Exploring the effect of interference and mitigating it through Channel Hopping

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Abstract

We studied the impact on 802.11 networks of RF interference from non-compliant 802.11 devices such as wireless jammers that seek to disrupt 802.11 operation. Specifically, we analyzed the relation between the observed throughput at the receiver and the channels of operation of the sender-receiver pair and the interferer. Our experiments showed that the interference effect on the transmission causes the drastic decrease throughput if the interferer and the sender/receive are on the same channel. This leads us to explore channel-hopping as a way of mitigating RF interference.

We studied how continuously changing the channel of operation of the sender-receiver pair, after detecting the presence of the interferer, affects the observed throughput at the receiver. Our experiments show that by changing the current working channel to an orthogonal channel where there is no interference we can alleviate the effect of interference.

1. Introduction

Our reliance on wireless communications such as 802.11 is increasing. Wireless technology is now used as an alternative to wired networks in enterprises, to enable mobility in safety critical settings like hospitals, and to provide city-wide Internet access. In each of these cases, high network availability is desirable. Unfortunately, by their nature, wireless transmissions are vulnerable to RF (Radio Frequency) interference from various sources. This weakness is a growing problem for technologies that operate in unlicensed frequency bands, as these bands are becoming more crowded over time. 802.11b/g networks which use the 2.4GHz band now compete with a wide range of wireless devices that includes 2.4GHz cordless phones, Bluetooth headsets, Zigbee (IEEE 802.15.4) embedded devices, 2.4GHz RFID tags, and proprietary devices such as the ANT radios, Chipcon 2.4GHz RF transceivers and Cypress “WirelessUSB” peripherals.

Although the use of unlicensed bands does not require coordination between the deployers of devices, not all forms of device behavior is permitted. To promote coexistence, devices must meet a number of FCC regulations that limit transmission power and force transmitters to spread their signals. Wireless technologies often have mechanisms in their MAC and PHY layers that go beyond the basic FCC/ITU rules to improve coexistence. For example, 802.11 uses carrier sense to detect and defer to 802.11 and other transmitters. Similarly, Bluetooth adaptively hops frequencies to decrease interference on 802.11. However, unlicensed band coexistence and additional precautions have not prevented a range of interference problems across the *n*2 combinations of wireless technologies that may interact. In fact, there are reports of interference between technologies that are specifically designed to coexist (e.g., 802.11 and Bluetooth). Moreover, mechanisms for politely accommodating other transmitters, such as carrier sense in 802.11, can make technologies more susceptible to interference from other devices.

Our goal was to explore the impact of interference on 802.11 links and the efficacy of channel hopping mechanism in mitigating the

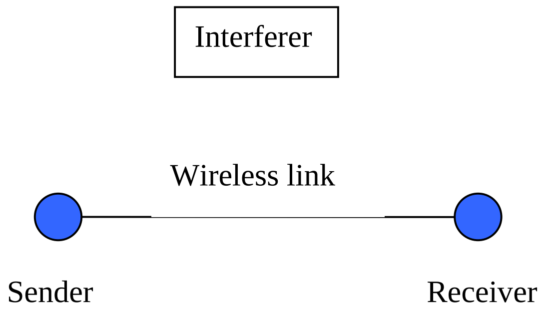

Figure 1: Experimental Setup

interference. We wanted to come up with answers for the following questions:

Given the eleven channels of 802.11b, and an interferer operating one channel "x"

1. What is the effect of interference on the observed throughput at the receiver, when the sender-receiver operate at channel "x".
2. Similarily, what will be the effect when the sender-receiver operate on channels other than "x".
3. What will be the observed throughput when the sender-receiver pair use channel-hopping while the interferer sends on a single channel?

We set up a 2 node adhoc network. The links are set up using high gain omni-directional antennas. We used the Soekris Engineering 4826 boards as our nodes with Voyage operating system installed in it. We used Ubiquiti XR2 wireless cards on our nodes. For the second part of our experiment, we implemented a channel hopping mechanism at the receiver and an algorithm by which the sender knows when the receiver has started channel hopping.

The rest of the report is organized as follows: In section 2 will be discussing about the hardware and softwares used, in section 3 we'll be describing the experiments that we have conducted and the results that we got, section 4 is the experiment where we are showing the solution in which we are changing the channel of sender and receiver to a steady channel where there is no interference, then we are concluding with the results that we got from the experiments that we have conducted.

2. Hardware and Software Used

2.1 Hardware Used

Our nodes are Soekris Engineering 4826 boards. Figure shows one such a board. It is actually a compact, low-power, low-cost, advanced communication computer and it is based on a 233 or 266 Mhz 586 class processor. It has one 10/100 Mbit ethernet ports, up to 256 Mbyte SDRAM main memory and uses a CompactFlash circuit soldered onboard for program and data storage. It can be expanded using up to two MiniPCI type III boards. It is economical in terms of form factor, cost and power as compared to conventionaly laptops. We powered these boards using POE (Power Over Ethernet) adapter.

