Proposal of Overhead-less Access Control Scheme for Multi-Beam Massive MIMO Transmission in WLAN Systems

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Abstract—**In recent years, advances in wireless local area network (WLAN) systems have led to large increases in the transmission speed. The IEEE 802.11ac standard allows for very high transmissions by using multi-user multiple input multiple output (MU-MIMO) techniques in the physical (PHY) layer. However, the transmission efficiency is decreased by the channel state information (CSI) estimation algorithm in the medium access control (MAC) sub-layer. Massive MIMO transmission has attracted attention as a new technology for wireless communication in 5th-generation mobile communication systems (5G). We propose a novel access control scheme for multi-beam massive MIMO technology called overhead-less access control. The proposed scheme allows random access control without CSI estimation for massive MIMO technology. Thus, it greatly reduces the overhead of the MAC sub-layer and improves the transmission efficiency. The proposed scheme can be used to control new massive MIMO systems. We evaluated our proposed overhead-less access control scheme for multi-beam massive MIMO transmission in WLAN systems.**

I. Introduction

Wireless local area network (WLAN) systems follow the IEEE 802.11 standard [1]. Advances in recent years have increased the transmission speed. For example, the IEEE 802.11ac standard [2] allows high-speed communication of up to about 6.93 Gbit/s. Multiple input multiple output (MIMO) transmission [3], [4] uses multiple antennas to transmit and receive data packets based on the IEEE 802.11n standard [5]. MIMO transmission can then increase the transmission speed several times in the background. The IEEE 802.11ac standard allows multi-user (MU)-MIMO transmission technology capable of transmitting different data to different terminals at the same frequency and same time to further increase the speed. Recent years have seen the research and development of massive MIMO with tens to hundreds of antennas [6], [7], [8].

However, MIMO and MU-MIMO transmissions are for antennas in the physical (PHY) layer. The transmission efficiency sharply decreases when the access control for the medium access control (MAC) sub-layer is considered. For MU-MIMO transmission following the IEEE 802.11ac standard, channel estimation called channel state information (CSI) feedback is performed for simultaneous data transmission to different terminal stations connected to the access point (AP). CSI feedback is performed after transmission packets for multiple terminal stations are generated and data for channel estimation are exchanged with all destination terminal stations. Thus, the required computation time is enormous, which becomes a large overhead when the number of terminals and number of streams are large. In addition, each terminal station that has received a packet transmits a block acknowledgment (BA) to the AP regarding whether or not a packet has been received. However, because the BA is transmitted from each terminal station by the time division, this algorithm has a large overhead. Therefore, the overhead occupies most of the transmission time. The transmission efficiency of massive MIMO transmission can deteriorate compared to that of MU-MIMO transmission when the CSI feedback procedure is adopted.

In [9], we proposed a multi-beam massive MIMO transmission technology that does not require overhead such as CSI feedback. This method eliminates the overhead by forming multiple beams in the analog part of the massive MIMO transmission. This method selects a beam from the formed multi-beam to realize a high received power. In the digital part, the interference signal can only be removed from the received signal by using a technique called the constant modulus algorithm (CMA). Because the beams can be separated at the AP and each terminal station belonging to the AP, it becomes possible to transmit and receive data while other terminal stations are transmitting. Multi-beam massive MIMO transmission allows for random access within the basic service set (BSS). However, this method is for the PHY layer, and studies on access control methods for the MAC sub-layer have not been conducted.

In this paper, we propose a novel access control scheme for multi-beam massive MIMO transmission. The proposed overhead-less access control scheme can eliminate large overhead costs such as the CSI feedback and BA. In addition, the multi-beam massive MIMO transmission uses separate beams, so carrier sensing is unnecessary, and pseudo one-to-one communication is possible.

The remainder of this paper is organized as follows. Section II discusses conventional technologies and the issues they face regarding MU-MIMO transmission. Section III outlines our proposed scheme. Section IV theoretical analysis and computer simulations comparing our scheme with others. Finally,

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Section V concludes this paper.

