

Adjacent Cell Interference in Wireless Networks

Lu Luo, SoYoung Park and João Pedro Sousa

*School of Computer Science
Carnegie Mellon University
Pittsburgh, PA 15213 USA*

1 Introduction

Wireless technology is becoming more and more popular in computer networking, as a means to provide the last hop to a whole new variety of mobile hosts, from laptops to handhelds, and foreseeably to wearables. Understanding the behavior of mobile hosts and access points as far as sharing the wireless media is an important piece of knowledge for people in charge of setting up such infrastructure. In particular, will covering an area with more access points always result in better channel capacity delivered to the mobile hosts? Is it always true that hosts operating in one wireless cell do not degrade the capacity of the channel in neighbor cells?

A negative answer to this last question can be taken for granted with respect to neighbor segments in wired networks, and one may be tempted to extend this assumption to wireless networks. However, in the research reported herein we conducted experiments that prove otherwise. We measured the degradation of the channel's capacity induced by a mobile host operating in a neighbor cell as a function of distance between mobile hosts; and concluded that hosts operating in different cells may cause each other a degradation of channel capacity comparable to the one experienced by hosts sharing the same access point. This phenomena occurs when the adjacent access points are operating in the same frequency – and one should remember that adjacency has to be considered in a three dimensional space when planning the layout of access points in a building.

In Section 2 we will explain the setup for our experiments, our design ideas, method of measurement, and the logistics of our experimental environment. Plots, analysis, comparisons of data coming from the experiments will be given in Section 3, along with some interesting observations. We will conclude our project in Section 4.

2 Experiment Setup

2.1 Design of Experiments

Intuitively we hypothesized that the introduction of a mobile host would degrade the capacity of an access point, and that the degradation should be proportional to the distance between the mobile hosts. In our experiments the degradations were measured in the form of the bandwidth decrease and the packets-drop-rate increase of the mobile hosts. Two mobile hosts were used in our experiments, one (namely Host1) acted as the host connecting normally to an access point, and the other (namely Host2) acted as the interfering host. Keeping Host1 within the scope of an access point, there are three possible situations that Host2 can interfere with the capacity of the channel Host1 was attaching to:

1. Host2 stays in the scope of the same access point
2. Host2 stays in the scope of an adjacent access point using the same channel

3. Host2 stays in the scope of an adjacent access point using a different channel as Host1

Figure 1 shows the layout of the positions of the Hosts and the scope of access points. We chose two different positions in Wean Hall to carry out our experiments. To measure situation 1 and 2, we did our experiments on the 7th floor of Wean Hall, where the two adjacent access points used the same channel. To measure situation 3, we did our experiments on the 6th floor of Wean Hall, where the two adjacent access points use different channels. The building structures of the two positions are very similar so that we use the same layout figure to illustrate both of them. In Figure 1, the shaded collapses are the scopes of two adjacent access points, partly overlapping. The little laptop icons show the positions in which the two hosts sit during our experiments. Located in the center of the overlapping area of both access points, position 0 was taken as the base point of all experiments. Positions 2 through 14 were the test positions for Host1 in the scope of access point 1, where the number indicated the position's distance to position 0. Similarly, positions 0 and position -2 to -6 were the test positions for Host2 in the scope of access point 2. The absolute values of the position numbers specified their distances from position 0.

