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Abstract:

The use of real Network topology parameters allows a validation of the optimization software for a real DVB network. A commercial network planning software has been used to perform initially a realistic coverage study. Later this is complemented with the design and use of an optimization software based in Simulated Annealing which returns, after several iterations, the optimum configuration in terms of a cost function. The specific cost function is defined to reduce the interference level.

1. Introduction

In the context of the Spanish FURIA project, new objectives at network level have been defined to lead a joint optimization of the future DVB-T2 standard deployment. This paper will depict the problems of this network optimization process, as well as the solutions proposed oriented to the network enhancement and closely related with the first trials and driving tests of this new technology.

I2CAT-UPC consortium has started a collaborative project with a national telecommunications provider to evaluate and optimize the current DVB-T network deployment in Catalonia. Using real system parameters allows validating the optimization software for a real network, assuring that when used to test DVB-T2 network topology performance, will help to find the optimal solution. For the accomplishment of this purpose the work methodology has been structured in four different steps:

- 1st Step: Definition and study of the problematic in the DVB-T network topology.
- 2nd Step: Development and implementation of new solutions to optimize the quality of the network.
- 3rd Step: Use of a commercial network planning software to perform a realistic coverage study.
- 4th Step: Design and implementation of an optimization software using Simulated Annealing for the improvement of the current network.

2. Problematic in DVB-T network planning

Different optimization problems in DVB-T network planning have been investigated by choosing different sets of transmitter parameters as decision variables (see [1] for a general framing). Namely, in emission powers and antenna heights are optimized by simulated annealing [2]; in a local search algorithm and a mixed integer programming model are presented for power and frequency assignment [3]; in [4], emission powers are optimized by a LP-based heuristic. The common feature among these problems is that the statistical receiver coverage assessment model recommended for implementation purposes [1, 4] makes difficult to identify a mathematical structure exploitable in algorithms design.

Along this chapter, a study of the optimization of the transmitters time offset (already introduced in [3]) is performed. The time offset problem (TOP) does not arise in analog systems, since it originates from specific features of the orthogonal frequency division multiplexing (OFDM) scheme, adopted by DVB-T and DVB-T2. The practical relevance of TOP has three major motivations:

- Any private broadcaster may implement its own time offset configuration for a network without affecting the service of other operating networks;
- Unlike the case of frequencies, changing time offsets does not require a remarkable economical effort;
- Optimized time offset configurations improve significantly the coverage (especially) of single frequency networks (SFNs), in which all transmitters are assigned with the same frequency.

3. Proposed solutions for DVB-T/T2 network planning

General descriptions of the DVB-T system are extensively presented in technical reports from major bodies involved in the DVB-T project, such as [5]. For that reason the proposed solution for the network optimization is based in an analysis of some features of the signal reception and the system exploiting.

A broadcasting network is designed to distribute video programs within a given territory portion called target area. This is decomposed into a set Z of “small”, approximately squared, areas (e.g., 2×2 km) called testpoints (TPs). For instance, the Catalonia territory is decomposed into 8,000 TPs. A TP is described by latitude, longitude, altitude and number of inhabitants, represents the behaviour of any receiver (i.e., a user receiving antenna) within it, which is supposed to have fixed directivity (which although it is a limitation of the model it seems quite reasonable).

