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Comparison of Frequency-Domain Contention Schemes in Wireless LANs

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Abstract**—**In IEEE 802.11 networks, it is well known that the traditional time-domain contention often leads to low channel utilization. The first frequency-domain contention scheme, the time to frequency (T2F), has recently been proposed to improve the channel utilization and has attracted a great deal of attention. In this paper, we present the latest research progress on the weighed frequency-domain contention. We compare the basic ideas, work principles of these related schemes and point out their differences. This paper is very useful for further study on frequency-domain contention.

Keywords**—**802.11, wireless LANs, frequency-domain contention, T2F.

I. Introduction

IEEE 802.11 (802.11) [1] wireless LANs (WLANs) have been widely deployed worldwide. In 802.11 networks, before data transmission, each node will perform the time-domain contention. That is, each node first chooses a random backoff number and then counts down. The backoff counter will be suspended if the channel is sensed busy and will be resumed once the channel becomes idle. It has been pointed out in [2] that more than 30% reduction in throughput is due to backing off, and there are many papers are interested in this topic [2]-[20].

Recently, [3] first proposed a time to frequency (T2F) protocol to improve the channel efficiency of wireless LANs. The purpose is to migrate the traditional time-domain contention to the frequency-domain. T2F employs OFDM subcarriers for channel contention. In T2F, each user signals on its chosen subcarrier and at the same time listens for all active subcarrier numbers. By sorting all subcarrier numbers, each node can independently find the winner who signals on the minimum subcarrier. T2F can generally arbitrate a winner within 2 slots, thereby shortening the channel contention time and further improving channel utilization significantly.

High channel utilization of T2F has attracted a great deal of attention. However, T2F only provide fair channel access opportunity. To achieve the diverse quality of service (QoS) requirement of different applications while improving the channel utilization, it calls for providing prioritized frequency-domain contention. Therefore, three schemes, namely Back2F [4], WT2F [5], and WiFi-BA [6] have recently been proposed, where Back2F emulates the countdown of 802.11 and expect to sustain fairness comparable to 802.11, WT2F can provide proportional priority, and finally WiFi-BA can support absolute priority. In this paper, we present the basic ideas, work principles of these related schemes and point out their differences for a single-cell WLAN.

The rest of the paper is organized as follows. Sections II-V present T2F, Back2F, WT2F, and WiFi-BA, respectively. Finally, Section VI summarizes the related schemes and concludes this paper.

II. T2F

In this section, we outline the time to frequency (T2F) protocol [3].

T2F is the first frequency-domain contention protocol for improving the channel efficiency of WLANs. It aims at providing fair channel access via frequency-domain contention. T2F is based on the OFDM technique, where the whole channel is divided into L subcarriers (e.g. $L = 52$ in 802.11a/g). In T2F, each user has two antennas: one for normal data transmission over the whole channel, and another for listening signals from each of L subcarriers.

With the help of Fig. 1 (which assumes a star-topology network consisting of one AP and four users, Ui, i=1,2,3,4, where all users can hear each other) and Fig. 2 (which demonstrates how the four users contend for channel), we now explain the frequency-domain contention process as follows.

In T2F, each user first senses channel idle for a DIFS (Distributed Inter Frame Space) time, then performs the 2-round contention process (i.e., R1 and R2 in Fig. 2) in two consecutive slots:

- In R1, each user signals on one subcarrier (via the transmit antenna) randomly chosen from a pool of L subcarriers, and at the same time listens to this subcarrier pool via the listening antenna. T2F users treat these subcarriers as integer numbers. By listening and checking all subcarriers, each node can independently determine the winners, who signal on the smallest subcarrier. In the example of Fig. 2, in R1, each node knows that U1 and U4 select No.5 subcarrier, U3 and U2 select No.8 and No.11 subcarriers, respectively, and therefore infers that the users signaling on No. 5 subcarrier are the winners, because No. 5 subcarrier is the minimum chosen subcarrier.
- In R2, all users choosing the smallest subcarrier enter the 2^{nd} round contention, while other users keep silent. Then, like that in R1, those users in R2, respectively, choose a new subcarrier from the pool of L subcarriers, signal, and listen to determine a new winner. In the example of Fig. 2, in R2, U1 and U4 enters the 2^{nd} round contention and select

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No. 4 and No. 8 subcarriers, respectively. As a result, U1 wins the channel.

