DVB Network Optimisation for Energy Efficiency

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***Abstract*—Based on OFDM and Single Frequency Network architecture (SFN), DVB-T systems can combine signals coming from several transmitters yielding to a diversity gain. The network planning for such systems has a great impact to quality of service and costs. This paper presents a network planning approach for DVB-T services and focuses the investigation on the optimisation of the network deployment in terms of energy efficiency. For the purpose of the investigation an evolution optimisation technique based on genetic algorithm method is developed and applied on a given network topology over a real Digital Elevation Map (DEM). The field computations are based on an accurate multiple diffraction model based on multi-shape Uniform Theory of Diffraction (UTD). Simulation results show a great energy consumption savings that yield to the green deployment of the network. Comparisons with the coverage and cost optimisation scenarios are also presented.**

***Keywords*— Network planning, DVB-T optimisation, Energy efficiency, coverage optimisation, genetic algorithms**

I. INTRODUCTION

The deployment of a network over a given geographical area is a complex task and great attention is payed by the engineers to various parameters of the network. The design and optimisation of the network is based on objectives such as quality of service (QoS) and costs. The requirement of additional services and high data rates has led to the deployment of a large number of networks increasing their energy consumption demands. The result is that the telecommunication industry is responsible for the same amount of CO_2 emissions as the airline transportation industry [1, 2]. The need to incorporate energy efficiency within the network design is obvious. Furthermore, if one considers the costs of the network, it is easily observed that energy efficiency can yield great electricity costs savings comparable to the installation of additional transmitting stations (over a period of time).

The total cost of ownership (TCO) of a network is divided to the capital expenditure (CAPEX) and the operational expenditure (OPEX). CAPEX incorporates the deployment and purchasing costs and OPEX incorporates the operation and maintenance costs. In general OPEX are responsible for the 60-70% of the TCO and CAPEX for the 30-40% of TCO. In addition, electricity costs and power consumption constitute the largest portion of OPEX.

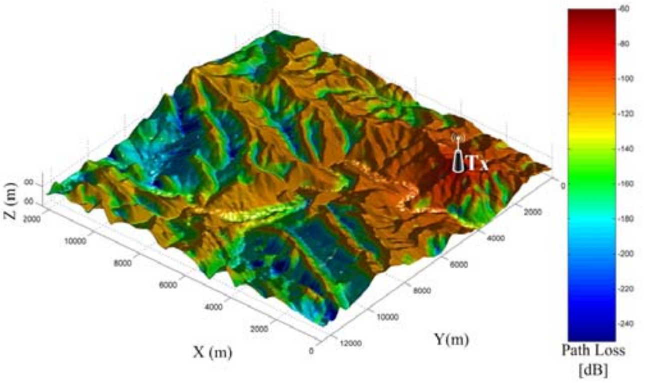

Figure 1. Coverage shape in real terrain (algorithm of [11]).

This analysis concludes that the cost of a network is not always optimised when the network is deployed with the minimum number of required base stations to cover a given area with a certain QoS but the minimisation of the total required power of the network can have a great affect.

Usually, the transmitter position, the power levels and the antenna characteristics (pattern and height) are used as the variable parameters for network optimisation. In [3] a minimal cost coverage planning for digital audio broadcast DAB application is presented that employ simulated annealing optimisation technique. The authors investigate three different optimisation scenarios. The first concerns the coverage optimisation without considering the cost of the network deployment. The second investigation concerns the coverage optimisation but the most cost effective solution was selected. The final scenario investigates the cost as an objective function within the simulated annealing technique.

In [4] a particle swarm optimisation method was used for DVB-T network design. The optimisation in this case explored the best network parameters (antennas characteristics and symbol durations and delays of the transmitters) for providing maximum coverage and minimum interference to the network. In [5] a coverage optimisation technique is presented that employs linear integer programming. The scope is to automatically select base station position and transmit power level for controlled overlap of cells. The algorithm is implemented for CDMA networks where overlap is required for soft handoff processes. It can be also implemented for DVB-T networks where cell overlap has a serious affect to network gain or interference.

