Deployment Guidelines for Highly Congested IEEE 802.11b/g Networks

Andrea G. Forte
Department of Computer Science
Columbia University
andreaf@cs.columbia.edu

Henning Schulzrinne
Department of Computer Science
Columbia University
hgs@cs.columbia.edu

***Abstract*— Over the years, IEEE 802.11b/g wireless networks have been deployed in various locations such as hotels, airports and enterprises. Although IEEE 802.11b/g can be considered a mature technology, its deployment still presents challenges due to the limited number of non-overlapping channels available. This is particularly true in scenarios with a high density of users where a large number of APs covering roughly the same area is required.**

Through measurements we investigate different deployment scenarios, trying to provide a set of guidelines for the deployment of IEEE 802.11b/g networks so to minimize co-channel interference and maximize throughput. This, when the number of APs required to cover an area is larger than the number of non-overlapping channels available. In particular, we show how using partially overlapping channels causes lower retry rate and higher throughput than if deploying multiple APs on each of the non-overlapping channels.

I. INTRODUCTION

Nowadays IEEE 802.11 networks can be found not only in private residences but also in airports, malls, enterprises, hotels, university campuses and covering entire cities. However, covering large areas while providing a satisfactory user experience is not trivial.

IEEE 802.11b/g works in the 2.4 GHz band, providing a total of 14 possible channels. Of these 14 channels, only 11 are used in the United States and of these 11 channels only three do not overlap in band, namely, channels 1, 6 and 11. This means that one Access Point (AP) on one non-overlapping channel will not be able to "see" another AP on a different non-overlapping channel even though the two APs cover the exact same area. In other words, by using different non-overlapping channels, APs do not interfere with each other, that is there is no co-channel interference.

In many cases three non-overlapping channels can be enough to cover small to medium-size areas when the density of users is not high. Things however change when there is a high density of users. In this case, three APs, one per each non-overlapping channel, might not be able to support the network load given by the large number of concurrent users [1]. Because of this, more APs would have to be deployed and a decision would have to be taken regarding the channels to assign to such APs. To complicate things further, all these APs would have to cover roughly the same area. In order to solve this problem, the typical approach is to deploy multiple APs on each one of the non-overlapping channels, thus having multiple APs on the same channel, covering the same area. As we pointed out in [2], this causes a large number of problems in terms of co-channel interference, inefficient handoffs and so on.

IEEE 802.11a works in the 5 GHz band providing a larger number of non-overlapping channels than IEEE 802.11b/g, hence making this technology more suitable for highly congested scenarios. Unfortunately, 802.11a networks are not widespread [2].

In the rest of the paper, we focus on IEEE 802.11b networks for simplicity. However, the exact same conclusions are valid for IEEE 802.11g. The only difference between the two technologies, in the present context, is the maximum capacity of the network. Since 802.11g operates at higher bit-rates than 802.11b, 802.11g networks can sustain a larger number of concurrent users. In order to keep the complexity of the experiments as low as possible, we decided to focus on 802.11b networks only.

Through extensive measurements we show how it is more beneficial to use a larger number of partially-overlapping channels accepting some co-channel interference rather than deploying multiple APs on each non-overlapping channel. We also show how in some cases, one single AP on a channel gives better performance than multiple APs on the same channel.

In those scenarios where the deployment of APs is unplanned and not coordinated (i.e., APs in private residences), using overlapping channels would be useful for automated channel assignment mechanisms. For example, a new AP in an existing environment would measure the radio-frequency environment and then pick the least-busy channel, among all channels, rather than just considering the overlapping ones.

The rest of the paper is organized as follows. Section II presents related work. In Section III we show our experiments and measurement results. Finally Section IV concludes the paper.

II. RELATED WORK

The networking community has done a lot of work to study inefficiencies and clients' behavior in highly congested wireless networks [2], [3], [4], [5], [6], [7], [8]. Furthermore, many algorithms have been proposed for automatic AP channel assignment [9], [10], [11]. Such algorithms, however, introduce high complexity trying to achieve the theoretical optimum in terms of co-channel interference vs. throughput and lack concrete guidelines for the deployment of wireless

