Mobile TV Network Planning

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Abstract

The present article addresses the problem of efficient planning of fixed and mobile Digital Terrestrial Television network planning, based on DVB-T, DVB-H and DVB-SH standards. DVB-T is the European standard to deliver digital television to fixed receivers. DVB-H is an extension to transmit multimedia content to handheld devices and DVB-SH is the evolution of DVB-H to provide digital content using a satellite. This article presents the network planning tool for mobile TV DVB-T/H/SH systems developed by the Mobile Communication Group of the iTEAM Research Institute. It describes the structure and functionality of the network planning tool, as well as the methodology to estimate the coverage provided by a network configuration. The planning tool includes a dynamic simulator that evaluates the overall system performance perceived by mobile users dynamically over time. The utilization of planning algorithms is studied in order to find those configurations which provide certain coverage level at a minimum network deployment cost. The planning algorithms are based on two different optimization techniques: multi-objective Genetic Algorithms and Simulated Annealing.

Keywords. DVB-T/H/SH, Mobile TV, network planning, dynamic simulator, NSGA-II, Simulated Annealing.

1. Introduction

Mobile TV is nowadays the most representative mobile multimedia service. Recent commercial trials all over the world reveal a strong consumer interest, and it is expected to become a key application in next generation wireless systems. The highest potential for providing mass multimedia services is presented by digital terrestrial broadcast networks especially designed for mobile services. Only these networks have the necessary capabilities to support large scale consumption of mobile TV, as they can deliver broadband multimedia services to large audiences covering very large areas making use of high bandwidth channels with high transmission speeds.

DVB-H (Digital Video Broadcast-Handheld) is the European standard for digital terrestrial mobile TV [1]. It is an extension of the European terrestrial digital TV standard, DVB-T (Digital Video Broadcast-Terrestrial) [2], to reach handheld devices. It adopts the same physical layer as DVB-T, and adds new features at the link layer, being capable of sharing the same network infrastructure (e.g., transmitters, multiplexers, etc.). DVB-SH (Digital Video Broadcast-Satellite Services to Handhelds) [3] is the evolution of DVB-H developed to transmit multimedia content using a geostationary satellite.

One of the major concerns about the roll-out of mobile TV systems is the network infrastructure cost, as it not only represents the vast majority of capital expenditures (CAPEX), but is also dominant in the operating expenditures (OPEX) [5]. Due to the much more severe propagation conditions than in fixed reception (especially for the most critical user cases, pedestrian indoor and vehicular reception, which are as well the most popular ones according to commercial trials [6]), a considerably large number of new sites is required complementing the already existing broadcasting towers for fixed TV and Radio. This penalty is particularly evident for high area coverage targets (over 90% of service area locations) [7]. Because of these reasons, efficient network planning is needed in order to minimize network deployment costs.

This paper addresses the problem of efficient digital TV network planning and presents the network planning tool developed by the Mobile Communications Group (iTEAM). It is organi-

Mobile TV is expected to become a key application in next generation wireless systems.

zed as follows: Section 2 describes the basis of DVB-T, DVB-H and DVB-SH. Section 3 explains the methodology to perform DVB-T/H/SH network planning. Section 4 presents the network planning tool developed by the MCG. Section 5 shows the graphic interface of the network planning tool and some network planning exercises performed in Valencia. Finally, Section 6 describes the future lines derived from this work.

2. Introduction to DVB-T/H/SH Overview standards

DVB-T is the European standard to broadcast digital terrestrial television. The first version of the standard was published in March 1997 and in June 2008 the DVB project published a new specification, DVB-T2, which applies new coding and modulation techniques to extend the capacity of DVB-T in order to accommodate high definition services. One of the most important features included in these three standards is the COFDM (Coded Orthogonal Frequency Division Multiplexing) modulation [4]. This type of modulation uses a large number of orthogonal sub-carriers to carry data. The main advantage of this kind of modulation is its ability to cope with multipath propagation and ISI (Inter-Symbol Interference). A guard interval is introduced to increase immunity to echoes and reflections. Thanks to COFDM modulation, SFNs (Single Frequency Networks) can be developed. An SFN is a network where several transmitters simultaneously send the same signal over the same frequency channel. The aim of SFNs is the efficient utilization of the spectrum. They also provide better coverage with less transmitted power and lower antenna heights.

