A Novel Priority-based Channel Access Algorithm for Contention-based MAC Protocol in WBANs

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ABSTRACT
Wireless body area networks (WBANs) which is standardized by IEEE 802.15 TG6 support communication service with in/on/around body. Similar to wireless sensor network (WSN) environment, devices of WBAN may be densely deployed. Compared with WSN, however, WBAN operates in a centralized manner, and thus, contention complexity on contention-based phase of WBAN may be larger than WSN. In this paper, we propose a novel channel access algorithm for contention based MAC protocol in WBANs. The proposed algorithm classifies the contention-based access phase into 4-levels by the priority of packet that is defined in WBAN draft document, and divides the contention-based access phase into sub-period by calculated offset. Extensive simulation results show that the proposed algorithm achieves low complexity such as reduced collisions, low power consumption, and high channel utilization compared with the IEEE 802.15.6 baseline MAC protocol.

Categories and Subject Descriptors
C.2.2 [**Network protocols**]: Channel access algorithm.

General Terms
Performance

Keywords
WBAN, MAC protocol, CAP, Channel access algorithm.

1. INTRODUCTION
In recent years, healthcare and/or lifecare services have attracted a great deal of attention. A wireless body area network (WBAN), which support both medical and consumer electronics (CE) services with sensor devices that function around, on, or in human bodies have become the next generation of wireless technology for wireless personal area networks (WPANs) [1], [2]. WBAN, which consist of a coordinator, medical devices, and CE devices, can provide various services in medical and non-medical areas.

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In early stage of WBAN development, the IEEE 802.15.4 protocol, a typical low-power protocol for WPANs, was considered for WBAN services [3]. The reason of considering IEEE 802.15.4 for WBAN is that IEEE 802.15.4 provides low data-rate, short transmission range and low power consumption and that is similar to requirements of the IEEE 802.15.6 [5]. The IEEE 802.15.4 MAC protocol provides 3 mode of frame structure such as beacon-enable superframe, beacon-enable non-superframe, and non-beacon mode. Both IEEE 802.15.4 with beacon-enable non-superframe and non-beacon mode only operate based on contention. On the other hand, the IEEE 802.15.4 with beacon-enable superframe mode consists of active period and inactive period. Its active period is divided into 16 equal-sized slots and consists of a contention-free period (CFP) and contention-access period (CAP). In addition, inactive period is used to reduce power consumption. However, both IEEE 802.15.4 with beacon-enable non-superframe and non-beacon mode only use in real field because the IEEE 802.15.4 with beacon-enable superframe mode needs additional time synchronization overhead.

Meanwhile, The IEEE 802.15.6 task group established WBAN standardization. The objective of the IEEE 802.15.6 task group is to standardize the PHY and MAC protocols for WBANs, which can provide various ubiquitous services. IEEE 802.15.6 task group published draft document on Mar, 2011 [1]. The draft document defines single MAC protocol which provides multiple PHY such as narrow band, ultra wide band (UWB), and human body communication (HBC) PHY. To provide multiple PHY, WBAN MAC protocol has hybrid superframe-based structure

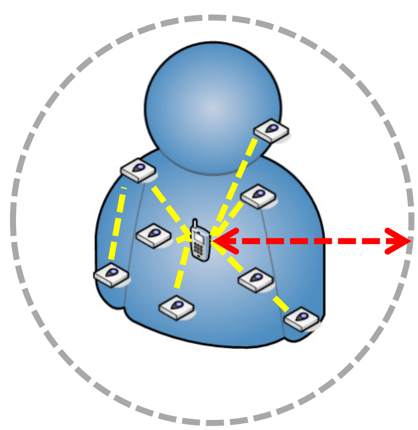

Figure 1. Composition of WBANs

which consists of contention-based access periods (CAPs) and contention free access periods (CFPs). We focus on channel access on CAP because the reason is similar to use only contention-based channel access on the IEEE 802.15.4 in real field.

In general, CAP consumes energy more than CFP because nodes operate based on contention. As mention above, However, CFP is not use in real field [4]. In focus of CAP, we can consider followed scenario. When many nodes are densely deployed on narrow region, contention complexity is increased, and it can lead to high power consumption and quantities of collisions. In WBAN environment which require ultra-low power consumption, meanwhile, low contention complexity can help to reduce power consumption. A WBAN network should consist of maximum 256 nodes in 3-5m around of human body, and maximum of 10 WBAN networks must coexist in $6 \times 6 \times 6m^3$ area with fair bandwidth sharing [5]. In this sense, the contention complexity, the number of collision, and power consumption should be increased. Therefore, contention complexity of WBAN is one of the most important key to satisfy requirements of WBAN.