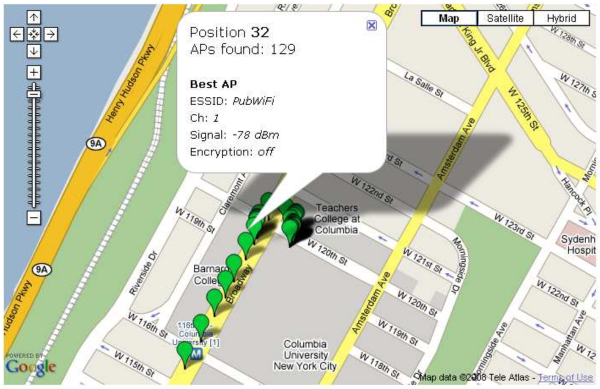


Fig. 1. Site survey of wireless networks in the Columbia University campus and its surroundings

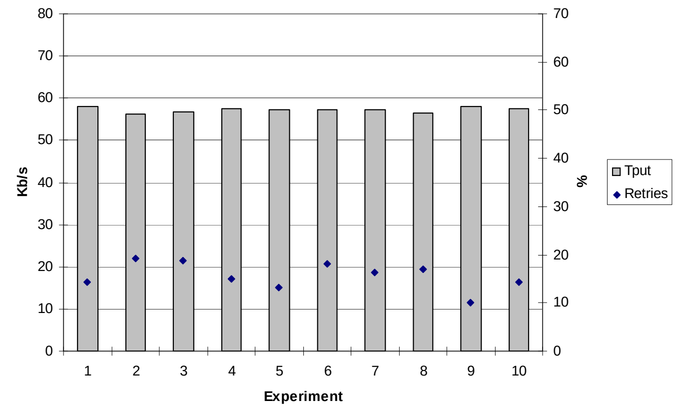


Fig. 3. Throughput and retry rate with interference on channel 1

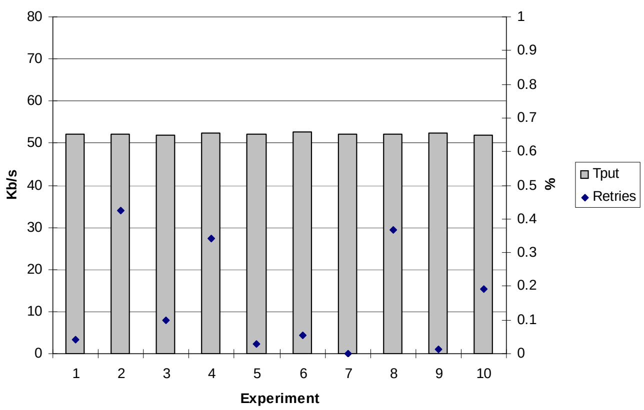


Fig. 2. Throughput and retry rate with no interference

networks. In particular, performance for most of them is verified through simulations only and none of them has been tested in highly congested scenarios.

Little work has been done to systematically study the effect of co-channel interference in existing deployments. Furthermore, no systematic study has been conducted to study how different channel configurations affect network performance in existing networks and in particular in highly congested networks where the density of users is very high.

In this paper, rather than proposing another algorithm, we study the problem of channel assignment in a practical manner by testing different channel configurations right in the field. We focus on the use of non-overlapping channels vs. overlapping channels and on the deployment of multiple APs on a single channel. In doing so, we try to define some general guidelines for the deployment of wireless networks so to achieve the best performance possible by using the current standards, without introducing new algorithms or network elements.

III. Experiments

We performed experiments in order to define a set of guidelines for the deployment of wireless networks in highly congested scenarios, that is above the network capacity. In particular, we wanted to measure the performance of the wireless network when using overlapping channels and see if their use can be a valid alternative to the typical approach of deploying multiple APs on each of the non-overlapping channels.

A. Site Survey

In order to study the effect of interference in IEEE 802.11 networks, we performed some preliminary measurements to study the wireless network environment in the surroundings of the Columbia University campus. We used one Lenovo T42 Thinkpad laptop with a 1.70 GHz Intel Pentium Mobile processor and 1 GB of RAM. Also, we used an external omni-directional antenna connected to a Proxim Orinoco Gold 802.11a/b/g PCMCIA wireless card. The laptop would scan for APs at a certain interval and at the same time would collect GPS coordinates for each scanning point. All these measurements were taken while moving in a car around the Columbia University campus at speeds below 20 miles per hour. GPS coordinates were taken at one second intervals. The results were later mapped on Google maps using the Google maps API [12]. Both the antenna connected to the wireless card and the GPS receiver were positioned on the roof of the car so to avoid attenuation due to the metal structure of the car itself.

Figure 1 shows some of the scanning points collected in the measurements [1]. As we can see, in some locations the wireless client could see well over 100 different APs.

