Far Beyond Wi-Fi: Measuring the Quality of Campus Wi-Fi Across Different Stony Brook University Networks

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Abstract. WolfieNet-Secure and Eduroam are two of the most widely used Wi-Fi networks on the Stony Brook University (SBU) West Campus. They both provide internet services to a campus boasting nearly 27,000 students across undergraduate and graduate programs, not to mention the thousands of staff and faculty that connect to these services in order to do their innovative work. It is also well known that the majority of these services are used in a popular area of campus known as the Academic Mall, which consist of several buildings that include the Melville Library and the Student Activities Center (SAC). While it is assumed that the Wi-Fi configuration in this area of campus is set up to provide optimal Wi-Fi coverage, it is not known how well each of these Wi-Fi networks perform in different buildings across the Academic Mall, nor is it known which network is better to use for a given location. In this work, we perform an experiment to determine how WolfieNet-Secure and Eduroam fare on different parts of the Academic Mall and learn which network is better to use and under which circumstances. We also use the data collected from this experiment to build a regression model that can predict Wi-Fi quality based on their current network conditions [1] [2].

1 Introduction

1.1 Problem Statement

Our project is motivated by understanding whether WolfieNet-Secure or Eduroam is better to use on-campus and under which circumstances, which will help us empower students and faculty with information to determine the optimal Wi-Fi network for on-campus

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[1] Code can be found at `https://github.com/kong0716/cse534project`
[2] Presentation Slide Deck can be found at `https://docs.google.com/presentation/d/1ydKZI5BAm_KvbxBWQoZADtpxArGBYFTfQn-FjM2j-Oo/edit?usp=sharing`

usage, depending on their current network conditions. This information may be of some use to on-campus organizations, such as Stony Brook University's Division of Information Technology (DoIT), to help them assess internet quality across campus and better improve their network infrastructure.

1.2 Background

WolfieNet-Secure WolfieNet-Secure is touted as Stony Brook University's recommended wireless network on West Campus [3]. It is available to all faculty, students, and staff with a valid NetID and password. It also utilizes WPA2-Enterprise authentication, making it one of the most secure networks to use on campus. SBU also performs routine maintenance on WolfieNet-Secure's infrastructure and coverage as wireless technology and equipment continue to evolve, in addition to the growing number of on-campus users that wish to connect to the network. Coverage for this network includes all campus buildings, common areas, and residence halls, with a fully detailed list found here [4].

Eduroam Eduroam is an network that allows educational institutions to provide access to their wireless networks from other participating institutions. It is particularly secure because it uses a Remote Authentication Dial-In User Service (RADIUS) situated within the institution's network to authenticate the user, and the host institution performs the authorization. Eduroam is used worldwide by 12,000 participating locations, which include over 500 colleges, universities, and research labs in the U.S. It is also known for providing a seamless user experience, since users do not need to be explicitly provided access when connected to a participating institution, which eliminates significant administrative overhead [17]. For visiting faculty, academics traveling for conferences, and study-abroad students, this type of network proves beneficial. Similar to WolfieNet-Secure, coverage for this network includes all campus locations, with the exception of the Stony Brook Hospital [5].

Related Work Since this work aims to perform a in-depth study into the performance of WolfieNet-Secure and Eduroam, naturally we looked at similar works in this area.

One such work discusses the challenges and future recommendations on measuring internet speed, which is related to our topic at a broad level [10]. The article mentions how speed tests are the current standard, but claims that it cannot be the sole indicator of internet quality because of a design assumption made that the ISP last mile access network was a bottleneck. Now that network technologies have advanced in the past decade, it was discovered that many other factors can affect the results of an internet speed test. The article highlights round trip latency, jitter, and packet loss rate as factors to consider in such an internet speed test, and were also factors we considered in our experiment.

Another such work focuses on analyzing link quality for IEE 802.11 wireless networks, which has relevance to our topic [1]. This paper looks at four metrics, which are Received Signal Strength Indication (RSSI), Signal-to-Interference-plus-Noise Ratio (SINR), Packet-Delivery Ratio (PDR), and Bit-Error Rate (BER), to assess which of these metrics are appropriate to use when evaluating such wireless networks. They performed their tests indoors, as we did in our study. The result of their paper was that you cannot solely determine network quality from one metric alone, but individually each metric can reveal interesting insights about the link quality. The important detail about this paper, in the words of the author, is that the work "does not attempt to construct a new metric which combines the different primary metrics in an intelligent way. Instead, it is a precursor to the design of such a metric."

An example of one such design that leverages this idea is used in an enterprise information technology monitoring tool called PingPlotter Pro. This tool aims to be a user-friendly network monitoring tool that aims to enhance the functionalities of *ping* and *traceroute* but in a more user-friendly way [2]. One of the metrics that this tool calculates to diagnose and monitor a given network is called the Mean Opinion Score, or MOS. MOS is an estimation metric that uses factors such as average latency, jitter, and packet loss to establish a network quality score, which ranges from 1-5, 1 being unacceptable network quality and 5 being optimal quality [9]. The use of MOS in

PingPlotter Pro gives us a starting point when attempting to assess Wi-Fi quality as a whole.

Suppose we had a singular value or multiple data points to define Wi-Fi quality, how can we leverage other concepts to help predict Wi-Fi quality based on this data? The author of the paper in [13] analyzed various Wi-Fi factors and created a machine learning model using Support Vector Machines (SVMs) to predict Wi-Fi throughput, the target value of this study. The SVM model classifies the Wi-Fi throughput as 'good', 'medium', 'poor', or 'very poor'. It is not only relevant to what we are trying to do but was important in helping us analyze our parameters in more detail and find better correlations between the features and our performance metric for a predictive model that we constructed.

1.3 Wi-Fi Metrics Considered

For our study, we considered an approach that was similar in nature to [1], in the sense that we did not want to (yet) pool several primary metrics together when analyzing the quality of WolfieNet-Secure and Eduroam into one composite metric, and instead wanted to look at them individually to determine the better on-campus network. We identified several metrics that were included in our experiment.

