OFDMA Based Synchronization Protocol for Distributed MIMO in the Next Generation WLAN

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Abstract. In the next generation Wireless Local Area Network (WLAN), IEEE 802.11 regards improving the throughput of the network as a major technical goal. Distributed Multiple Input Multiple Output (D-MIMO) System is an important issue to improve system capacity efficiency, but D-MIMO technology requires extremely high clock consistency between nodes. Therefore, this paper proposes a synchronization protocol based on Orthogonal Frequency Division Multiple Access (OFDMA) for D-MIMO. Firstly, this paper chooses a new clock synchronization process for the synchronization protocol (Two-Way Message Exchange), which is characterized by high synchronization accuracy. Second, we propose and refine the procedure of the synchronization protocol and design the frame structure of the protocol to make it compatible with IEEE 802.11 frame format. The simulation results show that with the increase of the number of APs in D-MIMO, proposed synchronization protocol reduces the overhead by nearly 50% compared with single user (SU) based synchronization protocol. Moreover, the clock synchronization accuracy increases with the increase of the number of information interactions.

Keywords: D-MIMO · OFDMA · Two-Way Message Exchange · Synchronization

1 Introduction

With the popularity of portable devices such as smartphones and tablet computers, and the proliferation of multimedia mobile services such as video conferencing, social applications and virtual reality, users are eager to access the network wirelessly anytime, anywhere to enjoy various business services. Under this circumstance, WLAN with the advantages of high throughput, low cost and simple network layout has been favored by users. The IEEE 802 officially established the Extremely High Throughput (EHT) Topic Interest Group/Study Group (TIG/SG) in May 2018, which will further improve throughput as a

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major technical goal. The MIMO technology can significantly improve the system throughput [1]. In theory, by increasing the number of antennas, the system capacity and spectrum utilization can be doubled. EHT hopes to increase throughput by increasing spatial streams (such as 16 streams), but limited by device capabilities, a single access point (AP) is often difficult to provide 16 spatial streams, and due to cost issues, it is impossible to install multiple roots. The antenna and the AP will not install large number of antennas. Therefore, D-MIMO, also known as Joint Transmission, is a technical means to achieve large number of spatial streams.

D-MIMO means that the transmitting end or the receiving end of the communication is composed of a plurality of devices, that is, the antennas of the plurality of devices are integrated and used in a coordinated manner to achieve the effect of MIMO. D-MIMO has been proposed by Broadcom, Huawei, Marvell, MTK, Intel and other companies as one of the key EHT technologies [2]. However, since D-MIMO is to transmit and receive data between multiple devices, the clock between devices should be synchronized in order to transmit data accuracy and data packets transmitted or received between devices are not interfered with each other. So how to make multiple devices ensure synchronization on the clock is a technical prerequisite for implementing D-MIMO and must be solved. Unfortunately, the synchronization algorithms proposed by 802.11 are difficult to meet the synchronization requirements of D-MIMO systems.

Through the investigation of D-MIMO in the existing WLAN, the existing literature does not propose a particularly effective solution to the synchronization problem of D-MIMO system. Literature [3] introduced a new D-MIMO mechanism, but the specific process of system clock synchronization is still traditional. Literature [4] just introduced the main technology of D-MIMO, indicating that clock synchronization is a big problem for D-MIMO, but it does not propose an effective solution. Based on this, this paper proposes a new OFDMA-based synchronization protocol algorithm for the next generation wireless LAN. This is also the first in the field of WLAN to adopt the two-way message exchange method to solve the D-MIMO time synchronization problem.

This paper gives a brief overview of D-MIMO technology and an introduction to clock synchronization technology, focusing on the two-way message exchange synchronization information exchange. Then, in the D-MIMO system, this paper proposes a new synchronization mechanism protocol, OFDMA based Synchronization protocol, to achieve the extremely high precision of D-MIMO. Explain the detailed protocol flow and improve its frame structure to make it compatible with 802.11 frame structure. Finally, set up the simulation scenario and perform verification tests, explain the simulation results, and look into the future.

In the following sections of the article, we will introduce the basic principles of D-MIMO and several methods related to clock synchronization in the second chapter. In the third chapter, the basic idea and detailed flow based on the OFDMA synchronization protocol algorithm will be described in detail. Then, the simulation scenario is designed and compared with the traditional synchronization results in Chapter four. Finally, in Chapter five, we will draw conclusions and prospects.

