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Multi-Hop N-Screen Traffic Mechanism for Wearable Health-Monitoring System in Hospital Wireless Networks

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Abstract

In this paper, we propose a multi-hop N-screen traffic mechanism, by using a coordinated resource allocation and an N-screen multi-hop DRP Information Element, in wearable health-monitoring systems (WHMS) networks. The proposed scheme can improve multi-hop throughput performance of WHMS Vital Video (WVV) applications. Also, proposed scheme can reduce WVV link establishment time since it minimizes the multi-hop WVV data delivery process. Compared with the legacy WHMS system, the proposed multi-hop N-screen traffic mechanism is very simple and efficient as it does not require additional wireless bio-channel information. These merits make the proposed multi-hop WHMS system extremely inexpensive to implement in hospital WHMS networks and bio-cloud computing applications.

Keywords: *Bio-informatics, Body Sensor Networks, IEEE 802.15.6, N-screen, U-health services.*

1. Introduction

Wearable health-monitoring systems (WHMS) have drawn a lot of attention from the research community and the industry during the last decade as it is pointed out by the numerous and yearly increasing corresponding research and development efforts [1]. To address this demand, a variety of system prototypes and commercial products have been produced in the course of recent years, which aim at providing real-time feedback information about one's health condition, either to the user himself, to a medical center, or straight to a supervising professional physician, while being able to alert the individual in case of possible imminent health-threatening conditions. In addition to that, WHMS constitute a new means to address the issues of managing and monitoring chronic diseases, elderly people, postoperative rehabilitation patients, and persons with special abilities [1, 2].

Development in wireless communication and the miniaturization of computing devices, such as wearable and implantable sensors, enable next-generation communication known as body sensor networks (BSNs). Each BSN comprises several intelligent sensor nodes that should have a communication range of 3 m and dynamic data rates from 10 kbps to 10 Mbps according to application requirements [3]. Each sensor nodes monitors a human's biometric or surrounding environment information, and forward it to a hub. Using this information, several applications can derive benefits from the BSN. IEEE 802.15 Task Group 6 (IEEE 802.15.6) has recently presented a draft dealing with BSNs [1-3].

IEEE 802.15.6, which describes the application of wearable computing devices, allows the integration of intelligent, miniaturized, low-power, invasive/non-invasive sensor

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nodes that monitor body functions and the surrounding environment. Each intelligent node has sufficient capability to process and forward information to a base station for diagnosis and prescription. A wireless body area network (WBAN) provides long-term health monitoring of patients under their natural physiological states without constraining their normal activities. The WBAN can be used to develop a smart and affordable health care system, and it can handle functions including basic diagnostic procedures, supervision of a chronic condition, supervising recovery from a surgical procedure, and emergency events [3].

A recent major development in computer technology is the advent of the wearable computer system that is based on human-centric interface technology trends and ubiquitous computing environments. Wearable computer systems use the wireless universal serial bus (WUSB) refers to USB technology that is merged with WiMedia PHY/MAC technical specifications [4]. Unlike a wired USB that physically separates the USB host and USB device, WUSB allows a device to separately function as both a WUSB host and WUSB device on a single transceiver; such devices are referred to as the dual role devices (DRD) [4].

The WiMedia Alliance has specified a distributed MAC (D-MAC) protocol based on UWB for High-Rate WPANs [5-6]. The WiMedia D-MAC supports a distributed MAC approach. In contrast to the IEEE 802.15.3, the D-MAC UWB supports DRP mechanism which makes all devices be connected using self-organizing approach. In the distributed architecture, by exchanging resource reservation and control information among the devices, especially via the distributed reservation protocol Information Element (DRP IE) and DRP Availability IE in each device’s beacon signal, the WiMedia D-MAC removes the SOP (Simultaneous Operating Piconet) problem in the centralized IEEE 802.15.3 MAC. In the D-MAC, each node broadcasts its own beacon containing IEs per superframe. The IEs convey certain control and management information. The distributed nature of D-MAC protocol can provide a full mobility support and a scalable and fault tolerant medium access method [5-6].

