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Enhanced MAC Protocol and Scheduling Algorithm for High Rate WPANs*

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Abstract — The demands for higher data rate in Wireless personal area network (WPAN) than one in Bluetooth has been completed with IEEE 802.15.3 standard. The standard, named High-rate WPAN (HR-WPAN), adopts TDMA-based Medium access control (MAC) protocol. In this paper, we propose novel MAC protocol and scheduling algorithm to achieve efficient time-slots allocation. Time slots for data transmissions are allocated by two steps. In the first step, the time slots are initially allocated using a proposed allocation algorithm based on statistical packet inter-arrival time. Then, the initial allocation is dynamically adjusted by utilizing feedback information coming from each device. Performance evaluations are carried out through extensive simulations and significant performance enhancements are observed.

Key words — Wireless personal area network (WPAN), Wireless MAC, Link adaptation, Piconet.

I. Introduction

As the MAC protocol in the IEEE 802.15.3 standard is expected to play a crucial role for the formation of home networks or small office networks, a few efforts for improving the performance of the MAC protocol have been made. Performance enhancements by informing queue-status (Q-status) of each node to a Piconet controller (PNC) are shown in Ref.[4]. In this scheme, the number of pending packets at each DEV is included in the MAC header of every packet. Thus, by overhearing every packet exchange, a PNC can allocate appropriate channel time for transmitting packets stored at a DEV in the next superframe. This scheme aims at handling Variable bit rate (VBR) traffics and adopts a flexible superframe size. One potential drawback is that the size of superframe may change too frequently. This may introduce some difficulties in accurate timing and positioning for strictly time-bounded applications as suggested in Refs.[5, 6]. Furthermore, the piggybacked information can be useful only when there is a burst to transmit. Moreover, the channel time allocation algorithm for different traffic types is not considered. An algorithm proposed in Ref.[6] focuses on utilizing wasted or remaining channel times. The algorithm in Ref.[6] uses a constant superframe size. A superframe with two static channel times, one for CBR traffic and the other for real-time VBR (rt-VBR) traffic is used. This scheme also does not consider how to allocate the channel times. The authors in Ref.[7] propose a channel time allocation scheme for the specific application, MPEG 4 traffic. Since packets generated from a MPEG 4 encoder are classified into three types and are arranged in a periodic pattern, a central device can allocate channel time for transmissions of MPEG 4 packets according to the packet pattern. A packet transmission method without a preamble is introduced in Ref.[8] because the physical preamble overhead remains as a dominant factor to overcome in the high transmission rate UWB technology. A rate-adaptive MAC protocol for HR-WPAN is proposed in our previous work[9]. Based on the channel quality estimated using the received packet, the receiver chooses an appropriate data rate and sends it back to the transmitter. The target applications considered in Ref.[9] are asynchronous bursty data transmission requiring an acknowledgement feedback such as MP3 file transfer. However, this method is not applicable for real-time services, which do not require acknowledgement feedback.

In the next section, the MAC protocol in the IEEE 802.15.3 standard is briefly described. In addition, the way to support multi-rates defined in the standard is illustrated in the same section. With the issues in the MAC protocol of the IEEE 802.15.3 standard described, the proposed MAC protocol for HR WPAN is introduced in Section III. Section IV describes the simulation environment under which the performance of the proposed protocol is evaluated. Finally, conclusions are provided in Section V.

II. IEEE 802.15.3 (High-Rate WPAN)

1. MAC protocol

In the HR-WPAN standard specifications, DEVs are communicating on a centralized and connection-oriented ad-hoc