DVB-T has a high flexibility because it allows the selection of the modulation scheme (QPSK, 16-QAM, 64-QAM), the guard interval length, the number of sub-carriers (2k, 8k) and the FEC (Forward Error Correction) rate.

DVB-H is an extension of DVB-T to reach mobile and handheld devices (small, lightweight, portable, single antenna reception and especially battery-powered). The main technical features introduced are:

- A discontinuous transmission technique where data is periodically sent in bursts, which reduces the power consumption of terminals and enables smooth and seamless handovers, an optional intra-burst.
- Larger Single Frequency Network (SFN) planning flexibility.
- Forward Error Correction mechanism at the link layer called MPE-FEC (Multiprotocol Encapsulation-Forward Error Correction), which ensures more robust transmissions, especially under mobility and impulsive interference conditions.

Finally DVB-SH is the evolution of DVB-H to deliver IP based media content and data to handheld terminals via satellite. The most important feature of DVB-SH is the fact that it is a hybrid satellite/terrestrial system that will allow the use of a satellite to achieve coverage of large regions or even a whole country. In areas where direct reception of the satellite signal is not possible, such as large cities and dense urban scenarios, terrestrial gap fillers can be used to provide coverage. DVB-SH is designed to work in S band, which ranges between 2 and 4 GHz. This frequency band is available in Europe for hybrid satellite/terrestrial systems. The specification includes features such as turbo coding for forward error correction. Another feature of DVB-SH is the definition of two operational modes: SH-A and SH-B. SH-A specifies the use of COFDM on both satellite and terrestrial components. SH-B uses a Time Division Multiplex (TDM) on satellite with COFDM on the terrestrial component.

3. Mobile television network planning

Generally speaking, the objective of coverage planning for digital terrestrial broadcast networks is to provide sufficient signal quality over the service area with minimal network cost, while keeping the potential interference under a specified level. However, mobile TV network planning requires a different approach as it considers mobile reception use cases instead of fixed rooftop reception. Network planning consists on, given a deployment scenario and the operation frequency, determining from a candidate set of sites, in which ones a transmitter will be placed, along with the type of transmitter and its configuration (transmitter height and transmitted power, antenna radiation pattern, tilt and azimuth). In case of using a gap-filler, the transmitter from which it receives and amplifies signal has to be determined as well. To perform planning exercises, it is required to estimate the coverage level and the quality of service in the target service area for each of the different possible network configurations, as well as a detailed cost model with the cost information of using each of the transmitters and gap-fillers considered in each potential site.

3.1. Coverage Calculation

In order to compute accurately the area coverage in a DVB-T/H/SH SFN, it is not only necessary an accurate prediction of the received power at each location from each transmission site in the network, but also to determine how signals from the different sites contribute to the useful received signal or cause self-interference at each location. The coverage performance measure in an SFN is the Carrier-to-Interference plus Noise Ratio (CINR). A particular receiving location is assumed to be covered if the CINR fulfils the so-called CNR requirement, which depends on the transmission mode. CINR is defined as follows:

$$\Gamma = \frac{C}{I_{Self} + I_{Ext} + P_N} = \frac{\sum_i P_{Tx_i} \cdot w(t_i - t_o) \cdot l_i}{\sum_i P_{Tx_i} \cdot [1 - w(t_i - t_o)] \cdot l_i + I_{Ext} + P_N} \quad (1)$$

Where C is the useful received power, I_{self} and I_{ext} are the interferences caused by the own system and other systems respectively, and P_N is the thermal noise. The useful received power is the sum of the product of the received power of each transmitter i, P_i, and the function w gives a different weight to each one of the contributions arriving to the receiver, representing by this way the receiver response. t_i, is the time when a signal arrives from transmitter i and t_o, is the synchronization time. The received power, depends on the transmitted power and the attenuation suffered by the transmitted signal form each one of the antennas of the SFN to the receiver, being P_{Txi} and l_i transmitted power and propagation losses between the transmitter and the receiver.

