Network Condition Check

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Table of Contents

Contents *Page*

Introduction

Internet is a global system, interconnecting computer networks. The network consists of millions of private, public, academic, business, and government networks. The history of Internet began back in the research commissioned by the US government in the 1960s to build robust fault-tolerant communication via computer networks. Although Internet was used for military service at first, in the mid-1990s it had a revolutionary impact on culture and commerce, including the rise of near-instant communication by electronic mail (email), instance messaging, two-way interactive video calls, etc.

The development of Internet makes communication faster and more accessible to greater number of populations. Nowadays Internet plays a vital role in daily lives. For college students, it provides students with better and easier access to academic resources. It gives students new forms of learning. Students no longer have to go to libraries. They can just go on Internet and use any search engine to find the knowledge outside classrooms. Moreover, it allows students to discuss and share knowledge with people around the world in a fraction of a second. Internet has become an essential academic tool for college students.

Background—Access Point

Before we have the wireless networks, setting up a computer network required running cables through walls and ceilings in order to deliver network access to all of the network-enable devices in the building. With an invention of the Wireless Access Point (AP), we now can add new devices to the network without any cable. This reduces the cost and time of the network setup. AP is basically a device that allows wireless devices, such as computer, mobile phones and tablets to connect to wired network using WiFi or related standards [2]. It can connect to a router as a standalone device or be an integral component of the router itself. Most APs support connections of multiple wireless devices to one wired connection. They are commonly used to support public Internet hotspots or internal networks to extend their WiFi signal range.

To make sure that students have enough network coverage Duke provides plenty of APs throughout the campus. However, a dense cluster of APs does not guarantee a well working network. The APs which Duke is using are from Cisco. Cisco also provides a management tool that has APs' location information (building, floor and map of APs) as well as the numbers and types of wireless devices that connect to each AP at each time.

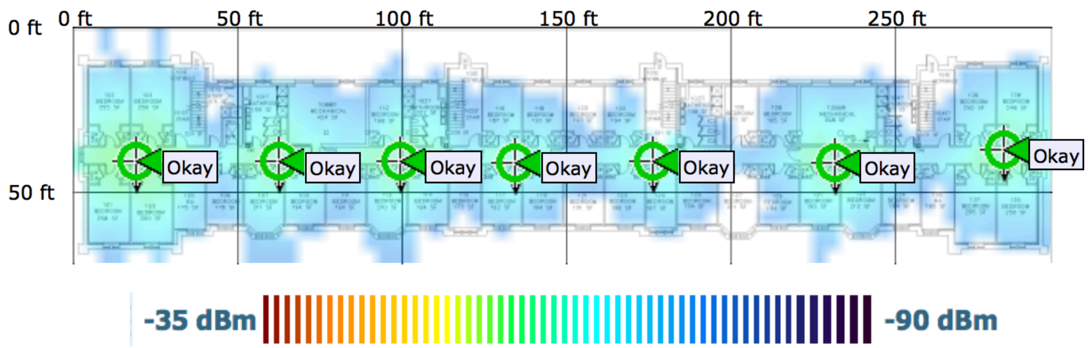

Figure 1: Coverage heatmap of Wannamaker (1st floor) [1]

Figure 1 is a coverage heatmap from the management tool. It is the heatmap of Wannamaker dormitory (1st floor). Within roughly 22,500 square feet, there are a total of 7 APs, which is quite plentiful for a single floor. The colors on the map show the strength of the wireless signal. The green area is the area with stronger signal (higher dBm) compared to the blue zone (lower dBm). Even with packed bundle of APs, there are still a couple of spots that do not have coverage (white spaces). The following section will elaborate why the huge number of APs does not always mean that we will have a great network performance.

Understanding Wireless Network Performance

There is a popular misbelief that the network performance depends on signal power. In fact, the absolute signal power level is irrelevant to the performance. The critical factor in measuring overall performance of any communication system is signal-to-noise ratio (SNR) [1]. SNR is the ratio of the signal power to the noise power. The higher the SNR, the better the performance. As a device moves farther away from an AP, the signal power decreases while the background noise remains constant, leading to a decline in SNR. If the device continues to move away from the AP, it will eventually get lost in the background noise. In other words, the SNR will no longer support communications. See Figure 2 and 3.