We inserted Ubiquiti XR2 wireless cards into these Soekris boards for wireless communication. In each board, the wireless card was connected to an 8 dBi omni-directional antenna through a pig tail.
The interferer is a IBM thinkpad R60 laptop. An external Ubiquiti wireless card is inserted into this laptop's card slot and all wireless communication takes place through this interface. An 8 dBi antenna is connected to this Ubiquiti card.

In one of the experiments, we used Bluetooth devices as interferer. These were two mobile phones, with a data transfer going on between them as interferer.

2.2 Software Used

We use madwifi driver to control the various wireless parameters of the nodes. The communication between the sender and the receiver is a UDP flow that is generated by a program called "bwUDP" developed by Prof. Bhaskaran Raman. This program outputs the observed throughput when started in "receiver mode".

We use a patched version of Madwifi driver in the interferer. This patch basically CCA so that the interferer can send packets regardless of any other communication that may be going on.

Also, we modified the Madwifi driver, to generate packets with corrupted headers, so that any genuine 802.11 device does not identify the packets. In this way, the laptop is acting as a pure interferer. We also add a small program, in the madwifi code itself, which generates 5000 packets/second each of length 1000 bytes. This was enough to fill up the sending queue for 1 second. That's how we have designed saturated interferer which always has packets to send.

3. Experimental Setup and Methodology

We have conducted all our experiments in the networks lab of IITB which does not have any Wifi interference. The setup is shown in the Figure 1. The sender and the receiver are placed 8 metres apart from each other. The interferer is placed at 4 metres from both the sender and the receiver.

In all the experiments, a UDP flow is running between the sender and receiver nodes, which is done by using a program called "bwUDP" at both sender and receiver.

3.1 Experiments Conducted

We conducted the experiments in two stages. In the first stage, the experiments were meant for analyzing the effects of interference on the observed throughput. For this we varied the following parameters, of the nodes as well as the interferer:

1. Transmit Power
2. Data rate
3. 802.11 channel of operation

3.2 Experiment 1

Without interferer – Sender Power (vs) Number of packets received

The objective of this experiment was to observe the effect of sender transmit power on the number of packets received correctly by the receiver node, when no interfering device is present.

The two nodes(Soekris boards) were placed 1.5 meters apart from each other. No omni-directional antenna was used and only pigtails were connected to the wireless cards of the boards. The sender was sending at a rate of 1Mbps. Figure 2 indicates the results obtained:

From this we find that when the sender transmit power increases, the number of packets received at the receiver increases.

Technically, this experiment is not indicative of a real scenario as we have not used antennae. Only pigtails, which are only connectors, were connected to the cards. Hence the numbers obtained here should not be taken to be indicative of actual scenario but only as a proof of concept that number of packets increase with increasing sender transmit power.

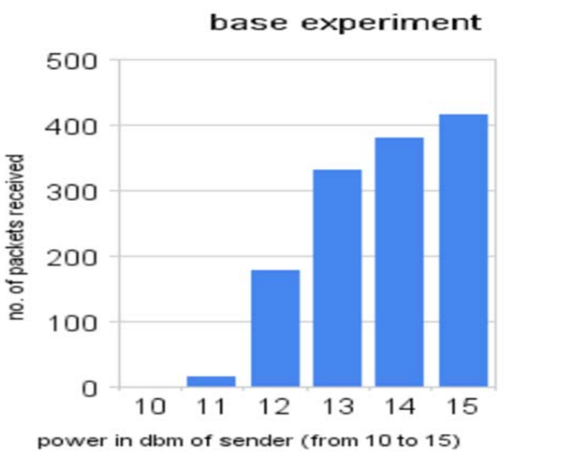

Figure 2: Effect of increasing sender transmit power

3.2 Experiment 2

Without interferer – Sender Transmit power (vs) Observed throughput at receiver.

The objective of this experiment was to understand the effect of sender transmit power on the observed throughput at the receiver. We wanted to find out the maximum throughput possible at the receiver, when no interfering device was present.

