Intelligent radio resource management for IEEE 802.11 WLAN

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Abstract: **IEEE 802.11 based WLANs have been widely deployed. Currently research is concentrating on how to find the best location for these access points plus tuning their antennas in order to seamlessly cover large areas. With more and more WLAN users, the air interface acts as bottleneck even in high-speed WLAN systems such as IEEE 802.11a. To improve the overall performance of IEEE 802.11 WLAN systems under congestion conditions, an agent-based radio resource management system is proposed that can dynamically change an AP's radio coverage pattern in cooperation with surrounding APs. A low-cost four sector semi-smart antenna array is used for access points. In this paper we present results from a simulation showing system performance. The use of intelligent agents and negotiations for in-door radio resource management is presented and discussed.**

I. INTRODUCTION

IEEE 802.11 standard [1] WLAN products have experienced a dramatic growth in recent years. They offer mobility and are especially appropriate for temporary configurations like conferences, or public areas such as an airport (also called public hot spots). In order to provide high bandwidth to users, the standard has evolved to provide high-rate extension of the physical (PHY) layer [1]. The high-rate PHY extension of the direct sequence spread spectrum (DSSS) system (IEEE 802.11b) operates on the 2.4 GHz industrial, scientific and medical (ISM) band and builds on the data rate capabilities to provide 5.5 and 11 Mbit/s payload data rates in addition to the 1 and 2 Mbit/s. The other selection is the orthogonal frequency-division multiplexing (ODFM) as the basis for the new 5GHz standard (IEEE 802.11a), targeting a range of data rates from 6 up to 54 Mbit/s. The latest PHY extension IEEE 802.11g using ODFM delivers data up to 54 Mbit/s and operates at the 2.4 GHz band the same as IEEE 802.11b.

In a WLAN the medium access control (MAC) protocol is the main element for determining the efficiency in sharing the limited communication bandwidth of the wireless channel. The MAC layer has two sub-layers: basic distributed coordination function (DCF) and additional point coordination function (PCF). The DCF is mandatory for all WLAN devices and is based on a multiple access spread spectrum scheme called CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance), which supports best effort delivery of packets and allows multiple users fairly to share a common air channel.

For 802.11b based products, the maximum data rate is 11 Mbit/s, but with the effect of overall MAC and PHY layer overheads, the net throughput is only 47% of 11 Mbit/s. For 802.11a a net throughput of 55% at 54 Mbit/s has been observed [4]. The capacity of WLANs is adequate for home or small office light usage, but for public installations, with more users and heavier application demand, WLAN users will experience lower throughput and longer delay due to the congestion in the air interface. The reason is that all the WLAN stations have to share the limited bandwidth if they all associate to the same Access Point (AP). One way of expanding the WLAN system capacity is to mount more APs in the heavily loaded area, but this method is an expensive approach because it requires extra site surveys with accurate design to minimise interference between APs and occurrence of dead spots. Moreover, this approach cannot cope with a dynamic environment when the geographically distributed congestion varies frequently (this usually happens in public areas such as in an airport where WLAN users tend to gather into a certain area to wait for a flight thus forming a temporary hot-spot). Based on experience [5] of load balancing CDMA systems, we propose a dynamic, distributed intelligent agent controlled WLAN system to cope with congestion conditions and performing automatic load balancing.

II. THE CONCEPT AND THE PROPOSED 4-SECTOR ARRAY ANTENNA FOR WLAN

In a cellular system, radio resources are reused after a certain distance. The whole area is divided up into a number of small cells, with one base station giving radio coverage for each cell. In the most common usage, the antennas' power control is fixed so that each base station's radio coverage is static. Previous work on 3G mobile networks [5] has developed a dynamic distributed agent-controlled system to change the coverage patterns of the cells according to the geographical traffic load. The formation of cells is based upon call traffic needs. Capacity in a heavily loaded cell can be increased by contracting the antenna pattern around the source of peak traffic and expanding adjacent antenna pattern to fill in the coverage loss. So far, the studies only concentrate on out-door usage (ideal free space radio propagation model) and static user traffic demand.