2 Motivation

2.1 The Principle of D-MIMO

By jointly transmitting data of antennas distributed in different geographical locations, D-MIMO can transform the interference signals of other base stations into useful signals, While coordinating interference of the same frequency among base stations, it can also make full use of antennas of multiple cells to jointly transmit downlink multi-space flow and receive up-link multi-space flow. Therefore, D-MIMO can improve the number of spatial streams transmitted, thereby improving single-user throughput and system spectrum efficiency, it also can ensure the throughput per unit area grows steadily with the increase of the number of stations [5]. D-MIMO is one of the important interference resolution and capacity enhancement technologies in high-density networking scenarios [6]. However, D-MIMO requires extremely high synchronization time of the system, so how to make the clock synchronization of each AP of the D-MIMO system become a research hotspot of D-MIMO.

As shown below (Fig. 1). In high-density station network, D-MIMO combines multiple transmitting points (APs) that interfere with each other into a cluster, and the AP weights the user data to be transmitted by using orthogonal transmission vectors. The orthogonal user data is jointly transmitted in parallel, does not interfere with each other, and the interference signal of the neighboring cell becomes a useful signal [7].

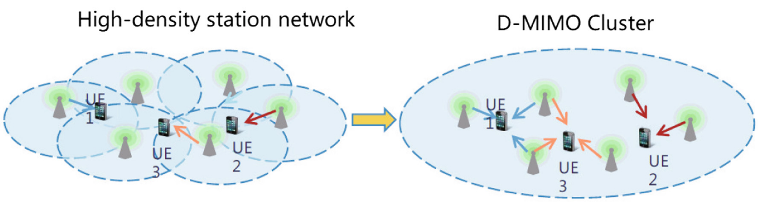

Fig. 1. Schematic diagram of D-MIMO system

2.2 The Principle of Clock Synchronous

In D-MIMO systems, nodes have their own independent clocks. Ideally, the clock for each node should be of the formula C(t) = t (t is the ideal time). BHowever, due to differences in the hardware configuration of each node, the frequency, period, phase, and duty cycle of the clock signals between nodes may be different, As shown in Fig. 2, in practice, the clock model of the node should be:

$$C(t) = f * t + \theta \tag{1}$$

Where: f is the clock phase difference and is the clock offset. As can be seen from Fig. 2, the AP's clock relationship (e.g, node A and B) can be expressed as:

$$C_B(t) = f^{AB} \cdot C_A(t) + \theta^{AB} \tag{2}$$

Where: f^{AB} and θ^{AB} represent the clock phase difference and clock offset of node B relative to node A. When $\theta^{AB} = 0$ and $f^{AB} = 1$, nodes A and B reach full synchronization. If there are N nodes in the D-MIMO system, if the clock of each node is equal to other clocks in the whole network, that is, $C_i(t) = C_j(t)$ i and j = 1, 2, 3,$\cdots\cdots$, N. The whole system clock is considered completely synchronous.

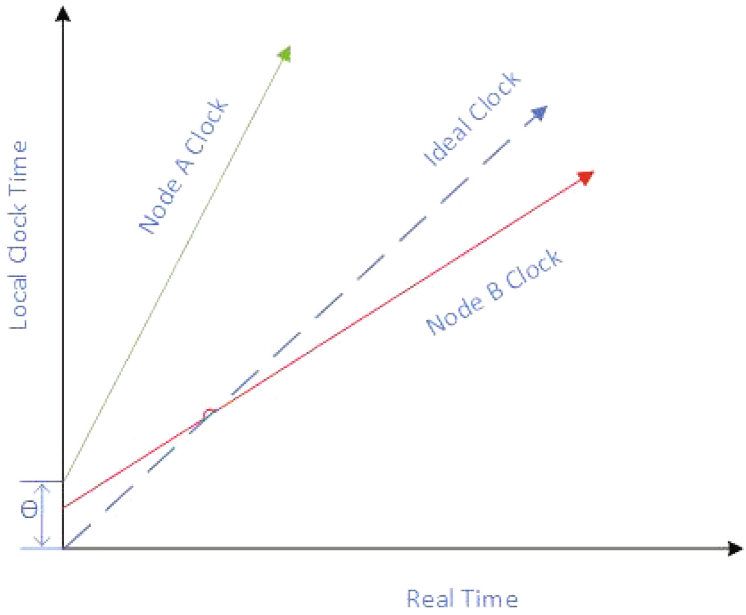

Fig. 2. Clock model of wireless nodes

In the Wireless Local Area Network, clock synchronization between nodes can be achieved by transmitting a set of timing messages to the nodes to be synchronized, and the transmitted data packets mainly contain timestamp information about the transmitting nodes. There are many algorithms for implementing system synchronization. Here, the Two-Way Message Exchange and the One-Way Message Exchange are mainly introduced.