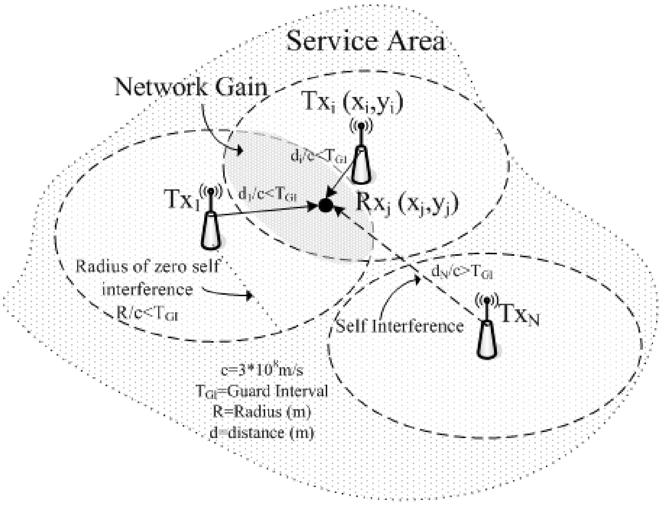

Figure 2. System Model

In [6] a case study for DVB-T network planning for Greece is presented and frequency assignments, interference minimisation and coverage maximisation is the target of the optimisation process. Finally, in [7-10] several methods for network coverage optimisations are presented that are based on genetic algorithms, greedy algorithms and simulated annealing.

The cost in most of the found research papers is associated to the number of the required transmitting stations of the network. The main targets concern the minimization of the required number of stations maintaining a given QoS or the maximisation of the coverage of the network. In practical scenarios, it is not possible to deploy the network in the optimal theoretical locations since various restrictions exist. In addition, coverage is usually referred to a randomly selection of receiving positions, neglecting the real receiver locations. Furthermore, most of the found related works used propagation models that are based on empirical or semi-empirical approximations. These models usually estimate circular coverage cells that do not reflect real scenarios (fig. 1). Of course this bounds the accuracy of the final estimations.

In this paper, an evolution optimisation technique is developed based on genetic algorithms that can automatically select best transmitter position from a set of real available sites, and power levels in order to cover with a certain QoS a real area of Northern Greece providing the minimum required energy consumption by the network. The coverage is estimated to real receiver locations that correspond to villages, towns and cities of Northern Greece. In addition, a deterministic propagation model based on multi-shape UTD is used for field predictions over the irregular terrain. In [11] the performance of the used model is presented and a very good fit between predictions and real measurements over irregular terrain are shown. As the cost of the network, the energy consumption is investigated and it is compared to scenarios where the cost is associated to the coverage percentage or the number of transmitters and important conclusions are drawn.

II. DESCRIPTION OF THE SYSTEM

The DVB-T network is deployed in order to provide digital television over a target area that is named as service area. The service area incorporates the towns and villages where the video program should be broadcasted with an acceptable QoS. The transmitters of the scenario (*Tx*) are indexed from a set of predefined available transmitting locations Tx_N, $\mathbf{N}=\{1,\dots i,\dots N\}$ where N is the maximum number of transmitters. Each *Tx* has coordinates $\{x_i, y_i\}$. The receivers are indexed Rx_M, $\mathbf{M}=\{1..,j,\dots.M\}$ where M is the maximum number of receivers. Each *Rx* has coordinates $\{x_j, y_j\}$ as presented in fig. 2. The DVB system is based on a SFN approach where all the transmitters are assumed to be synchronised and transmit at the same frequency. The system operates under OFDM and this provides great network gain that arises from space diversity. In OFDM systems the delay spread of the signals are bounded by employing a longer symbol duration T_s that consists of the useful part T_u and the guard interval T_{GI}. In case a strong signal component arrives from a transmitter having a great distance from the receiving point then self interference can cause intersymbol interference and degradation of the QoS.

The guard interval defines the maximum distance between the transmitter and receiving point for interference considerations (Fig. 1). In DVB applications overlap of the coverage area between the transmitters is important and minimizes violent degradation of reception quality caused by the brick-wall effect of digital signals. In case of uncontrolled overlap self interference and degradation of the services may arise.