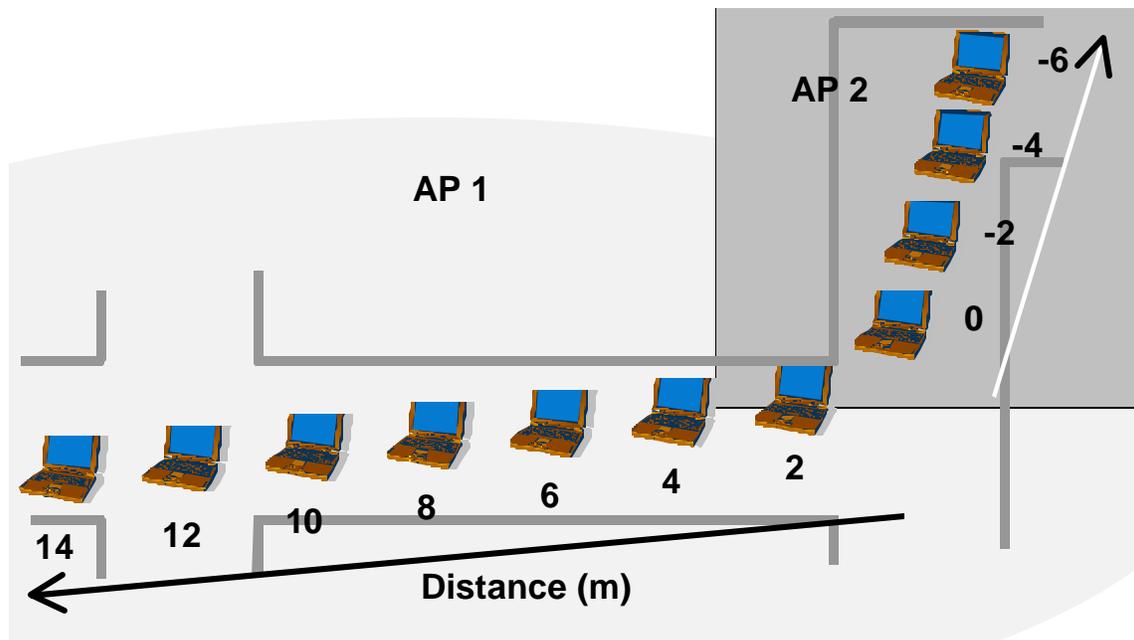


Figure 1. Layout of host positions and access points scopes

For experimenting situation 1, we had Host2 stay in position 2, while Host1 moved along the black arrowed line with the distance between the hosts increasing by 2 meters each time. In other words we collected one set of traffic data on each positions from 2 to 14. We did one group of experiment for this situation and got seven sets of data.

For experimenting situation 2, we had Host1 move in the same way as above, and had Host2 move along the white arrowed line on positions 0, -2, -4 and -6, where Host2 went deeper from the margin of the overlapped area into the center of access point 2. For each position of Host2, we had seven sets of data for the seven positions of Host1.

Experiments for situation 3 are much like those for situation 2. The difference is that access point 1 and 2 were using different channels in situation 3. We got one group of data for this situation. Host2 sit on position -2 during this experiment.

2.2 Data Measurement

From the initial trials of our experiments we found that the raw data we got from each round of experiment could be affected by factors other than the other host we introduced. Sources of interference include other mobile hosts nearby, signal bounces on walls, and probably even a bus running on Forbes Avenue. To reduce the interference from these foreign sources, we employed an alternate data measurement method, which turned out to be a better solution to expose the phenomena we are looking for. Another observation in our initial trials was that when the mobile hosts were sending packets, the channel capacity reduction due to adjacent cell interference wasn't obvious enough to make an interesting study. We thus focused on measuring the incoming traffics to the mobile hosts. Our final experimental results came from the method described below.

We measured two kinds of connections in our experiments, as is shown in Figure 2. In both connections, we set the desktop workstation, which was connected via wired network, as client; we set the mobile hosts, which were connected via wireless network, as servers. The client sent packets to the servers. In Figure 2 (a), the wired host sent packets to one of the mobile hosts, one at a time. In Figure 2 (b), the wired host sent packets to both mobile hosts at the same time.

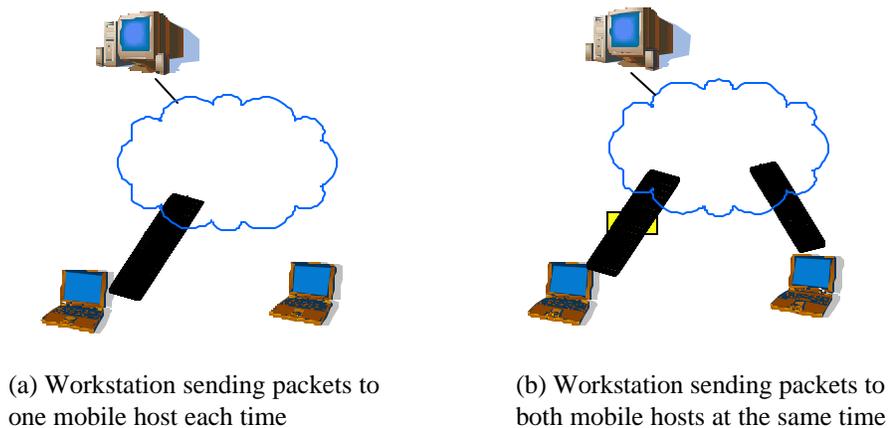


Figure 2. Reference traffic vs. experiment traffic

Instead of measuring the absolute bandwidth/drop-rate of mobile hosts in different positions, which was observed to be unstable, we measured the bandwidth/drop-rate of one mobile host with the interference from the other mobile host against that without interferences. To achieve this, we measured three pieces of traffic for each different position of the moving host. First, we had the client send 10 seconds' packets to each mobile host, one after the other. This kind of traffic could be called *reference traffic*. Second, we had the client send 30 seconds' packets to both mobile hosts at the same time. We called this kind of traffic *test traffic*. Third, we repeat the reference traffic again. We average the two reference traffic measurements to get the average bandwidth/drop-rate of the mobile hosts without adjacent-cell interference. When comparing the test traffic measurement with the average, we know how the bandwidth/drop-rate changed due to the interference from the other host. Here we assumed that the outside interferences to our mobile hosts wouldn't change too much during the approximate 1-minute period of the three rounds of traffics. This method yielded more accurate result than measuring without the reference.

