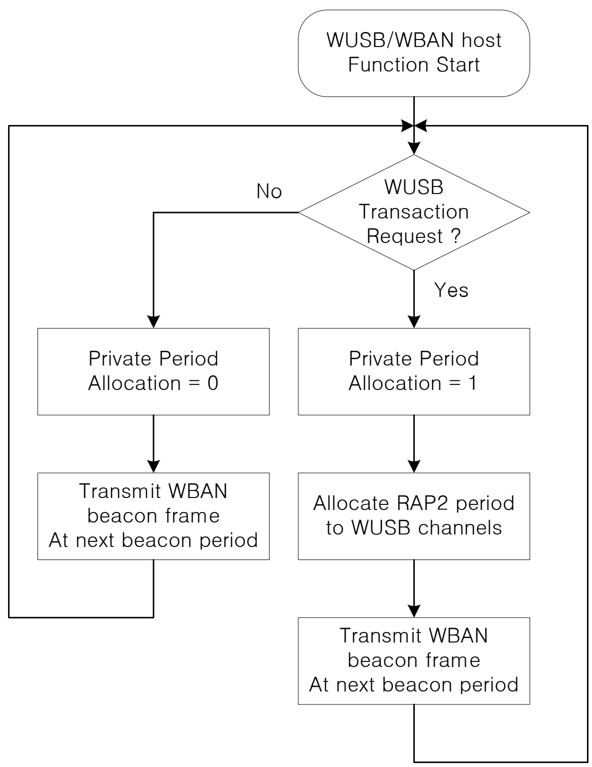

Figure 9. WBAN Host Beacon Transmission Procedure for WUSB Private Channel Allocation

Figure 9 shows the WBAN host Beacon transmission procedure for WUSB private channel allocation. 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 Fig. 6. And the WUSB/WBAN host also sets the WBAN beacon's RAP2 length field to the length required for MMC scheduling in the WUSB private channel. Then, the WUSB/WBAN host transmits its beacon frame. After receiving beacons, non-WUSB WBAN slave devices enter into sleep mode during the RAP2 period. On the contrary, the WUSB/WBAN slave devices enter into active mode during the RAP2 period and they enter into sleep mode during the other periods. The RAP2 length is determined by the WUSB/WBAN host according to priorities between WUSB transactions and WBAN traffic.

5. Performance Evaluation

Performance of the proposed scheme is evaluated through OMNet++ simulations [8-13]. Table 2 shows WBAN PHY/MAC simulation parameters used in this paper; the network size is 10m*10m; the maximum 20 devices are randomly deployed into this area.

Table 2. WBAN PHY/MAC Parameters

Parameter	Value
LPreamble	64 bits
LPHY_Hdr	15 bits
LMAC_Hdr	56 bits
LFCS	16 bits
pMIFS	20 μs
pSIFS	75 μs
pAllocationSlotMin	16 μs
pAllocationSlotResolution	16 μs
pAllocationSlotLength	32 μs
mSuperframeLength	256
pSuperframeLength	mSuperframeLength*pAllocationSlotLength
mBeaconSlotLength	96 μs
mBPExtention	24 μs
mBeacon2SlotLength	80 μs
mB2PExtention	24 μs

