Poster: IEEE 802.11ax User Scheduling Algorithm for Low Latency

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Abstract

It is well known that many user-intensive industrial applications need to work with low latency, such as multi-AGVs logistics system. In this study, End-to-end delay is analyzed and modeled, and a user scheduling algorithm for low latency based on IEEE 802.11ax is proposed. Preliminary simulation experiments show that the algorithm has better performance than traditional algorithms.

1 Introduction

IEEE 802.11ax introduces OFDMA in WiFi network. It does not improve peak data rate but allows efficient transmissions of small frames to a group of users simultaneously which provides the basis for the normal operation of application in the user-intensive scenarios. The whole bandwidth is divided into multiple sets of subcarriers, each set called a resource unit (RU) [2]. Each RU is assigned with a user or a user group which is typically referred to as user scheduling.

WiFi networks typically work in a multipath environment. The end-to-end delay of each user or user group changes on different subcarriers, especially when MU-MIMO is used. A good user schedule can assign RUs to different users or user groups based on their channel state information (CSI) so that the corresponding delay is minimized, and the overall network capacity is not greatly affected. Several heuristics, greedy or recursive user scheduling algorithms have been proposed in previous work [1], but these are optimized relative to network capacity and are not applicable to certain delay-sensitive user-intensive scenarios, such as multi-AGVs logistics system.

In this study, we have analyzed the end-to-end delay structure of 802.11ax and establish a delay model. A recursive user scheduling algorithm is designed for this model. Based on the minimum delay, we studied how to optimally assign users and user groups to subcarriers. Preliminary simulation shows that the performance of the algorithm is greatly improved compared with the traditional algorithms.

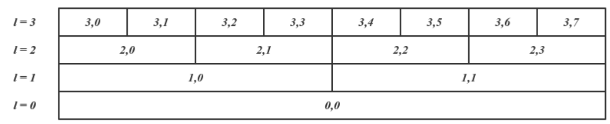

Figure 1. RUs of a 20MHz HE PPDU.

2 Models Design

2.1 Resource Scheduling Model

In 802.11ax, each RU of more than 26 subcarriers can be divided into two smaller RUs. The entire bandwidth can be split up to *L-1* times, where L is the number of levels. 802.11ax supports 20MHz, 40MHz, 80MHz and 160MHz, and L ranges from 4 to 7. Each RU may be represented by *RU(l,i)*, where l is the partitioning level of the current RU, and i is the index of the RU of its level. Note that *RU(0,0)* refers to the RU that occupies the entire bandwidth. The whole bandwidth can be divided into 2^l RUs of equal size at level l $(l \in 0,1,...,L-1)$. In other words, each RU (not the highest layer), if represented as *RU(l,i)*, can be divided into *RU(l+1,2i)* and *RU(l+1,2i+1)*. An example where we label the RUs of a 20MHz HE PPDU is showed as **Figure 1**.

In an OFDMA transmission, the entire bandwidth is divided into combinations of RUs from different levels. Let $p = \{p_j ...\}$ be an efficient partitioning scheme for the bandwidth, where $p_j = RU(l_j, i_j)$ is the j_{th} RU in p.

After obtaining an effective bandwidth partitioning scheme, we need to allocate users to the RUs. Suppose $g = (p_j, u_j)$ is a valid user schedule, where $p_j = RU(l_j, i_j)$ is the j_{th} RU in the effective partition of the entire bandwidth, and u_j is the set of users assigned to p_j.

We want to optimally allocate the RU to the user/user group with minimal end-to-end delay.

2.2 End-to-end Delay Model

End-to-end delay refers to the time that a packet goes through from leaving the source node to being received successfully by the receiving node. Analysis of the data transmission process shows that the end-to-end delay (*ED*) can be divided into transmission delay (*TD*) and queuing delay (*QD*) [3]. End-to-end delay is the sum of all the single-hop delays (*HD*) on the link. The link transmission delay can be further decomposed into two parts: a data transmission time

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(*SD*) and a channel contention delay (*CD*). Here we ignore the time of the ACK for the last successful transmission. The following formula is represented for end-to-end delay:

$$ED(u) = \sum_{i=1}^{d(u)} HD_i(u), \quad \forall u \in R \tag{1}$$

Where R is the set of nodes (users); *d(u)* represents the hops of the source node to node u. To solve the above equation (1), the remaining components are given by (2):

$$HD_i(u) = QD_i(u) + TD_i(u)$$

$$= \sum_{j=1}^{Q_i(u)+1} [TD_i(u)]_j = \sum_{j=1}^{Q_i(u)+1} [SD_i(u) + CD_i(u)]_j$$

$$SD_i(u) = P_k / (B(u,i) \times p(u,i)) \tag{2}$$

$$CD_i(u) = \sum_{j=1}^{\infty} [1 - p(u,i)]^{j-1} p(u,i) \sum_{t=1}^{j} E[S_t]$$

