Interference Avoidance and Dynamic Frequency Planning for WiMAX Femtocells Networks

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Abstract— **Femtocells have been recently proposed as a potential good solution to increase not only indoor radio coverage, but also system capacity. In this paper, a framework for radio coverage prediction and system level simulation for WiMAX macrocell/femtocell scenarios is presented. Furthermore, the feasibility of the co-channel deployment of WiMAX femtocell in an existing WiMAX macrocell network is investigated, and a method for interference avoidance based on *DFP (Dynamic Frequency Planning)* is proposed. The resulting impact of DFP in a macrocell/femtocell scenario compared with other frequency assignment strategies is analyzed. Experimental evaluations carried out using our framework show the boost in the system capacity when using DFP and femtocells.**

I. INTRODUCTION

According to recent surveys [1], in the next years, around 90% of the data services and 60% of the phone calls will take place on indoor environments (e.g. home, office, school). Therefore, indoor coverage, providing high data rates and *QoS (Quality of Service)*, will shortly be needed by the operators. Since macrocell coverage becomes extremely expensive to serve indoor users with large service demands, new solutions for the indoor coverage and capacity problem are required.

One solution to improve indoor coverage is the so-called *FAPs (Femtocell Access Points)* or home base stations [2]. Femtocells are low-power base stations initially designed for indoor usage that allow cellular network service providers to extend indoor coverage where it is limited or unavailable. On one side, femtocells provide radio coverage of a certain cellular network standard, e.g. *GSM, UMTS, WiMAX, LTE*. On the other side, they are connected to the service provider via broadband connection, e.g. *DSL (Digital Subscriber Line)*. Femtocells can also offer other advantages such as new killer applications or high indoor data rates, reduced indoor call costs and savings of phone battery.

It is estimated that by 2012 there could be 70 million UMTS femtocells installed at homes and in offices around the world, serving more than 150 million users [3].

Conversely, several aspects of these femtocells such as the access method or the frequency band allocation still need further investigation before femtocells become widely deployed.

Special attention must be paid to interference avoidance when deploying a femtocells network [4] [5], since it cannot be handled by the operator by using network planning because the number and positions of the femtocells are now unknown.

Femtocells operating in a dedicated and separated frequency band is a possible and optimal solution for the macrocell to femtocell interference avoidance problem and viceversa. However, it will drive the operators to a reduced spectral efficiency usage, which is extremely expensive and undesired. Therefore, femtocells operating in a co-channel frequency band with existing macrocells seems to be a more appropriate, but technically more challenging solution.

A good alternative to the use of UMTS femtocells is WiMAX femtocells due to its multi-subcarrier nature and its interference avoidance characteristics [6].

WiMAX uses *OFDMA (Orthogonal Frequency Division Multiple Access)* as multi-access technique [7], where different users are allocated to different subsets of sub-carriers called sub-channels. This fact introduces the possibility of using frequency assignment techniques, or exploiting multi-user or frequency diversity to significantly improve the system capacity and user experience. These frequency or sub-channel assignment techniques will allow the operator to reduce the overall system interference, and make femtocells more efficient in terms of throughput and QoS.

The aim of this paper is to introduce a simulation framework for OFDMA WiMAX macrocells and femtocells at both radio and system level, in order to test different interference avoidance techniques such as DFP [8].

The rest of the paper is organized as follows: In section II, a WIMAX femtocell deployment tool is introduced, based on radio coverage simulation to compute the received signal and system level simulation to evaluate the users performance. Section III presents a DFP algorithm as interference avoidance technique for WiMAX macrocell and femtocell hybrid scenarios. In section IV, experimental evaluations shows the boost in capacity when using DFP in this kind of scenarios. Finally, in the last section some conclusions are drawn.

II. FEMTOCELL SIMULATION

In this section a simulation and evaluation framework for OFDMA WiMAX macrocells and femtocells is summarized. As explained in the following paragraphs, this simulation tool is comprised of two parts: radio coverage prediction and system level simulation.

