Experimental Characterization of Interference in a 802.11g Wireless Mesh Network

Ashish Sharma, Ramya Raghavendra, Krishna Puttaswamy, Henrik Lundgren, Kevin Almeroth, Elizabeth Belding-Royer
Department of Computer Science
University of California Santa Barbara
Santa Barbara, CA 93106
Email: {asharma, ramya, krishnap, henrikl, almeroth, ebelding}@cs.ucsb.edu

***Abstract*— Multi-channel wireless networks are being studied as a means to increase wireless network capacity. The implicit assumption is that network throughput increases in direct proportion with the number of non-overlapping channels used. But there have been very few studies which have experimentally verified this premise. In this paper we characterize the performance of multi-channel wireless networks consisting of IEEE 802.11g devices. We conducted our experiments on a sample topology consisting of just two flows on non-overlapping channels. We expected the combined throughput of the two flows to double. However, our results showed that the expected increase in throughput is seen only when the separation between the antennas of the radio devices is above a threshold value. In our experimental setup, we observed a reduction of 25-40% in the expected total throughput value of the two flows. Further, we show that the effect of interference also varied with the transmission power of the radio devices and the packet size of individual flows. We believe that our results will be important when configuring a multi-channel wireless network using off-the-shelf devices.**

I. INTRODUCTION

Increasing popularity of wireless networks and the need to achieve faster data rates have created widespread interest in studies related to multi-channel multi-radio wireless networks. Future wireless networks need to cope with the growing demand for increased data rates and robustness. Even though multiple non-overlapping channels exist in IEEE 802.11 networks which operate in the 2.4GHz and 5GHz spectrum, most networks utilize only a single channel. As a result, the aggregate bandwidth available is not exploited fully [4]. Decreasing cost of radios has further motivated the design of communicating devices with multiple radios. Several architectures and routing schemes that show increased throughput on multi-radio multi-channel wireless mesh networks have also been proposed recently [4], [7] . They use efficient channel assignment schemes which relieve the interference effect of close-by transmissions; alleviate potential congestion on any gateways to the Internet, thereby improving per-client throughput [3], [6]. Multi-channel wireless mesh networks, consequently, are a promising solution to the “last mile” problem. Most of these networks are configured with the assumption that the non-overlapping channels do not interfere with each other. In IEEE 802.11g, channels 1, 6 and 11 are considered to be non-overlapping and hence the premise that these channels (or other sets with similar gaps) can be used such that multiple networks can operate in close proximity without interfering with each other [5].

This work is motivated by the need to investigate the potential interference in a subset of the nodes currently being deployed in the UCSB MeshNet Testbed [2]. The nodes of interest are comprised of two LinkSys WRT54g devices strapped together. One of these devices is a mesh node, while the other is a management node. The management node is connected to a WiFi network, and provides a means to connect to the mesh node and also perform out-of-band management. The two devices communicate with each other by means of an Ethernet cable. Both these devices operate on two non-overlapping channels so as to avoid interference between the management traffic from the WiFi network and the mesh network traffic. Due to their physical proximity, it is critical to investigate their cross-channel interference. We expect similar characteristics for other 802.11g devices that have multiple interfaces that are operating in parallel on different channels. With the advances in wireless technology, devices such as laptops and access points that are equipped with multiple radios which can communicate on multiple channels would be popular. Engim, Inc. already has such multi-channel wireless LAN chips that are designed to use three channels at a time [1]. These devices are built with the assumptions that there is no interference between multiple radios transmitting on non-overlapping channels. However, our experiments show that these assumptions are over-simplified in a network that has been configured using off-the-shelf devices and interference effects do exist when antennas are in close proxmity, even though they are transmitting on non-overlapping channels. For optimal performance, the network design must consider the separation between the antennas, the output power settings of the radios and their operating frequency ranges.

We conducted our experiments on a topology consisting of two transmitting and two receiving nodes, both operating on non-overlapping channels. The transmitters are placed close to each other and their separation varied, while keeping the distance between each of the transmitter-receiver pair constant. In one of the other experiments we also keep the receivers close by and measure the effect of varying distance between the two receiving antennas on the throughput achieved. Although one would not expect any interference between non-overlapping channels, experiments showed that there is interfernce when the transmitters or receievers are in close proxmity. The non-overlapping nature of the channels is true when the antennas are beyond a certain distance from each other.

