User Demand based WLAN Design and Optimisation

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***Abstract*— The rapid increase in the use of IEEE 802.11 Wireless Local Area Networks (WLAN) for a diverse range of applications, has introduced an increased complexity into WLAN design, as regards to accurate access point (AP) position assessment, which can severely impact the performance of large scale WLANs. This paper presents two approaches to WLAN design that allows the designer to describe where the WLAN is to be deployed and define the design requirements based on signal coverage and usage. Both methods automatically optimise and suggest a WLAN design that satisfies the user requirements. Both approaches have been implemented and evaluated based on signal coverage and maximum achievable throughput.**

WLAN Design; Optimisation; Evolution Stratagies; WLAN Measurment

I. Introduction

Large Scale WLAN design is a demanding task for the designer when creating a reliable, cost effective, and performing WLAN. There are many elements that need to be considered when undertaking this task, such as technology, required service type, number of users and most importantly the number of APs and their locations. Many of the existing approaches to aid design involve considering some best guess AP positions and the use of a propagation model to estimate the radio signal coverage. This tends to be an iterative process that is continued until it seems that the design provides sufficient coverage [1, 2, 3]. In these approaches a wireless network planner or Wireless Internet Service Provider (WISP) decides on a number of potential AP positions. Combinations of which are evaluated using a propagation model, this continues until the designer is satisfied with the combination. These approaches [1, 2, 3, 4, 5, 6] have a number of drawbacks, the majority depend on signal level prediction for the design. Coverage alone is not sufficient when trying to ensure an efficient and complete design. Although these techniques can accurately predict signal coverage they need to be combined with site specific user demands to achieve optimal number and position of APs. Here, the designer is required to be experienced in WLAN design to suggest possible ideal positions of APs and for much larger environments scalability can become an issue. Although in [7] 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 this paper we present an approach for automatic design for highly customisable WLANs based not only on signal coverage but also on site specific user demands. The paper presents two approaches, firstly optimisation based on signal coverage and secondly, optimisation based on user requirements, such as number of users and their usage demands. Each approach provides a satisfactory design based on the inputs to the optimisation, but as stated signal coverage alone is not sufficient to create a complete design. The paper is organised as follows, Section II describes the optimisation technique employed for WLAN design. The pre-processing required is described and the two approaches to the optimisation are captured within the fitness function. Section III describes a case study that was undertaken to evaluate both approaches. Section IV presents the results of this case study and Section V concludes the paper.

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II. WLAN Design and Optimisation

Evolution Strategies (ES) were employed as the optimisation technique for the WLAN design [8]. ES is an efficient stochastic optimal search method and initial results suggest that it is well suited for WLAN design [9]. To use ES for the purpose of optimisation of AP placement an environment pre-processing technique is also required.

A. Environment Pre-Processing

Pre-processing requires the designer to define the environment where the WLAN will be deployed. This is done by constructing a skeleton of a building - by grouping walls, windows and doors, target areas can be constructed. Following the environment description demand areas are defined that specify where it is desirable to provide radio signal coverage and the necessary usage requirements for those demand areas. This includes specifying the usage requirements, e.g. in terms of average data rate, number of users in that area and signal coverage threshold. Other constraints can be added at this stage such as whether APs can be placed in a specific area. It may also be necessary not to cover a particular area due to safety reasons or interference with other devices, for example in a hospital. The third and final part of pre-processing is the generation of candidate APs. This is done automatically using algorithms based on a Self Growing Neural Gas Algorithm [10]. The main advantage of using this algorithm is that candidate AP positions can be evenly distributed throughout a complex environment, while maintaining desirable AP positions, such as on walls. Each of the candidate APs have a position, a signal coverage map based on a propagation model and a list of its neighbours, which when connected form edges of a graph that is traversed during the optimisation process. The use of this candidate AP grid speeds up the optimisation by reducing the search space. Once the pre-processing is complete the next step is the use of ES to optimise AP positions. In every generation of the optimisation a suggested solution is evaluated using a fitness function. The accuracy of the optimisation is dependent on the validity of the fitness function.

