# Evaluation of developed WLAN Optimisation Tool

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## Abstract

*The popularity of IEEE 802.11 based wireless local area networks (WLANs) has increased substantially in recent years. Many applications have been developed that take advantage of WLANs low cost and high-speed data rate capabilities, including voice over IP, asset tracking, location, managing manufacturing and inventory. The performance of applications, such as those listed, is correlated with the WLAN design. The current approach to WLAN design is based on rules of thumb and a designer's experience. This ad-hoc approach can limit performance of a WLAN, hence there is a need for a methodical design process and a suitable software planning tool to allow even the inexperienced designer to automatically design and achieve maximum performance for a site-specific WLAN. This paper presents such a tool that allows for the automatic design of highly customisable and efficient WLANs.*

## 1. Introduction

Due to the ever increasing number of applications taking advantage of IEEE802.11 wireless technology and to over come the ad-hoc nature of site-specific WLAN design, a software tool is required to allow the designer to easily describe and optimise a required WLAN. There are many issues that need to be considered when designing a WLAN, such as the influence of people on radio propagation, the number of access points required, the cost of a design, to name but a few. The purpose of the research presented here is to develop a software tool that allows a user overcome the demanding task of planning IEEE 802.11 a/b/g networks. The tool should provide automatic design and optimisation of site-specific WLANs in order to gain maximum network performance. As the kernel of the software tool it is proposed to design a WLAN using algorithms based on Evolution Strategies (ES) [1] to optimise access point (AP) positions. ES is an efficient stochastic optimal search method that can be used to solve complex and non-linear optimisation problems. Initial results suggest that our ES based approach is stable and well suited to the purposes of access point placement optimisation as the same results are found in multiple runs on the same environment. To evaluate the performance of our technique the software tool was used to generate a plan of a WLAN. This suggested WLAN design was then deployed, signal coverage and throughput measurements were taken throughout the environment.

The paper is organised as follows, section 2 will present related work in AP placement optimisation. Section 3 will describe the simulation test bed that was developed to allow the automatic design of a WLAN based on user defined requirements, such as required coverage areas and number of users, the section will show the software architecture and describe each software module used. In section 4 the optimisation technique, especially the fitness function used to evaluate a suggested solution, will be presented. Section 5 and 6 reports on a case study that was undertaken within the Cork Institute of Technology to evaluate the implemented design tool, the analysis of results from the deployed network will be presented in section 7. Section 8 will conclude the paper.

## 2. Related Work

The optimisation of AP placement is essential for accurate and fast design of large scale WLANS. In [2] a network planner decides on a number of potential Access Point locations, based on their experience. Combinations of the potential AP are assessed using a Ray tracing model and a suggestive result is presented to the network planner. The network planner can then continue to evaluate other combinations and decide on the overall result. This approach is comparable to a site survey, different combinations are assessed and evaluated to decide what the best AP positioning and combination is. This technique does not find a global model but yields a suggestive solution for the network planner to gauge.

In [3] the optimisation of AP placement is carried out by formulating an Integer Linear programming problem. Considering load balancing, with the over all objective being to minimize the maximum channel utilisation. As an input for the optimisation a complete coverage map is required from an Internet Service Provider (ISP), who in turn decides on potential AP positions in this demand area. Demand points, representing a traffic demand area, are defined and based on signal strength are assigned to a specific AP. Using these demand points a channel assignment procedure is utilised out to reduce the co-channel interference in the WLAN. In [4] the Nelder-Mead Method is implemented to optimise base station placement in Wireless Applications. It is suggested in [4] that Direct Search Methods are well suited to finding an optimal AP placement, since they only require the value of the function to be optimised. The main property of the fitness function in [4] is the total number of grid points covered divided by the total number of grid points. Coverage alone is not enough to consider when evaluating a possible solution to AP placement. In [5] and [6] Ray optical propagation modelling is used to evaluate possible AP locations in urban and indoor environments. Although these models can accurately predict signal coverage they need to be combined with site specific user demands to achieve optimal number and position of APs.

In [7] a continuous non-linear programming problem is used to derive the number of access points and their positions based on locations or clusters of users. The authors' use an objective function based on path loss by combining the average and the maximal path losses with different coefficients. The algorithm begins with one single access point and increases until the objective function is satisfied. In rapidly changing environments where the number of users varies and obstacles influence signal propagation path loss alone is not sufficient to be considered with designing the WLAN. For much larger environments scalability could become and issue. Although in [8] the authors concentrate on optimising network capacity rather than high signal level it does require initial specification of possible candidate APs and does not consider complex indoor environments.

