Balancing handover areas in UMTS networks

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Abstract

In this paper, we consider the problem of aligning uplink and downlink handover areas in UMTS networks. Our optimization approach, based on simulated annealing, gives good solutions to the problem without any parameter tuning. We report the results of our experiments for three UMTS networks of different sizes based on a real network currently deployed in Slovenia.

1 Problem description

In mobile networks, handover is one of the main features that allow user's mobility [4]. The concept behind the handover operation is simple: when a user moves from the coverage area of a cell (e.g. cell 1) to the coverage area of a neighboring cell (e.g. cell 2), the system creates a new connection with cell 2 and disconnects the user from cell 1 while keeping the current connection active. For the correct operation of the handover procedure, the layout of the mobile network should ensure some coverage overlapping at the border areas of neighboring cells. Without coverage overlapping, the system would not be able to maintain an active connection during the passage from the coverage of one cell to the coverage of the neighboring one. Figure 1 shows the overlapping between Cell 1 and Cell 2. The distribution of these areas "of multiple coverage" is always centered around the border[1] of neighboring cells.

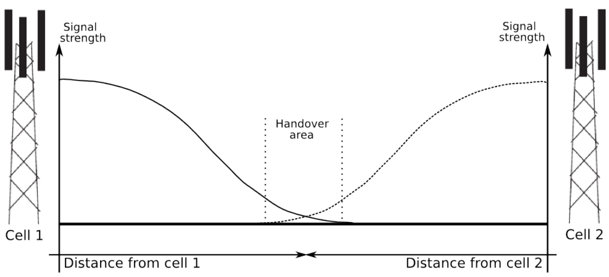

Figure 1: Cell coverage must overlap for handover to work correctly.

[1]This border is defined by the relationship between pilot power and interference among neighboring cells. It is important to notice that this is not a geographical border and it is constantly changing, since the range of radio signals is affected by many external factors (weather, network traffic, terrain and many more).

In UMTS, transmissions are categorized regarding the direction of the connection; there are two different types: downlink (i.e. from the network towards the mobile terminal) and uplink (i.e. from the mobile terminal towards the network).

Every mobile terminal constantly monitors the downlink pilot power channel (CPICH) of the connected cell and its neighbors. The information about these measurements is sent to the network in the uplink direction. When the CPICH of the connected cell is lower than a specified threshold, the network sends a command to the mobile terminal to handover to the best[2] measured neighboring cell.

Because handover involves control messages being sent to and from the network, cell coverage overlap must exist for connections in both directions: downlink and uplink. If the downlink and uplink coverage areas do not match, handover suffers from different kinds of malfunctioning [4]. Many UMTS networks exhibit differences in the downlink and uplink coverage areas, hence around the border of neighboring cells. One reason for this incorrect alignment is the diversity of hardware installed at the base stations. Different kinds of amplifiers, cables and antennas create power lags and/or gains in a certain direction.

Downlink cell coverage is controlled by the CPICH power level of the cell and its configuration may be changed through software. On the other hand, uplink coverage is defined by the hardware installed at the base station and cannot be regulated with a control parameter. Take, for example, Figure 2, which shows a simplified case of power gap between two cells. Coverage of Cell 2 is broader in the uplink, and the gap it has created with its neighbor, Cell 1, is marked. A trivial solution to this problem would be to decrease the CPICH power of Cell 1, so that the downlink cell border would match the uplink cell border, and, at the same time, ensure enough coverage overlap.

When working with real UMTS networks, there are no trivial solutions. A typical UMTS network has thousands of cells, each of them being able to recognize tens of neighboring cells. In such cases, the challenge is to find such a combination of CPICH power levels that min-

[2]There are several strategies to choose the best neighbor cell [4], but a common factor to all of them is the CPICH received power.

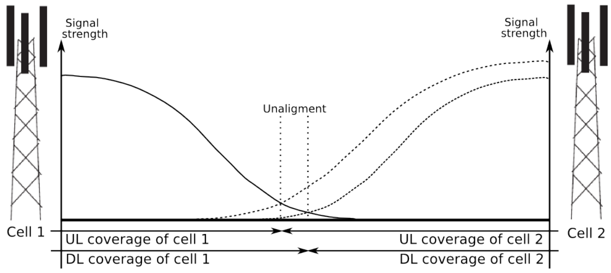

Figure 2: Non-aligned downlink and uplink power levels.

imizes the difference between downlink and uplink powers among neighboring cells, while ensuring enough coverage overlap to enable flawless handover procedures.