[1] Source: Figure 1 provided by Cisco Prime Infrastructure

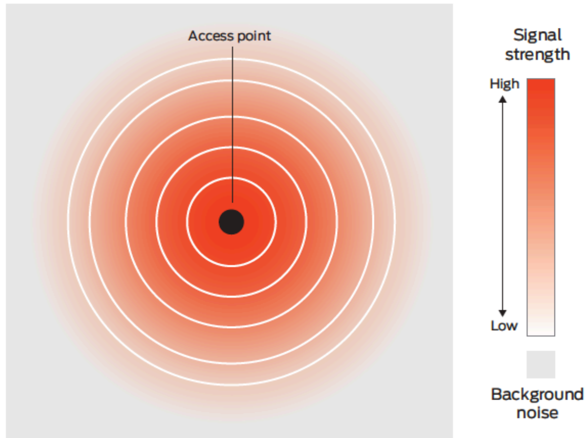

Figure 2: Signal Strength and Background Noise[2]

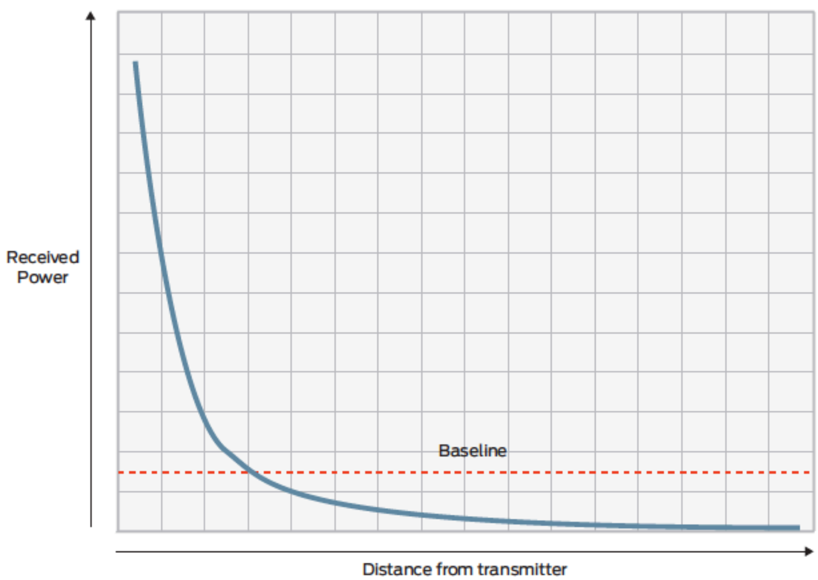

Figure 3: Signal Strength vs. distance[3]

When an SNR falls below the baseline depicted in Figure 3, it will no longer support wireless communications. Practically, there are other transient parameters than the distance that lower the SNR, such as people and interference from other type of signals, etc. The SNR declines as the distance from an AP increases. Therefore, to keep the received power above the baseline, we can place several APs in the service area. However, this will increase the costs of the network setup. The common solution to the cost low is deploying as few APs as possible and turning up the APs' signal power. This technique works for the locations where cost-effective coverage is more important than performance. Increasing the power will create problems for sites that requires high throughput.

[2] Source: Figure 2 provided by Juniper Networks Inc.
[3] Source: Figure 3 provided by Juniper Networks Inc.

Turning up an AP’s power causes an exponential rise in adjacent channel interference, which affects the performance of neighboring APs and degrades the network performance. This explains why we have the area without coverage in the heatmap in Figure 1 though all the APs indicated that they were all working.

Additionally, there are other factors that affect the network performance, for example the number of users sharing the network, physical obstructions, signal reflection, etc. So while all the tools seem to work from the service provider’s aspect, from the users’ side the network may not be working as expected. This is the motivation for me to work on this project.

Goal and Solution of This Project

The aim of this project is to find ways to gather wireless network performance information at various locations throughout the campus from the students, who are the main users of Duke wireless network. To get the wireless network performance information, we need a device that can report its own location information, along with data on the network performance. The testing device has to be accessible to as many students as possible. We picked cell phones to be the testing devices. The plan is to create an iOS (iPhone) application to get the devices’ location information and allow the users to report the wireless network condition.

