Femtocell Resource Allocation to Maximize Performance in Mobile WiMAX Systems

Yee Ming Chen[1*], Chun-Ta Lin[2], Shang-Hsuan Lee[3]

[1,3]Department of Industrial Engineering and Management Yuan Ze University, Taoyuan, Taiwan, Republic of China

[2]Department of Information Management, Yu-Da University, Miao-li, Taiwan, ROC

chenyeeming@saturn.yzu.edu.tw[1*]

Abstract- **Femtocell is one of the promising technologies for improving service quality and data rate of indoor users. Even though femtocell can provide improved home coverage and throughput for indoor users, it causes interference to WiMAX macrocell users when femtocell uses the same frequency band of macrocell. To reduce the interference between existing WiMAX and femtocell, it is needed to analyze the characteristic of macrocell and femtocell considering various interference scenarios. In this paper, we develop an analytical model of femtocell resource allocation based on WiMAX femtocell network. Further, it employs genetic algorithm to dynamic channel allocation to maximize signal-to-interference-plus-noise ratio (SIN) in a near-optimal fashion.**

Keywords- WiMAX; Femtocell; SINR; Genetic Algorithm; QoS

I. INTRODUCTION

Macrocell networks currently used have drawbacks that the users are far from macrocell and the users in indoor undergo poor service relative to the others. Femtocells are capable of providing services in shadowed areas of the WiMAX macrocell (cell coverage enhancement) and can relieve traffic from the macrocell networks, reduce infrastructure costs for the network operators, provide high-data-rate services to the users in a cost-effective manner and at the same time, enhance network capacity. In this regard, femtocells are considered as a promising option for the home base stations to improve the cell coverage, especially in the interiors of houses and buildings and to provide ubiquitous high speed connectivity to the end users or User Equipments (UEs). Femtocells or Femto Access Points (FAPs) are small, short-ranged (10~30 m) low powered (10~100 mW) access points developed to provide cost-effective and high-bandwidth services [1]. One of the main advantages of femtocell deployment is the improvement of indoor coverage where macrocell base station (referred to as MBS) signal is weak. Femtocells provide high data rate and improved quality-of-service (QoS) to the subscribers. It also lengthens the battery life of the mobile phones since the mobile phones do not need to communicate with a distant macrocell base station. Femtocells can easily be deployed by the end users in indoor environments on a “plug-and-play” basis. As femtocell networks are user-deployed without proper network planning, their interference environment tends to be much more complicated than the traditional cellular networks. Thus, interference problems in femtocell networks cannot be handled by existing schemes typically used for macrocell deployments [2]. In addition to the increased user throughput from short ranges, the smaller size of femtocells increases the system capacity by enabling spatial reuse. This allows broadband access service providers to (1) improve coverage and service quality, (2) effectively balance load by offloading traffic from macrocell to femtocells, and (3) reduce operational expenses and subscriber hand off.

The scope of this paper is hence to examine how users in WiMAX macrocell networks with femtocell resource allocation can share the available radio resources efficiently in order to mitigate co-channel interference and thus enhance the signal-to-interference-plus-noise ratio (SINR) of the networks. This article also proposed genetic algorithm (GA) heuristic approach on a prototype WiMAX femtocell network testbed and show that it assigns channels to interfering femtocells in a near-optimal fashion.

The rest of this paper is organized as follows. Section II provides the background and related WiMAX femtocell research. Section III describes the system model and path loss models. Femtocell resource allocation using genetic algorithm presented in Section IV. In Section V, a prototype WiMAX femtocell network tested and showed its simulation results. Finally, we conclude in Section VI.

II. BACKGROUND AND RELATED WORK

In this section, we describe relevant related work. We then provide a brief background on WiMAX femtocell systems.

Mobile WiMAX (Worldwide Interoperability for Microwave Access) based on IEEE 802.16 standard has been commercialized in 2006 with rapid growth of various multimedia applications [3, 4]. WiMAX uses OFDMA (Orthogonal Frequency Division Multiple Access) as multi-access technique [5], where different users are allocated to different subsets of sub-carriers called sub-channels. This fact introduces the possibility of using frequency allocation techniques. In current mobile communication systems, the signal strength transmitted from base station (BS) can be very low in indoor environments because the signal strength may be severely attenuated when it penetrates the obstacles such as walls. Thus, providing high data rate services to indoor users is difficult only in mobile WiMAX systems. To improve indoor (home or small office) user’s signal strength, which is usually attenuated through walls, IEEE 802.16m SDD (System Description Document) [6] introduces the “femtocell”. Femtocells are small wireless access points deployed inside buildings and connected to an operator’s network commonly through a digital subscriber line (DSL) connection or fiber. Femtocells Access Points (FAP) are administered by operators and make use of licensed spectrum technology (e.g. WiMAX, LT). In a WiMAX network with both macrocells and femtocells, frequency bands used by macrocells and femtocells are necessarily overlapped, though with distance separation between cells to reduce the degree of interference. How to mitigate the interference between macrocells and high density of femtocells in a WiMAX network is certainly an important issue.

