PILOT POWER OPTIMIZATION IN UMTS: A MULTI-AGENT APPROACH

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ABSTRACT

In the context of coverage planning and control, the power of the CPICH signal determines the coverage area of the cell. It also impacts the network capacity, and thus the quality of service. Pilot power is the parameter that allows us to control the strength of the CPICH signal. A higher power for pilot signals means better coverage. On the other hand, more pilot power translates in less power available to serve user traffic.

We consider the problem of minimizing the total amount of pilot power subject to a full coverage constraint. Our solution approach, based on multiple autonomous agents, gives very good solutions to the problem within an acceptable amount of time. We report the results of our experiments for three UMTS networks of different sizes based on realistic planning scenarios.

1 INTRODUCTION

Coverage planning is a key problem that all mobile operators have to deal with. Its intricacy arises from the wide range of different combinations of configuration parameters and their evaluation-time complexity. One crucial parameter, which is mainly subject of adjustment, is the transmit power of the common pilot channel (CPICH). The CPICH transmit power is common to many different planning and optimization problems in UMTS networks.

The CPICH transmits in the downlink of a UMTS cell system. The transmit power is usually between 5% and 10% of the total power available at the base station [4]. From the network point of view, the capacity of a cell is limited by the amount of available power at the base station and the interference level at the mobile terminal. The coverage area of any cell is controlled by changing its pilot power, which consequently modifies the service area of the network.

There are different approaches in the literature that are able to solve the coverage problem [6, 8]. Some of them even claim to achieve near-optimal solutions [9]. As a matter of fact, such formulations have proven useful only for small network instances and often fail when challenged with real-world networks.

The idea of using autonomous agents for optimization is not new. It has proven to be a solid optimization approach for solving different types of problems, not only within the area of mobile networks [2], but also in other fields [13].

Our optimization approach is based on a state-of-the-art mathematical model, that has been previously used to solve a comparable problem [1]. We tackle the problem of computational complexity, when dealing with big problem instances, by deploying a greater number of agents working in parallel over the service area of the network. Our approach is tested on real-world UMTS networks of different sizes. The results show that the solutions found, and more importantly their quality, are greatly improved when compared to other common planning techniques.

We begin our discussion with a description of the coverage problem and formally introduce some of its key elements. We then discuss our multi-agent approach in detail, as well as the strategy used for result comparison. Having introduced the multi-agent approach, we move on to describe the simulations and experimentation done on three real-world networks. We conclude with an overview of the achieved results and discuss future research directions.

2 PROBLEM DESCRIPTION

In the problem of optimization of pilot powers for service coverage, the objective is to find a set of pilot power settings for all cells in the network, such that the total pilot power used is minimized, and a given service coverage constraint is fulfilled. We consider the pilot power minimization problem subject to a full coverage constraint of the service area.

Because the mathematical model of the problem is not of primary interest here, we will just outline it, so that all problem elements are formally defined and represented. For additional information regarding mathematical models of comparable problems, see [6].

2.1 Problem elements

We start by considering a UMTS network of m cells and use C to denote the set of cells, i.e. $C = \{1, ..., m\}$. A pixel grid of a given resolution represents the service area for which the signal propagation predictions are known. Let n denote the total number of pixels in the service area and let S denote the pixel set, i.e. $S = \{1, ..., n\}$. We also denote g_{cs}, $0 \leq g_{cs} \leq 1$, as the attenuation factor between a cell c and a pixel s, which is calculated by performing signal propagation predictions for every pair of $c \in C$ and $s \in S$.

For every $c \in C$, we define p_c^T as the total transmission power available in cell c. This power is shared among all channels in the cell (i.e. CPICH, other common channels, and dedicated traffic channels). We define p_c as the amount of power allocated to the pilot signal of cell c, where p_c may adopt any value from a finite set of possible pilot power levels, $P_c = \{p_c^1, p_c^2, ..., p_c^T\}$. Consequently, the received pilot power of cell c in pixel s is $g_{cs}p_c$.