Finally, the winner executes the data transmission over the whole channel. In the example of Fig. 2, U1 is the winner and transmits data.

For the next data transmission, each node repeats the whole contention process.

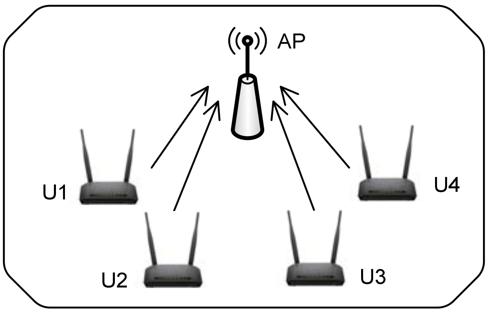

Fig. 1 A star-topology WLAN for T2F [5]

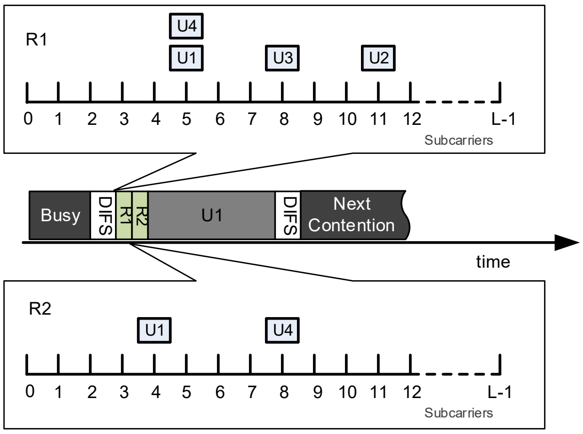

Fig. 2 Two-round contention in T2F

III. BACK2F

In order to emulate the countdown of 802.11 and sustain fairness comparable to 802.11, Back2F [4] is proposed to migrate WiFi backoff to the frequency domain.

Back2F is a modification on T2F. For the first data transmission, Back2F is exactly like T2F. However, for subsequent data transmissions, Back2F behaves differently. Rather than re-choosing a new subcarrier randomly from the pool of L subcarriers, each user (losing in the last data transmission) revises its subcarrier number (like 802.11); the revised number is the result that its chosen subcarrier number subtracts the minimum subcarrier number in R1 in the last data transmission process. Fig. 3 illustrates this as a follow up to Fig. 2. The smallest subcarrier of 5 in R1 in Fig. 2 is deducted from the subcarrier numbers of all the losing users (i.e., U4, U3, U2). Thus, the resulting subcarrier numbers of U4, U3, and U2 are 0, 3, and 6, respectively. These users next repeat the subsequent contention process and finally transmit data. Note that the winner in Fig. 2 (i.e., U1) should choose a new subcarrier from the pool of L subcarriers and participate the contention in R1 and R2 in Fig. 3; we no longer plot the winner in Fig. 3 to avoid confusion.

For the next data transmission, each node repeats the whole contention process.

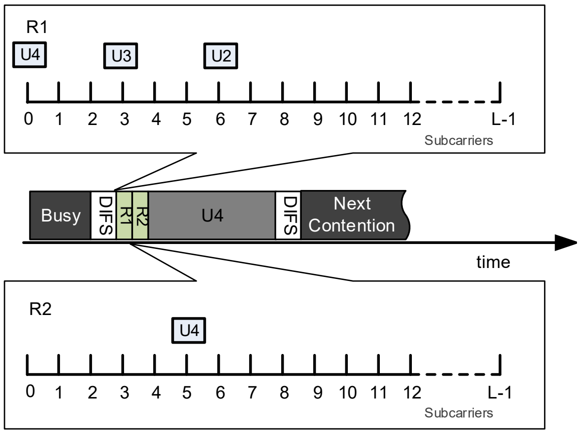

Fig. 3 Two-round contention in Back2F, where Back2F emulates the countdown of 802.11. This figure illustrates the contention as a follow up to Fig. 2

IV. WT2F

T2F and Back2F provide fair channel access opportunity, because each user uniformly selects a subcarrier from the same subcarrier pool. However, in reality, different applications have different QoS requirements. For example, voice packet should have a more stringent delay requirement than data packet and therefore should be assigned a higher transmission opportunity. Therefore, the weighted T2F (WT2F) [5] was proposed to provide fair channel access opportunity.

