# ACCESS POINT TUNING IN CHAOTIC WIRELESS NETWORKS

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## ABSTRACT

In dense wireless environments a large number of WLANs may overlap and interfere with one another. This paper reports on two wireless measurement experiments designed to study access point (AP) interference. The first experiment shows that using only non-overlapping channels may not be optimal. The second experiment examines the relationship between access point transmission power and throughput in relation to adjacent wireless networks.

## KEY WORDS

Wireless networks, transmission power, access points, interference

## 1. Introduction

The rapid proliferation of residential wireless networks has led to wireless access points (APs) being positioned such that their effective ranges overlap without any coordinated or cooperative channel allocation strategies. These chaotic wireless deployments are prevalent in dense urban areas and apartment buildings. Moreover, given the recent popularity of cost-effective signal and range boosters, it is not uncommon to see five or more wireless networks accessible from one's home even in less populated suburban neighborhoods.

While several possible schemes exist for adjusting to this chaotic AP deployment, this research operates under the assumption that given the significant numbers and types of retail wireless components purchased recently, it is reasonable to assume this equipment will remain in circulation in the near-term. Hence, this investigation seeks to minimize overlapping AP interference effects while using currently available, low-cost wireless infrastructures.

To methodically examine interference effects arising from overlapping 802.11 WLAN coverage areas, this project is divided into two distinct sets of experiments designed to isolate those independent effects most likely to impact WLAN performance in both common and worst-case configuration settings. The goal is to collect experimental measurement data that illuminates one's choices when seeking the least-interfering channel for wireless transmissions in a chaotic environment.

There have been a few previous research efforts attempting to mitigate chaotic wireless network performance problems [1]. Akella et al. [2] propose PERF, a rate adaptation algorithm designed to minimize the WLAN transmission radius while maintaining acceptable data rates. Ihmig and Steenkiste [3] suggest a dynamic channel shifting algorithm to ensure a WLAN operates over the channel with least load at all times. These studies differ from our experiments in two ways. First, this paper does not propose a new algorithm or technique that requires implementation on either an access point or its clients. Instead, the experiments use simple measurements to seek out the best channel and transmit power settings for an access point given common worst-case scenarios. Second, the experimental configuration does not assume cooperative or altruistic behavior from the access point or its neighbors. Specifically, the first set of experiments presented in this paper considers channel allocation and transmission distance in situations where all non-overlapping channels are utilized by at least one other active WLAN. Namely, this setting captures AP performance in an apartment environment where AP density is typically high.

Subsequently, a second set of experiments was conducted to understand the impact of access point transmission power on throughput when two APs operate with overlapping communication ranges. By varying transmission power from a lower bound (determined by minimum signal strength for 54 Mbps on IEEE 802.11g WLANs) to the access point's maximum power setting, implicit tradeoffs between hidden terminals, signal strength and interference in chaotic wireless networks are analyzed.

The major contributions from these two sets of experiments are AP tuning recommendations in chaotic environments to improve overall AP throughput while providing a relative degree of fairness among competing AP neighbors.

# 2. Experiment 1: Channel Selection and Distance

The wireless environment consists of transmitters and receivers communicating with each other over a shared wireless medium. Thus, transmitters compete with each other when broadcasting their data. IEEE 802.11 resolves this issue by dividing the 2.4GHz wireless spectrum into 11 channels where only channels 1, 6, and 11 are non-overlapping. Hence, it is very common for 802.11 WLANs to configure their wireless interfaces to use one of the three ‘clear’ channels [4]. However, this often causes unnecessary congestion and poor performance in residential wireless neighborhoods [5]. The objective is to experimentally discern a simple heuristic by which the least-interfering channel can be chosen.

The first set of experiments was run in a residential environment where there exist multiple additional chaotic wireless networks (see Table 1). Throughput in packets per second and Signal-to-Noise Ratio (SNR) are the performance metrics for these experiments.