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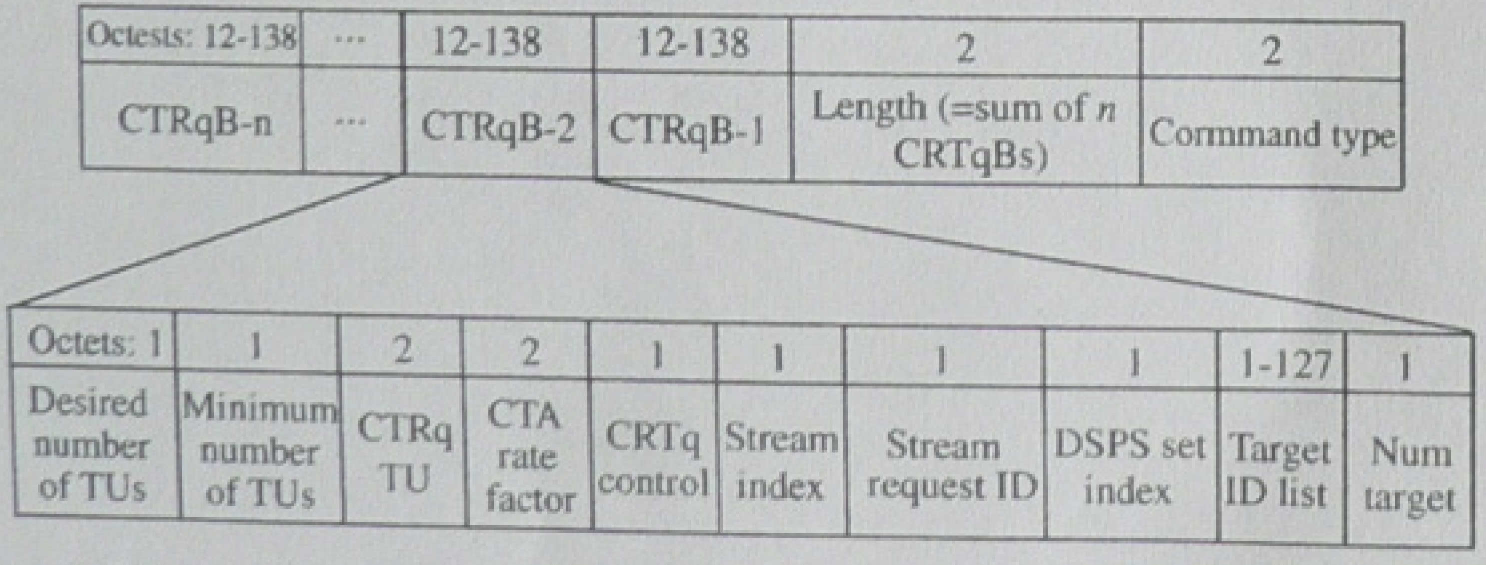
network called piconet. One of the participating DEVs must be designated as a Piconet coordinator (PNC). The PNC provides basic timing information for the operation of the piconet and manages the Quality of service (QoS) for delay sensitive applications.

The MAC layer in the IEEE 802.15.3 standard employs a time-slotted superframe structure. The superframe consists of three major parts: a beacon, an optional Contention access period (CAP) and a Channel time allocation period (CTAP). The beacon packet is transmitted by the PNC at the beginning of each superframe. It allows all DEVs in a piconet know about the specific information for controlling a piconet, such as superframe duration, channel time allocations, used frequencies and etc. The CAP is used for transmissions of short and non-QoS data packets and command/response packets. The medium access mechanism during the CAP is Carrier sense multiple access with Collision avoidance (CSMA/CA). The remaining period in the superframe is CTAP. The CTAP is composed of Channel time allocation (CTA) periods and Management channel time allocation (MCTA). While MCTA like CAP is used for sending command packets, the slotted ALOHA mechanism is used for channel access. When a DEV needs a CTA on a regular basis, it sends a Channel time request (CTRq) command to the PNC during the CAP or MCTA. Thus the PNC decides the duration of the superframe, CAP, and CTAP based on the DEVs' requests. During one CTA period, one DEV can transmit several packets to one target DEV without collision. Each packet transmission may be followed by an Acknowledgement (ACK) packet. A Short interframe spacing (SIFS) idle time is added for a sufficient turnaround time between two consecutive packet transmissions in a CTA. In addition to SIFS, a guard time is required to prevent collision of two adjacent CTAs. Although the scheduling algorithm for allocating CAP, MCTAs, and CTAs plays a critical role on a performance of WPAN, such algorithm is not specified in the 802.15.3 standard.



Octests: 12-138	···	12-138	12-138	2	2
CTRqB-n	···	CTRqB-2	CTRqB-1	Length (=sum of *n* CRTqBs)	Command type

Octets: 1	1	2	2	1	1	1	1	1-127	1
Desired number of TUs	Minimum number of TUs	CTRq TU	CTA rate factor	CRTq control	Stream index	Stream request ID	DSPS set index	Target ID list	Num target

Fig. 1. Channel time request command format and channel time request block field format specified in IEEE 802.15.3 standard

2. Multi-rate support

In the IEEE 802.15.3, the raw PHY layer data rates are 11Mbps for uncoded QPSK modulation, and 22, 33, 44, and 55 Mbps for trellis-coded QPSK, 16/32/64-QAM, respectively. The specification in the IEEE 802.15.3 MAC suggests two methods to obtain channel condition information and to select the data rate for transmission. The first method is to periodically transmit the channel status request command to the target DEV. When receiving that command, the target DEV sends a channel status response command back to the transmitting DEV. The channel status response command includes the number of successfully received packets, the number of erroneous packets and the number of measured packets. The source DEV decides the data rate based on this information. In the second method, the channel condition is evaluated by the presence or absence of ACKs for the transmitted packets. This information is used to decide the data rate for the next packet transmissions. However, the second method is not applicable for the case of using No-ACK. If the Dly-ACK mechanism is used, all packets in a burst are transmitted with the same data rate.

III. Proposed MAC Protocol

1. Motivation

Even small delay in HR-WPAN may cause serious performance degradations since HR-WPAN is targeting on delay-constrained real time multimedia services with a bulky traffic size and high bit rate, such as home theater systems with HDTV. Therefore, the channel time allocation algorithm plays an essential role to guarantee delay bound performance of real-time applications in HR-WPAN. Nevertheless, the information delivered by a CTRq command as shown in Fig.1 is insufficient for the PNC to decide the duration and location of a CTA for the requesting DEV. The IEEE 802.15.3 TG considers the scenario that DEVs frequently join and leave a piconet as mentioned in Ref.[1]. In this scenario, many factors, such as a superframe length and a number of flows, vary in time. As a consequence, the CTA allocation algorithm is required to support the QoS requirements over these variable factors.