B. Fitness Function

The fitness function (1) consists of weighted elements including the user demand satisfaction *D* which is described later, *A* encourages a solution with the minimum number of APs, *R* ensures the solution considers coverage in restricted areas where required. *B* was introduced into the fitness function in order to encourage an even spread of the signal coverage throughout the environment.

$$F(y) = w_1 D + w_2 A + w_3 R + w_4 B \qquad (1)$$

Where,

- D......................User Demand Satisfaction
- A......................Number of Access Points
- R......................Restricted Area
- B......................Solution Balance
- w_i.....................Weighting Factors

$$\sum_{i=0}^{1} w_i = 1 \qquad (2)$$

Each of the elements are weighted by w_i (2), the sum of which is one, to force the emphasis on a particular element. For example if cost is an issue the designer can have a larger weighting factor on *A* thus encouraging a solution that may sacrifice the user demand satisfaction to ensure a lower number of APs. The most important element of the fitness function is *D,* the user demand satisfaction. Two types of demand satisfaction were investigated and implemented. Initially user demands were based on signal coverage and then were considered based on throughput prediction.

1) Signal Coverage User Demand

For signal coverage a complete coverage map is created based on the selected APs. Using this coverage map, *D* is calculated by $C_r - C_s$, where C_r is the required coverage and C_s (3) is the sum of demand points that are greater than or equal to the required threshold, divided by the total number of demand points.

Where,

- C_r..................Required Coverage (e.g. 90%,100%) (-)
- Cs ....Success Covered (-)

$$C_s = \frac{\sum_{i=0}^{N_{dp}} P_{p_i} \geq P_{d_i}}{N_{dp}} \qquad (3)$$

- P_p..................Signal Power prediction (dBm)
- P_d..................Demand Signal Power (dBm)
- N_{dp} ....Number of Demand points (-)

2) Usage Requirements Coverage

To allow the designer to identify the class of users to be catered for by the WLAN, the usage requirements have been grouped into three types as shown in Table 2. Low identifies users that have a low traffic content of 100 kbits/user for web and email usage, Medium suggests users who have a slightly higher requirement on the WLAN and High indicates the running of all applications via WLAN requiring 300 kbits/user.

TABLE I. USER DEMAND CLASSIFICATION

Type	Traffic Content	Traffic Load (T_{UR})
Low	Web,Email	100 kbits/user
Medium	Web,Email,File Transfer	150 kbits/user
High	All Applications via WLAN (multimedia, VoIP)	300 kbits/user

Subsequent to the demand area requirement definition, *D* is calculated using (4).

$$D = \frac{\sum_{i=0}^{i<N_{da}} T_{r_i} \overline{T_{p_i}}}{\sum_{i=0}^{i<N_{da}} T_{r_i}} \qquad (4)$$

Where,

- N_{da} ....Number of Demand Areas (-)
- N_{user} ....Number of Users (-)
- T_{ur}.................User Throughput Requirement (bit s^{-1})
- T_r ....Total User Requirements (bit s^{-1})
- S_{dp}.................Demand Area Size (m^2)
- T_p..................Throughput Prediction (bit s^{-1})

$$T_r = N_{user} T_{ur} \qquad (5)$$

$$\overline{T_{p_i}} = \frac{1}{S_{da_i}} \sum^{S_{da_i}} T_p \qquad (6)$$

During fitness evaluation, throughput is predicted using signal-to-noise ratio (SNR) (6) generated from the overall coverage map and the number of users already connected to the APs. The overall User Demand Satisfaction *D* is weighted by the required throughput (5) in each demand area.

Due to the consideration of throughput prediction as part of the fitness function and to utilise the implemented ES the format of an Individual in the ES optimisation was extended from that detailed in [9]. An Individual in ES represents a single solution in a population of a generation and consists of the parameters that need to be optimised (*y*), their mutation strengths (*s*) and their fitness function *F(y)*.