The rest of the paper is organized as follows. In section II, we discuss the related work. Section III describes the experimental setup used in our experiments. The evaluation metrics and methodology are explained in Section IV. The results obtained are described in Section V. We present our conclusions and discuss fututre work in Sections VI.

II. RELATED WORK

There are very few studies that have experimentally measured the interference in multi-channel wireless networks. One such is the work by Liese et al wherein they study the relative performances of single and multiple channels in both single hop and multi hop wireless mesh networks [8]. In one of their experiments, they study the effect of antenna placement on the access point and determine the impact on performance. Their setup consisted of two ORiNOCO AP-2000 access points with internal PC card antennas less than one inch from each other. Observing unfavorable results even when the two access points were communicating on non-overlapping channels, they attached external antennas to the PC cards and varied the antenna proximity. They concluded that goodput varies significantly with antenna proximity. In our work, we do a more extensive and systematic study of the channel interference, taking into consideration various factors such as antenna separation, radio transmit-power and packet size. We have compared the interference effects in channels 1, 6 and 11. The effect of interference both at the senders and receivers has been studied.results obtained are described in Section 5. Sections 6 and 7 consist of conclusion and future work.

III. EXPERIMENTAL SETUP

The experiments were conducted with two Linksys WRT54Gv2.2 routers which are based on Broadcom 4712 board. They have a 200 MHz CPU, 4 MB flash and 16 MB DDR-SDRAM. The wireless NIC is integrated to the board. The switch is a BCM5325. The clients for our experiments were Dell Lattitude laptops running Red Hat 9 (2.4.20-8). They were equipped with IEEE 802.11 a/b/g PCMCIA network cards on the each of them. The laptops were running linux kernel 2.4.20-8 and MADWIFI wireless drivers.

The APs and laptops were arranged in a linear topology with the Laptops (acting as clients) on opposite extremes and the two APs placed in the middle. Each laptop was positioned 9 feet from the AP to which it was associated. Both the APs and the Laptops were placed 3 feet above the ground and within line of sight of each other. There were two flows set up, on combinations of channels 1, 6 and 11, each between an AP and a laptop as shown in Figure 1. Each flow was monitored using a sniffer running in monitor mode to capture the MAC layer traces on the two channels. These traces were later analyzed to study the number of retransmissions at the MAC layer. Iperf was used to generate UDP packets at a desired rate and to measure the throughput, packet loss and jitter.

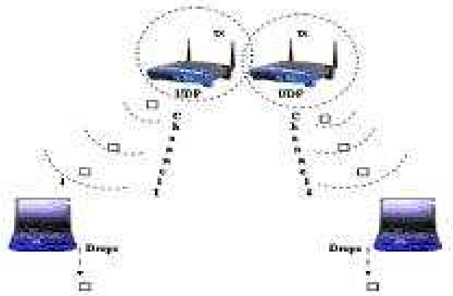

Fig. 1. Experimental Setup

The first set of experiments were conducted in an indoor conference hall and then repeated in an open space, with no radio interference from any other wireless network. In both the cases, we obtained similar results, verifying the validity of the effect observed.

In the above explained topology consisting of two flows, each between a Laptop-AP pair, two possible configurations exist: (a) When the transmitting nodes are placed close by and receivers on the two extremes. (b) When the receivers are placed close by and the transmitters on the two extremes.

We conducted experiments for both these configurations, by first setting the access points as traffic generators in iperf and the laptops as receivers and then reversing the roles. We show results for both these configurations in Sec V.

IV. EVALUATION METHODOLOGY

A. Performance Metrics

In our experiments we characterize the interference observed between non-overlapping channels based on the following three metrics:

Throughput: The amount of data excluding the protocol headers (payload) received successfully at the receiver per second.

Packet loss: The difference between the number of packets sent by the transmitter and the number of packets successfully received at the receiver.

Jitter: The inter-packet arrival time at the receiver, mainly attributable to the queuing delay on a link. The values of throughput, packet loss and jitter were determined using *iperf* - an open source bandwidth measurement tool [5].

We believe that throughout value calculated by *iperf*— can be treated as a fairly accurate measure of the raw wireless link capacity, as in the absence of RTS/CTS mechanism, the protocol header is a small fraction of the actual traffic.