A. Radio coverage simulation

Different models have been proposed to perform radio propagation predictions in different environments. Empirical models (Okumura-Hata like) are often used, but suffer from a lack of accuracy when modeling the geometry of the environment for dense urban areas. The propagation conditions in urban areas, where a lot of reflections and diffractions occur, are very different from rural places. Therefore in a real case, the result of the femtocell frequency configuration will be also highly dependant on the environment. Deterministic models taking into account the environment geometry are thus more suitable for this purpose.

Ray tracing like models based on optical geometry are widely used [9], [10], but taking diffraction into account requires the use of the *UTD/GTD (Uniform/General Theory of Diffraction)*, which increases the complexity of the method. To overcome this problems, this paper applies an *FDTD (Finite-Difference Time-Domain)* like model [11]. This approach is typically more accurate but also requires more memory and is more time consuming when computing larger areas. The model, called *MR-FDPF (Multi Resolution Frequency Domain ParFlow)*, is described in [12], and has been implemented in the WIPLAN propagation tool [13]. Unlike Ray Tracing, this model considers all the physical propagation effects, such as reflections and diffractions but without having to restrict the number of such phenomena. The use of such a propagation tool requires an input database containing the environment (obstacles and materials), so the quality of the prediction will depend on the accuracy of this database. On the other hand, operators rarely know the location of all the walls and the exact materials the buildings are constructed of. That is why, in this approach, the outer walls of the buildings are represented using a unique material which corresponds to concrete. This approximation is not a disadvantage, because the simplifications done in the building database can be compensated by a good calibration of the model as seen in [12].

For convenience, the scenario to be used for this study is a part of the town of Luton (UK), which is shown in Fig.1. The macrocell is located in the upper left corner of the environment and the resulting radio coverage is presented in Fig.2.

For the study of femtocells, the simulation is run at the resolution of the homogeneous blocks, which corresponds to the mean signal power in larger areas containing only air (see [12] for more details).

B. System level simulation

The static system level simulation proposed here is based on the WiMAX standard [6] and multiple *Montecarlo Snapshots*.

During each snapshot, the cell layout is fixed and the users are independently and randomly spread on the planning area. Different users can support different services such as *VoIP (Voice over IP)*, Videoconference, Webbrowsing, Mail or FTP.

In addition, the channel undergoes fast fading according to the motion of the users, which is model by SUI models. Therefore, during the simulation, channel state information is fed back from the users to the cells in terms of signal quality. Note that this information will be used to select the user profile or *RAB (Radio Access Bearer)* (modulation, coding ...).

Fig. 1. Considered scenario in Luton town center.

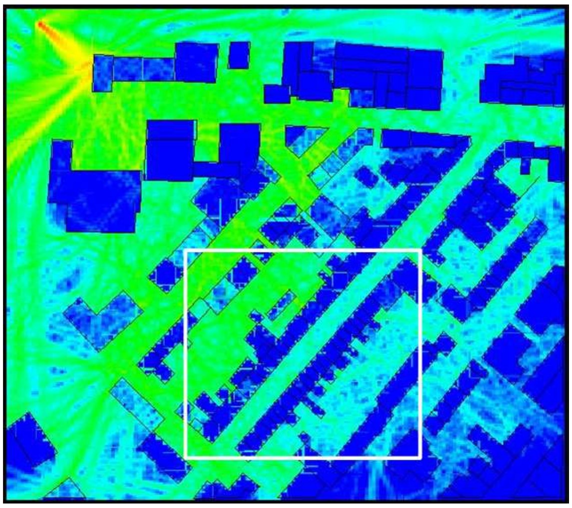


Fig. 2. Received power from the Macrocell computed with the WIPLAN tool, from $-30dBm$ (red) to $-110dBm$ (blue).