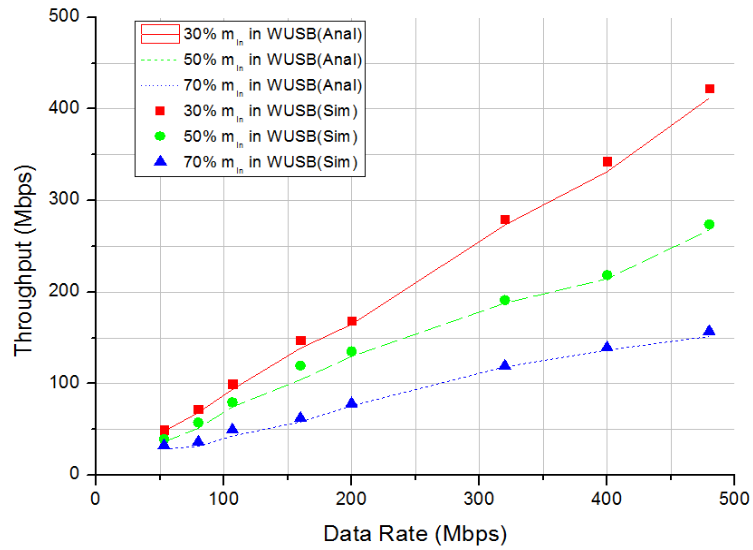

Figure 10. Throughput of a WUSB Device According to each UWB PHY Data Rate

Figure 10 shows throughputs of a WUSB device according to each UWB PHY data rate for each mIn situation. The m_{In} parameter indicates the occupation ratio of non-WUSB WBAN traffic for the entire WBAN superframe length. In Figure 10, the frame size transmitted by devices in a WBAN beacon group is fixed to 4095 bytes.

In this result, it show that the larger mIn ratio of WBAN traffic reduces throughput of a WUSB device more. This result caused by the reason that the increase of m_{In} ratio reduces the length of RAP2 period. In the proposed WBS scheme, only the RAP 2 period can be allocated to the WUSB private channel. Therefore, the reduced RAP2 period leads to the decrease of throughput of a WUSB device or a WUSB transaction.

Figure 11 shows the relationship between throughput of a WUSB device and the frame size transmitted. In Figure 11 the UWB PHY data rate of devices is fixed to 480Mbps. As shown in Figure 11, the throughput of WUSB devices doesn't vary largely according to the frame size after the frame size exceeds a certain threshold. Because the WUSB transactions in RAP2 period are performed privately without contention, the increase of frame size doesn't cause the increase of frame collision probability. But the throughput of WUSB device decreases extremely and it decreases proportionally according to mIn ratio of WBAN traffic because the increase of mIn ratio reduces the length of RAP2 period.

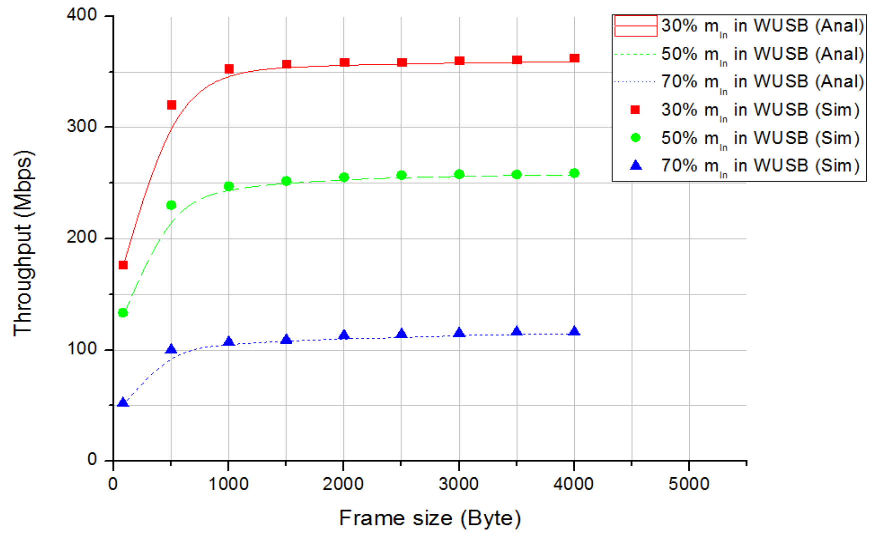

Figure 11. Throughput of a WUSB Device According to Each Frame Size

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). Furthermore, we proposed a WBAN beacon structure (WBS) of IEEE 802.15.6 WBAN to set up WUSB channel efficiently. Simulation results showed that the WBS integrate WUSB transactions and WBAN traffic efficiently in the hierarchical WUSB/WBAN MAC. Proposed WBS technique has compatibility with current IEEE 802.15.6 WBAN and Wireless USB standards.

Acknowledgements

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