Interference Type based Channel Management using Adaptive Bandwidth in Wireless LANs

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Abstract—In IEEE 802.11 based Wireless LANs, the channel bandwidth is considered as a fixed parameter. Recently, the concept of adaptive bandwidth has been newly introduced, making it possible to allocate the channel bandwidth adaptively according to the interference type of users. Such a capability enables to enhance the previous way of channel usage where each Access Point (AP) is restricted to use a fixed bandwidth channel to serve all users. In this paper, we propose a scheme where each AP is allowed to use an adaptive bandwidth channel that is adjusted by a central controller. The channel bandwidth is determined according to whether a user to be served experiences interference or not. If the user is vulnerable to interference from other APs, not its serving AP, it is served through a channel assigned to the serving AP. On the contrary, when serving interference-free users, the AP can exploit more bandwidth which is available at the moment. In this way, our proposed scheme can enhance the spectrum utilization of interference-free users without harming the other users. Simulation results show that our scheme significantly improves the average spectrum utilization of each AP.

I. INTRODUCTION

A wireless channel can be characterized by several parameters such as center frequency and bandwidth. The center frequency determines the position of the channel in frequency domain, whereas the bandwidth specifies how wide the channel is. In today’s Wireless LANs (WLANs), these two parameters are considered as fixed. For example, in the IEEE 802.11b/g standard, the entire spectrum is divided into 11 channels at predefined positions, and each channel has a fixed bandwidth of 20MHz.

Recently, the concept of adaptive bandwidth is newly introduced. In [1], it has been shown that the channel bandwidth can be configured on the fly to handle varying network conditions. For example, it can be made possible via software configuration to change the bandwidth between 5, 10, 20, and 40MHz at any time even in some off-the-shelf WLAN network interface cards. In addition, the center frequency can be moved to any point in frequency domain. Such an adaptability allows Access Points (APs) to use more spectrum whenever possible, which enables the efficient use of scarce wireless resources.

In the last decade, there have been a lot of research efforts on the channel allocation problem in WLANs. One of the chief concerns in this problem is to reduce interference between APs. For clear explanation, we define two APs are interfering; 1) when they are in the coverage range of each other1, or 2) when a user associated with one AP is located in the coverage range of the other AP.

When two APs indirectly interfere with each other by having a user in the overlapped coverage area and using the same channel, some users of one AP, referred to as interfered users, are vulnerable to the interference from the other AP, while the others are free from such interference. To mitigate the interference that may occur when an AP communicates with the interfered users, the AP should use an assigned channel as in the literature [2][3]. However, the common limitation of the previous studies lies in that they force the AP to use only the assigned channel even when communicating with the interference-free users. In this case, the AP can serve the interference-free users by utilizing other available channels with wider bandwidths, thereby improving spectrum utilization. This can be made possible owing to the aforementioned bandwidth adaptability.

In this paper, we propose a superframe structure that allows different bandwidth allocation for each user according to whether the user to be served is interfered or not, i.e., interference free or interfered. When serving the interference-free users, an AP can exploit a channel with a wider bandwidth than its assigned channel without harming the performance of the other interfered users. On the contrary, the assigned channel is used for the interfered users. In this way, the AP and the interference-free users can enjoy more spectrum. However, if an AP defines its superframe structure without taking into account the interference relationship with other APs, the AP and some interfered users associated with other APs may suffer from severe interference. To solve this problem, we propose an algorithm which operates in a centralized manner.

The rest of the paper is organized as follows. The motivation of our work is given in Section II. In Section III, the considered system model is described. The details of the proposed scheme is explained in Section IV, followed by simulation results in Section V. Finally, we conclude this paper in Section VI.

II. MOTIVATION

We now illustrate the motivation of our work using an example shown in Fig. 1. Consider a WLAN consisting of three APs: AP1, AP2, and AP3. The transmission range of each AP is indicated by a circle. Each user is depicted as either a square or a triangle, and the index inside represents the AP with which the user is associated. Since all the APs interfere with each other in the example, they should be assigned three
non-overlapping channels [2]. Without loss of generality, we assume that AP1, AP2, and AP3 are assigned Ch1, Ch2, and Ch3, respectively. The bandwidth of each channel is assumed to be 20MHz.