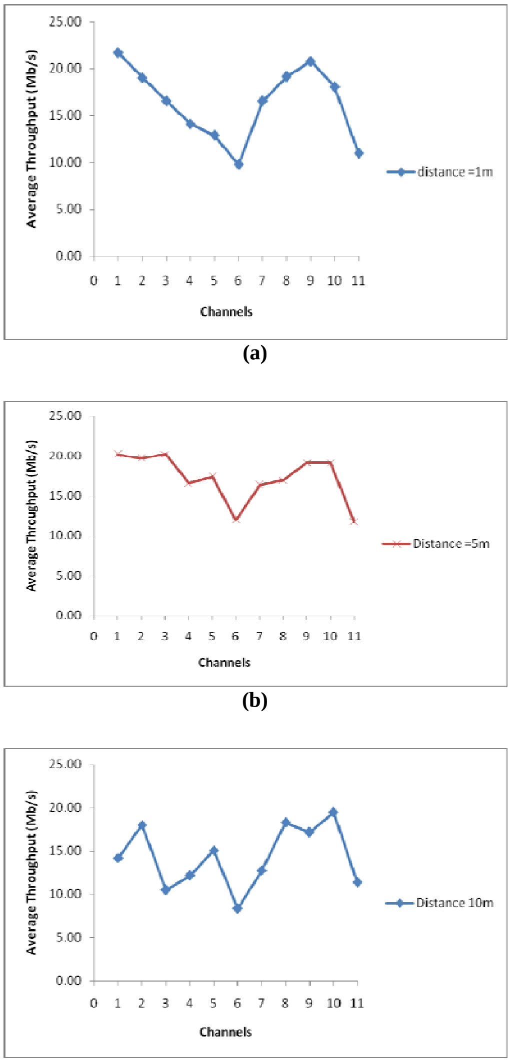
| Channel | Networks |
|---|---|
| 1 | 2 |
| 6 | 7 |
| 8 | 1 |
| 9 | 1 |
| 10 | 1 |
| 11 | 6 |

**Table 1 – Residential Wireless Environment**

The experimental equipment consisted of two Compaq NC 6230 laptops running with 802.11 a/b/g wireless interfaces and a retail-grade NetGear WGR614 802.11g access point [6] with fixed transmit power of 100mw and a 2.0 dBi antenna to communicate with the two nodes. RTS/CTS is disabled. The two nodes were separated by distances of 1, 5 and 10 meters by keeping node A, a laptop with a wired connection to the AP, stationary and moving node B, the second laptop. At each distance a one minute TCP downstream transmission was sent from node A to node B. The Iperf [7] traffic generator was used to create and manage the TCP flows and Kismet [8], a packet sniffing tool, was employed to obtain packets transmitted per second and signal-to-noise ratios. NetStumbler was used to monitor SNR [9].

Three sets of experiments (one each day) were run between 9:00 a.m. and 11:00 a.m. on November 11-13, 2007. This time period was chosen because preliminary measurements indicated that the communications activity of wireless AP neighbors was fairly consistent during this time interval.

Figure 1 shows average throughput plotted against the channel selection at different distances. In all three graphs, the throughput is significantly lower when channel 6 is used. This low data rate can be attributed to the high likelihood of the usage of channel 6 by the surrounding AP networks. This increases channel utilization/contention and, if RTS/CTS is disabled, potentially increases the number of hidden terminals present [10]. Being a clear channel, many of the APs in the environment are configured to broadcast on channel 6. Note the decline in throughput over the other clear channels, 1 and 11. The performance at a distance of 10 meters, as shown in (c), is slightly different than performance at distance 1m or 5m. The throughput rises, falls, and begins to rise again as channel selection moves from an adjacent overlapping channel for channel 1 to an adjacent overlapping channel for channel 6. Beyond channel 6 throughput increases steadily before falling off at heavily-utilized channel 11. Additionally, note that the throughput on any particular channel at 10 meters distance is less than the throughput at shorter distances on the same channel shown in (a) and (b). This decrease in throughput is attributed to both packet loss and multipath fading. The loss of signal strength may be compounded