For WLAN systems, the "cell" concept can still be used to represent the Access Point layout. In public WLANs, APs' coverage areas are always laid out as cells just like those of cellular systems (there are non-overlapping radio channels to be used for adjacent cells for WLANs operating operate at 2.4 and 5GHz). Multiple APs can cover a wider area seamlessly; some areas are covered by more than one channel from different APs to support WLAN Station (STA) cross-AP mobility. The most common antennas used in WLAN AP are omni-directional diverse antennas, which apply a circular shape coverage area. In order to achieve more controllable radio coverage patterns, we propose 4-sector semi-smart array antenna for APs. Each sector will have individual power control (changing the relative power transmitted to or received from the sectors: which is straightforward and cheap to implement), thus the combination of four sector antennas will give an AP the ability to produce flexible radio coverage patterns (Fig. 1, 2). The four sector antenna patterns add to give the overall cell coverage pattern.

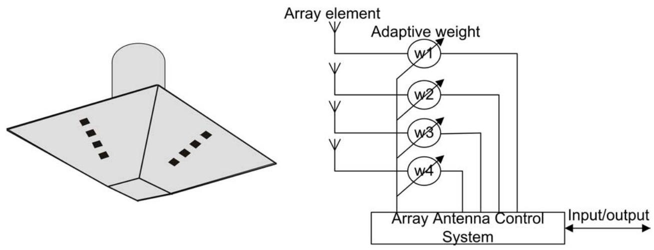


Figure 1. The appearance and working diagram of the four-sector ceiling mounted antenna array.

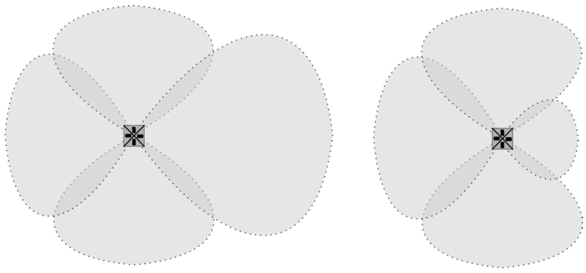


Figure 2. Coverage patterns of the antenna sectors with different power control

The choice of a four sector antenna array is a compromise between performance and cost. More sectors will increase the flexibility of coverage shaping but has disadvantages:

- More RF power controllers are needed.
- Each sector needs a narrower antenna pattern, so that each sector antenna needs to be physically bigger.

Another branch of research tries to utilise fully adaptive smart antennas to trace signal Direction of Arrival (DOA) and then synthesise the antenna pattern towards the desired user, thus minimizing the interference, providing spatial re-use, and hence increasing capacity [6]. However, with the fully-spread, largely multipath-influenced indoor channel, multiple user interference and with the computational limitation of DSP technology, the performance is not ideal [7] [8].

III. The Agent Approach

Intelligent Agent and Multi-Agent Systems (MAS) have been widely used in cooperative environments like e-commerce, distributed AI and new IP routing protocols [9] [10]. They have also been proposed for resource management of CDMA cellular networks [11]. The advantage of the MAS is that it provides a distributed, robust platform that allows agents to act both individually and cooperatively. Within our WLAN simulation, these agents are AP agents and antenna agents; they all have their own initiative and co-operation ability (Fig. 3).

