Channel Bonding in Short-Range WLANs

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Abstract—Channel bonding is one of the strategies considered in the IEEE 802.11ac amendment to improve the performance of Wireless Local Area Networks (WLANs). However, besides the obvious gains attainable from using wider channels in terms of higher achievable transmission rates, there are also several potential drawbacks that may seriously compromise the overall WLAN performance, most notably the higher probability to suffer from external interference. The goal of this paper is to assess the suitability of channel bonding for enhancing the performance of short-range WLANs, which are highly susceptible to external interference. We analytically model and evaluate the performance of the two channel access schemes proposed for the IEEE 802.11ac amendment that enable the use of channel bonding. The results show that for short-range WLANs, the use of channel bonding is able to provide a significant performance boost when the presence of external interference is low to moderate, specially if the dynamic bandwidth channel access scheme is enabled.

Index Terms—IEEE 802.11ac, channel bonding, static and dynamic bandwidth channel access, WLANs

I. INTRODUCTION

Multimedia communications between nearby multimedia devices, such as smart TVs, high definition video and music players, file storage servers, tablets, and laptops using Short-Range Wireless Local Area Networks (SR-WLANs), is one of the scenarios targeted by next generation IEEE 802.11ac-based WLANs [1], since SR-WLANs are able to offer high transmission rates and low power consumption. Typical scenarios can be desktop, room, and vehicular networks. Moreover, deploying multiple SR-WLANs allows for improving the spectrum utilization by channel reuse.

One of the strategies considered in IEEE 802.11ac WLANs that can be used to satisfy the performance requirements of multimedia applications in SR-WLANs is channel bonding [2]. Channel bonding simply consists in grouping several basic channels to obtain a wider one, which allows for higher transmission rates and throughput [3], [4].

In order to support channel bonding, two extensions for the default CSMA-based channel access scheme used in WLANs are being considered: the Static Bandwidth Channel Access Protocol (SBCA), which uses a fixed number of bonded basic channels and requires finding all those basic channels empty before starting a packet transmission; and the Dynamic Bandwidth Channel Access scheme (DBCA), which is able to dynamically adapt the channel width to the instantaneous spectrum availability [5], [6]. Moreover, to guarantee backward compatibility with devices that are not able to use channel bonding, control and management frames are transmitted only over a single basic channel, which is called the primary channel. The rest of the channels are referred to as secondary channels. For data transmission, one or more basic channels can be used, depending on the channel bonding capabilities of each transmitter and receiver pair. When the receiver is only able to use a single channel, only the primary channel will be used for data transmission.

In the case of SR-WLANs, the higher bandwidth provided by channel bonding can be specially advantageous for communicating multimedia data, without causing any interference on the neighboring WLANs. However, due to their small coverage, SR-WLANs are also prone to external interference coming from neighboring WLANs operating at a higher power in the same channels, since the interfering WLANs may not be able to hear ongoing transmissions from the SR-WLAN and start transmitting before the SR-WLANs transmission is over. This situation worsens when channel bonding is used, as the resulting wider channel exposes the SR-WLANs to a larger number of such interfering WLANs.

In this paper, we study exactly this tradeoff by evaluating the performance of SR-WLANs in presence of external interference when channel bonding is enabled. We develop an analytical model that is able to capture the relationship between different system parameters for both SBCA and DBCA channel bonding schemes. The analytical model is then used to investigate the cases and conditions in which each channel access scheme is effective, in terms of the number of channels bonded, the activity from the interfering wireless networks, and the position of the primary channel of the target SR-WLAN within the channel width. The presented analytical model is general enough to be able to highlight the relationships between the different parameters and the effect of tuning them, as well as to assess the negative impact that external interferers have on the network performance.

This paper is structured as follows. In Section II, both SBCA and DBCA schemes are described. The analytical model is presented in Section III. In Section IV, we provide graphical presentations of the throughput of each scheme for different values of channel bonding and system parameters to determine the conditions under which each scheme performs best. Finally, conclusions and some future directions are presented in Section V.