In SFNs, contributions received within the OFDM symbol guard interval contribute to the useful signal, whereas signals suffering a time delay larger than the guard interval cause self-interference. Usually, a weighting function according to the signal delay is employed to determine the ratio between the useful and interfering contribution. This function is usually defined as [4]:

$$w(t_i - t_o) = w(\tau) = \begin{cases} 0 & \tau \le T_g - T_p \\ \left(T_u + \dfrac{\tau}{T_u}\right)^2 & T_g - T_p < \tau \le 0 \\ 1 & 0 < \tau \le T_g \\ \left(1 - \dfrac{(\tau - T_g)}{T_u}\right)^2 & T_g < \tau \le T_p \\ 0 & \tau > T_p \end{cases} \quad (2)$$

where T_g y T_u are the absolute guard interval and the useful symbol period, respectively and τ the time of arrival of the contribution relative to the synchronization time of the receiver. In practice $T_p = 7T_u/24$ as a reasonable limit for real receiver filters. Fig 1 shows w graphically:

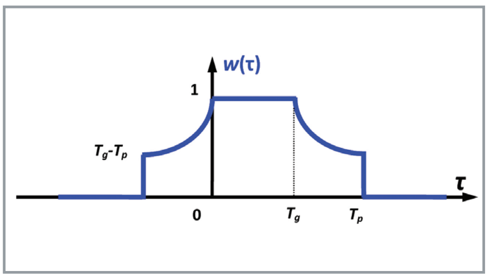


Fig. 1. *Weighting function w.*

The performance of receivers strongly depends on the FFT window synchronization strategy used to determine the time synchronization point. There are several synchronization techniques. The most commonly used in receiver modeling are: synchronization to the strongest signal, to the first signal above a threshold level, to the centre of gravity and to the maximum C/I [4].

Finally, received signals from each transmitter are traditionally assumed to have log-normal power distributions and they can be correlated each other. There are several methods to perform the combination of log-normally distributed random variables. Most of them consider that the sum of log-normal random variables is another log-normal variable, providing a method to estimate the mean and standard deviation of the resulting signal. Some examples of combination methods are the log-normal method [8], Schwarz & Yeh method [9]. These methods don't take into account correlation between signals. In case of considering correlation Safak method or Wilkinson method [10] should be used.

3.2. Propagation models

Propagation models are used to estimate the signal level received in each point of the scenario, taking into consideration the propagation losses suffered by the signal due to different propagation mechanisms such as reflection, refraction or scattering.

There are three types of propagation models: deterministic propagation models, physical-statistical models and empirical models. Deterministic models are based on theoretical calculations over a fixed geometry using ray tracing theory. Physical-statistical models combine deterministic models with statistics about the environment and empirical models, which are based on the results of measurement campaigns over different scenarios.

Satellite propagation and terrestrial propagation must be distinguished because propagation mechanisms vary from one type of propagation to the other. When considering terrestrial propagation, mechanisms such as diffraction over buildings and final diffraction have to be taken into account, while for satellite propagation another type of losses must be included. These additional losses are produced by atmospheric gasses, rain and atmospheric diffraction.

There are several propagation models and the decision of which one is the most appropriate depends on different factors such as the frequency band, the type and resolution of available geographic data, transmitter height and reception conditions.

For the terrestrial component different propagation models can be selected, taking into account that the propagation model used will depend on the frequency band and therefore will be diffe-

To compute the coverage level in an SFN it is necessary a prediction of the received power from each transmission site and to determine how signals contribute to the useful signal or cause self-interference.