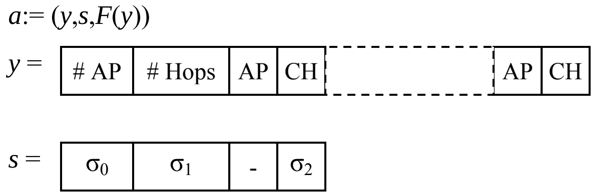

Figure 1 - Individual for AP Placement

Figure 1 shows the structure of the vector *y*, this contains the number of APs required, the number of edges that can be traversed through the candidate AP grid during optimisation, the remaining parameters represent the actual AP position, derived by the combination of the first two parameters and the channel allocated to that AP. The evolvable set *s* represents the mutation strengths used when generating offspring for the next generation of the optimisation. Due to the dependency of the channel on throughput prediction, a mutation strength is also used when generating a channel for a selected AP. With these parameters defined it is then the goal of the fitness function to evaluate if this suggested solution maximises user demands with a minimum number of APs. A case study was undertaken to evaluate the validity of the implemented fitness functions and results are presented in the following.

III. CASE STUDY

We have implemented the design and optimisation approach into a software tool. We used this to generate two optimal designs that satisfy the user requirements within the Department of Electronic Engineering at Cork Institute of Technology. Figure 2 shows the user demands and areas where WLAN coverage is required on one of the floors of the building. The software tool automatically divides the WLAN site into suggested demand areas using a segmentation algorithm. The designer then uses the User Demand Wizard to specify the required constraints on the WLAN design. Firstly, a design was required that allowed for full coverage with an acceptable threshold of -70 dBm in each lab or office. For the second design, the designer indicates the number of users in each office or lab and suggests required usage based on the classifications in Table 1. For example, in Figure 2, 25M indicates that in these areas there will be approximately 25 users with Medium usage (150kbits/user) at any one time.

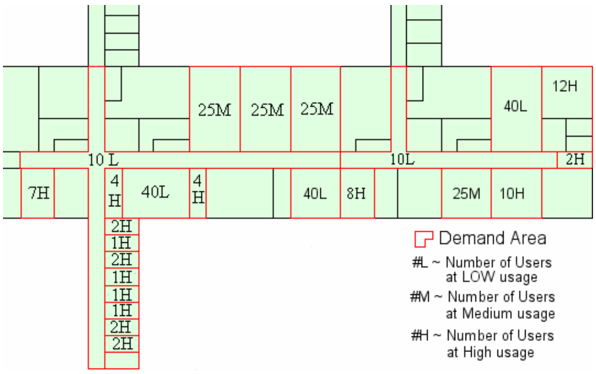

Figure 2 - Case Study Demand Areas

With the area defined and demands specified, both approaches to user demand satisfaction were assessed using the developed software tool. WLAN designs were generated using both methods. The optimisation results based on the fitness function driven by signal coverage threshold are shown in Figure 3. Six APs were suggested to provide the required coverage throughout the environment.

Secondly the optimisation was run using the fitness function that relies on user demand satisfaction and throughput prediction. Figure 4 presents the results of this optimisation study, ten APs were suggested for deployment in order to satisfy the usage requirements.