A. Interference Modeling

The model assumes an SFN network that the only cause of interference is caused the delayed signals from the same network. Interference from other existing networks is not considered at this stage. The QoS at a given location depends on the *C/I* ratio and for acceptable service it should be greater than a specific value U_0 that is imposed by the network parameters (modulation, code rate, channel type, etc…). For the purpose of this investigation a very simple receiver is assumed and the signal can cause interference only when the delay is greater than the guard interval of the system. Around each transmitter of the scenario a radius of zero and non zero interference areas can be distinguished with length that depends on the guard interval (fig. 2). A simplified weighting function is used to model interference signals, $w(\delta_i-\delta_0)$ where δ_i represents the relative delay and δ_0 represents the staring point of the receiver detection window.

$$w(t)=\begin{cases}0 & ,t<0\\ 1 & ,0\le t\le T_{GI}\\ 0 & ,t>T_{GI}\end{cases} \tag{1}$$

For a given receiver location the C/I ratio is computed according to

$$U=\frac{C}{I}=\frac{\sum_{i\varepsilon N} P_i w_i(\delta_i - \delta_0)}{\sum_{i\varepsilon N} P_i\left[1-w_i(\delta_i - \delta_0)\right]+N_0}\ge U_0 \tag{2}$$

where P_i is the received power from the i^{th} transmitter and N_0 is the background noise level.

B. *Coverage Modelling*

In order for a receiving location to be adequately covered by the network, the SNIR should be greater than a threshold value U_0 that is imposed by the system's parameters. The coverage probability is defined as

$$p_c(x_i,y_i)=P[U(x_i,y_i)\ge U_0] \tag{3}$$

For digital systems the probability of coverage should be high enough to overcome the rapid degradation of signal quality caused by the brick-wall effect. For DVB systems p_c should follow the relation $p_c(x_i,y_i)\ge P_0, 70\%\le P_0\le 95\%$.

C. *Scenario Under Investigation*

The scenario under investigation is presented in fig. 3. The terrain is modelled by a DEM with resolution of 90m (gridsize) and accuracy of the database of 16m. The mean altitude is 905m and the terrain incorporates areas with altitudes from 150m to 2350m above sea level. An area of 150x150Km is examined with 40 possible transmitter locations. The receiving points are considered to be real towns and cities in the area, thing that will reflect the optimisation of the algorithm to real needs. The receiving locations that are examined is 600 (circles points of Fig. 3). The height of the transmitters is assumed to be 40m above ground and fixed reception is assumed with receiving antennas at 10m above ground.

The DVB system has the following parameters.

Table 1. DVB-T SYSTEM PARAMETERS

System Parameter	**Value**
Frequency	600MHz
Bandwidth	7.6MHz
Receiver noise figure	7dB
Feeder Loss	3dB
Transmitter Cable Loss	3dB
Antenna Gains (both Tx, Rx)	10dB
DVB-T	**SFN**
Modulation	64-QAM
Code Rate	2/3
Guard Interval (T_{GI})	¼ (224μsec)
Mode	8K
Bit Rate	19.91MBbits
Minimum C/I for fixed reception (Ricean channel)	17,1dB
Location Variation (std)	5.5dB
Max. Distance between Tx without interference d(T_{GI})	67.2Km

The used propagation model is based on slope UTD approximation and utilises the *'strecthed string'* technique to distinguish the main obstacles in a given terrain profile. It applies the multi-shape slope UTD solution to model the terrain irregularities by a cascade of best fitted canonical obstructions (cylinders, wedges, knife edges) [11]. The terrain profile from the given DEM and *Tx* and *Rx* points is extracted by employing a bi-cubic spline interpolation algorithm that has been proven to work with acceptable accuracy in 3D terrain maps.