Project Strategy
Our Testing Devices

There are several cell phone platforms. The one that we will be using is the Apple phone or iPhone. The problem with the iPhone is that Apple limits an access to low-level radio performance parameters, so we will not be able to get much in depth information about the network that the devices are connected to. Moreover, there are other restrictions that Apple places on iPhones; for instance, we cannot run Flash on iPhones and we will have to go through complicated method set by Apple to distribute the iPhone application we developed. For beta testing Apple allows us to register only up to 100 devices. We are aware of the limited information we will get from using iPhones as the testing devices. The biggest advantage of using iPhones is that it is the most common cell phone platform used among Duke students.

Developed iPhone Application

Location Information

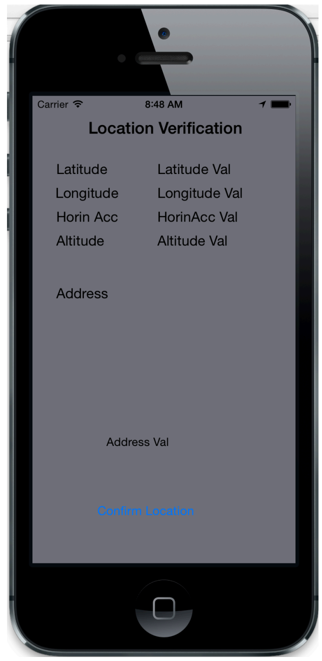

Figure 4:Location Verification Section of the iPhone application

The most common positioning technique is the Global Positioning System (GPS). For outdoor environment, GPS works extremely well. However, the GPS signal is too weak to penetrate most buildings, making it challenging for indoors positioning. A number of schemes have been envisioned for indoor localization. One of the most promising strategies is using a mechanism by which wireless network card can measure the signal strength of all stations within its broadcast range. A device will attempt to use this information to determine its distance from these fixed base stations, based on the known base stations' locations. Nevertheless, converting signal strength into distance is not an easy task, as the relationship is nonlinear. Additionally, the signal strength is most likely to have non-Gaussian noise, resulting from multipath and environmental effects.

Intuitively, most students will be using Internet, Duke wireless network in particular, at indoor locations more than at the outdoors. So most locations we will be dealing with are unsurprisingly indoor locations. Generally, the location service using cell phone will blend information from GPS, WiFi and cellular data. But as mentioned earlier, GPS signal cannot penetrate into indoor locations. Therefore, we expect to get higher errors from the readings for indoor locations compared to outdoors.

For our iPhone application, we use latitude, longitude, address, altitude and accuracy of the horizontal location values as a matrix of location information. The latitude and longitude values are determined first using the 'CoreLocation' framework provided by the iOS Software Development Kit (SDK). Then the coordinate is converted to the address value, using the information from the Apple database. Our application does a good job in getting a pretty precise location coordinates and address values both indoor and outdoor. It can distinguish between buildings. Furthermore, the application continues to update the location information as the device moves even when the movement is entirely indoor.

To have the network condition check, we would like to know how the network performs in each location and which AP is responsible for network service. The latitude and longitude values themselves do not give enough location information about which APs the devices are connected to. Although the cell phone possesses the information of the AP to which it is connected, Apple restricts us from accessing this information. So apart from the horizontal coordinates, we need to get information about the level or altitude of the devices. The CoreLocation framework in the iOS SDK also enables the device to find the information about its altitude value. The altitude value indicates distance above the sea level in meters. However, the values obtained from the application fluctuated a lot and thus were not useful. GPS signal degrades indoors, leading to an inaccurate location service in terms of altitude. Hence, to get an accurate and usable data, we added a section for the users to report which floor they are in instead of getting the altitude value from the CoreLocation framework.

Determining location indoor is a challenging task. We will most likely have uncertainty of the measurements. This leads us to the accuracy value provided by the CoreLocation. The accuracy value is the radius of uncertainty of the horizontal location information measured in meters. The hypothesis is that the accuracy value of outdoors should be lower than the indoor locations and WiFi should help to improve the accuracy of the location information indoor. Table 1 shows the range of the accuracy values from running the iPhone application with and without WiFi and both indoors and outdoors.