Five different service types with different service priorities are distinguished: UGS, rtPS, ErtPS, nrtPS and BE [14]. Therefore, the users are scheduled independently in each cell first by the service priority and then by the scheduling policy. Two scheduling polices are supported by this simulation tool: best *SNIR (Signal to Noise plus Interference Ratio)* and *PF (Proportional Fair)*.

It is considered that in the buffer of each user, the data queue is always full so that we focus on the system performance.

When assigning the resources, the users are served in the order indicated by the scheduler. Then, the indicated user gets as many slots as needed in order to fulfill its minimum service throughput requirement. After using all the users in the queues with the minimum requirement, more resources are given to all the users until they get their maximum requirement. The process stops when all the users are satisfied with their maximum requirement or all the resources are gone.

Subsequently, the SNIR value of each slot is computed and compared to a SNIR threshold just to decide if the information transmitted in such a slot was received with or without errors. The SNIR threshold is pseudo-randomly selected within a given range, according to link level simulation results of the used RAB stored in look up tables, BLER versus SNIR.

Multiple iterations are carried out on each snapshot looking for the stability of the final solution in terms of RAB selection. Such stability is achieved when the changes in the RAB selection of the users remain along several iterations.

Finally, the user state is estimated. The different possible states are defined in the following:

- Success: A user is considered to be in this status, if it has achieved the minimum requested service throughput.
- No coverage: if the power received coming from the user's best server is smaller than the user's equipment sensitivity.
- No resource: when all the resources are gone and the user has not achieved the minimum requested service throughput during the resource allocation process.
- No RAB: when the SINR reported by the channel state information is smaller than the SINR level required to get the minimum RAB defined in the simulation.
- Transmission failure: if the user has got a RAB and has transmitted its information, but the throughput achieved is smaller than the minimum requested service throughput.

III. WIMAX FEMTOCELLS AND DYNAMIC FREQUENCY PLANNING

Although the access method for deployed femtocells still remains an open question, customers surveys [15] show that private access is the customer's favorite option.

However, this approach imposes some interference problems to macrocell and femtocell users [16]. Some of these problems are summarized in the following: First, a DL (*DownLink*) user connected to a far macro-cell could be jammed due to the presence of a closer DL femtocell user who is using the same frequency/time. Second, a UL (*UpLink*) user connected to a femtocell could be jammed due to the presence of a close UL user connected to a macrocell using the same frequency/time (Fig.3). Therefore, interference avoidance techniques need to be applied to reduce the impact of femtocells on the macrocells and viceversa.

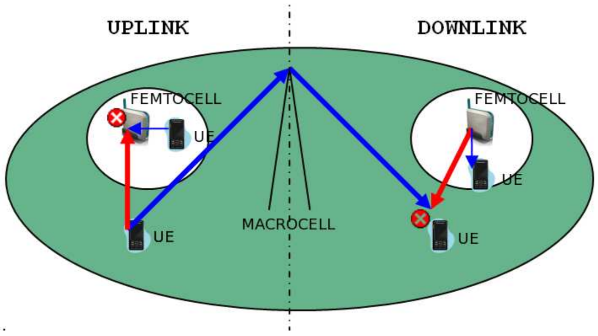


Fig. 3. Interference Scenario.

In WiMAX networks, intra-cell interference may be neglected due to the sub-carrier orthogonality features of OFDMA. Operators must therefore cope with inter-cell interference in order to enhance the network performance.

To overcome inter-cell interference, OFDMA networks are flexible in terms of radio resource management techniques, supporting different frequency reuse schemes and sub-channel allocation techniques, which in turn may decrease the inter-cell interference and increase the network capacity. However, these fixed schemes and techniques are not the most suitable solution in mobile scenarios, where the behavior of the channel and the users are continuously changing.