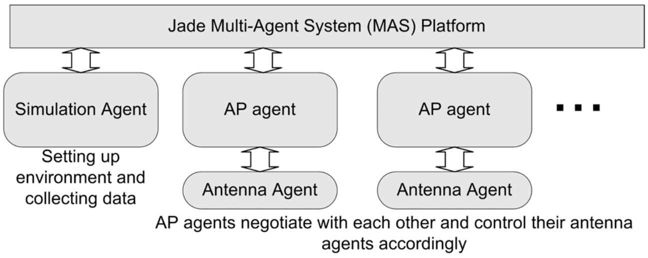


Figure 3. The multiple agent simulation system

The AP agents can talk to each other through the MAS platform and change the radio coverage patterns through the Antenna Agents according to the geographical load distribution. The Simulation Agent initialises the simulation environment, provides the program interface, and collects the resulting data. It also acts as a directory facilitator to allow AP Agents to find their neighbours.

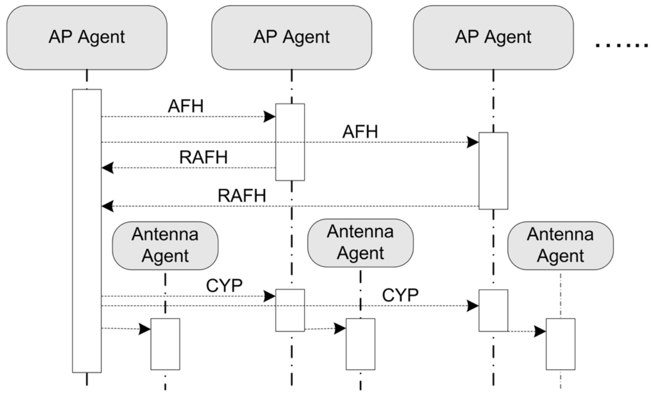


Figure 4. The basic negotiation sequence diagram.

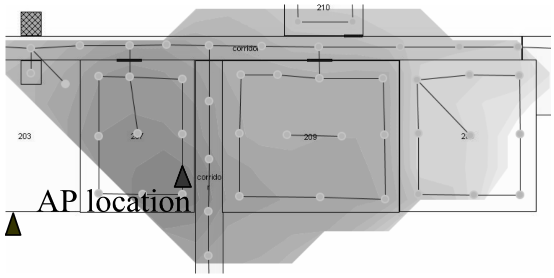
The basic negotiation process for WLAN resource management is shown in Fig. 4. Each AP agent monitors its own traffic load in real time; when the overall traffic load is over a certain threshold (we have used 95% of the maximum data rate supported by the AP), a negotiation procedure will be triggered. The overloaded AP agent will first create some hypotheses that could reduce its own traffic load by reducing some of the antenna sectors' power. As a consequence of reducing its own coverage area, the AP needs adjacent APs to enlarge their coverage pattern to cover this loss. The result will cause some of the client stations to handover to the lighter loaded APs, thus achieving load balancing. These hypotheses will be evaluated by the AP agent according to the disturbance caused to the AP (more antenna power change will cause more disturbance); in the mean time, a set of AFH (Ask For Help) messages will be created and sent by the AP agent to adjacent APs. Each hypothesis could have one or more AFHs because it could need more than one neighbouring AP to help. After evaluating the AFHs, these helper APs will send back RAFH (Reply AFH) messages along with a price if they could help. When it has collected enough responses, the heavy-loaded AP chooses the most suitable hypothesis (causing least disturbance to the whole system) and sends CYC (Change Your Pattern) messages to finalise the whole negotiation process. All affected APs change the radio coverage patterns simultaneously to make sure of continuous coverage. In order to maintain the whole system stability, all the messages are carefully designed to reduce the communication load and message loops are checked to avoid deadlock.

The direct result of negotiation leads to the mutual changing of radio coverage patterns by related APs. The client stations located in the proposed handover area will experience a decrease of radio signal strength from the heavy loaded AP and an increase from the helper AP. In the 802.11 MAC standards, the station scans for all available radio channels and tries to associate/re-associate to the AP that provides the best signal strength and quality [12]. It first disassociates from the currently associated AP, and then initiates the association process to the AP with “better” signal. The handover processes of these stations can be achieved as expected. Most WLAN vendors’ products already support seamless hand-over (although handover is not yet part of the IEEE published standard) so that the IP layer connection will stay on during the whole handover process. For the whole system’s point of view, the traffic load is balanced and stations in the congested area will then experience better link quality (higher data rate and less delay).