For notational brevity, we refer to an interfered user (depicted as a triangle) as an i-user. Likewise, an f-user means an interference-free user (depicted as a square). When the APs communicate with the i-users, they should use their assigned channels to prevent the interference from the other APs. In contrast, if the APs communicate with their f-users at the same time, e.g., if three communication links indicated as dotted lines start and end simultaneously, Ch4 of 60MHz can be used between each AP and the associated f-users. By using a wider channel than the assigned channel when serving the f-users, both the APs and the f-users can achieve the increased spectrum utilization. That is, differentiated channel usage according to the interference type of users (i.e., f-user or i-user) can help to fully utilize the otherwise wasted spectrum.

III. SYSTEM MODEL

We consider an enterprise network consisting of multiple APs and a central controller. All APs are connected to the central controller through a backhaul network, and managed by the central controller. The central controller defines the superframe structure and allocates a channel to each AP based on the network topology.

The network topology can be modeled as a graph where APs are represented as vertices, and each edge connects two interfering APs (vertices). To obtain the network topology, each AP requests its associated users to search their interfering APs, i.e., the APs from which a user can receive beacons [4]. Then, the users scan all the channels and send their informations to their serving APs. Upon receiving the report, each AP becomes aware of the following: 1) its interfering APs, 2) the number of associated users, and 3) the interference type of each user. Note that when two APs are in the coverage of each other, all the users associated with these APs are treated as i-users even though some of them may not be located in the overlapped coverage area of the two APs. Finally, this information is sent to the central controller. Through this process, the central controller can construct the network topology.

For the constructed topology, the central controller assigns a dedicated channel (defined by center frequency and bandwidth) to each AP. We refer to such a channel as an Assigned Channel (ACh). In [3], the authors proposed GreedyRaising algorithm which allocates an ACh to each AP in a centralized manner. We adopt the GreedyRaising algorithm as the baseline algorithm in our proposed scheme.

It is assumed that the total available spectrum in the network is fixed, and it starts from 0MHz in frequency domain for clarity. The bandwidth of each channel can be configured adaptively as one of the available bandwidth options of [5, 10, 20, 40, 60] MHz. We define the Widest Channel (WCh) as the channel with the widest bandwidth, starting from 0MHz.

IV. ADAPTIVE BANDWIDTH ALLOCATION CONSIDERING USER’S INTERFERENCE TYPE

A. Superframe Structure

As mentioned before, the previous approaches force APs to communicate with f-users only through AChs even if there are channels with more available bandwidth. This results in a waste of spectrum which is the most precious resource in wireless networks. To tackle this, we introduce a superframe structure shown in Fig. 2 to use different channels according to the interference type of users. The superframe consists of several beacon intervals (BIs). At the beginning of each beacon interval, an AP sends a beacon containing the information explained below:

- **Channel-to-be-used:** This information element specifies the channel to be used during the beacon interval. The communication between the AP and its users will occur on the specified channel.
- **Interference-Type:** This information element is included to determine the interference type of users that are allowed to participate in the contention during the beacon interval. For example, if this is set to “f”, then only f-users are allowed to contend for the channel.

2Due to the user mobility, the network topology may change over the time. To reflect the change, the central controller can request the APs to re-investigate the network topology periodically or when it is required.
3To the best of our knowledge, the first and only work utilizing the adaptive bandwidth in the AP channel allocation is given in [3].
After receiving the beacon from the AP, each user obtains the information in the beacon and follows the given instruction. As a result, only the allowed users will contend and communicate with the AP through the specified channel.

By allowing only users with certain interference type to contend for the channel, it is possible to use different channels based on the interference type in order to increase the spectrum utilization. The rule for determining the channel for each interference type is given as follows:

- **WCh for f-users**: Since f-users are not influenced by interference, we can use the WCh instead of the ACh. The bandwidth difference between the WCh and the ACh implies the additional spectrum used by the AP and the f-users. For example, if the bandwidths of the WCh and the ACh are 60MHz and 20MHz, respectively, then the bandwidth gain of 40MHz is earned.

- **ACh for i-users**: In order to avoid interference, the ACh should be used when the AP communicates with i-users.

To facilitate the above channel usage, the superframe is divided into two periods\(^4\): **Wide Channel Period (WCP)** and **Assigned Channel Period (ACP)**. Without loss of generality, we assume that the WCP precedes the ACP in the superframe. In a beacon interval, the AP is said to be in the WCP (ACP) if it communicates with the f-users (i-users) over the WCh (ACh).