Keeping in mind the future of wireless networks, as being capable of carrying multimedia traffic at high data rates, we also measured the effect of non-overlapping channel interference on jitter and packet loss.

We measured the effect on the above mentioned metrics by varying the following three factors: antenna separation, transmit power, packet size. The range of the parameters and their nominal values are shown in Table I.

TABLE I
FACTORS

Factors	Range	Nominal Value
Antenna Distance	0-5 feet	0-5 feet
Transmit Power	10 - 15 dBm	10 dBm
Packet Size	100 - 1470 Bytes	1470 Bytes
Interference measurement	Transmitter/ Receiver	NA

Other parameters which may have influenced the exact values of our experiments, and which we took of note of are shown in Table II. The standard configuration utility 'iwconfig' was used to measure the link quality, signal and noise level.

TABLE II
PARAMETERS

Parameters	Observed/Chosen values
Link Quality	28 to 60
Signal Level	-30 to -75 dBm
Noise Level	-95 dBm
Manufacturer	Linksys
Bit Rate	36 Mbps

Throughput, jitter and packet loss measurements were done for various values of antenna separation, transmit power and packet size. Antenna separation between the two transmitting radios ranging was varied between 0-5 feet at a 6 inch interval. Packet size of the UDP traffic was varied from very small to very large values of data payload (100/500/ 1000/1470 bytes). Each experiment was conducted for three transmit power settings (10/15/30 dBm) suitable for short, medium and large range wireless networks. Virtual carrier sensing mechanism (RTS/CTS) was disabled in all of our experiments and the bit rate left at a default value of 36Mbps. The experiments were repeated three times both at the indoor and outdoor locations, with similar results.

Since the results were more interesting for throughput, this paper focuses on the effect of interference in non-overlapping channels on the overall throughout.

B. Experiment Methodology

The experiments were conducted in an incremental fashion, first taking measurements individually for Flow 1 and Flow 2, followed by the case when both the flows operate on a common channel and finally when both operate on two non-overlapping channels.This was done to evaluate the advantages of using multiple channels on multiple radios over the use of a single channel, as a function of the separation between antennas, transmit power and packet size of the flows. The three sets of experiments are described in detail below:

(a) Single flow:

In the first set of experiments, we measured the maximum throughput of a single flow, without having any interference from other flows. The setup consisted of a single AP acting as the transmitter for UDP traffic and a laptop acting as client measuring throughput. The goal was to measure the maximum achievable throughput in our experimental settings. This served as a baseline for comparison with the throughput achieved during other experiments.

(b) Two flows on the same channel:

This is the setup shown in Figure 1, with both A-A' and B-B' on channel 1. The goal of this experiment was to measure and characterize the performance of two flows when they are on the same channel. In this case we expect the throughput of each flow to decrease significantly, due to contention on the same channel. This experiment also provided us the worst case value for throughput with maximum contention.

(c) Two flows on different channels:

This experiment has the same setup as in Figure 1, but this time A and A' were on one channel while B and B' were on a non-overlapping channel. This experiment was conducted in two stages: stage 1 had A and A' communicating on Channel 1 while B and B were communicating on Channel 6; stage 2 had A and A' communicating on channel 1 while B and B' were on Channel 11.

In this case, since the two flows are on non - overlapping channels, we do not expect any decrease in the throughput, however our results show that not only does interference exist between the two flows but also the effect of interference varies with antenna separation. We measure and characterize the level of interference between two flows when they are on non-overlapping channels, as a fucntion of distance between the APs, their transmit power and the packet sizes of the two flows.

V. EXPERIMENTAL RESULTS

Each experiment was conducted for 20 seconds and the results averaged to obtain the graphs. We found that for a given experiment, the results obtained were consistent across different runs. The results below have been classified based on the factor that was being varied.

A. Effect of varying antenna separation on throughput

In the setup shown in Figure 1, the APs were initially placed next to each other, with their antennas at distance 0. Both flows were on channel 1. UDP flows started at the APs at the maximum achievable rate and transmit power at the AP was 10dBM. Measurements were taken at the respective clients. The experiment was repeated after varying the distances between the APs.

Figure 2 shows the result of the experiments (a) and (b). The reference line named Peak is the throughput with a single flow and the reference line named 2 X Peak is two times the Peak value that indicates the total throughput achievable with two separate single flows. From Figure 2, it can be seen that the maximum throughput achievable is approximately 21Mbps with a single flow and the maximum throughput achievable is approximately 14 Mbps/flow in the presence of another flow on the same channel. This decrease in throughput is expected as the two flows now have to contend for the medium.

