A Group-aware Multicast Scheme in 60GHz WLANs

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Abstract

The relation of multicast transmission and directional antennas is an open problem that has been debated for a long period of time. In this paper, we propose a group-aware multicast scheme of efficient multicast communication using the directional antennas for 60GHz millimeter wave wireless networks. For this purpose, we first derive the relation among beamwidth, distance between devices and most suitable data rate in the 60GHz frequency-based wireless network. In addition, for the dynamic beamforming of multicast communication, the *x* and *y* coordinates of any point with sender device at the center is generated, and a best-chosen group is deduced based on the Euclidean distance. Then the most suitable data rate for the group is obtained using the law of cosine. Using the Standard IEEE 802.11ad MAC protocol as an example, extensive simulation results demonstrate that the proposed scheme outperforms the existing multicast communication schemes with directional antennas under different situations.

Keywords: Multicast communication, directional antenna, IEEE 802.11ad, 60GHz millimeter wave network

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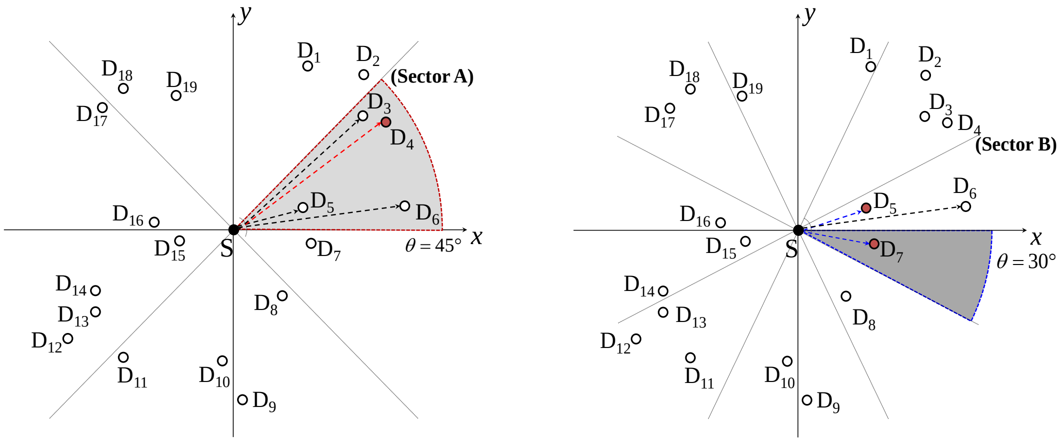
1. Introduction

Recently, the 60GHz millimeter wave (mmWave) wireless networks have drawn a lot of attention due to the capability of supporting very high data rate services for short range wireless communication with steerable directional antennas. It will actualize many killer applications such as sync-n-go file transfer systems, VoD services, and projection to TV/projector [1]. The applications of advanced group communication such as conference rooms, wireless display, and social networking especially demand an efficient multicast scheme for mmWave wireless networks. This approach is necessary since such applications not only need a large number of devices but also essentially demand multicast transmissions that send a large amount of data at the same time. Due to the development of many killer applications and wireless communication, an efficient scheduling scheme for multicast communication has slowly become a crucial technology. Nevertheless, there is a problem because the concept of multicast communication is directly opposed to the idea of a directional antenna. The multicast nature of the wireless medium basically includes the characteristics of both broadcast and unicast communication, and therefore multicast communications can promise a high transmission efficiency for data transmissions to specific devices. However, in the case of communication involving a large number of wireless media scattered in all directions, as in a conference room, the characteristics of multicast and directional antenna may cause the problem of devices that are left behind or the even opportunities for every device may rather cause the problem of unfairness. In addition, the broadcast nature of multicast communication influences low system performance affected by the lowest data rate of the weakest device (i.e., the most distant device from the source). If an omni-antenna that can reflect the broadcast characteristics itself is used, communication of very low data rate is possible compared to a directional-antenna. For example, if IEEE 802.11 of 2.4GHz bandwidth that uses an omni-directional antenna or WiMedia MAC that provides high data rate is used for multicast communication, a data rate of maximum 480Mbps is used [2][3]. This is a very low data rate compared to a directional-antenna, and it is not sufficient to satisfy the needs of the latest large file transmission systems or multimedia file transmissions. Ultimately we are force to present a new scheme for efficient use of a directional antenna.



(a) The effect of distant device **(b)** The effect of a fine beam

Fig. 1. Description of the multicast problem

In **Fig. 1**, multicast transmission to a specific sector (e.g., sector A) is inefficient, since all the devices (D_3, D_4, D_5, and D_6) have to follow the data rate of the most distant device (D_4) (see Fig. 1(a)). In addition, a fixed beam sector (e.g., 30°) also shows in ineffective, because communication with nearby devices (D_5 and D_7) has to be made at different data rates (e.g., D_5 has the low data rate less than D_7 due to distant device of sector B) and in different orders (i.e., different time) (see Fig. 1(b)). In 60GHz frequency-based directional communication, even though the multicast scheme is useful to the group transmissions, devices demand a more efficient multicast scheme due to large free space loss and high penetration loss in this band compared to other frequency bands (i.e., 2.4 and 5GHz of IEEE 802.11) [4]. In summary, the multicast performance will be drastically degraded when the dispersion among the devices is large and the channel condition is variable. To ensure the system performance of mmWave wireless networks, we must know how to manage steerable beamforming for multicast devices, which is the main focus of this paper. Thus, in order to overcome these mmWave frequency drawbacks, we propose a novel multicast directional antenna-aware scheme to maximize system performance of multicast communication that is compatible with the IEEE 802.11 ad [5].

In this paper, we first explore the characteristics of the directional antenna model and network architecture for mmWave based IEEE 802.11ad. We then investigate the key problem of mmWave frequency (i.e., multicast communication vs. directional antenna) and propose a group-aware multicast scheme called GAMS that is a best-chosen grouping algorithm based scheduling scheme to improve system performance in mmWave wireless networks. GAMS consists of two components a rational group estimator (RGE) and an asymmetric beamforming scheduler (ABS). First, we introduce how to perform grouping to adapt scattered devices, and propose an RGE using the Euclidean distance. Second, given the scattered receivers, we analytically examine the dynamic beamwidth and the most suitable data rate to apply ABS utilizing the law of cosine. Through the two steps, it becomes possible to make groups that allow for high transmission efficiency for omni-directionally-dispersed multicast devices, and to provide multicast transmission at the most suitable data rate.