2.3 Logistics

2.3.1 Machine Specifications

We used two laptops as the mobile hosts and one desktop workstation as the wired host in our experiments. Interference from other mobile hosts in adjacent access points would be more interesting, but our human resource was limited due to our project group size of three. The laptop computers were equipped with Lucent WaveLAN network cards provided and supported by SCS facilities. Table 1 shows the specifications of the test-bed laptops used in our experiments.

	Laptop 1	Laptop 2	Desktop
Model	Dell Inspiron 4000	IBM ThinkPad 560X	N/A
CPU	Intel Celeron 600MHz	Intel Mobile Pentium MMX 233MHz	Intel Pentium III 733MHz
Memory	128 MB	64 MB	256 MB
OS	Windows Millennium	Linux OS	
Network Interface	2Mbps WaveLAN	2Mbps WaveLAN	Ethernet

Table 1. Machine Specifications

The driver of WaveLAN card installed on Laptop 1 provided a GUI display of all necessary information of the access point the host is attaching to, including the name, MAC address, channel, etc. of the access point. When the mobile host switches corresponding message will display immediately. This feature helps us to demarcate the scope of adjacent base stations.

2.3.2 Selection of Time/Location

Although the improved measurement method was adopted, it was not easy to find suitable location and time for our experiments due to the population of mobile users in Wean Hall. We tended to carry out our experiments during the time that hopefully had the least possible use of wireless networks. Two of the three groups of experiments were done after 10 p.m.; the third was done on Saturday afternoon, when most people are not working. All our experiments were done in Wean Hall, since we only had the location layout of access points in this building.

2.3.3 Tools

Iperf v1.1, a tool for measuring maximum TCP/UDP bandwidth performance, was used in our experiments to generate the traffic needed between clients and servers. Iperf has both Linux and Windows versions, which was suitable for our machine specs. Iperf runs in a client-server mode. Client can create UDP streams of specified bandwidth for a specified period of time, rather than a set amount of data to transfer. Iperf prints periodic, intermediate bandwidth, jitter, and loss reports at specified intervals. The information of constant bit rate UDP streams used in our experiments is as follows:

UDP packet size 1470 bytes

Client sending rate: 1 Mbps

UDP server buffer size: 64 KB

Intermediate loss report interval: 1 second

3 Results

The graphs we present in this paper show normalized bandwidth loss as a fraction of the average measured reference bandwidth. The measured bandwidth for each test is normalized to the average of the two reference bandwidths sampled before and after the test. This bandwidth is less than or equal to the average reference. We plot on the y-axes the fraction of bandwidth lost with respect to the average reference. So a value of 0 means that the reference and the normalized bandwidth were the same, and no loss occurred. A value of 0.7 indicates that the normalized bandwidth was 70% loss with respect to the average reference bandwidth. The x-axes show the distance between the two hosts. We looked at bandwidth loss and packet drop rate. The packet drop rates were very similar to normalized bandwidth loss, so we include only the bandwidth plots.

As expected, when the two mobile hosts are in the same cell, the bandwidth is split between them regardless of the distance between the hosts. Host1's normalized bandwidth loss ranged from 0.5 to 0.65, while Host2's loss ranged from 0.21 to 0.34, as shown in Figure 3. Because one host receiving more bandwidth sometimes resulted in the other host losing more bandwidth, we also looked at the average bandwidth loss of the two hosts. Their average loss is about half of the reference bandwidth, as shown in Figure 4.

Also as expected, we saw almost no loss at the mobile host servers when they were set up in adjacent cells with different channels, as shown in Figure 5. In the adjacent-cell-same-channel experiment, the two servers' bandwidth loss depended not only on the physical distance between them, but also on their positions within the base stations' cells. Host1's bandwidth loss depended mostly on its own location within its cell. Host2's bandwidth loss depended first on whether it was in the *border zone* or the *safe zone*, then on its distance from Host1. In following sections, we will first explain what we mean by the different zones. Then we present the results from the adjacent-cell-same-channel experiment (situation 2) in more detail, first for Host1 then for Host2.