A new approach to the frequency assignment problem tailored to OFDMA networks called Dynamic Frequency Planning is presented in [8]. DFP can decrease the network interference and increase significantly the network capacity by dynamically adapting the radio frequency parameters to the environment. It operates on a regular basis to cope with the changing behavior of the traffic and the channel throughout the day. DFP can run from a few times a day down to on a second by second basis depending on the needs of the operator.

DFP can also be applied on WiMAX femtocell scenarios to avoid macrocell to femtocell interference and also femtocell to femtocell interference, improving the network capacity and the user experience in outdoor and indoor scenarios.

When applying DFP, the process is divided in two blocks: capacity and interference estimation and, frequency assignment optimization. Both blocks are briefly summarized next.

A. DFP Capacity and Interference Estimation

Let us model an OFDMA network as a set of N sectors $\{S_1, S_2, S_i...S_N\}$, where each sector S_i requires a certain number of sub-channels D_i.

The DFP problem consists on assigning a certain number of sub-channels D_i to each sector S_i, while minimizing the global system interference, taking into account interference restrictions between sectors. Since the number of required sub-channels is typically larger than what is available, sub-channel reuse is needed. The sub-channel reuse leads to frequency interference.

The first key step of DFP is to estimate the number of sub-channels D_i required to satisfy the users bandwidth demand per sector. This can be estimated on a regular basis, since each sector knows the number of connected user and their requirements in terms of capacity and throughput at each time.

The second key step is to characterize the inter-cell interference $w[i, j]$ between the sectors of the network. The model used for sensing the environment and estimating the interference is based on the *User Measurement Report* and the so called *Restriction Matrix*. In this approach, it is considered that two sectors, S_i (server) and S_j (neighbor), interfere with each other (*interference event*$_{ij}$) every time the power level of the carrier signal (coming from S_i to a served user) is smaller than the addition of the power level of a neighboring interfering signal (coming from S_j to the user) and a set threshold. The threshold is considered as a protection margin against interference and it is set by the operator. The percentage of time of interference between both sectors S_i and S_j is calculated as the ratio between the total number of interference events and measurement reports. Note that this ratio does not accurately quantify the real interference between sectors, it only characterizes it. The total number of interference events and measurement reports can be obtained from real measurements data or accurate path loss simulations. The higher the accuracy of the estimated interference, the better the radio frequency planning performance will be.

B. DFP Frequency Assignment Optimization

Given a network defined by N sectors $\{S_1, S_i ... S_N\}$ with D_i required sub-channels, NF available sub-channels $\{1, k ... NF\}$, and the restriction matrix $W[N, N]$, the optimization problem can be defined as a Mixed Integer Program as follows, where the target is to find the optimal solution that minimizes the given cost function representing the overall network interference.

$$min \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=0}^{K} \frac{W_{i,j}}{D_i \cdot D_j} \cdot y_{i,j,k} \tag{1}$$

subject to:

$$\sum_{k=0}^{K} x_{i,k} = D_i \qquad \forall i, k \tag{2}$$

$$x_{i,k} + x_{j,k} - 1 \leq y_{i,j,k} \qquad \forall i, j, k \tag{3}$$

$$y_{i,j,k} \geq 0 \qquad \forall i, j, k \tag{4}$$

$$x_{i,k} \in \{0, 1\} \qquad \forall i, k, \tag{5}$$

where $x_{i,k}$ indicates that sector S_i uses frequency k. Constraint (2) imposes that sector S_i must use D_i sub-channels. Inequalities (3) and (4) together force that in an optimal solution $y_{i,j,k} = 1$ if and only if both sectors S_i and S_j use frequency k and $y_{i,j,k} = 0$ otherwise. Finally, the cost function is the sum of the interference between all pair of sectors S_i, S_j taking into account all the frequencies k. Since the capacity of the sectors is not considered when the restriction matrix $W[N, N]$ is built, the interference restrictions $w_{i,j}$ must be divided by the number of used sub-channels D_i, D_i for both sectors S_i, S_j. In this way, the percentage of time in which both sectors S_i and S_j are transmitting with the same frequency k is estimated.