In our survey of the Columbia University campus and its surrounding areas, we found a total of 668 APs, 49% of which were open and 51% of which were secure. Furthermore, the signal strength went from a maximum of -54 dBm to a

[1] http://www1.cs.columbia.edu/~andreaf/new/documents/ap_gmap.html

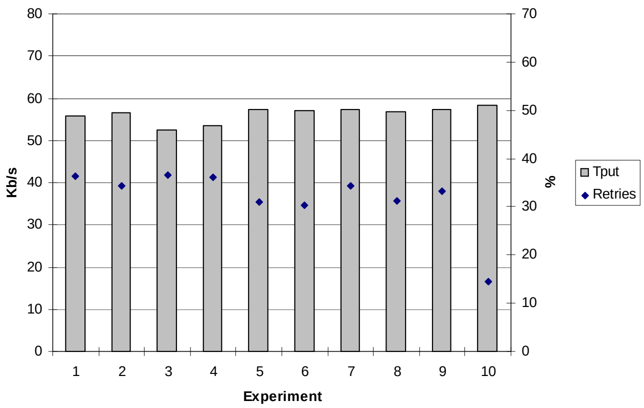


Fig. 4. Throughput and retry rate with interference on channel 6

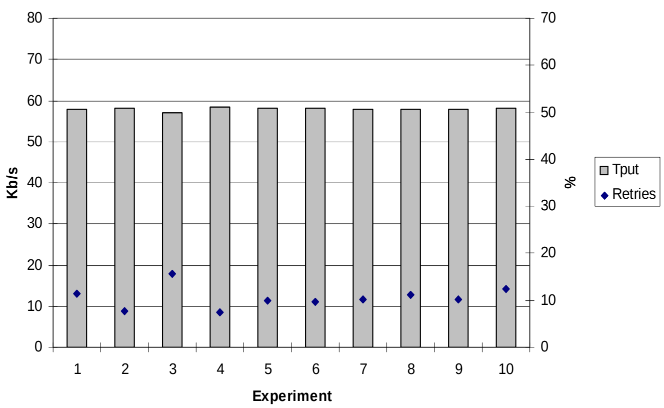


Fig. 5. Throughput and retry rate with interference on channel 11

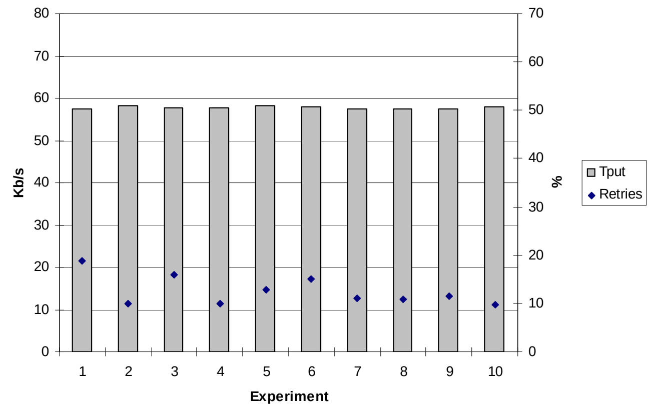


Fig. 6. Throughput and retry rate with interference on channel 4

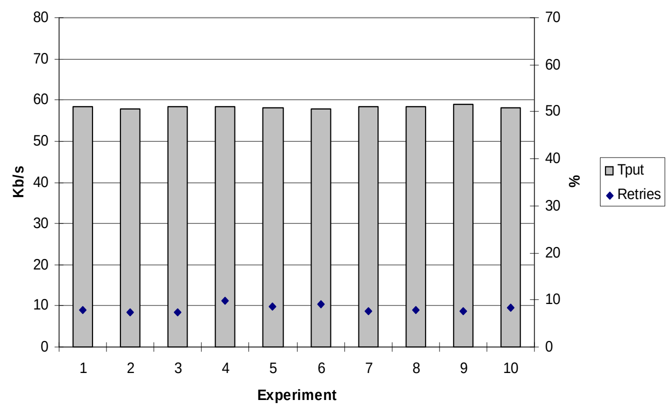


Fig. 7. Throughput and retry rate with interference on channel 8

minimum of -98 dBm. We found a total of 365 unique wireless networks. Of these, 340 were made up of one single AP and 25 were made up of more than one AP. We assumed that networks made up of one single AP represented "private" networks while networks made up of more than one AP represented "public" networks. It is important to note that "public" does not necessarily mean open. In particular, a network meant for public use might still require some kind of authentication, while a private network such as a home network, might be left open without any authentication required. Among the networks with the highest number of APs there were Columbia University with 143 APs, PubWiFi (Teachers College) with 33 APs, COWSECURE with 12 APs, Columbia University – Law with 11 APs and Barnard College with 10 APs.

