# Optimized Coverage and Capacity Planning of Wi-Fi Network based on Radio Frequency Modeling & Propagation Simulation

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Investigation for optimized coverage and capacity planning of Wi-Fi network is carried out in the testbed for the purpose of optimization in terms of Received Signal Strength Indicator (RSSI), Signal to Noise & Interference Ratio (SNIR), Interference + Noise (I+N), downlink/uplink data rate and user capacity. The plan is carried out by conducting a site prediction survey through Altair's Win Prop Software which is a Radio Frequency (RF) modeling and signal propagation simulation software, using the configuration of actual Wireless Local Area Network-Access Points (WLAN-APs). First, the map of the testbed with all respective material properties is drawn in Win Prop's Wall Manager (Wall Man) Tool as a 3-Dimentional (3D) model. Then that 3D model is implemented in Win Prop's Propagation Manager (ProMan) Tool where APs are deployed and wave propagation analysis as well as capacity planning is done. Results are analyzed for optimal signal strength, data rate, and user handling capacity. The results are validated by a smartphone-embedded software known as Cellular-Z. The average optimization increase in coverage, downlink & uplink data rates is 3.95 dB, 2.53 Mbps & 3.42 Mbps respectively.

**Keywords:** Capacity; Coverage; Heatmap; Optimization; Wi-Fi.

## Introduction:

Wi-Fi means wireless fidelity. It is the technology of providing wireless signals for internet connectivity to the users within an area of deployment. Wi-Fi works on IEEE standards of 802.11b/g/n/a/ac/ax, mainly within 2.4GHz and 5.6GHz Industrial Scientific Medical (ISM) bands. The available bandwidth within each band is further divided into sub-bands/channels which are responsible for user handling capacity. The 2.4GHz band provides a low data rate but large coverage as compared to the 5.6GHz band and vice versa. The Wi-Fi is provided to the internet users through a Wireless Local Area Network Access Point (WLAN-AP). The antennas of this AP are nearly omnidirectional with some gain, radiating radio signals in maximum directions toward the users. The Received Signal Strength (RSS) of the Wi-Fi signals decreases as the user moves away from the WLAN-AP. This variable signal strength as the users move towards and away from the WLAN-AP results in a variable data rate [1].

To provide connectivity of the internet to a maximum number of users with an acceptable data rate, it is important to know the optimum location of WLAN-AP for providing coverage at a specific RSS level to the internet users, the number of users that can be handled by a WLAN-AP and sufficient data rate that is provided to each user at a specific time. Conventional ways of performing this task are practical deployment and modification of the location of WLAN-APs and measuring the RSS at different portions of the area of interest without prior simulation surveys. This approach is tedious as well as costly, having low accuracy and taking more time to complete. To address the above issues, software-based simulation surveys are performed before the actual deployment of the WiFi network.

In the background study, the same software is used for a similar type of survey but the study did not use the actual WLAN-AP configuration, assumed omnidirectional antennas and the same antenna pattern (single frequency) for all WLAN-APs throughout the simulation process which lacks the opportunity of handling the co-channel interference and did not determine the number of users that could be supported with a specific minimum guaranteed data rate i.e. that survey is limited to propagation with no capacity planning [2].

## Literature Review:

S. Zvanovec, P. Pechac, and M. Klepal experimented to analyze the merits and demerits of two distinct methods for Wi-Fi Network Deployment Survey. One was the practical survey in which Wi-Fi transmitters were deployed in a testbed and Received Signal Strength Indicator (RSSI) measurements were taken on multiple points and the second method was a simulation of the signal propagation model in a software tool. The experimental data was simulated in MATLAB. Results from both methods were analyzed and the software simulation method was preferred for Wi-Fi Network Deployment [3].

T. Honda, M. Ikeda, and L. Barolli conducted experiments to optimize the coverage by correct placement of Wi-Fi APs through site surveys and network simulations for the solution of connectivity problems. Results indicated that the received power from APs was not uniform [4]. T. Witono and Y. Dicky did practical site measurements of RSS for the optimization of 12 Wi-Fi transmitters in an overlapping Wi-Fi environment. The key controllers of a single Wi-Fi transmitter were the direction of transmitting antennas, the combination of channels, and the transmit power, all of which were adjusted for the optimization of Wi-Fi deployment [5].

U. Mir, O. U. Sabir, H. Ullah, and A. U. Khan experimented to achieve coverage optimization through accurate placement of APs based on RSSI measurements in the testbed. Site simulation survey was conducted through Tamograph and real-time measurements were taken through SSIDer software and Air Magnet hardware (validation). The results from the simulation and measurements were analyzed for optimization along with the voltage variation effects on the RSSI measurements [6].