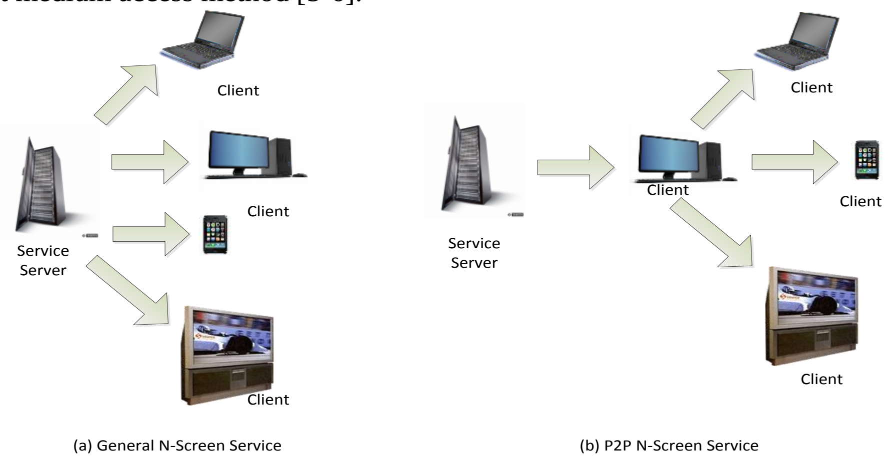


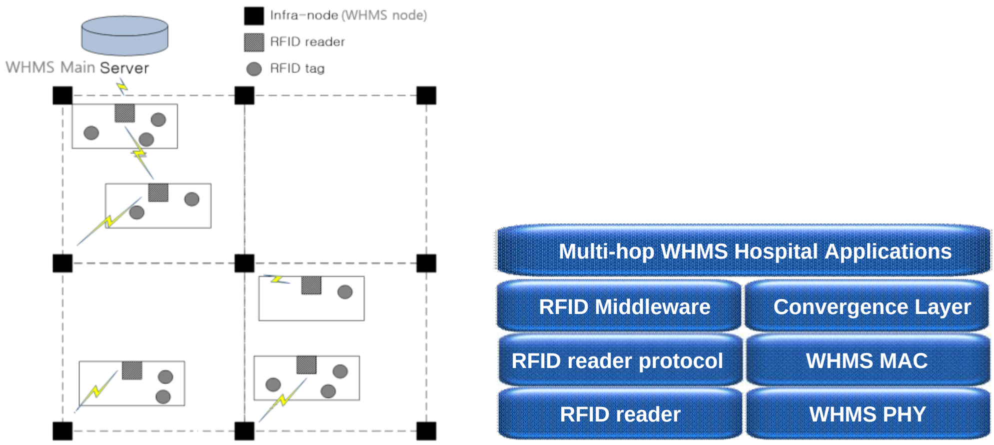
Figure 1. P2P N-screen Service Networks

As shown in Fig. 1, N-screen means multi-screen that is an emerging one source multiple use (OSMU) technology and a demand of future to support multimedia multicasting, content sharing, content mobility, media scalability, media synchronization, and seamless mobility. The initial N-Screen service has begun from three-screen services of AT&T in 2007 and has meant the service that enables the users to utilize content with various ways by connecting TV, PC, and mobile phone the most commonly used by users [7-8]. In this paper, a hierarchical system of WUSB over WBAN is adopted for wearable health-monitoring systems (WHMS). It is executed on the basis of WUSB over WBAN protocol at each wearable sensor node comprising the WHMS. Basically, a single WHMS operates based on WUSB over WBAN protocol. And the multiple WHMSs operate based on the WiMedia D-MAC protocol and dual-role device (DRD) function, combined with RFID systems.

In a hospital, the OSMU (One Source Multi Use) P2P N-screen applications must be required by using WHMS networks. But, data traffics must be delivered to multi-hop points in multiple rooms. In this paper, we propose a multi-hop N-screen traffic mechanism, by using a coordinated resource allocation and an N-screen multi-hop DRP Information Element, in WHMS networks. The proposed scheme can improve multi-hop throughput performance of WHMS Vital Video (WVV) applications. Also, proposed scheme can reduce WVV link establishment time since it minimizes the multi-hop WVV data delivery process.

2. RFID-based Multi-hop WHMS Networks

The RFID (Radio Frequency IDentification) identifies a target using wireless radio and reads the target's information. A RFID system is composed of RFID tag and RFID reader. Current RFID technology is used in the area such as security, health care, and toll gate fee management systems. The RFID-based WHMS can be composed of RFID tag, RFID reader, and WHMS nodes as in Fig. 2. And when the RFID system is combined with some WHMS infra-nodes, more efficient and stable networking can be guaranteed. The RFID reader identifies RFID tags, collects the related data, and delivers them to its WHMS main host server. By collecting information about environment such as temperature, humidity and air pressure, the whole WHMS controls environment according to features of a hospital floor through its attached RFID tag. Therefore, communications between the RFID reader and the WHMS infra-nodes or WHMS server, and communications between WHMS infra-nodes should be expanded to the multi-hop range and energy-efficient. For the case where many RFID tags are located in the corresponding RFID reader's range, delivery of abundant information should be possible through efficient multi-hop DRP reservations.