In wireless networks, channel conditions need to be estimated to dynamically choose the appropriate transmission data rate over the time varying wireless channel, so that Error rate reduce as well as Goodput increases. As illustrated in Section II.2, the channel condition in IEEE 802.15.3 is estimated based on the results of attempted transfers of data packets between two DEVs that are actively participating in a data transfer. However, using this method cannot cope with fast channel changes and may cause incorrect channel information, which leads to performance degradation. Moreover, for traffics with long packet inter-arrival time, this estimation method are futile since the transmission history for such a long time period can not represent the current channel condition. Recently the use of Signal-to-noise ratio (SNR) has been suggested to estimate the channel condition. In Ref.[12], the two methods, using transmission history and SNR, for the channel condition estimation are evaluated over a WLAN environment. The evaluation in Ref.[12] shows that the method using SNR achieves a higher performance gain than that using the result of attempted transfers of data packets. However, this formal method requires feedback information from the receiver, which is not applicable to real time applications without acknowledgements.

To solve the aforementioned considerations, we propose an enhanced MAC protocol and scheduling algorithm for time-bounded services in the next subsections.

2. Proposed protocol for high-rate wireless PAN

(1) CTA allocation algorithm

As mentioned in the previous section, providing delay-bounded services is critical to the real-time traffics and no algorithm to allocate channel times is specified in the standard. Here, we propose a channel time allocation algorithm to synchronize a CTA to the packet arrival instant. We introduce two main parameters that affect the channel time allocation process. The first one is the service period of DEV i, IA_i. The value of IA_i is the estimated inter-arrival time of packets at DEV i with payload P_i. It is given by

$$IA_i = \left\lfloor \frac{P_i \cdot 8}{M_i} \right\rfloor \tag{1}$$

where P_i and M_i are the payload in the MAC packet in bytes and the data arrival rate for CBR traffic (or the mean arrival rate for real-time VBR (rt-VBR) traffic) in the MAC layer at DEV i, respectively. IA_i is calculated by DEV i and informed to the PNC using the channel time request command. In a general wireless network, the two parameters, P_i and M_i, can be obtained from the admission control unit in the central controller during the association period described in Refs.[15, 16]. For informing IA_i to PNC, the channel time request command shown in Fig.1 is modified. The CTA rate factor field in the channel time request command is changed to the Traffic arrival rate field. Since it doesn't add any overhead, it gives no impact on the network performance. We define another parameter Ptr_i, which is related to IA_i in order to allocate CTA for DEV i. Ptr_i is a timer that is initialized to be IA_i and decreased as time elapse. The moment, when Ptr_i reaches zero, is the time instant to allocate CTA for DEV i. That means that the Ptr_i indicates the remaining time for the CTA allocation for DEV i.

At first, the PNC gathers DEVs whose Ptr_is are less than the current superframe duration since CTAs of those DEVs must be allocated in the current superframe. Therefore, the ensuing steps are applicable only to those DEVs. Then, the PNC decides the number of CTAs that will be allocated in the current superframe. The PNC needs information of $NumCTA_i$, ST_i^j and DT_i^j for each DEV to allocate CTAs in the superframe. $NumCTA_i$ is the required CTAs for a DEV i during a superframe period. It is defined as

$$NumCTA_i = \left\lfloor \frac{T_{SF} - Ptr_i}{IA_i} \right\rfloor + 1 \tag{2}$$

where T_{SF} is the time duration of the superframe. ST_i^j is the time instant of the beginning of CTA j for DEV i. It is defined as

$$ST_i^j = Ptr_i + (j-1) \times IA_i, \quad 1 \leq j \leq NumCTA_i \tag{3}$$

Note that ST_i^j is less than T_{SF}. DT_i^j is the time duration to be allocated to CTA j of DEV i. It is calculated as

$$DT_i^j = \left[T_{OH} + T_{SIFS} + \frac{(L_{len}^i + L_{FCS})}{R_i} \right] \cdot Q_i + T_{guard} \tag{4}$$

where T_{OH} is the time overhead including the preamble, PHY header, MAC header, Header check sequence (HCS), and guard time. In the IEEE 802.15.3 standard, the value of T_{OH} at 11Mbps is different from those at the other rates. T_{SIFS} is the SIFS idle time. L_{len}^i is the length of the payload in bits for DEV i. L_{FCS} is the length of the Frame check sequence (FCS). R_i is the data rate in the physical layer and Q_i is the number of packets to be transmitted during CTA j of DEV i. The beacon packet in a superframe has information fields for the location and duration of all CTAs as described in the IEEE 802.15.3 standard. Thus, the proposed scheme can be implemented without any additional modification to the standard.