Considering the full coverage constraint, each pixel in the service area should have at least one cell covering it. We assume that a pixel s is under coverage of a cell c if its carrier-to-interference ratio, E_c/I_o at pixel s, is not lower than a given threshold, γ_c, i.e.

$$E_c/I_o(c,s) = \frac{g_{cs}p_c}{\sum_{i \in C} p_i^T g_{is} + \tau_0} \geq \gamma_c \qquad (1)$$

where τ_0 is the thermal noise. In (1), we are assuming that all cells in the network operate at full power, which is the worst case scenario. The same assumption has been also used in [1, 9].

The optimization problem corresponds to finding the pilot power levels p_c, for all cells $c \in C$, such that coverage of at least b pixels is guaranteed, while the total amount of pilot power used is minimized. Since we are considering full coverage, we denote $b = n$.

2.2 Optimization objective and constraints

The optimization objective is defined as follows

$$P^* = \min \sum_{c \in C} p_c; \qquad (2)$$

subject to

$$\frac{\sum_{s \in S} cov(s)}{b} = 1, \qquad (3)$$

where

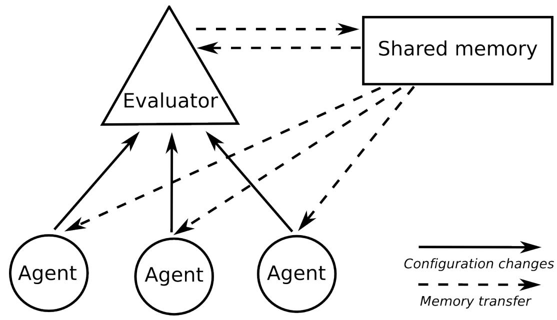
$$cov(s) = \begin{cases} 1 & \exists c \mid E_c/I_o(c,s) \geq \gamma_c \\ 0 & otherwise \end{cases} \qquad (4)$$

The definition of (4) provides us with a simple way of asserting the coverage of a given pixel, s. It follows that if the pilot signal of at least one cell c satisfies the imposed E_c/I_o threshold, γ_c, the pixel is covered and hence $cov(s) = 1$.

3 OPTIMIZATION APPROACHES

The comparison of the experimental results involve two different strategies for setting the pilot power. The first strategy is uniform pilot power, presented in [12], by which the pilot power of all cells in the network is set to the same level. The second strategy is our multi-agent approach, based on ideas inspired by two-dimensional cellular automata [7] and meta-heuristics [10].

Figure 1: *Architecture of the multi-agent system.*



3.1 Uniform pilot power

This kind of pilot power setting is efficient in scenarios where the signal attenuation is essentially determined by distance (i.e. the signal propagation conditions are mostly constant). In such cases, the cell coverage areas will be approximately the same for uniformly distributed traffic and similarly-distributed site locations. On the other hand, when dealing with heterogeneous scenarios, having all cells equally set to the same pilot power, results in an unnecessary large power consumption. This not only reduces the power available to user traffic, but it also produces areas of high pilot pollution [4].

3.2 Multiple autonomous agents

In the multi-agent approach, a set of autonomous agents and an evaluator work together in order to optimize the pilot power consumption of the network. Each agent randomly moves over the service area as it proposes different changes to the pilot power of the cells. The quality of the final solution gradually improves over time, as better solutions are accepted and poor solutions are discarded by the evaluator.

Figure 1 gives an overview of the multi-agent architecture. Within this architecture, agents work in an autonomous and asynchronous manner.

3.2.1 The agents

Each agent encapsulates a set of steps that is consistently applied as it randomly moves through the service area of the network. Whenever an agent arrives at a pixel s, it asks the evaluator for the set of cells covering the current pixel, namely

$$B(s) = \{c \in C \mid E_c/I_o(c,s) \geq \gamma_c\} \qquad (5)$$

The step set applied from this point on depends on the cardinality of $B(s)$. The agent's behavior is regulated by the pseudo-code shown in Table 1. Hence, the agent applies step sets SS_0 and SS_1 based on the number of cells in $B(s)$.