In addressing these solutions, we make the following contributions, which are twofold. First, we provide an efficient beamforming solution under the mmWave frequency band for the many multicast devices. This is an essential algorithm for multicast transmission in mmWave networks. Second, the paper supplies an easy-to-implement solution with general theories to find the best-chosen groups and steer dynamic beamwidth with directional antennas. Thus, GAMS does not involve system overhead due to compatibility with the standard by constitution. Since GAMS do not require additional elements of MAC protocol provided by IEEE 802.11ad standard and only added the mathematical calculation in the beamforming process, it has an excellent compatibility with the standard and it also has a very low system overhead since there are no modifications in the MAC level. The IEEE 802.11ad network is applied for extensive simulations, and the simulation results demonstrate a significant throughput improvement compared to existing multicast communications. We also show that the proposed scheduling scheme could be a practical solution to meet the performance requirements of multicast applications under various channel conditions.

The remainder of this paper is organized as follows: In Section 2, we briefly survey the related work. In Section 3, we overview the directional antenna model and mmWave-based IEEE 802.11ad network in the system description. Then we explain the problem description of multicast and beamforming and present a proposed group-aware multicast scheme in Section 4.

A performance evaluation is given in Section 5 and concluding remarks are presented in Section 6.

2. Related Work

Although the mmWave bands allow very high data rates at the physical layer, it is hard to provide the increased data rate to the application layer without any MAC layer enhancements. For this reason, a number of studies have been developed in an attempt to improve the MAC layer throughput. Especially, a lot of research considers the problem of designing efficient multicast/broadcast mechanism with steerable direction antennas [6][7][8][9]. Most of the work deals with adaptive beamforming or MIMO techniques, which have higher complexity to compute the beamwidth and antenna weights and need many feedback values for channel condition, as opposed to sectored beamforming algorithms.

1) How can we enhance the MAC layer performance using wireless multicasting? Much research has focused on MAC layer techniques for enhancing multicast communications. In [10], a rate adaptation algorithm is proposed for high quality multimedia content using the MAC layer multicast mechanism. In [11][12], efficient feedback mechanisms are introduced to improve the multicasting reliability. Efficient resource allocation algorithms are presented for multicast scalable video stream in [13].

2) How can we solve the existing problems of a tradeoff between beamforming and multicast transmission? Recently, only a few studies present the integrated problem of beamforming and multicast communications. In [14], a combination of omnidirectional and beamforming antenna modes is used to execute multiple high data rate transmissions by using the multicast scheduler and the dynamic programming recursive solution. In [15], the problem of efficient link layer multicasting in wireless networks with switched beamforming antennas is treated by using composite beam patterns. In addition, the impact of using directional antennas for multicast communication in wireless networks is studied over dense networks with a heavy traffic load in [16]. In [17], the multicasting routing problem is investigated for energy constrained wireless networks with a single beam directional antenna. Also, the beam partitioning and multicast problem is considered with transmission power in [18].

3) Why do we need efficient MAC scheduling algorithms with steerable directional antennas in the mmWave frequency band? To cope with the attenuation problem, directional antennas with high directive gains can be utilized. In [19][20], smart directional neighbor scanning strategies are proposed to reduce the directional neighbor discovery time in indoor networks at mmWave frequence. In [21], the deafness and hidden node problem is discussed for short range transmission limitations due to large propagation losses and reduced diffraction around obstacles with directional antennas over the mmWave frequency band.

While the directional beamforming scheme provides increased signal strength (i.e., leading to high data rates), it reduces the signal range compared with omnidirectional transmissions. In particular, the multicast transmission to the mmWave frequency band with the directional beamforming scheme still remains a crucial problem. After all, unlike previous research, this paper deals simultaneously with the problems of both multicast communication and steerable directional antenna in 60GHz mmWave wireless networks for the first time. In the mmWave frequency band, it was shown to be very efficient to use multicast communication according to the characteristics of frequency such as atmosphere attenuation and oxygen absorption and target application such as wireless displays and conference rooms. It is expected that GAMS can be applied to many target applications, especially because multicast devices in many cases are clustered in a personal area.

3. System Description

3.1. 60GHz Radio Properties and Directional Antenna Model

60GHz radio has attractive and some unique properties, high path loss and small wavelength, which is different from radio on the 2.4 or 5GHz frequency band. This is due to intense atmosphere attenuation and oxygen absorption. In addition, a typical wireless links by the transmitter/receiver is perfectly fed into the transmitting/receiving antenna with a gain and effective area of $G_T(i)(G_R(i))$ and $A_{eT}(i)(A_{eR}(i))$, respectively. If the intervening medium is linear, passive, and isotropic, the power density at the receiving antenna is $S_R(i) = P_T(i)G_T(i)/4\pi r_{TR}^2$. Assuming the receiving antenna is lossless, the received power of the receiving antenna is $P_R(i) = S_R(i)A_{eR}(i)$. The relationship between the effective area A_e and the directivity Δ of an antenna is $\Delta = 4\pi A_e / \lambda^2$ where λ is the wavelength. When the antenna is matched perfectly, the gain equals to the directivity based on the equation $\Delta = \eta G$, where η is the antenna's radiating efficiency factor, e.g., $\eta = 1$, which indicates no side lobe exists. Therefore, combining equations, the relationship between transmitting and receiving power can be expressed as:

$$\frac{P_R(i)}{P_T(i)} = \left(\frac{\lambda}{4\pi\delta_{TR}}\right)^2 G_R(i)G_T(i) \tag{1}$$

where $G_T(i)$, $G_R(i)$, and δ_{TR} are the antenna gains of the transmitter and the receiver of flow i, and the distance between them, respectively, which is called the Friis transmission formula [22]. Then the average received signal power of flow i is given by:

$$P_R(i) = \kappa G_T(i)G_R(i)\delta_{TR}^{-\Omega}P_T(i) \tag{2}$$

where $\kappa \propto (\lambda/4\pi)^2$ is a constant coefficient depending on the wavelength and Ω is a path loss exponent dependent on the propagation environment. Ω gets the value through the path loss model for a line of sight (LOS) scenario between devices based on the Friis transmission formula $PL_{LOS}[dB] = A_{LOS} + 20\log_{10}(f) + 10n_{LOS}\log_{10}(\delta)$, where A_{LOS} is specific for the selected type of antennas configuration, antenna beamwidth, and beamforming algorithm which usually takes 32.5dB, $n_{LOS} = 2$, and f is the carrier frequency in GHz, respectively [23].

