Using Partially Overlapped Channels in Wireless Meshes

Extended Abstract

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I. INTRODUCTION

The IEEE 802.11 (a/b/g) based networks operate in the unlicensed ISM band in the 2.4 Ghz and 5 Ghz frequencies. The 2.4 Ghz band is divided into 11 channels with the channel number indicating the center frequency. For example, channel 1 is at 2.412 Ghz. The basic 802.11 and the 802.11b extension use the Direct Sequence Spread Spectrum (DSSS) which takes about 22 Mhz of bandwidth on each side of the center frequency. However, the channel center frequencies are spaced only 5 Mhz apart. Thus, a single channel overlaps with upto 4 successive neighboring channels. As a result, the 2.4 Ghz ISM band has only 3 non-overlapping channels, namely channels 1, 6 and 11.

The overlap among adjacent channels is typically detrimental in nature. For example, a transmission on channel 1 will interfere with transmissions in the vicinity on an adjacent channel such as channel 2 or 3. Such type of interference is termed *adjacent channel interference*. In order to avoid such interference, network designers tend to use only non-overlapping channels in their wireless network. For example, prior research on channel assignment in wireless meshes [1], [2], [3], [4], [5], [6], [7] and wireless LANs [8], [9] has focused solely on using a given set of non-overlapping channels. In this writeup, we demonstrate the possibility of carefully taking advantage of this partial overlap among channels in wireless mesh scenarios.

II. ADJACENT CHANNEL COMMUNICATION

Consider a simple experiment where a transmitting station is placed on channel 6, and a receiving station is moved from channel 1 through 11. The two stations are placed in close proximity to each other to preclude effects of signal attenuation due to distance. Table I shows the signal-to-noise ratio (SNR) of the received signal on channels $1 \ldots 11$. The SNR is normalized to a scale of $0 \ldots 1$ with 1 denoting the maximum signal received and 0 the minimum (indicating background noise level). We can see that the interference between channels 1 and 6, and channels 6 and 11 is minimum – hence they are considered non-overlapping. However, there exist other channel pairs (eg:- $\langle 2, 6\rangle$ and $\langle 6, 10\rangle$) where the interference is fairly low.

We define a term *Interference-factor* or simply *I-factor* denoted by $I(i, j)$ as the *extent* of overlap between channels i and j. If P_i denotes the power received at a given location of a particular signal, and P_j denote the power received of the same signal at the same location on channel j, then $I(i, j)$ is defined as $\frac{P_i}{P_j}$. $I(i, j)$ gives the fraction of a signal's power on channel j that will be received on channel i. Table I thus shows $I(i, 6)$ normalized to a scale of $0 \ldots 1$. I-factor shown here was calculated empirically and does not depend on the radio propagation properties of the environment (i.e. open space or indoors). It depends on the extent of frequency overlap between the signals on channels i and j after they have suffered degradation due to radio propagation.

We now discuss the concept of I-factor from a signals and communication perspective. The Direct Sequence Spread Spectrum (DSSS) communication method takes a narrow-band signal and combines it with a spreading code to produce a wide-band signal which is tolerant to interference effects. As a result this signal spreads to about 22 Mhz on each side of the center frequency for DSSS.

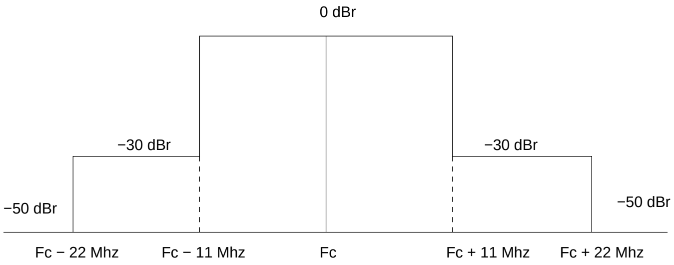

Fig. 1. Transmit Spectrum Mask.

Figure 1 shows the transmit spectrum mask which is *applied* onto the outgoing signal in a regulatory fashion. At the center frequency, the mask is set to 0 dBr^1 – the output power is equal to the input power and the signal is passed unaffected. At frequencies beyond $Fc + 11$Mhz and $Fc - 11$ Mhz, the power is attenuated down by -30 dBr and further to -50 dBr at $Fc \pm 22$Mhz, where Fc is the center frequency for the

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[1] Relative power in $dBr = 10log(P_{out}/P_{in})$.