(a)

(b)

(c)

**Figure 1 – Channel Throughput**

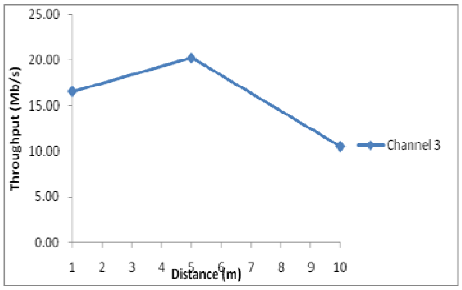
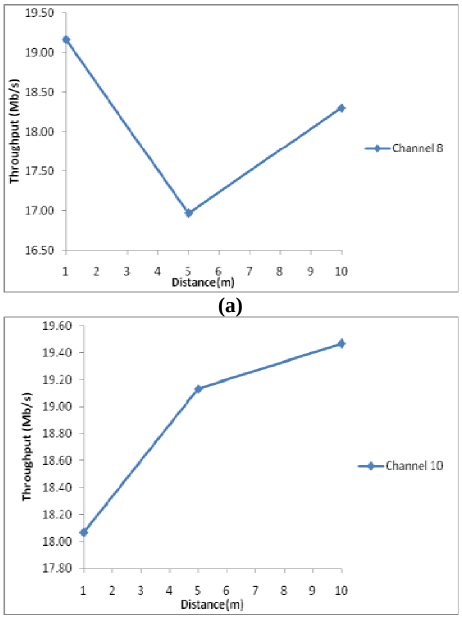


**Figure 2 – Node separation**



(a)

(b)

**Figure 3 - Anomalous Node Separation**

by interference from other wireless networks. Note, the overlapping channels such as channel 9 perform strongly at all distances. This implies that increased background noise is sometimes less detrimental to performance than heavy channel utilization.

### 2.1 Distance

To understand the impact of node physical separation on throughput, Figure 2 provides more detail on channel 3 measurements. The majority of the other channels emulate channel 3 behavior. Namely, throughput increases at 5 meters of separation and sharply declines at 10 meters. The performance gains at 5 meters may be attributable to interference between the AP's radio and node's radio at 1m of separation. However, channels 8 and 10 in Figure 3 do not exhibit this behavior. While channel 8 experiences a sharp drop in throughput at 5 meters, Channel 10, conversely, enjoys steadily increasing throughput as distance increased.

### 2.2 Traffic Variance

For Experiment 1 throughput in relation to traffic burstiness was also evaluated by recording packets per second and finding the statistical variance of these values. Figure 4 provides variance for three channels averaged over all distances. Due to space limitations other channels were not included, but their behavior was similar. Each graph clearly indicates a drop in throughput as the traffic variance increases. This is true for both overlapping and non-overlapping channels. Thus, high instantaneous traffic loads causes significant throughput degradation. This effect is likely due to the use of TCP flows in this experiment. Sudden increases in channel utilization increase the probability of collision, which causes TCP timeouts and higher back off behavior. The resultant decline in throughput is quite noticeable in one-minute flows**.**

