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Concurrent Channel Time Allocation for Resource Management in WPANs

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Abstract

This paper presents a concurrent channel time allocation scheme used in the reservation period for concurrent transmissions in 60-GHz wireless personal area networks (WPANs). To this end, the proposed resource allocation scheme includes an efficient method for creating a concurrent transmission group by using a table that indicates whether individual streams experience interference from other streams or not. The coordinator device calculates the number of streams that can be concurrently transmitted with each stream and groups them together on the basis of the calculation result. Then, the coordinator device allocates resources to each group such that the streams belonging to the same group can transmit data concurrently. Therefore, when the piconet coordinator (PNC) allocates the channel time to the individual groups, it should allow for maximizing the overall capacity. The performance evaluation result demonstrates that the proposed scheme outperforms the random grouping scheme in terms of the overall capacity when the beamwidth is 30° and the radiation efficiency is 0.9.

Index Terms: Concurrent transmission, Directional antenna, IEEE 802.15.3c, Resource management

I. INTRODUCTION

With the recent advances in complementary metal oxide semi-conductor (CMOS) technology and the extremely increasing mobile data traffic, the 60-GHz frequency technology offering a contiguous and worldwide 7-GHz bandwidth as an unlicensed spectrum is regarded as a promising candidate for the future home network. The 60-GHz radio has characteristics, such as oxygen absorption, high path loss, short wavelength, and high antenna directivity. These characteristics can cause an impediment in terms of the transmission coverage. However, these features can also help to attain high security, high-frequency reuse, and low interference for 60-GHz links [1, 2].

In particular, antenna directivity enables devices to not only extend their transmission range with the same power but also concurrently communicate in the same channel and geographical area by means of spatial reuse. The narrower the beamwidth of the radiation is, the greater is the increase in the overall capacity. However, there could be heavy collisions among devices transmitting concurrently since they can experience a much severe deafness problem when devices use a relatively narrow beam [3]. Hence, an efficient resource management scheme for concurrent transmissions is necessary to not only resolve this problem but also increase the overall capacity.

As for the standardization with respect to the 60-GHz short-range communications, there are currently two

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standards to be accessed in public, namely, the IEEE 802.15.3c and the ECMA-387 developed by ECMA International. The IEEE 802.15.3c devices are managed by a piconet coordinator (PNC) [4], whereas the ECMA-387 devices are distributed and self-organized [5]. Both standards aim to provide a data rate of more than 2 Gbps. Moreover, the IEEE 802.11ad standardization is in process based on centralized networks offering a data rate of up to 7 Gbps [6].

Device discovery is an essential procedure in which a certain device identifies its neighbors and chooses a desired device to communicate with. Device discovery should be performed in wireless ad-hoc networks. On the other hand, in centralized networks, a coordinator device notifies the information on the neighbor devices to all the devices in the piconet by periodically transmitting beacons. In other words, a coordinator device fulfills a device discovery procedure instead of the devices belonging to its piconet. In [5], all devices should get to the discovery channel, which is the dedicated channel for device discovery, and perform device discovery as an initial step. Many researches on device discovery have been accomplished in wireless ad-hoc networks by using an omnidirectional antenna [7-9] or a directional antenna [10-13].

Localization or location positioning techniques can be accompanied by device discovery. Since the use of the global positioning system is not available in an indoor environment, the location of devices can be obtained by using a ranging procedure including the received signal strength, time difference of arrival, time of arrival (TOA), direction of arrival (DOA), and angle of arrival (AOA) information [14, 15]. Considering a wide channel bandwidth and sub-nanosecond sampling rate, we can obtain a localization accuracy of 10 cm or less in a millimeter wave band [15].

The importance of the efficient use of resources is increasing in the field of wireless communication networks that employ millimeter waves. While resource scheduling can be easily carried out for a small amount of data to be processed, if the amount of data to be processed is increased, the users are subject to experience a transmission delay under any standards according to the resource scheduling. Thus, an efficient resource management scheme is required, particularly in a wireless communication network using a directional antenna. There are researches on resource allocation policies and scheduling algorithms using directional antennas. In [16], in order to support multi-class traffic with different quality of service (QoS) constraints, a scheduling priority factor consisting of the service priority and the ratio of the backlogged time was considered for resource allocation. A directional transmission scheduling algorithm based on first-come first-serve was proposed for millimeter-wave-based wireless personal area networks (WPANs) [11]. The spatial multiplexing gain in millimeter-wave WPANs using directional antennas and an exclusive region (ER)-based resource management scheme for concurrent transmission was investigated [17-19]. In [19], the management scheme for a specific IPTV application requiring a high data rate and strict QoS constraints was evaluated in terms of the delay and the packet loss rate. A power-controlled concurrent transmission using a directional antenna was analyzed according to different antenna beamwidths [20].