In [9][10][11][12] many other methods of optimisation of WLAN are investigated including Genetic Algorithms (GA), Simulated Annealing (SA), Tabu Search (TS) and Random Walk Algorithms (RW).

It is proposed to use ES to optimise AP placement in WLAN design in order to speed up the optimisation process and address the issue of scalability when considering large scale WLANs. The majority of the techniques described base the WLAN design on signal coverage alone, although this is a major part in the design it is not enough on its own. In the current implementation of the WLAN design tool, signal coverage is an integral part of the optimisation, however to ensure a more accurate WLAN design the optimisation technique will be developed to consider real user demands on the deployed network including number of users and traffic load requirements.

## 3. Simulation Test bed

In order to overcome the demanding task imposed on a designer when attempting to maximise performance of a WLAN, a software tool was developed. This design tool allows the designer to describe the environment where the WLAN is to be deployed and specify the user requirements throughout the environment. It is at this point the software takes over and automatically generates possible AP positions and optimises the number of APs required and particularly the positions of these APs in order to satisfy user demands. The software simulation tool comprises four main modules, Visualisation, Environment, Segmentation and Optimisation as shown in Figure 1.

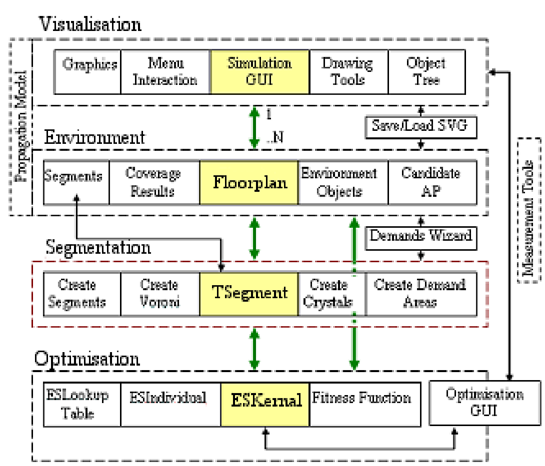


**Figure 1 Simulation Test bed Architecture**

The visualisation module was designed using Borland C++ VCL library, a user friendly GUI was developed to provide the designer with an interface to specify, visualise an environment and invoke optimisation on the specified environment. The environment module describes where the WLAN will be deployed and must be at a minimum to allow designers specify the required area easily. A environment can be described with walls. Using specified walls and floors, a skeleton of a building or environment can be constructed. The combination of these walls allows for the specification of rooms or areas that can be used as demand areas to define user requirements.

The resultant environment is used as an input for the propagation model, which allows for accurate prediction of signal coverage. Accurate propagation models are essential for WLAN design as they need to provide realistic signal coverage prediction in a described environment. After close investigation into existing indoor propagation models it is clear that there is a trade off between computational time and model accuracy. Two models were chosen to evaluate, firstly the empirical Multi Wall Model (MWM) [13] due to its speed and the minimum environment description that is required. While considering the material properties of the wall, the aggregate set of walls crossed by a direct line from transmitter and receiver accumulates to the total penetration loss caused by the building walls giving a more accurate prediction than a simple path loss model. Secondly the Motif Model [14] was considered. The motif model is much faster to compute than other ray optical based models because it takes advantage of the simple line-drawing technique of dividing the environment description into a grid. To investigate further the suitability of these propagation models for the purposes of optimisation, measurement was carried out.

Figure 2 shows the configuration of the environment where measurements took place. A single AP was placed at a height of approx 1.5 metres at the end of a corridor. Using a wireless enabled laptop, measurements were taken in various locations throughout the environment as shown in Figure 3. The MWM and Motif Model were implemented in software for analysis and comparison with measurement. Marked out on Figure 4 and Figure 5 is predicted signal level in dBm using the MWM and Motif Model respectively.

