

A Dynamic CAP Allocation Algorithm using Directional Antennas in IEEE 802.15.3c WPANs

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Abstract— Directional antennas have considerable benefits of higher antenna gain, long transmission distance and spatial reuse compared to omni-directional antenna. To support directional antenna, IEEE 802.15.3c specifies high data transmission rate and short frequency range communication based on characteristics of 60GHz frequency band. However, IEEE 802.15.3c has the room to be enhanced in terms of the use of its own characteristics with directional antenna during contention access period (CAP). For example, there are assigned same CAP and initial value of the contention window (CW) per each direction. Therefore this paper proposes dynamic allocation of CAP considering the number of devices per each direction during contention period. In addition, this paper also proposes an algorithm increasing system efficiency by adjusting an initial value of the CW. Given proposed algorithm numerical results show the proposed algorithm has less overhead than the legacy CSMA/CA mechanism based on IEEE 802.15.3c. The simulation results also show the proposed algorithm has maximum 5% of performance improvement comparing to existing CSMA/CA mechanism in terms of throughput.

Keywords— Directional antenna, WPAN, CAP, IEEE 80.15.3, mmWave

I. INTRODUCTION

In recent home network high speed wireless communication is drawing considerable attention in order to support for device to device communication among multiple electronic products. Especially, wireless data transmission rate requirement of customers have been increased rapidly in proportion as the increase of smart phone users. From the standardization perspective, IEEE 802.11ad [1] is finalizing its standardization for 60GHz WLAN supporting more than 6Gbps while IEEE 802.15.3c [2], which was implemented in 2009, is supporting more than 7Gbps in 60GHz WPAN.

The frequency band between 57GHz and 64GHz in USA/Canada and Korea or 59GHz and 66GHz in Japan was already allocated as flexible access common spectrum (FACS), allowing anyone to use this band without any payment. IEEE 802.15.3c uses this unlicensed 60 GHz frequency band to allow for fast data transmission rate as maximum. Therefore, considering current circumstances lack of frequency band, it has profitable merit for mass supply. Also, in case of IEEE 802.15.3c, it has merits such as higher antenna gain, spatial reuse and longer transmission range than omni-directional

antenna because it supports directional antenna. However, given that devices experiences higher propagation loss according to distance and get much interfered by surrounding environment like obstacles, many researches have been carried out considering many cases [4], [5], [6].

Existing studies proposed the optimized directional CSMA/CA mechanism to mmWave WPANs by finding optimal CW_{min} value [3] and enabled channel time access (CTA) sections to be used effectively by offering ultra superframe amended from IEEE 802.15.3 superframe.

However, the previously proposed algorithms have some weak points in a sense that they should amend the existing superframe structure of the standard to apply or could not utilize the characteristics such as directional antenna and spatial reuse.

If directional antenna is used, the communication space is supposed to be divided to several sectors according to antenna element. It has the same effect of using omni-antenna though directional antenna is actually used because it communicates with devices of the sector as it rotates in the circular manner. In general, device is not distributed uniformly in the space.

Therefore, the number of devices existing in each sector gets different, and number of devices to communicate with PNC also gets different as a result. Though the number of device exists in each sector is different, IEEE 802.15.3c allocates Regular S-CAP to all sectors uniformly for device to send command to PNC. Furthermore, initial CW_{min} values per sector are fixed as value 7 uniformly. This is also supposed to take unnecessary backoff phase.

This paper proposes algorithm which allocates Regular S-CAP within dynamic CAP according to the number of device for each sector and dynamically allocates required initial contention window size during backoff procedure.

The remainder of the paper is organized as follows. In section II, we briefly describe the IEEE 802.15.3 MAC protocol. In section III, we propose a dynamic CAP allocation algorithm considering directional antenna and dynamic CW_{min} allocation. Simulation results are presented in section IV and section V makes conclusions.