J. Tan, X. Fan, S. Wang, and Y. Ren collected RSS measurements from the inertial sensors of a smartphone by walking in the testbed of the Wi-Fi environment for the purpose of accurate Radio Map (Wi-Fi Fingerprint) construction. The RSS data was processed by the pedestrian dead-reckoning algorithm for the production of raw trajectories. Those trajectories were refined by the assembling of constraints collected at the landmarks, by the use of Factor Graph Optimization (FGO). Then k-Nearest Neibour (kNN) algorithm was applied for the validation and localization performance testing of the Radio Map. The Radio Map was practically implemented in a shopping mall and a mean error of 1.10m and maximum error of 2.25m was recorded for Wi-Fi transmitter locations which is an acceptable error for Radio Map [7]. A. Srivastava, R. Vatti, V. Deshpande, J. Patil and O. Nikte did practical measurement of RSSI for finding dead zones with less or no coverage of Wi-Fi signals in the area through Netspot Tool. Further, optimization techniques of Particle Swarm Optimization {PSO (responsible for optimal Wi-Fi transmitter placement)} and Repeater deployment were implemented to solve the problem of coverage in the dead zones [8].

Y. Tian, B. Huang, B. Jia, and L. Zhao, developed an algorithm for the accurate placement of Wi-Fi access points and Bluetooth beacons in a Wi-Fi / Bluetooth hybrid environment. The "heuristic differential evolution algorithm" (HDEA) is based on the "Cramer-Rao lower bound (CRLB)". The CRLB is considered a standard for the localization and coverage of Wi-Fi/Bluetooth signals. Further, the Motley-Keenan model is assembled in the algorithm instead of the ideal Log Distance Path Loss (LDPL) model for the analysis of the effects caused by obstacles in the indoor environment. Based on these contents, the algorithm is deployed in a software application that is used with Geo-Tools for the localization of Wi-Fi access points and Bluetooth beacons. Extensive simulations and experiments in the field were conducted to validate the efficiency of the algorithm [9].

N. A. M. Maung and W. Zaw, conducted experiments to compare and analyze the performance of two techniques of Wi-Fi indoor positioning in 2.4GHz and 5GHz frequency bands. The implemented techniques were the path loss model and RSS Fingerprint. Results show that the RSS-based indoor Wi-Fi positioning performed with better accuracy than the other technique because the path loss model takes a direct reading of RSS value (highly variable due to multipath and interference) and estimates the location which leads to positioning error [10].

M. R. Akram, A. H. Al-Nakkash, O. N. M. Salim, and A. A. S. AlAbdullah, developed a multi-objective algorithm for the optimization of Wi-Fi coverage, location, and number of access points by the use of MATLAB software. The algorithm works on the Binary Particle Swarm Optimization (BPSO) technique which takes predefined RSS values to estimate the optimization of the aforesaid objectives. The deployment of the algorithm resulted in 64.6% coverage and 7dBm on average received power optimization [11]. O. S. Naif and I. J. Mohammed experimented Binary Particle Swarm Optimization (BPSO) algorithm used with Wireless Insite (WI) simulation software, to optimize the coverage and interference parameters of a multi-floor Wi-Fi AP deployment. The WI takes RSS values, signal thresholds, and current AP deployment locations to process the optimization in conjunction with BPSO. Results depict that the proposed work outperforms the present Wi-Fi deployment in RSS (-11.5dBm), path loss (11.5dBm), interference (7.87%), and coverage/ optimal AP placement of 39.23% [12].

A. S. Haron, Z. Mansor, I. Ahmad, and S. M. M. Maharum did a simulation-based survey to optimize the location of presently deployed Wi-Fi transmitters in 2.4GHz and 5GHz bands in terms of signal strength to overcome the problem of connectivity in the Communication Technology Laboratories Area at University of Kuala Lumpur British Malaysian Institute. Hyper Works' Win Prop simulation software was used. First, the layout of the testbed was modeled in the Win Prop's WallMan Tool, having similar properties/sizes of materials from the map. Then omni-directional antenna patterns of 2.4GHz and 5GHz were modeled in Win Prop's A Man Tool. After that, both models from WallMan and A Man were implemented in Win Prop's Pro Man Tool where the signal propagation analysis was done for each antenna with the exact deployment location as was in real. The simulation was carried out in 2.4GHz and 5GHz bands separately for all antennas with modification in the location of WLAN-APs and results were compared. After that physical validation of the acquired results was done using In SSIDer by measuring the RSS and the optimum location for the Wi-Fi transmitters was determined [2].