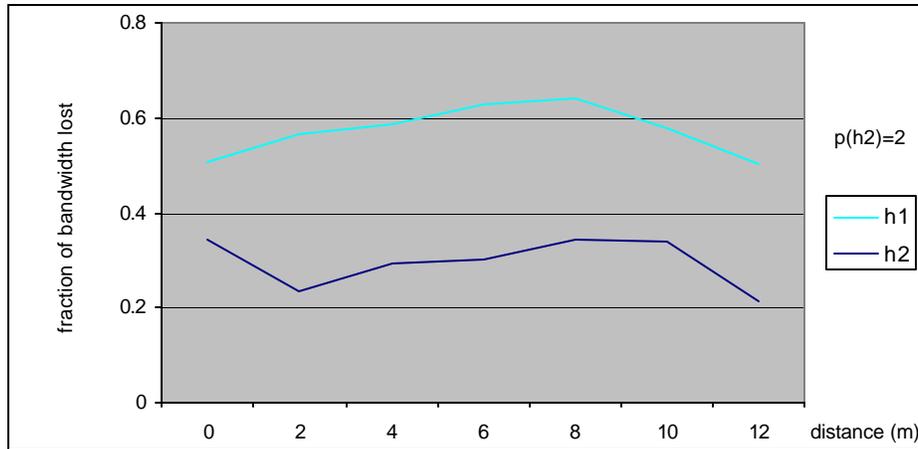


Figure 3. Bandwidth lost when hosts were in the same cell

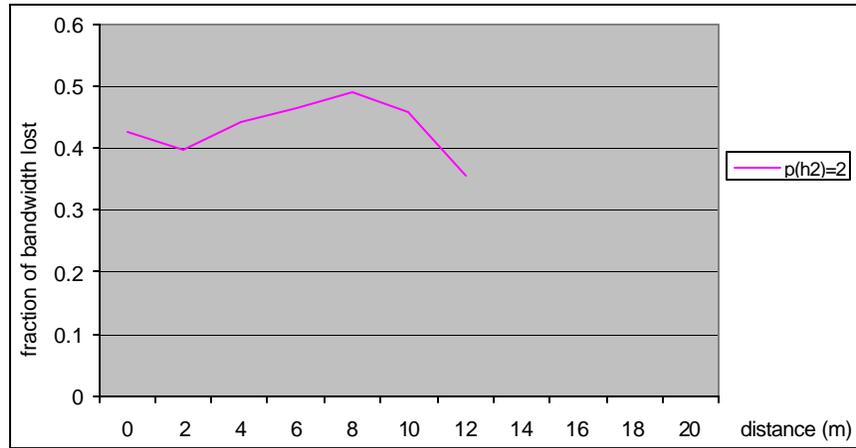


Figure 4. Average Bandwidth lost when hosts were in the same cell

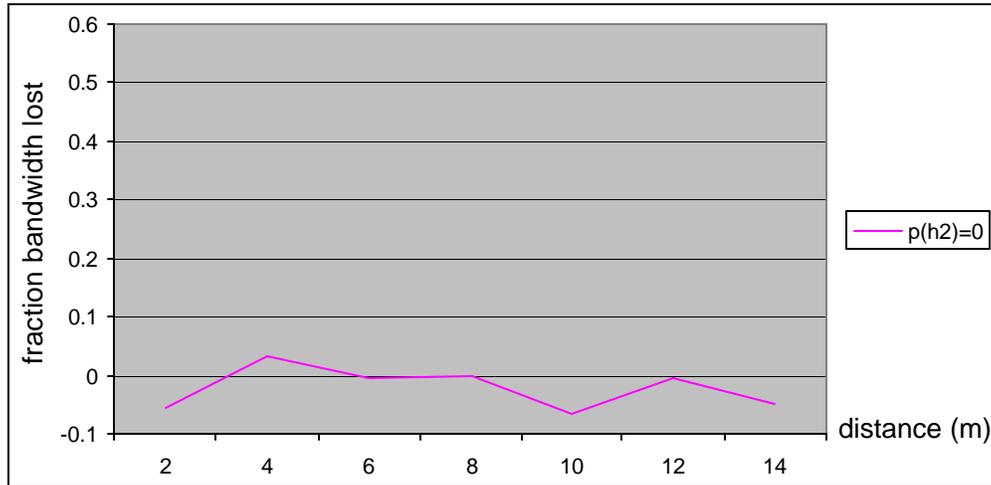


Figure 5. Average bandwidth lost when hosts in adjacent cells, different channels

3.1 Border zone and safe zone

We observed, as we conducted our experiments, that there is no single borderline that separates the adjacent cells and which, upon crossing it in either way, causes the mobile host to switch access points. Rather, there is a *hysteresis* effect, which is illustrated in Figure 6. After a mobile host enters far enough into the adjacent cell for its base station to switch from *Access Point 1* to *Access Point 2*, tracing a few steps back the other way doesn't result in a switch back to the original base station. The mobile host needs to return deeper into the original cell before the switch back to access point 1 takes place. In other words, the mobile host tries to hold on to an access point as long as it can before it switches. We call this area of overlapping base stations cells the *border zone*, which is bounded by the two switching points. The *safe zone* refers to the physical space outside the border zone, where the host is safely attached to a single base station.

In our adjacent-cell-same-channel experiment, Host2 spends half of its time in the border zone (positions 0 and -2) of AP2 in Figure 1, and the other half in the safe zone (positions -4 and -6) of AP2. We expected that when Host2 is positioned in the border zone, it would have higher sensitivity to the wireless traffic in the adjacent cell. Host1, on the other hand, spends all of its time in the safe zone and is used to create different distances between the two mobile hosts.