II. IEEE 802.15.3 MAC OVERVIEW

IEEE 802.15.3 communicates by composing Piconet. Piconet consists of one Piconet coordinator (PNC) and

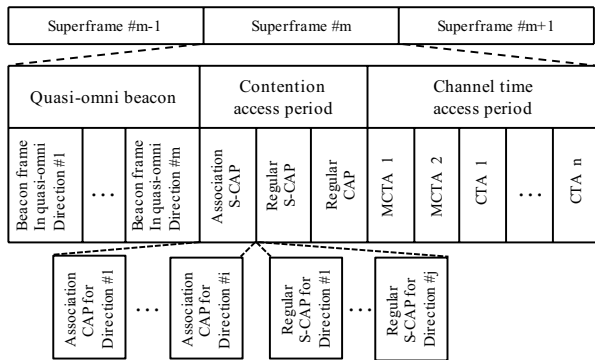


Figure 1. IEEE 802.15.3c Superframe Structure

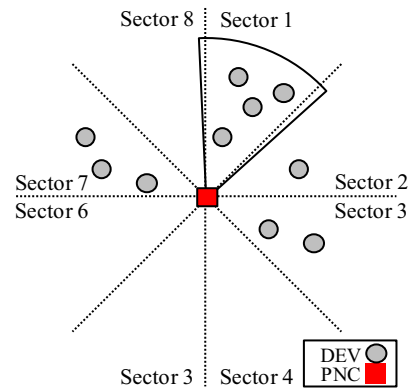


Figure 2. System Model

multiple devices. The PNC synchronizes with devices by transmitting beacon frames in each direction to all devices existing in the Piconet and exchange command frames with devices through CAP. Through this procedure, device gets allocated CTA and exchange data with other device in the CTA section.

Superframe structure of IEEE 802.15.3c is shown in Figure 1. Superframe is divided by three sections such as beacon, CAP and CTA. Beacon section is used for devices to be synchronized with the PNC as the PNC transmits beacon frames to devices. CAP operates based on CSMA/CA mechanism and is used for transmitting asynchronous data or communication command. CTA period is used in case of guaranteeing transmission of command or data.

CAP section is divided to three sub-sections such as Association S-CAP, Regular S-CAP and Regular CAP. Association S-CAP manages join of new devices from Piconet and Regular S-CAP transmits command to PNC to get allocation of CTAP for data transmission of devices. Regular S-CAP enables transmission of both command and data.

In case of IEEE 802.15.3c using directional antenna, the PNC and device communicate for each section. PNC transmits beacon to each sector and allocates CAP. At this time, devices existed in the sectors get allocated CTA required for data transmission by transmitting command to PNC [3]. However in this procedure, Regular S-CAP within CAP required for transmission of command is allocated to each sector with same size (transmitting time). Therefore, its efficiency can get affected along the number of device existed in each sector.

Also, the same contention window initial value against each sector gets allocated in procedure of CSMA/CA mechanism, IEEE 802.15.3c [3]. Regarding existing sector having few devices, unnecessary backoff procedure appears. On the contrary, the sector having number of devices may show frequently conflict of each command to transmit to PNC. Due to that, efficiency of entire system may get worse by no-allocation of CTA for devices which require transmitting data.

III. PROPOSED ALGORITHM

Proposing algorithm consists of two phases. First phase allocates Regular S-CAP dynamically according to the

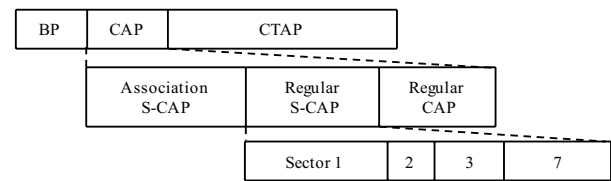


Figure 3. Dynamic CAP Allocation

number of device existing in each sector. Second phase allocates initial CW values considering the number of device against allocated Regular S-CAP.

A. Dynamic CAP allocation

In case of using directional antenna in IEEE 802.15.3c, the PNC communicates per sector and can get table by checking number of devices exist in each sector. In case of using directional antenna in IEEE 802.15.3c, PNC can get a form of table as it controls Piconet join of device communicating per sector and checking the number of devices. Existing data transmission method is that the PNC allocates the same size of Regular S-CAP to each sector device which preoccupied channels gets allocated CTA sections through CSMA/CA mechanism and transmits data to other device. Devices which exist in the same sector have to compete each other in the same size of allocated Regular S-CAP to preoccupy channels for data transmission regardless their number. Therefore, probability of command conflict gets relatively higher in the sector having more number of devices than less one. Furthermore, probability of conflict would get much higher because it is not easy to find out which device and the PNC are communicating even within the same sector in environment of using directional antenna. Therefore, in order to reduce the probability, it is required to allocate dynamic Regular S-CAP according to the number of devices which exist along each direction.