Where $Q_i(u)$ is the current queue length of the i_{th} hop node on the link from the source node to the node u; j is used to identify the j_{th} packet in the current queue of the node; *p(u,i)* represents the probability of successful transmission of the channel where the i_{th} hop node is located on the link from the source node to the node u. *B(u,i)* represents the link bandwidth of node u at the i_{th} hop; S_t is the number of the slots occupied by the contention window when the t_{th} collision occurs.

The user scheduling includes two subtasks. One is dividing the bandwidth into one or more RUs, and the other is allocating the RU to the user (SU-MIMO) or the user group (MU-MIMO). There are three constraints: 1) Users or user groups can only be assigned no more than one RU. 2) MU-MIMO is only applicable to RUs of more than 106 subcarriers, in other words, $l \leq L-3$. 3) The number of users allocated on *RU(l,i)* is between 1 and *M(l)*, where *M(l)* is the maximum number of users allowed on *RU(l,i)*. So this optimization problem can be described as below (3):

$$\min_{g \in G} ED(g)$$

$$st \quad 0 \leq \sum_j c_{j,k} \leq 1; \tag{3}$$

$$1 \leq \sum_k c_{j,k} \leq M(l_j), \quad c_{j,k} \in \{0,1\}$$

Where $c_{j,k}$ indicates whether user k is allocated on the j_{th} RU or not and G is a set of all valid user schedules.

2.3 User Scheduling Algorithm

In view of the above problems, considering the computational complexity, we designed a recursive resource scheduling algorithm.

1) Select a level l and then splits the whole bandwidth to RUs of equal size. The level l is chosen so that each RU can be assigned with at least one user/user group.

2) Given a total number of N users with $N_R = 1$ antenna each, if every RU were to be assigned with the max possible number of users N_T, then we could assign users to N/N_T RUs. Here N_R is the number of antennas of the user, while N_T is the number of antennas of the AP.

3) The algorithm moves from left to right within the chosen level to select the best user or user group for each RU. Next, according to the delay model (1), decide to whether the current RU is allocated to the user which generating the alternative scheduling $g_s(l,i)$ or recursively divided into two parts (4).

$$RU(l,i) \rightarrow RU(l+1,2i) + RU(l+1,2i+1) \tag{4}$$

If the allocation of *RU(l+1,2i)* is solved first, the user selected by the former is removed from the *RU(l+1,2i+1)* subproblem, which leads to one alternative scheduling $g_m(l,i)$. On the contrary, it will generate another alternative scheduling $g_m^{'}(l,i)$.

The global optimal resource scheduling is based on the delay model to select the scheduling scheme with the smallest delay from $\{g_s(l,i), g_m(l,i), g_m^{'}(l,i)\}$.

3 Results

Since the 802.11ax client device is not yet available, the simulation is used here to evaluate the performance of the algorithm. We use exhaustive search resource scheduling as the optimal resource scheduling scheme. Since exhaustive search is further more computationally expensive than ours, we consider a small-scale scenario: In the $50m \times 50m$ region, consider downlink MU transmission in a single 802.11ax Basic Service Set (BSS) consisted of 1 AP and 30 users with $N_T = 4$ and $N_R = 1$ antenna. The bandwidth is 40MHz (*L=5*). We keep the AP's location fixed and create 500 different topology by randomly assigning users. The user scheduling algorithm proposed in this poster is that the total delay is 10% higher than the exhaustive method, but 26% lower than the traditional algorithm [4].

4 Future Works

As a next step, we plan to consider the collaborative user scheduling algorithm under multi-AP and carry out larger-scale simulation experiments in the professional-level NS-3 network simulator. In addition, because of the time-varying characteristics of the channel due to the Doppler frequency offset of the environment, when the Channel coherence time is exceeded, the CSI will have a significant deviation, making it difficult to accurately acquire the user CSI. We can use deep neural network to train prediction model based on a large number of CSI data mining in order to further improve the performance of the user scheduling algorithm.

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