Channel	1	2	3	4	5	6	7	8	9	10	11
Normalized SNR (I-factor)	0	0.22	0.60	0.72	0.77	1.0	0.96	0.77	0.66	0.39	0

TABLE I

TABLE SHOWS THE SIGNAL-TO-NOISE RATIO (SNR) NORMALIZED TO A SCALE OF $0 \dots 1$ OF THE TRANSMISSION MADE ON CHANNEL 6 AS RECEIVED ON CHANNELS $1 \dots 11$. WE CALL THIS QUANTITY *I-factor*.

channel c. Note that this transmit spectrum mask is ideal and in reality only a continuous trigonometric approximation is achieved. The corresponding receiver uses a bandpass filter centered around Fc with a spread of 22 Mhz on either side.

Based on this ideal transmit power distribution shown in Figure 1 and assuming an ideal bandpass filter at the receiver side we can perform an idealistic calculation for I-factor. As the receiver is progressively moved from the center frequency onto adjacent channels, this reduces the overlap of the bandpass filter with the spectrum mask. Figure 2 plots the ideal and the empirically calculated values for I-factor. The ideal values were calculated using the area under the intersection of the transmit mask shown in Figure 1 and the ideal band pass filter. The empirical values were determined using experiments discussed earlier in this section.

Conceptually, transmission on a adjacent channel j can be viewed on a channel i as a transmission with a reduced power given by the I-factor $I(i, j)$. The formulation given above can be used as idealistic for I-factor; however, this quantity can also be measured empirically as affected by the receiver radio characteristics.

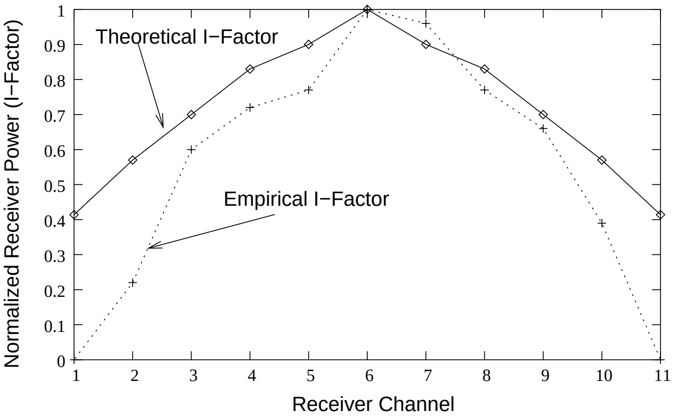

Fig. 2. Theoretical versus Empirically calculated I-Factor.

III. APPLICATIONS TO WIRELESS MESHES

We discuss three specific scenarios where partial overlap among channels can be useful:

Multi-channel Communication: We conduct the following simple experiment: Two nodes are placed on channels with decreasing overlap, and the UDP throughput is measured. One node was kept fixed on channel 6, while the other was progressively moved from channel 1 through 11. The nodes were configured at a datarate of 2Mbps. Figure 3 shows the plots at distances of 15 and 30 feet between the two nodes. Figure shows that the throughput achieved by communicating on an adjacent channel degrades gracefully as the overlap reduces. This can be closely modeled using the I-factor concept discussed in the previous section. The plot demonstrates how a partially overlapping channel can be used to communicate at the cost of reduction in the throughput. This allows a node with a single interface to communicate with nodes on two non-overlapping channels by operating on a channel that partially overlaps with both. We note that there are prior techniques most notably by [10] that rely on channel switching and power-save mode capability to communicate with nodes on different non-overlapping channels. Although this approach limits communication on the atmost two non-overlapping channels that have partial overlap with a node's current channel, it nevertheless imposes absolutely no overhead in terms of channel switching to enable such communication. This capability gives the network designer flexibility with routing and topology constraints in mesh networks.

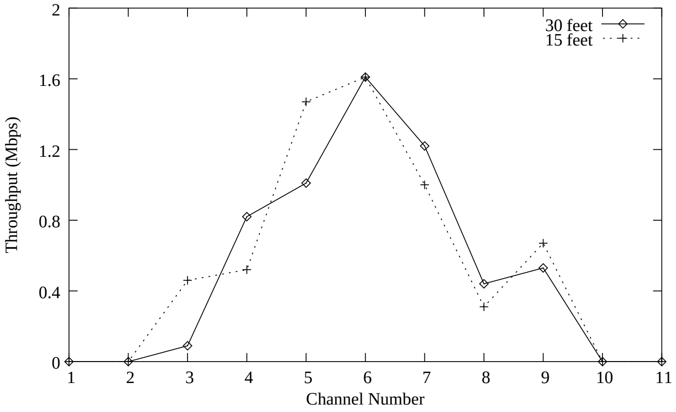

Fig. 3. Throughput versus channel separation.