S. Baua and S. Karuppuswami, presented the Machine Learning (ML) technique of Modified Extensible Lattice Sequence (MELS) which is a regression-based supervised learning algorithm used with the Global Response Search Method (GRSM) optimization routine to optimize the coverage by correct placement of transmitters and number of Wi-Fi APs for an office area. A dual-slot antenna is designed operating in 5.2GHz (S46 / S54 bands) and having 6dBi of gain, to represent a single Wi-Fi AP for the processing of radio optimization. The target of optimization is to reduce the number of APs, place them in inaccurate locations for wider coverage, and provide at least 13Mbps of data rate at a 15000 square foot area at the office location [13].

I. Bridova and M. Moravcik did predictive and passive surveys to overcome the problem of Wi-Fi connectivity at the Department of Information Networks, University of Zilina. The methodology includes model construction from a Map and the creation of predictive heat maps in Ekahau simulation software in terms of relocation of APs with respect to hotspots and unnecessary areas. During prediction, no objects (furniture, electronic devices) were considered. Then physical readings were collected in the form of a passive survey and results were analyzed for optimal coverage, Signal to Noise Ratio, and Throughput [14]. All studies have focused on coverage optimization with no capacity planning. This research work performed propagation (coverage optimization) as well as network simulations (capacity planning) which provided radiation patterns for all antennas at once in the testbed. As a result, the RSSI, Signal Noise & Interference Ratio (SNIR), and Interference + Noise (I+N) in the testbed are analyzed as a combined result of all antennas at once (received power of the network) as well as data rate (downlink/uplink) and user handling capacity calculations are done.

**Methodology:**

It consists of three parts i.e. Physical data collection, implementation of collected data as 3D model generation & Wi-Fi network simulations, and optimization analysis & validation of results. The First part is carried out by acquiring physical data of the testbed including a 2D map with construction objects' sizes and materials; a technical datasheet of the access point with supporting Wi-Fi technologies, antenna patterns with respective gain, transmit powers, receiver sensitivities, polarizations & operational bands; RSSI values and downlink/uplink data rates as real-time measurements of the present case acquired through Cellular-Z. In the second part, the collected data is practically implemented in Altair's Win Prop software in which WallMan is a 3D modeling construction Tool and Pro Man is a signal propagation simulation Tool. Map with all details of the floor plan, construction sizes, and material properties are designed for the area where the Wi-Fi network is optimized as a 3D model in the WallMan Tool.

Then, [1] Access Point's Wi-Fi technologies, antenna patterns with respective gain, transmit powers, receiver sensitivities, polarizations & operational bands; RSSI values, and downlink/uplink data rates are created and deployed within the 3D model created in the previous step through Win Prop's Pro Man Tool. Then, radio coverage and network capacity planning in the modeled environment are simulated for all Wi-Fi APs using Win Prop's Pro Man for the present case. The simulation process is repeated 73 times in pursuit of coverage and capacity optimization, comparing each simulated case with the present case. Results are acquired for the 2.4GHz band. In the third part, results are analyzed for optimal signal strength, data rate, and user handling capacity. The best case is selected and applied in the testbed. The results are validated by smartphone-embedded software (Cellular-Z).

**Results:**

The results in Table 1 & Table 2 show the difference in RSSI, Data Rate, SNIR, I+N, and Modulation & Coding Schemes (MCSs) in the testbed.

**Table 1**: Before Optimization of APs

| Received Power | | | |
|---|---|---|---|
| **Mean (dBm)** | **Median (dBm)** | **Standard Deviation (dBm)** | **Maximum (dBm)** |
| -73.13 | -73.58 | 12.07 | -45.02 |
| Downlink/ Uplink Data Rate (Mbps) | Downlink: Signal to Noise & Interference Ratio (dB) | Downlink: Interference + Noise (dBm) | The number of Modulation & Coding Schemes Operated |
| 19.48 / 4.10 | 10.17 | -53 | 3 |

**Table 2:** After Optimization of APs:

| Received Power | | | |
|---|---|---|---|
| **Mean (dBm)** | **Median (dBm)** | **Standard Deviation (dBm)** | **Maximum (dBm)** |
| -71.71 | -72.62 | 11.12 | -43.25 |
| Downlink / Uplink Data Rate (Mbps) | Downlink: Signal to Noise & Interference Ratio (dB) | Downlink: Interference + Noise (dBm) | The number of Modulation & Coding Schemes Operated |
| 64.94 / 13.67 | 63.59 | -65 | 8 |