As for a directional antenna used in mmWave networks, there can be two candidates as the antenna model: the flat-top model neglecting the side-lobe of the radiation and the cone plus circle/sphere model considering the side-lobe of the radiation. In this paper, assuming that all devices are located in a two dimensional space, the cone plus circle model is applied. Then, t he antenna gain for main-lobe is defined by

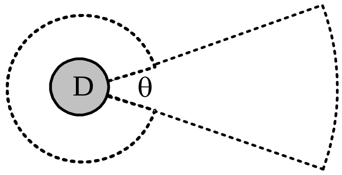


Fig. 2. Radiation form for cone plus circle antenna model

$$G_{ML} = \eta \frac{2\pi}{\theta}, \qquad (3)$$

where G_{ML}, η and θ are the antenna gain for main-lobe, the radiation efficiency and the bea mwidth, respectively. The antenna gain for side-lobe is defined by

$$G_{SL} = (1-\eta)\frac{2\pi}{2\pi-\theta}. \qquad (4)$$

Fig. 2 shows the radiation pattern when the cone plus circle antenna model is employed. The distance between devices can eventually be obtained by considering $P_R(i)$, receiver sensitivit y (*dBm*) according to modulation and coding scheme (MCS) index, and a data rate according to MCS-dependent parameters.

3.2. mmWave-based IEEE 802.11ad Network Architecture

Since the base service set (BSS) defined by IEEE 802.11 WLAN architecture and Independent BSS (IBSS) do not fit many target usages of IEEE 802.11ad, tasking group ad (TG ad) suggests a new architecture model, Personal BSS (PBSS). PBSS is similar to the IBSS architecture, but does not depend on a special device such as AP. Instead, a specific device plays the role of AP according to the application environment to form a peer-to-peer architecture. Here, the device that plays the role of AP to send a beacon to devices is defined as PBSS Central Point (PCP). For example, if a device waiting to hear the beacon within a single PBSS does not hear any beacon frames, it is defined that such device will perform the role of the PCP. In general, PCP plays not only a manageable role to consider the directional channel access problem among devices, but also the role of the general management of PBSS, such as QoS support and power management.

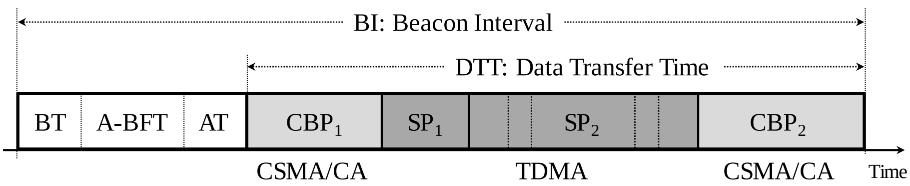


Fig. 3. mmWave-based IEEE 802.11ad architecture

The MAC design for IEEE 802.11ad uses not only a CSMA/CA mechanism but also scheduled access such as TDMA, as its channel access method, and it defines three kinds of time models in a beacon interval (BI) to consider directional antennas. **Fig. 3** shows the structure of BI. First, beacon time (BT) is the access period when PCP sends one or more mmWave beacon frames to omnidirectional devices. PCP can perform neighbor discovery by sending an mmWave beacon frame to omnidirectional devices through BT. Then, Association Beamforming Training (A-BFT) is the period when beamforming is carried out between PCP and devices through the sending and receiving of an Association request/response frame. To achieve multicast communication, the A-BFT period generally involves sectored beamforming using the lowest data rate available. During Announcement Time (AT), in order to make data transmission, an announcement is performed between PCP and the devices by requesting and responding to action frames such as an announce frame. During the AT period in general, PCP allocates a service period to devices for data transmission by sending Extended Schedule elements. PCP uses such a mechanism as a polling mechanism in which PCP sends requests to devices and then the devices send response back to the PCP. It is because a mechanism in which devices send request message can cause the occurrence of a lot of overhead by operating as a CSMA/CA mechanism. The access period for data transmission is defined as the data transfer period (DTT), which is subdivided into contention-based periods (CBPs) and service periods (SPs). As shown in **Fig. 3**, the DTT of BI consists of a CSMA/CA mechanism and TDMA allocated by PCP. For example, an application that has to support better QoS, such as video, carries out SP allocation using such a channel access scheme as TDMA. Whereas a bursty type of application, such as one for web browsing, can use the CSMA/CA mechanism as a random access method. Thus, as in the case of general MAC protocols, the use of such methods depends on the target applications.

4. Group-aware Multicast Scheme

In this section, the process of beamforming before data transmission is described, and then the proposed GAMS is explained according to two steps.

4.1. Beamforming Procedure for Multicast Communications

Existing mmWave wireless networks, such as IEEE 802.11ad, do not involve a concrete technology for multicast communication. For this reason we first define multicast elements for supporting multicast communication. **Fig. 4** shows two elements suggested for supporting multicasting. First, **Fig. 4-(a)** shows an mmWave Capability element for use during the association process of A-BFT. Using 1 byte that is reserved among the bits for mmWave STA Capability information, this field marks the information as to whether a device can support multicasting. Whereas, as shown in **Fig. 4-(b)**, a scheduled multicast element carries information as to whether a device will seek a join/release in/from multicast communication during the announcement process of AT, as well as information about the multicast group to which a device belongs. The sending of these additional two elements in the action frame endows a device with the capability to support multicasting, allowing compatibility without the modification of existing MAC architecture.