In this paper, we propose an efficient resource management scheme for concurrent transmissions called the concurrent channel time allocation (CCTA) scheme in IEEE 802.15.3c WPAN. The CCTA scheme includes a method of creating a concurrent transmission group by using a table that indicates whether individual streams experience interference from other streams or not. In addition, the proposed CCTA scheme is basically based on the concept of an ER, which is introduced in [20].

II. SYSTEM MODEL

In this section, IEEE 802.15.3c WPAN is considered a network model. Fig. 1 shows the superframe structure of IEEE 802.15.3c WPANs. In Fig. 1, the superframe comprises three major parts: beacon period, contention access period (CAP), and channel time allocation period (CTAP). The CAP is divided into the association CAP used only for the association procedure with the PNC and the regular CAP used for all other commands and asynchronous data exchanges. During the CAP, devices should operate in the way of 'listen before talk', whereas during the CTAP, devices can communicate only in their allocated time period referred to as channel time allocation (CTA) in a time division multiple access fashion.

In IEEE 802.15.3c WPANs, the CTAP is mainly used for the data communications between the devices to guarantee reliable connectivity. It is because there could be heavy collisions by the deafness problem when the CAP is used for the data communications at the 60-GHz band with high directivity [3].

The association and CTA procedures in IEEE 802.15.3c WPANs are as follows: once a device willing to join a certain piconet listens to the beacon transmitted by PNC, it sends the association request command frame to the PNC during association CAP indicated in the received beacon. In response to the association request command frame, the PNC sends the association response command frame allowing it to join the piconet. The PNC can notify the information on devices available in the piconet by transmitting the beacon frame or the announcement frame with the DEV association information element including the

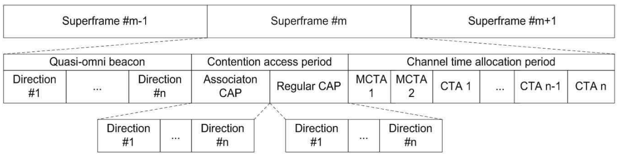

Fig. 1. IEEE 802.15.3c superframe structure.

current member information.

The device willing to perform data communication during CTAP sends the channel time request command frame including the desired time unit. For isochronous stream requests, the PNC responds to it with the channel time response command frame including the available time unit, which can be less than the desired time unit. On the other hand, for an asynchronous stream request, the response frame is sent only if the PNC cannot fulfill the request. Prior to the allocation of the CTA for data communication, if both devices of the stream are capable of supporting beamforming, the source device should request the PNC to allocate the beamforming CTA and perform the beamforming with the destination device in the allocated beamforming CTA. Once the beamforming procedure is completed, if necessary and the PNC gathers all the CTA requests during one superframe, the PNC it assigns the CTAs to the requested devices through the beacon frame or the announcement frame including the CTA information element (CTA IE).

The format of the CTA IE includes a number of CTA blocks that consist of the CTA duration, CTA location, stream index, source ID, and destination ID. The CTA location field indicates the offset value, in the unit of microseconds, from the start of the beacon and the duration field is the duration, in the unit of microseconds, between the start of the CTA and the end of the CTA. The stream index field indicates the value generated by the PNC for the purpose of differentiating streams in the same device. Some values are reserved for asynchronous data, management CTA traffic, beamforming CTA, and unassigned streams.

The PNC can assign several CTAs to a specific stream by including multiple CTA blocks within the CTA information element. If the number of CTA blocks exceeds 255, more CTA IEs can be included in the beacon frame or the announcement frame. Therefore, in IEEE 802.15.3c, the PNC can allocate the overlapped CTAs to the streams belonging to the same concurrent transmission group such that the streams can have the same CTA locations and the individual CTA duration can be less than or equal to the longest CTA duration from the concurrent group. However, the PNC should exclusively allocate the beamforming CTA since the beamforming procedure could cause severe collisions with other streams.