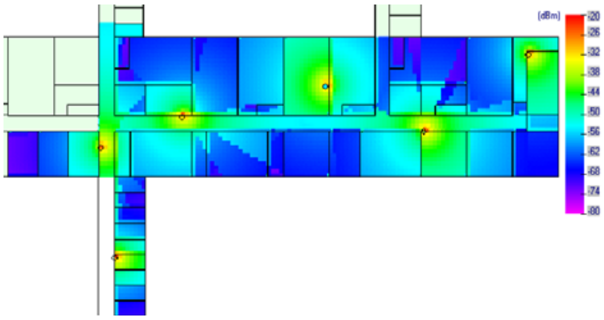

Figure 3 - Optimisation Results based on Signal Coverage

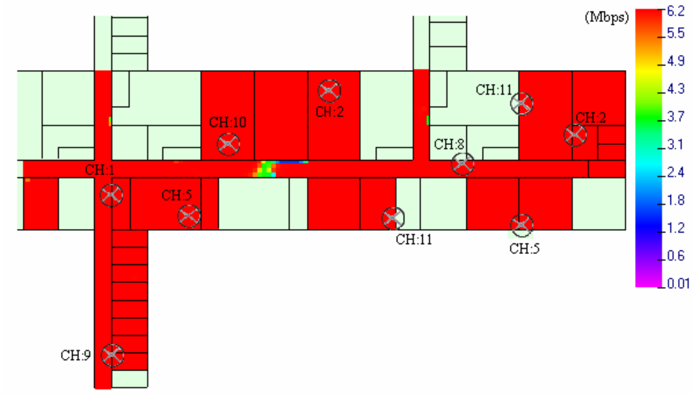

Figure 4 - Optimisation Results based on User Demands

Each of the designs were deployed within the specified environment and using our specifically developed measurement tools, the suggested solutions were evaluated based on signal coverage and throughput. The following section will present the results of the measurements and results of the design evaluation.

IV. RESULTS

In order to evaluate both optimisation approaches the lower section of the environment was analysed. Figure 5 and Figure 6 show the area and position of the APs for each design. Signal Level (SL) Design suggests that two APs are required to cover the specified area whereas Throughput (TP) Design suggests that four APs are required in order to satisfy the data rate requirements for the number of users of the WLAN.

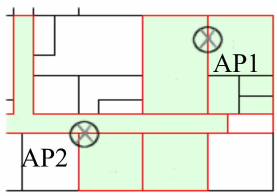

Figure 5 - Signal Level Design Area

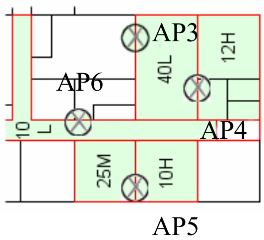

Figure 6 - User Demand Based Design Area

These access points were then deployed in the specified positions and measurements were carried out to evaluate each design. This involved measuring signal coverage and achievable throughput. The results of this measurement will be divided into three parts, Signal Level measurement of a single user, throughput measurement of a single user and finally the Maximum Achievable Throughput per user as clients join the network.

A. Signal Level Measurement(Single Client)

Figure 7 shows the signal coverage for the SL Design. The location of these access points provides adequate signal coverage with an average of -49.61 dBm covering the area. Figure 8 presents the measured signal coverage when the access points were placed as suggested in Figure 6. Again the coverage within the evaluation area is more than adequate to provide signal coverage to every user within the area with an average of -42.34 dBm. It is clear from the signal level measurement that both designs provide sufficient coverage to all users by meeting the defined threshold.

The next step was to evaluate the achievable throughput and provide some indication of the number of users that can be accommodated by both designs.