<table>
<tr><td></td><td>Element ID</td><td>Length</td><td>STA address</td><td>AID</td><td colspan="2">mmWave STA Capability information</td><td>mmWave PCP/AP Capability information</td></tr>
<tr><td>Octets:</td><td>1</td><td>1</td><td>6</td><td>1</td><td>8</td><td>1</td><td>2</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>Multicast supported</td><td></td></tr>
</table>

(a) mmWave capability element proposed for supporting multicasting

	Element ID	Length	Command	Multicast group indication	Reserved
Octets:	1	1	1	0 - 255	*n*

0	Multicast Join
1	Multicast Release
2	Group information
3-7	Reserved

(b) Scheduled multicast element proposed for suporting multicasting

Fig. 4. Multicasting elements

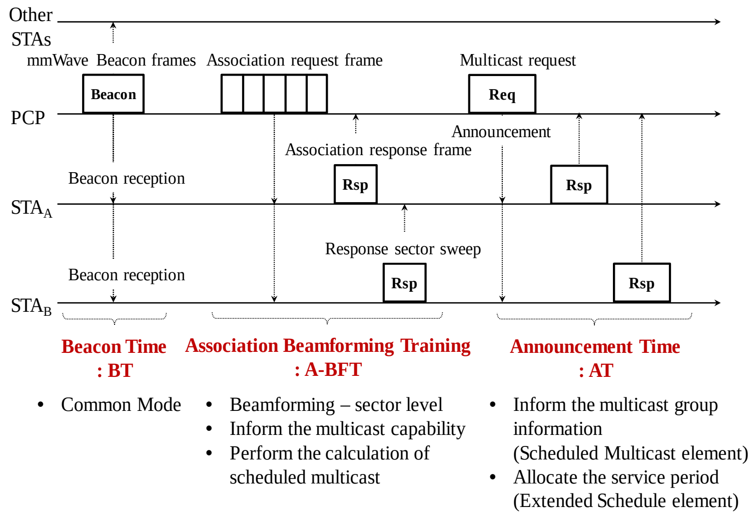


Fig. 5. Multicast beamforming procedure

Fig. 5 shows the three periods in order to send data to multicast devices that have different beam directions and that are dispersed in all directions. First, assuming that the source device plays the role of PCP, the PCP transmits an mmWave Beacon frame for neighbor discovery to the devices in all directions. At this time, the beacon frame is transmitted in common mode (MCS 0), and therefore can be heard/overheard by all devices. Here, MCS 0 is an identifier for the best receiver sensitivity and it uses the lowest data rate of 25.8Mbps. After the transmission of the beacon frame, multicast beamforming is performed through the process of A-BFT[1]. During the beamforming in order to carry out multicast communication, PCP sends a request frame to multicast devices, and then devices send association responses and information as to whether they support multicasting, by means of the mmWave Capability element. To be more concrete, in the beamforming process shown in **Fig. 4**, devices that have received association request frames from PCP responds by marking 1 on the multicast supported field within mmWave capability element which notifies that it is a device that supports multicast transmission for multicast communication. And it provides a multicast response that includes the scheduled multicast element in the announce time for the join/release process of the multicast group. In this process, PCP involves the internal process of obtaining the distances between devices, beamwidth and optimal data rate in order to perform GAMS. The detailed mechanism for this process will be described in the next subsection. Then, during the process of AT, PCP sends optimal multicast group information as

[1] During the process of A-BFT, in general, beamforming is achieved at a fixed sector level and the lowest data rate.

well as multicast announcements to devices for joining on the multicast. In addition, the SP allocation method is used for multicast transmission to receive data at the same time, so PCP informs multicast groups of SP allocation starting points as well as SP allocation duration.

4.2. Description of Group-aware Multicast Scheme

Step 1: Rational group estimator

We assume that the accurate position values of each device can be obtained by the Directional of Arrival (DoA) estimation technique [24]. With this assumption, the coordinates are generated with the PCP as reference in order to make decision on the direction of communication. And the order of communication is set in such a way that communication begins with the multicast device that is closest to the y-axis in the clockwise direction.

For example, D_1 is the first device in **Fig. 6**. PCP can figure out the distance from every device, from D_1 through D_m. Upon finding out the distances of each device from PCP ($\delta(i),\ i=1,\cdots,m$), PCP then identifies the distances between devices based on the Euclidean distance. Let S be an initial point of $<x_0,\ y_0>$ and D_i be a terminal point of $<x_i,\ y_i>$. The distance ($\delta(i)$) of each device from S is the length of the path connecting them. In the plane, the distance between points $<x_0,\ y_0>$ and $<x_i,\ y_i>$ is given by the Pythagorean Theorem:

$$\delta(i)=\sqrt{(x_i-x_0)^2+(y_i-y_0)^2},\ i=1,\cdots,m \tag{5}$$

In general, the distance ($d_n(i,j)$) between vectors $\mathbf{v}_i$ and $\mathbf{v}_j$ in Euclidean space $\mathbf{R}^n$ is given by:

$$d_n(\mathbf{v}_i,\mathbf{v}_j)=\sqrt{\sum_{i}^{m-1}\left\|\delta(i)-\delta(j)\right\|^2},\ (j=i+1) \tag{6}$$

where $\mathbf{v}_i$ and $\mathbf{v}_j$ are vectors form S to D_i and D_j.

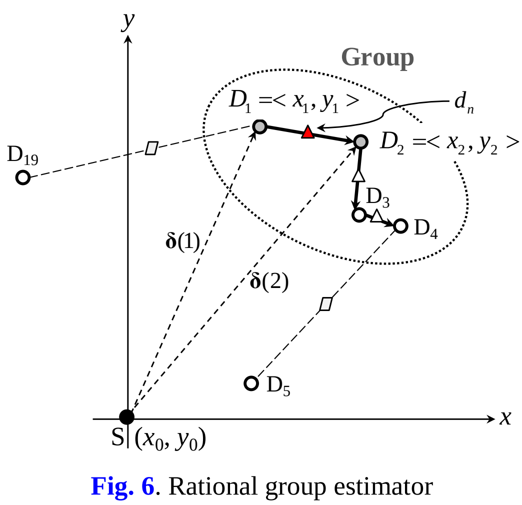


Fig. 6. Rational group estimator

The reason for measuring the distances between devices is to generate the set of most optimal group by finding out the dispersion of devices. For example, based on the **v** vector

(S-D_1) and the u vector (S-D_2) in **Fig. 6**, the distance between D_1 and D_2 can be obtained using the following (6).