II. Issues with Conventional Schemes

In this section, we introduce issues with the access control scheme for MU-MIMO transmission technology using IEEE 802.11ac. Figure 1 shows an example access control procedure for MU-MIMO transmission technology using CSI feedback and the BA algorithm. First, the carrier is sensed in the distributed coordination function interframe space (DIFS) with the binary backoff algorithm, and the channel is estimated. When packets are transmitted simultaneously to each terminal station (STA), the AP transmits null data packet announcement (NDPA) frames to start the channel estimation for each STA. The null data packet (NDP) frames are then transmitted to all STAs, and channel estimation is started by the CSI feedback algorithm. STA #1, which receives the NDP frame, returns a beamforming report (BR) frame to the AP. Subsequently, the AP receives the BR frame from STA #1 transmitting the beamforming report poll (BRP) frame to STA #2 in succession. When it receives the BRP frame, STA #2 returns the BR frame to the AP. This exchange of the BRP frame and BR frame is carried out while the STA transmits packets at the same time. When the channel estimation is completed, the AP transmits the data packets to each STA. Then, the AP transmits a block ACK request (BAR) frame to the STA that has received the data packet, and the STA that receives the BAR frame returns the block ACK (BA) frame to the AP. As in the case of CSI estimation, this procedure alternately exchanges frames between the AP and each STA. Through these procedure, data packets can be sent to multiple STAs simultaneously at the same time.

Thus, MU-MIMO transmission achieves higher transmission speed in the PHY layer by transmitting multiplex data. On the other hand, in the MAC sub-layer, the time spent for CSI feedback and BA leads to a very large overhead, and the transmission efficiency decreases sharply. Further, the CSI feedback algorithm is not performed until packets addressed to multiple transmitting STAs are aligned. The transmission from the generated packet not only takes time, it also sends synchronization data. Therefore, STAs that receive a small amount of data need to wait until another STA receives data and transmits a BA frame. In addition, the CSI feedback and BA algorithm need to be exchanged between the AP and each STA. Those procedures cause the overhead to increase with the number of STAs and streams.

Figure 2 shows the throughput characteristics when the CSI feedback and BA algorithm were performed for MU-MIMO transmission. The horizontal axis is the transmission rate per stream, and the vertical axis is the throughput per stream. This evaluation considered the results of an AP with four streams communicating with four STAs, each having one stream. The transmission rate was based on an IEEE 802.11ac standard compliant modulation and coding scheme (MCS) index for a bandwidth of 20 MHz, and the packet size was 1500 bytes. The results showed a large overhead from the CSI feedback and BA algorithm in the MAC sub-layer, and the transmission rate of the PHY layer was confirmed to be inefficient. When the transmission rate was 78 Mbit/s, the throughput per stream decreased to about 11.5 Mbit/s, so a transmission efficiency of only 15% was obtained.

We propose a novel access control scheme called overhead-less access control to reduce the overhead, such as that caused by CSI feedback. The proposed access control scheme for multi-beam massive MIMO transmission combines technologies for the PHY layer and MAC sub-layer.

III. Overview of the proposed scheme

The proposed overhead-less access control scheme for multi-beam massive MIMO transmission makes CSI feedback unnecessary by analog beam separation and can reduce a large overhead. Multi-beam massive MIMO transmission is a technology for the PHY layer. By forming a narrow directional beam that is mostly fixed in the analog part, the beam can be separated for each STA, as shown in Fig. 3. Because this technology used separated beams, CSI feedback is unnecessary. Each connected STA can separate the signals by selecting the optimum fixed beam from the received power, and the AP can receive data from multiple STAs. In the digital part, interference in the reception signal can be canceled only by CMA signal processing, and only the desired signal can be taken out and processed. Thus, the AP and each STA are completely separated in a pseudo manner. For a network environment configured with this proposed scheme, it is not necessary to judge whether the network is busy or idle. Therefore, carrier sensing becomes unnecessary, and overhead can be further reduced. Because CSI feedback is unnecessary and beam separation is required, performing the BA algorithm between the AP and each STA is unnecessary. In addition, the proposed scheme does not use a carrier sense time such as backoff. Thus, a high throughput can be obtained for the MAC sub-layer that is nearly at the transmission speed of the PHY layer.