The next step is to determine the lengths of the WCP and the ACP in the superframe. Since the superframe is composed of beacon intervals (BIs), it is natural to use BI as a unit length, for instance, the length of the WCP is 3BIs. Let \( L_{WCP} \), \( L_{ACP} \), and \( L_{SF} \) denote the lengths of WCP, ACP, and superframe, respectively. We also denote the number of f-users and i-users associated with the AP by \( N_f \) and \( N_i \), respectively.

We now introduce a new metric of **spectrum-per-user (SPU)** that represents how much spectrum a user can use on average during a beacon interval, and is calculated as the average channel bandwidth divided by the number of users contending for the channel. For example, if the channel bandwidth alternates between 40MHz and 20MHz, the average channel bandwidth becomes 30MHz. If there are 5 users contending for the channel, then each user has a SPU of 6MHz (30MHz/5users). If all the users, regardless of their interference types, contend for the ACh as in the standard WLANs, the SPU of each user is simply \( \frac{B_{ACh}}{N_f+N_i} \) where \( B_{ACh} \) denotes the bandwidth of the ACh.

In the proposed superframe structure, if \( L_{WCP} \) is highly larger than \( L_{ACP} \), the spectrum utilization of the AP and f-users will increase since they have a long time period to use the WCh. However, the other i-users unable to access the channel during the WCP will starve, leading to a reduced SPU. Therefore, it is desirable to set \( L_{WCP} \) and \( L_{ACP} \) so as to guarantee the SPU of each i-user no less than \( \frac{B_{ACh}}{N_f+N_i} \), while allowing the AP and the f-users to use the WCh as much as possible, i.e., there should be no victim. For this, we propose two rules for determining \( L_{WCP} \) and \( L_{ACP} \); they are **Proportional Rule and Ratio Rounding Rule**.

**Proportional Rule**: The ratio of \( L_{WCP} \) to \( L_{ACP} \) is set to the ratio of \( N_f \) to \( N_i \), i.e., \( L_{WCP} : L_{ACP} = N_f : N_i \). For example, if \( N_f=6 \) and \( N_i=4 \), then one possible choice is \( L_{WCP}=3\text{BIs}, \ L_{ACP}=2\text{BIs} \). Now, let us calculate the SPU of each user under this rule to see how it changes from \( \frac{B_{ACP}}{N_f+N_i} \). The average channel bandwidth from the viewpoint of the f-users is \( \frac{B_{WCh}L_{WCP}}{(L_{WCP}+L_{ACP})N_f} \) where \( B_{WCh} \) is the bandwidth of the WCh. Hence, the SPU of each f-user becomes \( \frac{B_{WCh}L_{WCP}}{(L_{WCP}+L_{ACP})N_f} \). It is straightforward to obtain the following inequality:

\[
\frac{B_{WCh}L_{WCP}}{(L_{WCP}+L_{ACP})N_f} = \frac{B_{WCh}N_f}{N_f + N_i} \geq \frac{B_{ACh}N_i}{N_f + N_i}.
\]

Similarly, the SPU of each i-user becomes \( \frac{B_{ACP}L_{ACP}}{(L_{WCP}+L_{ACP})N_i} \). We can show that the SPU of each i-user is guaranteed as follows:

\[
\frac{B_{ACP}L_{ACP}}{(L_{WCP}+L_{ACP})N_i} = \frac{B_{ACP}N_i}{N_f + N_i} = \frac{B_{ACh}N_i}{N_f + N_i}.
\]

**Ratio Rounding Rule**: The proportional rule can lead to a superframe which is too long. For example, if \( N_f=13 \) and \( N_i=7 \), then \( L_{WCP}=13\text{BIs}, \ L_{ACP}=7\text{BIs} \). To prevent having such a long superframe, \( L_{WCP} \) and \( L_{ACP} \) can be determined as below.