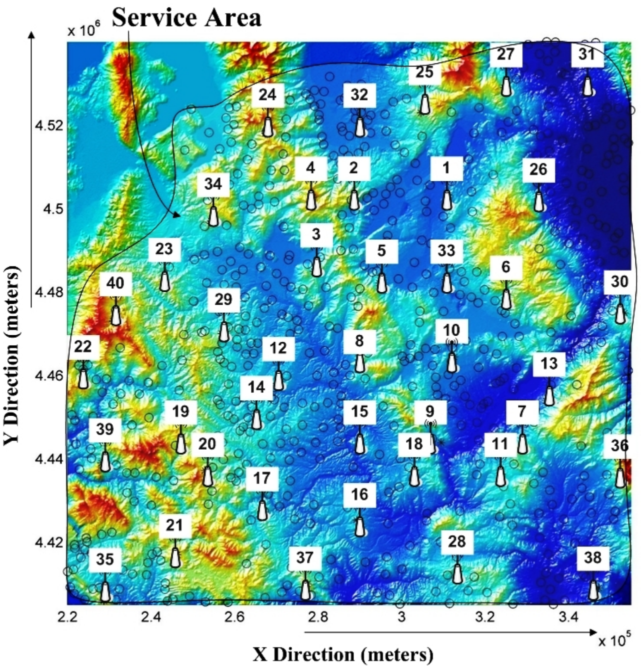

Figure 3. DVB-T network scenario. The DEM, tranmitter positions and indeces and the service area with the reception points are presented

Comparison between the used propagation model and real measurements show a very good fit [11].

III. PROBLEM DEFINITION

The decision variables and the objective functions are defined at this stage. The problem under investigation is to achieve energy efficiency to the network and this has as a consequence the reduction of the OPEX of the network. Furthermore, minimization of required power yields a decrease of CO_2 emissions. Finally, a reduction of the overall required power can enable renewable energy sources to penetrate smoothly to base station infrastructure. The research follows the initiatives for sustainable growth and green deployments commenced by different operators worldwide.

A. *Decision Variables*

The DVB network incorporates transmitting stations that are situated in feasible locations. These are shown in fig. 3. The receiving locations are real towns and villages or touristic areas of a northern part of Greece and are presented as circles in fig. 3. Both transmitters (Tx) and receivers (Rx) are considered as a set of geographical coordinates with

$$Tx \to N=[x_i,y_i], i\in[1 \quad N_{=40}] \tag{4}$$

$$Rx \to M=[x_j,y_j], j\in[1 \quad M_{=600}] \tag{5}$$

The scope of the optimisation algorithm is to define the proper Tx locations (x_i, y_i) and transmission power EIRP (p_i) in order to provide minimum overall system power (W) and maintain the required QoS (C/I) defined by the system (Table. 1). The overall power of the system is computed as:

$$W_{EIRP(dBW)} = \sum_i a_i p_i, i = 1 \rightarrow N \tag{6}$$
$$W_{(Watt)} = 10^{\frac{W_{EIRP} - G_{Tx} + L_c}{10}}$$

where G_{Tx} is the transmitter antenna gain, L_c is the transmitter cable loss, α_i is an on-off (1-0) parameter indicating if a transmitter exist at the specific location or not and p_i is a set of available power levels (EIRP) defined in the range

$$\begin{aligned} &a_i \in \{0 \quad 1\} \\ &p_i \in \{20 \quad 25 \quad 30 \quad 35 \quad 40 \quad 45\} dBW \end{aligned} \tag{7}$$

The optimization problem is then defined as

$$\begin{aligned} &\min imize \rightarrow W_{EIRP}(a,p) \\ &considering \rightarrow p_{c\,j}(a,p) \geq P_0 \quad j \in [1, M] \\ &adjusting \rightarrow a_i, p_i \quad i \in [1, N] \end{aligned} \tag{8}$$

A genetic algorithm optimization technique is used for the purpose of the investigation.

B. Genetic Algorithm

The main elements of the genetic algorithm (GA) are the genes, the chromosomes that consist of genes and the generation that consists of a population of chromosomes (usually between 30-50). The gene refers to a single transmitter and has two entries. One describes the parameter *a* (exist or not a transmitter) and the other the parameter *p* (power level of the transmitter). The chromosome is a set of genes and is considered as a possible solution to our problem. The generation contains a number of chromosomes (population) that participate to the evolution process. Each generation is assumed to consist of a population of 30 chromosomes. Starting from a randomly generated first generation, the GA follows some basic rules of natural evolution to provide an optimised sum of chromosomes after *x* generations ('years'). The optimisation is performed through a *fit function* that describes the optimisation target. In our case the fit function is equation (6) that needs to be minimised in the chromosomes of the final generation. The developed GA is based on the *elitism* approach. The process of the GA follows the rules:

1. *First Generation*: The first generation is a set of randomly selected possible network configurations. This means that for each transmitter (gene) the parameters *a*, *p* are randomly computed and they provide the first network configuration. This process is repeated for the population of 30 chromosomes of the first generation.
2. *Fit Function*: From the population of the generation the fit function of each chromosome is computed. The fit function is given by (6) and describes the overall transmit power of the network.
3. *Constraint check*: For each chromosome a check if the constrains are satisfied is performed. If the QoS and C/I is satisfied from equation (3) the fit function is unchanged. If the chromosome do not satisfies the constraint (meaning that it is not a desired solution) a linear penalty is applied that degrades the fit function.
4. *Elitism*: From the population of chromosomes of each generation the one with the minimum fit function is selected. This chromosome will be used to produce the next generation matched with the best 50% of the members of the population.
5. *Crossover*: The cross over is used to produce next generations. A multi point cross over method is applied with a probability of 90%.
6. *Mutation*: Mutation is an important step in GA and increases the performance of the optimisation process. Mutation occurs at the genes of the chromosome. A mutation probability of 0.2% was used.

IV. RESULTS

The scenario under investigation is presented in fig. 3. The investigation explores three different scenarios. The first concerns the optimisation of the network in terms of coverage (*CO*). In that case, energy efficiency is not considered in the GA and the coverage percentage of the testpoints is set as the fit function that requires to reach a maximum level. The second investigation concerns the minimization of the number of transmitting stations (*TX*). The fit function is set to be the number of Tx and needs to reach a minimum level. The final investigation covers the area of energy efficiency (*EE*). In that case the fit function is eq. 6 and needs to be minimized. In all scenarios the total energy requirements of the found networks are computed and compared to the *EE* case. For the clarity of the results, randomly generated network topologies are also demonstrated. For each scenario 100 independent runs of GA are performed.

GA do not converge to a unique global optimal solution but to a set of possible solutions that equal the number of the population. The optimum solution can be retrieved by the final generation considering specific restrictions. For example for the scenario (TX) in some cases the network topology consisted of a small amount of tower stations that transmit at maximum level of EIRP (tower stations). Of course this is not a feasible solution since it contrasts the Tower-Gap Filler model of DVB-T networks. Another restriction that is usually applied at such cases is to retrieve the solution that produces the minimum exposure. All these are subject to the network planner decision.

The first simulation result concerns a randomly generated network that satisfies the coverage percentage ($p_c=85\%$). The results are presented in fig. 4. It can be observed that the required network power is distributed around 43dBW-52.5dBW and the required number of Tx between 15-25. This is expected since there are 40 possible Tx sites. The rest of the simulation results concern the scenarios (*CO*), (*TX*) and (*EE*) and the mean value over 100 independent runs are presented (asterisk points). In addition, histograms of the required power and number of Tx of the best found configuration at each run are also presented for the three possible scenarios (*CO*), (*TX*) and (*EE*).

(CO)- The objective at this stage is the coverage. The GA optimizes the network for best coverage of the receiving points. The simulation results are presented in fig. 5.

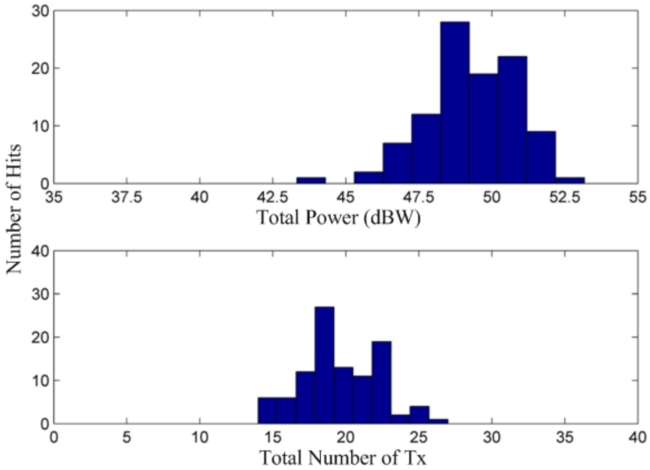

Figure 4. **Randomly generated network for p_c=85%. Total network energy demands and number of Tx are presented.**

It can be observed that the network is deployed in such a way to provide an almost 100% acceptable QoS at the receivers. The drawback is that high energy demands and number of Tx are required.