	Indoors	**Outdoors**
With WiFi	10-65	5
Without WiFi (only LTE)	200+ to 1414	5

Table 1 Accuracy Value from running the iPhone Application

With WiFi turned on, the accuracy value indoor went from 10 meters when the device just entered the buildings. The value continued to increase from 10 meters to the maximum of 65 meters as we moved further into the buildings, away from the entrances'. The accuracy value for outdoor locations was constant at 5 meters. This data coressponds with our expectation that we do not have sufficient GPS signal to get precise location information indoors, compared to outdoors where GPS signal works extremely well.

Tests were run to find the accuracy value with WiFi turning off. The value indoors ranged from roughly 200 meters up to 1414 meters. While the outdoor values were consistent at 5 meters. This shows us that for localization, WiFi and GPS play an important role to get the most accurate location information indoor and outdoor respectively. Our iPhone application will allow the users to confirm the location information it gets. If the location is not correct, the users can run the application again to get the updated location information.

Network Performance—Qualitative Measurement

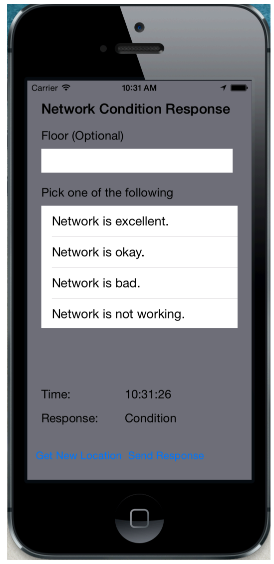

Figure 5:Qualitative Network Performance Section of the iPhone application

Having all the APs working does not mean that the users will have a well working integrated network as mentioned earlier. Therefore, getting information about how network performs from the users' side is crucial. After the users confirm the location and report which floor they are in (for indoor locations), our iPhone application will allow the users to manually pick qualitative performance of the network, whether the network is excellent, okay, bad or not working at all.

However, when the network is not working then it is impossible for the iPhone application to connect to the server, so the users will not be able to report the network performance. To solve the problem we add a timestamp function to get the time value when the users want to report the network performance. Then once the network is available, the network performance information along with the timestamp will be sent to the server. We will know exactly what time does the network does not work at each location.

Internet services come in various forms, such as web browsing, e-mail and multimedia on demand. Different users have different purposes of using the Internet services. There are different quality of service (QoS) requirements perceived from the users' standpoint that determine whether the service is acceptable. There are 4 different QoS classes: conversational, streaming, interactive and background classes.

Traffic class	Real Time		Best Effort	
	Conversational	Streaming	Interactive	Background
Fundamental Characteristic	Preserve time relation between information entities in the stream, Small time delay tolerance)	Preserve time relation between information entities in the stream, Typically unidirectional service, high requirements on error tolerance	Request response mode, data integrity must be maintained. High requirements on error tolerance, low requirements on time delay tolerance	Destination is not expecting the data within a certain time, Data integrity should be maintained, Small delay restriction
Example of the application	Voice service, Videophone	Streaming multimedia	Web browsing, Network game	Email

Table 2: QoS classes[4]

Figure 6 shows that different QoS classes will have different acceptable service requirements: error ratio and time delay. For example, though a video call (conversational class) has high error tolerance, it should have as short delay as possible to be acceptable for the users. While emailing (background class) does not concern how long it will take to complete the process but the data integrity should be maintained.