Dynamic system-level simulations are used to evaluate the overall system performace perceived by mobile users dynamically over time

rent for DVB-T/H and DVB-SH. Okumura-Hata [11] can be used for UHF frequencies, and Xia-Bertoni [13] can be used for both UHF and S frequency bands. With reference to the satellite component, a the propagation model must take into account losses due to free space, atmospheric gasses, rain and multiple and final diffraction [14].

Performance of propagation models depend on transmitter height, available geographic information and its resolution. As Okumura-Hata does not consider building and terrain information to perform path loss calculations, this model will be suitable for high transmitters or if there is not information about the deployment scenario. For transmitters whose height is similar to building height, propagation models which consider diffraction in building are more suitable.

When considering a real scenario, the accuracy of the radio propagation models, which give a prediction of the mean received power at each location in the service area from each transmission site in the network, depends on the available cartography and its resolution. Geographical data can be classified in terrain height (topography), terrain morphology (land usage or clutter class), and building heights and shapes. In order to further increase the accuracy of the results, radio propagation models can be calibrated based on field measurement campaigns.

3.3 Network planning algorithms

As described before, network planning consists on deciding where a synchronized transmitter or a gap-filler will be placed and its configuration in order to fulfill some objectives. Due to the high number of decision variables, network planning becomes in a complex computational problem. Planning algorithms are needed in order to reduce the computational cost of network planning. Planning algorithms seek the minimum cost network configurations as a function of the coverage level. Two different optimization techniques have been studied: Genetic algorithms, specifically Non-Dominated Sort Genetic Algorithm – version II (NSGA-II), and Simulated Annealing (SA).

Genetic algorithms are inspired on biological evolution and its mechanisms to seek the minimum network configuration cost.

Each network configuration is an individual of the population. In each generation, the performance of every individual in the population is evaluated. Then selection techniques are applied to choose the parent population. The next generation is created by means of crossing and mutation techniques. The new population is then used in the next iteration of the algorithm, which finishes when a maximum number of generations has been produced.

Simulated Annealing is a modification of local search algorithms that allows movements to worse solutions in order to avoid the permanence in a local solution. Each step of the SA algorithm replaces the current solution by a random nearby solution, chosen with a probability that depends on the difference between the corresponding function values and on a global parameter T (called the temperature), that is gradually decreased during the process. The dependency is such that the current solution changes almost randomly when T is large, but increasingly downhill as T goes to zero.

A detailed description of NSGA and SA can be found in [15] and [16] respectively.

3.4 Dynamic system-level simulations

Dynamic simulations are used specifically to evaluate the overall system performance perceived by mobile users dynamically over time. Such simulations can be used as a complement of traditional radio coverage planning tools for analyzing quality of service and radio resource management aspects of the network.

Field measurements are obviously the most accurate way to measure the performance of any wireless communication system. However, results obtained apply only for the specific receiver trajectories and, in order to extract conclusions about the overall system performance experienced by users in a service area, a large number of measurements is needed. With a dynamic system level simulator it would be possible to evaluate the overall QoS perceived by the users for a given service as a function of the transmission configuration. For example, simulations could be performed for monitoring the time evolution of the errors perceived by mobile users of a streaming service, or determining the users that successfully receive a file (and the amount of repair information needed by each user not able to decode the file). To achieve this, it is necessary to model accurately the time-variant error behavior of the receiver physical layer, and emulate the upper protocol layers based on this error information [17].

4. Network planning tool

Fig. 2 shows the structure of the network planning tool designed by the MCG. It has been developed using ArcGIS due to its potential to manage geographical information. Its design is modular in order to allow changes and improvements. By means of the network planning tool the user is able to perform DVB-T, DVB-H and DVB-SH network planning and fulfill capacity QoS requirements.