Existing work presents several methods to cope with the interference in a WiMAX femtocell network, such as: radio resource management (e.g. Timeslot, frequency etc.), power control. As in a spectrum allocation solution, carriers (in CDMA) or sub-carriers (in OFDMA) are manually ordynamically arranged to optimally reduce the interference [7]. In solutions with power control, the maximum transmit power of femtocell users is adjusted to suppress the cross-tier interference at a macrocell base station to a fixed or adaptive threshold. Other interference mitigation methods have also been explored, such as access management, femtocell location management, and other solutions such as user assisted coverage and interference optimization [8]. The optimal solutions are difficult to get due to high computational complexity. Instead, suboptimal solutions based on relaxation, problem splitting, or heuristic algorithms have to be proposed to reduce computational complexity [9, 10].

III. WIMAX FEMTOCELLS SYSTEM MODEL

To analyze the performance when femtocells are deployed in mobile WiMAX systems, we consider existing WiMAX and femtocell users as shown in Fig. 1. In this scenario, femtocells are deployed in the centered macrocell 1. The attenuation of transmitted signal, called path loss, can differ according to channel environment (e.g., indoor or outdoor). As path loss models, we apply Wireless World Initiative New Radio (WINNER) II model to evaluate the throughput [11].

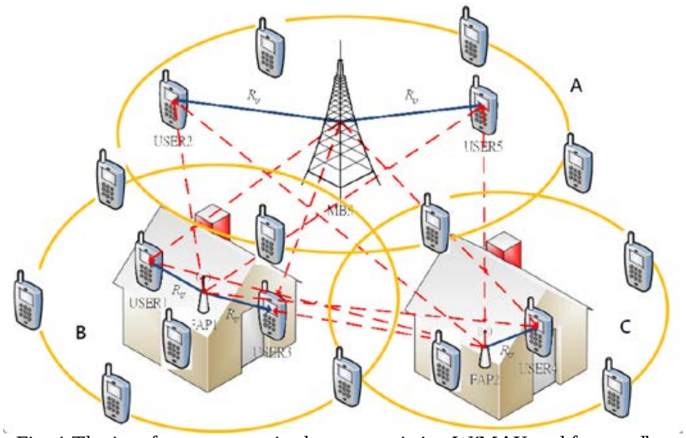

Fig. 1 The interference scenarios between existing WiMAX and femtocell operations

Path loss models for the various WINNER scenarios are typically of the form in equation 1, where d is the distance between the transmitter and the receiver in [m], fe is the system frequency in [GHz], the fitting parameter A includes the path loss exponent, parameter B is the constant term, parameter C describes the path loss frequency dependence, and X is an optional, environment specific term.

$$PL(d) = A \cdot \log_{10}(d) + B + C \cdot \log_{10}\left(\frac{fe}{5}\right) + X \tag{1}$$

There are several interference path loss cases in femtocell-to-femtocell and femtocell-to-WiMAX MBS. The interference path loss can be divided in the following cases which illustrated in Fig.1

B, C cases: indoor-to-indoor interference.

A-B, A-C cases: outdoor-to-indoor interference.

B-A, C-A cases: indoor-to-outdoor interference.

B-C case: indoor-to-outdoor-to-indoor interference.

To calculate the path loss between WiMAX MBS and femtocell UEs, we use non-line of sight (NLOS) outdoor propagation model. Also, we use NLOS indoor propagation model for calculating path loss between MBS and femtocells. Path loss of the indoor and outdoor signal is given as

$$\begin{aligned} PL_{in\to in}(d) &= 36.8 \cdot \log_{10}(d) + 37.78 \\ PL_{out\to in}(d_{out}, d_{in}) &= PL_b^{out} + 0.5 \cdot d_{in} + 29 \\ PL_{in\to out}(d_{in}, d_{out}) &= PL_b^{in} + 0.5 \cdot d_{in} + 29 \end{aligned} \tag{2}$$

where

$$PL_b^{in} = PL(d_{in}, d_{out})$$
$$PL_b^{out} = PL(d_{out}, d_{in})$$

and

$$\begin{aligned} PL(d_1, d_2) &= 22.7 \cdot \log_{10}(d_1) \\ &-12.5 \cdot \{\max(2.8 - 0.0024 \cdot d_1, 1.84)\} \\ &+10 \cdot \{\max(2.8 - 0.0024 \cdot d_1, 1.84)\} + 19.1 \end{aligned}$$