Network Bandwidth/Speed Network bandwidth is a metric that indicates the maximum capacity of a network link, which can be wired or wireless, over a given time period. A good analogy for bandwidth is water flowing through a pipe. The wider the pipe, the more water that can flow through it [8]. Often times, bandwidth can be affected by many things, such as the physical limitations of the network device (ex. router or modem), cabling, wireless frequencies in use, or could be intentionally rate limited by an ISP, among other factors.

Network speed, on the other hand, is how much data can be transferred per second. Going back to the water pipe analogy, this would be how fast the water travels out of the pipe. In our study specifically, we looked at download and upload speeds when assessing the SBU networks. Download speeds tend to matter more when streaming an online lecture, or viewing papers related to a project using a browser. Upload speeds are more important in cases such as Zoom calls or conferences, or sending emails with large attachments [15].

Signal Strength Signal strength is the measurement of power from the perspective of a Wi-Fi-enabled device. Since Wi-Fi signals are considered an electromagnetic wavelength that is transmitted in the air, they are also considered Radio Frequency (RF) waves for this reason. Wi-Fi networks use these waves to deliver packets from one device to another through bands called Wi-Fi channels to an access point. These Wi-Fi channels come in two flavors, 2.4 GHz and 5GHz bands. Signal strength is measured in many forms, but in this work we measure this metric using decibel-milliwatts (dBm). A key thing to note is that since Wi-Fi signal strength is less than 0 dBm, this metric is measured using negative values, where -30 dBm is optimal and anything below -70 dBm would be poor [14].

Average Latency Latency is a network metric that measures delay. Specifically, it measures the time taken to send data packets to its destination. It is usually measured in terms of round trip time (RTT). We consider this a critical measurement because of the way TCP-level connections work. Since packets are sent in limited quantities to its destination and waits for acknowledgement before sending more, latency could be affected if the device needs to re-transmit packets frequently [7]. In our study, we measure latency by sending 40 packets of data and measuring the latency via command-line interface tools. The unit for this measurement is done in milliseconds.

Packet Loss A metric relevant to latency, packet loss is measured as the number of packets that fails to reach the destination. This metric is also important because lost packets can slow down network speeds (such as download/upload speeds) and cause bottlenecks, which could be costly in most organizations. Some causes that could lead to packet loss include network congestion, network hardware problems, software bugs, among others [11].

Jitter Another metric related to latency and directly associated with packet loss, jitter is the variation in time delay between when packets are sent to a destination and received over the network. Jitter is something that should be minimized as much as possible, but is also dependent on what one accepts as an irregularity and fluctuation in data transfers. However, high jitter could mean poor application performance and could negatively affect the user experience as well. Jitter below 30 milliseconds is considered under ideal conditions. The same causes that could lead to packet loss also could make jitter higher than normal [12].

2 Hypothesis

Before performing our study, we hypothesized that Eduroam would perform better in our network tests compared to WolfieNet-Secure because it is a global standard not specific to SBU and is implemented across supported campuses worldwide, which might mean that it is well supported and maintained compared to typical network infrastructure for many organizations. Furthermore, a majority of students and faculty use WolfieNet-Secure, since it is the recommended network that all technology staff on campus recommend to use, and thus may have more congestion and may lead to degraded performance.

3 Approach

To get an accurate and quantifying measure of the quality of the two Wi-Fi networks, we decided to take measurements from seventeen various locations around campus. These locations were picked based on popularity and geographical spread.

One thing we wanted to consider during our evaluation was whether we wanted to test at each location when the overall usage was low or high. While evaluating each Wi-Fi network when usage is low would give us optimal metrics at each location, it wouldn't be a true representation of how it would perform under a typical load. Even though students and faculty use the network uniformly throughout the day, there are times when the network usage peaks, such as when someone uses the internet during an in-person lecture on their laptop or uses a lounging space to stream one over Zoom, for example. We believe that running our tests when network load is high would give a better representation of general performance at a given location. Hence, we decided to perform our tests while network usage was higher in order to see what the results were under typical conditions.

The way we determined a ”peak” time to perform our measurements involved using help from SBU ClassFind [6]. We primarily targeted large lecture undergraduate and graduate classes, and general population density around popular meals such as lunch, and performed our network measurements around those times. We also performed some of our tests during Campus Lifetime (1-2pm on Wednesdays), which has significant activity as a result of club general body meetings in many parts of campus.

4 Evaluation

4.1 Setup

To accurately measure the Wi-Fi quality of each network, we focused upon specific properties of each network in a myriad of locations. We had chosen specific buildings that are part of Stony Brook's West Campus, specifically parts of the Academic Mall. The buildings we tested were:

- Melville Library
- Engineering Building
- Frey Hall
- Humanities
- Wang Center
- New Computer Science
- Roth Cafe
- Student Activities Center (SAC)
- Student Union
- Schomburg Apartments (to test on before evaluating the above locations, but was included in our results)

Each specific building was tested with an average of two populous locations within those buildings. These locations were denoted by their latitude and longitude based on GPS.

For each network in each of the chosen geographic locations, measurements were taken of the signal strength and bandwidth at the location of the test. In addition to the above measurements, we also measured the latency, jitter, and packet loss for forty pings to twenty-five of the top fifty websites from [16]. These twenty-five websites were vetted to see if they still exist and whether or not they were able to respond to a ping request. In addition to those twenty five websites from the top fifty, we also included additional websites that are typically visited by Stony Brook students and faculty. These additional websites include:

– blackboard.stonybrook.edu
– chegg.com
– psns.cc.stonybrook.edu (houses SOLAR and other university services)
– classroom.google.com
– coursehero.com
– quizlet.com
– messenger.com
– discord.com
– github.com
– stackoverflow.com

The entire measurement script was written using Python, which called some Unix-based command line tools and other modules that we installed to perform our tests. These tools include *pingparsing*, *iwconfig*, and *speedtest-cli*.

The results of a *pingparsing* test returns a JSON object that can be parsed for the relevant fields needed for our measurements. We utilized the 'rtt' field to get the latency of the packet in the network. Jitter was easily calculated by taking the mean absolute difference of latency for each consecutive pair of requests to the website. The amount of packets lost in the network was itself a field in the JSON object that we simply used.