In the IEEE 802.15.3c network topology, the PNC coordinates all the associated devices in its piconet and assigns CAP and CTAP. During the association procedure, the PNC can earn the device list of the piconet. Then, the PNC notifies the device list to all devices through the beacon frame or the announcement frame, including the DEV association IE. Therefore, all devices can be aware of which devices lie in the piconet and choose a peer device. Device discovery in the ad-hoc networks are studied [12, 13], but only centralized networks are considered in this dissertation.

The PNC should send out the directional beacon in each sector in every superframe to cover all directions. In order to associate with the PNC, devices should transmit the association request frame to the PNC. Then, the PNC can be aware of the location of an individual device. However, it does not guarantee the exact location of the devices. Therefore, the PNC needs to execute a specific locating algorithm such as the received signal strength, TOA, DTOA, and AOA in order to ensure the exact location of the devices [14, 15]. According to [15], these localization schemes enable the localization accuracy to be 10 cm or less in a millimeter wave band. In this paper, we assume that the PNC can be aware of the exact location of devices. In addition, the association, beamforming, and localization procedures are accomplished at the initial stage. Therefore, it is obvious that these initial overheads can be neglected in the performance analysis.

III. GROUPING ALGORITHM FOR RESOURCE MANAGEMENT

In this section, we propose an efficient resource management scheme for concurrent transmissions in IEEE 802.15.3c WPAN. The CCTA scheme includes the method of creating a concurrent transmission group by using the table referred to as the exclusive region vector (ERV), which indicates whether individual streams experience interference from other streams or not. We propose a CTA grouping algorithm for concurrent transmission and compare the performance including a random grouping algorithm (RGA) for concurrent transmission.

The PNC carries out resource scheduling, considering priority, channel efficiency, and fairness with respect to streams requested by the devices. In particular, the PNC makes a group of streams formed between devices in an environment, such as a wireless network by using a directional beam that allows concurrent transmission through the same channel. Here, the PNC calculates the transmission time for each stream and the number of streams that can be concurrently transmitted, and groups together the streams that can be concurrently transmitted on the basis of the calculation result. The transmission time for each stream is equal to the amount of transmission or the amount of load assuming that the transmission rate is fixed at 1.65 Gbps. The number of streams that can be concurrently transmitted is the number of different streams that can be transmitted concurrently. The PNC allocates the channel time to devices such that the respective devices can transmit streams belonging to the same group concurrently. Accordingly, the overall throughput (i.e., the total amount of transmission divided by the total allocated channel time in a superframe) can be maximized.

A. Exclusive Region Vector

The ERV indicates whether individual streams experience interference from other streams or not by using an ER condition. Let *N* traffic streams, $S = \{S_i : i = 1, \dots, L, \dots, N\}$, lie in a piconet. Let *E* and E_i be the ERV set and the ERV set of stream S_i, respectively.

Then, $E_i = \{a_{ij} : j = 1, \dots, L, \dots, N\}, i \neq j$, where a_{ij} has a binary value. The value of one indicates that stream *i* and stream *j* can concurrently transmit without any interference, while the value of zero indicates that two streams cannot transmit concurrently. Therefore, the ERV set, *E*, can be given by

$$E = \{E_i\}_{i=1}^{N} = \{a_{ij} : j = 1, \dots, L, \dots, N\}_{i=1}^{N}, i \neq j \quad . \qquad (1)$$

B. Random Grouping Algorithm

N traffic streams can be grouped into several disjoint sets on the basis of the ER criterion as follows: Let S_i be a group that is a subset of S consisting of concurrently transmittable streams. The grouping algorithm is a procedure for creating S_i. The RGA is as follows: The PNC randomly chooses a stream from S and inserts it into S_1 and then, removes it from *S*. It then selects another stream in *S* and checks the ER conditions for concurrent transmission with individual streams in S_1. If the newly selected stream is concurrently transmittable with each stream in S_1, it is put into S_1 and removed from *S*. Once the PNC completes checking the ER condition for the remaining streams in *S*, S_1 is generated. As for the remaining streams in *S*, the same procedure is used to generate S_2. Repeat these procedures until $S = \emptyset$. Assume that $\{S_i\}_{i=1}^{k}, k \leq N$, groups are generated. Let G_i be a group that consists of the loads of streams belonging to S_i. Let l_{ij} and g_i be the load of stream j in the group G_i and the number of loads in the group S_i, respectively, i.e., $G_i = \{l_{i1}, L, l_{ig_i}\}$. Then, $\sum_{i=1}^{k} g_i = N$ and $\sum_{j=1}^{g_i} l_{ij}$ loads can be transmitted in the same channel time. It is assumed that the stream loads $\{l_i\}_{i=1}^{N}$ are independent and identically distributed (i.i.d.) with an exponential distribution of parameter *1/d*, where *d* is the average traffic load for each device. It is also assumed that the data transmission rates of streams are the same, while the transmission powers of streams vary depending on the distance between the transmitter and the receiver of a stream.