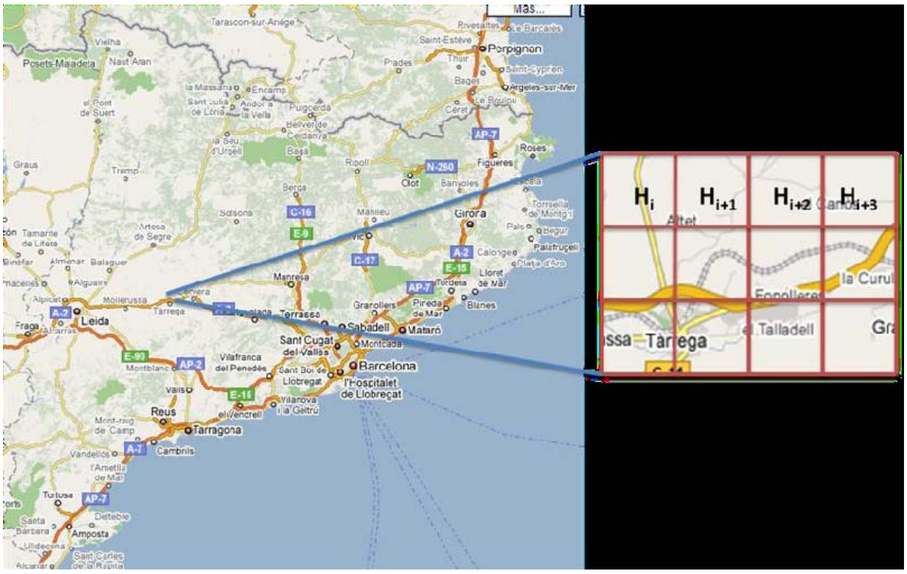

Fig.1: Decomposition in square areas of the Catalonian area Network Optimization with Simulated Annealing

The signal emitted by a transmitter propagates according to transmitter directivity and topography. Taking into account that a transmission consists of a stream of symbols and the propagation delay, the arriving time of a symbol emitted by transmitter i in TPj has the expression:

$$\tau_{ij} = t_i + \Delta\tau_{ij}$$

The power density Pij (μW/m2) received in TPj from a transmitter i is proportional to the emitted power Pi, for example, Pij =Pi·Aij. Thus a matrix [i,j] with the received power densities can be defined as seen in figure 2

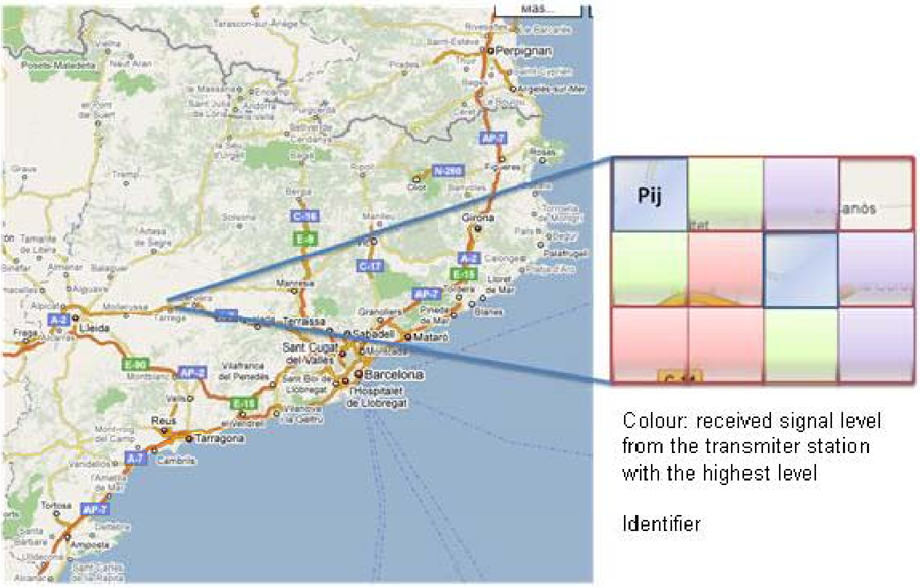

Fig. 2: Received density power matrix example

In fact associated with the received signal from each transmitting station a single contribution is not received. The reception stage receives different copies of the signal due to multipath (reflections, diffraction and combinations of both) effects. However, these delays are in general quite close to Δτij, and are considered negligible in this study. Just in some special environments (as for example coverage in rural and mountain areas) different delays from a transmitter station are possible due to the travelled distance differences between the signals. A delay matrix (similar to the previous figures) can be defined.

At the TPj the signal of a certain number of stations is received: T(j) indicates the T subgroup detected at j. In this way a graphical representation for each TP can be performed with the following parameters:

- Number of transmission stations detected T(j).
- Power level (or power density level) received at each station.
- Total associated delay.

In the definition of the TOP problem the key notion in the coverage assessment is the notion of interference. In analog systems, different signals arriving on a receiver with the same frequency always interfere (co-channel interference). Due to the OFDM scheme, this is not always the case in digital systems. In fact, the receiver (in TP) j locates at time τj a detection window: all signals falling into the window are wanted, whilst the others are interfering. Figure 3 shows an example of the different received signals at a given point.