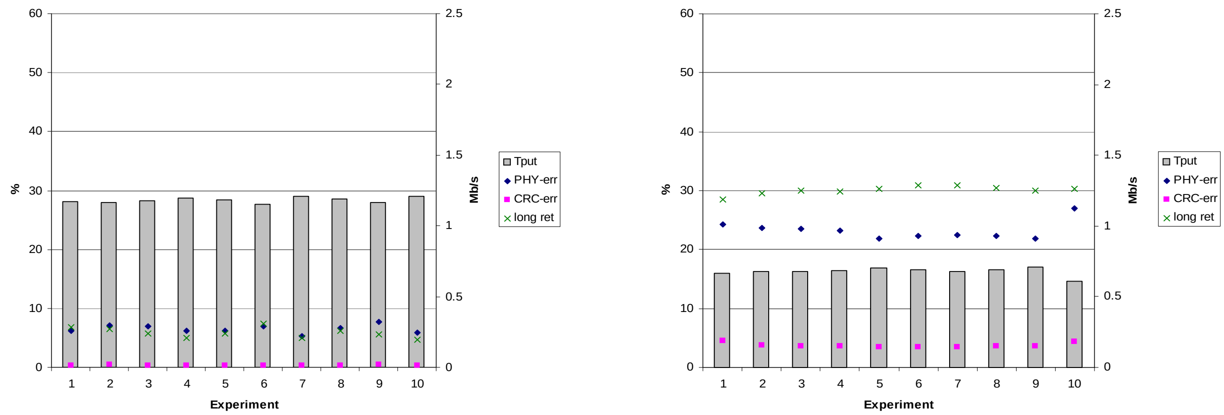
APs information such as channel used, ESSID and encryption were recorded. For the experiments on co-channel interference, the information regarding the channels used was the most critical.

B. Experimental Setup

We performed two sets of experiments. In one set we studied how different channel configurations affect performance in existing wireless networks while in another set we studied interference in highly congested scenarios. For the first set of experiments we used three laptops, one acting as AP, one as client and the third as wireless sniffer. The laptops were three T42 Lenovo Thinkpad laptops with a 1.70 GHz Intel Pentium Mobile processor and 1 GB of RAM. Two of them were running the Linux operating system with kernel version 2.6. The laptop used as a sniffer was running Windows XP with SP2. We used Airopeek NX [13] as wireless sniffer. All the T42 laptops were equipped with Intel Centrino Mobile Technology. For the second set of experiments we used the ORBIT testbed [14]. ORBIT is a wireless testbed made up of a grid of 20x20 wireless nodes with each node being remotely accessible and configurable.

C. Experimental Results

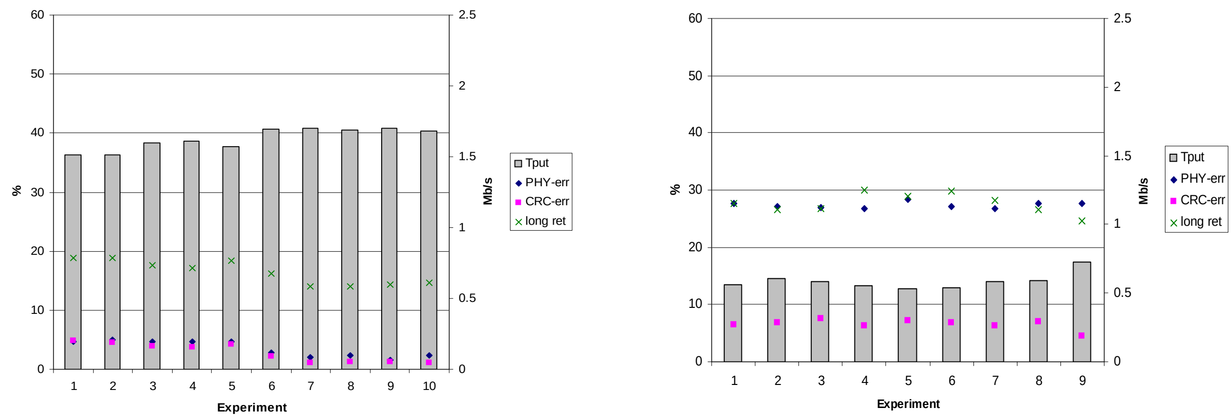
1) Congested Channels: In order to study the level of congestion for overlapping and non-overlapping channels in