We can obtain 4 different ERs around the receiver of each stream with respect to 4 cases. In addition, we can calculate the ERV for each stream by checking the ER conditions with respect to those of the other streams. Fig. 2 shows the ER table for this example. In Fig. 2, each row denotes the stream index that intends to check the ER condition, and each column indicates the stream index checked by the row index stream. 1 means *concurrently transmittable*. For example, the stream with index 1 is concurrently transmittable with streams 2, 3, 5, 7, and 9.

C. Concurrent Channel Time Allocation based on the Grouping Algorithm

Prior to grouping streams, the PNC creates ERV on the basis of the ER condition. Then, the PNC chooses the stream. The element $l_{(1)}$ of the group *G* indicates from *S*. If several streams have the same value, the PNC chooses a stream from *S* such that $\sum_{j=1}^{N} a_{ij}$ is the largest of the streams and inserts it into S_1; then, the PNC removes this stream from *S*. Next, the PNC chooses another stream in *S* such that $\sum_{j=1}^{N} a_{ij}$ is the largest out of the streams and checks the ER conditions for concurrent transmission with individual streams in S_1.

If the newly selected stream is concurrently transmittable with each stream in S_1, it is put into S_1 and removed from *S*. Once the PNC completes checking the ER condition for the remaining streams in *S*, S_1 is generated. As for the remaining streams in *S*, the same procedure is used to generate S_2. Repeat these procedures until $S = \emptyset$.

For instance, we consider Fig. 2. Since the stream with the largest CTA value is included in the first group at first, the 8th or 9th stream is chosen for the first group. If the 8th stream is included in the first group, then the 5th stream should be checked with the 8th stream since the 5th stream is the biggest value of the ERT summation of each row. Then, the 9th stream should be checked because it has the

$$\begin{bmatrix} 0&1&1&0&1&0&1&0&1&0 \\ 1&0&1&0&1&0&1&1&1&0 \\ 1&1&0&0&1&1&0&1&1&0 \\ 0&0&0&0&1&0&0&1&0&0 \\ 1&1&1&1&0&1&1&1&1&1 \\ 0&0&1&0&1&0&1&1&1&1 \\ 1&1&0&0&1&1&0&1&0&0 \\ 0&1&1&1&1&1&1&0&1&0 \\ 1&1&1&0&1&1&0&1&0&1 \\ 0&0&0&0&1&1&0&0&1&0 \end{bmatrix}$$

Fig. 2. Exclusive region vector.

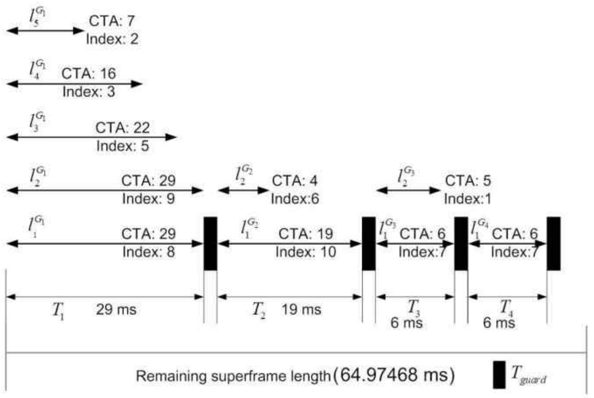

Fig. 3. An example of the concurrent channel time allocation (CCTA) scheme.