To measure the signal strength of the network at a given location, we used *iwconfig* to grab the signal strength of the network via the Received Signal Strength Indication.

As for the network speed measurements, we used the *speedtest-cli* module to determine both the upload and download speed of the network. The scripts were run on two supplied laptops, both of which were Dell laptops running Ubuntu 20.04. To maintain consistency with our philosophy in simulating as much real-world usage as possible for the typical student, we did not use end-to-end tools such as *iPerf* for our measurements.

For each run of the script per location, we closed all running programs (except for VSCode and the script) and tasks and restarted our laptops each time before connecting to the network to test. This allowed us to connect to the closest WiFi router for each of the networks each time to get more realistic performance results.

4.2 Results

Location	**WolfieNet-Secure**	**Eduroam**	**Difference**
Melville Library - Central Reading Room	-59	-60.0	1.0
Engineering - Room 145	-50	-53.0	3.0
Engineering - Lobby Lounge	-42	-48.0	6.0
Frey Hall - Lobby	-64	-64.0	0.0
Humanities - 2nd Floor Lounge	-49	-50.0	1.0
Humanities - Atrium	-51	-52.0	1.0
Wang Center - Jasmine	-63	-67.0	4.0
New Computer Science - Room 106	-48	-49.0	1.0
New Computer Science - Room 120	-46	-49.0	3.0
Melville Library - North Reading Room Fl. 1	-58	-63.0	5.0
Melville Library - North Reading Room Fl. 2	-52	-60.0	8.0
Roth Cafe	-80	-60.0	-20.0
SAC - Cafeteria	-59	-63.0	4.0
SAC - Lobby	-56	-55.0	-1.0
Schomburg A	-48	-44.0	-4.0
Student Union - Fl. 1	-49	-62.0	13.0
Student Union - Fl. 2	-60	-45.0	-15.0

Fig. 1: Signal Strength Per Location

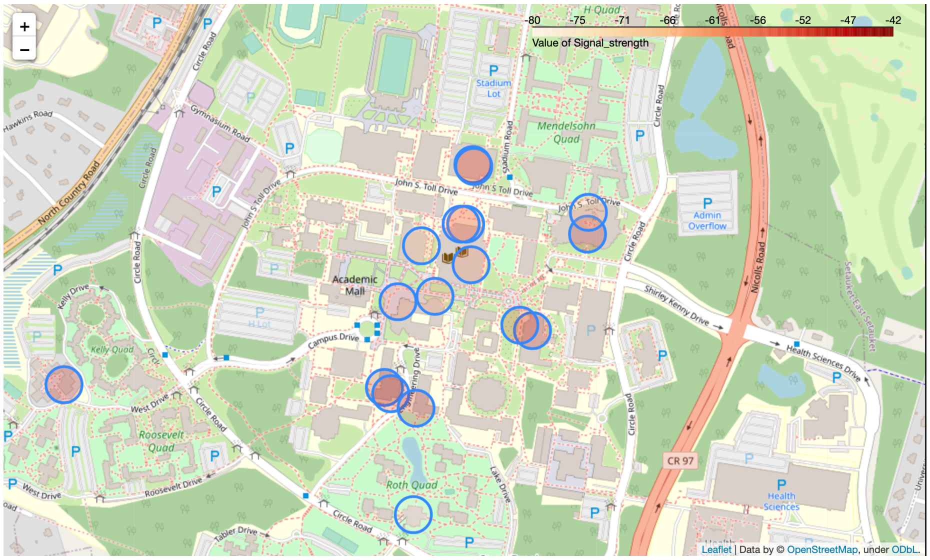

Fig. 2: Signal Strength for WolfieNet-Secure

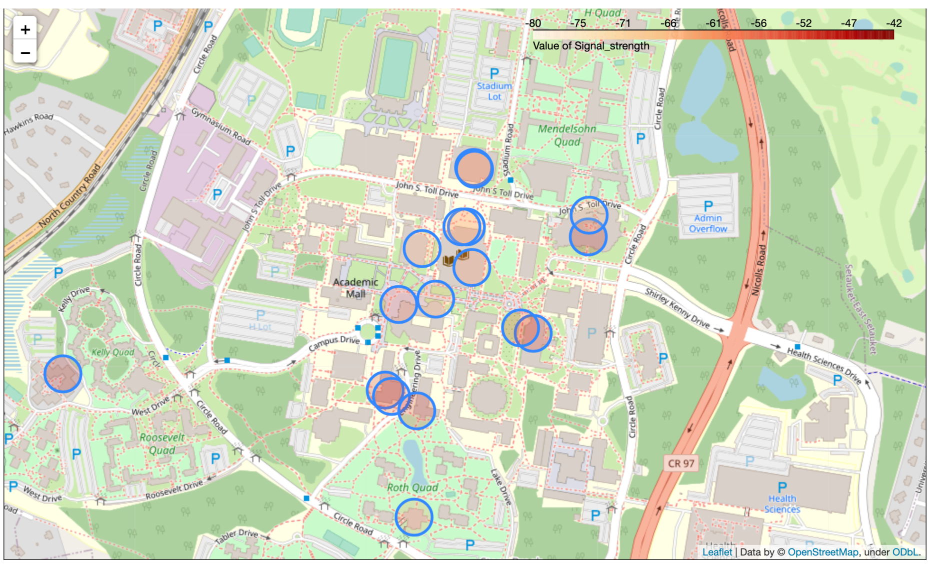

Fig. 3: Signal Strength for Eduroam

Signal Strength Figure 1 shows that in the majority of the locations that were tested, WolfieNet-Secure had better signal strength than that of Eduroam. The obvious outlier was Roth Cafe and the first floor of the Student Union with a signal strength difference of 20dBm and 15dBm respectively. A visual representation is also given in Figures 2 and 3 for both WolfieNet-Secure and Eduroam.

We observe that WolfieNet-Secure edges out Eduroam in most on-campus buildings overall, with Eduroam performing better in Roth Cafe, part of the SAC, and the second floor of the Student Union. Possible reasons for this could be where we sat relative to the closest network router, as well as any barriers/walls that the signal may have had to pass through to reach our device.