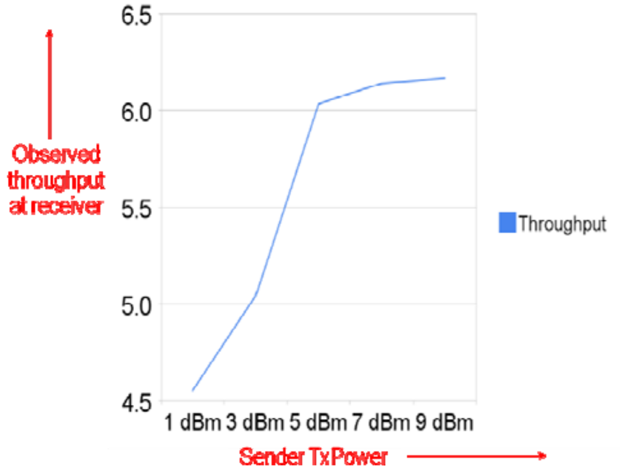

Figure 3: Effect of sender txpower on observed throughput

The sender and receiver nodes were placed at a distance of 8 meters from each other and the interferer(IBM thinkpad laptop) was placed at a distance of 4 meters from both the sender and receiver. Both the sender and receiver were fitted with 8 dBi omni-directional antenna. The results are as shown above. The sender's data rate was 11Mbps.

The primary result that we can infer from the graph is that the maximum throughput achievable is 6.3Mbps which is achieved at 9dbm sender transmit power.

In experiment 1, we found that the maximum throughput achieved was 0.8Mbps(not mentioned earlier). So, the throughput changes from 0 to 0.8Mbps. This is about 80% increase in a span of 5dbm.

But, in this experiment we find only a gradual change in throughput from 4.5Mbps to 6.3Mbps, a 10% increase in a span of 9dbm increase in sender transmit power. This change is due to the fact that in this experiment we use omni-directional antenna. When antennas are used the throughput change should not be very large for a small change in sender transmit power.

3.3 Experiment 3

In the presence of interferer – Interferer transmit power (vs) Observed throughput at receiver

In this experiment, we analyze the effect of interferer power on the observed throughput at the receiver node. For this, we use a non-complaint 802.11device(which is the Thinkpad laptop) and a Bluetooth device(mobile phones) as interferers.

The experimental setup is same as that of experiment 2. Both the nodes had omni-directional antennas. Firstly, we used the laptop as the interferer and found the throughput at the receiver. Then, we used two mobile phones with data transfer going on between them, and this was the interference. Both sender receiver nodes and the interferer were operating on Channel 11 of 802.11b. The results are as shown:

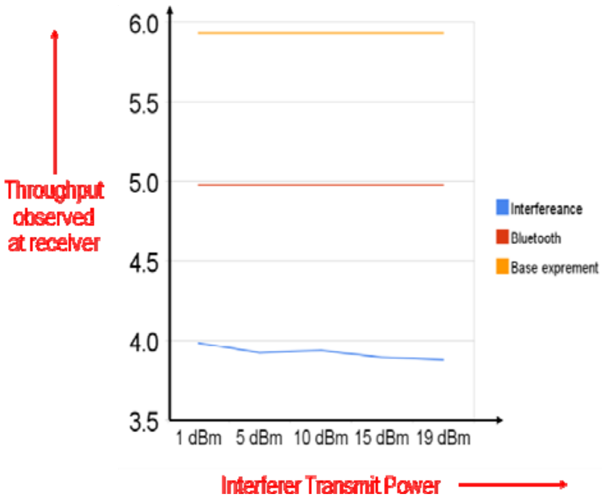

Figure 4: Effect of interfer txpower on received throughput

However, it should be noted that the interferer here backs off whenever there is any transmission in its channel of operation. This was because the interferer was doing CCA. Hence, the results of the interferer(blue line) should be considered accordingly.

We can still find that the reduction in throughput when Bluetooth device was used was less as compared to the non-complaint 802.11device(laptop) because Bluetooth uses FHSS and its power is very low.

3.4 Experiment 4

Effect on number of packets received with/without interferer

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In this experiment, we analyze two aspects. Firstly, in the absence of interferer, with increasing sender transmit power what is the number of packets received at the receiver. This corresponds to the upper part shown in Figure 5. Secondly, we analyze, in the presence of interferer, what happens to the number of packets received at the receiver, with increasing interferer transmit power .

The other parts of the experimental setup is same as for earlier experiments. The results are shown below:

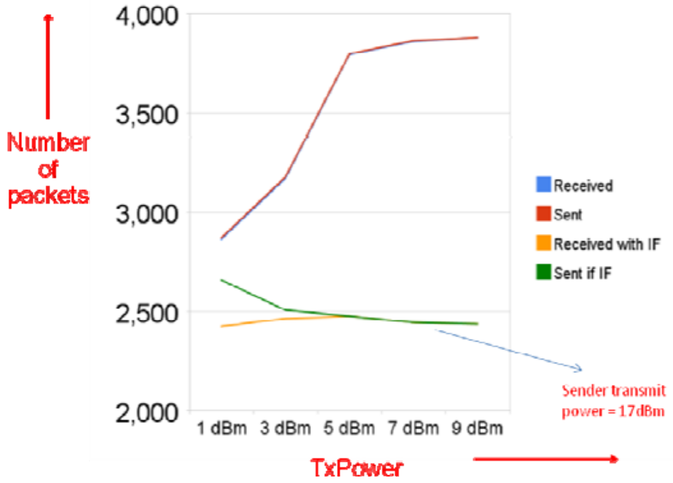

Figure 5: Effect on number of packets received with/without interferer

The x-axis corresponds to sender txpower for the upper part of the graph and interferer txpower for the lower part of the graph.