Once the distances between each device have been found out, it is now necessary to determine the reference value in order to subdivide them into the most optimal groups. The reference value here means the criteria to be satisfied by a device for that device to be included in a group. That is, after the distances between devices have been found out, an optimal group is generated by combining only those devices whose distances from each other are smaller than the reference value, while classifying the other devices into different groups:

$$\omega_{ref} = \sum_{k=1}^{m} \mathbf{v}_k \Big/ m \tag{7}$$

In order to determine the reference value, a measurement was made using three methods (i.e., standard deviation, average, and the confidence-interval estimation using 90% confidential interval). And the optimal result is obtained when the average value is used as a reference. The use of standard deviation as a reference for grouping resulted in a subdivision into too many groups, because the reference value is too small, consequently causing a frequent and unnecessarily divided beamforming. On the contrary, the use of confidence-interval estimation as a reference for grouping resulted in generating too large of a group when devices are clustered within a certain distance, because the reference value is too large. When such a large group is generated, the diversity of distance between devices within a group works against the application of optimal data rate, since there is a high possibility that such a large group contains a device of a low data rate. Therefore, subdivision into optimal groups is carried out using (7), which proposed the most optimal reference value. That is, the devices with $d_n(i, j) < \omega_{ref}$ are combined together as one group, while the other devices with $d_n(i, j) \geq \omega_{ref}$ are separated from that group to be considered for another group.

Step 2: Asymmetric beamforming scheduler

After generating an optimal group, it is necessary to determine the optimal data rate for multicast scheduling. For this purpose, the beamwidth of the optimal group is calculated. Beamwidth can be calculated using the law of cosine, since it is possible to know the vector values of the devices that are located at the very edges of both sides of the group.

For example, as shown in **Fig. 8**, it is possible to know the vector values of D_1 and D_4 so an accurate beamwidth can be calculated using the (8):

$$\theta = \cos^{-1}\left(\frac{\mathbf{v}\cdot\mathbf{u}}{\|\mathbf{v}\|\cdot\|\mathbf{u}\|}\right) \tag{8}$$

where $\mathbf{v}$ and $\mathbf{u}$ are the vector values of $\mathbf{v} = < x_i, y_i >$ and $\mathbf{u} = < x_j, y_j >$, $\mathbf{v}\cdot\mathbf{u} = x_i x_j + y_i y_j$ is the inner product value, and $\|\mathbf{v}\| = \sqrt{x_i^2 + y_i^2}$ and $\|\mathbf{u}\| = \sqrt{x_j^2 + y_j^2}$ are magnitudes, respectively. After the group's beamwidth has been obtained in this way, it becomes possible to obtain the optimal data rate for multicast data transmission. For this purpose, a relation table that represents the relations among beamwidth, distance and data rate can be derived using Friis transmission equation and path loss model.

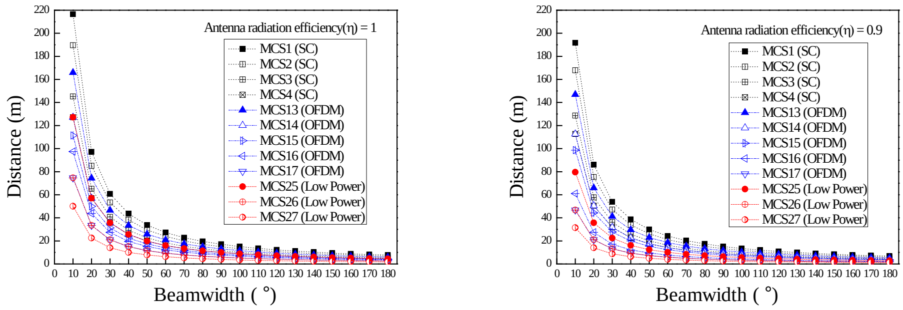
The actual transmission range can be derived by (1) and (2) in the relation table with data rate and beamwidth. **Table 1** is part of the table calculated by applying path loss exponent 2, transceiver efficiency value from 0.7 to 1, and receiver sensitivity -78dBm (MCS 0) in consideration of the PHY parameters of IEEE 802.11ad network. Then, the actual transmission range is given by:

$$\log_{10}\delta = \frac{(\kappa - P_R(i) + G_T(i) + G_R(i) - PL_{LOS})}{10\cdot\Omega}, \tag{9}$$

where $P_R(i)$, $G_T(i)$, $G_R(i)$, and PL_{LOS} are expressed as a *dB* value. In addition, **Fig. 7** represents the relation table in a concrete manner, shows that the broadening of beamwidth results in the rapid shortening of distance, and that distance is affected by transceiver efficiency. In other words, distance and beamwidth shows similar tendencies according to data rate, but the lowering of transceiver efficiency results in the much shortening of distance.

Table 1. The relation table

Modulation	Data rate	Beamwidth	Distance
SC Modulation	1155Mbps (MCS 4)	30°	35.7089m
		50°	19.7835m
		60°	16.0238m
		90°	10.0275m
		120°	7.1904m
		150°	5.5554m
		180°	4.4997m
OFDM Modulation	2079Mbps (MCS 17)	30°	20.9682m
		50°	11.6169m
		60°	9.4092m
		90°	5.8881m
		120°	4.2222m
		150°	3.2622m
		180°	2.6422m
	6756.8Mbps (MCS 24)	30°	3.7164m
		50°	2.0589m
		60°	1.6677m
		90°	1.0436m
		120°	0.7483m
		150°	0.5782m
		180°	0.4683m



(a) Antenna radiation efficiency = 1 **(b)** Antenna radiation efficiency =0.9

Fig. 7. Relation graph of beamwidth and actual transmission range

Table 1 is part of the table derived based on (1) and (2) by applying the path loss exponent=2, transceiver efficiency value=0.7~1 and receiver sensitivity=-78dBm (MCS 0) in consideration of the PHY factor of IEEE 802.11ad WLAN. In addition, **Fig. 7** represents the relation table in a concrete manner, shows that the broadening of beamwidth results in the rapid shortening of distance, and that distance is affected by transceiver efficiency. In other words, distance and beamwidth shows similar tendencies according to data rate, but the lowering of transceiver efficiency results in the much shortening of distance.