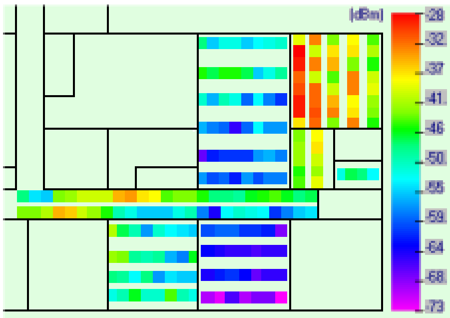

Figure 7 - Signal Coverage SL Design

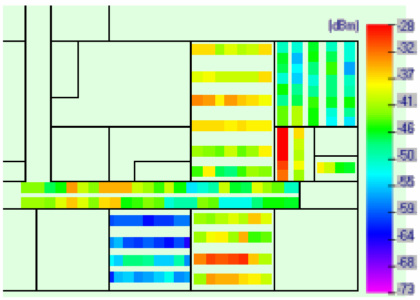

Figure 8 - Signal Coverage TP Design

B. Throughput Measuremen(Single Client)

Throughput measurements were carried out in the same areas, the results of which can be seen in Figure 9 and Figure 10. To measure throughput, Proxim AP-700 APs with IEEE 802.11b radio access were installed and connected to a power over Ethernet switch. A wireless enabled laptop with an integrated Intel(R) Pro/Wireless 2200BG network adaptor (RTS/CTS enabled) running the measurement client was used to record the throughput. Clients connected to a server on the network and throughput was measured by randomly generating TCP/IP traffic. The measured achievable throughput for a single user can be seen in both figures. The SL design suggests that sufficient throughput (average of 3.75 Mbps) can be attained in the majority of areas except for one where the throughput drops to between 0 and 0.5 Mbps. This is what can be expect as there is signal coverage in all areas.

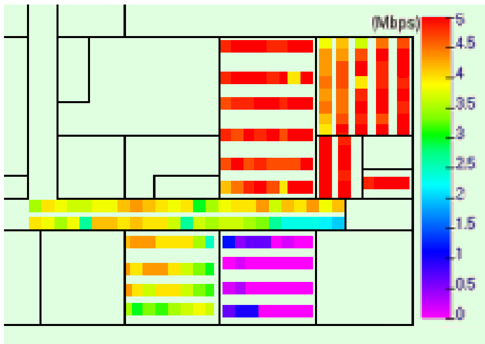

Figure 9-SL Design Throughput Prediction

On the other hand the TP Design provides an average of 4.61 Mbps throughput through out the entire evaluation area. Although both designs provide a satisfactory throughput to a single user in the area we need to evaluate how many users can be supplied with their required throughput.

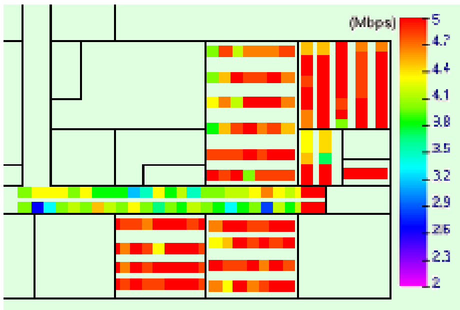

Figure 10 - TP Design Throughput Prediction

Table 2 shows the required throughput versus measured throughput for both designs. The SL Design falls short of providing total coverage to all users within the area because there are only two APs covering the area, with the alternative of four APs every user will be supplied with adequate coverage. The results presented above show that although both designs provide adequate coverage two APs is not sufficient to provide suitable throughput to the number of users required. The average measured throughput for the second design shows that it provides more than satisfactory throughput and coverage to each user.

TABLE II. ACHIEVABLE VS REQUIRED THROUGHPUT

Signal Level Design			
Access Point	***Usage Required***	***Required Throughput (Mbps)***	***Available Throughput (Mbps)***
1	40L+12H	7.6	5.14
2	25M+10H+10L	7.75	2.97
Throughput Design			
3	40L	4	5.11
4	12H	3.6	5.19
5	10H	3	5.19
6	25M+10L	4.75	4.84

C. *Maximum Achivable Throughput (Ten Clients)*

To investigate the impact of users entering the network on achievable throughput, measurements were carried out using a number of laptops each with IEEE 802.11b enabled wireless cards (RTS/CTS enabled). The area where 10 users require High usage was selected for the measurements.

Figure 11 shows the throughput measured for a client that begins on its own in the cell close to the AP and as time passes more clients join the WLAN. Figure 11 shows that between sample seconds 1- 25 there is only one user in the network, at 25 seconds a second client joins the network and the average throughput drops from 5.14 Mbps to 2.4 Mbps. As a third client joins the network (50 seconds) the average throughput again drops from 2.4 Mbps to 1.45 Mbps. When a fourth client joins the WLAN the average throughput per user drops to 0.97 Mbps.