Meanwhile, WBAN draft document defines 8 priorities for various packets such as background, best effort, excellent effort, video, voice, medical data or network control, high priority medical data or network control, emergency or medical event report [1]. Each priority has differentiated maximum/minimum contention window and contention probability values to provide priority-based channel access to satisfy QoS requirement of WBANs. Likewise IEEE 802.11, however, the contention complexity of WBAN can cause many collisions and more power consumption because maximum 256 nodes can join in a WBAN and nodes are densely deployed in narrow region. Therefore, priority-based channel access policy which is defined on WBAN draft document cannot resolve fundamental contention complexity problem too.

In this paper, we propose a novel channel access algorithm for contention-based MAC protocol for WBANs. The proposed algorithm categorizes contention-based access phase into 4-levels by priority of packet that is defined WBAN draft document. And, proposed algorithm divides contention-based access phase into sub-period and calculates offset to apply categorized 4-levels. The contention complexity on WBAN can be reduced by the proposed algorithm which provides authorities of graded channel access by classified priority.

The rest of the paper is organized as follows: Section 2 discusses existed studies of contention-based MAC protocol and WBAN baseline MAC protocol to guarantee QoS. In Section 3, we describe the proposed channel access algorithm and its performance is evaluated via extensive simulations in Section 4. Finally, Section 5 highlights our conclusion and future work.

2. REQUIREMENT OF WBAN

WBAN consists of various devices with different characteristics (i.e., medical, consumer electronics application) that exist within the vicinity of human bodies. In order to flexible and reliably support these different characteristics, WBAN MAC protocol must satisfy the following requirements [5].

First, WBAN devices should operate via battery power in, on, and around human bodies in order to provide mobility. Due to this requirement, low power consumption of WBAN devices is one of the most important factors. To satisfy this requirement, WBAN technical requirement document (TRD) defines factor of duty-cycle (i.e., <1% or 10%).

Second, scalability is an indispensable requirement in WBAN. WBAN networks should be able to accommodate 256 devices, as well as satisfy various transmission rates (10kbps ~ 100Mbps).

Third, most medical devices have a periodic characteristic. Conversely, consumer electronics (CE) devices have sporadic characteristics including burst data transmission in an event-driven manner. WBAN should be able to satisfy both of these characteristics with the ability to function both periodically and sporadically.

Finally, WBAN must be able to guarantee highly reliable and prompt transmission during an emergency situation. Medical services on WBAN may directly affect the life or death of a user. When devices sense an irregular data by monitoring vital signal, the service provider should immediately handle the situation. The ability to immediately respond to sporadic emergency data is one of the important requirements of WBAN.

For this reasons, the WBAN MAC protocol should be designed to satisfy all of these different requirements. In particular, QoS is one of the most important issues of designing WBAN MAC protocol. Medical and CE services has different requirements as follows. Characteristics of medical services are 'periodic' and 'small data'. Health monitoring and medical teleconsult services are typical examples. On the other hand, characteristics of CE services are 'sporadic' and 'burst data'. Typical examples of CE services are video, audio, game, and web browsing [2].

Meanwhile, power consumption is important requirement of WBAN too. Generally, WBAN devices operate based on battery, and communication power of each device is larger than processing power. In this point of view, low power MAC protocol should be provided.

To guarantee QoS requirement of medical and CE service, IEEE 802.15 TG6 defines priority-based channel access method. The priority-based channel access method flexibly helps to guarantee QoS requirements of different applications [1]. However, if many devices are in a WBAN network and each device generate amount of traffic, contention complexity is increased and it may cause more power consumption. Moreover, a WBAN can operate with maximum 256 devices and handle traffics which have differentiated characteristics In addition, at least 10 randomly distributed WBANs must coexist in a volume of $6 \times 6 \times 6m^3$ with fair bandwidth sharing [5]. Therefore, the problem of contention complexity on WBAN environment must be solved to satisfy QoS and reduce power consumption.

In summary, QoS and power consumption are one of the most important requirements. The problem of contention complexity on WBAN environment should be solved to support QoS and reduce power consumption.