The user provides the planning tool information about the deployment scenario, specifically the position of the potential sites, operation frequency, transmission mode, equipment, satellite configuration and quality requirements. Using this information, the network planning tool is able to determine optimal configurations by means of planning algorithms. To do so, it is necessary to calculate the coverage provided by a configuration.

Received power from each transmitter is estimated evaluating all the gains and losses experimented by the signal (link budget). Propagation model calculates path losses from transmitters to each receiving point. The time of arrival of each signal is calculated as well. It is possible to choose between different terrestrial propagation models for DVB-H: Okumura-Hata, Xia-Bertoni and Walfich Ikegami. A new model based on Hata formulation which adds diffraction losses has been implemented as well. For DVB-SH systems Okumura-Hata is not available because this propagation model is not suitable for S frequency band. DVB-T systems include models developed for fixed receivers.

Using the information relative to the power and delay of the signal received from each transmitter and giving a synchronization method, the synchronization module decides where synchronization window will be placed. Total useful and interfering signal are estimated with the combination module and finally, using the coverage requirements and the total CINR, the coverage level is calculated.

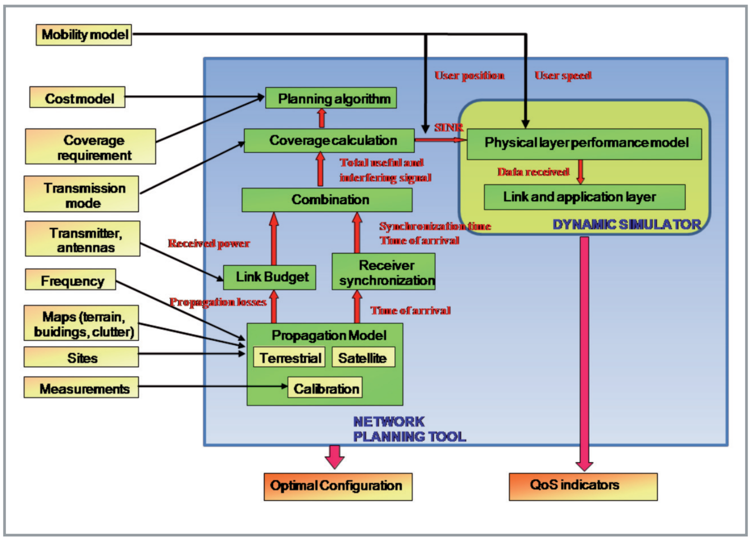
The network planning tool includes a dynamic simulator that provides information about the quality of service when the receiver is moving inside the service area. To do so, a mobility model based on real traffic patterns of the scenario under study is needed. The physical layer performance model computes which information is correctly received based on the information of the time-variant reception conditions obtained from the mobility and radio coverage models. Finally, this information is used in the link and application layers to compute the QoS indicators for the service under study.

5. Example of Results

In this section some illustrative results obtained with the network planning tool are presented. The deployment scenario under study is the city of Valencia (Spain).

The planning tool is able to perform calculations using geographical information of the deployment scenario. After defining geographical information, transmitters or potential sites are defined. It is necessary to define position, height and equipment used. In case of DVB-SH systems, satellite configuration must be defined.

Different types of emitters can be used: synchronized transmitters and gap-fillers. Transmitters receive the base band signal by means of a dedicated transport network (terrestrial link, digital network or satellite link), modulate it using COFDM, amplify it and transmit it. They