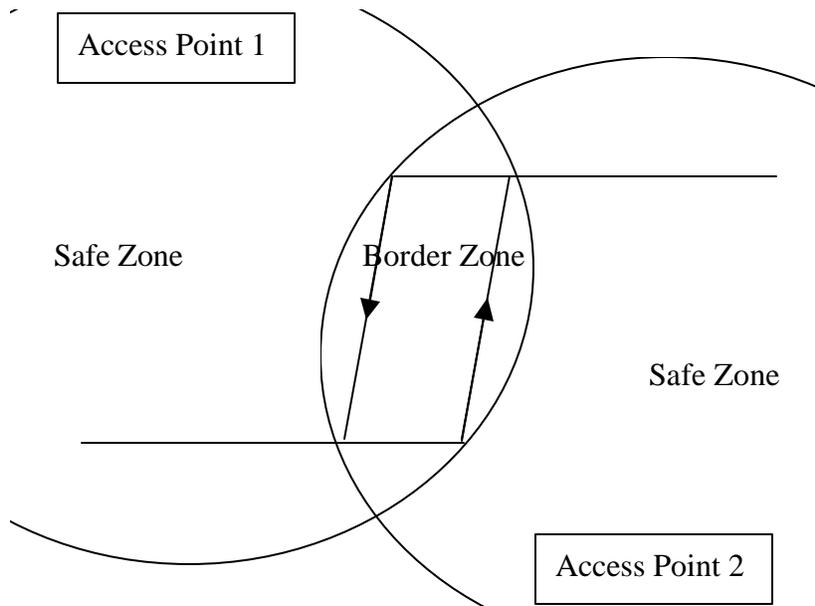


Figure 6. Roaming histeresys

3.2 Host1

Figure 7, 8, 9, and 10 show the bandwidth loss of the two mobile hosts when Host2 is in positions 0, -2, -4, and -6, respectively. We focus on Host1's measurements in this section. Notice that the bandwidth loss of Host1 follows fairly the same pattern regardless of Host2's location and of the distance between the two hosts. Host1's loss does not decrease along with Host2's loss. Host1's loss stays below 0.4 of the reference bandwidth for the first 5 locations. The last two locations always result in loss of less than 0.2. Host1 always stays within the safe zone.

We believe that this is the reason for its moderate loss levels even when the two hosts are very close together (i.e. 4 meters or less apart). The first five locations must be within a physical area where the signals from the base station is strong enough for the receiving WaveLAN card on Host1 so that it would not switch base stations, but not so strong that they completely overwhelm the weaker signals from the adjacent base station. When Host1 retreats even deeper into its base station's wireless cell in the last two locations, its base station signals dominate, and its bandwidth loss decreases even more.

One interesting fact that a comparison between these Figures and the Host1's line in Figure 4 show is that for Host1, it would be better to be within a few steps (i.e. 2 meters) away from another mobile host who is using an adjacent base station than to be 12 meters away from another host sharing the same base station. As long as Host1 is within the safe zone of its base station, it is better not to share base stations with a second user.