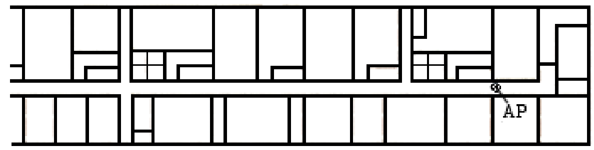


**Figure 2 Measurement Environment**

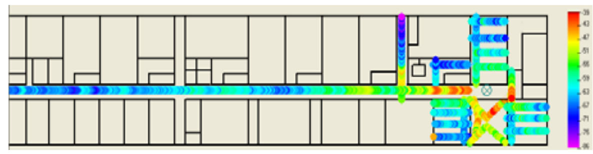

**Figure 3 Measured Signal Level (IEEE802.11b)**

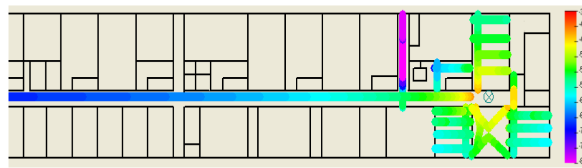

**Figure 4 Optimised MWM Signal Level Prediction**

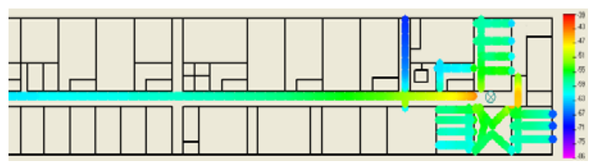

**Figure 5 Motif Model Signal Level Prediction**

Table 1 shows the statistical analysis of both models. Both models give an accurate prediction when compared to real measurements; this is evident from Figure 6 which graphs the sample measurement points and the predicted signal level. Figure 7 shows a sample of measurement location within the environment and graphed samples. The MWM is very fast therefore suitable for optimisation where many coverage maps need to be generated for a described environment but accuracy can vary with different environments. While the Motif model is more accurate and suitable for general environments it is computationally demanding compared to the MWM. It was decided to use the MWM for preliminary evaluation but the final software tool will ultimately use the Motif Model.

**Table 1 Model analysis results**

| | Standard Deviation | Mean Error | Time (sec) |
|---|---|---|---|
| **Multi Wall Model (Optimised)** | 7.58 | 0 | < 1 |
| **Motif Model** | 5.98 | -0.28 | 6 |

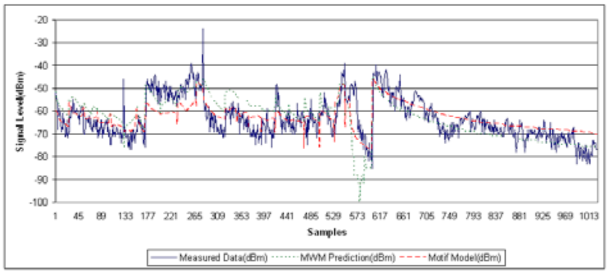


**Figure 6 Propagation Model Comparisons**

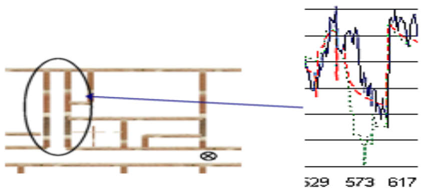


**Figure 7 Sample Measured Area**

The Segmentation and Optimisation modules make up the optimisation kernel. Optimisation is carried out using ES, this will be described further in section 4. The Segmentation module was implemented for optimisation of large-scale WLANs where the scalability of ES is an issue. The segmentation reduces the environment into a number of more manageable segments. The algorithm breaks the environment into demand segments, and then proceeds to group these segments into a crystal, where a crystal represents a section of the environment that can be optimised independently using ES. As the algorithm grows or moves through the environment the result of the previous crystal optimisation is considered as part of the fitness evaluation (boundary function) when the next crystal is optimised. The segmentation provides stability when designing large-scale WLANs such as large college campuses.

## 4. Optimisation

As previously stated it is proposed to use ES for the optimisation of AP placement. The basic principle of ES is to begin with a selection of candidate solutions or individuals and evolve these solutions, using mutation, with subsequent generations improving. To use the implemented ES for the AP placement optimisation problem specific inputs must be defined. Also, some pre-processing of these requirements is needed.

Once the environment has been defined and described the next step is to define site-specific user demands. The simulation test bed provides a demand wizard tool to allow the designer to easily specify requirements on demand areas including signal level threshold, number of users, and traffic usage. The designer can also define restricted areas, where it is not desirable to provide cover, such as in a hospital where the WLAN might cause interference with existing devices or for safety reasons.