Signal Strength Winner: **WolfieNet-Secure**

Network Speed Looking specifically at the download speed numbers from Figure 4, it seems that both networks' download speed is heavily based upon building and sometimes the floors of the buildings. For example, in the first floor of the Student Union building, WolfieNet-Secure and Eduroam have only a download speed difference of .82 MB/s. However, moving onto the second floor, it appears that Eduroam was able to beat the download speed of WolfieNet-Secure by 85 MB/s. A similar story is told with the SAC-based locations. The SAC Cafeteria has WolfieNet Secure beating Eduroam by 25 MB/s but re-running the evaluation in the SAC lobby has Eduroam beating WolfieNet-Secure by 56 MB/s.

Location	WolfieNet-Secure	Eduroam	Difference
Melville Library - Central Reading Room	51.009037	73.878649	-22.869612
Engineering - Room 145	180.647292	214.483755	-33.836463
Engineering - Lobby Lounge	203.401241	248.331222	-44.929981
Frey Hall - Lobby	8.345845	79.409176	-71.063331
Humanities - 2nd Floor Lounge	197.427995	213.533758	-16.105763
Humanities - Atrium	55.195317	63.399907	-8.204590
Wang Center - Jasmine	136.464276	73.461958	63.002318
New Computer Science - Room 106	246.577984	210.348198	36.229785
New Computer Science - Room 120	202.773587	208.598130	-5.824543
Melville Library - North Reading Room Fl. 1	5.898175	45.340249	-39.442074
Melville Library - North Reading Room Fl. 2	47.258784	41.563387	5.695397
Roth Cafe	60.796935	36.478626	24.318309
SAC - Cafeteria	181.071065	155.715868	25.355198
SAC - Lobby	10.643223	67.051410	-56.408187
Schomburg A	254.404421	222.595768	31.808653
Student Union - Fl. 1	100.384098	99.560185	0.823913
Student Union - Fl. 2	113.702474	198.953203	-85.250729

Fig. 4: Download Bandwidth Per Location

Based on the heatmaps in Figures 5 and 6, it appears that Eduroam edges out WolfieNet-Secure in combined total download speeds.

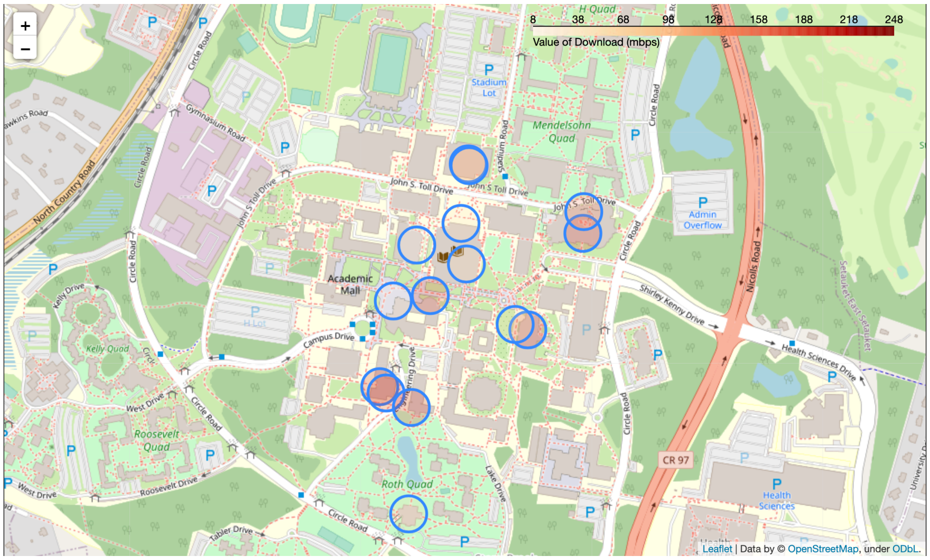

Fig. 5: Download Speeds for WolfieNet-Secure

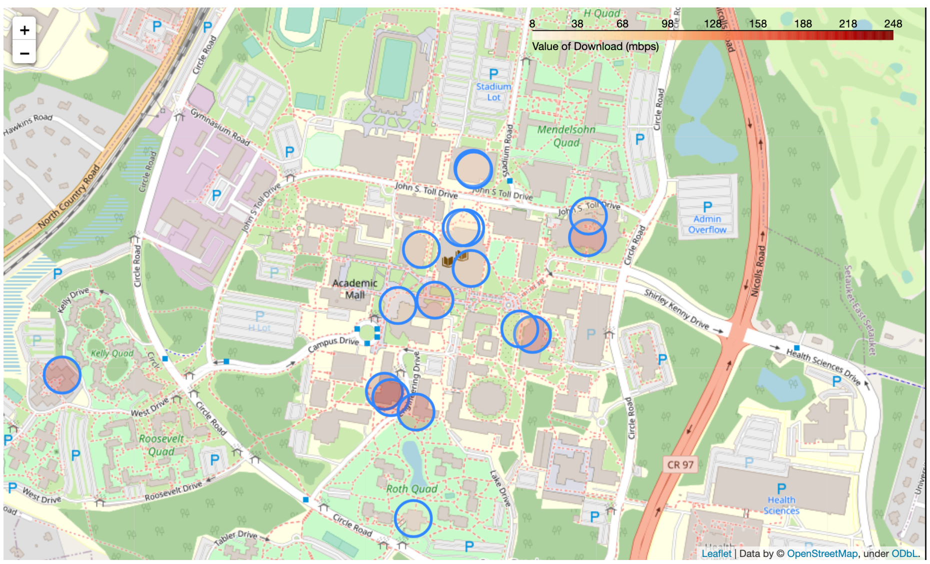

Fig. 6: Download Speeds for Eduroam

A similar story is seen with upload bandwidth as shown in the heatmaps in Figures 7, 8, and the table in Figure 9. However, the examples of such discrepancies are fewer. There is a very stark difference between the first and second floor of the Humanities building. The Humanities Atrium had better upload bandwidth of 87MB/s for Eduroam and 71MB/s WolfieNet-Secure. However, this changed when the second floor lounge was measured, where WolfieNet-Secure had a lead over Eduroam by 43 MB/s. This is the opposite lead when looking back at download bandwidth.