Throughput improvements using partially overlapping channels: Apart from utilizing partially overlapping channels for topology flexibility in mesh settings, they can be applied to improve the throughput capacity of such networks. Consider the multihop setup shown in Figure 4. There are four nodes; each with a single radio interface. Because of this limitation, technically the network can utilize only one channel or the network would get partitioned. Say, nodes A, B and C are within communication range of each other. Nodes D and E are each within communication range of nodes A,B and C. The transmission ranges of nodes A,B and C are shown using dashed circles. With all nodes operating on a single channel to prevent network partition, each node shares the channel with two other nodes, thus achieving roughly $1/3$rd of the maximum available bandwidth on one channel.

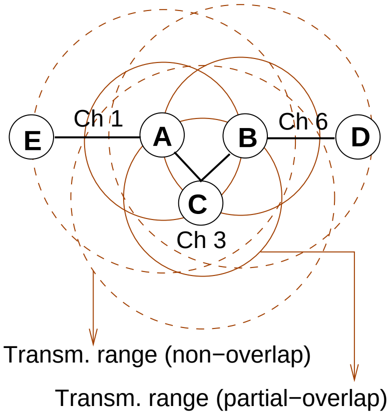

Fig. 4. Example multihop scenario.

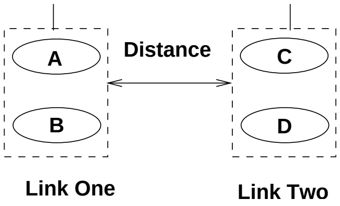

Fig. 5. Experimental setup to demonstrate channel re-use.

Now, using partially overlapping channels, an assignment can be performed as follows. Nodes A and E are assigned channel 1; nodes B and D are on channel 6. These links do not interfere with each other. Node C is placed on channel 4, which allows communication with both A and B. Channel 4 is chosen such that the reduction in the communication range as determined by the extent of overlap between $\langle 4, 6\rangle$ and $\langle 4, 1\rangle$ allows communication with both A and B. The network thus utilizes the maximum bandwidth available on two non-overlapping channels and hence this can result in significant throughput improvements.

Improving Channel Re-use: Two interfering links can be assigned partially overlapping channels rather than using up non-overlapping ones, thus improving the channel re-use in general. Figure 6 plots the UDP throughput achieved by an individual link in an experiment with two interfering links. Figure 5 shows the experimental setup. The plot studies the effect of spatial separation along with the channel separation. The legend *ChSep* indicates the separation in their channel of operation. A channel separation of 5 or more indicates non-overlap. In the case where both links are on the same channel, a separation of about 30 feet is required for them to not interfere with each other. However, it can be observed that this distance of non-interference is reduced as the channel separation is increased. For example, with a channel separation of 2, both links achieve the maximum throughput with a spatial separation of about 20 feet. Thus, a careful assignment of channels to the various links in a mesh network can significantly improve the overall channel re-use and thus bringing about better application perceived throughput. This assignment of channels and expected throughput gains can be modeled using the I-factor concept.

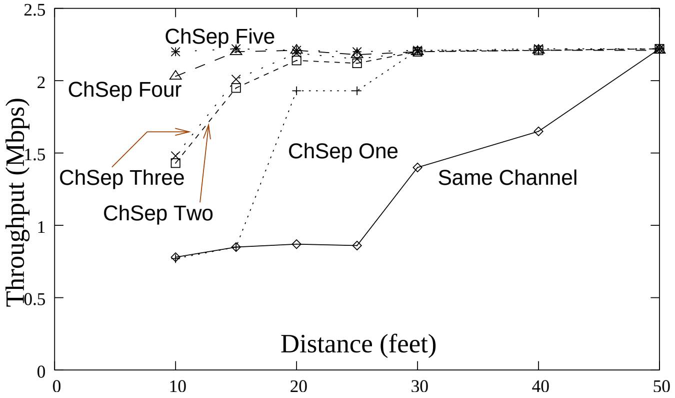

Fig. 6. UDP throughput of two interfering links as their channel separation and distance is increased.

IV. SUMMARY

This writeup has presented a novel approach of taking advantage of the partial overlap among channels which is otherwise traditionally seen as adjacent channel interference. Based on this discussion, a detailed study of how adjacent channels can be used in mesh scenarios based on the I-factor model and the tradeoffs involved is the next step to understanding the full potential of viewing channel assignment as a problem in the continuum.

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