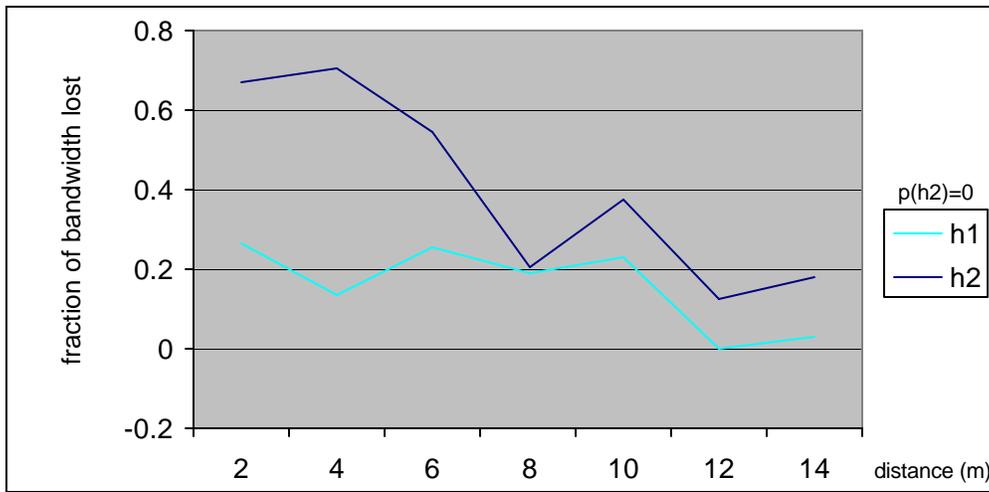


Figure 7. Bandwidth lost when Host2 is in position 0

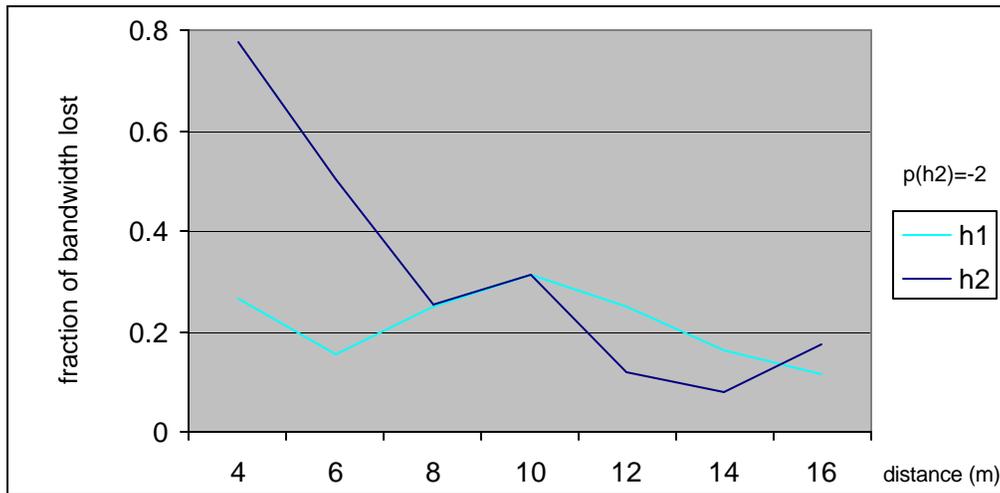


Figure 8. Bandwidth lost when Host2 is in position -2

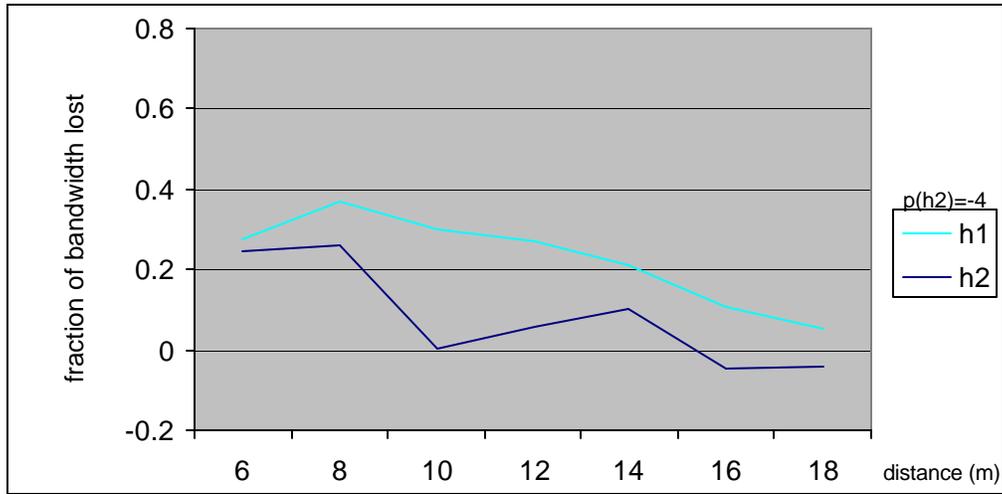


Figure 9. Bandwidth lost when Host2 is in position -4

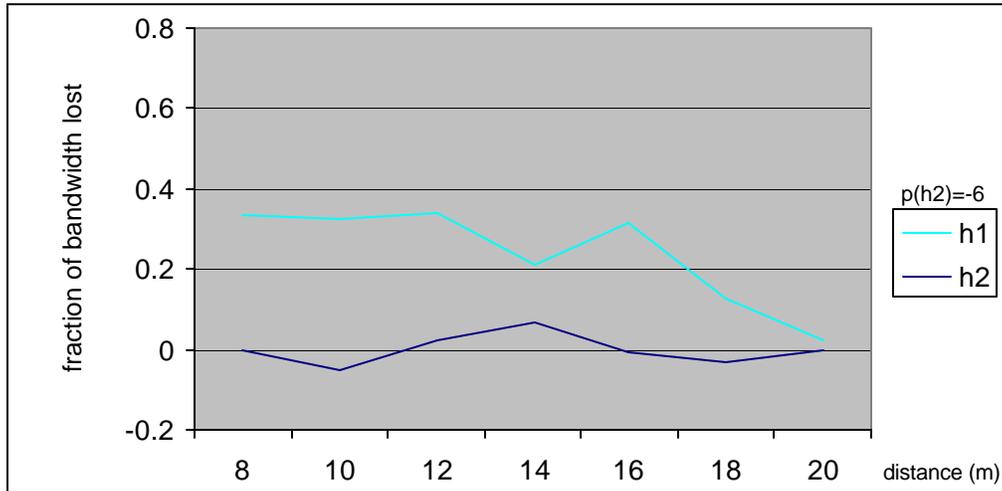


Figure 10. Bandwidth lost when Host2 is in position -6

3.3 Host2

Host2's situation is different from Host1 because two out of its four locations are within the border zone, and the other two safe zone locations are still very close to the border zone, analogous to Host1's two closest locations to the border zone (positions 2 and 4). Upon initial glance at the Host2's plot lines in Figures 7, 8, 9, and 10, it is clear that, in all positions except for position -6 (the one furthest inside its base station's cell), bandwidth loss decreases as host1 moves away. However, upon closer examination, we see that the bandwidth loss for when Host2 is in the border zone is drastically different from when Host2 is in the safe zone.