II. CHANNEL BONDING IN IEEE 802.11AC WLANS

An IEEE 802.11ac WLAN composed of a group of stations is considered. A set of predefined 20 MHz channels, to which
we will refer as basic channels hereafter, are at the disposal of the WLAN. When the WLAN is initiated, it selects a channel \( C \) of width \( W \), comprising a contiguous subset of the basic channels. The width \( W \) is selected based on the WLAN's capabilities and can take values from \( B = \{20, 40, 80, 160\} \) MHz, as specified by IEEE 802.11ac. In other words, the selected channel \( C \) can be composed of \( N \in \{1, 2, 4, 8\} \) basic channels. A single basic channel within \( C \) is set as the primary channel, and all the others are considered as secondary. The selected bandwidth, \( W \), is the maximum allowed channel width, from which a contiguous subset of channels containing the primary are selected for each transmission, based on their availability and the channel access scheme used. We denote the channel selected for transmission by \( c \subseteq C \), its width in MHz by \( w \leq W \), and the number of basic channels it contains by \( n \leq N \). The transmission channel also has to comply with the width specification of the standard, i.e., \( w \in B \). Note that the values of \( c, w, \) and \( n \) may change at each transmission. In contrast, \( C, W, \) and \( N \) are selected during the initialization and are fixed for all transmissions.

A. Channel Access Schemes

The two channel access schemes, SBCA and DBCA, share the same operation until their backoff counter reaches zero. When a node has a packet ready for transmission, it listens to the WLAN’s primary channel. Once the channel has been sensed free for the duration of an AIFS (Arbitration InterFrame Space), the node starts the backoff procedure by randomly initializing a counter. This counter will be decremented by one at each empty slot until it reaches zero, and the node starts transmitting. The channel on which the packet will be transmitted is selected based on the status of the basic channels, which are sensed for a time equal to PIFS (Point coordination function Interframe Space) before the backoff counter reaches zero. Based on the channel access scheme, the channel \( c \) is selected as follows:

- **SBCA**: If all the basic channels included in \( C \) have been empty during the PIFS period, a packet transmission over the entire channel width will be initiated, i.e., \( w = W \), or equivalently, \( c = C \). Otherwise, the current transmission is deferred, and the entire procedure is repeated.

- **DBCA**: From the subset of channels that have been detected empty during the PIFS period, the largest contiguous subset that has one of the allowed widths in \( B \) and includes the primary channel is chosen and used for the next transmission.

In Figure 1, the operation of the two schemes is shown for a specific case in which the primary channel is always empty. Unlike SBCA, DBCA is able to transmit more often, although not always using all the basic channels in \( C \). Note that if any interference appears in a basic channel during a transmission, it may corrupt the ongoing packet transmission resulting in

![Temporal evolution of the SBCA and DBCA schemes](image-url)

Fig. 1. Temporal evolution of the SBCA and DBCA schemes. In the Figures, P indicates the primary and \( S_i \) the secondary channels. The PLCP protocol data unit (PPDU) is depicted in blue.
transmission errors.

B. Position of the Primary Channel in DBCA

When the DBCA scheme is used, the position of the primary channel within $C$ affects the performance. Selecting a channel in the center of $C$ as the primary channel, increases the chances of finding larger contiguous sets of basic channels that include the primary, as shown in Figure 2. For example, for $W = 160$ MHz, by positioning the primary channel on the 4th basic channel within $C$, we can obtain two channels of $w = 40$ MHz and two of $w = 80$ MHz, instead of only one of each if we place the primary channel at the extremes of $C$.

III. SYSTEM MODEL AND PERFORMANCE ANALYSIS

We focus on a single SR-WLAN in which all nodes are able to transmit and receive packets using a channel width of $W$ MHz. The target SR-WLAN is assumed to be surrounded by a group of other WLANs operating at the normal transmission range (i.e., using a higher power than the target WLAN), as shown in Figure 3. We assume that the SR-WLAN is able to find an empty basic channel, where it places the primary channel. We also assume that all the secondary channels in $W$ are occupied by one or more of the interfering WLANs. These two assumptions allow us to build a simple scenario where the tradeoff between the potential advantages (i.e., higher transmission rates) and drawbacks (i.e., higher packet error rates) of channel bonding can be clearly assessed through a comparison with a reference scenario in which channel bonding is not used. When the primary channel is assumed to be empty, the achieved performance of the reference scenario is independent of the external interference activity.