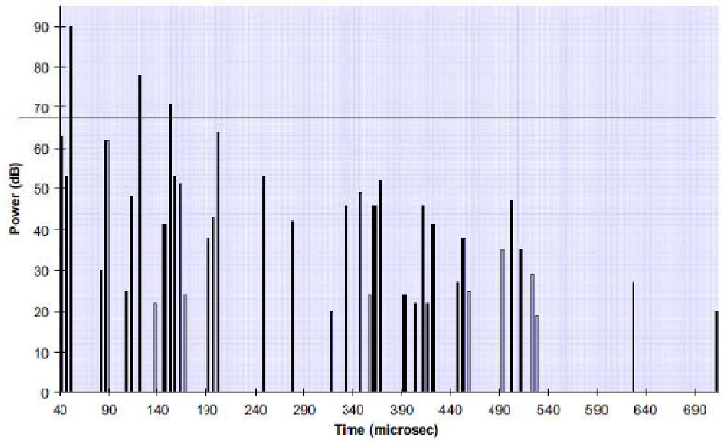

Fig. 3: Received signals at the receiver

If the shape of the detection windows is considered as it can be seen in figure 4 a signal (symbol) from transmitter h arriving in TPj at time τhj contributes to the wanted signal if $\tau hj \leq \tau j + Tg$ (Guard intervals) while it is interfering if $\tau hj > \tau j + Tg$.

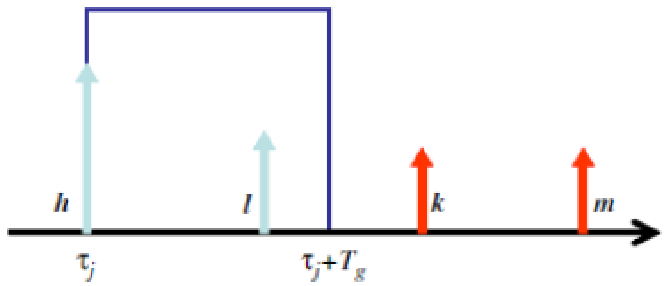

Fig. 4: Detection window in TP j and synchronized with signal h: signals h and l are fully wanted; k and m are fully interfering

Another point that has to be taken into consideration is that the different transmitter stations are configured with certain guard intervals periods, and these guard intervals can be different from one station to another.

Definition of the guard interval periods could also reduce the interference at a given reception point.
Once the problematic has been defined the proposed solution for the TOP problem is based in the Simulated Annealing algorithm. Simulated Annealing allows obtaining the optimal temporal offset of each transmitter station, minimising the absolute cost in the entire region. It is based in the measure of the interference level, specially penalising the produced interferences in highly populated TPs. It also provides:

- If a new transmitter or repeater station is added, the network calculations can be easily remade, obtaining the new optimal network configuration.
- If a problematic zone is detected, the algorithm allows a relatively fast calculation if the problem can be solved modifying the configuration of certain transmitter stations, and detecting the influence of these modifications over other TPs.
- Finally if the problem does not have a solution with the present stations, it allows to quickly detecting if the addition of a new transmitter or repeater station could reduce the problematic.

4. Description of the Simulated Annealing optimization

Simulated Annealing has proven to be one of the most efficient tools for the frequency deployment optimization in GSM-GPRS and TETRA networks, obtaining a great cost reduction (interferences) in front of other heuristic techniques (iterative and non iterative). It also has been employed in the 3G networks for the optimization of the pilot levels, base station antennas downtilt, terminal Active Set parameters, etc.

The Simulated Annealing is a metaheuristic algorithm that optimizes the cost function of the defined TOP problem. However for the solution implementation the different scenario parameters have to be well defined. In the next points a description of the scenario parameters and the estimated optimal values are shown.