2.3 Two-Way Message Exchange

Two-Way Message Exchange is a classic mechanism, mainly used to exchange clock information between two adjacent nodes. Protocols using this mechanism are Lightweight Time Synchronization (LTS)[8], Timing Synchronization Protocol Sensor Network (TPSN) [9], etc. As shown in Fig. 3, node A is a reference node and node B is the node to be synchronized. In the Two-Way Message Exchange process. Node B wants to be fully synchronized with the reference node A on clock [8,10]. As can be seen from the figure, After the Kth information interaction, the node B to be synchronized sends a synchronization frame to the node A at $T_{K,1}$, the node A receives the synchronization frame at $T_{K,2}$ and replies to the node B with a synchronization frame at time $T_{K,3}$,at $T_{K,4}$, the node B receives the synchronization frame sent by node A. After N rounds of synchronization information frame exchange, node B obtains a set of timestamp data$\{T_{K,1}T_{K,2}T_{K,3}T_{K,4}\}$. here, K = 1, 2, 3, $\cdots\cdots$, N. The above process can be expressed as a mathematical model [11]:

$$T_{K,2} = f(T_{K,1} + \tau + X_K) + \theta \tag{3}$$

$$T_{K,3} = f(T_{K,4} - \tau + Y_K) + \theta \tag{4}$$

where: f is the relative clock skew of node B with respect to node A, θ is the relative clock offset, we can know τ is to determine the delay time, Y_K is the transmission duration of A to B, X_K is the transmission duration of B to A.

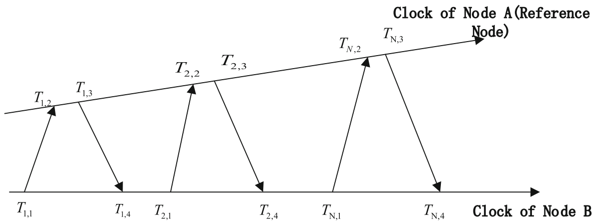

Fig. 3. The process of Two-Way Message Exchange

From Eqs. (3) and (4), it is necessary to estimate three parameters f,θ and τ. After N rounds of message exchange, an expression in the form of a matrix can be obtained according to (3) and (4) [12], as follows:

$$\begin{bmatrix} T_{1,1} \\ \vdots \\ T_{N,1} \\ -T_{1,4} \\ \vdots \\ -T_{N,4} \end{bmatrix} + \tau \cdot 1_{2N} = \begin{bmatrix} T_{1,2} & -1 \\ \vdots & \vdots \\ T_{N,2} & -1 \\ -T_{1,3} & 1 \\ \vdots & \vdots \\ -T_{N,3} & 1 \end{bmatrix} \begin{bmatrix} 1/f \\ \theta/f \end{bmatrix} - \begin{bmatrix} X_1 \\ \vdots \\ X_N \\ Y_1 \\ \vdots \\ Y_N \end{bmatrix} \tag{5}$$

Where: 1_{2N} is a column vector with a length of 2 N and all value are 1. According to the above expression, frequency offset and phase offset can be estimated by the Maximum Likelihood Estimation (MLE) and its corresponding Kramer-law boundary [8].

2.4 One-Way Message Exchange

As shown in Fig. 4, in the One-Way Message Exchange process, the master AP will broadcast a synchronization frame carrying the timestamp of the transmission time and the number of synchronization rounds to the plurality of slave APs. When the APs to be synchronized receives the synchronization frame, it obtains the timestamp sent by the master AP. After the Kth round of information exchange, the slave APs can know the timestamp of the transmission of the master AP in the Kth round and the synchronization frame received by itself. Timestamp. it is given by:

$$T_{K,2} = f(T_{K,1} + \tau + X_K) + \theta \tag{6}$$

After the N round of synchronization information frame exchange, the node to be synchronized can estimate the value of f and θ by linear regression [13]. Thereby achieving the entire network clock synchronization.

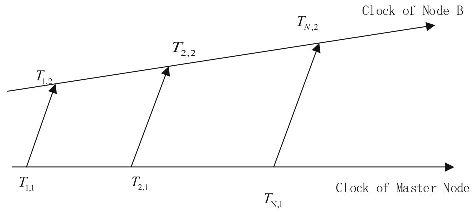

Fig. 4. The process of One-Way Message Exchange

In D-MIMO system, the requirements for clock synchronization of each node are particularly high. It can be seen from the above that the two-way message exchange can achieve higher accuracy than the one-way message exchange. Therefore, it is worth studying how to support the two-way clock synchronization method in DMIMO. This is also the research place of this paper.