Many different approaches can be proposed to find the optimal or at least a good solution for the DFP problem in a femtocell environment. Since in the future this optimization algorithm will run on the femtocell itself, the trade-off between the quality of the solution and the running time should be taken into account. Note that the faster the optimization method, the more responsive the system will be to the changes of the traffic. As indicated in [8], meta-heuristics will find slightly higher quality solutions than greedy algorithms when solving DFP, but at the expense of longer running times. Therefore, when using DFP in an on-line scenario, it is worth using faster algorithms since they produce only slightly worse solutions.

TABLE I

SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Macrocell	1	Fem Ant. Height	1 m
Femtocell	30	Fem Ant. Tilt	0
Carrier Frequency	3.5 GHz	Fem Noise Figure	4 dB
Channel Bandwidth	10 MHz	Fem Cable Loss	3 dB
DL:UL Ratio	1:1	CPE Tx Power	23 dBm
Permutation Scheme	AMC	CPE Ant. Pattern	Omni
Frame Duration	5 ms	CPE Ant. Height	1.5 m
Sub-channels	16	CPE Noise Figure	5 dB
DL symbols	19	CPE Cable Loss	0 dB
BS TX Power	43 dBm	Service	Video
BS Ant. Gain	18 dBi	Min Service TP	64.0 $Kbps$
BS Ant. Pattern	Omni	Max Service TP	128.0 $Kbps$
BS Ant. Height	30 m	Average Symbol Eff.	19.9 $Kbps$
BS Ant. Tilt	3	σ(Shadow Fading)	8 dB
BS Noise Figure	4 dB	Intra BS correlation	0.7
BS Cable Loss	3 dB	Inter BS correlation	0.5
Femto TX Power	10 dBm	Snapshots	100
Fem Ant. Gain	0 dBi	Path Loss Model	FDTD
Fem Ant. Pattern	Omni	Snapshots	100

IV. EXPERIMENTAL EVALUATION AND RESULTS

This section presents an experimental evaluation of the proposed DFP solution for interference avoidance in macrocell and femtocell hybrid environments, using the simulation tool presented above.

A. Scenario

The scenario used for this experimental evaluation was Cardigan Street and its surroundings, Luton, UK (Fig. 2). A non-uniform deployed WiMAX hybrid network formed by 1 macrocell and 30 femtocells was used for this simulation. The 30 femtocells were located in 30 different households on this street, corresponding to a worst case scenario in terms of interference, since every household has a femtocell. To perform the system level simulation, different traffic maps were used for indoor and outdoor environments. There was one indoor traffic map per femtocell and house, containing 2 randomly positioned users. There were three different outdoor traffic maps with three different user densities: 5, 3 and 3 users, respectively.

This simulation makes use of a private access method for each femtocell. Indoor users will therefore connect to their femtocell or to the macrocell, and outdoor users will only connect to the macrocell. The environment and parameters of the system level simulation are shown in and Tab.I and Fig.2.

Note that for simplicity only DL is studied in the rest of the paper and UL information is omitted.