(a) Channels: 1, 6; APs coord: (20, 1), (10, 6); num of clients: 43

(b) Channel: 1; APs coord: (20, 1), (10, 6); num of clients: 43

Fig. 8. Different channels vs. same channel when using non-overlapping channels



(a) Channels: 1, 4; APs coord.: (13, 7), (17, 4); num. of clients: 67

(b) Channel: 4; APs coord.: (13, 7), (17, 4); num. of clients: 67

Fig. 9. Different channels vs. same channel when using overlapping channels

existing wireless networks, we performed measurements in wireless networks in and around the Columbia University campus. For these experiments, one laptop was used as AP; a second laptop, the client, would connect to the AP and start sending packets to it. The sniffer would then record the whole process, including retries, CRC errors and other statistics. All three laptops were in close proximity of each other so to maximize the effects of interference due to the presence of other networks and minimize other forms of loss due for example to the presence of obstacles. The experiments were run using different channel configurations to see how co-channel interference would affect performance and in which measure on the different channels.

Based on the site survey explained in the previous section, such experiments were run in two different locations. One location was chosen because of the complete absence of other wireless networks so that measurements could be taken in the absence of interference. The second location was chosen as one of the locations around campus with the largest number of active APs so that measurements could be taken in the presence of very high interference. Ten experiments of three minutes each on overlapping and non-overlapping channels were performed. In all the experiments packets were sent from the client to the AP using a simple UDP sender. Traffic was generated so to emulate a G.711 codec with packets having a payload of 160 bytes and a packet rate of 20 ms. In reality, due to some delays introduced by the printing of debugging information and system calls, the actual packet interval was between 20 ms and 25 ms. As a consequence, the actual throughput in the experiments was below the expected 64 Kb/s.

As we can see from Figure 2, when no other network is present, that is the environment is free from other sources of interference, the retry rate is below 0.5%. Naturally, in such environment, any channel will give the same results.

In a congested environment, however, things are very different. Figures 3, 4 and 5 show throughput and retry rate in a highly congested environment when sending packets on the non-overlapping channels. We can see that on each non-overlapping channel the retry rate is above 10% with channel 6 (see Figure 4) being the most congested channel. The retry rate on channel 6 is considerably higher than on channels 1 and 11, reaching almost 40%. This is due to the fact that most of the surrounding wireless networks used channel 6 for their operations.

What would have happened if we had positioned our AP on an overlapping channel instead? This is shown in Figures 6 and 7. As we can see, the retry rate is around 10% for channel 8 and around 15% for channel 4. The difference in throughput and retry rate between overlapping channels and non-overlapping channels is not significant. Clearly, using either channel 4 or channel 8 would represent a much better choice than channel 6. In any case, using overlapping channels does not affect performance negatively. Furthermore, the use of overlapping channels such as 1, 4, 8 and 11 would achieve a better spatial re-use having now four channels to use rather than just three.

One more thing to notice is that in our experiments we have tested a worst-case scenario in terms of performance on the overlapping channels. In particular, when testing channels 4 and 8, many of the surrounding APs were using channel 6, thus overlapping in band more than if only channels 1, 4, 8 and 11 were to be used.

We have mentioned channels 1, 4, 8 and 11 because these represent the four channels for which we would have minimum overlapping in band. As our experiments show, however, the use of other channel combinations is also possible without significantly affecting performance. It is expected however, that the more the channels overlap, the lower the performance.

2) Channel Assignment: As mentioned earlier, in order to study the performance of different AP channel configurations in highly congested scenarios, we used the ORBIT testbed. The testbed has a grid of 20x20 wireless nodes which can be turned on at will in different configurations. In our experiments we considered a large number of nodes acting as clients and two nodes acting as APs. All nodes were forced to use only the maximum bit-rate of 11 Mb/s [2] so to avoid problems associated with Auto-Rate Fallback (ARF) [2]. Each client exchanged packets with another client so to simulate a Constant Bit Rate (CBR) voice call, that is, without silence suppression. The parameters used were those typical of a G.711 codec, that is, each packet had a payload of 160 bytes and the packet interval was set at 20 ms. The channel used by the APs was changed so to study the impact of channel selection on performance. In this way, we studied throughput, retry rate, physical-error rate and other metrics in different channel configurations and always with a number of clients exceeding capacity. As shown in [1], the maximum capacity for IEEE 802.11b networks for CBR at 11 Mb/s is 10 concurrent calls.