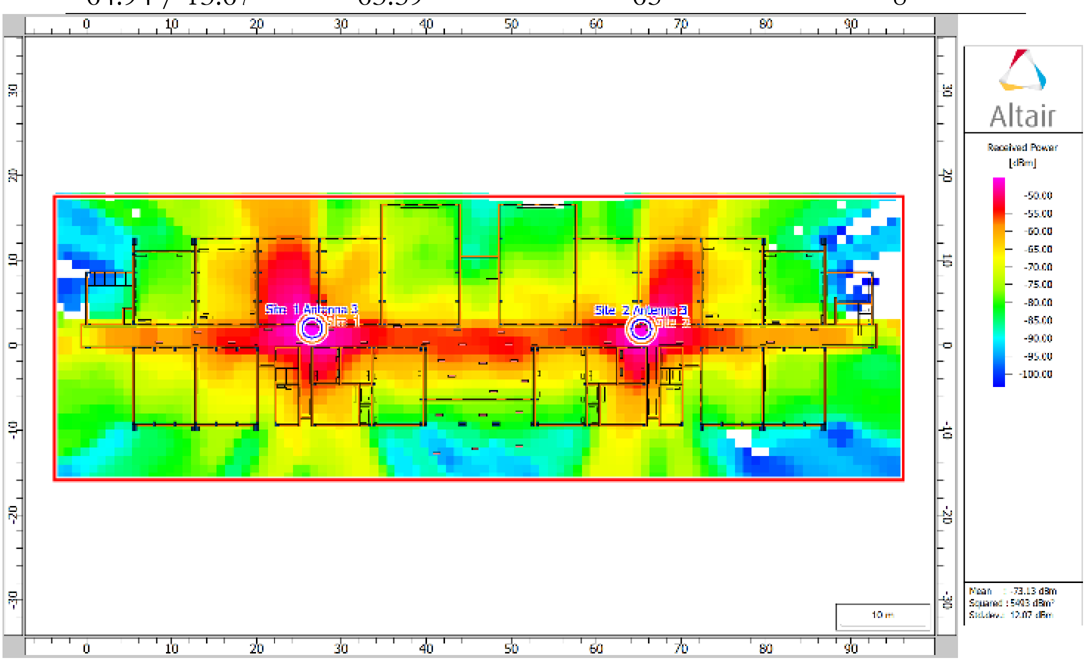


**Figure 1:** Simulation Values of RSSI Before Optimization

In Table 4, 19 location points are taken for comparison between real-time measurements and simulation predictions before & after optimization. The simulation data can be visualized in Figure 3 & Figure 4 respectively. The average optimization difference between non-optimized real measurements & optimized real measurements is 2.53 Mbps, the average optimization difference between non-optimized simulation predictions & optimized simulation predictions is 0.75 Mbps, and the average optimization difference between optimized simulation prediction & optimized real measurements is 4.17 Mbps.

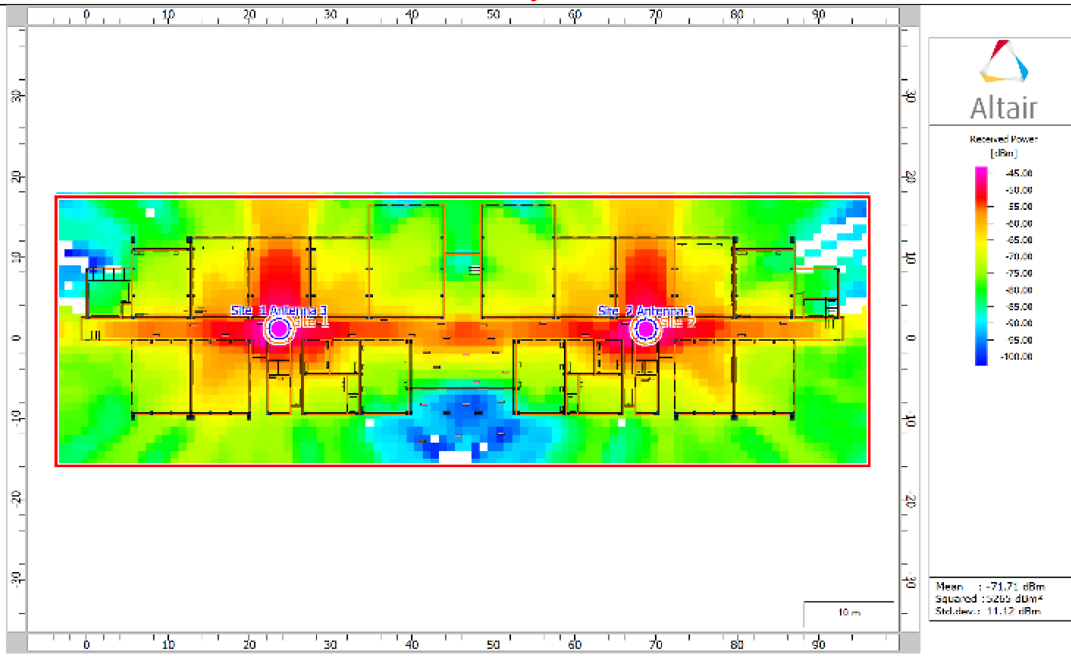

**Figure 2:** Simulation Values of RSSI After Optimization

In Table 3, 20 In-location points are taken for comparison between real-time measurements and simulation predictions before & after optimization. The simulation data can be visualized in Figure 1 & Figure 2 respectively. The average optimization difference between non-optimized real measurements & optimized real measurements is 3.95 dB, the average optimization difference between non-optimized simulation predictions & optimized simulation predictions is 0.75 dB, and the average optimization difference between optimized simulation predictions & optimized real measurements is 1.47 dB.