3. PROPOSED ALGORITHM

As mentioned earlier, since providing QoS and low power consumption for various applications by dispersion of contention complexity is the main goal, we propose a novel channel access algorithm for contention-based MAC protocols for the WBAN. The proposed algorithm focuses on the following ideas:

First, we categorize priority of packet into 4-levels such as highest priority medical services, general health service, mixed medical and non-medical service, and non-medical services. These categories are used to calculate average delay of D_{avg}, where l is level of packet priority. The coordinator calculates D_{avg} every superframe. D_{avg} is given by:

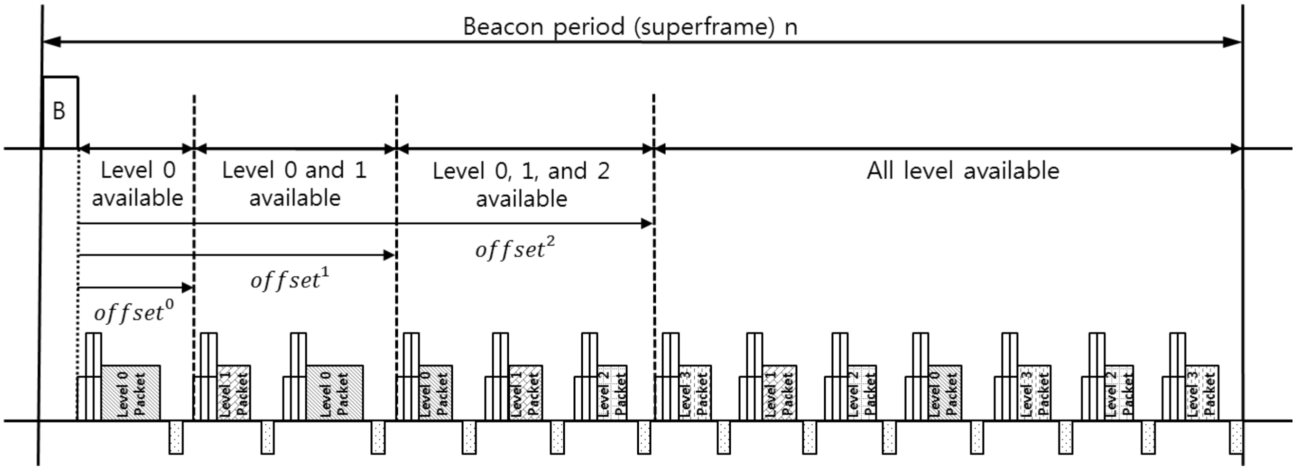

Figure 2. An example of proposed algorithm

$$D_{avg}^{l} = \left(\sum_{k=0}^{i} D_{k}^{l}\right) / N^{l}$$

where l is level of category, and D_k^l is delay of each packet on category l. N^l is the number of packet on category l.

Second, WBAN TRD defines delay requirements both delay of medical and CE service. Medical service must satisfy 125ms or less delay requirement and CE service has to satisfy 250ms or less delay requirement. Based on these delay requirements, we define delay threshold of τ^l which uses to divide CAP into sub-phases. The first, second, and third categories have 125ms of τ^l, and last category have 250ms of τ^l because the first, second, and third categories has medical traffics but last category has only non-medical traffic [2], [5].

Third, we divide CAP into sub-phase for each category which exceeds delay requirement. If one of categories exceeds τ^l, CAP is divided into a sub-phase for channel access of exceeded category and a sub-phase for channel access of all categories. If more than one category exceeds τ^l, CAP is divided into sub-phases of number of exceeded categories + 1. Divided sub-phases are sorted by priority of each category. The reason of sorting is to provide differentiated channel access and dispersion of contention complexity. An example of our algorithm is shown in Figure 2. When a number of categories which exceed threshold τ^l are 3 or 4, CAP is divided into 4 sub-phases. On the first sub-phase, only the level 0 of categories can access channel, and the level 0 and 1 of categories can access channel on the second sub-phase. And, the level 0, 1, and 2 can access channel on third sub-phase. In last sub-phase, all categories can access channel.

Finally, we calculate offset for starting point of sub-phase, $offset^l$. The $offset^l$ is given by:

$$offset^{l} = \sum_{k=0}^{l-1} offset^{l} + L_{CAP}(N^{l}/N_{total})$$

where L_{CAP} is length of CAP, N^l is the number of generated packets on category l, and N_{total} is total number of packets of a superframe. The $offset^l$ is calculated at start of every superframe by coordinator and the beacon message which is sent by coordinator at start of superframe contains the $offset^l$. Every nodes which want to transmit data decide starting point of channel access by both $offset^l$ and level of its packet.