Figures 8 and 9 show throughput, physical-error rate, CRC error rate and long retry rate when using non-overlapping and overlapping channels, respectively. In particular, from Figures 8(b) and 9(b), we can see that when considering two APs on the same channel, the throughput is drastically reduced while physical-error rate and retry rate increase.

Figures 8(a) and 9(a) show that when using the overlapping channels 1 and 4, all the parameters and in particular the physical-error rate, are not affected negatively if compared to when the non-overlapping channels 1 and 6 are used. Also, we can see from Figures 8(b) and 9(a) that when using channels 1 and 4, the system performs significantly better than when using two APs on the same non-overlapping channel, that is channel 1. The difference in throughput that we can see from Figures 8(a) and 9(a) is due to the different number of clients used in the two sets of experiments. In particular, 43 clients were active during the experiments shown in Figure 8 and 67 were active during the experiments shown in Figure 9.

Although, here we have shown the results only for channels 1, 4 and 6, the same is true for channels 8 and 11. Such results clearly show how the practice of deploying multiple APs on

[2]As mentioned earlier, all nodes use IEEE 802.11b.

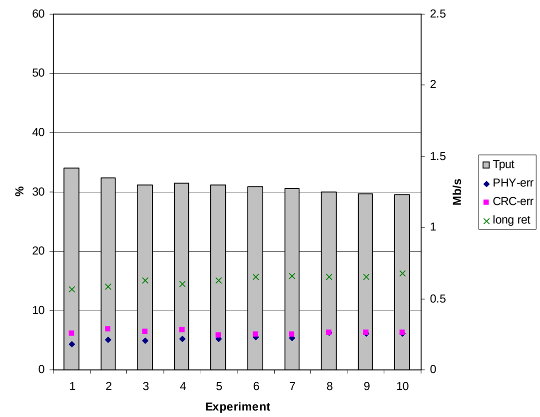


Fig. 10. Network performance with single AP in highly congested scenarios

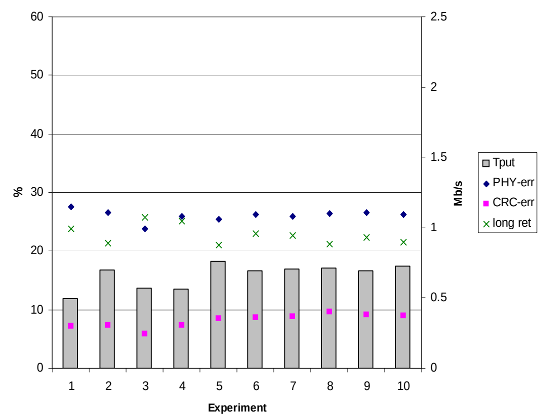


Fig. 11. Network performance with two APs on the same channel in highly congested scenarios

each non-overlapping channel is not a good practice. For such congested scenarios overlapping channels should be used as much as possible.

Also, we found that when the density of users is very high (82 clients in our experiments), using two APs on the same channel performs worst than using one single AP. In particular, as shown in Figures 10 and 11, when using two APs on the same channel the throughput decreases while physical-error rate and long retransmission rate increase when compared to the single-AP case. This clearly shows how just increasing the number of APs is not always the best solution and particular attention must be paid to channel assignment.

IV. Conclusion

We have conducted experiments to study how channel selection affects performance in IEEE 802.11b/g wireless networks. In particular, we have looked at scenarios where the number of clients is very high thus requiring a number of APs to be deployed that is larger than the number of non-overlapping channels. We have also studied how network performance changes with different channels, in a dense urban environment with a very large number of interfering wireless networks.

We have shown how using partially overlapping channels does not affect performance negatively. In particular, deploying multiple APs on the same channel performs consistently worst than deploying multiple APs on overlapping channels. Furthermore, having multiple APs on the same channel perform worst than having one single AP.

From all of this we can conclude that, when possible, single APs on overlapping channels should be deployed and multiple APs on the same channel should be avoided. Furthermore, the common practice of just using non-overlapping channels should be avoided as it has proven to lead to poor performance.

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