Moreover, for the target WLAN, a single saturated transmitter is considered, i.e., it always has packets ready for transmission. This means that there will be no collisions on the primary channel of the target SR-WLAN, and therefore, we consider that it will always stay in the first backoff stage.

A. External Interferers’ Behavior

The duration of the active and inactive periods of the other WLANs is assumed to be exponentially distributed. In reality, it is difficult to know the exact behavior of the neighboring WLANs, however, the exponential distribution is suitable to model highly random behavior and is commonly adopted in similar scenarios, as it greatly simplifies the analysis [7]. Consequently, the activity in each secondary channel, can be modeled using a two-state Markov chain. A secondary channel will be in the free state if none of the WLANs operating in it are transmitting. Otherwise, the secondary channel will be in the busy state.

To avoid unnecessary complexity, we consider that the activity in all secondary channels from external interferers is homogeneously distributed among them. Moreover, the busy and free periods in secondary channels are assumed to be exponentially distributed with parameters $\lambda_b$ and $\lambda_f$ respectively. Therefore, thefractions of time that the channel is busy and free are respectively

$$p_b = \frac{\lambda_f}{\lambda_f + \lambda_b}$$
and

$$p_f = 1 - p_b,$$

and the average duration of busy and free periods are $T_b = \frac{1}{\lambda_b}$ and $T_f = \frac{1}{\lambda_f}$ respectively.

Finally, the probability that the transmitter of the target SR-WLAN finds a secondary channel empty for the last PIFS seconds of its backoff procedure is

$$\theta = p_f e^{-\lambda_f \text{PIFS}}$$

(1)
B. Performance Analysis

The throughput for channel access scheme $\psi \in \{\text{SBCA, DBCA}\}$ when the primary channel is in position $k \in \{1, \ldots, N\}$ within $C$ is calculated as follows

$$S^\psi_k = \frac{1}{1 - \alpha^\psi} \left( \sum_{n=1}^{N} \phi^\psi_{n[k,N]} \beta(n, L) L \right)$$

(2)

where $\phi^\psi_{n[k,N]}$ is the probability that a transmission is done using $n$ basic channels, when the primary channel is the $k$th out of the $N$ basic channels in $C$. $\beta(n, L)$ is the probability that the transmission of a packet of length $L$ bits over the $n$ selected channels has not been corrupted by interference (i.e., all the channels used to transmit this packet have remained free for the entire transmission time). Therefore, the numerator expression gives the expected number of bits successfully transmitted per channel attempt. Finally, $D^\psi(n, L)$ is the expected transmission delay of a channel attempt. Therefore, the denominator in (2) is the total expected time spent per attempt. $D^\psi(n, L)$ is given by:

$$D^\psi(n, L) = \frac{1}{1 - \alpha^\psi} (\text{AIFS} + T_{\text{backoff}} + T(n, L))$$

(3)

where $\alpha^\psi$ is the probability that a transmission is deferred due to channel unavailability, and therefore, $1/(1 - \alpha^\psi)$ is the expected number of attempts required for a successful channel access. $T_{\text{backoff}}$ is the average time spent in backoff at each attempt. Finally, $T(n, L)$ is the packet transmission duration, which is

$$T(n, L) = T_{\text{PHY}} + \left[ \frac{\text{SF} + (\text{MH} + L) + \text{TB}}{L_{\text{DBPS}}(n)} \right] T_s +$$

$$+ \text{SIFS} + \left[ \frac{\text{SF} + \text{ACK} + \text{TB}}{L_{\text{DBPS}}(1)} \right] T_s$$

(4)

where $T_{\text{PHY}} = 40\mu s$ is the duration of the PHY-layer preamble and headers, and $T_s = 4\mu s$, the duration of an OFDM (Orthogonal Frequency Division Multiplexing) symbol. SF is the service field (16 bits), MH is the MAC header (288 bits), TB is the number of tail bits (6 bits), and L_ACK is the ACK length (256 bits). $L_{\text{DBPS}}(n) = N_m N_c \xi(n)$ is the number of bits in each OFDM symbol, where $N_m$ is the number of bits per modulation symbol, $N_c$ is the coding rate, and $\xi(n)$ is the number of data subcarriers when $n$ basic channels are bonded together. The utilized values are from the IEEE 802.11ac standard [2].