■ **Fig. 2.** *Structure of the network planning tool.*

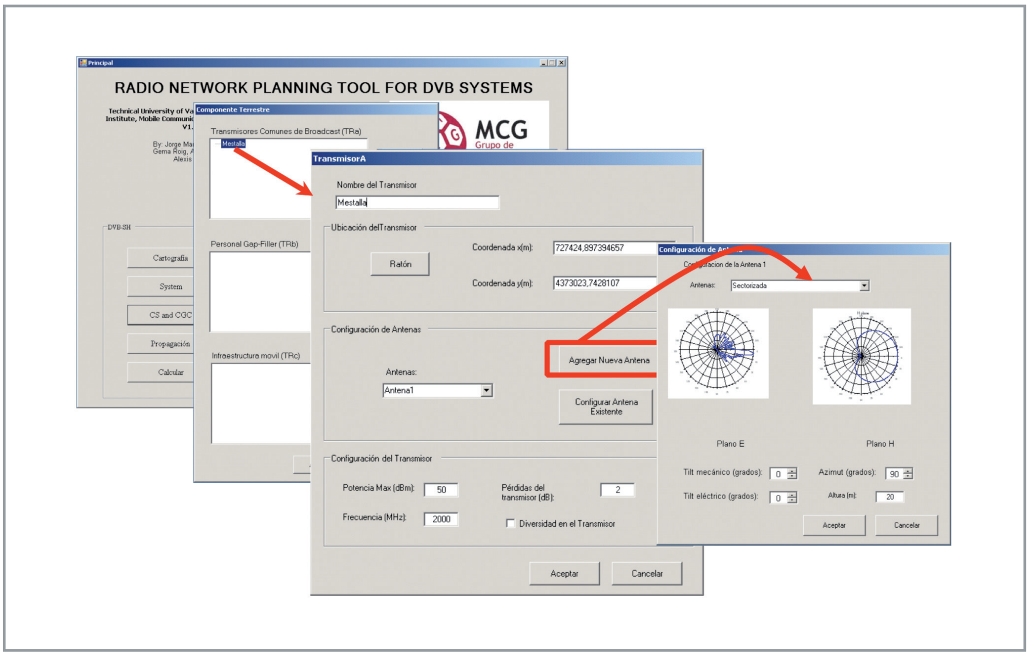
are synchronized in both time and frequency using a GPS reference signal.

Transmitters provide high quality in the transmitted signal and support high transmitted power. However, they may be a costly solution for a low-power site. On the other hand, gap-fillers are on-channel repeaters that receive the RF signal from one site of the network, amplify it and retransmit it at the same frequency. Compared to transmitters, gap-fillers are lower cost solutions, as they do not need a transport network, a COFDM modulator, and a GPS synchronization system. However, due to the coupling between the receiving and the transmitting antennas, the maximum output power is limited in order to avoid system oscillation (and hence the coverage level). Definition of gap-fillers is different from transmitters. Receiver antenna and its configuration, as well as isolation between receiver and transmitter antennas have to be defined. Isolation between antennas depends on the separation between antennas and their position.

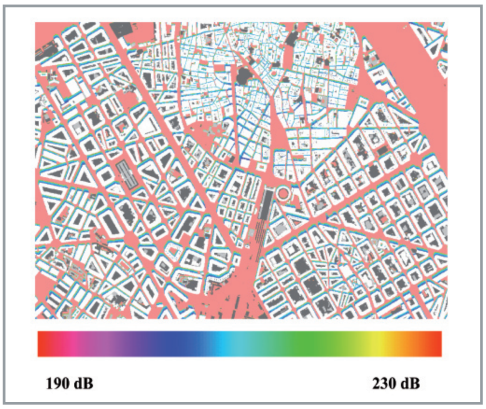
The network planning tool uses all the information described before to perform calculations such as received power from each transmitter, received power from an SFN and coverage provided by a network configuration. Fig 3 shows the propagation losses experimented by a signal from a geostationary satellite. The satellite under study is Intelsat 901, at -18ºW. Figs. 4 and 5 present, respectively, the signal level and the coverage provided by a SFN formed by two transmitters.