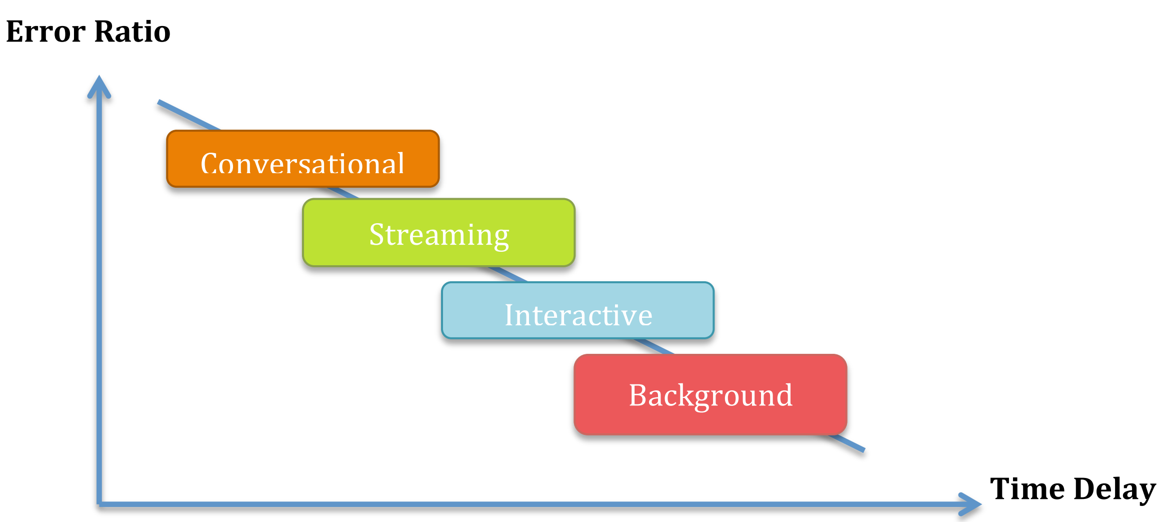

Figure 6: Error Ratio vs. Time Delay for different Internet Service Application[5]

[4] Source: Table 2 provided by Huawei
[5] Source: Figure 6 provided by Huawei

Unsurprisingly, at the same level of network performance, different users may perceive different levels of acceptable service. Therefore, qualitative network performance is not a perfect indicator for the actual system performance. This leads us to a requirement for the iPhone application to be able to get quantitative data on the network condition.

Network Performance—Quantitative Measurement

To be able to compare the network performance at each location, we are required to get the quantitative network performance information. The approach we took is to setup a server to perform a test that measures the speed of the wireless network. We requested a virtual machine from Duke Co-Lab. The task of the server is to collect all of the information from the iPhone application and to allow the speed test for the quantitative network performance measurement.

Similarly to widely available network speed test applications we get download speed, upload speed, and latency value as a matrix of the network performance. However, we have added an extra capability for our speed test to be able to get the IP of the devices as well as the hostname to which the devices are connected. The IP address gives us the information about which device we are running the test on. The hostname will indicate whether the device is on Duke wireless network or its cellular data. Hence, we will know whether or not we are testing the Duke wireless network as sometimes the users may forget to turn on the WiFi on their devices. Figure 7 shows the output from running our speed test on our browser.

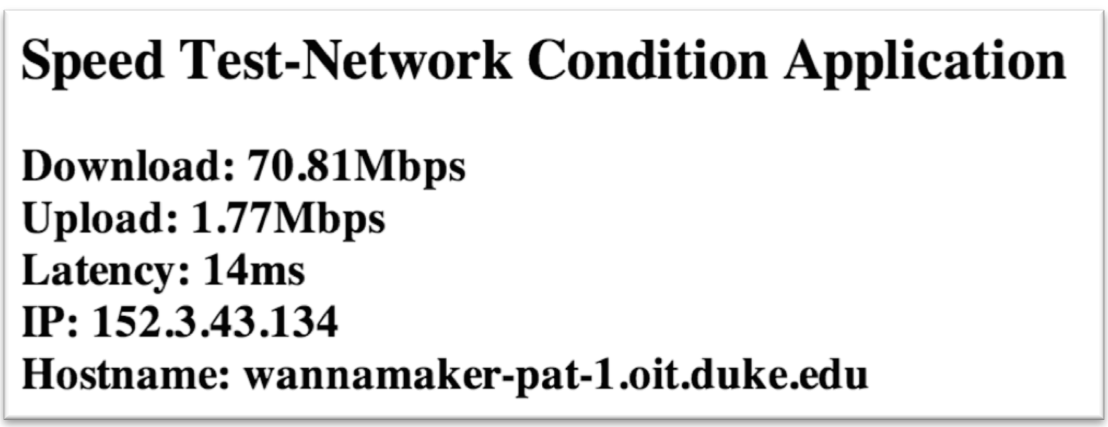

Figure 7: Output from our speed test

Our speed test is developed from an API that ‘speedof.me’ makes available to the public. The system tests the network connection by directly downloading and uploading sample files from our browser. It begins with downloading the smallest sample file with the size of 128KB. Then if the download process takes less than 8 seconds, the next sample file with twice the size will be transferred. Otherwise it continues with the upload test. For the download test, the biggest sample file size is 128MB. Half of the last downloaded sample file will be sent back to the server to calculate the upload speed of the network system.