The equations adopted WINNER and IEEE 802.16j Relay Task Group NLOS path loss models [10] and [11], respectively.The received signal to interference ratio (SIR) is defined as the ratio of a signal power to the interference power. Let p_s^r and I_s^r be strengths of received signal and interference from sender s to receiver r, and M and F be the number of macrocells and femtocells. N is white noise. SINR of user n in the downlink at MBS^i is:

$$SINR_{MBS\ i}^{n} = \frac{P_{MBS\ i}^{n}}{\sum_{j=1}^{F} I_{FAP\ j}^{n} + \sum_{k=1,k\neq i}^{M} I_{MAB\ k}^{n} + N} \tag{3}$$

SINR of user n in the uplink at FAP i is:

$$SINR_{user\ i}^{n} = \frac{P_{user\ i}^{n}}{\sum_{j=1,j\neq i}^{F} I_{user\ i}^{n} + \sum_{k=1}^{M} I_{FAP\ k}^{n} + N} \tag{4}$$

The received SINR is used to calculate channel capacity with the Shannon-Hartley theorem. Channel capacity C is calculated as follows.

$$C = BW \times \log_2(1 + SINR) \tag{5}$$

where BW is channel bandwidth in Hz.

IV. FEMTOCELL RESOURCE ALLOCATION USING GENETIC ALGORITHM

Genetic algorithms are widely used stochastic search algorithm to find solution of complex problems [12]. A general GA uses selection, crossover and mutation operations to generate a new population with better fitness than actual population similarly to natural selection and sexual recombination. Generally, a population is a set of individual and an individual consists of genes. The so called elite individuals are the individuals in a population with best fitness scores. Parents are individuals of the actual population whereas children are the individuals of the new generated population. The evolution of the population takes place following the general GA principles through tournament selection, crossover and mutation. In addition, other genetic operators and techniques can be used to improve the performance of the GA, such as Elitism, It is implemented so that the best solution of every generation is copied to the next so that the possibility of its destruction through a genetic operator is eliminated. The flow chart of Fig. 2 describes the main steps of the GA procedure. The contents of the blocks in the flow chart are explained in greater details in the next paragraphs.

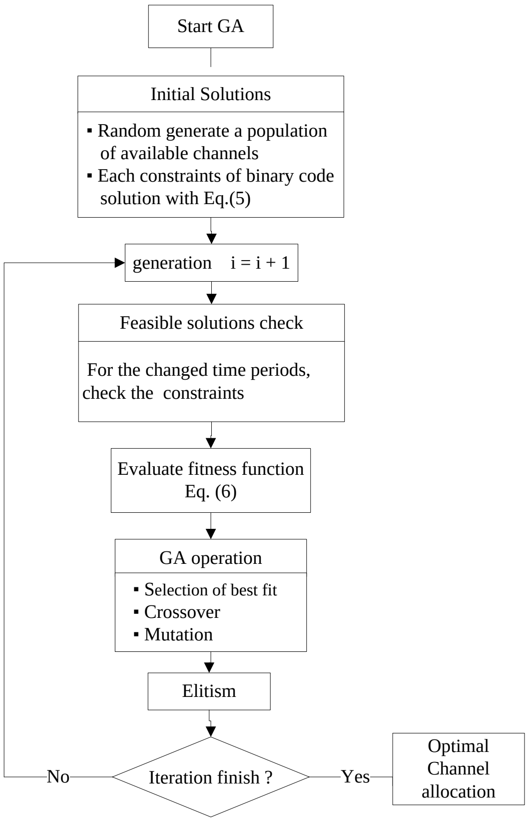

Fig. 2 The GA procedure for WiMAX femtocell channel allocation

A. Initial Solution

As it can be seen from the Fig. 2, an initial population is randomly generated. The population size can be designed by the user. The population is formed so that there are 12 individuals represented as vectors. The length of each of the individuals is the same as the number of FAPs connected to the network. The i-th value in the vector gives the frequency channel that MBS is using