Now, CTAs are allocated at time ST_i^j with duration DT_i^j on a superframe. When several CTAs overlap, the CTA with lower ST_i^j is allocated in advance of the one with higher ST_i^j. However, the CTAs can also be allocated based on same specified performance requirements such as priority and throughput. In the former case, CTAs of DEV with higher priority are allocated ahead of those from another DEV with lower priority. In the latter case, CTAs of a DEV with a higher transmission data rate is allocated ahead of one with lower data rate. If there is time remaining between two consecutive CTAs, this duration becomes MCTA for transmitting command packets. However, if the remaining time is less then the threshold T_{thr}, it is merged to previous or next CTA. Therefore, MCTA allocation is also defined. The threshold T_{thr} is a sum of the slot time and the time duration of a CTRq packet. This choice ensures that at least one command packet can be transmitted in the MCTA. The total duration of CTAs and MCTAs allocated in a superframe should be less than T_{SF}. If its total duration is larger than T_{SF}, CTAs at the end will be removed until it is less than T_{SF}.

At the final step, Ptr_i is reset to a value for the next superframe formation. This value is given by

$$Ptr_i = IA_i - (T_{SF} - ST_i^{last}) \tag{5}$$

where ST_i^{last} is the time duration of the lastly allocated CTA for DEV i. For a DEV whose CTAs are not allocated in this superframe, the corresponding Ptr_i is subtracted by T_{SF}.

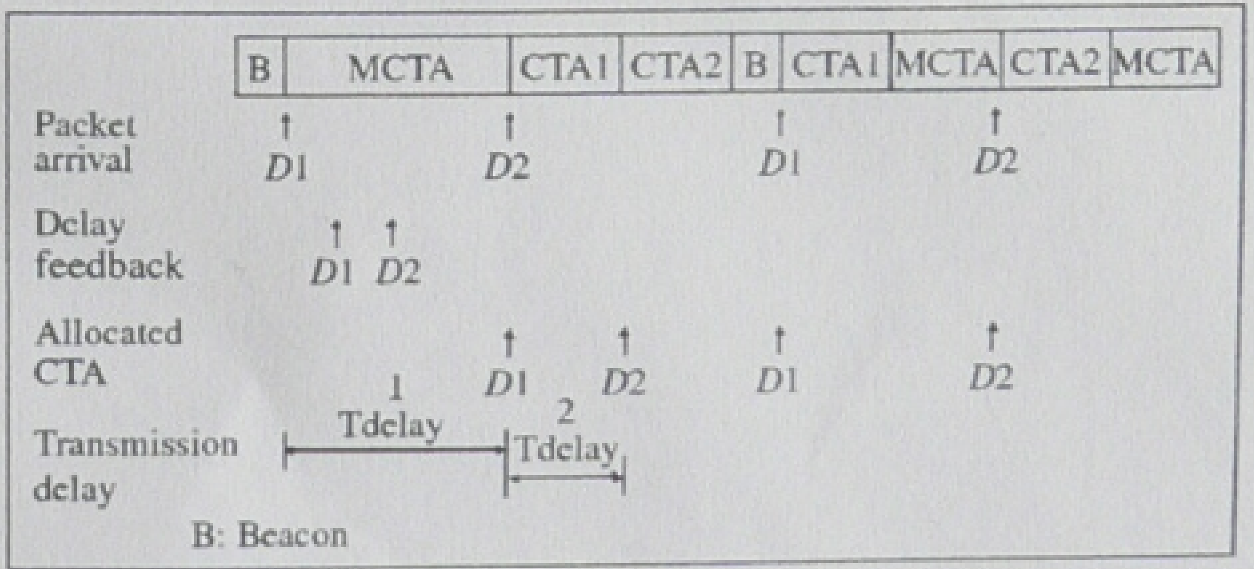


Fig. 2. An example of CTA synchronization

(2) Feedback-assisted CTA allocation

Employing CTA allocation algorithms based only on statistical packet inter-arrival time is not sufficient to overcome the aforementioned problem for strictly time-bounded services. Since information given by a channel time request command does not include the optimal time instant of a CTA, the PNC may allocate the CTA at any position within a superframe. This causes time wasted from packet arrival at the MAC layer to the transmission of that packet. This wasted time is called transmission delay. Fig.2 shows an example of transmission delay caused by the lack of information about the actual packet arrival instant at the PNC. This delay increases as the packet inter-arrival time increases and may maintain until the end of the flow. Furthermore, it can be longer in heavy load cases since several CTAs overlap. Because of this problem, rt-VBR traffics whose packet inter-arrival time is variable cannot be handled. For rt-VBR traffic, instantaneous bit rate fluctuates widely about a mean value as shown in Ref.[19]. As a consequence, the inter-arrival time at DEV i also fluctuates and is different from IA_i statistically calculated by the PNC. That means that more than one packet can be stored in the buffer at the instant CTA allocation. If PNC allocates CTAs for rt-VBR traffic using the peak inter-arrival time, utilization of channel time will be degraded.