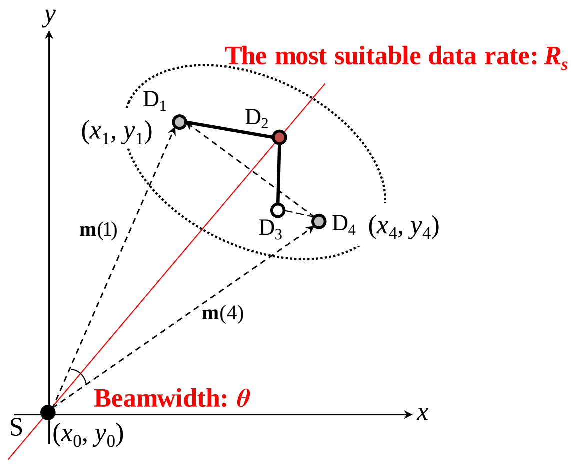
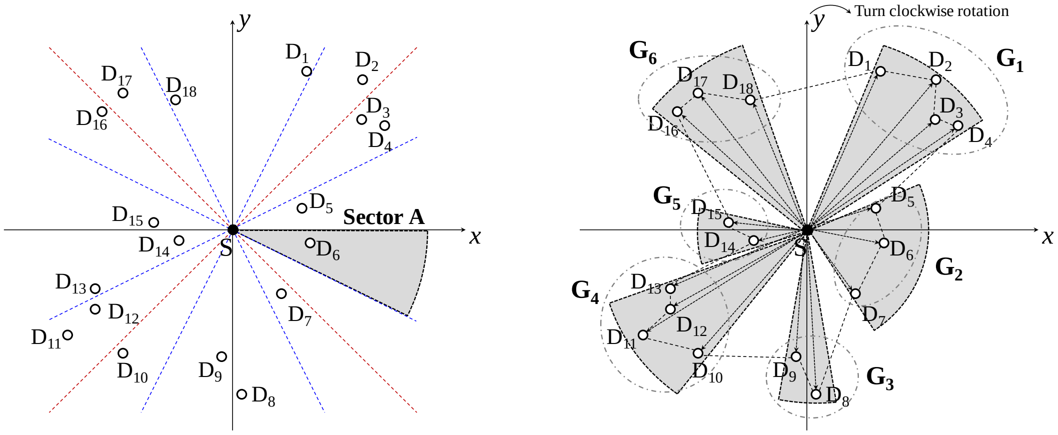


Fig. 8. Asymmetric beamforming scheduler

In order to obtain the optimal data rate for a group, the distance is first obtained between PCP and the most distant device in that group (e.g., D_2 in **Fig. 8**). By applying the distance from that device and the already calculated beamwidth to **Table 1**, the most suitable data rate can be found out that satisfies both conditions.

Fig. 9 allows the comparison between existing multicast communication at the sectored level (a) and the proposed GAMS (b). In both cases, SP allocation is as shown in **Fig. 10**. The allocation of $SP_{previous}$ allows data transmission only in consideration of the low data rate of D_4, which is the most distant device in sector A of **Fig. 9**, causing the waste of a time slot for D_3 and D_5 in the allocated SP period. In addition, according to the standard of generally suggested multicast communication, communication is not considered using the data rate of sector A, but using the lowest rate suggested by the PHY model in simultaneous consideration of all the devices in all directions. On the contrary, as shown in **Fig. 10**, SP_{GAMS} shows a little waste of time slot, since the distances between devices are similar based on the data rate that is optimal for the group generated through the two steps of RGE and ABS. In the case of SP allocation through GAMS, PCP needs time to calculate the proposed algorithm such as RGE and ABS. However, such calculation occurs only in the specific period of A-BFT, and therefore does not cause the occurrence of overhead during the period of date transmission.



(a) Sectored level beamforming **(b)** The proposed beamforming

Fig. 9.Comparison between sectored level beamforming and GAMS beamforming

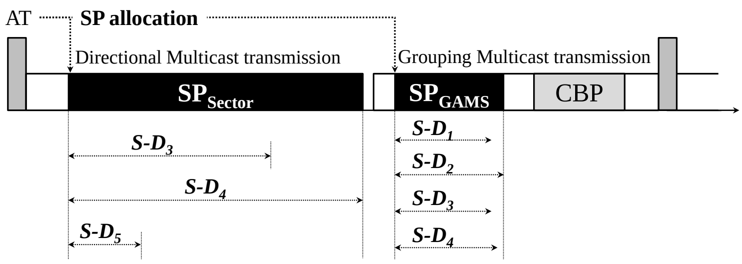


Fig. 10. Comparison of SP allocation

5. Performance Evaluation

In this section, simulation environment is described first, and then simulation results will be presented that demonstrate the change in throughput according to multicast devices in diverse environments.

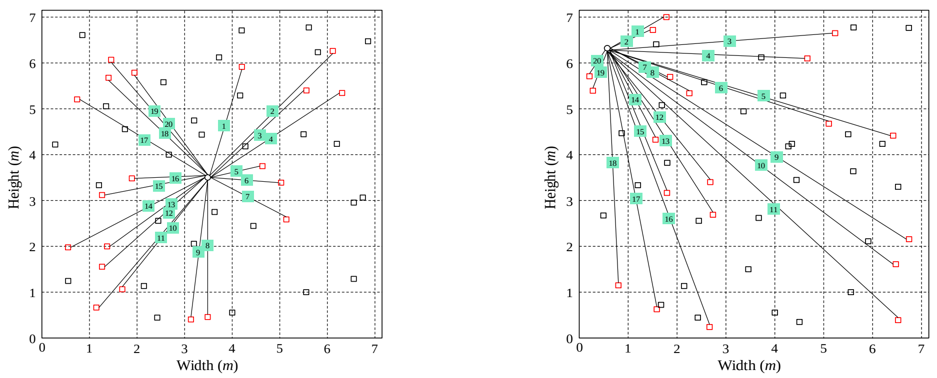
5.1. Simulation Environment

In order to perform the simulation according to the environment of mmWave wireless networks, we define parameters as shown in **Table 2** [5]. Two kinds of PHY model, single carrier (SC) and orthogonal frequency-division multiplexing (OFDM), are considered for modulation technique; while the area size of 7m x 7m is considered so that a device can be placed at the distance of up to 10m in diagonal direction. The environment of conference room, which is one of target usages of TGad, is assumed, so the number of devices is fixed to 50, of which the number of multicast devices is varied from 5 to 45. The transmission power of devices is fixed at 10mW, while beamwidth and distance are varied according to simulation scenario.

Two kinds of topology are considered for the simulation scenario: One is central topology, with a sender positioned at the center as in **Fig. 11-(a)**, and the other is a random topology with sender positioned randomly as in **Fig. 11-(b)**. Consideration is given so that the random topology is close to a real environment by varying the distance to target devices up to the maximum of 10m.