Figure 3 and 4 shows pshuedo code of proposed algorithm on coordinator and node. By using our proposed algorithm, we can expect to reduce contention complexity and power consumption.

Algorithm on Coordinator

```
Start of Superframe

while(!EndOfSuperframe)
  SumOfDelay[l] += PacketDelay
  CountOfReceivedPkt[l]++
end of while

for(i=0;i<3;i++)
  if(SumOfDelay[i]/CountOfReceivedPkt >= t[l])
    offset[l] = CountOfReciedPkt[i]/CountOfReceivedPkt
  end of if
end of for

insert offset[l] into Beacon message
broadcast Beacon message
```

Figure 3. Pshuedo code of proposed algorithm on coordinator

Algorithm on Node

```
Start of Superframe

delayL = 0

receive Beacon message

if(Packet arrive from upper layer)
  for(i = 0 to PacketLevel+1)
    delayL += Beacon.offset[i]
  end of for
  delay(delayL)
  operate Slotted-CSMA/CA
end of if
```

Figure 4. Pshuedo code of proposed algorithm on node

4. PERFORMANCE EVALUATION

In this section, we first describe our simulation model that was used to evaluate the performance of the proposed algorithm. The performance of the proposed algorithm is then compared with IEEE 802.15.4 MAC protocol [3] and WBAN baseline MAC protocol [1]. The simulator has been implemented with the OMNeT++ [6].

4.1 Simulation Environment

For PHY model, we assume the ISM band, O-QPSK modulation, 2,000 kcps chip rate, and 250 kbps data rate. Such conditions are identical to those of IEEE 802.15.4 [3]. Both of the protocols used for comparison are based on the beacon-enable non-superframe structure mode, and BO and SO values determine the superframe length and the active period length, respectively, in order to fair evaluate and satisfy requirement of WBAN service (as mentioned in Section 2). Therefore, we set BO=3 which means each round time is 122.88ms. And the simulation performs 1,000 rounds.

In the traffic model, there exist 4 type of medical devices for 12 channel electrocardiography (ECG), (250 Hz), breathing rate (50 Hz), arterial pressure (120 Hz), and respiration rate (20 Hz) [2]. These devices send a packet of 40 bytes periodically. Emergent packets occur randomly, and their packet size is same to normal medical data. In contrast, a CE device sends a message of 2500 bytes sporadically. The message is divided into MAC layer packets of 127 byte which is the maximum size in IEEE 802.15.4 [3].

In model of network topology, we assume that all nodes are randomly deployed within 5m around coordinator. The network topology is star-topology and data are transmitted by one-hop and all nodes have non-limited battery. And, we assume mobility of nodes does not occur because single WBAN has only network level mobility. Random backoff exponential and contention window values are not prioritized in the IEEE 802.15.4. However, both WBAN baseline MAC protocol and our algorithm exploit the priority-based contention window value defined in the IEEE 802.15.6 draft [1].

4.2 Simulation Result

In this simulation, we consider comparison factors of average delay, collision ratio, and power consumption. Results and analysis are as follows:

Figure 5 represents the average delay. In the IEEE 802.15.4 MAC protocol, it operates slotted CSMA/CA without priority-based channel access policy. Thus, as shown in the figure, the average delay of the IEEE 802.15.4 MAC protocol has the largest delay. However, because the proposed algorithm and the IEEE 802.15.6 baseline MAC protocol perform slotted CSMA/CA with