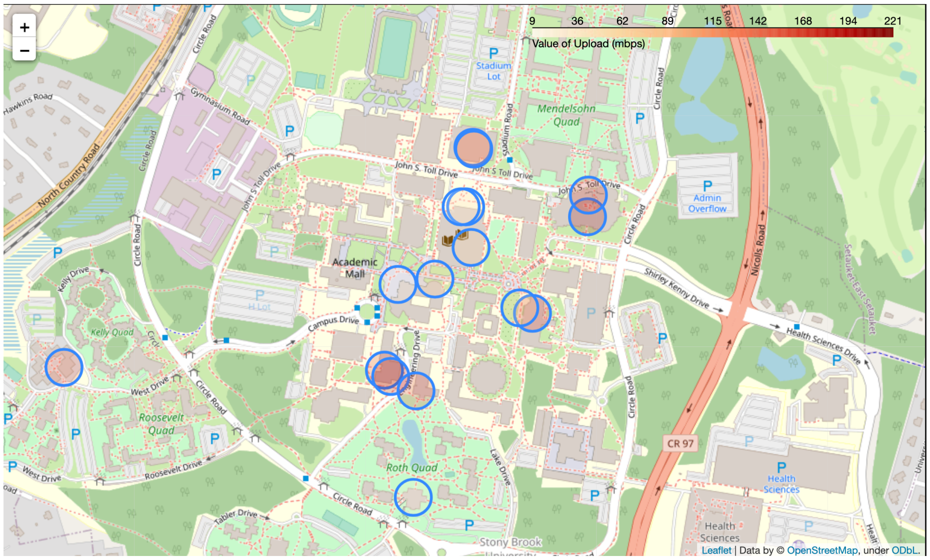

Fig. 7: Upload Speeds for WolfieNet-Secure

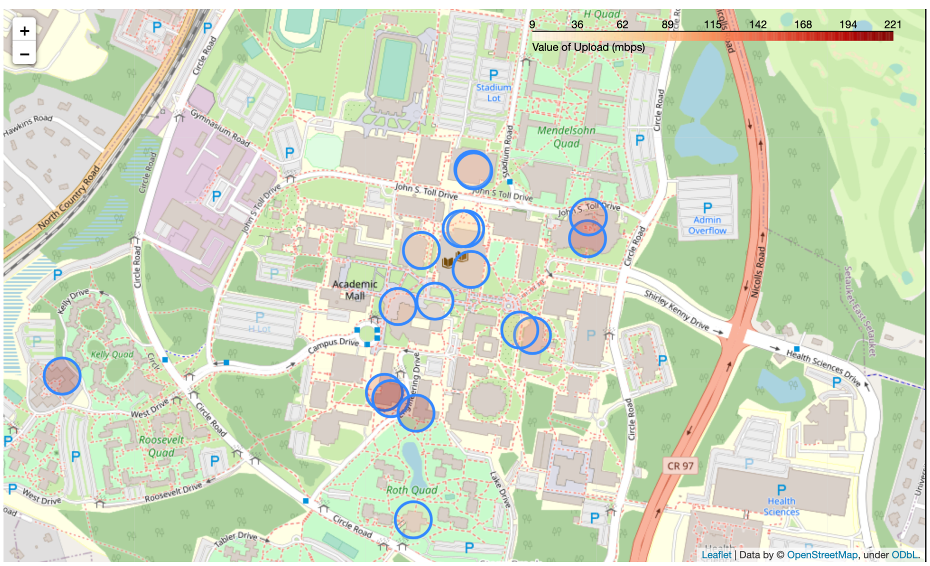

Fig. 8: Upload Speeds for Eduroam

The various differences in network download and upload speed could be the overall load of the network at that particular location. Specifically in one location, there might be more users utilizing

Eduroam as opposed to WolfieNet-Secure. In the case of our results, it appears that the usage of Eduroam was less than that of WolfieNet-Secure, which may explain why it won our upload tests and barely surpassed our download tests.

Location	WolfieNet-Secure	Eduroam	Difference
Melville Library - Central Reading Room	61.287276	79.902893	-18.615618
Engineering - Room 145	203.839668	220.830256	-16.990588
Engineering - Lobby Lounge	168.602730	173.483326	-4.880596
Frey Hall - Lobby	2.898055	82.817935	-79.919880
Humanities - 2nd Floor Lounge	174.538138	130.960958	43.577180
Humanities - Atrium	71.617969	87.818501	-16.200532
Wang Center - Jasmine	170.694240	148.567924	22.126316
New Computer Science - Room 106	235.306000	202.984366	32.321634
New Computer Science - Room 120	169.889743	216.426290	-46.536547
Melville Library - North Reading Room Fl. 1	14.695338	54.894079	-40.198741
Melville Library - North Reading Room Fl. 2	61.632813	84.759453	-23.126640
Roth Cafe	22.604130	67.546373	-44.942244
SAC - Cafeteria	70.053480	17.999846	52.053634
SAC - Lobby	9.290205	102.163304	-92.873099
Schomburg A	141.832720	219.284979	-77.452260
Student Union - Fl. 1	124.007270	135.713866	-11.706596
Student Union - Fl. 2	136.557833	202.395398	-65.837564

Fig. 9: Upload Bandwidth Per Location

4.3 Additional Commentary on Signal Strength, Download/Upload Speeds

	Wolfie-Net Secure	eduroam
Signal Strength (dBm)	-53.78947368421053	-55.666666666666664
Download Speed (MB/s)	128.3128506783433	125.57746196394325
Upload Speed (MB/s)	114.59135561280705	125.28344766392723

Fig. 10: Average Measurements Per Location

Taking the average of signal strength, upload and download speed, it seems that WolfieNet-Secure is the winner in two out of the three categories. WolfieNet-Secure has the higher signal strength and higher download speeds but loses to Eduroam on upload speed. However, as seen in Fig 9, Fig 4, and Fig 1, and our discussions of those figures, whichever network has the better specific property depends heavily on the location of our measurements.