With this strategy, unlike other speed tests, our speed test can measure connection speeds in a wide range: from slow 10Kbps mobile GPRS to a very fast 100Mbps cable users automatically. Our speed test tests the Internet directly from our web browser, not through Flash or Java plugins so we will have less overheads, leading to more accurate test than other general speed tests.

Sample Data Collected

Sample of the data collected with our speed test is displayed in Table 3. The test device was an iPhone5 which has been registered for the beta testing. The test was run in Wannamaker dorm (level 1). The locations of the device were directly below the APs (fixed both distance and height of the testing device from the APs). It is true that the number of devices attached to each AP will have an effect on the Internet speed. The more devices shared the service, the slower the speed will be. However, as we want to measure how well the APs perform in regular environment, we will run the test at normal condition for each location. In other words, we will not try to restrict other devices from using the network and have only the testing device is attached to the APs.

The latitude and longitude values for all the APs were approximately 35.998 and -78.939, respectively. The address was Wannamaker Drive Ext 27708 Durham NC, United States, except for the 7755-WANNAMAKER-113-H-W that the address was 1140-1498 Towerview Rd 27708 Durham NC, United States. The WiFi was turned on throughout the test. The accuracy value of the location information was constant at 65 meters. Although the accuracy value was much higher indoors (65 meters) than the value outdoors (5 meters), the address values we got from running the iPhone application in Wannamaker dorm proved that the application did well in finding the locations. Even when the device was indoor, it knew which street it was actually on. (Wannamaker dorm was at the corner of the Wannamaker Drive Ext and Towerview Road)

AP	Download Speed (Mbps)	Upload Speed (Mbps)	Latency (ms)
7755-WANNAMAKER-138-H-W	59.22	18.12	22
	65.50	11.64	37
	26.33	13.99	18
	72.64	12.01	19
	82.26	13.39	17
AVE	**61.19**	**13.83**	**23**
7755-WANNAMAKER-131-H-W	72.51	7.08	20
	55.02	9.33	24
	70.90	5.25	42
	44.59	9.44	65
	26.13	2.88	108
AVE	**53.83**	**6.80**	**52**
7755-WANNAMAKER-124-H-W	16.06	1.37	112
	30.59	1.43	113
	8.07	1.98	111

	30.99	2.01	109
	8.86	3.50	103
AVE	**18.91**	**2.06**	**110**
	53.79	6.68	68
	36.71	8.26	62
7755-WANNAMAKER-117-H-W	36.58	7.25	76
	36.50	9.76	55
	56.92	9.42	39
AVE	**44.10**	**8.27**	**60**
	85.63	11.99	17
	85.29	12.58	18
7755-WANNAMAKER-113-H-W	86.04	7.44	17
	70.66	10.30	18
	56.13	5.16	18
AVE	**76.75**	**9.49**	**18**
	61.22	7.75	17
	38.65	13.58	17
7755-WANNAMAKER-107-H-W	92.19	8.17	18
	67.43	13.63	18
	67.63	9.58	18
AVE	**65.42**	**10.54**	**18**
	69.17	14.47	18
	72.07	10.81	17
7755-WANNAMAKER-103-H-W	67.77	8.15	18
	64.88	13.56	18
	87.24	12.28	17
AVE	**72.23**	**11.85**	**18**

Table 3: Sample data collected for the speed test

The average values of download speed and upload speed for each AP were plotted in Figure 8.