- **Case 1**: \( N_f \geq N_i \)
  \[
  L_{WCP} = \left\lceil \frac{N_f}{N_i} \right\rceil, \ L_{ACP} = 1
  \]
- **Case 2**: \( N_i > N_f \)
  \[
  L_{WCP} = 1, \ L_{ACP} = \left\lceil \frac{N_i}{N_f} \right\rceil
  \]

In the above, if \( \frac{N_f}{N_i} \) (or \( \frac{N_i}{N_f} \)) has an integer value, the result is the same as that of the proportional rule. However, if not, we should round up or down to make \( L_{WCP} \) and \( L_{ACP} \) an integer. Note that different rounding schemes are used in each case. We round up \( \frac{N_f}{N_i} \) in case 1 whereas \( \frac{N_i}{N_f} \) is rounded down in case 2. The rounding should be done such that it is favorable to the i-users in order not to reduce the SPU of each i-user.

**B. Channel Synchronization Problem**

In the previous section, the superframe structure of an AP is defined depending on \( N_f \) and \( N_i \) of the AP. Since the number of users as well as each user’s interference type is different across APs, the superframe structures are also different in terms of \( L_{WCP} \) and \( L_{ACP} \). As an example, Fig. 3(a) shows the superframe structure of each AP for Fig. 1. The difference in the superframe structures causes a serious interference problem. For example, in the second beacon interval in Fig. 3(a), AP1 is in the WCP while the other two APs are in the ACP. Since the WCh used in the

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\(^4\)If there are only f-users (or i-users) in an AP, the superframe has just WCP (or ACP).

superframe of each AP belonging to the same component. More precisely, the spectrum of AP should have the same length. In order to achieve that, we propose the LCM-scaling shown in Algorithm 1. Firstly, the least common multiple is calculated (step 3). Then, the scale factor $\alpha_i$ is calculated as the ratio of $L_i$ to $L_{SF}$. Finally, we scale up $L_{SF}^i$, $L_{WCP}^i$, and $L_{ACP}^i$ by $\alpha_i$ (step 5-8). Note that even though $L_{WCP}^i$ and $L_{ACP}^i$ are scaled up, the ratio of $L_{WCP}^i$ to $L_{ACP}^i$ is unchanged. The results of the LCM-scaling on the superframes are shown in Fig. 3(b).

Next we introduce the vacant spectrum $V(i,j)$ which is a function of AP index $i$ and beacon interval index $j$. The vacant spectrum of AP $i$ in the $j$-th beacon interval ($1 \leq j \leq L_i$) is the spectrum not used by the interfering APs of AP $i$ that are in their ACPs. For example, in Fig. 3(b), the vacant spectrum of AP1 in the 3rd beacon interval is 0-40MHz since 40-60MHz is used by AP3. Note that only interfering APs in their ACPs, not the entire interfering APs, are considered for the calculation of the vacant spectrum. Correspondingly, we define the Widest Remaining Channel (WRCh) as the channel with the widest bandwidth in the vacant spectrum.

As a solution to the channel synchronization problem, we propose the Move-to-WRCh algorithm as shown in Algorithm 2. Given the interference relation between APs, the Move-to-WRCh algorithm first checks the superframe structure of each AP to find whether the channel synchronization problem occurs. When it happens, each AP involved in the problem is either in the WCP or in the ACP. The Move-to-WRCh algorithm makes the APs in the WCP use the WRCh. At first, all APs are sorted in descending order of $L_{WCP}$. Then the channel to be used in each beacon interval is adjusted, considering the interference between APs. In a beacon interval of the WCP, when there is no interfering AP in the ACP, the WCh is used (step 8). In contrast, the WRCh is chosen if there are interfering APs in the ACP (step 10). In an ACP, APs are forced to use the ACh in every beacon interval (step 14).

![Algorithm 1 LCM-scaling](image)

1. $A=$set of APs in a component $\{AP_1, ..., AP_n\}$
2. $(L_{SF}^1, L_{WCP}^1, L_{ACP}^1)$ of $AP_1$
3. $L_C=$LeastCommonMultiple$(L_{SF}^1, ..., L_{SF}^n)$
4. for $i=1..n$ do
5. $\alpha_i=L_C/L_{SF}^i$
6. $L_{SF}^i \leftarrow L_C$
7. $L_{WCP}^i \leftarrow \alpha_i \times L_{WCP}^i$
8. $L_{ACP}^i \leftarrow \alpha_i \times L_{ACP}^i$
9. end for

![Algorithm 2 Move-to-WRCh](image)