The developed software automatically generates a candidate access point grid, based on defined demand areas and restricted areas. This access point grid represents possible physical positions throughout the environment where an access point can be placed. The grid is generated using an algorithm based on a growing neural-gas algorithm proposed by Bernd Fritzke [15]. In this approach a network topology is generated incrementally using Competitive Hebbian Learning (CHL) and a Neural Gas method. The use of this algorithm allows for the generation and distribution of access points evenly in complex environments while maintaining desirable positions such as on walls and ceilings. Figure 8 shows the completed candidate access point grid mesh in a large open corridor scenario.

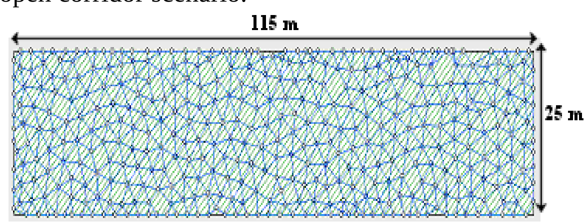


**Figure 8 Candidate AP Grid (Open Environment)**

The candidate access point not only has a physical position but it also has an associated coverage map generated using the appropriate propagation model and a list of neighbours, which when connected represent edges that can be traversed during the optimisation process. The generation of this access point grid reduces the optimisation search space and increases optimisation speed during fitness evaluation as the generation of the coverage map is only done once before the optimisation begins.

To optimise the access point positions a candidate solution must be described as an individual. An individual (*a*) consists of an object parameter vector *y*; endogenous strategy parameter set *s* and a corresponding fitness value *F(y)* (3.1). For optimisation of access point placement the parameter vector *y* consists of what is required to be optimised including the number of access points that should be used, the number of edges used to traverse through the candidate access point mesh and the actual position of an access point which is derived based on the first two parameters in the object vector.

ES uses the results of the fitness function *F(y)* to evaluate what the best solution to the optimisation is.

For the problem of AP placement the objective of the optimisation is to minimise the fitness function that assesses if the suggested solution satisfies user demands by maximising throughput with a minimum number of AP.

$$F(y) = w_1 D + w_2 A + w_3 R + w_4 B \quad (3.1)$$

Where,

$D$…………… User Demand Satisfaction

$A$…………… Number of Access Points

$R$…………… Restricted Area

$B$…………… Solution Balance

$w_i$………….. Weighting Factors

$$\sum_{i=0}^{1} w_i = 1 \quad (3.2)$$

The fitness function evaluates a complete signal level coverage map in relation to selected access point positions. Using this coverage map the fitness function evaluates successfully covered areas based on a user defined threshold (*D*). Other elements of the fitness function encourage a design with balanced coverage areas (*B)* using a minimum number of access points (*A*). The fitness function elements are normalised with weighting factors being used to put more emphasise on a particular element. The sum of all weighting factors is one (3.2). The fitness function is an integral part of the optimisation kernel and has been analysed and described in detail in a previous paper [16].

## 5. Tool Evaluation

Initial results show that the implemented technique is stable and performs well [16]. To further evaluate the tool a case study was undertaken within the Department of Electronic Engineering at Cork Institute of Technology. This involved designing a WLAN to accommodate students, lecturers and lab environments within the department. The first step was to use the simulation test bed to describe the environment. Figure 9 shows the environment with highlighted demand and restricted areas.

The demand areas are automatically created by the software using a segmentation algorithm. Walls are grouped together to form rooms or areas where user demand can be defined. The user demand wizard was used to specify the signal level threshold in each lab and office to be –70dBm, which is an acceptable signal level threshold.

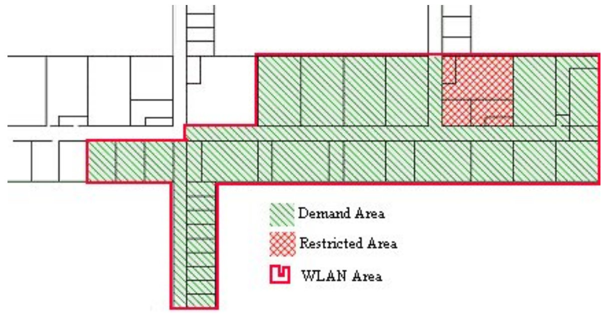


**Figure 9 CIT Electronics Department**

The simulation test bed now automatically creates the candidate access point grid and generates a coverage map for each of the access points within the grid using the MWM. Figure 10 shows the resulting access point grid. With all pre-processing of the environment complete, the WLAN can now be optimised.