B. Evaluation

A WiMAX femtocell channel allocation has basically two characteristics. Firstly, the average signal-to-interference-and-noise ratio, SINR that FAPs receive must be as high as possible. This reflects the overall performance of the network. On the other hand, the minimum SINR requirement for all the users must be met. The fitness function in this case has the following form:

$$\text{fitness} = \text{SINR} + \text{penalty} + \text{jitter} \tag{6}$$

where SINR is derived from (3) and (4), penalty decreases the fitness if some FAPs experience a SINR that is lower than 9 dBm (In this case the minimum requirement is set at SINR = 9 dB.), and jitter adds randomness. The penalty and jitter, respectively, are calculated with the following formulas [13]:

$$\text{penalty} = -5 \times (9 - \min(9, \min(\text{SINR}))) \tag{7}$$

$$\text{jitter} = \left(\frac{10}{\#G+1}\right) \times \text{U} \tag{8}$$

where #G is the order number of the corresponding generation, and U is a random number from a uniform distribution between 0 and 1.

C. Selection

Evaluation of the fitness criterion to choose which individuals from a population will go on to reproduce. Some general methods used are Roulette Wheel Selection and Tournament Selection. For this purpose, the chromosomes can be arranged in their increasing order of fitness values and the first half can be selected.

D. Crossover

Once a portion of the population has been selected, the number of chromosomes in the initial population decreases. But the population size must be maintained throughout. For this purpose, pick two chromosome parents from the current generation to create chromosome children for the next generation; parents can be chosen with equal probability; randomly obtain a crossover point for the parents; the parents are split into two parts, one child chromosome consists of the first part of the first parent and the second part of the other, while the other child chromosome consisting of the second part of the first parent and the first of the other; generate crossover children chromosomes for the next generation. For example, if the two parents had chromosomes: ‘ABCDEFG’ and ‘abcdefg’, single-point crossover would pick a random crossover point, say 5 in this case, and the children: ‘ABCDEfg’ and ‘abcdeFG’ would be generated. These child solutions have inherited genes from both of their parents, and will take their parents’ places in the population. Normally, two parents and a random crossover point, cross point, are selected. A general algorithm for one-point crossover can be shown as:

```
function [child1, child2]=crossover(parent1,parent2,pc);
if(rand<pc)
cross_point=round(rand*(stringlength-2))+1;
child1=[parent1(:,1:cross_point)
        parent2(:,cross_point+1:stringlength)];
child2=[parent2(:,1:cross_point)
        parent1(:,cross_point+1:stringlength)];
child1(:,stringlength+1)=fun(child1(:,stringlength+1));
child2(:,stringlength+1)=fun(child2(:,stringlength+1));
else
child1=parent1;
child2=parent2;
end
end
```

At *cross point*, the two chromosomes are split. Then the first part of parent1 and second half of parent2 form the first child chromosome. Similarly, the second part of parent1 and first part of parent2 form child2. *pc* is the probability of crossover. *Stringlength* represents the length of each chromosome.

E. Mutation

Mutation is carried out for the individuals after the crossover procedure. Mutation is the process where only one parent is involved to form a new chromosome. Some random genes are selected for mutation or change. Usually the probability of mutation is chosen to be less than the probability of crossover. Let *pm* be the probability of mutation; generate mutation children chromosomes for the next generation. A general algorithm for mutation can be shown as:

function [child]=crossover(parent,pm);
if(rand<pm)
mutation_point=round(rand(stringlength-1))+1;*
child=parent;
child[mutation_point]=abs(parent[mpoint]-1);
child(:,stringlength+1)=fun(child(:,stringlength+1));
else
child=parent;
end
end

A mutation point, or mutation_point, is selected as the point where mutation occurs. At that point, 0 changes to 1 and vice versa. The fitness value has to be calculated for the new individuals. Thus a new population will be formed, by maintaining the population size.

F. Elitism

It finds chromosomes with the highest fitness values; copy them into the next generation directly.

These processes take place in an iterative manner. But certain terminating criterions are provided. It could either be the number of iterations, or a particular threshold value that has to be attained, or else the time taken for implementation. When any of these criterions reaches, the iteration automatically stops, and the first chromosome in the current population is selected as the best individual, or as the optimum channel allocation to the problem.