Octets: 10	1	1–4	2	4
MAC header	Report ID	Report payload	Length	FCS

Fig. 3. Status report command packet format

To overcome these problems, we propose a feedback-assisted CTA allocation method. To achieve better CTA allocation, each DEV informs its current status to the PNC. For this purpose, during the MCTA, a DEV sends the status information to the PNC by using the status report command packet shown in Fig.3. This command packet specifies three statuses of a DEV: Q-status, Delay, and Rate. Q-status indicates the number of packets in queue. Delay is a time period from the instant of packet arrival at MAC layer to the beginning of allocated CTA. Rate is a physical transmission rate. The Report ID subfield in the status report command indicates one of seven possible report types and the Report Payload subfield is the value of each reporting item. When the PNC receives a status report command with the delay information from DEV i, the value of Ptr_i of DEV i at the PNC is subtracted by that delay. Hence, a CTA for DEV i in the next superframe will be allocated earlier than the current CTA position since Ptr_i is shortened by the status report command.

Fig.2 illustrates an example of the CTA synchronization process with packet arrivals. In the first superframe, DEVs $D1$ and $D2$ have the transmission delays, T^1_{delay} and T^2_{delay}, respectively. The transmission delay information is sent during the MCTA of the first superframe. The PNC changes the time instant of the CTAs in the second superframe. Thus, from the second superframe on, CTAs are located at the packet arrival time instants and the transmission delay becomes zero. If the packet arrival rate is constant as CBR traffic, a single status report with delay information is enough for the PNC scheduler since it a DEV with CBR traffic generates one packet in each inter-arrival time. However, for rt-VBR traffic, this assumption is not guaranteed as mentioned before. In order to dynamically allocate the duration of CTAs for DEVs with rt-VBR, the queue status of each DEV needs to be reported to the PNC scheduler frequently. This queue status information is also transmitted using the status report command during the MCTA. This information is used in Eq.(4) to provide the value for the parameter Q_i.

We use channel estimation information from the physical layer at a receiver to choose the transmission data rate. In our previous work, a rate adaptation mechanism for best effort traffic types such as the bulk file transfer is proposed[9]. On the other hand, since we are dealing with time-bounded real-time services with No-ACK policy here, a packet to inform the data rate to the sender is needed. For this purpose, the aforementioned Status Report command is used to report the selected data rate to the PNC as well as the sender. This command is transmitted during a CAP or MCTA only when the currently used rate is not appropriate to meet certain performance criteria like the Packet error rate (PER) in Refs.[9, 11]. The physical layer does the channel estimation process. This feedback rate information is utilized for decision of the CTA durations in the next superframe as shown in Eq.(4).

In the proposed scheme, the transmission of status report commands plays an important role in allocating CTAs in a superframe. However, the PNC may form a superframe without any MCTA due to a heavy traffic load or an insufficient superframe size. To ensure at least one status report command can be transmitted in a superframe, the PNC allocates at least one MCTA with the minimum MCTA time duration. Moreover, the last channel time in a superframe must be a MCTA, called Essential MCTA (E-MCTA). This allows the latest status information of each DEV to be delivered to the PNC and reflected in the next superframe.

IV. Simulation Analysis

1. Networking setting

We assume that all DEVs are uniformly distributed in the coverage area of a piconet with diameter 20 meters. The PNC is always located at the center of the area. We do not consider any neighboring piconet in this simulation. Moreover, perfect synchronization in the physical layer is assumed and the propagation delay is not considered. The simulator programmed by C language is used for this analysis. The parameters used in this simulation study are shown in Table 2. The choice of these parameters is based on the IEEE 802.15.3 standards[3].

Table 2. Simulation parameters

Parameter	Value
SIFS time	$10\mu s$
Guard time	$50\mu s$
Slot time	$17.3\mu s$
MAC header	10 octets
PHY header	2 octets
Preamble	$17.5\mu s$
HCS	16 bit
FCS	32 bits
Minimum MCTA	3ms

Since the proposed scheme is designed for the time-bounded services, we study two real-time traffic types, CBR and real rt-VBR in the simulation. The CBR traffic flow is generated at 912 kb/s. This rate is the maximum bit rate of the MPEG audio encoder in Ref.[21]. For the rt-VBR traffic model, the trace statistics of actual MPRG-4 video streams reported in Refs.[19, 20] are used. We use a high quality video stream from "Silence of the Lambs", which has a mean bit rate of 580kbps and a peak rate of 4.4Mbps. Each DEV has either a CBR or rt-VBR traffic flow. A DEV alternates between the two states, ON and OFF, and their durations are exponentially distributed with mean values of 20.0 sec and 0.05 sec, respectively. A traffic flow is generated only during ON state. At the beginning of the ON state, a DEV selects a destination DEV and transmits a CTRq command to the PNC during a MCTA. In this simulation, CAP allocation is not considered since it is optional in the standard[3]. In addition, two measurements for performance evaluation are considered: Job failure ratio (JFR), and Goodput. The JFR is the packet dropping rate because of missing delay bound[4,6].