Receiver considerations

In the SFN networks, different stations simultaneously transmit the same program. The signal originating from different sources at a given point can be considered as a constructive or destructive interference, depending on the delay of the signals from the dominant.
As it has been described in the previous section, the received signals at the receiver have time differences depending on the transmitter distance to the TP. If these time phase shifts allow the arriving of the desired signal out of the guard interval the auto-interference problem will take place on the SFN network.
Following this line, the receiver also has an important role since depending on the receiver type the synchronization with the desired signal is different. Currently two different synchronization methods have been deployed on the commercial systems:

- First echo receivers: These receivers evaluate the delay of the different signals from the dominant signal (see Fig.5). This delay is a function of the distance difference between the transmitters and the TP and also the relative delays from the transmitters.

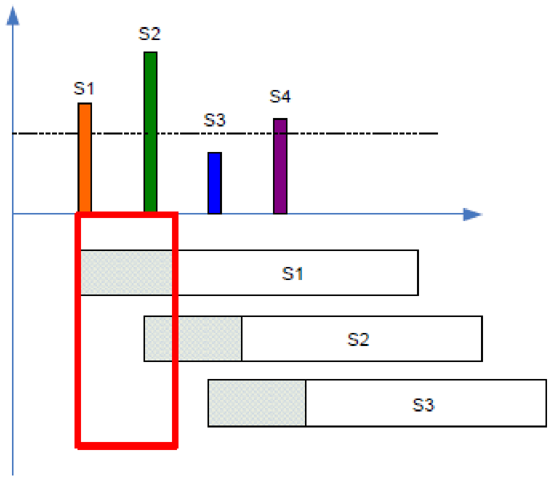

Fig. 5: Synchronization in first echo receivers

- Best echo receivers: These receivers establish the transmitter whose signal imposes the reference symbol (see fig.6). This transmitter can be whatever the desired one, or the transmitter that has whose signal has arrived first with a signal level above a certain threshold.

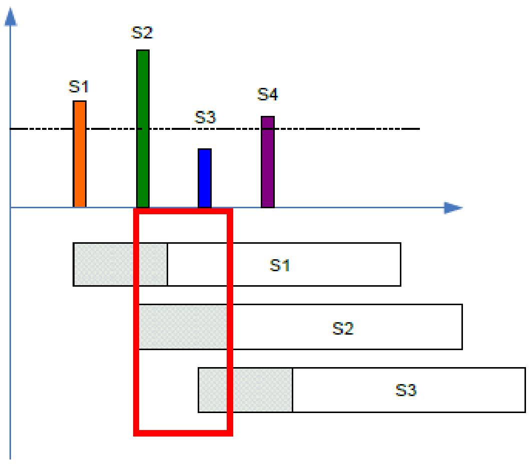

Fig. 6: Synchronization in best echo receivers

Radio planning scenario

The first parameter that has to be considered for the design of the proposed solution is the differences from the transmitter stations parameters. The most important parameter is the guard interval which may be different for many different groups of transmitter stations. In other hand it also has to be considered that the group T(j), listened transmitter stations at the TPj can be classified in two categories:

- W(j,τj) as desired contributions
- I(j,τj) as interference contributions

Different studies point out that a TPj is covered if the following condition is satisfied:

$$\sum_{i \in W(j,\tau_j)} P_{ij} \geq K \sum_{i \in I(j,\tau_j)} P_{ij}$$

Once all the parameters are lineally defined a K constant is defined. This parameter depends on the required CIR (*carrier to interference ratio*) which can vary between 20 to 40 dB depending on the environment and the kind of the scenarios. Therefore the solution has to:

- Fixed Offset: test if with the different τj possible values (this values match up with the arrival times from the signals received at the TPj) there is anyone that satisfies the previous defined equation
- Unsettled Offset: assign to every transmitter a Ti optimal offset value that satisfies the previous defined equation.

In this case it could be said that the TPj is well covered. The subset of covered TPs is noted as C. The function to be optimized, also denominated "global coverage area" is: $\sum_{j \in C} w_j$

Where wj, usually in practice represents the weight function, which is equal to Hj (the number of inhabitants at the TPj). The reason of taking the number of inhabitants as the optimization parameter is defined in order to prioritize the maximization of the reception over populated areas instead of inhabited areas where the maximization of the coverage area would not suppose an added value for the service providers. The higher value of the function represents a better solution obtained, furthermore in the Simulated Annealing tool, the cost function (that has to be minimized) will be inverse proportional to the global coverage area.