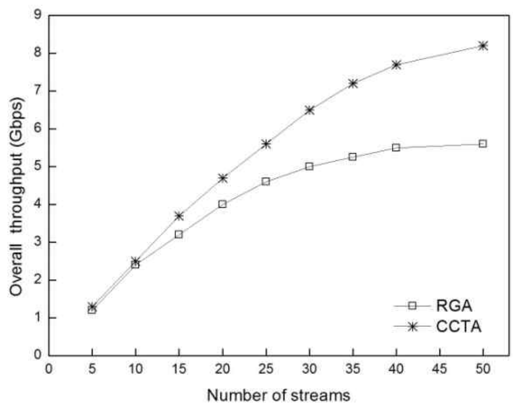

Fig. 4. Numerical result for the overall throughput according to the beamwidth is 30° and the radiation efficiency is 0.9. RGA: random grouping algorithm, CCTA: concurrent channel time allocation.

largest CTA value among the remaining streams to be checked. The 9th stream is checked to ensure that it could be concurrently transmitted with the streams that already belong to the first group.

When the CCTA scheme for this example is applied, the resource scheduling is performed as shown in Fig. 3. Fig. 3 shows that the entire group can be transmitted completely within the current superframe.

IV. NUMERICAL RESULTS

The parameters used are W = 1,728 MHz, k_1 = 68 dB, and $N_0 = -92$ dBm/MHz, which are obtained using the Friis path loss model [20]. The received power (dBm), P_R, is set to -55 dBm supporting the 1.65-Gbps data rate, and P_T is fixed at 10 mW. The active streams are distributed randomly in a square room measuring $L \times L$. It is considered that 5 to 50 active streams are deployed, and the room size varies according to the communication range, which is determined on the basis of the beamwidth, data rate, and radiation efficiency. The average required time for transmission is assumed to be 20 ms, which is denoted simply as d = 10 m. Also, θ = 30, 45, and 60 and η = 0.9 are used for obtaining the numerical results.

The performance of the proposed scheme is compared with that of an RGA. Fig. 4 shows that the CCTA scheme outperforms RGA in terms of the overall capacity when the beamwidth is 30° and the radiation efficiency is 0.9.

Fig. 5 shows that the CCTA scheme outperforms RGA in terms of the overall capacity when the beamwidth is 45° and the radiation efficiency is 0.8. In addition, Fig. 6 shows that the CCTA scheme outperforms RGA in terms of the overall capacity when the beamwidth is 60° and the radiation efficiency is 0.7. The simulation results show that the overall capacity decreases as the beamwidth increases.

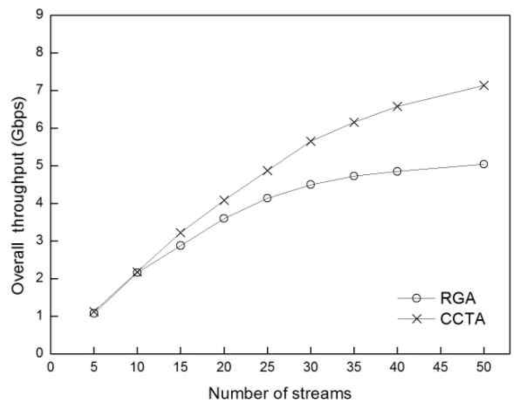

Fig. 5. Numerical result for the overall throughput according to the beamwidth is 45° and the radiation efficiency is 0.8. RGA: random grouping algorithm, CCTA: concurrent channel time allocation.

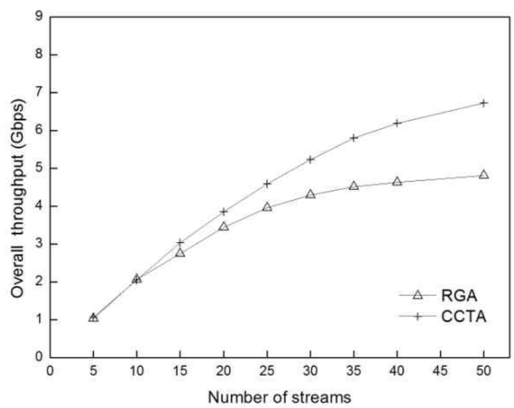

Fig. 6. Numerical result for the overall throughput according to the beamwidth is 60° and the radiation efficiency is 0.7. RGA: random grouping algorithm, CCTA: concurrent channel time allocation.

V. CONCLUSION

In this paper, we proposed a new concurrent channel allocation scheme for a directional concurrent transmission and compared it to an RGA. The proposed scheme offers better performance in terms of the overall capacity than the RGA. The future plan is to enhance grouping algorithms and search for an optimal solution.

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