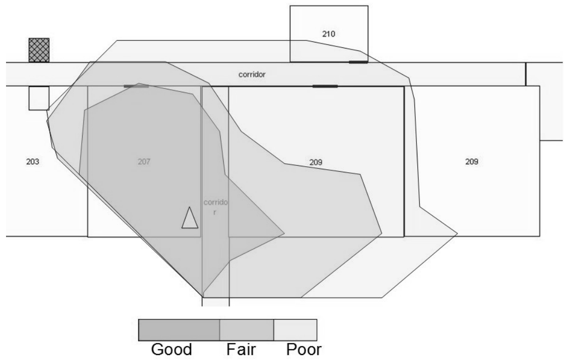
The AP agent needs to know its own geographic radio coverage pattern as the basis for negotiation. We are using a site-survey and machine-learning based technique to find the AP’s radio propagation in an in-door environment. The site survey uses the Ekahau positioning engine [13]; this is also used to track the location of individual STAs.

This process involves the following steps (Fig. 5):

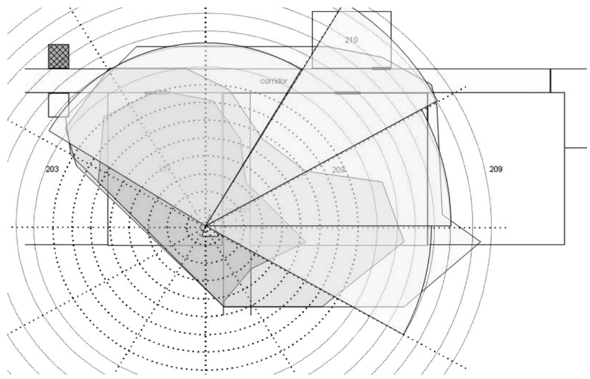
- Select sample points to cover the area of interest; these points can be randomly selected but more sample points will increase the resolution and accuracy of the radio coverage pattern generated. The first diagram in the figure shows these sample points are distributed (normally spaced several metres apart from each other) in part of our department.
- Use the 802.11 client to record the signal strength at each sample point under maximum and minimum power control of all AP antenna sectors. These raw data will be input to the agent system to help to calculate the radio patterns. The first two diagrams in Fig. 5 show how the signal strength is recorded and then converted to contours.
- A generalized radio coverage pattern will be produced. By mapping this to polar coordinates, we can represent simplified patterns in our agent system, making the complex radio coverage patterns mathematically easier to handle. This is important because the agents need to have a simple mathematical model in order to reduce the amount of computational complexity.



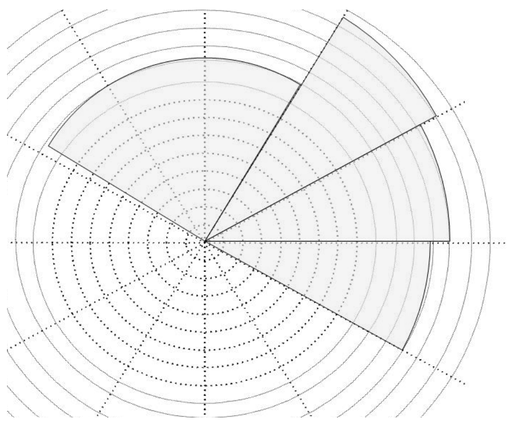
1. Measuring at sample points.



2. The generalised radio coverage pattern.



3. Applying the polar coordinates.



4. The final representation of the radio coverage area in the agent’s knowledge.

Figure 5. Polar coordinate representation of radio coverage pattern (only half circle of the radio coverage pattern to show the concept).