The PNC can recognize the number of device for each sector up to previous superframe through its own information about table. Utilizing the information, the PNC allocates Regular S-CAP area out of CAP in proportion to the number of each device as (1).

$$\begin{aligned} & \text{Size of } n^{\text{th}} \text{ sector} \\ &= \frac{\# \text{ of DEVs in } n^{\text{th}} \text{ sector}}{\# \text{ of total DEVs}} \times (\text{size of total Regular S-CAP}). \end{aligned} \quad (1)$$

If there is no device in a certain sector, Regular S-CAP is not allocated in the sector. At this time, control on device of new joins to Piconet or leaving is implemented through association S-CAP, device which newly joined participates in Piconet from next superframe. In Figure 3, it shows activity of proposed algorithm of dynamic Regular S-CAP allocation.

Figure 2 indicates an example of co-existence of one PNC and ten devices in one Piconet. At this time, antenna elements of PNC are 8 and suppose to be divided into 8 sectors. There exists 4, 1, 2, 3 devices in direction 1, 2, 3, 7 and even a single device does not exist in direction 4, 5, 6, 8. If proposed algorithm is not applied in this circumstance, area for sector 1~8 in Regular S-CAP would exist by the same size altogether. On the other hand, if proposed algorithm is applied, it can be recognized that Regular S-CAP in CAP is allocated only for sector 1, 2, 3, 7 in proportion to device and not allocated for sector 4, 5, 6, 8 as Figure 3. Such that, if proposed algorithm is used, system efficiency can be increased by reducing probability of conflict between commands of device along more allocation of Regular S-CAP to more sector as well as prevention of unnecessary allocation of Regular S-CAP.

B. Dynamic $CW_{\min}$ allocation

For devices of Piconet to transmit data to other device, command to obtain CTA section has to be transmitted to PNC first. While the procedure is implemented through CAP, existing CSMA/CA mechanism allocates the same competing window initial value for each sector. In case of sector with less number of devices due to that, system efficiency is to be reduced by unnecessary back procedure. On the other hand, in case of sector with more number of devices, probability of conflict is to be increased than previous case. Therefore, it is proposed as algorithm of controlling competing window initial value considering the number of device which exists for each sector.

In order to decide optimal initial value of competing window, the method of applying approximation of p out of p -persistent MAC to contention window size of CSMA/CA mechanism [8]. If value of backoff counter is selected from $[0, CW-1]$,

$$CW_{\min} = \frac{2}{p_t} - 1, \quad (2)$$

where p_t can be found from $np_t = 1$ as optimal transmission

Table 1. Dynamic $CW_{\min}$ Allocation

Sector	$CW_{\min}$		Sector	$CW_{\min}$	
	Standard	Proposed		Standard	Proposed
1	7	7	5	7	0
2	7	1	6	7	0
3	7	3	7	7	5
4	7	0	8	7	0

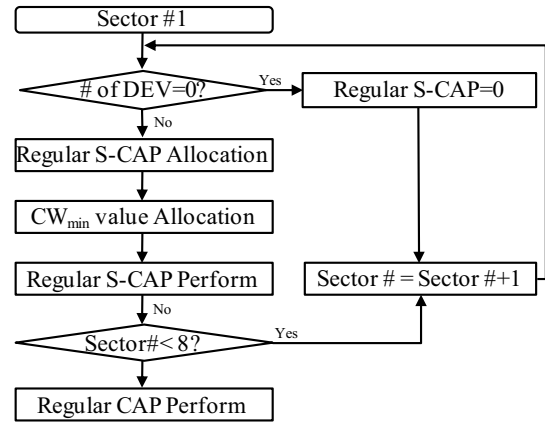


Figure 4. Flow char of a dynamic CAP allocation algorithm

Table 2. Simulation Parameters

Parameter	Value	Parameter	Value
Antenna Type	Directional	Superframe length	65ms
PHY	802.15.3c	aSlotTime	20 μ s
Application	CBR	aSIFSTime	3 μ s
Retry Limit	3	Mobility	None
Elements	8	Terrain dimension	7m x 7m

probability [9]. In here, n is the number of device existing in the sector. Therefore, value of $CW_{\min}$ would be same as Table 1 with above formula against Figure 2.