In WT2F, all users are classified into different groups. Each user behaves exactly like that in T2F, except that in R1, users in the same group, respectively, choose a subcarrier from the same subcarrier pool; users in different groups, respectively, choose a subcarrier from different subcarrier pools. If subcarrier pools are in different subcarrier ranges, users will have different opportunities to win the channel. When all subcarrier pools are the same, WT2F reduces to T2F. For example, in Fig. 4, we group all users, Ui, i=1,2,3,4, into two priority classes: high priority (HP) and low priority (LP), where U1 and U2 are HP nodes, whereas U3 and U4 are LP nodes. In Fig. 5, we show that HP nodes choose subcarrier numbers from [0, S -1], while LP nodes choose subcarrier numbers in [0, L -1], where S≤L. In R1, HP nodes (i.e., U1 and U2) will choose smaller subcarriers with higher probability than LP nodes (i.e., U3 and U4) and therefore will enter the R2 contention with higher probability.

V.WIFI-BA

In the previous designs (i.e., T2F, Back2F, WT2F), each user only selects one subcarrier. WiFi-BA [6] enables a user to select several subcarriers simultaneously and provide absolute priority.

In WiFi-BA, a binary mapping scheme is introduced to pick subcarriers and set contention priority.

- Pick subcarriers. Before each contention, a user randomly picks a number (except $2^i, 0 \leq i \leq k$, to prevent the user from choosing one subcarrier only) from $[1,2^k - 1]$, where k denotes the number of available subcarriers; k is usually much less than the total available subcarrier numbers due to power leakage or side lobe jamming and is set to 8 in [6]. The k-bit binary sequence is mapped to subcarriers as follows: if bit i, $0 \leq i \leq k$, is equal to 1, subcarrier i is selected; otherwise, subcarrier i is not selected. When a user activates their selected subcarriers, and generate an OFDM symbol through Inverse Fast Fourier Transform (IFFT), we call the OFDM symbol as an arbitration preamble. For example, in Fig. 6, user A chooses 01011010, implying that it selects subcarriers 1, 3, 4, 6, while user B chooses 01010110, implying that it selects subcarriers 1, 3, 5, 6.

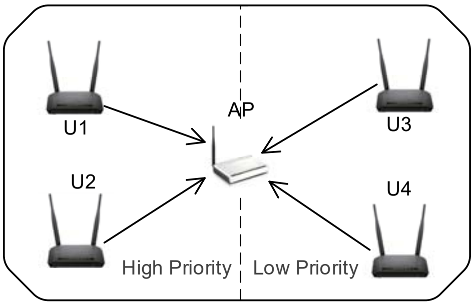

Fig. 4 A star-topology WLAN with priority for WT2F [5]

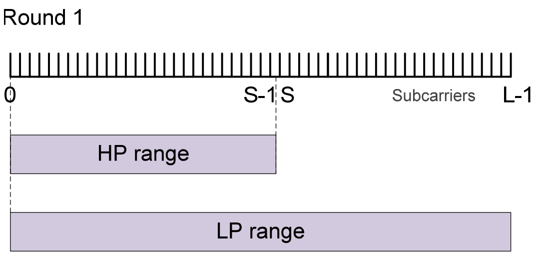

Fig. 5 HP and LP subcarrier ranges for WT2F [5]

- Set contention priority. WiFi-BA can use the binary mapping scheme to assign different priorities to users. For example, we can set two priorities with the first 1 most significant bit: if a user selects a binary code with the most significant bit being set to 1 (i.e., 1xxxxxxx), then the user will have the highest priority; otherwise, if the most significant bit of the binary code is 0 (i.e., 0xxxxxxx), the user have the lowest priority. In the same way, we can set several levels of priorities with the first m most significant bits.

Like T2F, each user in WiFi-BA has two antennas: one for normal data transmission over the whole channel, and another for listening signals from each of k subcarriers. With the help of Fig. 7, we outline WiFi-BA as follows. All uses will sense channel idle for a clear channel assessment (CCA) time, then pass through the collision probe phase and the arbitration phase sequentially to determine a winner.