When Host2 is in the border zone, its physical proximity to Host1 is highly correlated to its bandwidth loss: the closer it is to Host1, the greater the loss. In fact, Host2's plot for Figure 8 seems to be just a

smoothed out version of the plot in Figure 7. In both Figures, Host1 does not see a loss of less than 0.5 until the distance separating the two hosts is at least 8 meters. The loss does not drop to below 0.2 until the hosts are 12 meters apart. The increase of the initial distance between the hosts in the two figures does not noticeably improve the bandwidth for Host2.

Collecting bandwidth measurements for Host2 at the border zone location farthest away from its base station (position 0) was very difficult because the host would frequently switch to the other base station in the middle of the 30-second tests as well as while taking the 10-second reference measurements. In the other border zone location (position -2), station switching was much less frequent. This shows further that the border zone is a very unstable region, and the hosts in it are sensitive to interference from adjacent cell traffic of nearby hosts and prone to losing the current base station. To keep within the scope of this study, we do not include the bandwidth measurements from those tests in which Host2 switched base stations, but it is worth noting that the bandwidth loss of Host2 was the greatest in those cases.

From these observations, it is apparent that the weaker signals of the base station at the edge of its cell impacts wireless bandwidth. The host becomes very sensitive to adjacent cell traffic involving nearby hosts. Since Host2's loss decreases as Host1 moves away, the interference causing loss must come mainly from Host1's WaveLAN activity rather than the adjacent cell's base station broadcasting to hosts in its cell. We find from these results that, while a host stays in the border zone, the best thing that can be hoped for, which would work toward better bandwidth, is for the second host in the adjacent cell to move as far away as possible.

Once Host2 steps into the safe zone, there is significant drop in bandwidth loss (Figure 9). In fact, the bandwidth losses for both positions in the safe zone are below 0.4. As with Host1, the stronger signals from the base station received in the safe zone contributes to the decrease in loss. However, the interference from the adjacent cell is still present, especially when the hosts are 6 and 8 meters apart. This interference disappears when Host2 takes a few steps farther into its own cell, in Figure 10. We attribute the sensitivity of the WaveLAN receiver at Host1 to its greater bandwidth loss even when Host2 is well inside its safe zone and the two hosts are far apart.