The scheme proposed in this paper, namely Feedback-assisted WPAN (FA-WPAN), is compared with the HR-WPAN scheme suggested in Ref.[4]. HR-WPAN adopts an aggressive CTA allocation algorithm. CTA durations for both CBR and rt-VBR traffic flows are evenly allocated over the superframe duration in the allocation algorithm in Ref.[4]. However, since the rt-VBR traffic may generate more packets than the CBR traffic does, it is unfair to allocate same CTA durations for both traffics. Therefore, in this simulation, the CTA duration for the rt-VBR traffic is roughly two-time longer than that for the CBR traffic. HR-WPAN also allocates a MCTA of 3ms duration as the first CTA in every superframe. Therefore, the duration of each CTA is

$$\frac{(T_{SF}-T_{bec}-T_{MCTA})}{(1\cdot N_{vbr}+2\cdot N_{cbr})}\times\begin{cases}2, & \text{for } rt-VBR\\ 1, & \text{for } CBR\end{cases}\tag{6}$$

where T_{bec} and T_{MCTA} are time durations of the beacon packet and E-MCTA, respectively. N_{vbr} and N_{cbr} are the number of flows of rt-VBR and CBR traffics, respectively. The position of the MCTA in HR-WPAN does not affect to the performance since no command packet, except the CTRq command, is considered.

Each scenario is simulated for 10 minutes.

2. Wireless channel model

We employ the log-distance path loss channel model in Ref.[22]. The path loss $\overline{PL}$ at distance d is

$$\overline{PL}(d)[dB]=\overline{PL}(d_0)[dB]+10n\log\left(d/d_0\right)\tag{7}$$

where d_0 is the close-in reference distance and n is the path loss exponent. We set n to 3.3 according to the SG3a alternate PHY selection criteria in Ref.[24]. To estimate $\overline{PL}(d_0)$, we use the Friis free space equation

$$P_r(d_0)=P_tG_tG_r\lambda^2/(4\pi)^2d_0^2L\tag{8}$$

where P_t and P_r are the transmit and receive power, G_t and G_r are the antenna gains of the transmitter and receiver, λ is the carrier wavelength, and L is the system loss factor which is set to 1 in our simulation. The transmit power and antenna gain are set to 0 dBm and 0 dBi, respectively, based on Ref.[24]. The received power is

$$P_r(d)[dBm]=P_t[dBm]-\overline{PL}(d)\tag{9}$$

Finally, the long-term signal-to-noise ratio is

$$SNR_L[dB]=P_t-\overline{PL}(d)-N\tag{10}$$

where N is the noise power set to −95 dBm.

For the data rate in the physical layer for each communication link, we assume that the system adapts the data rate by properly choosing one from a set of modulation schemes according to the channel condition. The set of modulation schemes used in our simulation studies are BPSK, QPSK, 8QAM, 16QAM, and 32QAM. For simplicity, we ignore other common physical layer components such as error correction coding. With 11MHz symbol rate and the above modulation schemes, the achieved data rates are 11, 22, 33, 44, and 55 Mbps, respectively, which are same data rates in the standard. Assuming that the symbol errors within a data packet are independent, the Packet error rate (PER) is related to the Symbol error rate (SER) by

$$PER=1-(1-SER)^N\tag{12}$$

where N is the number of symbols in the payload of an MAC packet. We set the target FER to 8% according to the IEEE 802.15.3 standard[3]. The SER equation to determine the SNR can be found in Ref.[23]. For BPSK,

$$SER=Q\left(\sqrt{2E_s/N_0}\right)\tag{13}$$

and for QPSK and M-ary QAM,

$$SER\le 1-\left[1-2Q\left(\sqrt{\frac{3E_s}{(M-1)N_0}}\right)\right]^2\tag{14}$$

where E_s/N_0 is the SNR per symbol and M is the signal constellation size. From the SER performance curves calculated from Eqs.(13) and (14), the SNR ranges for the corresponding modulation schemes that the target SER is satisfied are given as follows, respectively,

$$R=\begin{cases}11(BPSK), & SNR<SNR_{22}\\ 22(QPSK), & SNR_{22}\le SNR<SNR_{33}\\ 33(8QAM), & SNR_{33}\le SNR<SNR_{44}\\ 44(16QAM), & SNR_{44}\le SNR<SNR_{55}\\ 55(32QAM), & SNR_{55}\le SNR\end{cases}\tag{15}$$

where SNR_i is the SNR threshold for the data rate i to meet the target SER.

3. Performance evaluation

In this section, the proposed protocol is evaluated with three superframe sizes: 25, 45, 65ms. The maximum superframe size described in the IEEE 802.15.3 standard is 65536μs. The delay bound is set to the packet inter-arrival time used in Refs.[17, 18]. That is, all packets arriving at the MAC layer must be transmitted before the next packet arrives. The inter-arrival times are varied by changing the packet size with a constant traffic bit rate for CBR (or the mean traffic bit rate for rt-VBR). The packet sizes used in this simulation are 512, 1024, 1286, 1536, 1792, and 2048 octets defined as preferred packet sizes in the IEEE 802.15.3 standard.