**Table 3:** Coverage Optimization Comparison

| **Locations (x, y)** | **Real-Time RSSI (dBm)** | | **Simulation Predictions RSSI (dBm)** | |
|---|---|---|---|---|
| | **Non-Optimized** | **Optimized** | **Non-Optimized** | **Optimized** |
| 19.5, -8.5 | -71 | -66 | -74.48 | -67.26 |
| 27.5, -8.5 | -71 | -68 | -65.58 | -72.22 |
| 31.5, -8.5 | -74 | -69 | -69.93 | -74.26 |
| 27.5, -5.5 | -71 | -68 | -58.33 | -67.01 |
| 9.5, -4.5 | -76 | -72 | -71.23 | -71.33 |
| 23.5, -1.5 | -54 | -51 | -53.89 | -50.93 |
| 27.5, -1.5 | -53 | -51 | -49.91 | -53.88 |
| 18.5, 0.5 | -58 | -53 | -53.98 | -52.09 |
| 23.5, 0.5 | -42 | -41 | -47.77 | -44.13 |
| 18.5, 1.5 | -58 | -53 | -54.66 | -52.09 |
| 23.5, 1.5 | -42 | -41 | -47.23 | -44.13 |
| 0.5, 3.5 | -85 | -80 | -85.3 | -78.98 |
| 4.5, 3.5 | -84 | -77 | -80.15 | -70.94 |
| 19.5, 3.5 | -63 | -56 | -59.04 | -55.91 |
| 26.5, 3.5 | -51 | -47 | -49.84 | -53.11 |
| 4.5, 6.5 | -80 | -79 | -84.94 | -80.64 |
| 39.5, 9.5 | -78 | -72 | -77.37 | -71.47 |
| 47.5, 9.5 | -82 | -77 | -80.14 | -82.73 |
| 35.5,15.5 | -77 | -75 | -73.79 | -80.62 |
| 42.5,15.5 | -82 | -77 | -79.87 | -78.65 |

**Table I:** Capacity Optimization Comparison {Per User Data Rate (Downlink)}

| Locations (x, y) | Real-Time Data Rate (Mbps) | | Simulation Predictions Data Rate (Mbps) | |
|---|---|---|---|---|
| | Non-Optimized | Optimized | Non-Optimized | Optimized |
| 2.7, 4.5 | 0.5 | 1 | 0.08 | 0.61 |
| 16.2, 7.5 | 4.3 | 5.6 | 0.08 | 0.93 |
| 24, 7.4 | 4.5 | 11.5 | 0.08 | 0.61 |
| 31, 7.6 | 2.6 | 2.6 | 0.08 | 0.93 |
| 39, 9.3 | 1.2 | 1.2 | 0.08 | 0.93 |
| 46, 6 | 1.4 | 4.9 | 0.08 | 0.81 |
| 9, 1 | 0.8 | 10.3 | 0.08 | 1.03 |
| 16.5, 1 | 1 | 5.8 | 0.08 | 1.03 |
| 23.6, 1 | 2.6 | 10.3 | 0.08 | 1.03 |
| 29.7, 1 | 1.3 | 6.3 | 0.08 | 1.03 |
| 36.7, 1 | 1.3 | 5.6 | 0.08 | 1.03 |
| 42, -3 | 1.4 | 1.2 | 0.08 | 0.61 |
| 45.8, -3 | 1.8 | 1 | 0.08 | 0.61 |
| 50.6, -3 | 2.4 | 1.6 | 0.08 | 0.61 |
| 9, -4.9 | 4.3 | 1.2 | 0.08 | 0.81 |
| 16.5, -4.9 | 11.8 | 4.5 | 0.08 | 0.81 |
| 28, -2.5 | 1.5 | 11.7 | 0.08 | 0.81 |
| 29, -7 | 1 | 5.3 | 0.08 | 0.93 |
| 36.5, -5 | 1.2 | 3.4 | 0.08 | 0.61 |