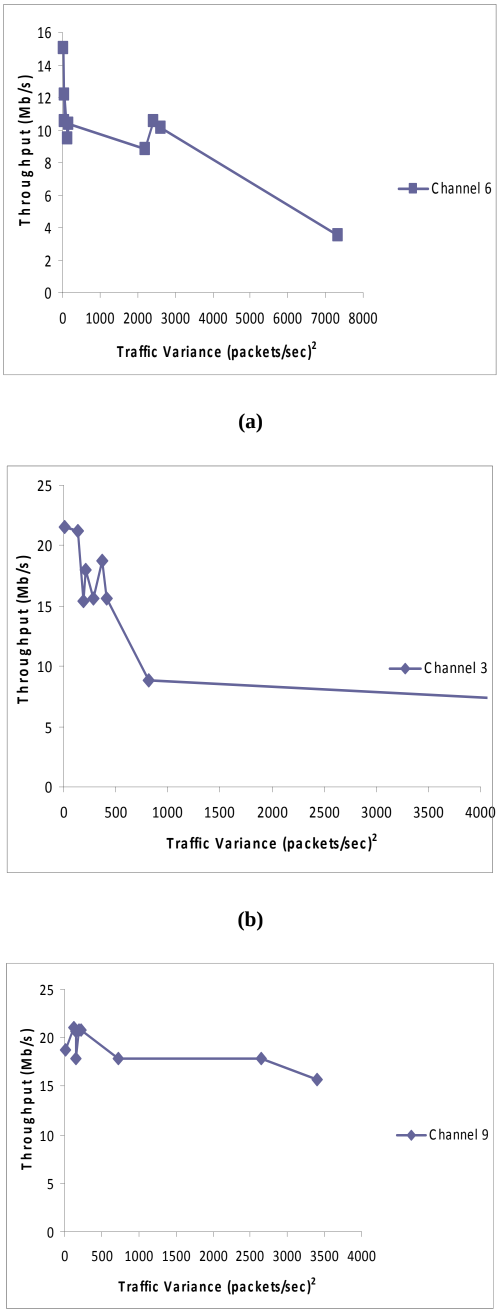
In summary, the Experiment 1 measurements indicate that using overlapping channels increases throughput when clear channels are heavily utilized by neighboring WLANs. Particularly, channels 3 and 9 that are midway between two non-overlapping channels provide high throughput and thus are reasonable alternatives for data transmission.

## 3. Experiment 2: Transmit Power and Exposed Terminals

Most retail APs default to the maximum allowable transmit power for their region (e.g. 100mW in the United States) to provide the strongest signal, the fewest hidden terminals and the longest range possible. Experiment 2 focuses on the relationship between transmission power, interference, and network throughput. Specifically, transmission power for an access point is varied to understand the performance tradeoffs when two neighboring APs are concurrently transmitting.

The topology shown in Figure 5 was replicated under controlled conditions. Two wireless access points were placed in an indoor environment known to be clear of other wireless interference. A retail-grade Netgear WGR614 802.11g AP with a fixed transmit power of 100mw and a 2.0 dBi antenna was used to communicate with a Compaq NC 6230 laptop. The access point was separated from the host by a distance of five meters. A

Cisco Aironet 1100 using 802.11g with varying transmit power and a 2.2dBi antenna was used to communicate with another Compaq NC 6230, also at a distance of five meters. Note each host/AP pair was separated from the other by a distance of 8 meters and the wall of a room. These are referred to as Network B and Network A, respectively. Each laptop received downlink packets from a 54 Mbps TCP flow from a wired host connected to the access point, as described below. The following AP settings were used: 802.11g data rates, OFDM enabled, ARF enabled and RTS/CTS disabled. These represent the normal default settings on most retail-grade APs.



**(a)**

**(b)**

**(c)**

**Figure 4 - Traffic Variance**

After setting up the network hardware, AP A's transmission power was increased in discrete steps up to the maximum allowable strength (i.e., the Cisco Aironet 1100 allowed power settings of 1, 5, 20, 30, 50, and 100mW [11] while AP B's transmission power was kept at 100mW. At each power level a 60-second TCP downlink flow was simultaneously run on Network A and Network B at 54 Mbps. Actual throughput over each interval was measured for both networks at each power setting. To reduce the impact of isolated events, each experiment was repeated three times.