The simulation results of the JFR are shown in Fig.4. With 25ms superframe size, the JFR in FA-WPAN is 34% to 7% of that in HR-WPAN for the CBR traffic and is 45% to 24% of that in HR-WPAN for the rt-VBR traffic as the inter-arrival time increases. The performance differences increase with a lager superframe size. While the performance of HR-WPAN is influenced by the superframe size, the superframe size does not significantly affect the performance of FA-WPAN. Once a

CTA for a DEV is allocated in a superframe in HR-WPAN, the DEV holds its transmissions for the CTA in the next superframe. Therefore, if the delay bound is shorter than the holding time, the packet will be dropped. The effect of delay bound will be described later. On the other hand, since CTAs are allocated at the packet arrival instants in FA-WPAN, more than one CTA for a DEV may be allocated in a superframe.

For CBR traffic, beacon packets and E-MCTAs are more frequently generated in a short superframe than in a long one. Thus they obstruct appropriate CTA allocations. This reflects that JFR of 65ms superframe is slightly lower than that of 25ms superframe in Fig.4(a). However, this explanation is not applicable to the case of rt-VBR traffic. While the CTA location is a critical factor for the CBR traffic, fast changes of the CTA duration according to the Q-status is a critical factor for rt-VBR traffic. However, a CTA can not instantly be changed by the Q-status report. Although a DEV reports the number of pending packets to the PNC, CTAs allocated for a DEV are not changed during the current superframe and consequently non-transmitted packets in the current CTA are dropped. Thus, the CTA durations in a short superframe can be quickly adapted comparing to a long superframe. Therefore, the JFR of 65ms superframe is higher than that of 25ms superframe shown in Fig.4(b).

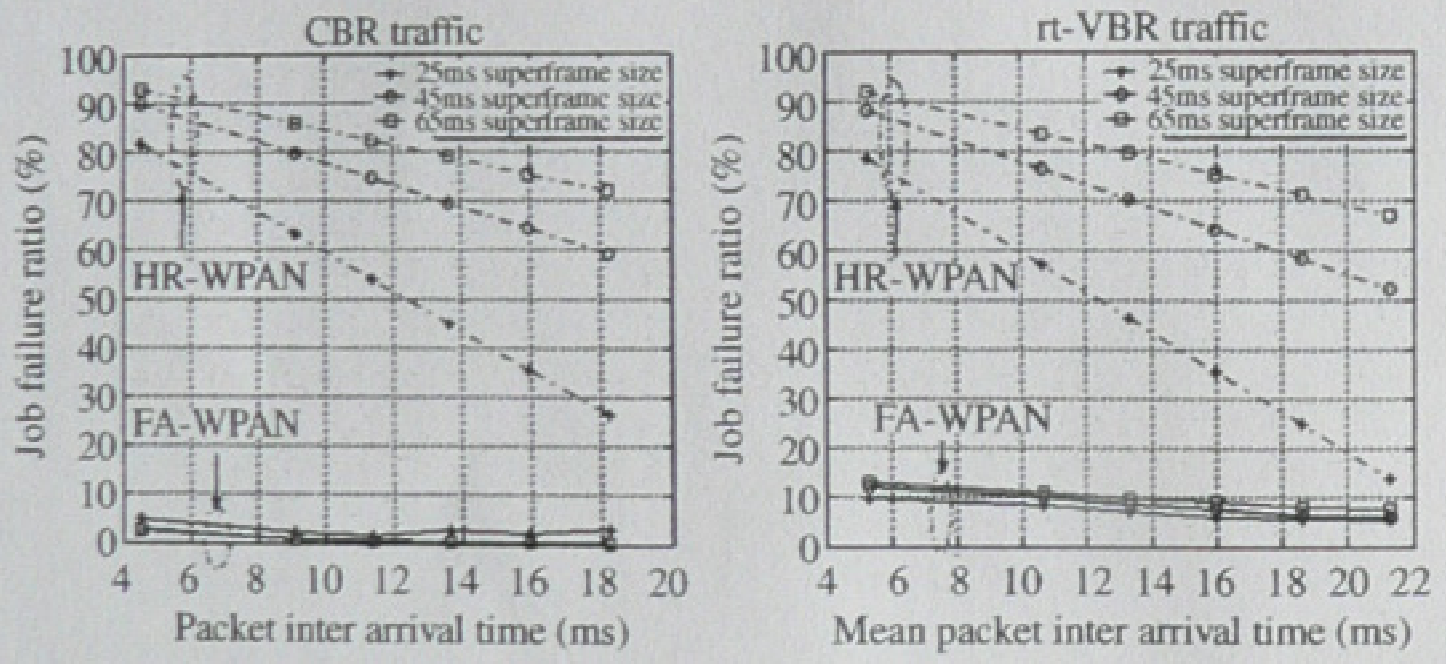


Fig. 4. Job failure rate as a function of the packet inter arrival time for different superframe sizes