Since the capture effect is not considered and the primary channel is assumed to be always free, the probability that a packet is not corrupted by interference is the probability that no secondary channel changes from the free to the busy state during the packet transmission, which is given by:

$$\beta(n, L) = e^{-(n-1)\lambda} T(n, L)$$

(5)

In the next subsections, $\phi^\psi_{n[k,N]}$ and $\alpha^\psi$ are derived for each channel-access scheme.

C. SBCA

In this case, $\alpha^\text{SBCA} = 1 - \theta^{N-1}$, which is the probability that at least one secondary channel of $N$ is detected busy when the backoff counter reaches zero.

To find $\phi^\text{SBCA}_{n[k,N]}$, we have to take into account that SBCA only transmits when all channels are free, which means that $n = N$. Therefore, the position of the primary channel becomes irrelevant, and we get

$$\phi^\text{SBCA}_{n[k,N]} = \begin{cases} 1, & n = N, \forall k \\ 0, & \text{otherwise} \end{cases}$$

(6)

D. DBCA

For DBCA, even if all secondary channels are busy, the primary channel can be selected as the transmission channel ($n = 1$ is a valid choice for DBCA). Therefore, $\alpha^\text{DBC} = 0$, since the primary channel is assumed interference free.

Furthermore, the position of the primary channel is relevant in this case. The probability to make a transmission using $n \leq N$ basic channels for DBCA is the probability to find a contiguous set of $n \in \{1, 2, 4, 8\}$ free basic channels containing the primary (recall that the transmission channel width, $w$, is required to be in $B$). This is the probability that, of the $N$ basic channels considered, at least $n$ but no more than $2n - 1$ are free (because if $2n$ are free, the selected channel can be of length $2n$ instead of $n$), i.e.,

$$\phi^\text{DBC}_{n[k,N]} = \sum_{l=n}^{\min(2n-1,N)} p[l|k,N]$$

(7)

Here $p[l|k,N]$, is the probability that a contiguous set of exactly $l$ basic channels containing the primary are empty, given by

$$p[l|k,N] = \theta^{l-1} (b_2(l) + (1 - \theta)b_1(l) + (1 - \theta)^2 b_0(l))$$

(8)

where, for given $k$ and $N$, $b_i(l)$ is the number of possible contiguous sets containing $l$ basic channels, including the $k$th, within $C$ that share $i$ of their boundaries (leftmost and rightmost basic channels in each set) with $C$. In other words, $b_0(l)$ is the number of possible sets of $l$ basic channels containing $k$ that do not contain neither the 1st nor the $N$th basic channel in $C$, $b_1(l)$ is the number of such sets that contain either the 1st or the $N$th basic channel (but not both), and finally, $b_2(l)$ is the number of such sets that contain both the 1st and the $N$th basic channels in $C$. They are computed as follows:

$$b_2(l) = I\{l = N\}$$

$$b_1(l) = I\{l \neq N\} (I\{k \leq l\} + I\{k > N - l\})$$

$$b_0(l) = [\min(k, N - l) - \max(2, k - l + 1) + 1]^+$$

where $I\{x\}$ is the indicator function, which is equal to 1 when the condition $x$ is true and is 0 otherwise, and $[x]^+$ is the non-negative part of $x$, which is equal to $x$ when $x \geq 0$ and is zero otherwise.
Unless the contrary is stated, the values for the parameters used by both the target SR-WLAN and the interfering WLANs are shown in Table I. The interfering WLANs are not using channel bonding, and therefore, each one is only active over a single basic channel (i.e., \( n = 1 \)). Hence, the busy period of the external interference in each basic channel is equivalent to the duration of a transmission by an interfering WLAN, which from (4) is equal to \( T_b = 0.316 \) ms.

A simulator developed from scratch in MATLAB has been used to validate the analytical results. In Table II, we present some specific examples to show the accuracy of the model with respect to the simulations. However, in the figures shown in this section, only the analytical results are plotted, since the curves obtained from simulations are so close to the analytical ones that the difference is not graphically appreciable.