- Collision probe. In this phase, each user will send its arbitration preamble on the transmit antenna, and at the same time will monitor active subcarriers on the listening antenna. The received signal is the superposition of all arbitration preambles. Each user performs Fast Fourier Transform (FFT) on the received signal to acquire the active subcarrier numbers, and then compare them with its chose subcarriers. If they are the same, the user is the winner and beginning to transmit immediately in the next slot; otherwise (i.e., a collision occur), the user enters the arbitration phase. For example, in Fig. 6, user A and B know that the active subcarrier numbers are 1, 3,4,5,6, which are different from their respective subcarrier numbers, and therefore both enter the arbitration phase.
- Arbitration phase. Each user in this phase checks its binary sequence slot by slot. In slot i, $0 \leq i \leq k$, if the i-th bit is 1, the user sends its arbitration preamble while listening for active subcarriers as in the collision probe phase: if no collision, the user sends data immediately; otherwise, it continue performing the arbitration. If the i-th bit is 0, the user just listens without sending; when it observes an obvious energy, it infers the contention failure and aborts the arbitration phase. The arbitration phase continues until a winner is determined or slot k is reached. From the arbitration phase, if the user chose the he binary code with the form of 1xxxxxxx, it will win the channel immediately and therefore have the higher priority to send data.

Finally, the winner begins transmitting data.

VI. Conclusion

In this paper, we survey four schemes: T2F, Back2F, WT2F, and WiFi-BA. T2F is the first time-domain contention scheme. Back2F modifies T2F by emulating the countdown of 802.11 to achieve fairness comparable to 802.11. T2F and Back2F only support fair channel access opportunity because each user uniformly selects a subcarrier from the same subcarrier pool. WT2F is proposed to provide prioritized channel access by dictating different users choose subcarriers from different subcarrier pools. Finally, different from the previous three schemes where each user only selects one subcarrier, WiFi-BA enables a user to select several subcarriers simultaneously and provide absolute priority.

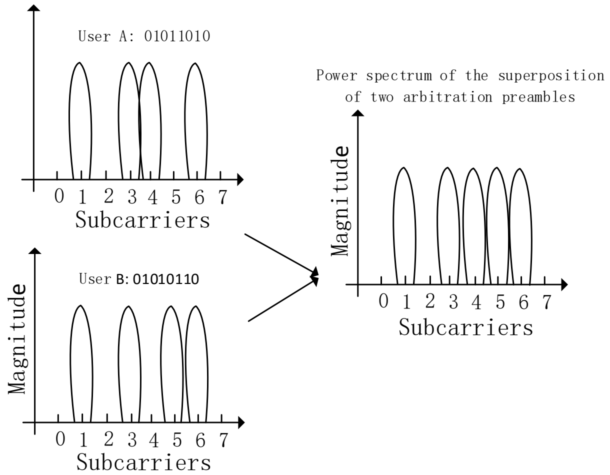

Fig. 6 (a) The binary mapping scheme in the left part, and (b) power spectrum of the superposition of two arbitration preambles in the right part [6]

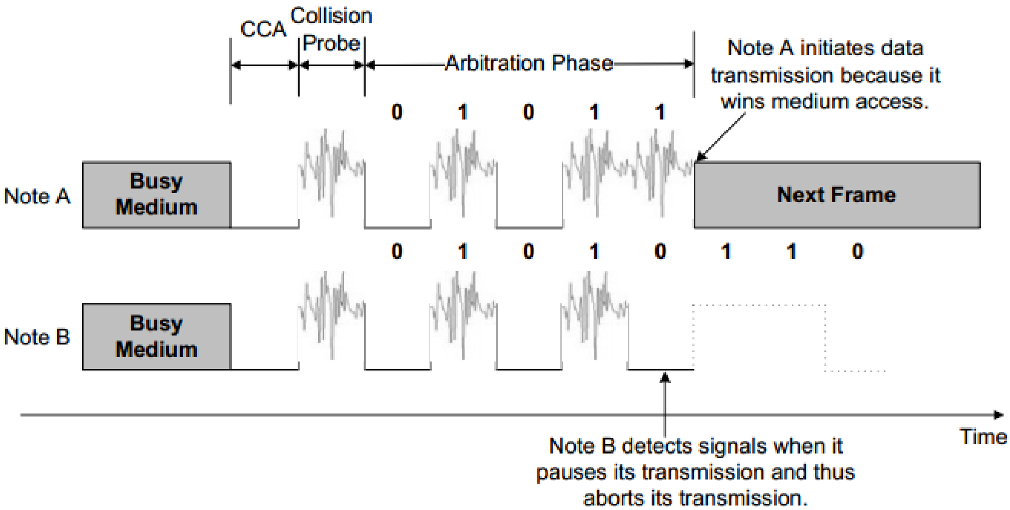

Fig. 7 An overview of WiFi-BA [6]

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