Table 2. Parameter specification in the simulation

Parameter	Value
Symbol interval	0.242 μs
MSDU size	4096 octets
Aggregated frame	8
Application traffic	CBR traffic
SIFS, SBIFS, RIFS time	3, 1, 1 μs
Slot time	3 μs
Guard interval duration	48.4 ns
High data rate	6756.75Mbps (MCS 24)
Low data rate	385Mbps (MCS 1)
Carrier frequency	60GHz
Path loss exponent	2
Directional antenna gain	3.01(180), 7.78(60), 0.79dBi(30)
Radiation angle	30, 45, 60, 90
Receiver sensitivity	-78dBm (MCS 0)
Transceiver efficiency	0.7, 0.8, 0.9, 1



(a) Centeralized topology **(b)** random topology

Fig. 11. Simulation topology

Matlab R2008 is used for executing the procedures and more than 5,000 times are iterated. In addition, vector functions are used to locate devices randomly in a $7\times 7m^2$ sized topology. Values for x-axis and y-axis are selected randomly and all devices are located randomly. Also, in order to locate the sender, the centralized topology assigns the values of <0, 0> for the sender's vector, and the values are randomly assigned within the range of remaining multicast devices. If using the random topology, the sender will also assign a value randomly within the range, and the random location of the sender is decided as <0, 0>.

5.2. Simulation Results

Fig. 12 shows the throughput result of the proposed GAMS and existing sectored level multicasts when transceiver efficiency is varied. First, with central topology and with the beamwidth of the sectored level multicast fixed at 45°, both schemes showed the steady increase of throughput as the number of multicast devices increased. In the case of GAMS, simultaneous transmission by group resulted in high throughput, in the range of 4 Gbps to 19 Gbps depending on the number of devices. Most importantly, when the number of devices is 20, there is about 6.593 Gbps of difference in throughput compared to 45◦ sectored level multicast. Sectored level multicast is affected by transceiver efficiency at a fixed beamwidth, and considers a lower data rate compared to the case of GAMS that accomplishes dynamic beamforming. This explains why the two schemes show more difference when transceiver efficiency is lower. For example, when the number of multicast devices is 20, the improvement of GAMS throughput is shown to be 62.51% (η = 1), 66.785% (η = 0.9), 72.247% (η = 0.8) or 79.561% (η = 0.7) according to the value of transceiver efficiency.

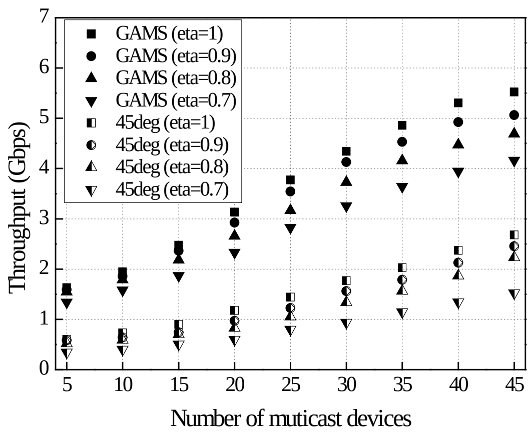


Fig. 12. The effect of the number of multicast devices on the throughput of sectored level multicast and GAMS under different transceiver efficiency in sender central topology

Fig. 13 shows the results of the experiment with a central topology when transceiver efficiency is 0.9 and when four kinds of beamwidth of the sectored level multicast are considered. There is the lowering of throughput as beamwidth of the sectored level multicast is increased, that is, as the beamwidth is varied, the ratio of the throughput of the sectored level multicast to that of GAMS shows a change of 1:0.593:0.332:0.268:0.137. The increase of beamwidth allows a larger coverage area, while it allows a lower data rate in a reciprocally proportional manner. Therefore, when the distance is fixed at 10m, there is a difference in data rate by about 2.6 times between 30° and 90° of beamwidth.

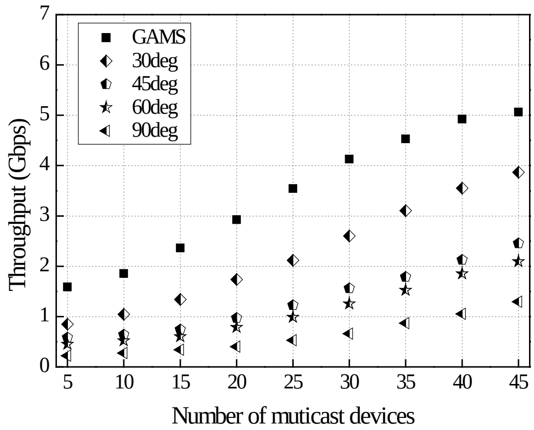


Fig. 13. The effect of the number of multicast devices on the throughput of sectored level multicast and GAMS under different antenna degrees in sender central topology

Fig. 14 shows the result of the experiment with random topology under the same conditions of Figure 10. The throughput is lower compared to the case of central topology. For example, when the number of multicast devices is 20, there is a difference of throughput according to the topological environment between central topology (9.842 Gbps) and random topology (7.554 Gbps). This is because random topology allows the random positioning of the sender and so grouping may be inefficient compared to the case of the central topology, especially when the sender is positioned in the corner. And the positioning of the sender at such a corner causes the distance between devices to become longer, consequently lowering the data rate.

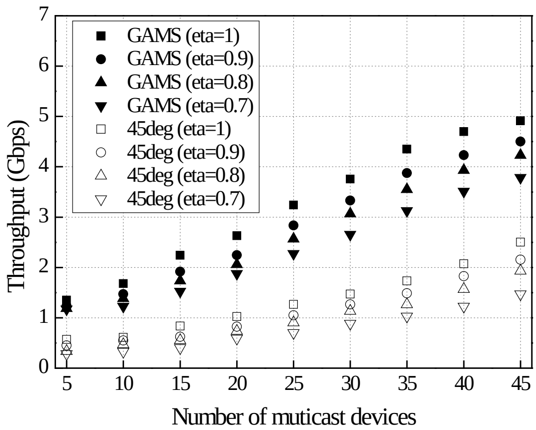


Fig. 14. The effect of the number of multicast devices on the throughput of sectored level multicast and GAMS under different transceiver efficiency in random topology

Fig. 15 also shows the result of an experiment with different topologies under the same conditions of **Fig. 13**. As the number of multicast devices is increased, there is a larger difference in throughput according to the beamwidth of the sectored level multicast. When the number of multicast devices is fixed to 45, a comparison of throughput between the 45° beamforming of the most commonly used 8 sectors and GAMS shows the improvement of performance by about 52.11%. The ratio of the throughput of sectored level multicast to that of

GAMS shows the gradual change of 1:0.780:0.478:0.397:0.235 when the number of multicast devices is 5; and 1:0.056:0.364:0.27:0.147 when the number is 45. This indicates that the efficiency of GAMS becomes better as the number of multicast devices becomes larger, compared to the existing sectored level multicast. The reason is that in the case of GAMS, a large number of multicast devices would result in the occurrence of many cases where devices that are randomly dispersed in all directions are optimally grouped to receive efficient GAMS service. While with the existing method, there would be an occurrence of many cases where a large number of devices has to receive service at a fixed data rate of a fixed sector.