Figure 4 shows the throughput achieved by the DBCA scheme as a function of the position of the primary channel for \( W = 160 \) MHz and several \( p_f \) values. Note that the SBCA scheme is not included in the figure because its performance is not affected by the position of the primary channel. In contrast, for the DBCA scheme, as seen in Section II, placing the primary channel on the center of \( C \) (i.e., \( k = \lfloor N/2 \rfloor \)), increases the chances of finding a wider channel. However, for low \( p_f \) values, using a wider channel may be detrimental in terms of throughput since it increases the probability that a transmission is corrupted by external interference, and the extra packets that can be transmitted per second do not compensate for the higher rate of packet loss.

Figure 5 shows the throughput versus \( p_f \), the probability that a secondary channel is free, achieved by the SBCA (Figure 5(a)) and DBCA (Figure 5(b)) schemes for different values of \( W \). The different values of \( p_f \) can be viewed as an indicator of the external interference activity in each secondary channel. In all the curves related to the DBCA scheme, the primary channel has been placed in the position that maximizes the throughput (i.e., \( k = \lfloor N/2 \rfloor \)). As observed, for any given \( W \), the DBCA scheme outperforms the SBCA scheme for all \( p_f \) values. In detail, using the SBCA scheme, channel bonding is effective for \( W = 40 \) MHz when \( p_f > 0.75 \), for \( W = 80 \) MHz when \( p_f > 0.82 \) and for \( W = 160 \) MHz when \( p_f > 0.90 \). For the DBCA scheme, channel bonding is effective for \( W = 40 \) MHz when \( p_f > 0.65 \), for \( W = 80 \) MHz when \( p_f > 0.70 \) and for \( W = 160 \) MHz when \( p_f > 0.75 \). As observed, in both cases, the value of \( W \) that maximizes the throughput increases with \( p_f \). Moreover, using the DBCA scheme, the difference in throughput achieved using the optimal \( W \) value

### Table I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of data subcarriers (for ( n = 1, 2, 4, 8, ) respectively)</td>
<td>( \xi(n) )</td>
<td>52, 108, 234, 468</td>
</tr>
<tr>
<td>Modulation (64-QAM)</td>
<td>( N_m )</td>
<td>6 bits</td>
</tr>
<tr>
<td>Coding Rate</td>
<td>( N_c )</td>
<td>3/4 bits</td>
</tr>
<tr>
<td>Packet Size</td>
<td>( L )</td>
<td>12000 bits</td>
</tr>
<tr>
<td>Backoff Contention Window</td>
<td>( CW )</td>
<td>16 slots</td>
</tr>
<tr>
<td>Average time spent in backoff</td>
<td>( T_{\text{backoff}} )</td>
<td>( \frac{9}{\mu s} )</td>
</tr>
<tr>
<td>AIFS</td>
<td>-</td>
<td>34 ( \mu s )</td>
</tr>
</tbody>
</table>

### Table II

Model Validation: Specific cases and Results. A single simulation has been executed for each case. The duration of the simulation was 500 seconds.

<table>
<thead>
<tr>
<th>Parameters for the SR-WLAN</th>
<th>Protocol</th>
<th>Primary Chl.</th>
<th>Throughput (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Simulation</td>
</tr>
<tr>
<td>( W = 40 ) MHz, ( L = 10 ) Kbits</td>
<td>SBCA</td>
<td>1</td>
<td>2.168</td>
</tr>
<tr>
<td>( p_f = 0.24311, T_b = 0.316 ) ms</td>
<td>DBCA</td>
<td>2</td>
<td>22.89</td>
</tr>
<tr>
<td>( W = 80 ) MHz, ( L = 10 ) Kbits</td>
<td>SBCA</td>
<td>2</td>
<td>7.764</td>
</tr>
<tr>
<td>( p_f = 0.5, T_b = 0.316 ) ms</td>
<td>DBCA</td>
<td>2</td>
<td>29.72</td>
</tr>
<tr>
<td>( W = 160 ) MHz, ( L = 100 ) Kbits</td>
<td>SBCA</td>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td>( p_f = 0.24311, T_b = 2 ) ms</td>
<td>DBCA</td>
<td>4</td>
<td>48.03</td>
</tr>
<tr>
<td>( W = 160 ) MHz, ( L = 1000 ) Kbits</td>
<td>SBCA</td>
<td>4</td>
<td>381.2</td>
</tr>
<tr>
<td>( p_f = 0.8, T_b = 2 ) ms</td>
<td>DBCA</td>
<td>4</td>
<td>203.3</td>
</tr>
</tbody>
</table>

**Fig. 4.** Throughput of the SR-WLAN versus the position of the primary channel, \( k \). The \( W = 20 \) MHz curve represents the case when channel bonding is not used.