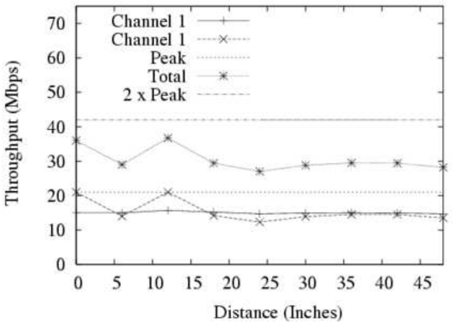

Fig. 2. Comparison of throughput with one flow and throughput with two flows, both on channel 1

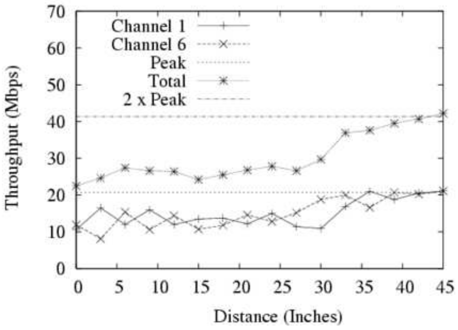

Fig. 3. Comparison of throughput when flows are on channels 1 and 6

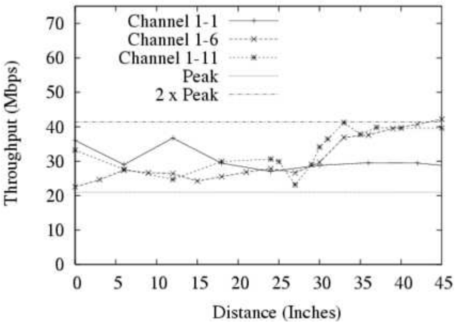

Fig. 4. Comparison of throughput with flows on channels 1-1, 1-6 and 1-11

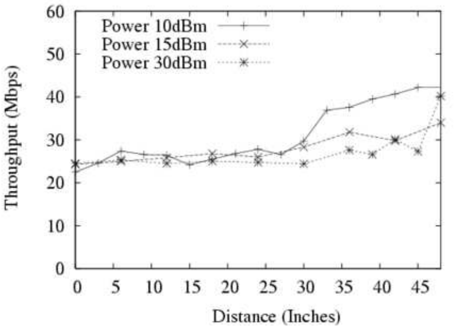

Fig. 5. Comparison of throughput on varying the tx power

The throughput remained nearly constant irrespective of the distance between the antennas, indicating that distance does not have an effect on the throughput as long as the APs are in the carrier sensing range. Another result which we observed was that just the presence of an AP, with no traffic being sent or received, does not affect the throughput on another flow which is within the AP's carrier sense range. The experiment was repeated after changing the channel used by B and B' to 6, while A and A' continued to be on channel 1. Initially, the UDP packets were of the maximum size, 1470 bytes. As can be seen from Figure 3, initial throughput was less than the maximum achievable throughput, but it increased steadily with increase in antenna separation. The two flows reach very close to the peak throughput value at approximately 33 inches.

The channel interference effects are evident from figure 3. For further understanding, we analysed the MAC layer traces that we collected using the snifffers. A large number of retransmissions were seen when there were two flows on non-overlaaping channels and antenna separation was small. This leads to an important conclusion that the sender on one channel does not sense the medium to be busy in the presence of another flow. The packet retranmissions indicates to us that a large number of packets were being corrupted in the medium at small separation between the antenna. When the throughput stabilises at around a peak value, the retransmissions also decrease implying that the interference effect fades with antenna separation.

Unlike the previous experiment where both flows were on the same channel 1, the peak value reached in this experiment was the equal to the peak value achieved with a single flow. The experiment was repeated after changing B and B' to channel 11. The goal of this experiment was to study if the interference effect is more between channels 1 and 6 as compared to channels 1 and 11. The comparison is shown in Figure 4.