2 Candidate solutions and their constraints

Given an operating UMTS network that suffers from the consequences of non-alignment of handover areas, we concentrate on the minimization of the difference between downlink and uplink powers. To achieve this, the algorithm should examine CPICH power levels for all the cells in the network, such that any newly proposed CPICH value doesn't differ from the initial one by more than 2 dB, i.e.

$$-2dB < CPICH_{initial} - CPICH_{proposed} < 2dB \quad (1)$$

For example, if a cell has an initial CPICH power of 30 dBm, then the candidate solutions for this cell would fall in the interval (28 dBm, 32 dBm). The objective of this hard-coded limit is to come up with a solution to the balancing problem that doesn't affect the initial coverage of the mobile network. Therefore, the coverage overlap between neighboring cells is also kept, so that handovers are operative after a newly found solution has been applied to the network. Larger intervals would potentially help the algorithm to find better solutions to the balancing problem, but at the cost of potentially altering network coverage.

3 Optimization objective

Let C denote the set of cells in a UMTS network and let G denote a finite undirected graph. We denote the set of vertices in G as V, representing the cells in C. It follows that $|V| = |C|$. An edge connecting two vertices $v_1, v_2 \in V$ shows that cells $c_1, c_2 \in C$ are neighbors. Let M denote the adjacency matrix of G. Consequently, M is the $|V| \times |V|$ matrix where the non-diagonal entry a_{ij}, $1 \leq i, j \leq |V|$, is 1 if and only if there is an edge connecting vertices i and j. All diagonal entries a_{ii} in M are 0 since no vertex has an edge to itself (i.e. no cell is neighbor of itself).

By considering the hardware installed on the base station and the CPICH power level of a cell, $c_i \in C$, we may calculate the uplink and downlink powers for each cell in the UMTS network. Hence we define the objective of this optimization problem as the minimization of the difference between downlink and uplink powers, i.e.

$$\min \sum_{i=1}^{|V|} \sum_{j=i}^{|V|} |a_{ij} d_{ij}|, \quad (2)$$

where a_{ij} is the entry in M at row i and column j, and d_{ij} is the power difference between cells c_i and c_j. Considering that M is a symmetric matrix, we take into account only the "upper half" of M not to calculate the power difference between two cells more than once. We are also assuming that the radio propagation conditions between neighboring cells are similar enough for them to be neglected, and thus excluded from the objective function evaluation.

The definition of d_{ij} is as follows

$$d_{ij} = \frac{(DL(c_i) - DL(c_j)) + (UL(c_i) - UL(c_j))}{-2}, \quad (3)$$

where $DL(c_i)$ is the downlink power of cell c_i, and $UL(c_j)$ is the uplink power of cell c_j. When $d = 0$, the CPICH power level needs no correction, either because there is no difference between the downlink and uplink powers of c_i and c_j, or because c_i and c_j aren't neighbors (i.e. $a_{ij} = 0$). A different value of d_{ij} (i.e. $d_{ij} < 0$ or $d_{ij} > 0$) represents the CPICH power adjustment of cell c_i that is required to balance both power levels.

4 Related work

The CPICH transmit power is typically between 5 % to 10 % of the total downlink transmit power of the base station [6], but there is no standardized method to find a CPICH power setting. A number of existing approaches to resolve this issue exist in the related literature (see [4, 9, 13, 14, 15]). The most effective ones are those based on optimization methods, but they are not always easy to implement or fast enough [1, 2, 3, 6, 7, 8, 10, 12]. Such a wide spectrum of proposed procedures is directly related to the diverse criteria taken into account when assigning the CPICH power of a cell. The fundamental reason behind this fact is that the CPICH transmit power is a common factor of various optimization problems in UMTS networks.

To the best of our knowledge, the balancing problem described in this paper has not yet been tackled by any formal optimization method.

5 Optimization approach

Our optimization approach is based on simulated annealing [5], a well-known metaheuristic algorithm often used when the search space is discrete. Simulated annealing has proved to be a solid optimization algorithm, capable of giving high-quality solutions to a wide scope of optimization problems [11].

At each time step during the process, the system under optimization is in a given *state*. The objective function maps a system state to a value known as the *energy* of the system in that state. A *move* in the search space represents a change in the state of the system. After making a move, the system may exhibit lower or higher energy,

Algorithm 1 *A move in the search space.*

Step	
	repeat
1	$c' = random\,cell(C)$
2	$n' = random\,neighbour(c')$
3	$d = power\,difference(c', n')$
4	**if** $(d > 0)$
5	$adj = 0.1$
6	**else if** $(d < 0)$
7	$adj = -0.1$
	end if
8	**while** $power(c') + adj$ **is not valid**
9	$adjust\,power(c', adj)$

depending on the results of the objective function. When dealing with minimization problems, a better state always describes lower energy than the previous one.

Simulated annealing incorporates the notion of *temperature*, by which the probability of moving the current state of the system into a worst one is lowered as the temperature decreases during the optimization process. Exploration of the search space is thus induced at higher temperature, whereas exploitation appears at lower temperature, when only improving moves are accepted.