B. DFP Solving Strategies

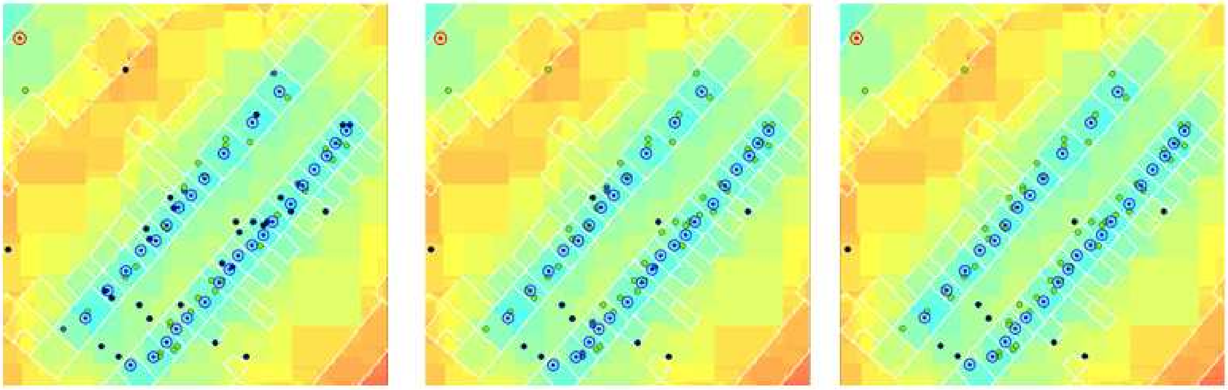
One assumption has been made for the sake of simplicity when solving the DFP problem proposed in the above section. The DFP solving algorithm is based on a centralized network architecture, where a centralized entity should collect the data, generate the plan and distribute the information.

In the following, the allocation strategies used to compare and evaluate the performance of DFP algorithm are presented. The first three strategies are non optimized techniques, but

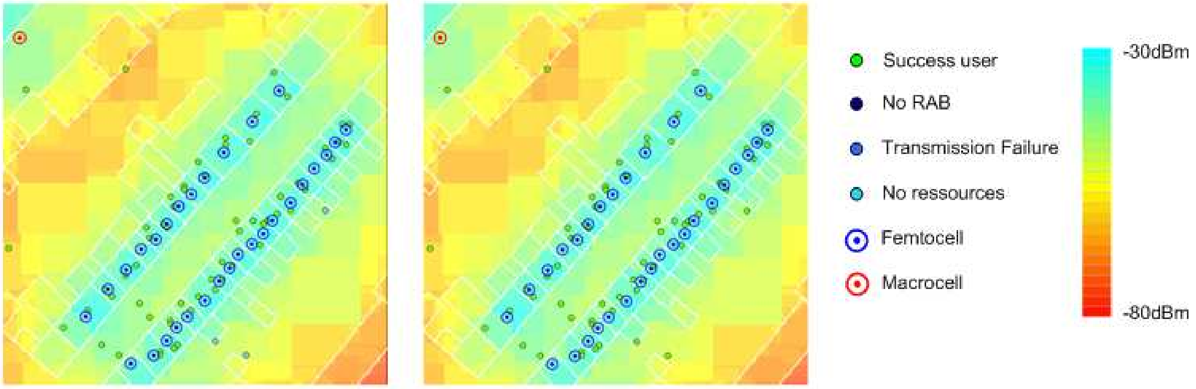
TABLE II

SYSTEM LEVEL SIMULATION RESULTS

Method	Number of users	Success	No resources	No RAB	Transmission Failure	Total Throughput	Cost Function
Same Channel Fragment	63	3	0	28	4	3168.0	2256.0
Unlucky Random Allocation	63	46	0	10	7	4752.0	607.9
Lucky Random Allocation	63	54	0	9	0	5702.0	325.7
FRS 1x1x3	63	56	4	3	0	5913.6	143.5
Femtocell Optimization	63	60	3	0	0	6336.0	22.5
Femto and Macro Optimization	63	63	0	0	0	6652.8	12.5



(a) Same Channel Fragment (b) Unlucky Random allocation (c) Lucky Random allocation



(d) Femtocell Optimization (e) Femto and Macro Optimization

Fig. 4. System level simulation results

based on random or pre-configured frequency reuse schemes. Since the DFP assignment problem has been solved by using greedy algorithms, the DFP algorithm runs extremely fast and the computing time is negligible as in the other strategies.