If value of $CW_{\min}$ is applied to each sector with the proposed method, sector with fewer devices can reduce unnecessary backoff procedure, probability of conflict between commands of device by allocating higher value of $CW_{\min}$ into the sector with relatively more device. As a result of that, entire system efficiency can be increased by smooth data transmission as device which wants data transmission increase probability of obtaining CTA section.

Figure 4 is a flow chart of the proposed algorithm. Start in number of sector 1, check the number of device which existed in its sector. Then, the proposed algorithm is applied in order that dynamic regular S-CAP and $CW_{\min}$ allocation.

IV. SIMULATION RESULT

We used Qualnet to test the performances of proposed Dynamic CAP allocation and $CW_{\min}$. We used general WPAN environment for basic topology. Both PNC and device operate in directional antenna mode. One PNC exists for one Piconet and devices are positioned around it randomly. Simulation parameter and their values are summarized in Table 2.

We compared proposed algorithm with existing CSMA/CA mechanism for comparison of performance improvement. Figure 5 and Figure 6 show its results. As a result of allocating Regular S-CAP and initial value of $CW_{\min}$ with the information of number of device which exist for each sector, we could recognize that command loss rate from competition in CAP was improved by maximum 5% comparing existing CSMA/CA mechanism as Figure 5, Figure 6 shows

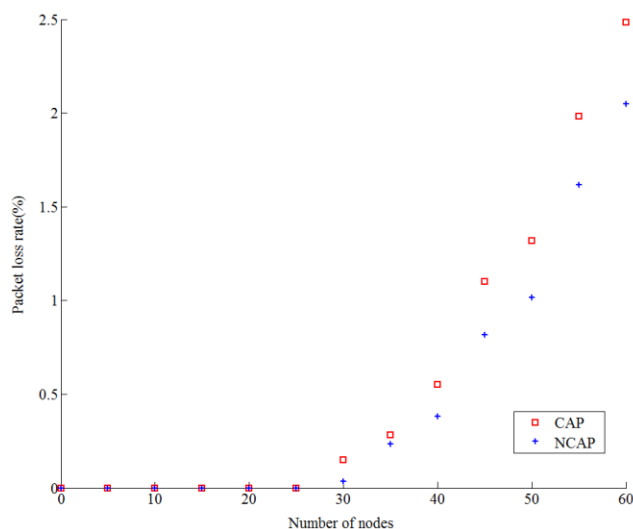


Figure 5. Pack loss rate

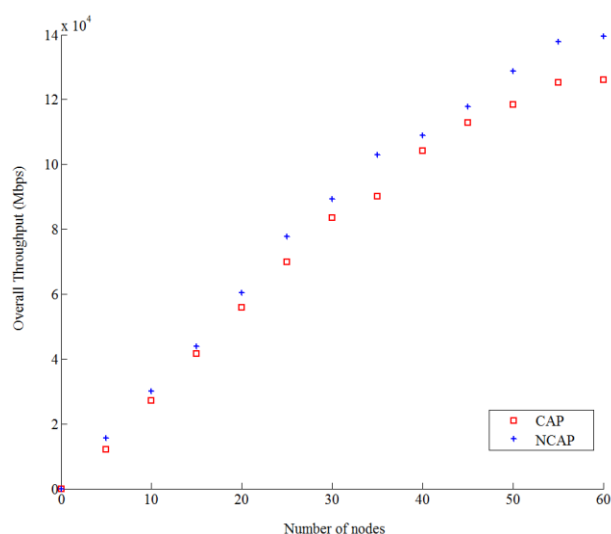


Figure 6. Overall Throughput

throughput of entire system was improved by increased occupying rate devices out of CTA section due to that.

V. CONCLUSION

This paper concentrates on maximizing benefits from use directional antenna. We propose the algorithm which allocates Regular S-CAP within CAP backoff competing window initial value dynamically based on the information after checking of existing number of device for each sector by PNC. Efficiency gets higher by reducing problems of not allocating CTA

section due to possible competition from previous case and unnecessary backoff procedure. We also recognized that proposed algorithm increased efficiency of MAC from simulation results. Proposed algorithm has merit of applying less overhead to all environments which uses directional antenna as well as IEEE 802.15.3c.

ACKNOWLEDGMENT

This work was supported by the IT R&D program of MKE/KEIT [KI001855 Wireless Local Area Communication Systems on Tera Hertz Band].

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