Algorithm 1 shows the pseudo-code executed as a move in the search space of possible CPICH power settings, resulting is a new state of the system.

At the first step, a cell, c', is randomly selected from the set of all cells in the network, C. In a similar manner, a neighbor of cell c' is randomly selected in step 2. In step 3, the power difference between c' and n' is calculated, based on (3). After checking if the difference in the power levels of both cells is positive (step 4), a 0.1 dB increase in the CPICH power level is saved in adj, in step 5. The power difference between c' and n' is inspected again in step 6, but this time for a negative value. If this is so, a CPICH power level adjustment of -0.1 dB is saved in adj, in step 7. Namely, the sign of d indicates the direction of the CPICH power adjustment that should be applied over c' for the non-alignment to disappear, and the ± 0.1 dB power adjustments define the discrete nature of the search.

The constraint defined in (1) is then checked over c' in step 8. If it is fulfilled, the move finishes in step 9 with the actual CPICH power change, by adj dB, to cell c'. The acceptance of the move is left to simulated annealing. Otherwise, the whole process is repeated, beginning with a new random selection of a cell in step 1.

6 Simulations

6.1 Test networks

All the test networks, Net_1, Net_2, and Net_3, are subsets of a real UMTS network deployed by Telekom Slovenije, d.d., in Slovenia. Net_1 represents a network deployed over a mostly rural area, where the network configuration emphasizes coverage over user capacity, since the resident population density is small. Network Net_2 represents a suburban area with a densely populated, but relatively small, downtown center, which contains a mixture of both urban and rural network configuration elements. The last network, Net_3, is deployed over a highly populated urban area, thus it presents a strict urban configuration profile. The three selected networks exhibit different operation and configuration schemes, depending on the dominant user's profile of each area. For this reason, the observed handover and soft-handover [4] behavior is fairly different among these scenarios, enabling the mobile operator to measure the impact of the optimization results given the particular conditions of each subnetwork. Moreover, by challenging our optimization approach with problem instances of different characteristics and sizes, we are confident to gain better understanding about the optimization process itself. Table 1 shows some key properties of the test networks presented.

Table 1: *Network properties.*

	Cells	Neighbor relations	Non-aligned relations
Net_1	42	126	99
Net_2	63	173	125
Net_3	151	1,143	1,038

Based on the number of cells and neighbor relations in each network, we have set the initial temperature and the number of iterations for simulated annealing. For the initial temperature, we have used half the number of neighbor relations, whereas the number of iterations is a thousand times the number of cells. The parameters used for each test network are shown in Table 2. In all three cases, we have used the exponential schema for lowering the temperature during the optimization process.

Table 2: *Parameter settings for simulated annealing.*

	Initial temperature	Number of iterations
Net_1	63.0	42,000
Net_2	86.5	63,000
Net_3	571.5	151,000

6.2 Experimental environment

All experiments were done on a 4-core Intel i7 2.67 GHz desktop computer with 6 GB of RAM running a 64-bit Linux operating system. The implementation language used was Python, with certain parts of the objective function evaluation implemented in C, which improved the overall performance of the optimization process.

6.3 Results

Table 3 presents the best results obtained after 20 independent runs. We may observe that our optimization approach improved the objective significantly in all three problem instances. Results show that we have reduced the number of non-aligned neighbor relations, without changing the CPICH setting of any single cell for more than ± 2 dB, as it is defined by (1). These results also in-

Table 3: *Optimization results.*

	Non-aligned relations	Improvement
Net_1	80	19.19%
Net_2	111	11.20%
Net_3	972	6.36%

dicate that the complexity of the problem quickly raises with the number of cells and neighbor relations in the network, since the achieved improvement is smaller for bigger networks. However, all tested problem instances are complex enough to make it very difficult and time consuming for an engineer to optimize them by hand.

The improvements observed provide a network configuration that should potentially help reduce the number of errors during handover procedures at the cell borders, although this fact has yet to be confirmed by the radio network experts at Telekom Slovenije, d.d..

7 Conclusion

We have presented an optimization approach to tackle the problem of non-alignment of handover areas in UMTS. The results presented confirm that our method, based on simulated annealing, is capable of improving the network by correcting many of the non-aligned relations present before the optimization.

One of the key advantages of the presented optimization method is that there is no need for parameter tuning to improve a given network configuration. This follows from the definitions given in section 6.1 for parameter setting, with which we have improved all three problem instances.

Future work shall include an in-depth analysis of the results presented regarding network performance. Nevertheless, the a priori assumption is that the optimized network configurations should help avoiding much of the malfunctioning observed during handover and soft-handover procedures in UMTS, since the number of non-aligned handover areas has been greatly reduced.

Acknowledgment

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