1. $A=\{AP_1, ..., AP_n\}$ in ascending order of $L_{WCP}$
2. Input: superframe of each AP
3. $L_C=$superframe length
4. $j=$beacon interval index ($1 \leq j \leq L_C$)
5. for $AP_i \in A$ do
6. for $j = 1 \ldots L_{WCP}^i$ do
7. if no interfering AP in the ACP then
8. Use the WCh
9. else
10. Use the WRCh of $AP_i$
11. end if
12. end for
13. for $j = (L_{WCP}^i + 1) \ldots L_C$ do
14. Use the ACh of $AP_i$
15. end for
16. end for

In Fig. 3(b), the channel synchronization problem occurs in the 3rd and 4th beacon intervals. In the 3rd beacon interval, AP3 is in the ACP using the ACh (40-60MHz). Therefore, AP1

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As mentioned in Section III, the network topology can be modeled as a graph where there is an edge between two interfering APs. We partition the network (the graph) into several components. A component is defined as a group of APs (vertices) which are connected to each other.
and AP2 have to avoid having the ACh of AP3. As a result, they use the WRCCh (0-40MHz) as in Fig. 3(c). Similarly in the 4th beacon interval, the AP1 uses the channel of 0-20Mhz since AP1 has to avoid using the channels for AP2 and AP3.

V. Simulation

We evaluate our proposed scheme for two topologies: Grid Topology and Random Topology. In the grid topology, APs are deployed in the form of a square array. As a result, the number of APs is always a square number [5]. In the random topology\(^7\), we place APs randomly in a square area of 500m × 500m, and the minimum distance between any two APs is larger than the transmission range of each AP which is set to 50m. The average number of users per AP is 8 in both topologies. Each topology is shown in Fig 4.

Since there are three non-overlapping channels of 20MHz in the standard WLANs, we assume that the total available spectrum is 0-60MHz (20MHz×3) for a fair comparison. We use two sets of available bandwidth options; set1=[5,10,20,40] MHz and set2=[5,10,20,40,60] MHz. In the simulation, we assign an ACh to each AP using the GreedyRaising(GR) algorithm in [3]. Then we measure the performance improvement achieved by our proposed scheme using the spectrum-per-AP (SPA) metric which is defined as the average channel bandwidth used by each AP.

Fig. 5 shows the results in the grid topology. In all cases, the SPA decreases until the number of APs reaches 16, then remains the same beyond that. This is due to the characteristic of the grid topology where most of APs except those at the side have four interfering APs with 16 or more APs. We can see that the proposed scheme outperforms the GR with the gains of 6MHz and 11MHz for the set1 and the set2, respectively. When the set2 is used, each AP can use the WCh of 60MHz in the WCP, resulting in a large performance improvement of 11MHz.

Fig. 6 gives the performance comparisons in the random topology. The proposed scheme shows a performance gain of approximately 5MHz when the set1 is used. In the case of using the set2, the performance gap reaches the maximum value of 13.6MHz with 30 APs, then decreases to 6.6MHz as the number of APs increases. This can be explained as follows. Each AP can use the WCh of 0-60MHz of set2 only when there is no interfering AP or all interfering APs as well as the corresponding AP are simultaneously in the WCP. However, as the number of APs increases, the probability of having no interfering AP declines in accordance with that. In addition, each AP is more likely to be in the ACP due to the increased

\(^7\)Pricisely, it is not a pure random topology in that there is a minimum distance constraint. However, our target system is an enterprise network where the deployment of APs can be controlled by the operator to some extent. In this case, it is unrealistic to have several APs in too small area, e.g., 5APs in an area of 3m × 3m, which could occur in a pure random topology.
i-users, leading to a less opportunity of using the WCh. As a result, the advantage of using the WCh of 60MHz continuously decreases as the network is getting denser.

VI. CONCLUSION

By leveraging the newly introduced concept of adaptive bandwidth, it is possible to change the allocated channel bandwidth adaptively. In this paper, we proposed a superframe structure to use different channels based on whether a user to be served is interfered or not. When serving interference-free users, the AP can use the widest channel without damaging the performance of the interfered users. In contrast, the assigned channel is used for the interfered users. In this way, the AP and the interference-free users can enjoy more spectrum. The channel synchronization problem occurs due to the difference between the superframe structures of APs, resulting in serious interference. To solve this problem, we proposed to use the Move-to-WRCh algorithm that tries to allocate the widest remaining channel rather than the widest channel. Through extensive simulations, we proved the performance improvement of our proposed scheme in the aspect of the average spectrum use per AP.

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