The inference from the above graph is that the presence of interferer is causing loss of packets as the number of packets received is going down in the presence of interferer.

3.5 Experiment 5

Effect of channel of operation of the interferer on the channel of operation of the sender-receiver pair

In this experiment, we fix the channel of the interferer on channel 11 and vary the channel of the sender-receiver pair. During this we observe the throughput at the receiver. The objective here is to see what effect the interferer is having on transmissions in its channel and on other channels. The experimental setup is same as for earlier experiments. The interferer considered here is the non-complaint 802.11 device i.e. laptop.

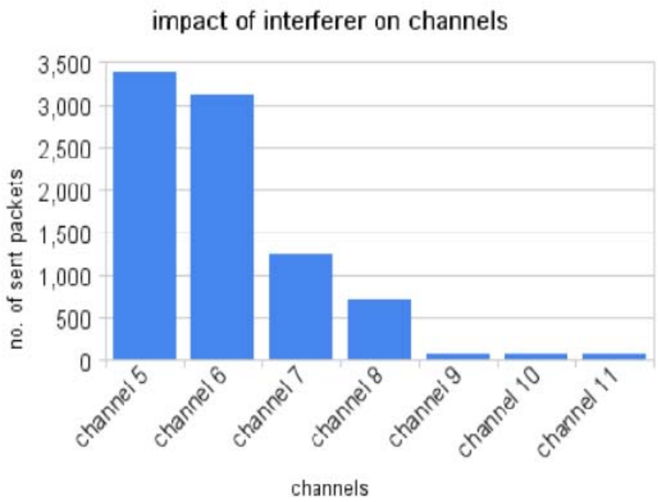

Figure 6: Effect of interferer on transmissions in different channels

We can observe that the most effect the interferer is having is on its own channel i.e. channel 11. As the sender receiver pair shift from an overlapping channel 7 to the orthogonal channel 6, there is more than 50% increase in the number of packets received.

4. Channel Hopping

From the last experiment, we can see to reduce the effect of interference, we have to change the channel of operation of the sender-receiver pair to an orthogonal channel. This mechanism is known as "Channel Hopping".

4.1 Mechanism and experiment

We implemented a channel hopping mechanism at the sender and receiver. When the receiver observes the throughput going below a certain threshold, it hops to the next orthogonal channel and stays there. The sender uses "ping" to determine whether the receiver has hopped or not. While sending data, the sender also periodically pings the receiver. When the sender doesn't receive a reply, it switches to the next channel.

The following graph summarizes the result of the experiment:

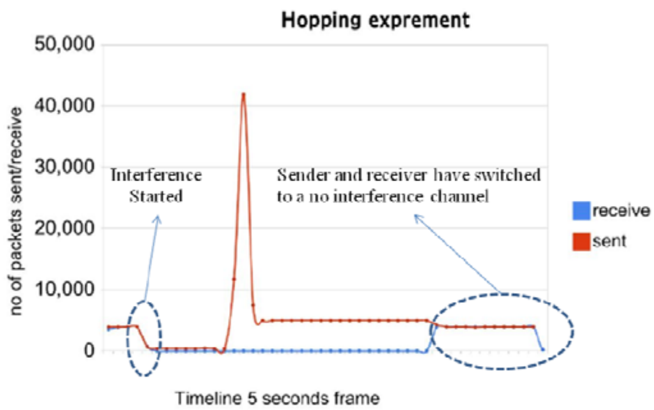

Figure 7: Channel Hopping

The sender switches the channel just after the peak. The peak corresponds to the cumulative total of all the packets that the sender was trying to send unsuccessfully in the previous 10 seconds after the receiver had switched the channel.

Still, the sender has not switched to a channel where the receiver is there hence the blue line is still at zero. Eventually, the sender reaches the channel on which the receiver is there. The peak will arise only once when there is a transmission going on and its broken in between due to switch of receiver channel.

5. Conclusion

From the experiments conducted, we conclude that interference on the channel of operation of the sender-receiver pair, reduces the throughput drastically. Hence, a solution to this is to switch the sender and receiver to a channel where there is no interference. Through an implementation, we have showed that such a hopping is possible in an adhoc network of nodes.