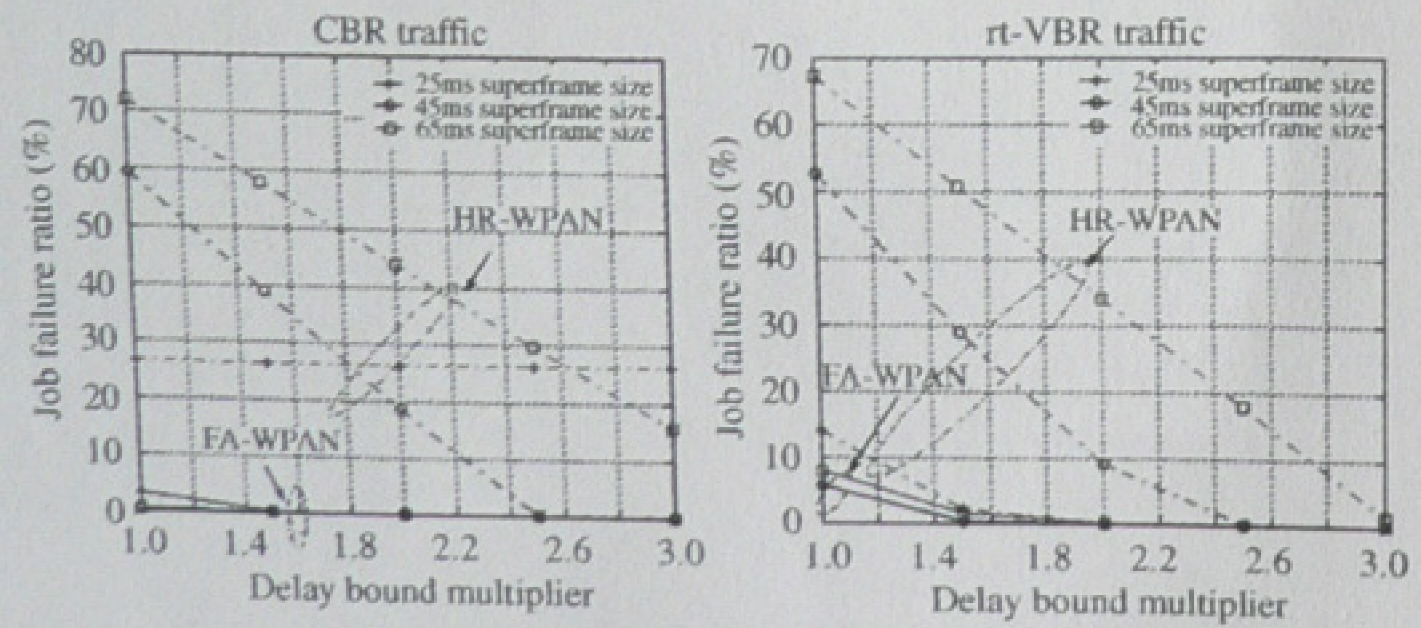


Fig. 5. Job failure ratio as a function of the delay bound multiplier

Previous evaluations are performed using the packet inter-arrival time as the delay bound. Some applications allow longer delay constraint than the inter-arrival time as shown in Refs.[4–7]. Therefore, the performance using different delay bounds should be evaluated. For this purpose, we define a delay bound multiplier, which is multiplier for the inter-arrival time. Here, 2048 octets packet size is used for both of traffic types. The inter-arrival times for CBR and rt-VBR traffic are 18ms and 28ms, respectively. Fig.5 shows the JFRs of both configurations. Both the JFRs of CBR and rt-VBR in FA-WPAN reaches to 0% at around 1.5 delay bound multiplier regardless of the superframe size. Although a longer delay bound generates more pending frames, the CTA duration in the 25ms superframe for CBR traffic in HR-WPAN is insufficient to deal with more than two packets. Therefore, the JFRs for CBR in HR-WPAN are constant, regardless of the delay bounds. Except for CBR traffic case in HR-WPAN, the JFRs in HR-WPAN reach to 0% at longer delay bound multiplier than in FA-WPAN. Considering the delay bound of 30ms, generally used maximum delay bound for MPEG-4 traffic in Refs.[4–7], the higher delay bound multipliers than 1.5 may not be practical.

V. Conclusion

In this paper, we enhance the IEEE802.15.3 MAC protocol by allowing feedback of essential information from DEVs. Furthermore, efficient channel time allocation algorithm is proposed, which utilizes the feedback information. We verify the performance enhancement by the extensive simulations. From the simulations, we have shown that the proposed scheme gives significant performance improvements over other comparative CTA allocation schemes. We note that the performance of the proposed scheme is not influenced by variable factors such as the superframe size, a delay bound, and number of flows. The proposed method shows smaller JFR and higher goodputs than the HR-WPAN standard. In the next step, we will try to provide the performance improvement in terms of Transmission delay and Packet error rate over time varying channel.

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