Figure 4 shows an example application of the overhead-less access control scheme. The proposed scheme operates the time division multiple access (TDMA) method. In a network environment, the number of AP streams (St.) is n, and the number of STAs is n. TDMA is used to prevent interference from bidirectional communication in the basic service set (BSS). First, the STAs perform a minimal carrier sense and burst transmit data packets. Then, the AP selects a beam with a high received power and starts communication. The AP then performs the minimal carrier sense and transmits BA to the STAs that receives the packets before bursting the packets. If the AP has transmission packets for STAs that have not received a packet, the AP transmits the burst packets. Likewise, subsequent exchanges transmit the BA + packet when an STA has received the packet or only the packet when it has not received it. Inserting the carrier sense time before a data frame is transmitted allows interference waves to be detected. Transmission is delayed when an interference wave is detected. The uplink and downlink can transmit packets at a timing generated during the TDMA period. Because the AP and each STA are separated by a physical beam, the proposed scheme can transmit with random timing during TDMA period. The transmission rates are selected according to the distance between the AP and STA and the arrangement of the STAs.

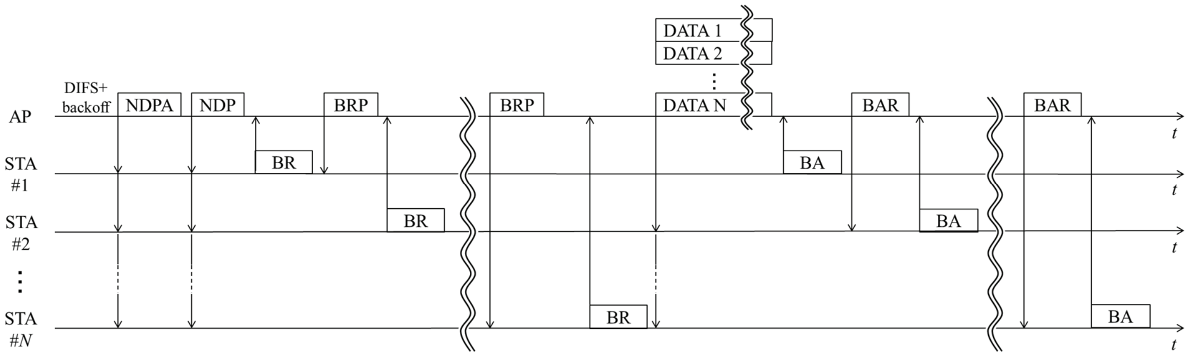


Fig. 1. Example access control scheme for MU-MIMO transmission

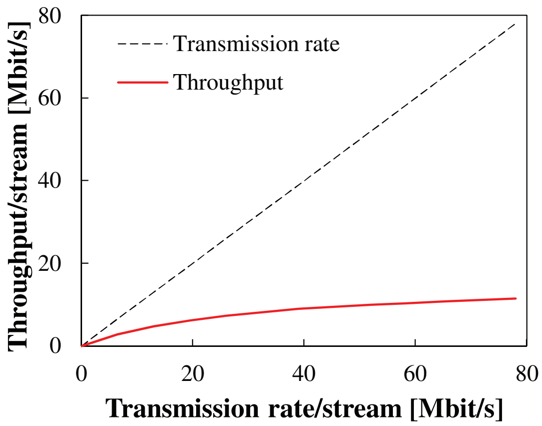


Fig. 2. Throughput evaluation of the MU-MIMO transmission

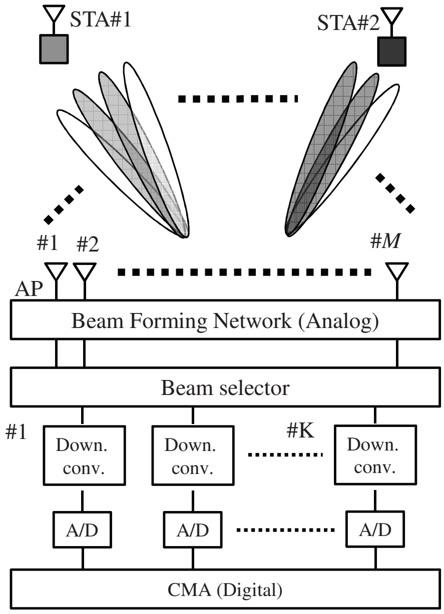


Fig. 3. Example multi-beam massive MIMO transmission

IV. Basic Evaluation of the Proposed Scheme

We evaluated the transmission efficiency and throughput characterization to confirm the effectiveness of the proposed scheme. We compared downlinks for MU-MIMO transmission with the IEEE 802.11ac standard and the proposed scheme. We used theoretical calculations and computer simulations [10] to evaluate the PHY layer and MAC sub-layer performances [11].

