UL-MU Transmissions in IEEE 802.11ax Networks

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Abstract—In IEEE 802.11ax networks, multiple uplink wireless-connectivity services are supported by an uplink multi-user multiple-input and multiple-output (MU-MIMO) technique. In this study, we propose a method for uplink multi-user (UL-MU) transmissions in IEEE 802.11ax networks. In the proposed method, stations are clustered on the basis of their transmission times, to efficiently utilize channels for UL-MU transmissions. From the performance evaluation, we demonstrate that the proposed method improves the network throughput performance by improving the channel utilization.

I. INTRODUCTION

As the demand for providing massive wireless connectivity services to stations increases, the consequent need for simultaneous data transmissions has attracted considerable attention in wireless local area networks. In IEEE 802.11ax networks, multiple uplink and downlink transmissions are supported using both the multi-user multiple-input and multiple-output (MU-MIMO) technique and the multi-user orthogonal frequency division multiple access (MU-OFDMA) technique. Hence, an IEEE 802.11ax-enabled access point (AP) can simultaneously provide multiple wireless connections to stations. To further improve the network throughput performance of IEEE 802.11ax networks, considerable recent research has focused on MU transmissions. In [1], a trade-off between the overall network throughput performance and the capability to support new stations was studied. The authors investigated the overhead problem of sharing buffer status report (BSR) of a newly joined station in dense IEEE 802.11ax networks. In [2], a learning-based MU-MIMO user selection method in IEEE 802.11ax networks was studied. The authors proposed to use a central controller that collects the historical channel state information to perform reinforcement learning-based user selection. However, how to schedule users for uplink transmissions is still an important issue to efficiently utilize uplink channels. In this study, we propose a scheduling method based on the transmission delay of stations to efficiently improve both channel utilization and throughput performance

II. SYSTEM MODEL

We consider a UL-MU transmission scenario in IEEE 802.11ax networks, where one AP simultaneously receives uplink signals from multiple stations. Let an IEEE 802.11ax-enabled AP and stations be denoted by \( a_S \) and \( S = \{s_1, s_2, \cdots, s_S\} \), respectively. Before performing UL-MU transmission, a channel sounding procedure can be performed to obtain the channel information between AP \( a_S \) and each station in \( S \). The buffer status information of each station is also transmitted to the AP through the BSR specified in IEEE 802.11ax. Using the obtained information such as the channel state and the buffer status, the AP can trigger UL-MU transmissions and, thereby, receive multiple data streams from the stations.

We denote the maximum number of UL-MU transmissions by \( B_{a_S} \); i.e., the AP can simultaneously receive \( B_{a_S} \) data streams from multiple stations. Figure 1 depicts the UL-MU transmission process in IEEE 802.11ax networks. First, AP \( a_S \) transmits multi-user request-to-send (MU-RTS) frames to the stations, following which stations \( s_i \in S \) transmit clear-to-send (CTS) frames to the AP. Subsequently, the AP transmits trigger frames to the stations. The trigger frame initiates UL-MU transmissions by notifying the scheduling information to the stations. After UL-MU transmissions, the AP aggregates the ACK information for each station and then transmits multi-station block ACK frame. However, as depicted in the Figure 1, if the uplink transmission delays of the stations are different from one another, the uplink channels before the block ACK frame are underutilized, and, therefore, we cannot obtain sufficient throughput improvement. To solve this problem, we propose a transmission delay-based UL-MU scheduling method that improves both channel utilization and network throughput performance in IEEE 802.11ax networks.

III. TRANSMISSION DELAY-BASED STATION CLUSTERING

Let the channel between an AP \( a_S \) and a station \( s_i \in S \) be denoted by \( H_{a_S:s_i} \). According to the channel state, the maximum uplink data transmission rate of \( s_i \) can be calculated on the basis of the modulation and coding scheme (MCS) defined in IEEE 802.11ax. We define a mapping function

![Fig. 1. UL-MU transmissions in IEEE 802.11ax networks.](image-url)
Algorithm 1 Transmission time-based station clustering

1: Initialize: \( C = \emptyset, i = 1 \)
2: while \( S \neq \emptyset \) do
3: \( C_i = C^{MU-UL} \)
4: \( S = S \setminus C^{MU-UL} \)
5: \( i = i + 1 \)
6: end while

\( R_{s_i}^{UL}(\cdot) \), which introduces the transmission rate on the basis of the channel state and MCS defined in IEEE 802.11ax. The stations attempt to transmit data \( Q_{s_i}, s_i \in S \) in their queues to AP \( a_S \) by using \( R_{s_i}^{UL}(H_{a_S,s_i}) \). The uplink transmission delay \( t_{s_i} \) of each station \( s_i \in S \) is calculated as follows:

\[
 t_{s_i} = Q_{s_i} / R_{s_i}^{UL}(H_{a_S,s_i})
\]

Note that the transmission delay of each station is different from one another. In this study, we determine uplink stations on the basis of \( t_{s_i} \) so that the stations requiring similar transmission time could be clustered together to increase the channel utilization for UL-MU transmissions in IEEE 802.11ax networks. Let \( C^{MU-UL} = \{ s_i | s_i \in S \} \) denote the set of stations clustered for UL-MU transmissions, and \( t_{s_i} \) to \( C^{MU-UL} \). Among the possible candidates of \( C^{MU-UL} \), we select the stations that minimize the maximum transmission time difference as follows:

\[
 \min_{C^{MU-UL}} \max_{s_i \in C^{MU-UL}} t_{s_i}
\]

subject to \( |C^{MU-UL}| \leq B_{a_S} \) \hspace{1cm} (1)

The optimization problem can be repeatedly solved for the remaining stations for uplink transmissions so that all the stations in IEEE 802.11ax networks are clustered as described in Algorithm 1. First, stations having a similar transmission delay are clustered together, as described in line 3 of the algorithm. Subsequently, for the remaining unclustered stations, line 3 is repeated until all the stations in the network are clustered. We denote the set of the clusters by \( C^{SET} = \{ C_1, C_2, C_3, \cdots \} \). Note that the stations within the same cluster require a similar transmission time for transmitting all the data in their queues, and, hence, the UL-MU transmission scheduling based on \( C^{SET} \) improves both channel utilization and network throughput performance.

IV. PERFORMANCE EVALUATION

To evaluate the performance of the proposed method, we constructed an IEEE 802.11ax network as in [3] by using MATLAB. The network consists of an AP and multiple stations, and it is assumed that all the stations have uplink data to transmit. The aggregated MAC protocol data unit (A-MPDU) sizes are randomly selected to be between 32 and 320 kbits, and the MCS is set between 0 and 11 according to the channel state. We compare the proposed method with a random-scheduling method, which randomly selects stations for UL-MU transmissions. Figure 2 depicts both the throughput and transmission delay performances with respect to the number of spatial streams. As shown in the results, the proposed transmission delay-based method demonstrates better average network throughput and delay performances than the those of the random-scheduling method. This is because the proposed method improves the channel utilization by clustering the stations having similar transmission delays for UL-MU transmissions.

V. CONCLUSION

In this study, a transmission delay-based UL-MU scheduling method was proposed. The proposed method clusters stations having similar transmission delays to efficiently utilize the uplink channels. From the various simulations, we demonstrated that the proposed method exhibited good network throughput and transmission delay performances.

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