Coverage calculations are utilized to find the optimal network configuration, specifically those configurations that provide certain coverage level with a minimum deployment cost. As explained in Section 2.3 two optimization algorithms have been used: NSGA-II and SA. As a result, the network planning algorithms provide the network configuration that obtains a given coverage level with a minimum network deployment cost. Fig. 7 shows a comparison

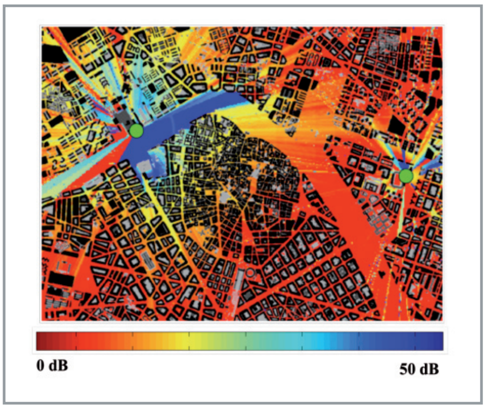
Future work includes calibrating the different propagation models and introduce new DVB technologies suchs as DVB-T2 and DVB-NGH.



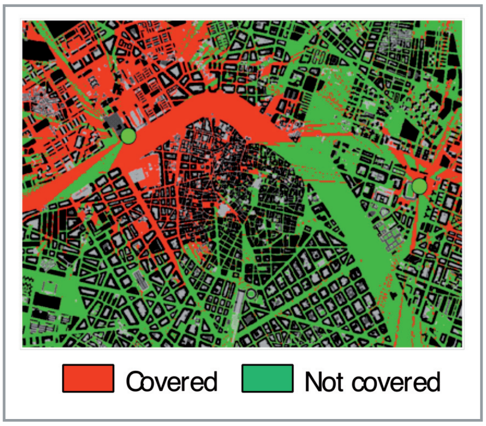
■ **Fig. 3.** *Interface of the network planning tool*



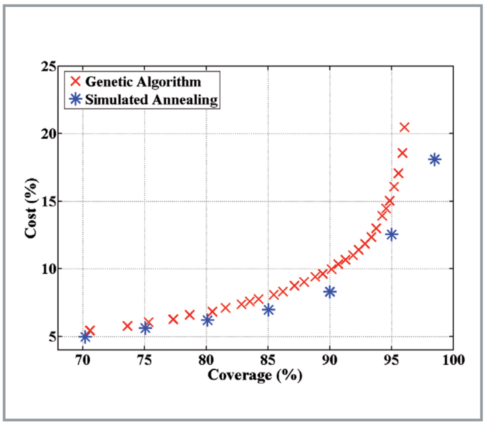
■ **Fig. 4.** *Propagation losses for the geostationary satellite.*



■ **Fig. 5.** *CNR with two syncronized transmitters*

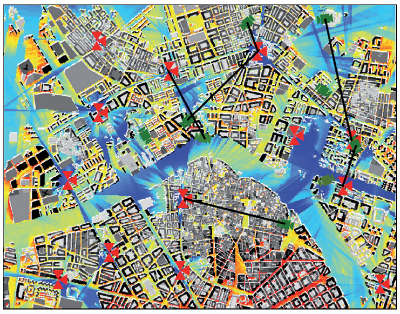


■ **Fig. 6.** *Coverage provided with two syncronized transmitters.*



■ **Fig. 7.** *Result os the planning algorithms. Network deployment cost vs. coverage.*

between NSGA and SA. SA gives better results than NSGA. However, NSGA obtains a wide range of coverage values only with an execution. Fig. 8 shows the optimal configuration for a DVB-H network, obtained by Simulated Annealing. Synchronized transmitters are represented with a red symbol and gap-fillers are represented with a green one.



■ **Fig. 8.** *Optimal configuration for coverage 95%.*

6. Conclusions and future work

In this article a network planning for mobile TV systems has been presented. With the network planning tool the user can estimate the coverage provided by a network configuration and find the optimal solutions to provide certain coverage level. Future work consists on improving and increasing its functionalities:

- Validation and calibration of satellite propagation model by means of field measurements.
- Include new DVB technologies, suchs as the second generation of digital terrestrial TV (DVB-T2), and the new generation handheld (DVB-NGH).

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Biographies

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