3 OFDMA Based Synchronization Protocol for D-MIMO

3.1 Protocol Overview

How to make the master AP and other slave APs as synchronized as possible on the clock? This is an urgent problem to be solved in the D-MIMO system. This is also one of the basic technologies for implementing D-MIMO. Only by maximizing synchronization, D-MIMO can greatly improve the throughput of the system and eliminate some interference. On the contrary, it will cause the Master AP and the Salve AP to interfere with each other's data. This not only does not improve the throughput of the network, but causes the D-MIMO system to fail to work properly and even crashes the entire network. Therefore, this paper proposes a new synchronization protocol algorithm - OFDMA based Synchronization protocol.

Expect to be able to synchronize D-MIMO as much as possible. The general idea of the protocol is that the Master AP broadcasts a synchronization frame to Slave APs to be synchronized, and the trigger frame contains the number of two-way message exchange exchanges and the resource allocation for the Slave APs to perform the two-way message exchange process. After receiving the trigger frame, the Slave APs perform N rounds of two-way message exchanges on the already allocated resource blocks. After the N rounds of exchange, the Slave APs should obtain N sets of timestamp data$\{T_{K,1}T_{K,2}T_{K,3}T_{K,4}\}$. Finally, the relative frequency offset and relative phase offset between the Slave APs and the Master AP are estimated according to the Maximum Likelihood Estimation and its corresponding Cramer-Labor Boundary to complete accurate time synchronization. Compared with SU, the synchronization protocol based on OFDMA has obvious advantages, not only the time overhead is small, but also the clock synchronization in the same time period makes the D-MIMO system more consistent in time.

3.2 The Process of the Synchronization Protocol

In the D-MIMO system, as shown in the Fig. 5, when the Master AP wants to invoke the surrounding AP for D-MIMO transmission, the specific process is divided into the following steps:

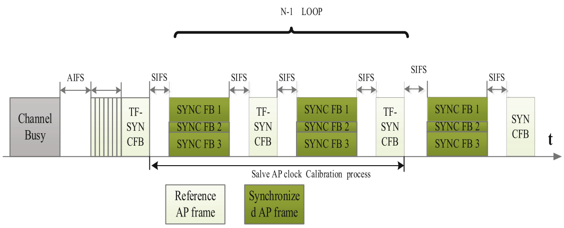

Fig. 5. The process of the OFDMA based Synchronization protocol

1. The clock reference source AP (which can be a master AP or a slave AP) sends Trigger Frame of Synchronization Feedback (TF-SYNC-FB) to trigger a synchronization feedback frame of the slave AP, where the frame carries the number N of synchronization information interactions and the APs that need to be scheduled.
2. After receiving the TF-SYNC-FB, the AP to be synchronized sends the synchronization feedback (SYNC-FB) on the corresponding RU and records the time at which the synchronization frame is transmitted.
3. The AP of the reference clock continues to transmit the TF-SYNC-FB, which carries the timestamp T2 of the AP receive SYNC-FB and the timestamp T3 of the AP send TF-SYNC-FB, and the N carried by the TF-SYN-FB is decremented by one.

4. After receiving the TF-SYNC-FB, the AP to be synchronized obtains T1, T2, T3 and the timestamp T4 of receiving the TF-SYNC-FB, then the Salve AP records these timestamps.
5. Cycling steps 2–4, after completing the N-1 TF and FB cycles, at this time, N = 0. The AP of the reference clock sends the SYNC-FB to all APs to be synchronized, and the N-way message exchange synchronization loop ends.
6. The AP to be synchronized obtains 4 N timestamps, and the accurate clock synchronization can be completed after the estimated parameter values.

3.3 Frame Structure Design

The frame structure of TF-SYNC-FB can be extended according to the MAC frame structure of 802.11. As shown in Fig. 6, the field in which the trigger frame is added is the common info field and the SYNC info field. The information carried in the SYNC field is the timestamp T2 of the SYNC FB received by the reference clock, the timestamp T3 of the TF-SYNC-FB, and the number of remaining handshaking. The Common field contains the type of trigger frame.