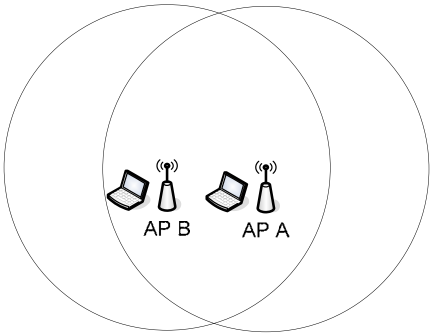


**Figure 5 - Network Topology**

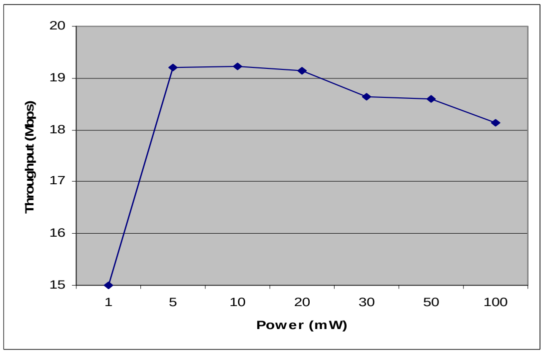


**Figure 6 - Network A Throughput**

### 3.1 Network A Performance

Figure 6 graphs the change in Network A throughput as transmit power is varied. The TCP throughput is significantly degraded at 1mw. Low signal strength compared to background noise at 1mW causes high loss of packets sent to the receiver. Interestingly, between 5 and 20mW, throughput exceeds the 100mW performance by approximately 1 Mbps.

Initially, this was attributed to the exposed terminal effect [12]. However, further analysis revealed that varying transmission power only effectively manipulates the transmit amplifier for an access point while receiver sensitivity remains unaffected [13]. This does not mean exposed terminals will not arise. Different APs display varying antenna gains. In Experiment 2, AP A uses a 2.2dBi antenna while AP B uses only 2dBi. This implies that Node B could theoretically be an exposed terminal for AP A. However, this effect does not change as AP A transmission power level varies and exposed terminals are not likely to be the cause of Network A's throughput loss at high transmit power levels. Results presented below support this conclusion.

Moreover, the performance degradation in Figure 6 is attributed to an increase in the degree of multipath Rician fading. As transmission power increases, the omnidirectional antenna broadcasts the signal in an increasingly larger radius. The probability that signals will reflect off of structural features and partially cancel the dominant line-of-sight radio link also increases proportionally in the indoor environment. This equates to a net loss in receiver SNR ratio and increased packet loss, despite increased signal strength over the background noise.

In situations where a wireless host has line of sight to the access point, Figure 6 suggests reducing AP transmission power to more moderate settings could increase throughput by eliminating self-interference caused by multipath fading. Since receiver sensitivity remains constant, this adjustment should not introduce new hidden terminals. However, hosts with which the AP previously had to contend will now effectively become exposed terminals. Carrier sense detects a busy medium and avoids transmitting, even though the reduced-strength signal may no longer interfere with neighboring networks.

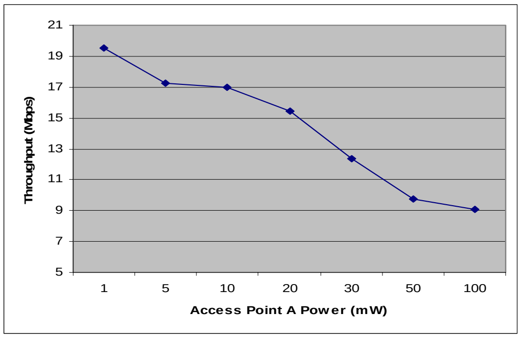


**Figure 7 - Network B Throughput**

### 3.2 Network B Performance

The effect of varying AP A transmit power on AP B is shown in Figure 7. Optimal AP B throughput is attained when AP A is set to the lowest available transmission power. Note as the signal strength of Network A's downlink traffic increases, Network B's TCP throughput steadily decreases. After AP A reaches a transmission power of 50mW this effect plateaus. The graph shows less than a 1 Mbps throughput loss as power increases to 100mW compared to nearly a 10 Mbps loss between 1mW and 50mW. This difference could be due to the presence of AP A acting as an increasingly powerful hidden terminal to Host B [14]. While AP A's carrier sense is aware of AP B and contends for use of the medium with its downlink TCP flow, it is not aware of Host B. Furthermore, the downlink traffic from AP A to Host A interferes with transmissions to AP B. As a result AP A's traffic collides with the TCP ACK uplink traffic from Host B to AP B. The resultant collisions do not affect Host A's reception of AP A's downlink traffic, but does cause Host B to retransmit ACKs. Responding to missing ACKs, AP B lowers its congestion window, and throughput declines.