First, we evaluated the transmission efficiency by theoretical analysis, as shown in Fig. 5. The horizontal axis is the signal-to-noise ratio (SNR), and the vertical axis is the transmission efficiency. This was obtained by normalizing the MAC throughput with respect to the PHY transmission rate.
The evaluation parameters were based on conventional MU-MIMO transmission. The network environment was one AP with eight streams and four STAs, each with two streams. The packet size was 1500 bytes, the aggregate-MAC protocol data unit (A-MPDU) size is 65535 bytes, the bandwidth was 20 MHz, and the guard interval (GI) was 800 ns. The traffic was saturated. For the conventional scheme, the transmission rate was calculated from the communication distance converted to the SNR. On the other hand, the throughput characteristics for the proposed scheme were derived from [12] based on the average selection frequency of each modulation scheme for each stream in a random terminal arrangement to determine the average throughput per STA. The results showed that the conventional scheme obtained a transmission efficiency of 80% or less because of the overhead. On the other hand, the proposed scheme was confirmed to obtain a transmission efficiency of 90% or more even if the SNR changed. Furthermore, the proposed scheme showed less change in the transmission efficiency and a higher transmission efficiency even when the number of users was increased.

Next, we evaluated the transmission efficiency by computer simulation, as shown in Fig. 6. The horizontal axis is the offered traffic, and the vertical axis is the total throughput. For the offered traffic, the transmission rate was normalized. For the network environment, there was one AP with eight streams and eight STAs, each with two streams. The communication distance from the AP to each STA was 1 m and average transmission rate of a stream is about 78 Mbit/s. The packet size was 1500 bytes, the bandwidth was 20 MHz, the GI was 800 ns, the size of the A-MPDU was 65,535 bytes for conventional MU-MIMO transmission, and the TDMA period of the proposed scheme was 2 ms. In addition, the number of