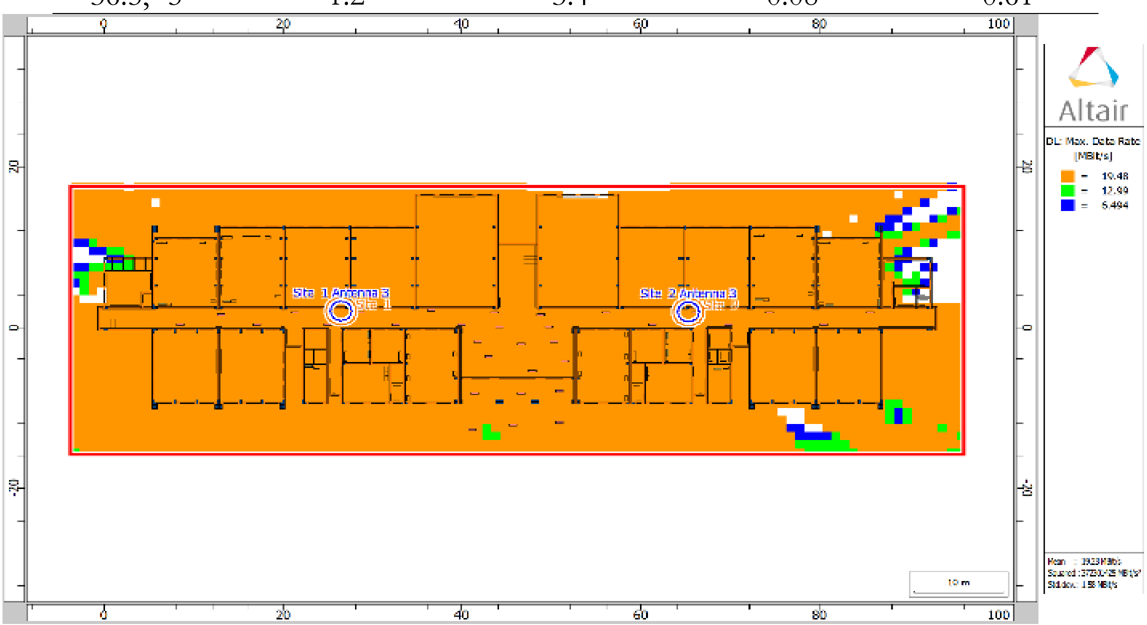


**Figure 3:** Downlink Data Rate Before Optimization

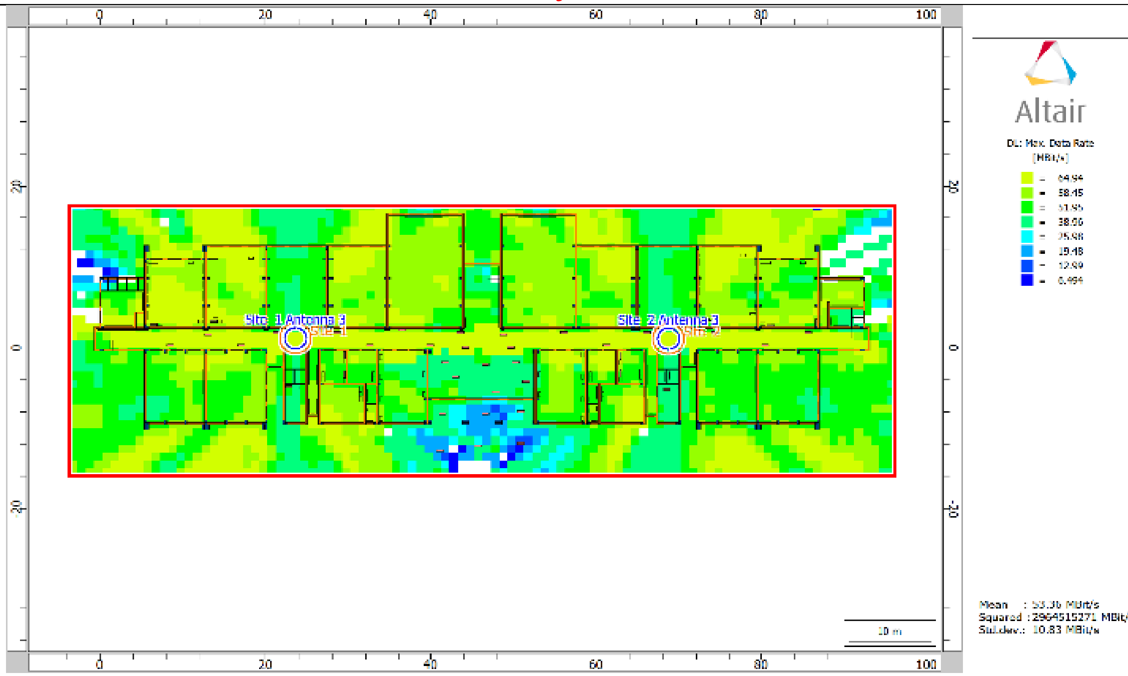


**Figure 4:** Downlink Data Rate After Optimization

In Table 5,19 location points are taken for comparison between real-time measurements and simulation predictions before & after optimization. The simulation data can be visualized in Figure 5 & Figure 6 respectively the average optimization difference between non-optimized real & optimized real measurements is 3.42 Mbps, the average optimization difference between non-optimized simulation & optimized simulation predictions is 0.16 Mbps and the average optimization difference between optimized simulation predictions & optimized real measurements is 7.55 Mbps.