- Same Channel Fragment: In this case, the same group of sub-channels from the palette of available ones is given to all the macrocells and femtocells. (i.e. the same 4 sub-channels are taken from the 16 available for each cell, Tab.I). This method should produce the worst performance.
- Random allocation: The sub-channels of all the macrocells and femtocells are randomly chosen from the palette of available sub-channels. (i.e. 4 random sub-channels are taken from the 16 available).
- FRS 1X1X3: The palette of available sub-channel is divided in three sub-groups. Afterward, each femtocell gets sub-channels only from its given sub-group. Neighboring femtocells are assigned to different sub-groups to reduce interference probability. (i.e. the 16 available sub-channels are divided in 3 sub-groups, then each sub-group is assign to one femtocell).
- DFP Femtocell Optimization: Greedy algorithms are used to solve the DFP problem. In this case, only the sub-channels of the femtocells are planned together.
- DFP Femtocell and Macrocell Optimization: Same as the previous strategy, however, not only the sub-channels of the femtocells are planned together, but also the sub-channels of the macrocell. This method should produce the best performance.

C. Comparison

The demand vector and the restriction matrix for the given scenario have been computed. Then, different planning strategies have been applied to solve the Mixed Integer Program. Finally, the performance of the resulting sub-channel allocation has been evaluated with different system level simulations. The results are shown in Fig.4 and summarized in Tab.II.

It can be concluded from the simulation results that when the same channel fragment is allocated to all the femtocells, the interference of the system is large (Cost Function Tab.II). This case represents the worse case strategy since all the femtocells and macrocell are using the same sub-channels. Therefore, the performance of the system is low as shown in Tab.II sections total throughput and success users.

The performance of the system improves compared to the method above when the sub-channels of the femtocells are randomly chosen from the palette of available sub-channels. It was verified that an unlucky random allocation in which neighboring femtocells use the same sub-channels performs worse than a lucky random allocation in which neighboring femtocells use different sub-channels.

When an organizative allocation method or fractional reuse scheme is used (FRS 1x1x3), the interference of the system notably decreases by around 95% compared to the worst case scenario, increasing the total throughput and success users by around 45% and 95% respectively.

Finally, when using optimization (last 2 methods), the interference is further reduced and the system performance improved. When all the femtocells are planned together using DFP, but not the macrocell, a notable and a good improvement is achieved compared with the worst case scenario and the FRS 1x1x3, respectively. In the last comparison, the cost function has been reduced around 85% and, the total throughput and success users are both increased around 7%.

However, the best results are obtained when not only all the femtocells are planned together, but also the macrocells. In this case, when using DFP, all the users are success and the result is close to the free interference assignment.

Therefore, the results confirm that the better the resource allocation technique, the larger the interference avoidance and the better the system performance will be.

V. CONCLUSION AND PERSPECTIVES

In this paper, a framework for radio coverage prediction and system level simulation for WiMAX macrocell and femtocell hybrid scenarios has been introduced. In addition, the feasibility of the co-channel deployment of WiMAX femtocells in an existing macrocell network has been investigated. Interference avoidance has been proven essential for a successful deployment of WiMAX femtocells in such scenarios.

This paper has also presented a new approach to the frequency assignment problem, called DFP, tailored to WiMAX femtocells. The performance of DFP and other allocation techniques have been compared by using different system level simulations. The results have shown that DFP can notably decrease network interference and increase system performance.

The ideas presented here depend on a centralized network architecture, where a centralized entity should collect the data, generate the plan and distribute the information. However, a distributed architecture where each femtocell is able to select its own sub-channels would be more suitable. Further improvements currently under research in our group, include the study of distributed algorithms to be used in on-line and truly dynamic frequency allocation for OFDMA networks.

ACKNOWLEDGMENT

This work is supported by the first EPSRC-funded research project on femtocells - “The feasibility study of WiMAX based femtocell for indoor coverage”(EP/F067364/1) and by EU FP6 “RANPLAN-HEC” project on 3G/4G Radio Access Network Design under grant number MEST-CT-2005-020958.

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