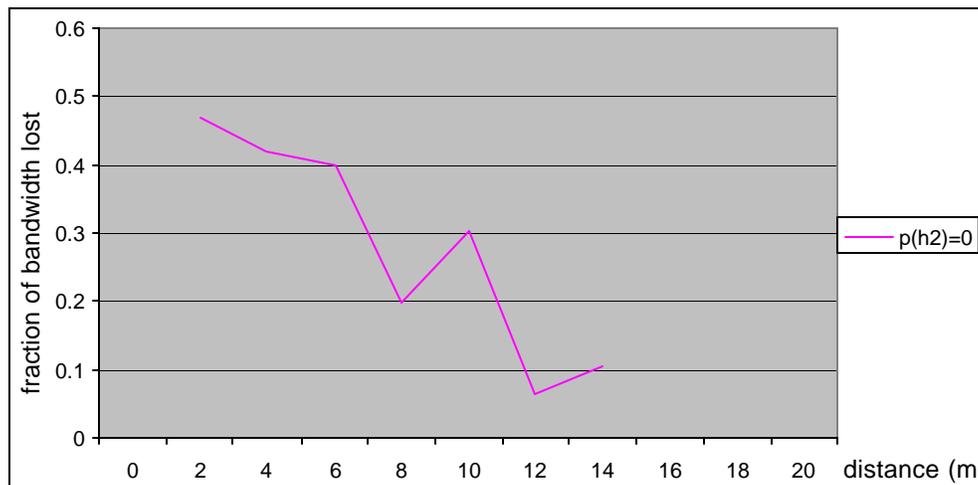


Figure 11. Average bandwidth lost for both hosts when Host2 is in position 0

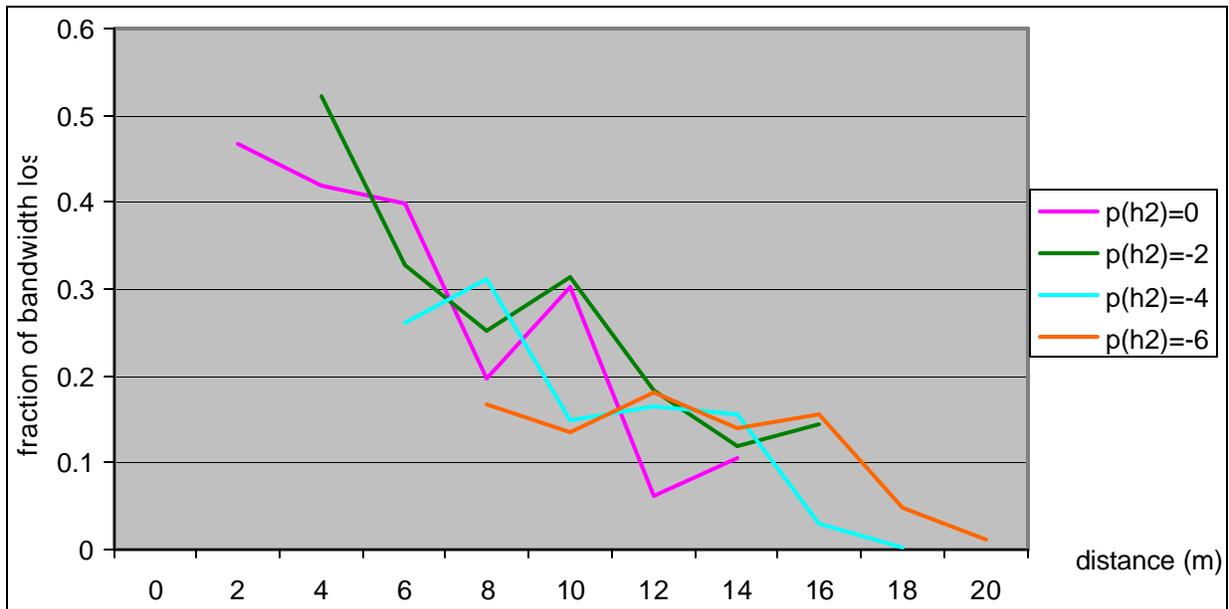


Figure 12. Average bandwidth lost for both hosts for all positions of Host2

Because one host receiving more bandwidth sometimes resulted in the other host losing more bandwidth, we averaged the two hosts' losses for each of Host2's location. Figure 11 shows the average loss (i.e. the average of the two plots in Figure 7) when Host2 is in position 0. This reflects the losses experienced by both hosts due to adjacent cell interference. The summary graph showing the averages losses for all of Host2's positions is in Figure 12. The plot lines for when Host2 was in the border zone (positions 0 and -2) definitely clump together. Also as Host2 moves farther into its cell, the lines flatten out. As the two hosts increase distance between each other, both can benefit from better bandwidth.

4 Conclusion

At the beginning of this paper, we raised the question: is it always true that hosts operating in one wireless cell do not degrade the capacity of the channel in neighbor cells? Our hypothesis was that there is degradation of the channel's capacity induced by a mobile host operating in adjacent cell. During the semester, we designed and conducted three groups of experiments. From the data we obtained, it is proved that our hypothesis is correct when the adjacent access points use the same channel. We conclude from our experiments that the capacity degradation of a channel is a function of distance between mobile hosts and the position of the hosts within the cell, when the adjacent access points are operating in the same frequency.

The best bandwidth is achieved when a host is alone in the safe zone of a cell with all adjacent cells using different channels. The next best thing would be for a host to stay alone within the safe zone of a cell, even when there is a second host in the adjacent cell using the same channel. We have shown that bandwidth loss in this case is less than when sharing a cell with another host. However, when a host is in the border zone, the story is different. If the second host is sufficiently far away, the bandwidth loss of the first host is similar to being alone in the safe zone, and it is also better than sharing the same cell. But when there is a second host nearby in the adjacent cell using the same channel, then the bandwidth loss far exceeds the loss experienced by sharing the same cell.

Therefore, when a host is within the safe zone, it doesn't need to worry too much about adjacent cell traffic regardless of the channel that the cell is using. Also, when a host is in the border zone, it needs to worry only about putting as much distance between itself and nearby hosts.

Another question we asked in section 1 is: will covering an area with more access points always result in better channel capacity delivered to the mobile hosts? Through our work we would answer no. If there are so many access points nearby that the host is constantly switching between them, the host will get very high bandwidth loss. For a host, switching often is like staying in the border zone. We have also observed during our experiments, switching access points during a test resulted in the highest bandwidth loss.

Another interesting observation worth mentioning was when we were experimenting on one floor in Wean Hall, the mobile host switched to access points on other floors occasionally. This reminded us that that adjacency of access points has to be considered in a three-dimensional space when planning the layout of access points in a building.

The main contribution of this paper is to draw some attributes of adjacent cell interactions. With future study this would lead to optimal design of wireless networking topologies. Another area that could benefit from our work is the wireless network weather map.

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