(TX)- The objective at this stage is the number of the required number of transmitters to provide an 85% coverage to the receivers. Simulations results are plotted in fig. 6. It can be observed that the number of the required Tx is dramatically reduced. The required total network energy is reduced compared to the *CO* and random scenario. It must be noticed that not all the final found solutions over the 100 runs were feasible in reality. For example, the case of 6 found Tx resulted to a network topology where all the Tx required to operate at the maximum level (tower stations). This configuration is incompatible to the Tower-Gap Filler model of DVB.

(EE)- The objective at this stage is the total required network power for an 85% coverage of the receivers. The simulation results are presented in fig. 7. A clear reduction of the required network power is achieved compared to the rest of the scenarios. The number of Tx is greater that the TX scenario. In general, the simulation results show that in terms of energy efficiency it is preferred to operate more Tx with less power levels. Of course, a solution where all Tx operating at the minimum level (gap fillers) was not considered as a feasible one since it is not met in real applications.

The obtained energy efficient network topology is presented in fig. 8. A network of 38.4 dBW total power was found that incorporates 13 transmitting stations. Two tower stations and 11 gap fillers. The characteristics of the network are also presented in Table. 2. A further investigation of the achieved goals of EE analysis is presented in Table. 3. The mean network power of the TX and EE scenarios were considered and compared in terms of their CO_2 emissions and electricity costs. The translation from energy to CO_2 emissions was based on anthracite electricity generation [12]. The energy cost was assumed as 0.1€/KWh.