TOP definition

For the formulation of the algorithm, the first that has to be taken in to account are the following two considerations:

1. Given a TPj, it can be defined from the received stations T(j), that a subgroup S constitutes a coverage group if the differences between the different delays , two-by-two from all of them, is lower than the guard interval time Tg. It is possible that a TP could have different coverage groups; the subset of coverage groups is noted as τj. The TPj will be covered (in the case of a fixed time offset) if it exists a coverage group whose all the received signals are inside the detection window (Tg). This coverage group would be the active coverage group. For the optimal reception it must exist at least one in each TP.
2. General case (for unsettled time offsets): the temporal offset values have to be found in order to guarantee the condition that at least an active coverage group is found at each TP. This is a complex problem where it may not exist a solution depending on the scenario.

The mathematical description of the algorithm is as follows:

As it has been defined every TP can accept more than one coverage group. For example a TPj can accept S1(j), S2(j) …Srj(j) coverage groups.

At this point two binary variables are defined:

- xj (1 if there is not a coverage group at TPj, otherwise it will be 0).
- yhj (1 if the h coverage group is active, and 0 otherwise).

With both variables and the optimization parameter the algorithm tries to satisfy the following conditions:

$$\min \sum_{j} w_j x_j \quad for\ all\ j$$

$$x_j + \sum_{h=1,\dots r_j} y_{hj} \ \geq 1\ for\ all\ j$$

$$\left|\tau_{ij} - \tau_{kj}\right| + M \cdot y_{hj} \leq T_g + M \ \ for\ all\ h = 1, \dots r_j\ , \quad i,k \in S_h(j)$$

This method requires knowing the τj set, this is all the coverage groups, for every single TPj which in fact can result in a computationally expensive method. However this calculation can be simplified with the following consideration:

$$\sum_{i \in S} P_{ij} \geq K \sum_{i \in TPj \setminus S} P_{ij}$$
$$P_{kj} > \frac{1}{K} \sum_{i \in TPj \setminus \{k\}} P_{ij} \ \ for\ k \in TPj$$

If this condition is satisfied, k belongs to all the TPj coverage groups. Defining S as the transmitter stations contained in all the TPj coverage groups, and being S a coverage group, it can also be demonstrated that the group S is the only coverage group of TPj. This assumption allows simplifying the computational complexity with an error value that can be considered negligible.

Simulated Annealing algorithm

Along the previous section it was explained that radio planning optimization can be posed as a combinatorial optimization problem. Indeed combinatorial optimization aims at finding the set of parameters that maximizes (or minimizes) an arbitrary cost function, in this case defined by the radio planning engineer. In this sense, the most popular resolution approach was the Local Search (LS), which can be roughly summarized as an iterative search procedure that, starting from an initial feasible solution S, progressively improves it with a series of modifications. In particular, the set of new solutions that can be generated from the current one is the solution neighborhood N(S) and all the possible solutions conforms the solutions space. The search terminates when it encounters a solution that cannot be improved with any modification. Thus, with almost all likelihood the algorithm will not reach the best possible solution and will get trapped in a local minimum.

$$P\ (energy\ state = x) = \ c_t\ exp\left(\frac{-x}{k_B T}\right)$$

Where:
C_t: Normalizing constant (cT > 0).
K_B: The Boltzmann constant (1,38 ·10-23J/K).

Likewise, from a physical viewpoint, there is some non-zero probability of reaching a higher energy state. As a consequence uphill movements are allowed with a certain probability too, which decreases as the temperature is lowered. Thanks to this strategy, the algorithm is able to escape from local minima, especially at the beginning of the optimization and facilitating a more efficient exploration of the solutions space.
In order to make of SA a robust procedure, it is desirable that the quality of the final solution is independent of the initial one. Thus, the value of T0 must be high enough so that most of transitions are accepted; otherwise the algorithm could be conditioned to be trapped in local minima.
The initial value can be easily found starting with a small value of T0 and multiplying it by a value greater than 1 until the ratio of accepted solutions is close to 100%. In the simulations of this work the search is stopped when this ratio is higher than 85%.
On the other hand another important parameter is the cooling strategy. In this case, for a slow enough cooling strategy, if stationary is achieved at level n, in the next one (n+1) the number of required iterations will be lower because results are going to be very similar and stationary will appear sooner. Hence, and outlining the importance of having a long enough iteration at T0 several authors have proposed as the most appropriate cooling update the following equation:

$$T_{n+1} = \frac{T_n}{1 + \frac{T_n \cdot (1 + \partial)}{3\ \sigma_n}}$$

The aggressiveness in the reduction of Tn can be controlled with δ so that simulation time can be adjusted to the available one. On the other hand, σn represents the standard deviation of the cost evolution with temperature Tn. The optimization of both parameters is the key point in order to obtain the optimal solution of the Simulated Annealing algorithm. In this report different values of δ and σn have been tested in order to obtain the optimal preliminary result. However in a real data network optimization stage these parameters should be found in order to exploit the Simulated Annealing algorithm benefits.

4 Preliminary Results

The goal of this first approach to the DVB-T and DVB-T2 planning optimization solution is to test the enhancement of this solution with the Simulated Annealing algorithm, since as it has been defined at the beginning of this paper, the idea is to optimize the whole Catalonian area network. This first approach will be

very useful in order to ask for the real data of the current implemented network and it also will show the improvement of the network with this almost implementation cero cost solution.
Thus the resources available for the network planning optimization are the following:

- Forsk Atoll
- Matlab
- Catalonia digital elevation model (20x20 m.)
- Catalonia ortophoto image (20x20 m.)

The Forsk Atoll tool is a very powerful network planning tool that allows to generate the coverage maps of different mobile communications systems (as for example GSM, WiMax, LTE, etc) and manage its parameters. However for the development of the project this tool has not been used in this stage since no network parameters (antenna allocation, transmitted power, offset parameters and population data) have been available. For that reason a previous Matlab scenario has been considered to test the functionalities of the Simulated Annealing algorithm.

The implementation has been done with the Catalonia digital elevation model available, in order to take into account the coverage area of the different transmitters with the selected channel model. In this first evaluation of the proposed Simulated Annealing based solution stage, it has been defined a possible scenario over the Lleida province

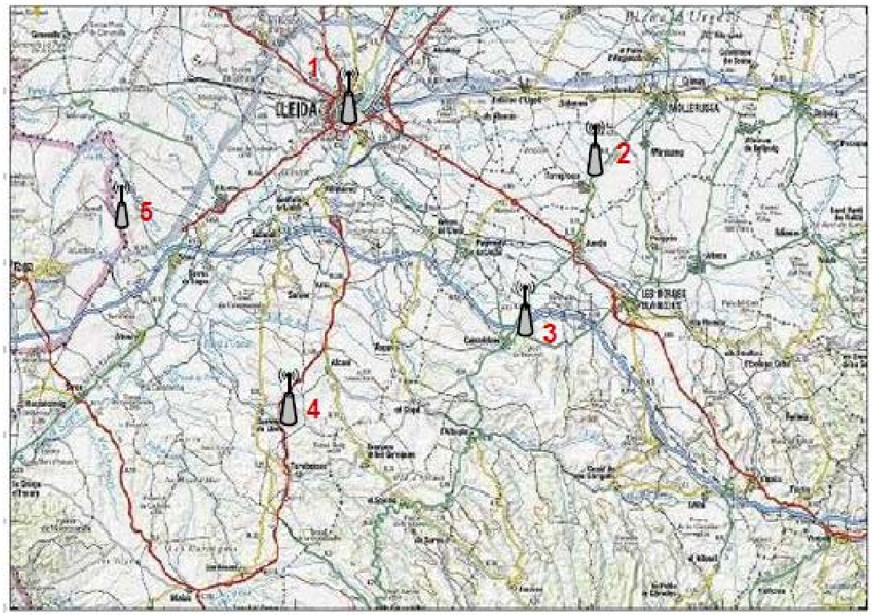

Fig. 7. Studied area for the network optimization

The parameters of this possible DVB-T network configuration are the following:

- Number of transmitting antennas: 5.
- Sites allocation: Lleida (1), Torregrossa (2), Puigverd de Lleida (3), Sarroca de Lleida (4), Lo Puntal (5).
- Initial transmission delay: 0 µs for all the transmitter stations
- Antennas: Omnidirectional.
- Transmitted power: 1 W for all the transmitter stations.
- Channel model: Okumura-Hata.
- Transmission mode: 32 K.
- Guard Interval: 1/128 (28 µs).
- Receiver Sensitivity: -78 dBm

For the definition of the simulation environment with Simulated Annealing the tests have been performed fixing all the transmitters with a specific guard interval value. However the simulation platform has been designed for supporting guard interval variability and it is prepared for a possible future development stage with real network parameters.

Coverage analysis
The first step to validate the proposed optimization solution is to generate the initial scenario coverage map. In this context with the previous defined parameters a study of the coverage area is performed.

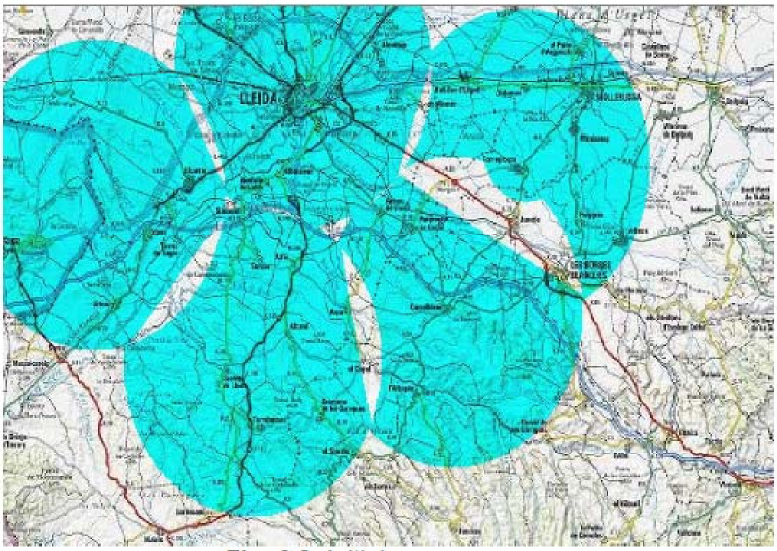

Figure 8. Initial coverage

The coverage represented in figure 8 is defined as the received power above the receiver‟s minimal sensitivity (-78 dBm) and taking into consideration the interferences produced by the different antennas at a given point. These interference signals generate a lack of coverage if the difference between the contributing signals (inside the guard interval) and the interfering signals (outside the guard interval) is bellow than a defined margin. The defined margin for this scenario is 20 dB, as it is defined in the DVB-T standard [7].

As it can be seen on the figure the omnidirectional antennas placed on the defined sites cover large areas of the Lleida province. With the channel model defined (Okumura-Hata) and taken into account that the scenario orography is almost flat; the coverage area of each site is almost a circular form. However in the neighbouring between sites there are small zones without signal coverage. The reason of this lack of coverage in these small zones is the time offset problem defined in the previous sections.

With these initial scenario definitions several tests have been performed in order to obtain the optimal cooling strategy for the Simulated Annealing algorithm and thus to optimize the overall network coverage. These parameters are the following

Table 6.1: Final cooling parameters

δ	0.1
σn	0.5

With both parameters defined the final coverage map of the scenario is shown at the figure below