If the agent's current location, at pixel s, is not covered by any cell (i.e. $|B(s)| = 0$), the step set SS_0 (shown in Table 2) is applied. It starts by defining N, the Moore neighborhood with radius 1 [7], around

Table 1: *Pseudo-code of the agent's behavior.*

Step	
	repeat
1	**if** $\lvert B(s)\rvert = 0$ **then**
2	*apply* SS_0
3	**else if** $\lvert B(s)\rvert = 1$ **then**
4	*Move randomly*
5	**else if** $\lvert B(s)\rvert > 1$ **then**
6	*apply* SS_1
	end if
	end repeat

Table 2: *Pseudo-code of step set* SS_0.

Step	
1	$N = Moore(s, radius = 1)$
2	$A = \emptyset$
3	**for each** *pixel* $r \in N$
4	$A = A \cup B(r)$
	end for
5	**if** $A \neq \emptyset$ **then**
6	$c' = Highest(A)$
7	$Adjust\, pilot(c', increase\, rate)$
	end if
8	*Move one step randomly*

the agent's current location s. The neighborhood is then analyzed, looking for cells covering any of the neighboring pixels $r \in N$ (steps 3 and 4). If a cell is found, the agent shall propose an increase in the pilot power of the cell c', that has the highest E_c/I_o in the neighborhood N (steps 6 and 7). Otherwise, if no cell is found covering any pixel within the neighborhood N, the agent moves one pixel in a random direction (step 8). It should be noted that the agent moves exclusively to adjacent pixels $r \in N$ when it reaches an uncovered pixel s. This behavior efficiently finds areas without coverage containing many uncovered pixels.

The step set SS_1 in Table 3 is applied whenever the agent's current location, at pixel s, is covered by more than one cell (i.e. $|B(s)| > 1$). The first step distinguishes the covering cell with the lowest E_c/I_o, c', from $B(s)$. The agent shall propose a decrease in the pilot power of c', and then move to a new random location (steps 2 and 3), that is generally not adjacent to the current one.

In both step sets, SS_0 and SS_1, the values *increase rate* and *decrease rate* are configuration parameters that should be given before starting the optimization process. They indicate the dB adjustment proposed to the pilot power of cell c'.

Table 3: *Pseudo-code of step set* SS_1.

Step	
1	$c' = Lowest(B(s))$
2	$Adjust\, pilot(c', decrease\, rate)$
3	*Move randomly*

3.2.2 *The evaluator*

The evaluator represents the global optimization component of the system, since it has access to the complete network, for it keeps track of the coverage area of each cell. In contrast, the agents propose their changes based exclusively on local information.

A tabu list is included in the evaluator as a mechanism to avoid solution degradation. A cell is included in the tabu list after its pilot power has been increased. While a cell is in the tabu list, any decrease of its pilot power is forbidden. The tabu list keeps track of the number of overall agents' moves since the cell was included in it. If the pilot power of a tabu cell is increased, its counter is reset to zero. By using a tabu list, the evaluator avoids coverage reduction within the context of the current solution, since increasing pilot power only occurs when uncovered pixels are discovered by the agents. The number of moves a cell should remain in the tabu list is an optimization parameter.

All changes proposed by the agents are subject to acceptance by the evaluator, that sequentially verifies the following conditions to each proposed change:

- if the change involves decreasing the pilot power setting of a cell c', then c' should not be an element of the tabu list;
- if the change involves increasing the pilot power setting of a cell c', then c' becomes/remains an element of the tabu list and its counter is set to zero;
- the new pilot power setting, after applying the agent's change, is an element of $P_{c'}$.

If the agent's proposed pilot-power adjustment breaks any of the enumerated conditions, the change is discarded without notice. This means that the agents do not know whether the proposed change has been applied or not.