(a) (b)

Figure 2. A RFID-based WHMS in Multi-rooms of a Hospital and its Protocol Layer

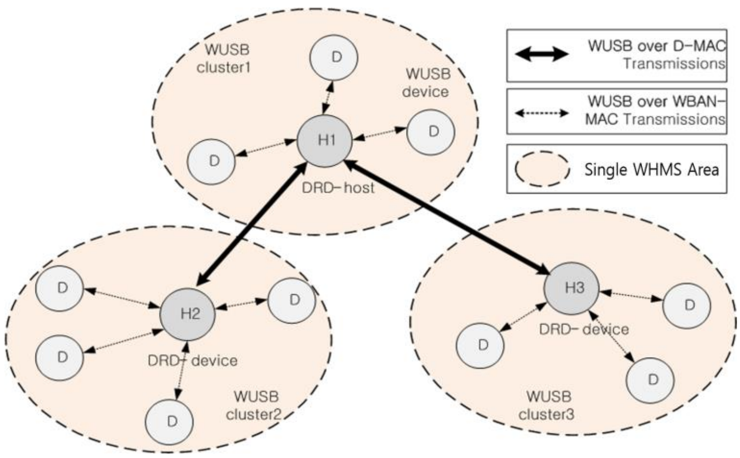


Figure 3. A WUSB Cluster Tree Topology Formed for Multiple WHMS Networks

In the WUSB specification [4], the WUSB host operating mode in a DRD is denoted as DRD-host, and the WUSB device operating mode in a DRD is denoted as DRD-device. In Fig. 3, a WUSB cluster tree topology is formed to configure multiple WHMSs. Basically a single WHMS operates based on WUSB over WBAN protocol. And the host in each WHMS denoted as H1 in Fig. 3 takes a role of DRD-host or DRD-device. The WUSB/WBAN flows in a WHMS are manipulated in a time period during a WBAN superframe. On the other hand, the DRD flows between WHMSs are manipulated in a time period during a WiMedia D-MAC superframe. By adopting the D-MAC, our WHMS solves the SOP problem in the centralized IEEE 802.15.3 MAC. In the D-MAC, each node broadcasts its own beacon containing IEs per superframe. The IEs convey certain control and management information. The distributed nature of D-MAC protocol can provide a full mobility support and a scalable and fault tolerant medium access method to a multiple WHMS environment.

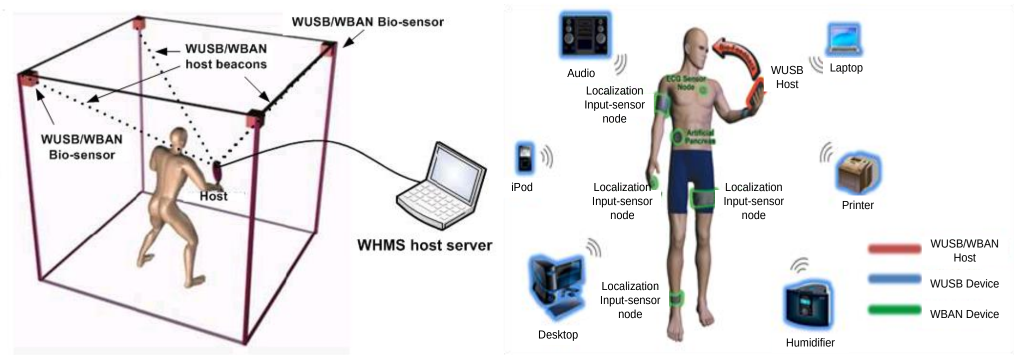


Figure 4. A WHMS System using WUSB over WBAN Architecture

In this WUSB cluster tree, the DRD-device H2 in WUSB cluster 2 and the DRD-device H3 in WUSB cluster 3 are connected with the DRD-host H1 in WUSB cluster 1. And the DRD-host H1 in the WUSB cluster 1 can manage WUSB devices belonging to WUSB cluster 2 and WUSB cluster 3 as well as WUSB member devices in its own WUSB cluster. In this way, large scale multi-hop WHMSs can be constructed. Figure 4 shows the user scenario of a WHMS when using the WUSB over WBAN architecture. 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 are formed. The attached input-sensor nodes perform the functions of localization-based input interfaces for healthcare monitoring.

3. WHMS Networking for P2P N-screen Services

Examples for specific use of cases of DRD devices are divided into three parts. Firstly, a printer works as a device (e.g. with PC), or as a host (e.g. with digital camera / mobile phone), intermittently. Static DRD is a device used for an example like this. Secondly, combinational DRD works as a device and as a host concurrently. For example, printer equipped with combinational DRD works as a device (e.g. with PC) and as a host (e.g. with digital camera / mobile phone) concurrently. In the combination scenario, the DRD operates as a WUSB device connected to a WUSB host. Separately in time, the same DRD also operates as a WUSB host that manages other WUSB devices. Lastly, an example of P2P DRD is two mobile phones / WHMS Vital Video (WVV) players / PDAs connecting to each other, sharing files, each displaying concurrently both Host and Device behavior towards each other. In the point-to-point scenario, two WHMS DRDs connect themselves with each other as both a WUSB host and a WUSB device. In other words, two WUSB DRDs linking to each other by one upstream and one downstream WUSB links are called paired P2P-DRDs. The WUSB link that is established first is called the default link; the link that is established later is called the reverse link [4].