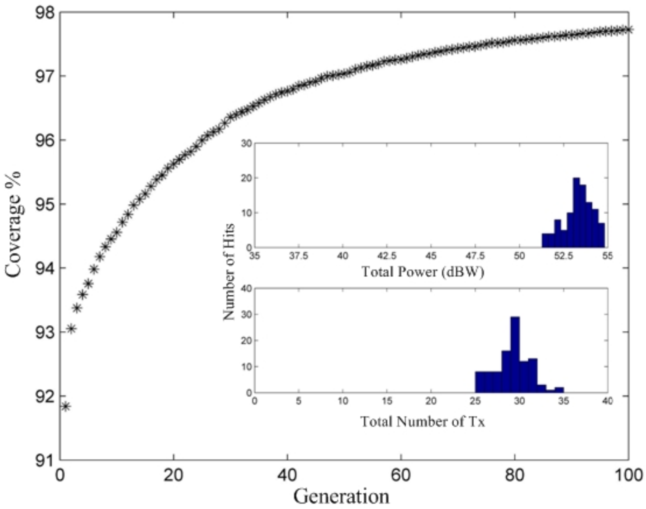

Figure 5. **CO- Coverage Optimisation.**

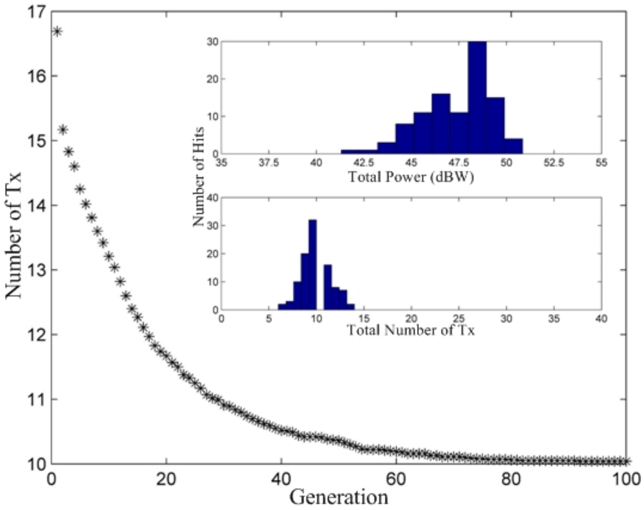

Figure 6. **TX-Tx number optimization for $p_c \geq 85\%$.**

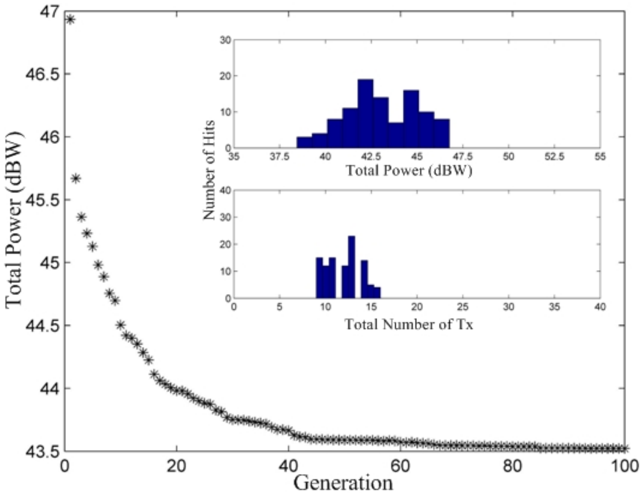

Figure 7. **EE- Energy optimization for $p_c \geq 85\%$.**

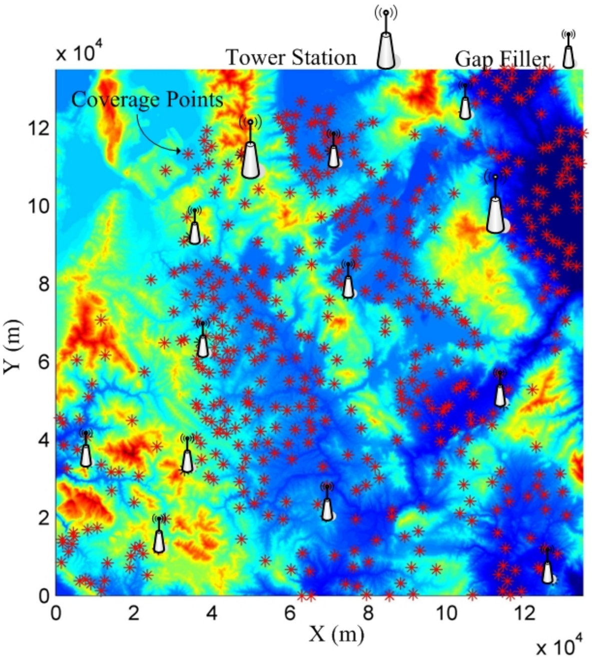

Figure 8. Energy Efficient network topology for $p_c \geq 85\%$.

V. CONCLUSIONS

This paper investigates the network optimization of DVB-T systems in terms of energy efficiency. For the purpose of the investigation a GA was developed and the field predictions over the DEM were based on multiple diffraction formulations. It was found that when energy efficiency is selected as the objective of the optimization process great savings can be obtained. The simulation results show that in terms of energy efficiency it is preferred to operate more Tx with lower EIRP levels. The result is a low power network topology that produces less CO_2 emissions and reduces the OPEX costs (electricity costs). In some cases the cost saving of OPEX (over a period of time) can be comparable to the CAPEX savings achieved when number of Tx is minimized. The criterion of energy efficiency for the network resulted to network architectures requiring a greater number of Tx compared to the TX scenario but operating at lower EIRP levels. This also provides the possibility of the penetration of renewable energy sources in the transmitting stations infrastructure. The simulation results are subject to each country costs and energy production characteristics.

Table 2. Energy Efficient Network Topology

Best Scenario			
Tx Number 13		**Total Power 38.4 [dBW]**	
Tx (id)	**EIRP [dbW]**	**Tx id**	**EIRP [dBW]**
5	Gap 20	29	Gap 20
13	Gap 30	32	Gap 20
16	Gap 30	34	Gap 25
20	Gap 30	38	Gap 30
21	Gap 20	39	Gap 25
24	Tower 35		
26	Tower 35		
27	Gap 20		

Table 3. CO_2 and cost comparison for TX and EE scenario

1KWh~807grCO$_2$ (Anthracite) [12], 1KWh~0.1€		
Scenario	**CO_2 [Kg/Year]**	**€/Year**
TX	422700	48586
EE	168280	19343
Savings	(TX-EE) 254420	(TX-EE) 29244

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