It can be inferred from the Figure 4 that with simultaneous flows on multiple channels, the flows on different channels eventually reach a total throughput which is higher than the total throughput achievable when the two flows are on the same channel. Also, when using multiple channels, the flows reach a throughput which is the same as that achieved using single flow. The experiment confirmed our hypothesis that flows on channels 1 and 11 reach the max throughput earlier than flows on channels 1 and 6. These flows reach their peak rate at approximately 33 inches after which the throughput remains almost constant.

B. *Effect of varying power on the throughput*

The experiments were repeated for different values of transmission power. The tx power setting at the AP was varied using the wl utility, simulataneous flows were sent on channels 1 and 6 and the throughput was measured. The results obtained are plotted in Figure 5.

It can be inferred from figure 5 that at higher power, the distance at which the flows reach max throughput is higher. For transmit power of 10dbm, the peak throughput is reached when the antenna separation is 33 inches, where as for 30 dBm

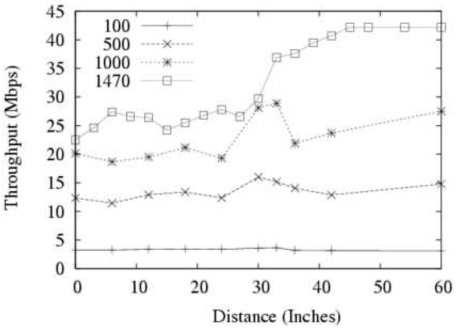

Fig. 6. Comparison of throughput varying the packet size

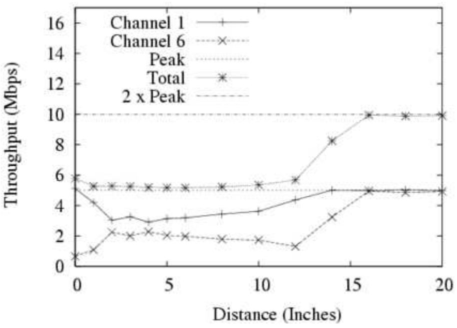

Fig. 7. Comparison of throughput with APs as receivers

the peak throughput is reached around 45 inches. Observing the MAC layer traces indicates that packet retransmissions increase in proportion to the power of the non-overlapping signal.

C. Effect of packet size on throughput

The next set of experiments was done for various sizes of the UDP packets. In the setup shown in Figure 1, A and A' were on channel 1 and B and B' were on channel 6. The throughput measurements on varying the packet sizes are shown in Figure 6. As can be seen in Figure 6, the interference effect increases with the increase in packet size. For very low packet sizes of 100 bytes, the interference effect was nearly zero, and for a maximum packet size of 1470 bytes, large interference effects were seen on the throughput.

On observing the MAC layer traces for this set of experiments, it was seen that the number of retransmissions increases with the increase in packet size. A possible explanation for this could be that the large packets have higher transmission times. This would inrease probablity of a packet corruption in presence of a packet from the non-overlapping flow.

D. Effect of interference at the receiver

All the previous experiments were conducted with the AP being the transmitter, sending data downstream to the laptop. In this experiment, we measured the interference effects when APs were receivers of UDP traffic. As can be seen from Figure 11, the aggregate throughput is low initially, and increases with the increase in antenna separation. At zero antenna separation, the aggregate throughput was only 60% of the throughput obtained in the absence of a second interfering flow. The MAC layer traces also show a large number of retransmissons at close antenna separations which imply that packets were being corrupted in the medium. One possible explanation of this could be that this drop is because the antennas are at distances on the order of the wavelength of the 2.4GHz signal. The result of this being that both antennas were absorb an in phase signal and are in effect dampening each other as they emit resulting magnetic fields that were in opposition of each other. However, more research is needed to confirm the same.

VI. CONCLUSION AND FUTURE WORK

Although much work is being done in efficient channel allocation schemes for multi-channel wireless mesh networks to obtain a performance gain, these studies do not consider the interference effects between the radios. Our experimental results show that there is a significant reduction in expected total throughput of two flows on non-overlapping channels, when the antennas of the communicating radios are placed in close proximity of each other. The performance of the radios depends on parameters like the antenna separation, transmit power and the packet size of the traffic flow. Our results also suggest a minimum distance between the radios operating on non-overlapping channels, required to achieve optimal performance on both channels. The next phase of our experiments will target at measuring the same effect in 802.11b and 802.11a networks.

We believe our results can be critical in the design of future multi-radio devices and multi-radio multi-channel wireless mesh networks using off-the-shelf components.

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