WUSB P2P-DRD has the default link that is established by DRD-host and the reverse link that is established by DRD-device. To establish the default link and the reverse link, DRD must be allocated the needed resources through private DRP reservation. Figure 5 shows the example of a link establishment between DRD devices in WHMS protocol.

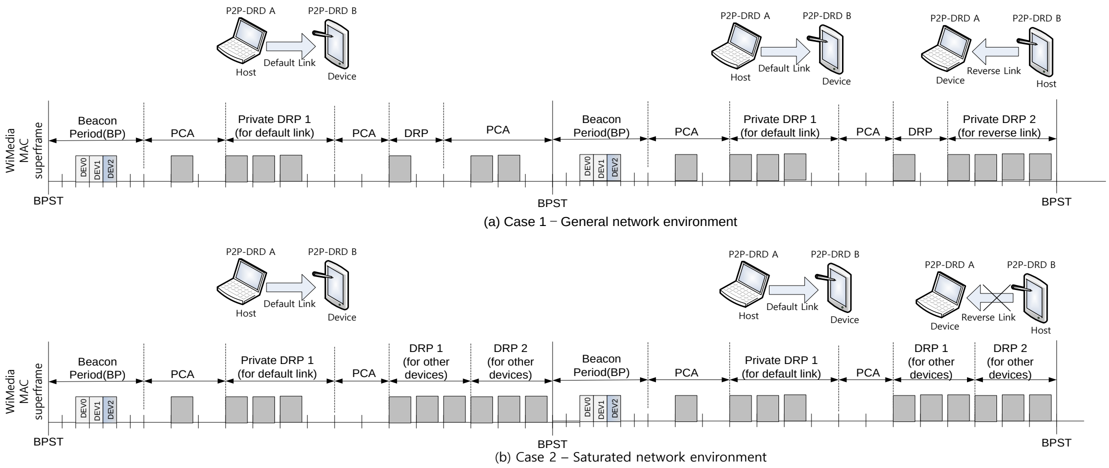


Figure 5. WHMS Channel Time Slot Allocation for the P2P N-screen Services

In Fig. 5(a), P2P-DRD A establishes the default link in Private DRP 1 duration. Also, P2P-DRD B establishes the reverse link in Private DRP 2 duration. Figure 5(b) shows the example of link establishment between DRD devices in the saturated network environment. As shown in Fig. 5(b), P2P-DRD A can establish the default link in Private DRP 1 duration. However, P2P-DRD B cannot establish the reverse link since the available resources do not exist in WiMedia D-MAC superframe.

4. Multi-hop Traffic Mechanism for WHMS N-screen Services

In a hospital, P2P N-screen applications must be required by using WHMS networks. But, data traffics must be delivered to multi-hop points in multiple rooms. In this paper, we propose a multi-hop N-screen traffic mechanism, by using a coordinated resource allocation and an N-screen multi-hop DRP Availability Information Element, in WHMS networks.

In this paper, we propose N-screen multi-hop MSCDRP (Multi-Stage Coordinated DRP) reservation scheme to minimize the end-to-end delay in WHMS network. As shown in Fig. 6, MSCDRP IE includes addresses of all devices on path between WHMS source device and WHMS destination device. Also, MSCDRP IE includes Element ID that describes the information element for multi-stage coordinated communication, and includes length field, control field, and many device address fields on its multi-hop path. The Length field is set to the length, in octets, of the MSCDRP IE field that follows. The control field includes the stream index field and DRP IE validity check request. The stream index field is used to indicate traffic flows provided by MSCDRP IE. DRP IE validity check request field is used to indicate whether target devices accept the received MSCDRP IE or not.

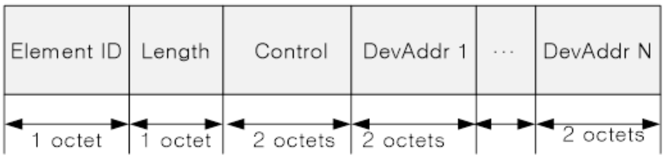


Figure 6. Format of a MSCDRP IE

Figure 7 shows reservation negotiation process for proposed WHMS MSCDRP scheme. The purpose of the negotiation process is to reserve MASs for data transmissions between the two devices. In this process, two different information elements, i.e. DRP IE defined in the current WiMedia standard and the proposed MSCDRP IE may be used. Reservation owner collects DRP IE validity check values of one or more devices to include into own MSCDRP IE. The device that receives the DRP validity check request responds to reservation owner using its own MSCDRP IE whether to reserve medium access slots (MAS) or not.