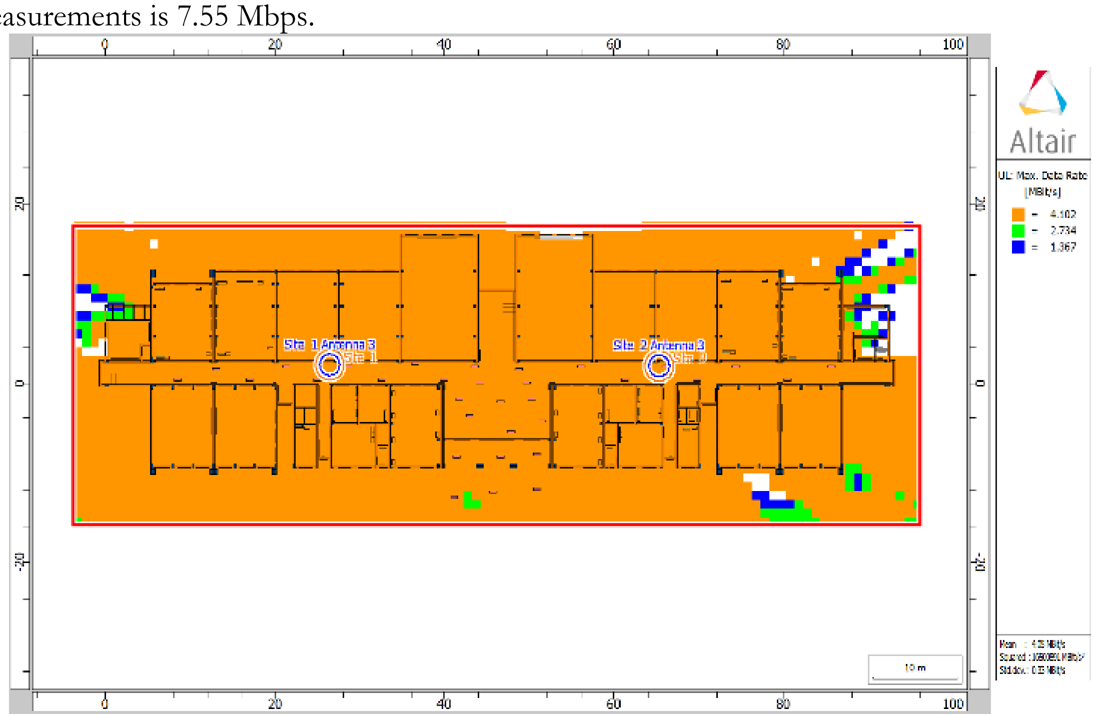


**Figure 5:** Uplink Data Rate Before Optimization

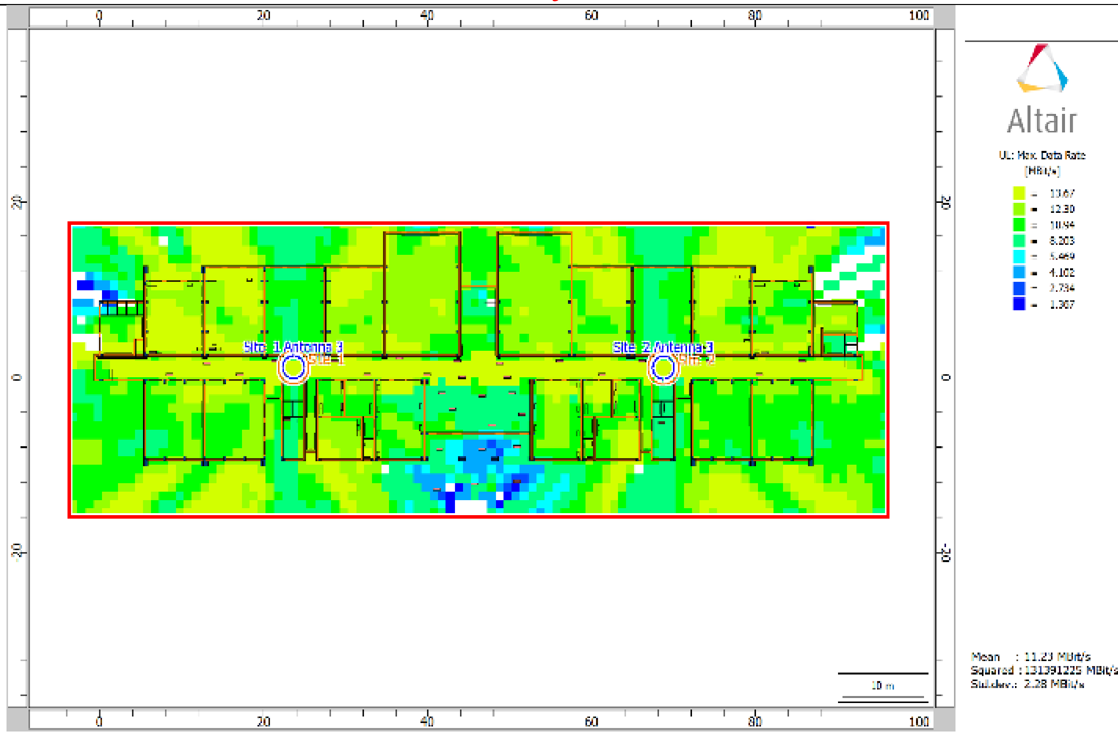


**Figure 6:** Uplink Data Rate After Optimization

**Table 5**. Capacity Optimization Comparison {Per User Data Rate (Uplink)}

| Locations (x, y) | Real-Time Data Rate (Mbps) | | Simulation Predictions Data Rate (Mbps) | |
|---|---|---|---|---|
| | Non-Optimized | Optimized | Non-Optimized | Optimized |
| 2.7, 4.5 | 0.5 | 0.2 | 0.02 | 0.13 |
| 16.2, 7.5 | 5 | 4.7 | 0.02 | 0.2 |
| 24, 7.4 | 7 | 12.9 | 0.02 | 0.13 |
| 31, 7.6 | 5.8 | 10.9 | 0.02 | 0.2 |
| 39, 9.3 | 1.1 | 9 | 0.02 | 0.2 |
| 46, 6 | 3 | 3 | 0.02 | 0.17 |
| 9, 1 | 6.4 | 10.3 | 0.02 | 0.22 |
| 16.5, 1 | 8 | 2.2 | 0.02 | 0.22 |
| 23.6, 1 | 9.4 | 11.8 | 0.02 | 0.22 |
| 29.7, 1 | 5.8 | 11.2 | 0.02 | 0.22 |
| 36.7, 1 | 4.5 | 8.4 | 0.02 | 0.22 |
| 42, -3 | 2.2 | 9.9 | 0.02 | 0.13 |
| 45.8, -3 | 2.2 | 6.1 | 0.02 | 0.13 |
| 50.6, -3 | 4.8 | 3.3 | 0.02 | 0.13 |
| 9, -4.9 | 1 | 6.8 | 0.02 | 0.17 |
| 16.5, -4.9 | 4.2 | 5.8 | 0.02 | 0.17 |
| 28, -2.5 | 4.4 | 11 | 0.02 | 0.17 |
| 29, -7 | 3.6 | 10.6 | 0.02 | 0.2 |
| 36.5, -5 | 2.9 | 8.7 | 0.02 | 0.13 |

The maximum logical user handling capacity of each AP is 254 users because they use Class C IPv4 addressing whose range is $2^8 = 256$ addresses in which the first address is allocated to the AP itself and the last one is a subnet mask, so 256 – 2 = 254. This setup of IP addressing is assigned by the network administration and the research for optimization is carried out within these bounds. If a Class B address is assigned, then capacity planning should be done to that setup accordingly. Practically, the user handling capacity of an AP is further limited by the physical resources but as the number of users under specific MCS decreases, the per-user data rate increases and vice versa.