4 SIMULATIONS

4.1 Test networks

All of our test networks, Net_1 of the city of Berlin (Germany), and Net_2 of the city of The Hague (Netherlands), are part of the publicly available MOMENTUM project [5]. The last network, Net_1', is a reduced version of Net_1 of the city of Berlin. This same network has been optimized in [9]. All networks include information about site locations, path loss predictions and realistic antennas. These scenarios also contain individual requirements for E_c and E_c/I_o coverage.

Based on the data available, we have produced network configurations based on the uniform pilot power approach. These configurations represent what could be an initial network setup by common planning standards [4]. Table 4 shows some statistics about the test networks used. The parameter values used during experimentation are shown in Table 5.

Table 4: *Network statistics.*

	Sites	Cells(m)	Pixels(n)	Area	Pixel size
Net_1	65	193	22500	7500×7500	50×50
Net_2	12	36	6400	4000×4000	50×50
Net'_1	50	148	22500	7500×7500	50×50

Table 5: *Network parameters.*

Parameter	Net_1	Net_2	Net'_1
p_c^T	19.95W	19.95W	19.95W
τ_0	$1.55{\cdot}10^{-14}$W	$1.55{\cdot}10^{-14}$W	$1.55{\cdot}10^{-14}$W
γ_c	-15dB	-15dB	-15dB

4.2 Results

After considerable experimentation, we found out that a tabu list value of $\frac{n}{2}$ gives good solutions regarding power use, while keeping coverage mostly at 100%. Experimentation also gave us valuable understanding regarding the agents' behavior, and helped us set the values of *increase rate* and *decrease rate*. By setting the *decrease rate* at 0.1dB, the agents are able to find possible uncovered areas quickly. On the other hand, increasing pilot power at *increase rate* 1dB, lets the agents correct uncovered areas containing many uncovered pixels with one change only. Using this setup, coverage values never dropped under 98% during experimentation. The stopping criterion was set by limiting the total number of agents' moves. This value was set to $5n$, even though the best solutions were always found in the first quarter of the experiment. Table 6 shows the optimization parameters used for each network.

All things considered, the results achieved by our optimization approach improved the objective significantly, as it is shown in Table 7. We reduced pilot power usage in all networks and kept the service area under full coverage. Moreover, when comparing our results of network Net'_1 to those of [9], we may see that our solution achieves full coverage with even lower pilot power usage.

5 CONCLUSION

In this paper, we have addressed the problem of providing full coverage to a service area of a UMTS network by using a minimum amount of pilot power. We have introduced a multi-agent approach aimed at giving good solutions to the problem in an acceptable amount of time. The experimental results show that our approach is able to find competitive solutions, when compared to other methods from the literature. The presented results also demonstrate that our algorithm is able to find high quality solutions even for large networks, that are out-of-reach for some exact techniques, like linear programming. Such solutions were found in a reduced amount of time by simply increasing the number of agents deployed during optimization. This fact reveals that our approach can be easily applied to bigger problem instances without compromising solution quality.

In any case, it would be useful to make a more extensive comparison of our experimental results with different algorithms and various heuristic and exact approaches. However, this task is not straightforward, since the results of several works (e.g. [3, 11]) depend on black-box evaluations, making experimental association very difficult, if possible at all.

Table 6: *Optimization parameters used.*

	Agents	Incr. rate	Decr. rate	Tabu value	Stopping criterion
Net_1	6	1dB	0.1dB	11250	112500
Net_2	2	1dB	0.1dB	3200	32000
Net'_1	6	1dB	0.1dB	11250	112500

Table 7: *Optimization results.*

	Uniform		Multi-agent	
	Total power (W)	Average power (W)	Total power (W)	Average power (W)
Net_1	422.226	2.1877	147.490	0.76412
Net_2	120.823	3.3562	32.621	0.9061
Net'_1	345.092	2.3317	112.125	0.7576

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