Reservation owner selects a group of devices to be included in its own MSCDRP reservation based on collected validity information. Addresses of the selected devices are specified in the newly created MSCDRP IE. The newly created MSCDRP IE is sent to all devices in the group with standard DRP IE. DRP IE and MSCDRP IE contain the same value for their individual stream index sub-field. Validity check may include whether both MSCDRP IE and DRP IE have the same stream index and MSCDRP IE includes the address of a receiving device. If the results of both validity checks are positive, the receiving device transmits DRP IE including whether the reservation request is accepted. When reservation request is accepted, the receiving device indicates acceptance of reservation request by transmitting DRP IE including the same reservation status bit with that received in the DRP IE.

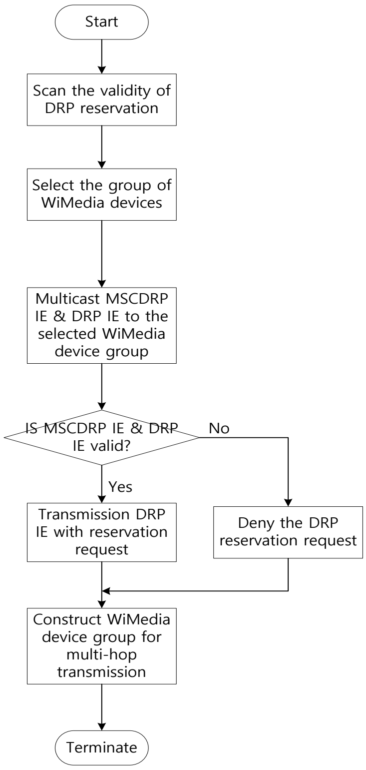


Figure 7. N-screen Multi-hop MSCDRP Reservation Process

Each WHMS device’s access to the channel is organized around a fundamental concept, the superframe. A superframe is a 65536 μs period which starts as demarcated by the device's beacon period start time [5]. WHMS subdivides the superframe into 16 equal pieces, called allocation zones. The nominal duration of an allocation zone is 4096 μs. Each allocation zone is identified by its index, a number between 0 and 15, inclusive. Allocation zone zero, the beacon zone, is reserved for the beacon period. Each allocation zone is subdivided into 16 medium access slots (MAS).

A MAS is the smallest quantum of channel time allocation, 256 μs. Each MAS is identified by its index, a number between 0 and 255, inclusive, which represents the position of the MAS within the superframe. An allocation zone consists of MAS_n through MAS_{n+15}, inclusive, where n is equal to 16 times the allocation zone's index. Within a superframe, MAS from different allocation zones are organized into coordinated MAS sets from [5].

There are 16 coordinated MAS sets in a superframe, all of which are disjoint with respect to each other. Each coordinated MAS set contains 15 MASs. For example, coordinated MAS set 10 consists of the eleventh MAS in each allocation zone other than the beacon zone. MASs within a coordinated MAS set are distributed as evenly as is possible within a superframe. This property can be used to minimize the service interval between successive transmit opportunities for a WHMS device. So long as they are members of the same set, MASs that belong to adjacent allocation zones are separated from each other by uniform 4096 μs service intervals. Because the beacon zone intervenes between allocation zones 15 and 1, MASs from these zones that belong to the same coordinated MAS set are separated by an 8096 μs service interval.