**Conclusion:**

This research has achieved coverage and capacity optimization in terms of RSSI, data rate, SNIR, I+N & user capacity in the already deployed Wi-Fi

network. The number of APs in the testbed is decreased from 7 to 2. The optimization is performed in Win Prop's Pro Man through simulations based on location and antenna polarization/ physical orientation variation of the APs in the testbed. Then the most optimum case with respect to coverage and capacity is selected within the dataset of all possible cases (73) and applied in a real-time environment. The real-time measurements are taken with respect to coverage and capacity (validation). In the calculation of the per-user data rate (simulation), the total number of users is divided by the total number of MCS operated in the testbed. In this case, every MCS serves an equal number of users. So, users within the same MCS get the same data rate in downlink and uplink. But in reality, more users come under the same MCS, less data rate each user will get, and vice versa.

The future work consists of Monte Carlo Simulation (location-dependent traffic analysis), Prediction analysis (Delay Spread, Angular Spread & Angular Means), Electromagnetic Compatibility (EMC) analysis, Consideration of Mobile Station properties (propagation & channel properties), MIMO analysis in uplink & downlink, designing accurate pattern of AP antennas in AMan, implementation and analysis of IEEE 802.11 a/ac/ax technologies for higher capacity and RSSI calculations for worst case scenario.

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