V. RESULTS OF SIMULATION

A. Scenarios Presentation

The simulation model for WiMAX femtocell system has been implemented using MATLAB programming language. For simulation simplicity, a MBS system of two FAPs cells has been considered. All randomly deployed FAP users also operate at the same 2GHz carrier frequency and 5MHz bandwidth as the central MBS, hence qualified as co-channel deployments. In addition, during random femtocell deployments, any two FAPs must be at least 20m apart from each other because each house defines an indoor region with a radius of 10m. An example of co-channel WiMAX femtocell network deployments from the simulation is shown in Fig. 3.

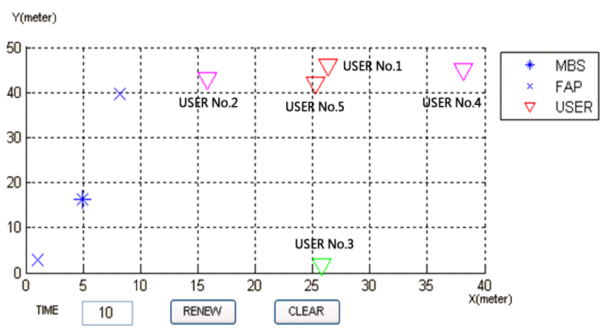

Fig. 3 The femtocell deployments with different users

All users, both indoors and outdoors, have a femtocell identification (i.e. femtoID) indicating the FAP the user owns (but may not necessary be connected to at the moment), or the FAP the user is allowed access.

After a user has selected a FAP to be connected based on the received pilot signal power, FAP will then execute the access control mechanism to determine whether or not to grant access to the requesting user based on the user classification. Currently, the two widely-recognized access control mechanisms are the Closed Access Control (CAC) and the Open access control (OAC). Based on different access control mechanisms deployed, a femtocell user may experience different treatments from the same FAP.

The performance of the GA algorithm optimizes SINR WiMAX femtocell network deployments in each timeslot. Fig. 4 illustrates a series of timeslot of SINR performance in a WiMAX femtocell network.The program was run 10 times to evaluate the results on the basis of an average fitness value. The fitness function represents the SINR in the WiMAX femtocell system. Hence penalty value should be as low as possible and SINR values for each user must be maximized. The Fig. 4 presented shows that the optimum SINR value for user 1 is 280 dB when a co-channel WiMAX femtocell network deployments is considered.

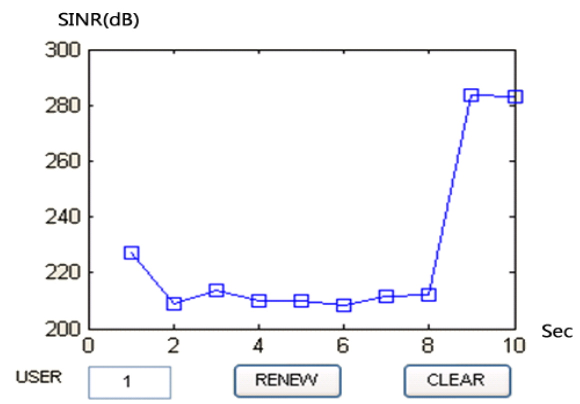

Fig. 4 The maximization SINR performance of WiMAX femtocell network for user 1 in each timeslot

In Fig. 5 how an allocation looks into the WiMAX femtocell network channel resource look. This allocation has been done with 5 FAP users and three channels. The different colour rectangles are adjacent users (due to the proximity of the FAP users that transmit data using different channel). Also it is noticed that Channel 2 also links with femtocell User 2 and 3 as the long distance between user2 and user3 does not cause interference.

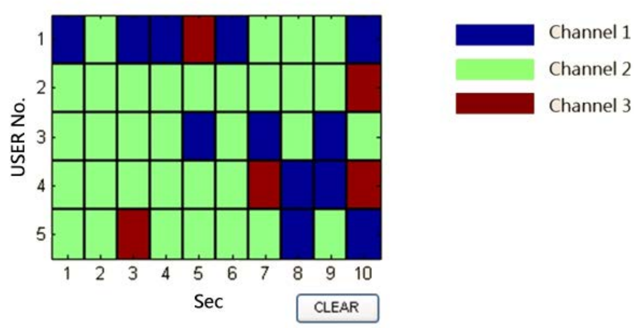

Fig. 5 The femotcell channel allocation

B. *Approaches Numerical Evaluation and Comparison*

This section we studied the scalability of the proposed

WiMAX femtocell network on a Linux machine with a 2.6 GHz CPU and 4 GBytes of RAM. In particular, we evaluated the impact that the number of femotocells, as well as the number of users created inside network, have on both maintaining Quality of Service (QoS) on achievable SINR of a femtocell users. Obtained performance has highlighted that the computational time, as well as the maximization SINR.