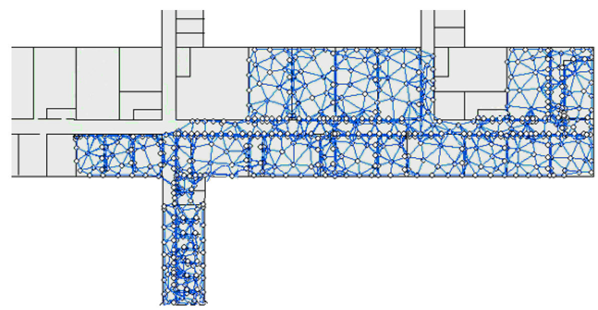

**Figure 10 Candidate Access Point Grid**

The optimisation took approx 30 seconds to arrive at an optimal solution. The graph in Figure 11 shows the progress of the fitness function during the optimisation. The fitness reached a steady state at 169 generations providing an optimal solution.

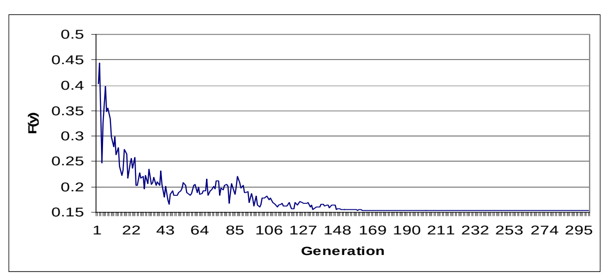


**Figure 11 Fitness Progress during optimisation**

It was predicted that 6 Access Points are required to fully cover the environment, based on environment description and user defined requirements (Figure 12). In order to evaluate the suggested solution some measurement was required. This involves deploying the WLAN and using measurement tools to analyse the coverage and throughput provided by the design.

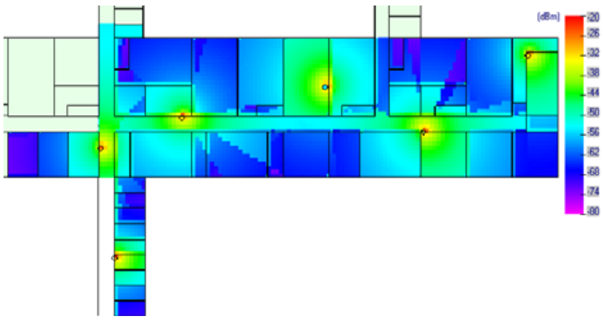

**Figure 12 Optimisation Results**

## 6. Measurement

To evaluate the optimisation, the main section of the environment was analysed. Due to access problems five of the suggested six access points were installed in the positions suggested. Proxim Orinoco AP-700 access points were used, operating IEEE802.11b and having the auto channel select enabled. Each access point was connected to the network through a power over Ethernet switch and 128bit WEP security was enabled.

To measure the signal level throughout the deployed WLAN a tool developed in the Centre of Adaptive Wireless Systems called AWSNet was used. AWSNet is a Wifi Scanner and measurement tool that allows for active scanning of APs, identifying BSSID and graphing the signal level. A feature of the tool is environment measurement that allows the user to load the environment saved in Scalable Vector Graphics (SVG) format and specify start and end position of measurements. This then allows the software to generate a coverage map of measured locations and received signal level from all APs at that location. The data is then stored in a database for later analysis. The advantage of this tool is that each access point can be measured at each location concurrently, allowing for a complete WLAN evaluation.

With a wireless enabled laptop running AWSNet the defined environment is imported and measurement locations specified, by walking slowly between start and end points the signal level is read and recorded in a database specifying the BSSID of the reading, the signal level and the position within the environment where the measurement took place. The resulting data can be visualised in the Simulation Test bed. Presented in Figure 13 are the results of the measurement within the environment with the APs and their positions marked.

To measure throughput another measurement tool was developed. This tool connects to a server running within the network and sends data packets, calculating the throughput based on the number of packets received within a sending time period. With this tool the measurement floor plan is imported and allows the user to specify which access point to connect to and specify the start and end locations of a measurement. In the same way the signal level is measured, the user starts the measurement and walks between start and end points of the measurement while the software records the throughput measurement in a data file.