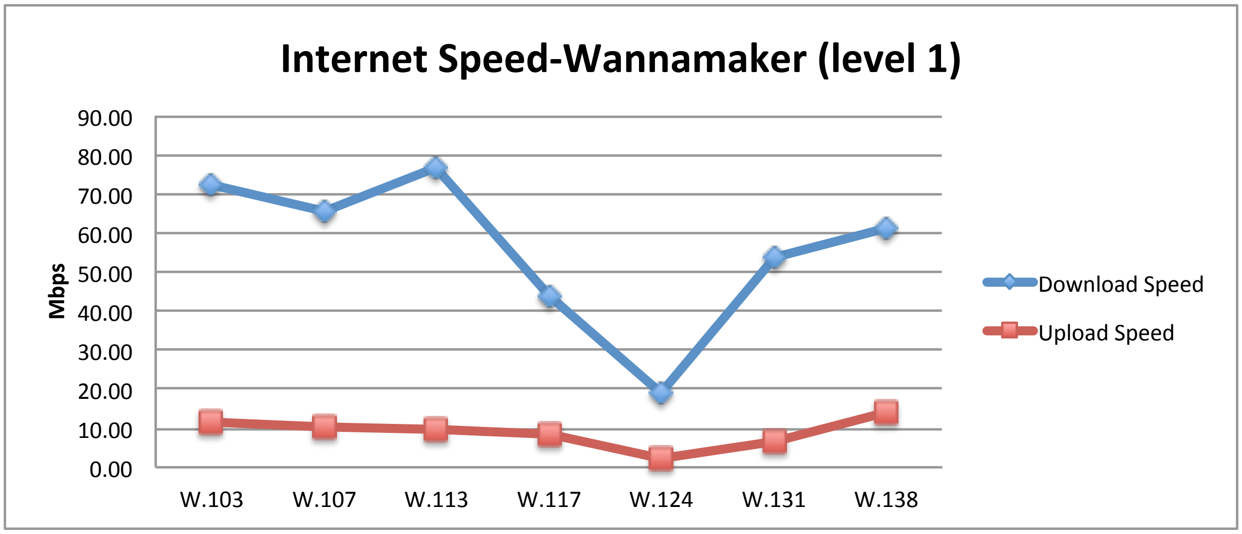

Figure 8: Average Download Speed and Upload Speed from Table 3

The figure below shows the information we got from the management tool for the APs in Wannamaker dorm (level 1).

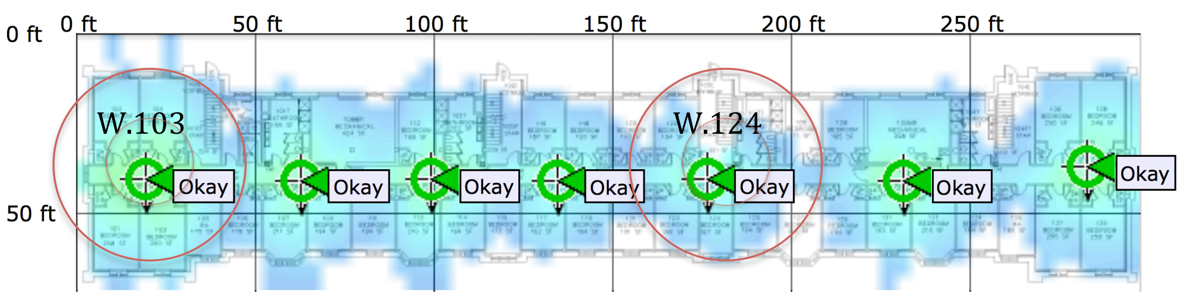

Figure 9: Wannamaker (level 1) network condition from Cisco management tool[6]

Our hypothesis is that the location with higher Internet speed should have stronger network signal. The data in Figure 8 and Figure 9 verifies the hypothesis. The AP 7755-WANNAMAKER-103-H-W has the higher average speed, both for uploading and downloading, than the AP 7755-WANNAMAKER-124-H-W in Figure 8. Figure 9 shows that the center of the AP 7755-WANNAMAKER-103-H-W is green, while it is blue (weaker signal) for the 7755-WANNAMAKER-124-H-W AP.

Our concern is that the alignment of the device while performing the speed test may have an effect on the measurements. So below are the results of the average upload and download speeds for each alignment at a fixed location and height.

[6] Source: Figure 9 provided by Cisco Prime Infrastructure

Alignment	Download speed (Mbps)	Upload speed (Mbps)	Latency (ms)
Facing the AP, vertical	68.83	12.16	18
Facing the AP, horizontal	69.39	13.36	18
The AP is on the left, vertical	66.30	12.91	17
The AP is on the left, horizontal	68.88	11.02	18
The AP is behind, horizontal	69.23	12.21	17
The AP is behind, vertical	66.39	11.29	18
The AP is on the right, horizontal	67.64	11.29	17
The AP is on the right, vertical	67.65	11.85	18

Table 4: Internet Speed with different device alignment at a fixed location and height

The data from Table 4 was plotted in Figure 10.