In the polar-coordinate representation of radio patterns, the smallest division is called the Quantisation Cell (QC); each QC area can contain many WLAN user stations. As stated before, when the AP reaches an over-loaded state, it produces a series of hypotheses that will abandon a number of QCs by changing the power control of the antenna sectors. The AP knows how much traffic will be shifted ***L*** with this hypothesis:

$$L = \sum_{Sectors} \sum_{QCs} \sum_{STAs} T_{STA} \tag{1}$$

where T_{STA} is the current traffic load of a WLAN user station.

As most WLAN systems are indoors, the free space radio exponential propagation model fails to represent the actual radio propagation characteristic because of severe multi-path effects. Experimental work has been published [14] showing that signal strength can dramatically change for a distance of as little as a single wavelength. Even worse, the radio propagation is site-specific (affected by layout of building structure, building material etc). In addition to our measured model of radio propagation, the calculation of the signal strength between sample-points utilises the in-door log-distance path loss model described in [15].

$$PL(dB) = PL(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \tag{2}$$

Here the value of n depends on the frequency used and the surroundings and building type, and X_σ represents a normal random variable in dB having a standard deviation of σ dB. With a 802.11b WLAN that uses the 2.4 GHz ISM band and a typical in-door building, the path loss propagation model (2) can be written as (3) [16].

$$PL(dB) = 40 + 35\log D + X_\sigma \tag{3}$$

where D is the distance between the transmitter and receiver.

To summarize our proposed approach of modelling, the in-door propagation model has two steps:

a) Select a series of sample points and measuring the signal strength using a WLAN client card (it actually records the Radio Signal Strength Indication (RSSI) parameter available in the PHY layer).
b) The rest of the area is calculated from these samples by using the indoor propagation model (3).

Every AP agent uses this mixed method to model its own surrounding area and the resulting model acts as the base knowledge for negotiation and changing its radio patterns. Through machine learning, the AP agent gradually improves the propagation model and even observes the longer-term effects. A good example is that aggregation of people can affect radio propagation and in a public area (like an airport), the distribution of people flow is time dependent (such as queues at different check-in counters). By observing this effect, the AP agent can adapt its propagation model accordingly.

As noted earlier, the location of the WLAN clients can be achieved by using the Ekahau WLAN positioning engine, which uses a patented probability method to estimate the user's location according to the signal strength received at a normal WLAN card. The overall accuracy can be up to few metres and is acceptable for our purposes. An alternative method that uses GPS requires extra equipment and has limitations indoors.

IV. THE SIMULATION:

Based on the system we have described, an agent-based WLAN radio resource management simulation system was developed. Client stations are distributed across the whole area and a hot spot is generated to test the efficiency of the negotiation process. The simulation has the following assumptions:

- 16 APs laid out on a 4*4 hexagonal pattern (similar to a cellular system), so one AP can have up to six neighbours. The maximum data rate for each AP is set to 11 Mbit/s.
- 96 client stations are normally distributed to produce a hot spot centred at AP 5.
- Each client station has static or dynamic data demand. The simulation results for the two settings are evaluated individually.
- Radio propagation characteristics and coverage area for each AP comes from setup file; it mimics the actual system where a site survey phase with sampling would produce the data.
- The client stations are presumed to always associate to the AP with the strongest signal strength.

The simulation uses Java and the Jade [17] Agent platform. With fully distributed MAS support, the whole system can be easily adapted to multiple machines where each machine represents an individual AP agent. The messages used in the system are based on FIPA ACL message [18]. With addition of Ontology [18] content language support, the negotiation protocols are scaleable and easy to use.

Two results (Fig. 6, 7) show dynamic changing of the radio coverage pattern according to the distribution of the users and their data demand dramatically increases the overall WLAN system performance.

One result was simulated under random data demand (each station's demand is between 0 and 2 Mbit/s); the other result is under fixed data demand. The random user demand simulates multiple users having different data rate applications (such as browsing WWW, Email, FTP downloading, Stream Audio and Video). For the static demand simulation, an average of 1.1 MBit/s data rate (which is adequate for most user applications) was set for all user stations.