4.4 Ping-based Properties

Network	**Wolfie-Net Secure**			**eduroam**		
Websites	**Latency(ms)**	**Jitter(ms)**	**PacketLoss**	**Latency(ms)**	**Jitter(ms)**	**PacketLoss**
360.cn	345.860778	67.884823	1.444444	347.758111	80.543067	1.944444
alipay.com	337.003235	58.379850	1.823529	356.298278	74.181347	1.611111
amazon.com	36.057444	22.246946	0.055556	32.188389	17.308301	0.055556
baidu.com	327.847526	78.508535	1.315789	356.541333	94.879898	2.333333
bing.com	25.583667	17.088816	0.055556	24.043556	15.139332	0.444444
blackboard.stonybrook.edu	24.480278	16.343138	0.000000	23.319333	15.160307	0.055556
chegg.com	61.227947	39.701930	0.526316	31.265556	16.748244	0.055556
classroom.google.com	29.802833	17.961973	0.111111	28.276833	15.075561	0.055556
coursehero.com	35.226000	28.920498	0.631579	28.175833	18.989699	0.055556
discord.com	23.947053	15.518180	0.052632	23.668778	15.269232	0.055556
facebook.com	61.287368	38.187515	0.473684	28.416667	14.012119	0.555556
github.com	30.069526	16.022964	0.052632	46.627556	32.712885	0.666667
google.com	60.388421	46.220486	0.631579	27.000389	17.733863	0.111111
instagram.com	33.086421	17.652522	0.105263	32.639056	14.985747	0.166667
jd.com	404.015778	62.200254	1.777778	393.124611	76.562487	5.666667
live.com	27.172056	19.266113	0.000000	26.020333	17.398433	0.111111
messenger.com	35.498500	17.146408	0.000000	30.251500	14.525644	0.055556
office.com	27.575158	16.304713	0.000000	23.410278	13.011986	0.000000
panda.tv	93.173526	64.026222	0.263158	23.277722	17.259914	0.111111
psns.cc.stonybrook.edu	22.525263	18.620679	0.052632	19.484222	14.189651	0.055556
qq.com	355.685053	91.800548	1.368421	345.071167	71.302341	2.055556
quizlet.com	24.533684	15.483682	0.000000	23.862667	15.702168	0.222222
reddit.com	27.006579	21.874383	0.105263	20.931889	13.183062	0.055556
sina.com.cn	424.404895	134.457818	4.578947	327.793611	67.451249	1.444444
sohu.com	337.250105	84.710767	1.842105	327.753444	72.981349	2.333333
stackoverflow.com	22.378842	14.594872	0.000000	20.045500	13.112681	0.111111
taobao.com	390.648526	100.954850	1.000000	359.237833	70.371793	0.944444
tmall.com	370.827842	85.143092	1.789474	356.235944	78.190552	1.500000
twitch.tv	25.094053	19.806967	0.052632	23.640111	16.656648	0.000000
twitter.com	53.542211	16.576388	0.052632	50.744778	14.914642	0.055556
weibo.com	482.326579	159.637327	1.894737	319.955611	71.266499	1.055556
wikipedia.org	86.149368	35.778856	0.052632	58.452667	18.017306	0.000000
yahoo.com	87.704368	37.627782	0.368421	64.523389	20.005889	0.000000
youtube.com	33.916526	21.336204	0.000000	27.598556	15.541495	0.111111
zhanqi.tv	351.005722	54.346786	1.222222	371.271444	71.405730	1.666667

Fig. 11: Average of Ping-based Properties Over All Sites

Network/Average Measurements	**Latency (ms)**	**Jitter (ms)**	**Packet Loss Count**
WolfieNet-Secure	146.122947	44.923797	0.677163
eduroam	131.397341	35.022604	0.734921

Fig. 12: Average of Ping-based Properties Over Network

As seen in Figure 11, there are higher measurements for latency, jitter, and packet loss based on whether or not a site is 'foreign'. For example, '360.cn', 'alipay.com', and 'baidu.com' have most of their servers in China. This would force a packet to travel through the network for a far longer distance which increases the latency and jitter of the packet. Also with a longer travel distance, the likelihood of a packet being dropped due to a filled buffer increases. In addition, these sites are quite popular in China compared to the US, thus the Domain Name Server (DNS) cache hits for the foreign website would be less.

Overall, WolfieNet-Secure had an average latency of 146.12ms and jitter of 44.92ms for each site while Eduroam had 131.39ms and 35.02ms, respectively. An explanation for WolfieNet-Secure having a higher latency than Eduroam is that more students and faculty are utilizing the network than Eduroam. As such, the network congestion would be higher and thus the latency and jitter would also increase overall. We conclude that WolfieNet-Secure suffers in both latency and jitter compared to Eduroam but is better than Eduroam in terms of packet loss, even though the difference between the two networks for this criteria is a small difference (0.06).

Ping-Based Winner: **Eduroam**

5 Predicting Wi-Fi Quality (Additional 30% Work)

5.1 Background - R-factor and MOS

In order to predict the Wi-Fi quality, we need a output metric that would serve as a ranking or score of a Wi-Fi network for a given location and website. We selected MOS (Mean Opinion Score) as the output metric for our model.

MOS is a metric used in the Voice Over IP (VoIP) industry to monitor the quality of voice calls [9]. Similarly, Rating Factor (aka R-factor) is another popular quality metric used in the VoIP industry. The main difference between both the factors is their respective range. R-factor can range from 0 to 100, where higher the R-factor the better. Similarly, in case of MOS, the values range from 1 to 5, 1 being the most unacceptable quality to 5 being the best quality [2]. While our project is not a VoIP specific measurement study, we believe that the nature of the MOS metric is a considerably good approximation to serve as the output metric for our Multiple Linear Regression model to predict the Wi-Fi quality on campus.