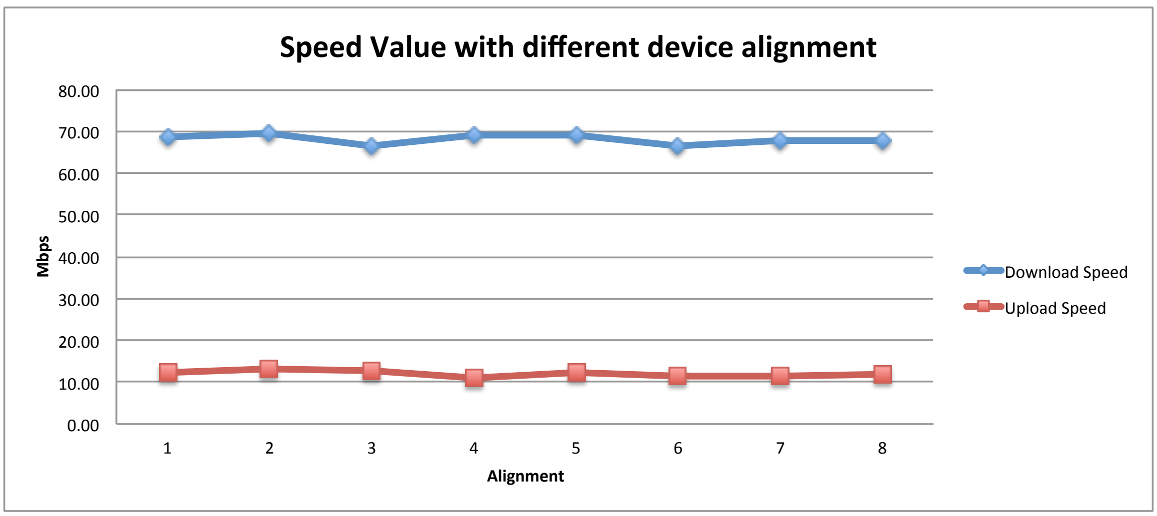

Figure 10: Plot of the Internet speed with different device alignment

We can see from Figure 10 that the lines are comparatively flat, meaning that different alignments will not have different impact on the readings.

It may seem that the quantitative network performance data itself should be enough to indicate the condition of the Duke wireless network. The reason we still keep the qualitative performance part is because we want to observe the trend of the students' demands on the Internet speed. For example, from the service provider's side the download speed of 60Mbps should be enough for the students to use wireless network in a dormitory. Nevertheless, students may use certain applications that need a large throughput, so the speed of 60Mbps may not be enough from the users' aspects. The quantitative performance, together with the qualitative network performance information, should give us the overall network performance both from the service provider's and the users' views.

Conclusion

Our iPhone application works well enough to distinguish the location between different buildings even when it is indoor. The indoor localization has considerably large uncertainly radius but the horizontal coordinates and the address values obtained from the CoreLocation framework of the iPhone application were reasonably accurate compared to the actual positions. It can tell us which street the device is on even when it is in a building.

The qualitative network performance information may not be a great indicator of how well the network is, but it reflects the users' demand on the wireless signal at each location. The quantitative network performance is the key parameter that will allow us to get a more comprehensive idea of how the network signal is throughout the campus. Moreover, we can compare the quantitative performance information with the information from Cisco management tool. The results should correlate. However, in some locations on campus, the APs' locations have not been updated in the management tool. Our iPhone application will help us indicate where on campus that the service provider needs to update its APs' information.

Future Work

We plan to make the user interface of the iPhone application more appealing for the final version. Then we will distribute the application to students on campus. Right now we only have limited number of testing devices. With larger number of testing devices, we hope to get more data in the area that we have not tested as well as the time period that we have not had information yet. This information will allow us to find the required network strength in different locations. This will help us to optimize the coverage plan, finding the locations where the APs should be, as well as the power strength that each AP should have. So that the integrated wireless network performance will effectively meet the users' demand.

References

[1] Juniper Networks, Inc. (2011). [Online]. Available: http://www.adtechglobal.com/Data/Sites/1/marketing/juniperwhitepaperwlancoverageorcapacity.pdf

[2] M. Bradley, (2014, April 11). [Online]. Available: http://compnetworking.about.com/cs/wireless/g/bldef_ap.htm