$$Max\ sum\_SINR = \sum_{u=1}^{U} SINR_{U_u, channel\_allocation_{U_u}} \tag{7}$$

subject to equation (3), (4) and (5). The defined optimization problem is a typical 0-1 linear problem, which is NP-Complete. In the following section, we proposed the GA procedure and mathematical programming (MP) to solve this problem. As we explained in Section III, solving the goal attainment maximization SINR optimally and consequently comparing the genetic algorithm results against the MP optimal results. Therefore, we try to compare the MP optimal results against the results of the proposed GA approximation to the problem. To do that, we design three experiments to study the effects of the two different methods (MP and the GA approximation) on the objective function value (SINR) and on the computational time (minutes). The computational time reported in this paper, using the GA procedure, is the recorded time that the best solution was found. Figs. 6 and 7 show the objective function values and the computational times of the two indicated methods, respectively. Fig. 6 shows that in three cases (i.e. 20, 50 and 100 users) the SINR value obtained using the genetic algorithm is less than the value obtained by the mathematical programming (MP). Additionally, the SINR is much smaller different for large-scale case.

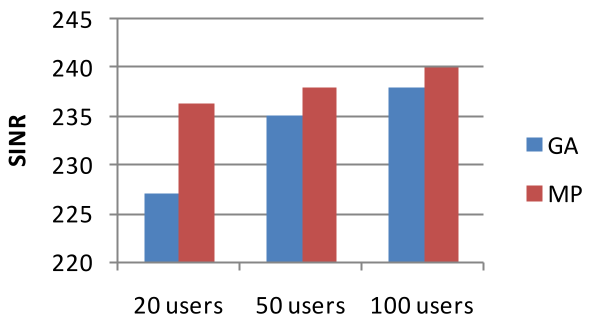

Fig. 6 The sum SINR values (in dB) vs. users and different methods

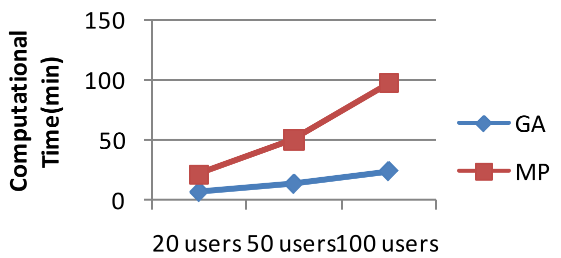

Fig. 7 The computational time (in sec) vs. users and different methods

Fig. 7 shows that the computational time is strongly dependent on the number of users. Additionally, the computational time used by the genetic algorithm is much smaller for large-scale cases.

One can also see that the resulting maximum SINR increases pretty consistently with the time varying. This suggests that the algorithm in each run finds a solution that is close to the global maximum. Getting stuck with local maximums would cause inconsistency in the curve. The number of possible allocations is N×F, where N is the total number of available frequencies, and F is the number of FAPs in the WiMAX femtocell network. Different scenarios, this is different number of FAPs up to 100. Clearly, finding the optimal allocations by going through all the possibilities is difficulty, which justifies the use of more intelligent methods such as genetic algorithms.

VI. CONCLUSIONS

In this paper, we have discussed some of the challenges of introducing femtocells coexistent with current WiMAX macrocell networks. Genetic algorithm also has been used to maximize the network performance and channel allocation. From simulations of WiMAX femtocell network, femtocell performance, and resource allocation, it was confirmed that the proposed approach. The Cognitive access control proposed in this paper is an ideal dynamic resource management mechanism for cellular operators to roll out femtocells autonomously, more works should be done to further improve various aspects, such as fair scheduling etc., of the WiMAX femtocell network.

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Yee Ming Chen is a professor in the Department of Industrial Engineering and Management at Yuan Ze University, where he carries out basic and applied research in agent-based computing. His current research interests include soft computing, sensor networks, and system diagnosis/prognosis.

Chun-Ta Lin is an associate professor in the Department of information Management at Yu-Da University, where he carries out basic and applied research in heuristic optimization and logistics management. His current research interests include cloud computing, supply chain management, and information engineering.

Shang-Hsuan Lee received the B.S. degree in the Department of Industrial Engineering and Management at Yuan Ze University, where he has worked ever as a research assistant, developing Radio Resource Management. Since 2011, he has also been studying for the Master degree at Yuan Ze University. His research interests include cognitive radio network, radio allocation management, and heuristic algorithms.