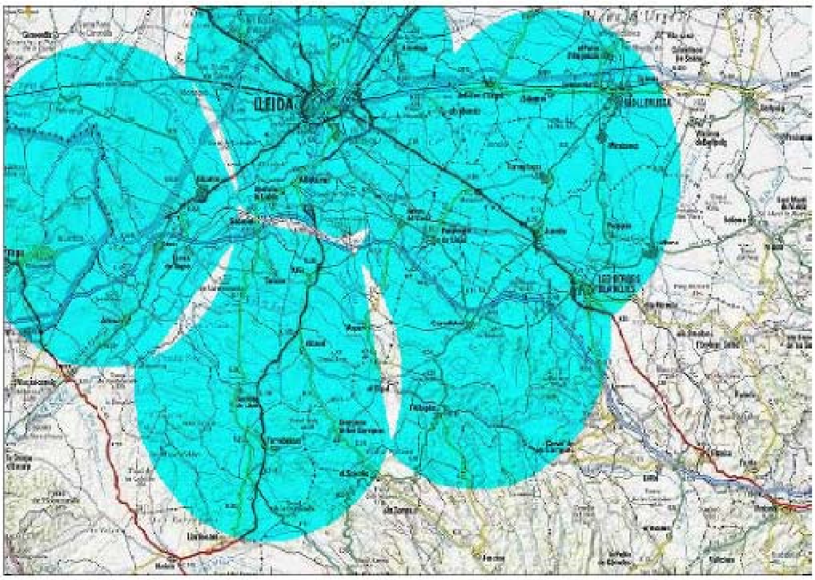

Figure 9: Final Coverage map

The final result after applying the simulated annealing algorithm is a coverage improvement of all the neighbouring zones. As it can be seen in the final map the worst affected zone (the east part of the map) is the one that has experienced a higher improvement and no uncovered pixels are found. Also the other neighbouring zones have reduced its lack of coverage.
Furthermore making a calculation of the pixels covered in both situations it can be seen that an increase of around a 5% in the number of coverage pixels is obtained.

On the other hand, the definition of the initial scenario was defined with a zero delay time synchronisation scheme. In the next table the time offset for each site is also represented.

Offset Parameters		
Site Number	Allocation	Time Offset (μs)
1	Lleida	0
2	Torregrossa	32
3	Puigverd de Lleida	87
4	Sarroca de Lleida	78
5	Lo Puntal	38

Table 2: *Offset parameters introduced by Simulated Annealing Algorithm*

Finally in order to validate the obtained results a figure representing the evolution of the cost function is shown at figure 10

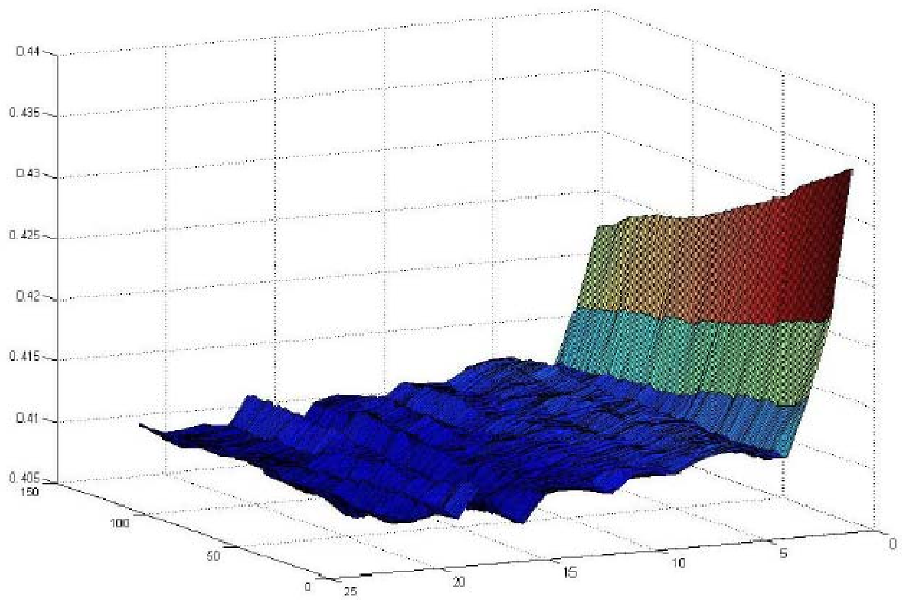

Figure 10: Cost function evolution

Thus as it was expected the cost function experiments increasing and decreasing processes during a given temperature value, and it also experiences the same effect with the temperature cooling. However after a temperature change the increase/decrease value is more abrupt than in a same temperature value.
Another important point that can be observed in the previous figure is the presence of local minima over the whole simulation process. The most important task in this stage is to evaluate which is the global minimum of the function in order to obtain the best possible solution. This result can only be achieved after a long iterative simulation stage.

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