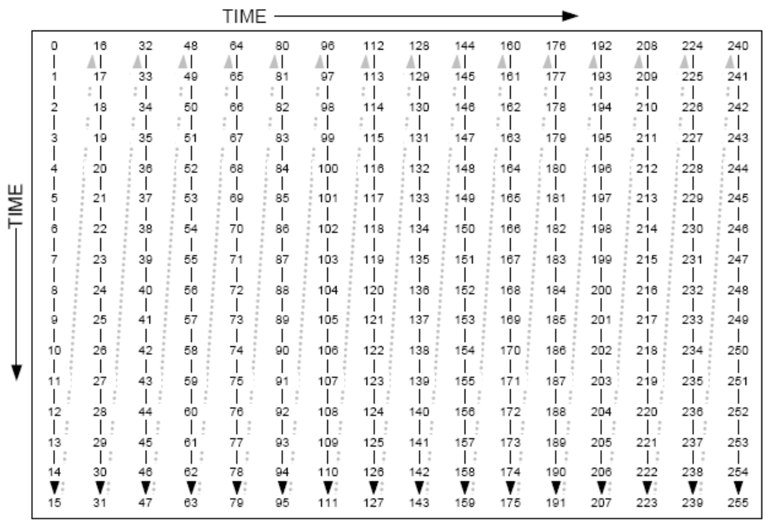


Figure 8. Two Dimensional MAS Locations within a D-MAC Superframe in WHMS

In Fig. 8, the rectangle represents the entire 65536 µs duration of a superframe, which is subdivided into 256 MAS, labeled MAS_0 through MAS_{255}, inclusive. The upper left corner of the rectangle represents beacon period start time (BPST). Within each column, time progresses from top to bottom; upon reaching the bottom of a column, time skips to the top of the right-hand adjacent column [5]. Figure 9 illustrates allocation zones and coordinated MAS sets in two-dimensional notation. Allocation zone n consists of MAS_{16n} through MAS_{16n+15}. Allocation zone 0 is a special case; it is reserved for MASs allocated to the beacon period and any unallocated MAS up to MAS_{15}. Coordinated MAS set n consists of MAS_{16+n}, MAS_{32+n}, MAS_{48+n} and so on through MAS_{240+n}.

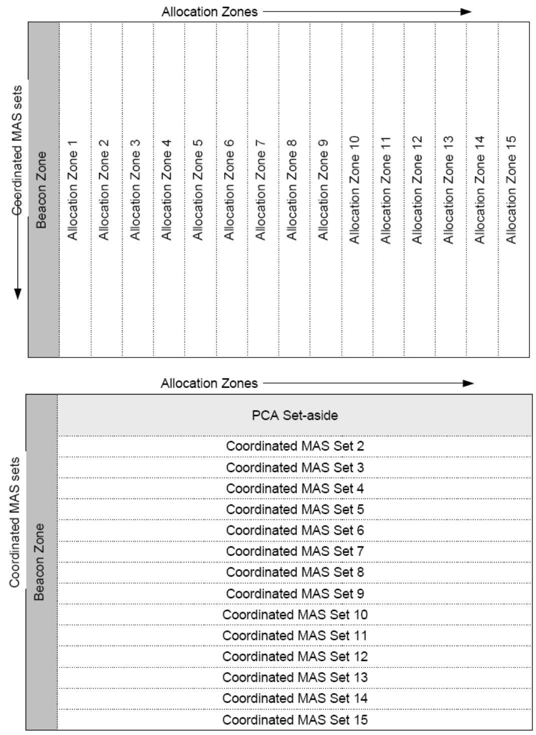


Figure 9. Allocation Zones and Coordinated MAS Sets within a Superframe in WHMS

Excluding the beacon zone (allocation zone 0), the remaining 15 allocation zones are grouped into 4 subsets of allocation zones, called isozones, as depicted in Fig. 10 from [5]. Each isozone is identified by its iso-index, which range from 0 through 3. Those MASs within an isozone are distributed evenly across the superframe. Two MASs, located in the same row and in adjacent allocation zones within the same isozone, are separated from each other by the isozone's native service interval. Table 1 lists the native service interval for each isozone. This isozone structure has the properties that are desirable for satisfying a range of service interval requirements while conditionally optimizing a WHMS reservation's bandwidth and power efficiency.

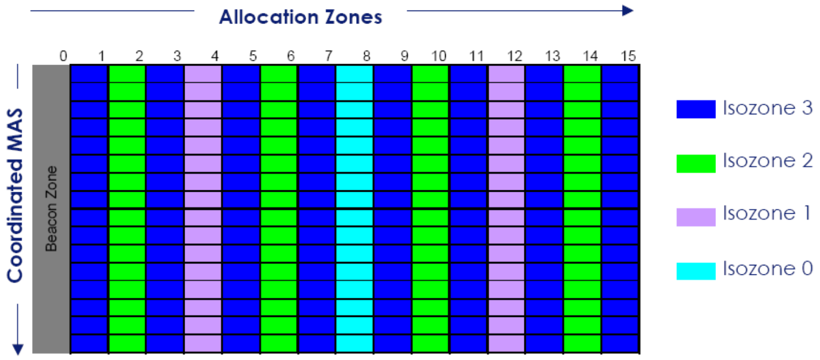


Figure 10. Isozone Structure within a D-MAC Superframe in the WHMS

Table 1. Isozone Index and Each Native Service Interval

Isozone Index	Native service interval (Number of allocation zones x duration)
0	16 x 4.094ms
1	8 x 4.094ms
2	4 x 4.094ms
3	2 x 4.094ms

5. Experiments

We designed the multiple WHMS networks and simulated it for performance evaluation with WBAN medical/non-medical service parameters and WiMedia PHY/MAC parameters as in Tables 2, 3 and 4 [3-8]. In the simulation, WHMS devices are connected through the D-MAC and DRD functions with RFID systems. WBAN frame size is fixed to 4095 bytes.