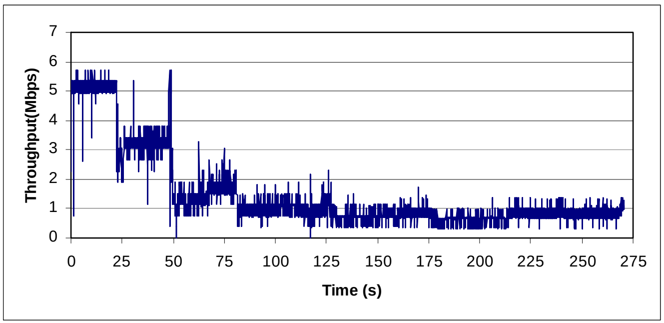

Figure 11 - Achievable Throughput Measurment

As further clients join the WLAN between samples seconds 100 and 275, the drop in throughput is not as dramatic. Between 5 and 10 users the throughput appears to level off (Average 0.72 Mbps). The graph shown in Figure 12 indicates the average achievable throughput per user as up to ten clients join the WLAN. The TP Design performs better after four access points have been added. When over eight clients become part of the WLAN the remaining users could not achieve any reliable throughput and began to drop from the network, explaining the lower achievable throughput at 9 and 10 users for the SL Design.

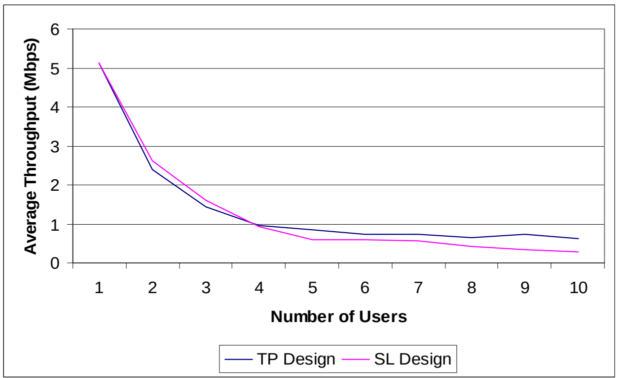

Figure 12 - Average Achievable Throughput per User

The measurements presented above indicate that all 10 users can be provided with there required data rate with all 10 users achieving 0.62 Mbps, twice the required usage of 0.3 Mbps. When 10 users are connected to the WLAN based on SL design, the achievable throughput was 0.29 Mbps. Based on this plus the fact that in the SL Design the considered access point also needs to cover 40 other users at low usage, thus two APs is not sufficient to provide the required data rate.

V. CONCLUSION

This paper presented an extension to our current approach to WLAN optimisation. The original approach provides a design based on signal coverage, although the designer can specify required signal coverage in each demand area, a viable WLAN for all users can not be achieved. In order to overcome this and allow for fast development of WLAN designs, we proposed an extension of the optimisation approach to allow the designer to specify the number of users required through out the specific site and classify there data rate requirements. Once the designer defines requirements for the WLAN the dedicated software optimises access point positions and channel allocation in order to achieve maximum throughput for each user. To evaluate both approaches and to highlight the advantage of the second approach a case study was undertaken. The resulting designs were presented in Section III. The signal coverage approach suggested 6 access points be deployed in order to cover the environment sufficiently, whereas the second approach suggested 10 access points should be deployed in order to achieve maximum coverage but for signal level and throughput per user.

In order to justify such an increase in the number of required access points a measurement campaign was under taken. The results described in Section IV show that both designs provide adequate coverage but the Signal Level design fails to provide sufficient throughput for each user of the WLAN. Therefore the optimisation based on User demand provides an approach that allows the designer to customise their WLAN design to specific user needs and automatically accomplish a reliable and cost effective design.

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