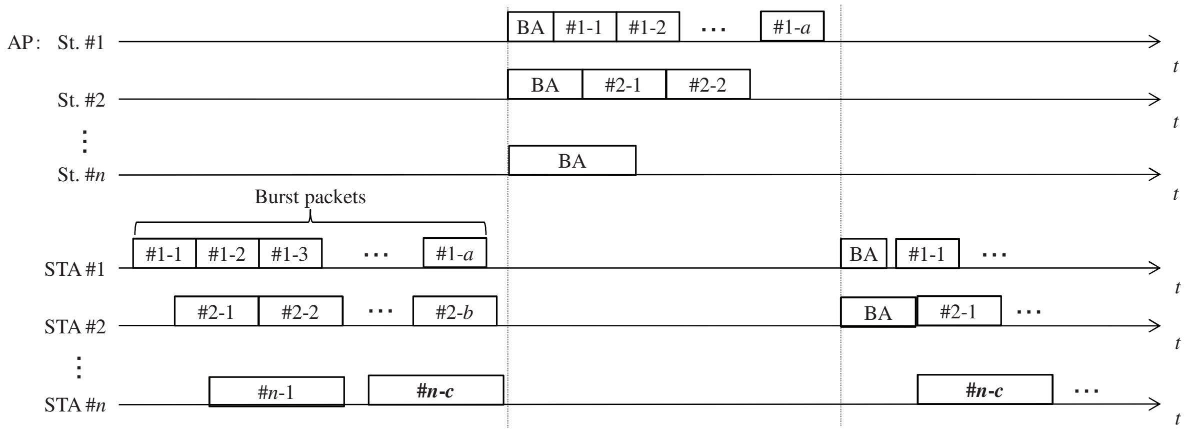


Fig. 4. Example of the overhead-less access control scheme

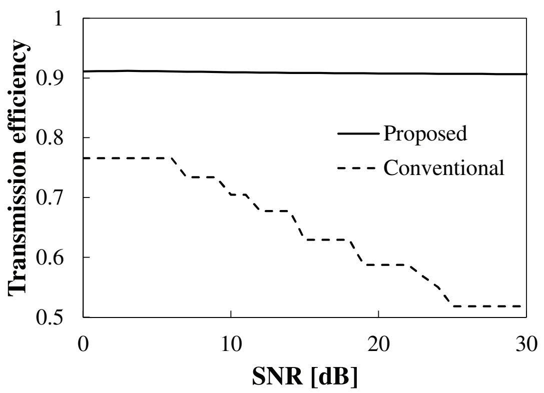
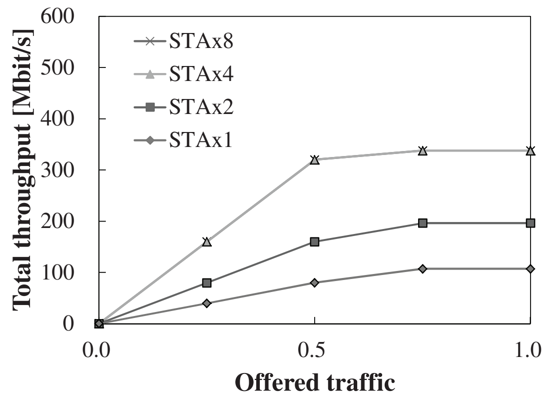
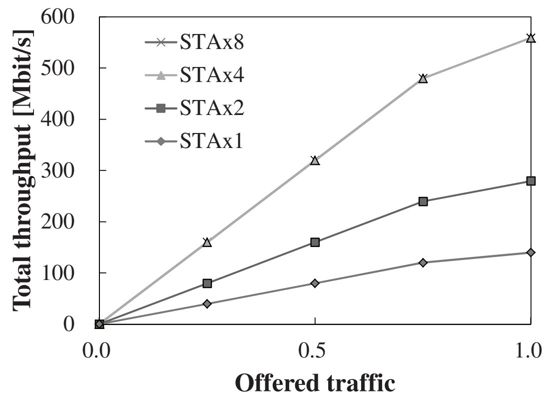


Fig. 5. Transmission efficiency characterizations vs. SNR



(a) Conventional scheme



(b) Proposed scheme

Fig. 6. Throughput characterizations vs. offered traffic

STAs that could be transmitted to at the same time was set to four. The results showed that the throughput was saturated when the traffic volume exceeded 75% for the conventional scheme. On the other hand, the throughput was confirmed to increase until the traffic was saturated with the proposed scheme because the overhead was greatly reduced.

The above results confirmed that the proposed scheme can obtain a high transmission efficiency and high throughput when the traffic is saturated. This confirms the effectiveness of the proposed scheme.

V. Conclusion

We evaluated our proposed overhead-less access control scheme for multi-beam massive MIMO transmission through theoretical calculations and computer simulations. Our proposed scheme utilizes multi-beam massive MIMO technology for the PHY layer and a novel access control scheme for MAC layer. The proposed scheme can reduce sources of large overhead such as CSI feedback and the BA procedure. We confirmed a transmission efficiency of over 80% in theoretical calculations and obtained a high throughput in a saturated traffic environment in computer simulations. These obtained results confirm the reliability and efficiency of the proposed scheme.

Acknowledgments

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