5.2 Computing R-factor and MOS

In order to use MOS as our output metric, we had to compute it. MOS can be calculated with the help of R-factor. The formula for calculating MOS from R-factor is:

$$MOS = 1 + (0.035) * R + (0.000007) * R * (R - 60) * (100 - R) \quad (1)$$

Here R is the R-factor. For calculating the R-factor we first compute Effective Latency with the help of Average Latency and Jitter values collected from our measurement study.

$$EffectiveLatency = AverageLatency + Jitter * 2 + 10 \quad (2)$$

Based on the computation for R-factor detailed in [9], we start with an initial R-value of 93.2. Based on the value of computed Effective Latency from equation (2), if the Effective Latency is less than 160ms then we aggressively deduct from the R-factor, otherwise we deduct 4 from the R-factor [9]. Next we deduct 2.5 from the R-value per packet loss percentage, and then finally use the computed R-factor value to compute MOS value by using equation (1). After this process is applied on our data, we get MOS values for all our data points and store it in a new column to use as the output metric for our Multiple Linear Regression model.

5.3 Correlation Matrix

We used *pandas* and *seaborn* Python libraries to compute and display the correlation matrix for all our features. The colormap legend on the right shows the colors associated with their correlation coefficient values from -1 to 1. Highly positive correlation values are depicted by shades closer to red, while highly negative correlation values are depicted by shades closer to blue. Shades closer to grey signify correlation values close to 0. Since MOS is the output variable we are interested in, it is easy to spot the features which have high positive and negative correlations with MOS. R-factor has a very high

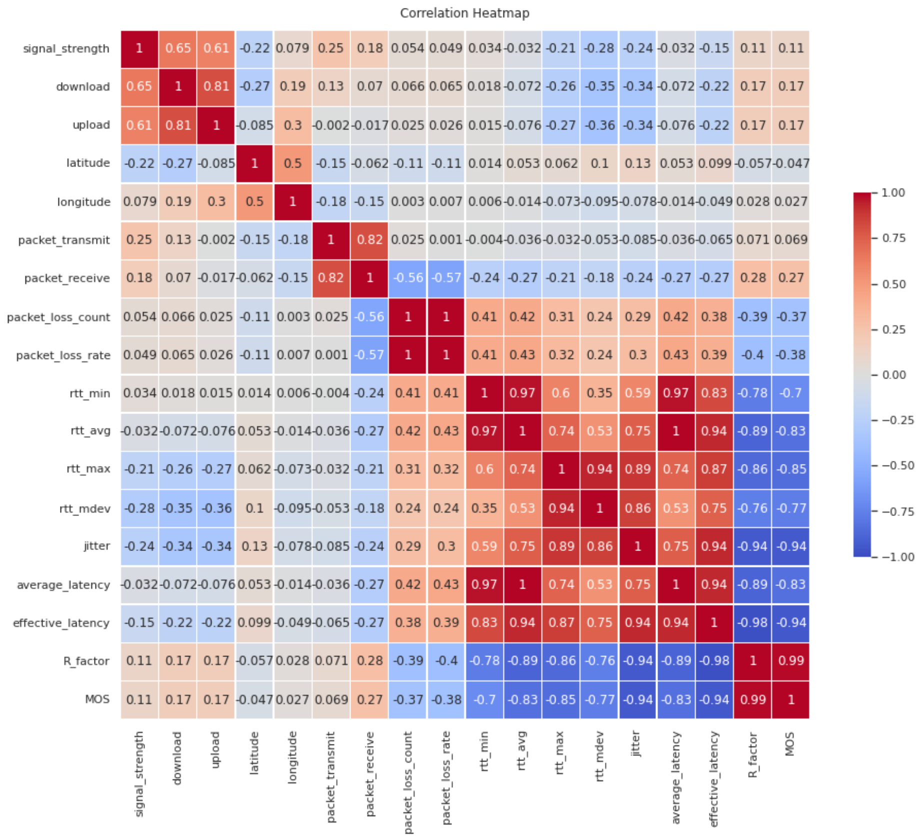

Fig. 13: Correlation Matrix for our integrated Data Frame

positive correlation with MOS and this makes sense because we used R-Factor to calculate MOS using equation (1) as described in Section 5.2. Similarly, Average and Effective Latency have a high negative correlation with R-Factor and MOS. All RTT features show heavy negative correlation which make sense as we want the MOS value to go up as the RTT goes down. Another notable part of the plot is how Jitter, Packet Loss Rate and Packet Loss Count variables also have high negative correlation with MOS. This makes sense, since packet loss should be negatively correlated with the quality of the network.

Signal Strength, Download, and Upload Speeds, have a slightly positive correlation value with MOS. This should hold true because increase in download speeds improves the quality and the same can be said for Signal Strength and Upload speeds.

On the other hand, latitude, longitude, packets received, packets transmitted, are factors that don't have any correlation with the quality of the network. So overall, the correlation matrix plot confirms the relationship between each of our features and their relationship with the output Wi-Fi quality metric that we used. This is why we believe MOS is a good approximate as a Wi-Fi quality metric even though it is primarily used for VoIP specific purposes.

5.4 Multiple Linear Regression

After collecting, preprocessing, and integrating the input data for our model as well as computing our output metric, we used the *sklearn* library to build a multiple linear regression model. In order to build this model, we needed to generate a feature matrix, which involved analyzing features that we had collected to decide which ones to include for our final model. This required performing feature reduction using the correlation matrix. Using the correlation matrix plot generated and displayed in Section 5.3, we removed features that were not significantly correlated with our output metric (MOS). We realized that having used the Jitter, Effective Latency and R-factor features to generate MOS, these features, if included in our final model, will always make the model overfit, so we decided not to include them in our model. This way we could fit our model on other features to generate and predict over unknown linear relationships between the MOS and the following features:

- Signal Strength
- Download Speed
- Upload Speed
- Packet Loss Rate
- RTT Min
- RTT Avg
- RTT Max
- RTT Median Deviation
- Average Latency

Using the above features and the MOS scores, we created our feature matrix X and y respectively. We input X and y into the train_test_split function from *sklearn* to get X_{train}, y_{train}, X_{test}, and

y_{test} based on a 70:30 split ratio(70 % training data and 30 % testing data). We trained our linear regression model after fitting it on X_{train} and y_{train} and used it to predict on X_{test} to get our predicted values in a y_{pred} vector.