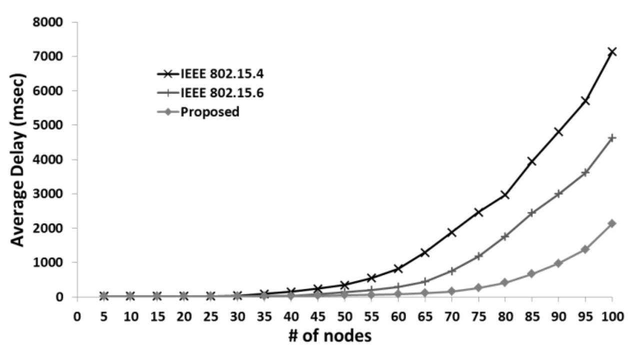

Figure 5. Average delay

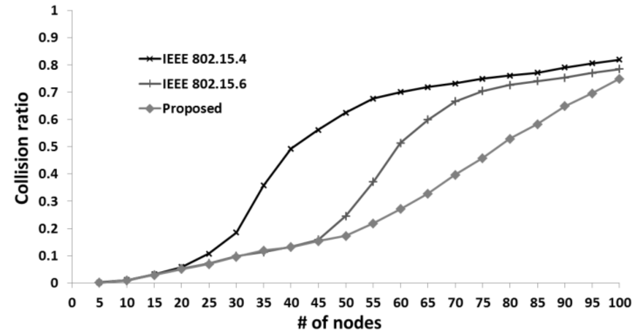

Figure 6. Collision ratio

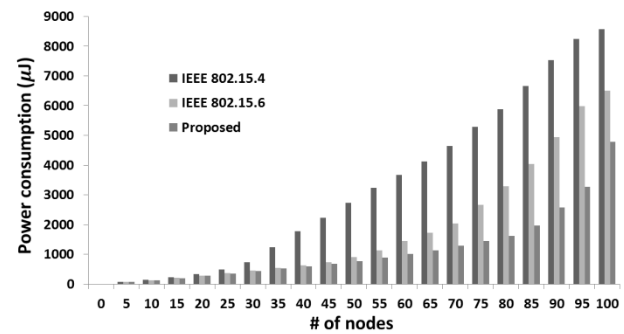

Figure 7. Power consumption

the priority-based channel access policy to access channel, they can gain lower average delay than the IEEE 802.15.4 MAC protocol. On the other hand, the proposed algorithm categorizes priority of packet into 4-level. That is since it can reduce contention complexity, it shows lower average delay then the IEEE 802.15.6 baseline MAC protocol.

Figure 6 shows the ratio of collision. Each node contends with slotted CSMA/CA mechanism. In general, when two or more nodes transmit data at same time, collision occur. If the network contains large number of node, the number of collision is increased. Since nodes access the channel without policy of prioritized CW, The IEEE 802.15.4 MAC protocol shows a large number of collision, respectively. Especially, when a network contains 30 nodes, collision ratio sharply increase because slotted-CSMA/CA without prioritized policy does not solve contention complexity problem. On the other hand, the number of collision for the IEEE 802.15.6 baseline MAC protocol and proposed algorithm is lower than the IEEE 802.15.4 because of prioritized clear channel assessment (CCA) and random backoff. However, the IEEE 802.15.6 baseline MAC protocol cannot handle problem of high contention complexity. When a network contains 50 nodes, collision ratio sharply increase like IEEE 802.15.4 MAC protocol. The proposed algorithm, however, provide low ratio of collision because priority-based categorized channels access can disperse channel complexity and it cause to reduce collision ratio.

The simulation result of power consumption is shown in Figure 7. In general, power consumption is increased by collision and retransmission. The IEEE 802.15.4 shows high power consumption because all nodes operate with same condition for contention such as contention window and backoff exponential value. Moreover, high contention complexity causes to increase a number of collided node at the same time and it makes a large number of retransmission. Therefore, power consumption of the IEEE 802.15.4 MAC protocol increase sharply. The other side, the IEEE 802.15.6 baseline MAC protocol and proposed algorithm are more less power consumption. The reasons of results of the IEEE 802.15.6 baseline MAC protocol and proposed algorithm are they provide prioritized channel access with differentiate contention window and backoff exponential values. Moreover, our proposed algorithm can disperse channel complexity and reduce contention complexity, and it help to reduce a number of collision and retransmission. As a result, our proposed algorithm shows the lowest power consumption by comparison with the IEEE 802.15.4 and the IEEE 802.15.6 baseline MAC protocol.

5. CONCLUSION

In this paper, we propose a novel channel access algorithm for contention-based MAC protocol in WBANs to solve contention complexity problem. The proposed algorithm using 4 ideas: categorizing packet into 4-levels, defining delay threshold for each level of packet, dividing CAP into sub-phases by threshold, and calculating offsets to decide length of divided sub-phase. By classifying categories of packets into 4-level and dividing CAP into sub-phases, our proposed algorithm can disperse contention complexity and reduce power consumption. And, efficiency of our proposal has been validated through extensive simulation. Our future work is optimization of calculating offset by using probabilistic analysis method because proposed algorithm is not optimized.

6. ACKNOWLEDGMENTS

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