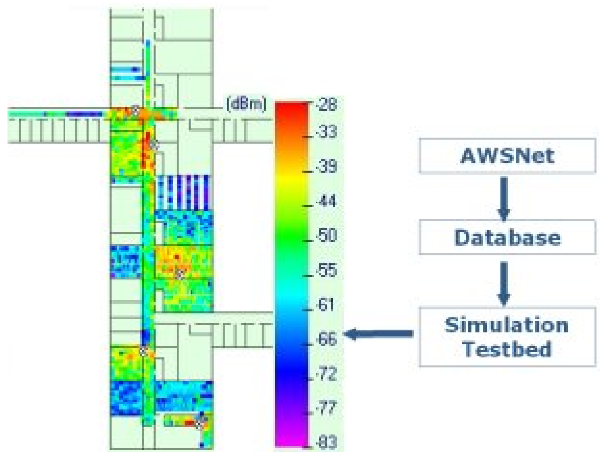


**Figure 13 Results of Signal Level Measurement**

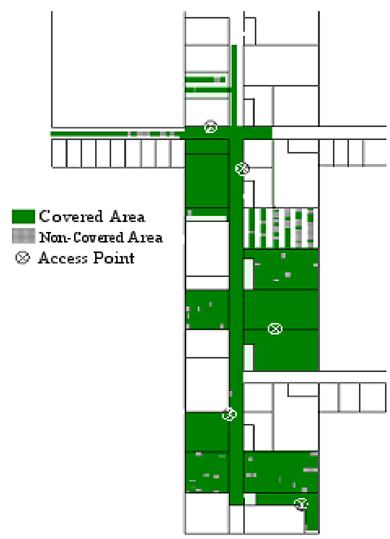


**Figure 14 Successfully Covered Area**

## 7. Results

The results show that the deployed APs satisfy user demands by successfully providing required signal coverage in the evaluated area. Figure 14 presents the successfully covered area, identified by the dark section, of the deployed WLAN. The lighter area indicates places where the required threshold is not met by the WLAN. It can be seen from this figure that the required areas are covered with an acceptable signal level. To further evaluate the deployed WLAN measurement was taken to assess the deployed network capacity based on achievable throughput.

For an IEEE 802.11b the theoretical data transport rate is 11Mbps, however due to the CSMA/CA mechanism used in the MAC layer and management frames used both in physical and data link layer, the effective data throughput of IEEE 802.11b is only 6.5 Mbps [17]. To evaluate the network capacity and usage requirements, the data traffic was classified by three groups Low, Medium and High.

**Table 2 Traffic Requirements Classification IEEE802.11b**

| | Traffic Content | Traffic Load | No of Simultaneous Users/AP |
|---|---|---|---|
| **Low** | Web, Email | 100 kbits/user | **65** |
| **Medium** | Web, Email, File Transfer | 150 kbits/user | **43** |
| **High** | All application via WLAN | 300 kbits/user | **21** |

Using the traffic usage classification referred to in Table 2 the theoretical number of simultaneous users can be calculating by dividing the achievable throughput by the required traffic load. To measured throughput was then used to find the number of simultaneous users that can be satisfied by the WLAN. The resulting analysis presented in Table 3 shows that with low traffic content an average of 52 simultaneous users can be satisfied, in a medium case an average of 35 users can be catered for within the environment and for high traffic content the average number of users that can be supported by the WLAN is 18. These values approach the theoretical values presented in Table 3.

**Table 3 Deployed WLAN Capacities**

| | | Number of Simultaneous Users | | |
|---|---|---|---|---|
| **Avg. Throughput (Mbps)** | | **Low** | **Medium** | **High** |
| **AP1** | **5.10** | 51 | 34 | 17 |
| **AP2** | **5.26** | 53 | 35 | 18 |
| **AP3** | **5.28** | 53 | 35 | 18 |
| **AP4** | **5.23** | 52 | 35 | 17 |

## 8. Conclusion & Future Work

Based on the extensive measurements taken to evaluate the design, it can be seen that the deployed network successfully satisfies user demands in specified areas. The network capacity analysis showed that the suggested solution is sufficient to satisfy various types of network users from basic web browsing to network applications. This also shows that the optimisation technique used to design WLAN performs well and provides an accurate prediction of network coverage within a site-specific scenario as the one described in the case study. This case study shows that the optimisation technique performs well but highlighted other issues when considering AP placement. Thought he current implementation of the optimisation techniques depends greatly on signal coverage, it is believed that by modifying the optimisation fitness function to optimise based on traffic requirements classification as specified in section 7 including traffic content, number of users and to consider influence of people on signal level fluctuations.


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