Figure 7 demonstrates that for this configuration this effect becomes increasingly powerful up to approximately a 50mW threshold. At low transmission power much of AP A's downlink traffic is lost due to background noise before ever propagating far enough to interfere with Network B's TCP flow. However, as transmit power increases, a larger fraction of Host A's packets survive only to interfere with Host B's uplink traffic. Eventually almost all packets survive and further increases in signal strength have little effect.

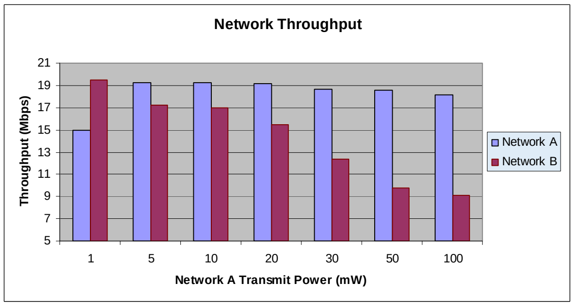


**Figure 8 – Throughput Comparison**

### 3.3 Transmission Power Tuning

Figure 8 plots the throughput of each network for each transmission power level used at AP A. The 1mW region clearly favors Network B while penalizing Network A for reducing its signal strength. The 5-20mW range represents the most favorable throughput for Network A while minimizing the interference caused at Network B. Beyond this point Network A begins to suffer from self-interference, and Network B suffers significantly from the hidden terminal effect. Finally, the 5 and 10 mW bar graphs demonstrate that these two settings provide the highest combined throughput and fairness for both networks. These results suggest that reducing the transmission power of wireless access points to more moderate levels have few negative consequences in high density settings and indeed may improve throughput, given the following assumptions:

1. The wireless host has line-of-sight to the AP. This is common in many home environments where the access point is placed in an elevated location and used within one or two rooms.

2. Background noise levels are less significant than the interference caused by multipath (most notably Rician) fading. This can occur in older buildings or near concentrations of radio-reflective material such as metal or water, including human beings.
3. RTS/CTS is disabled. This is the default setting for most wireless access points available for home and commercial use.

However, it is important to note that due to time constraints the effects of multiple or mixed flows, increased node densities and higher network populations were not investigated. Actual performance is likely be modified by these factors.

## 4. Conclusions and Future Work

Based on the results obtained in this study, it is apparent that access points can often be tuned for better performance. Specifically, transmission power and channel selection can be adapted to minimize both self interference from Rician fading and interference from nearby WLANs. To summarize our experimental results:

- Selection of midpoint overlapping channels between clear channels can increase throughput in areas of high channel utilization. This includes many of the most common chaotic wireless environments such as apartment buildings or dense residential areas.
- Access point transmission power can be reduced below 50mW in line-of-sight conditions. This may increase throughput by reducing the effects of Rician multipath fading on signal quality and improve the performance of nearby wireless networks.

While the focus of this paper is non-cooperative AP tuning techniques, the results suggest several paths for continued research and careful wireless measurements in the field. The transmission power measurements imply that cooperative AP power setting policies where local wireless knowledge is shared among WLAN neighbors could enhance the throughput of all the wireless networks. Integration of the adjustments highlighted in this paper into existing access points could produce adaptive auto-configuration strategies in response to changing environments. One of our future research initiatives will be to cooperatively utilize knowledge about the local wireless neighborhood to refine current wireless rate adaptation schemes. Finally, a more fine-grained analysis of channel overlap and interference could yield productive data on optimal channel allocation in dense wireless deployments.

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