Table 2. WBAN Medical Service Traffic Parameters

Service	Service data rate	Setup Time
EEG	*86.4kbps*	*< 3s*
ECG	*3kbps/ch*	*< 30s*
Vital monitor	*< 10kbps*	*< 30s*
SpO2	*< 32kbps*	*< 30s*
Hearing aid(communication)	*10kbps*	*< 1s*
Hearing aid(medium fidelity)	*256kbps*	*< 3s*
Glucose/brain liquid/drug delivery	*< 1kbps*	*< 3s*

capsule		
Endoscope capsule	*1Mbps*	*< 3s*
Brain-computer interface	*2Mbps*	*< 1s*
Pacemaker/ICD/actuator/insulin pump	*10kbps*	*< 3s*

Table 3. WBAN Non-medical Service Traffic Parameters

Service	Service data rate	Setup Time
Video streaming	*10~20Mbps*	*< 1s*
3D video	*100Mbps*	*< 1s*
Voice comm.	*256kbps*	*< 3s*
Sound track	*5Mbps*	*< 3s*
File transfer	*10Mbps*	*< 3s*
Gaming applications	*200kbps~2Mbps*	*< 1s*

Table 4. WiMedia PHY/MAC Parameters

Parameter	Value
T_{SYM}	312.5ns
T_{sync}	Standard Preamble: 9.375 μs
pMIFS	1.875 μs
pSIFS	10 μs
mMAXFramePayloadSize	4,095 octets
mMAXBPLength	96 beacon slots
mBeaconSlotLength	85 μs
mSuperframeLength	256*mMASLength
mMASLength	256 μs
mBPExtension	8 beacon slots
mTotalMASLimit	112 MASs

Also, we consider a multimedia application with a WHMS Vital Video (WVV) stream and a WHMS video recorder (WVR) recording the same program. At some point, the user tunes the set-top box (STB) to start the WVV program. The WVR in the STB simultaneously starts to record the same program to a wirelessly connected external hard disk drive that is located in multi-hop range spot from the operating room. Assume the WVV source generates an MPEG-4 stream using Real-Time Transport Protocol (RTP) as transport.

In order to comparatively evaluate the proposed scheme, we have conducted an in-depth simulation study. In this study, we measured and compared the probability of successfully established WVV channels under various WHMS network load conditions using the proposed scheme and the legacy WHMS system. All the channel links are assumed to have the same link quality. We also evaluated their operational time to establish the default and reverse WHMS links. The N-screen packet payload size transmitted by WHMS devices is 1024 bytes. The WHMS beacon and ACK frames are transmitted at a mandatory rate of 53.3Mbps. Also, the WVV data packets are transmitted at a mandatory rate of 200 Mbps. A WHMS network which consists of 100 WHMS nodes is considered. Values of the other parameters are summarized in Table 5 and these are consistent with the specifications in WiMedia D-MAC and WUSB [4-6].

Table 5. Simulation Parameters

Parameter	Value
Network Size	100m x 100m
WiMedia Frame Size	512, 1024, 2048, 4096 Bytes
Basic Data Rate	53.3Mbps
Bandwidth	528Mhz
Symbol Length	312.5ns
Preamble Length	9.375us
Header Length	3.75us
SIFS	10us
MIFS	1.875us
Transmission Power	-41.3dB/Mhz

Figure 11 is an ordinary rectangular mesh consisting of 100 WHMS nodes each [9-13]. We assume that the links connecting nodes in the topology consist of two unidirectional links, each with 200 Mbps transmission bandwidth. In order to evaluate the probability of successful link establishment, we have set load conditions as follows. We selected source-destination pairs between WHMS devices randomly, and established multi-hop default and reverse N-screen links between each pair using the proposed scheme. For the purpose of comparison, we applied the legacy WHMS system to the same source-destination pairs and measured the success probability.

All WHMS devices are deployed within communication range and new multi-hop N-screen WVV traffic streams are added every 50 sec. Thus, the number of multi-hop N-screen WVV traffic streams monotonically increases with time. After a certain amount of time elapsed, we counted the number of N-screen WVV traffic streams transmitted in the entire network, added them up, and divided the sum by the number of N-screen WVV traffic streams when the entire WHMS network was saturated. The resulting number was treated as the average load of the WHMS network. And, we measured the time to establish each multi-hop N-screen link for both approaches. The above process was executed while varying the given WHMS network load. The entire procedure was executed 100 times.

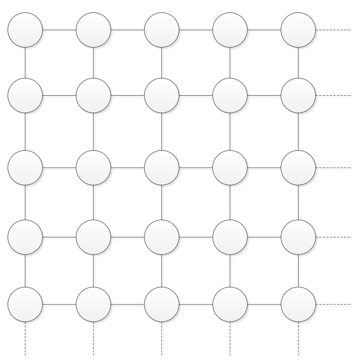


Figure 11. Rectangular Mesh Deployment of WHMS Nodes used for the Simulation

Figure 12 shows the WVV link establishment success rate under various WHMS network loads using both our approach and the legacy WHMS system. In Fig. 12, when the WHMS network is lightly loaded (i.e., the network load is under 30 percent), both approaches achieve an almost 100 percent WVV link establishment success rate. That is, abundant resources are available in such a case and hence, most of multi-hop WVV link establishment requests are accepted. Compared to the legacy WHMS system, our scheme shows a much higher success rate in this range. In Fig. 12, our approach outperforms the legacy WHMS system since our proposed scheme is guaranteed to find a qualified resource for multi-hop WVV link due to proposed N-screen multi-hop DRP IE and a coordinated resource allocation.