5.5 Evaluating our ML model

After training and predicting on our testing data, the final step involved using the regression model evaluation metrics to get the goodness of fit and the accuracy to determine its performance.

Mean Squared Error (MSE) The goal of any machine learning problem is to minimize error. So in order to check how well the machine learning model is performs, we need a metric to compute the average error value for the model. This is given by the MSE or Mean Squared Error value. To compute this value, we can manually compute the average of the difference between the predicted output values(y_{pred}) and observed output values(y_{test}), or we can simply use the *sklearn.metrics.mean_squared_error* module. So using this module, we computed the MSE to be **0.03**. This is a low value of error, which proves that the model is performing well.

***R^2* score (Coefficient of Determination)** R^2 score or otherwise also called as Coefficient of Determination is used to evaluate a linear regression model. The value of R^2 score can range from -1 to 1. Unlike other performance metrics, R^2 score can have a negative value if the model is bad. R^2 score can be computed using the *sklearn.metrics.r2_score* module. Using this, we compute the R^2 score for our model to be **0.87**. This is a considerably good R^2 score as it is close to 1.0, but not too high to suggest overfitting. Thus, it shows that the model is successful while predicting MOS values over the unseen testing data based on the input features.

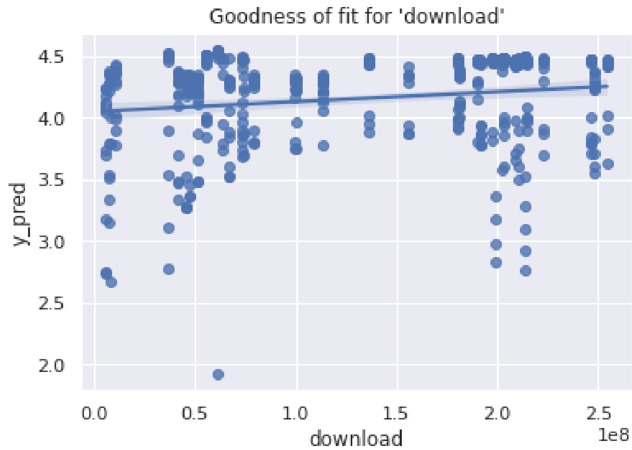

Fig. 14: Goodness of Fit for Download Speed

Goodness of Fit Plot for Download Speed In this plot we can see how download speed has a slightly positive slope with the predicted y value.

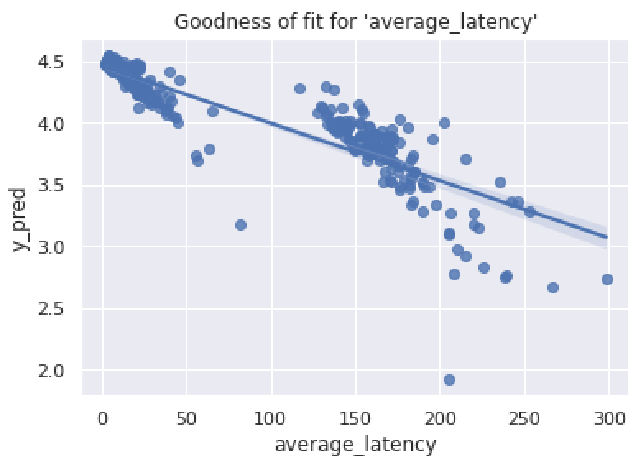

Fig. 15: Goodness of Fit for Average Latency

Goodness of Fit Plot for Average Latency In this plot we can see how average latency has a larger negative slope with the predicted y value.

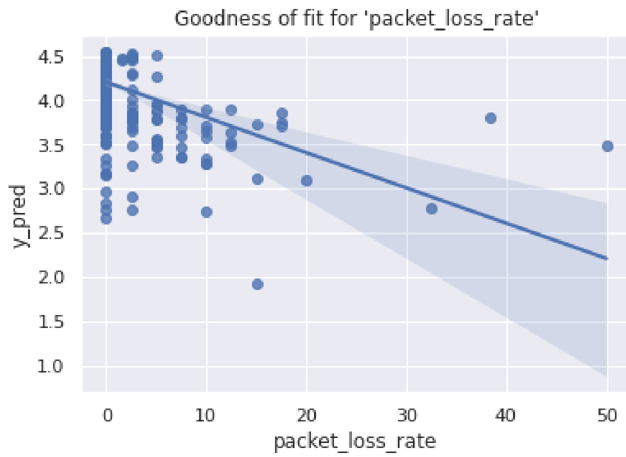

Fig. 16: Goodness of Fit for Packet Loss Rate

Goodness of Fit Plot for Packet Loss Rate: In this plot we can see how packet loss rate has a negative slope with the predicted y value.

Fig. 17: Goodness of Fit for Signal Strength

Goodness of Fit Plot for Signal Strength: In this plot we can see how signal strength has a small positive slope with the predicted y value.

We chose these subset of features to plot because they had a significant correlation with MOS.

Based on the above plots from Figures 14-17, the predicted values show trends that validate our previous understanding of the relationship between the features as well as the correctness of the model.

6 Conclusion

As a result of our extensive measurement study, we have concluded that Eduroam is the better overall network to use on campus as it performed well in the Network Speed, Average Latency, and Jitter tests. It is also worth noting Eduroam performed much better in locations such as the SAC, Roth Cafe, Student Union, and New Computer Science buildings. However, we also measured that WolfieNet-Secure outperformed Eduroam in Signal Strength and Packet Loss. The fact that WolfieNet-Secure did better in the Signal Strength test indicates that it has far wider coverage on campus compared to Eduroam, which confirms the wide area of coverage that SBU DoIT advertises. So while Eduroam is the more performant Wi-Fi network, WolfieNet-Secure also proves beneficial if you need access in more places than you would typically use on campus. We also succeeded in building a multiple linear regression model using the MOS score as a good approximation for determining Wi-Fi quality given a user's current network conditions. The evaluation for our model showed a low MSE and a high R^2 score, thus proving our model was a great success.

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