IV. Performance Evaluation

The differences in throughput achieved using the optimal \( W \) value...
and the throughput achieved using $W = 160$ MHz is small, which shows the adaptation capabilities of the DBCA scheme to the activity of the external interference in each secondary channel. Therefore, with the DBCA scheme, using $W = 160$ MHz seems a simple but effective solution, regardless of the activity level in secondary channels given that channel bonding is effective. On the other hand, if the SBCA scheme is considered, the use of a mechanism to dynamically select the optimal $W$ based on $p_f$ is recommended.

Figure 5 shows the throughput for the SBCA and DBCA schemes versus $T_f$, the expected duration of the free period of the interferers for $W = 160$ MHz and several $p_f$ values. Since for each plotted curve, $p_f$ is fixed, $T_b$ varies proportionally with $T_f$. In all the curves related to the DBCA scheme, the primary channel has been placed in the position that maximizes the number of possible channel bonding combinations (i.e., $k = \lfloor N/2 \rfloor$). As can be observed, when the secondary channels have longer free and busy periods, both SBCA and DBCA schemes perform better compared to the case where the secondary channels alternate rapidly between both states. For small $T_f$ values, not using channel bonding is recommended. Otherwise, the DBCA scheme is always the best option.

Finally, we investigate the impact of the packet size in the system performance. Figure 7 shows the throughput versus $L$, the packet size, achieved by SBCA and DBCA schemes for $T_b = 0.316$ ms, $W = 40$ and 160 MHz, and different values of $p_f$. It can be observed that there is an optimal packet size in terms of throughput, and that the optimal packet size increases with $W$. However, the most remarkable observation is that SBCA outperforms DBCA for a wide range of packet size values when $p_f$ is high. This is justified by the fact that when large packets are transmitted, the extra transmission duration by using less than $C$ channels may be significant. This extra delay has two negative effects. First, it increases the chances to suffer from external interference, and second, it reduces the transmission attempt rate of the SR-WLAN (i.e., the number of transmissions per unit of time). Therefore, for large packet sizes, it is better for the SR-WLAN to wait until all the channels are empty (i.e., using SBCA) than transmitting as soon as possible but using less channels (i.e., using DBCA).

V. CONCLUSIONS AND FINAL REMARKS

In this paper, we have assessed the suitability of channel bonding for SR-WLANs in presence of external interferers. To evaluate the system performance, we have developed an analytical model able to capture the relationship between different system parameters such as the number of channels bonded, the activity from the interfering wireless networks, and the position of the primary channel of the SR-WLAN. The results show that channel bonding is an effective solution for enhancing the performance of SR-WLANs when
the presence of external interference is low to moderate. Using a wider channel increases the chances to suffer from external interference. However, it also allows for faster transmissions, which compensates for the negative impact of the external interference. It was also observed that the DBCA scheme outperforms the SBCA scheme in most of the cases, since it is able to adapt the channel width to the instantaneous spectrum occupation.

The use of channel bonding in combination with the other mechanisms defined in IEEE 802.11ac, such as multi-user beamforming and packet aggregation is still an open challenge. In this respect, several new tradeoffs need to be considered. For instance, for a given transmission power, the use of wider channels implies that the signal to noise ratio per subcarrier will be lower, which may require the selection of more robust modulation schemes and coding rates, and the gain in throughput obtained by the former may be lost by the latter. Furthermore, when multi-user beamforming is considered, the use of wider channels requires a larger amount of Channel State Information to be fed back from the stations to the Access Point, hence increasing the network overheads. Finally, packet aggregation is needed to reduce the high frame and protocol overheads and fully achieve the gains that channel bonding is able to provide. However, it may not be a good solution if the secondary channels have a high alternating rate between busy and free states, as in such a case transmissions containing multiple packets have a higher chance of being corrupted by the external interference. The aforementioned tradeoffs need to be carefully studied in order to determine the appropriate configuration parameters in each specific scenario.

Other directions for future work include the assessment of the presented results in a test-bed, and the design of channel selection, channel switching and power control mechanisms for SR-WLANs.

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