Both scenarios show that with the load balancing, the data traffic in congested "hot spot" areas can be effectively balanced. The radio coverage patterns of APs around the "hot spot" area after the result of negotiation for the random data scenario can be seen in Fig. 8. It shows how the overloaded AP shrinks its own coverage pattern and the other APs enlarge theirs to help.

We have done 20 independent simulations with different random seeds for each data point shown in the figures and the confidence bars are shown on the results.

Both sets of show that as the number of users (and hence the load) increases, the data rate (expressed here as load/demand) available to users decreases. However, with dynamic agent-based radio pattern control, the congested APs negotiate and co-operatively change their radio propagation patterns. The performance is very much better than the system without dynamic radio control, with the full demand being satisfied for a greater number of users, in fact almost double the number of users can be served at full capacity.

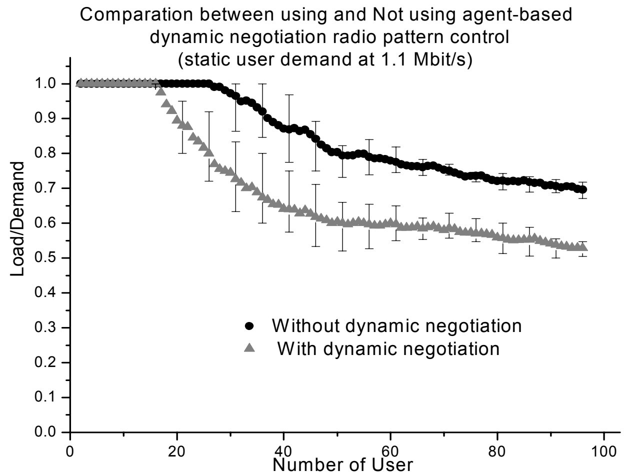


Figure 6. Simulation result of using static user demand.

Both results show the limits of results produced from the different random seeds as confidence bars with the curves being the average across all results. However, Fig. 7 additionally shows the result from a single set of results – this demonstrates that the improvement for the average and for this single result is substantially the same.

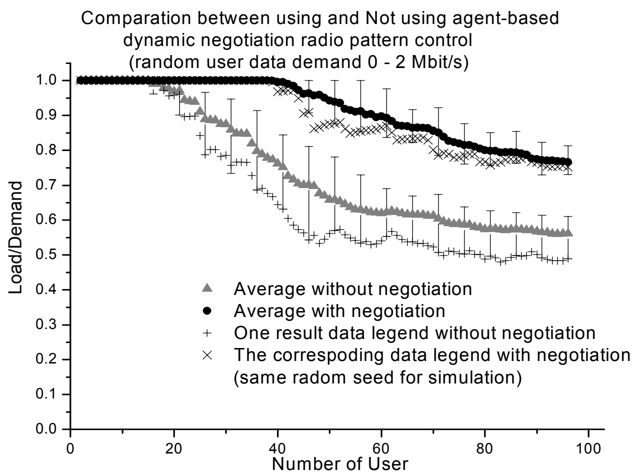


Figure 7. Simulation result of using variable user demand

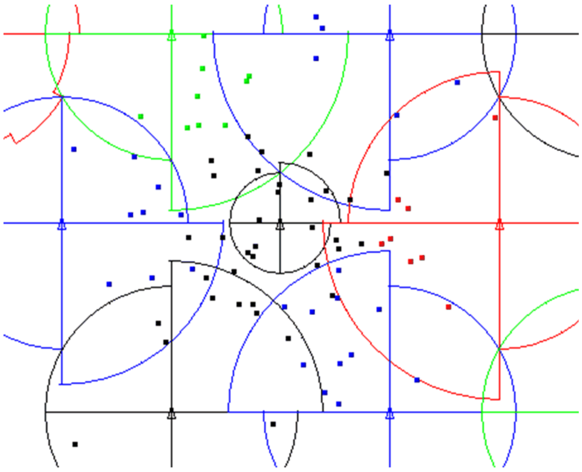


Figure 8. Screen shot of part of the simulation GUI

Fig. 9 shows the result using a different representation: this time plotting the improvement against number of users. That immediately shows an improvement of the order of 40% in terms of the maximum benefit. However, that figure shows other features:

- The system can handle approximately double the number of users at full capacity, i.e. with the carried load being the same as the demand.
- With greater congestion the system cannot carry all the demand, but the improvement continues to increase.
- As the congestion grows the benefit will naturally start to tail off, since there is only a finite capacity available and even better distribution of that capacity will not be able to cope with unlimited demand

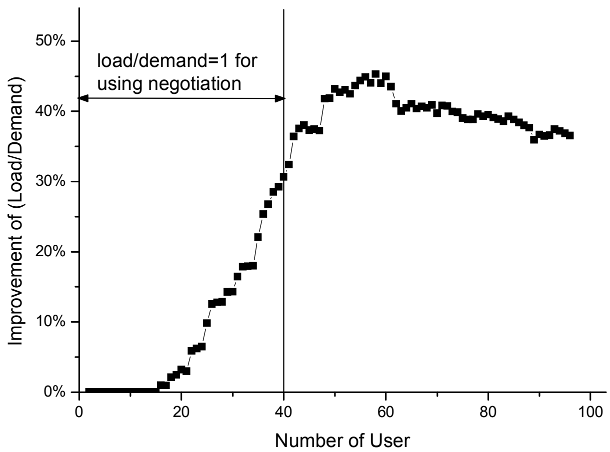


Figure 9. Improvement obtained with negotiation

Our Java based simulation guarantees smooth transfer to a real system. Real traffic load can be monitored through SNMP [19] accessing the MIB of the AP. The MIB II [20] defines parameters that can be monitored and controlled for IP layer network management and most network devices (including APs from common vendors) offer a public interface to it. By monitoring *Total Transmitted Counter* and *Total Received*

Counter (in bytes) against system time passed, the AP agent can calculate the real time traffic load and thus know the system is congested. Furthermore, by accessing the 802.11 MIB [1], an AP agent can have in-depth knowledge of traffic conditions of its hosted AP. This includes *TransmittedFragmentCount* and *ReceivedFragmentCount* (through with the MAC layer traffic condition can be estimated), *FailedCount,* which increments when the number of transmission attempts has been exceeded (it is normal for this counter to rise with increasing load on a particular BSS so that it could also be used for our purpose). Other relevant parameters are *RetryCount, FCSErrorCount* and *FrameDuplicateCount*.

The current simulation is based on IEEE 802.11b; for higher speed WLAN system such as 801.11a and 802.11g, agents can still be used to manage radio resources in the similar manor as the IEEE 802.11 family shares the same MAC layer standard. Current research involves refining the simulation under different WLAN standards and transforming simulation codes to actual embedded system.

V. CONCLUSION

We have proposed an agent-based radio resource management system using negotiations for WLANs, especially those covering relatively large public areas, such as airports. It uses site-survey and machine-learning based technique to represent the radio coverage patterns in the agent system. A low cost four-sector array semi-smart antenna for the Access Point is designed to achieve a certain level of flexibility to control the radio propagation pattern.

With the carefully designed negotiation of AP agents running on the Multiple Agent Platform, the agent controlled system can dynamically change the power from the semi-smart antennas to produce coverage patterns that dynamically adjust to cope with congested areas. The system's traffic load can be balanced at a certain level and users in those congested area will experience better performance (in terms of data rate and delay) than a traditional WLAN system with static AP antenna power control.

The simulation results presented show that the performance gains are significant.

ACKNOWLEDGEMENT

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