When the network is heavily loaded (e.g., over 80 percent), our approach and the legacy WHMS system, irrespective of the number of trials, both show low success ratios. This is mainly due to the limited resource in the saturated WHMS network. In fact, we could not obtain any meaningful results when the network load is over 80 percent, because the number of multi-hop WVV links established was very small. Compared to the legacy WHMS system, the proposed multi-hop N-screen traffic mechanism shows much higher success rate. In particular, our scheme's success rate is shown to have a larger increase than the legacy WHMS system; in fact, our scheme shows the highest success rate under most WHMS network loads. This result clearly demonstrates the superiority of our scheme for WHMS networks with better multi-hop N-screen WVV link connectivity.

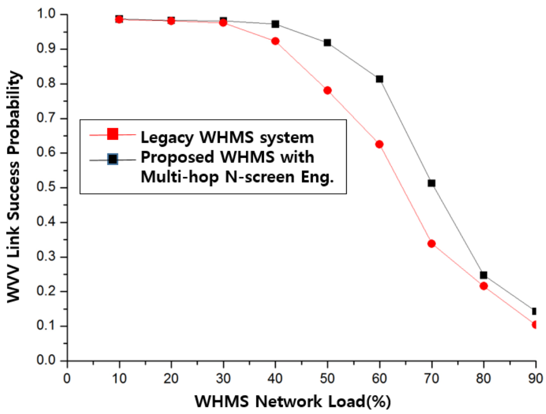


Figure 12. Comparison of WHMS Multi-hop Link Establishment Success Rates

Figure 13 shows the WVV link establishment times of both our multi-hop N-screen traffic mechanism and the legacy WHMS system, where the time unit is a packet transmission time over a single WVV link. In this paper, the WVV link establishment time is defined as the time measured from the issuance of a WVV link request to the notification of its WVV link acceptance. We assumed that the WVV packet size is constant throughout the network. In this Fig. 13, we showed the establishment time for only successful multi-hop WVV link requests. When the network is heavily loaded, WHMS superframe lacks available MASs for WVV link establishment. Thus, under an extremely-congested condition, WVV link establishment times of both schemes increase. As can be seen in Fig. 13, our multi-hop N-screen traffic mechanism is considerably better than the legacy WHMS system due to the proposed N-screen multi-hop DRP IE and a coordinated resource allocation.

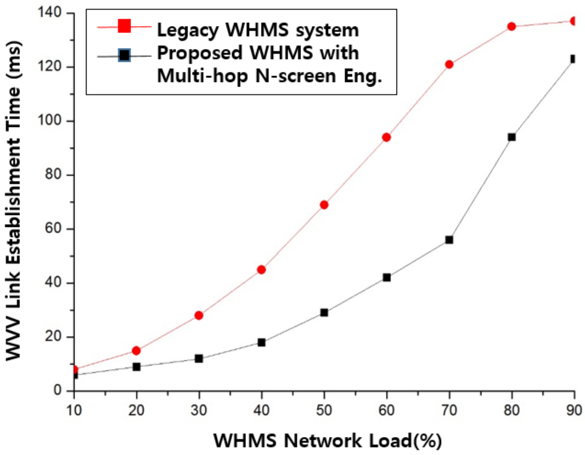


Figure 13. Comparison of WHMS Multi-hop Link Establishment Times

6. Conclusions

A hierarchical system of wireless USB (WUSB) over wireless body area networks (WBAN) is adopted for wearable health-monitoring systems (WHMS). It is executed on the basis of WUSB over WBAN protocol at each wearable sensor node comprising the WHMS. Basically, a single WHMS operates based on WUSB over WBAN protocol. And the multiple WHMSs operate based on the WiMedia D-MAC protocol and dual-role device (DRD) function. In this paper, a multi-hop N-screen traffic mechanism is proposed for WHMS networks. In a hospital, N-screen applications must be required by using WHMS networks. The multi-hop N-screen traffic mechanism is composed of a coordinated resource allocation and an N-screen multi-hop DRP Information Element. In simulation results, efficiency of the multi-hop N-screen traffic mechanism is proven through multi-hop link establishment success rate and delay performances at a WHMS network service scenario.

Author Contributions

Kyeong Hur wrote the manuscript. Won-Sung Sohn designed experiments. Kil Young Kwon provided technical supports.

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