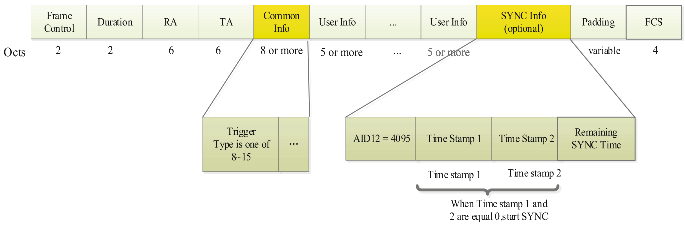

Fig. 6. Frame structure of Trigger Frame of Synchronization Feedback

The structure of the SYNC-FB frame is the same as that of the 802.11 MAC frame structure, and does not need to carry additional information, so the frame structure is not extended.

4 Simulation Design and Implementation

In the D-MIMO system, the accuracy of the clock synchronization reflects the advantages and disadvantages of the synchronization protocol. Based on this, we set up the simulation platform and design the simulation environment to verify the change of the clock synchronization accuracy of the AP to be synchronized as the number of synchronization information changes. We designed a simple scenario in which two nodes do clock synchronization. One node is the Master AP and the other is the Slave AP. The Master AP and the Salve AP use the synchronization protocol proposed in this paper to exchange synchronous frames. As shown in Fig. 7, when the number N of synchronization information interactions increases gradually, we find that the time difference between the primary

AP and the secondary AP is getting smaller and smaller, that is, the accuracy is getting higher and higher. Of course, for the universality of the results, we tested the synchronization accuracy test under different relative frequency offsets and phase offsets. It is found that the synchronization precision of the node to be synchronized is higher as the number N of synchronization information interactions increases.

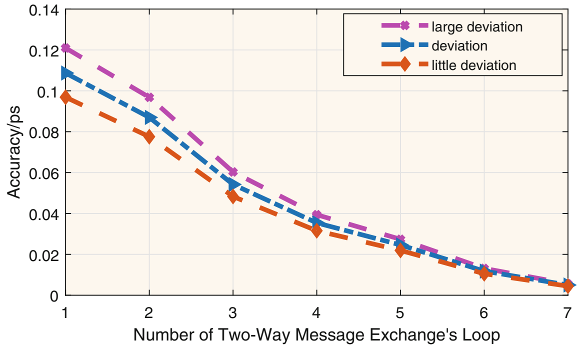

Fig. 7. Synchronization accuracy under different frequency offsets and the number of different synchronization information interactions

We have learned from the previous tests that the accuracy of clock synchronization increases rapidly as the number of interactions increases, but in wireless LANs, the overhead of an algorithm and whether the frame format designed according to the protocol is compatible with the traditional frame format prove whether the algorithm has practical possibilities. Based on the proposed synchronization protocol, we designed the frame format of the sync frame to be perfectly compatible with the 802.11 frame format. Here, we will compare the overhead of the OFDMA-based synchronization protocol proposed in this paper compared to the traditional SU-based synchronization protocol algorithm. As shown in Fig. 8, we find that the overhead of the OFDMA-based synchroniza-

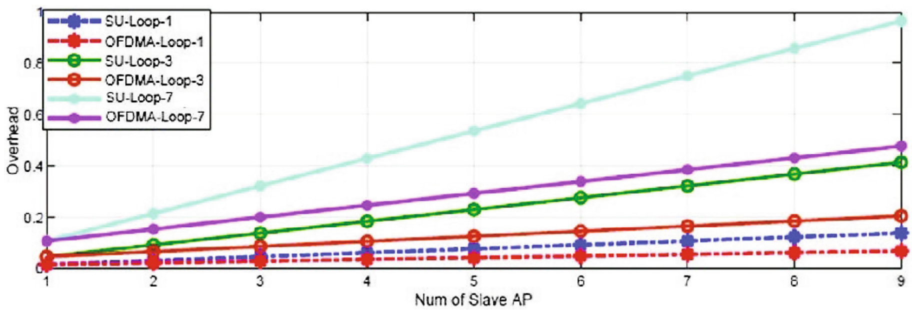

Fig. 8. Comparison of OFDMA-based synchronization protocol and SU-based synchronization protocol overhead

tion protocol algorithm is much lower than that of the traditional SU proposed synchronization protocol as the number of APs to be synchronized increases.

5 Conclusions and Future Works

It can be seen from the simulation results that within a certain range, as the number of interactions of the two-way increases, the accuracy of synchronization is higher and higher. As the number of APs to be synchronized increases, the protocol proposed in this paper is compared with the synchronization based on SU. There is a significant reduction in the time it takes for the protocol to reach accuracy. Follow-up research will Optimization protocol algorithm, So as to the network synchronization accuracy is more higher, lower overhead. So as to further improve system throughput.

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