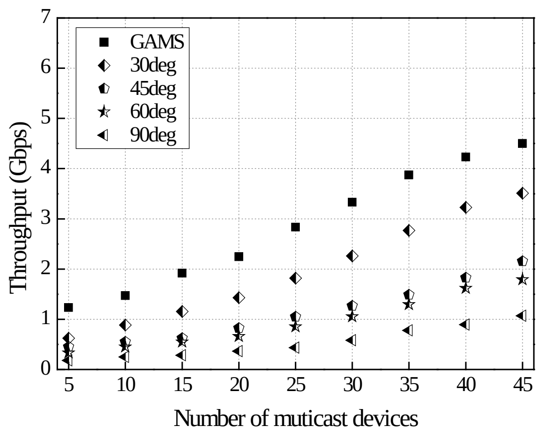


Fig. 15. The effect of the number of multicast devices on the throughput of sectored level multicast and GAMS under different antenna degrees in random topology

Fig. 16 shows the difference in throughput between GAMS and sectored level multicast when beamwidth is fixed to 60°. An experiment with existing techniques and with a beamwidth fixed to a wide range shows an interesting result. Since the increase of data rate causes the decrease of distance, MCS 17 and higher cannot cover as large a distance from sender as 10m. Accordingly, MCS 17 and higher showed rather the lowering of throughput as the number of multicast devices is increased. The reason is that there is the occurrence of many cases where randomly dispersed multicast devices are positioned at longer distances than the coverable distance, consequently causing the lowering of overall throughput. Especially in the case of MCS 24, the throughput is very low because the coverable distance of 1.4764 *m* caused the number of device that cannot receive service to increase as the number of multicast devices is increased, even though the data rate is as high as 6.7568 Gbps. Thus, the result indicates that in a real environment there would be a large difference in system performance between the proposed mechanism and existing mechanisms, since a real environment is more likely to have a random topology and in such an environment existing techniques would involve the occurrence of many cases where the coverage distance is short. In other words, GAMS is able to maintain high performance without such a problem, since it simultaneously considers all the factors of distance, data rate and beamwidth.

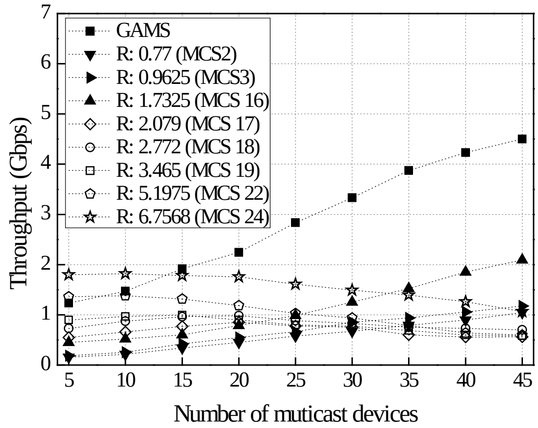


Fig. 16. The effect of the number of multicast devices on the throughput of sectored level multicast and GAMS under different data rates in random topology

Fig. 17 shows the average delay between the fixed beamwidth and proposed GAMS. For example, in case there are 30 devices, GAMS makes the comparison with 90 degrees of fixed beamwidth and shows the performance enhancement of approximately 3 times. Such difference can be explained in two reasons. 1) Fixed beam technique allows the devices to be served sequentially that increases the average delay gradually as the beamwidth increases. 2) GAMS forms a beam according to the group of beams that allow the beams to be formed in various angles, and resulting in serving as hopping according to the dynamic beam and not serving in a sliding manner as a fixed beam. Ultimately unnecessary time is reduced that reduces the average latency.

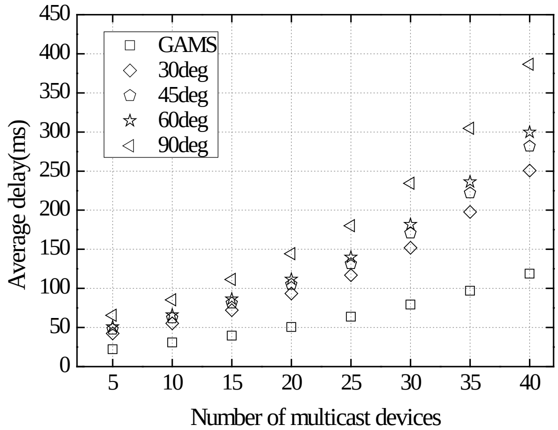


Fig. 17. The effect of the number of multicast devices on the average delay of sectored level multicast and GAMS under different antenna degrees in random topology

6. Conclusion

This paper proposed an efficient multicast mmWave directional model that is based on the architecture of the IEEE 802.11ad network, which is useful and has a lot of target uses. Friis transmission equation and path loss model were used to induce the relations among the beamwidth, distance and data rate of mmWave IEEE 802.11ad network-based devices. The proposed scheduled multicast scheme consists of two steps: The first-step is RGE, to generate groups for the efficient beamforming to multicast devices that are scattered in all directions. And the second step is ABS, to obtain the most suitable data rate for data transmission to the properly divided groups. The superiority of GAMS in system performance was proved by means of extensive simulation by comparing it with the existing technique of multicast data transmission through the beamforming of the sectored level. There are still a lot of open issues related to efficient multicast transmission and directional antenna model, and we suggested a solution for the problems of how to construct the optimal multicast groups; how to achieve efficient scheduling between the multicast groups; and how to guarantee the high throughput requirement for scattered multicast devices dependent on the distance.

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