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Coverage Optimization for DVB-T2 SFN Networks

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ABSTRACT:*Single Frequency Network (SFN) television broadcasting systems have been widely deployed in broadcast network, such as more recently in DVB-T2 which is based on coded orthogonal frequency-division multiplexing (COFDM) modulation. One of the benefits of DVB-T2 versus DVB-T is the larger SFNs which make possible to use more effectively the frequencies. The need to release Digital Dividend 1 and Digital Dividend 2 has reduced evidently the capacities of Albanian Plan of Digital Frequencies approved by GE-06 Agreement. As such the coverage optimization of existing digital networks is a very important issue currently in Albania. Taking into account that two of the main issues regarding SFNs is the requirement for synchronization among transmitters and the multipath interference (MPI) at the receiver antenna, the optimization should take into consideration both these properties. This paper give some result of implementing coverage optimization, performed using the heuristic genetic algorithm (GA) approach for DVB-T2 SFNs in two allotments of Albanian territory.*

KEYWORDS -*Single frequency networks, DVB-/T2,guard interval,simulated annealing,heuristicalgorithm*

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I. Introduction

For purpose of UHF digital transmission Albania is divided in 11 allotments, each of which covering approximately one administrative divide. Each allotment is covered by a single frequency network (SFN). To create larger coverage than one allotment two or more SFNs are combined and to create a national network all the SFNs of the 11 allotments are combined, i.e. an MFN (Multi Frequency Network) has created – the type of the network shall be 11 SFN.

Respecting the GE-06 Agreement frequency plan, which has been based in DVB-T technology, in Albania has been licensed and operate seven national digital networks based in DVB-T2 and using frequencies in band 470-694 MHz. Five of these networks use some 800 MHz frequencies (part of DD2), which need be released no later than 2022.

Efforts are to be done to find solution for releasing DD2 band while maintain the number of digital networks. To achieve this is needed to optimize the existing digital networks without changing the locations of existing transmitters.

II. SFNin Terrestrial Television Broadcasting

One of the most important advantage of SFN is the increase of the spectral efficiency. In a SFN all transmitters covering the service area use a single frequency and transmit the same signal. SFNs presents also the advantage to expand the network adding gap-fillers without the need for re-planning.The presence of several transmitters, each transmitting simultaneously the same signal on the same frequency, from different directions, decreases the variability of the signal's field strength from one location to another, creating another advantage which is network gain.

But the main challenge needed to face with SFNs is the self-interference which is the main constraint on the size of an SFN. In COFDM modulation technique used in DVB-T2 broadcasting networks, the beginning of each symbol is preceded by a guard interval. Guard intervals is the key to ensure that distinct transmissions do not interfere with one another. As long as the echoes fall within guard interval, they will not affect the receiver's ability to safely decode the actual data, as data is only interpreted outside the guard interval.

Furthermore, transmitters within an SFN should be synchronized to transmit the same content, and the time at which they transmit it must be precisely controlled.

The coverage can be extended by increasing the signal's guard interval, but doing this will reduce the network's throughput, and it becomes necessary to trade off coverage against throughput in order to find the most satisfactory combination of the two. One of the advantages of DVB-T2 compared with DVB-T is the increased guard interval durationsthat allow the maximum practical size of SFN to be extended while maintaining high throughputs.

Another alternative for extending the size of SFNs isthrough increasing the number of sites within the network. This options not treated in this paper considering the very high cost neededto be add and moreover taking into account that, as its set out in GE-06 Agreement, for each new site coordination with neighbor countries need to be done which take a long duration of time.

Two studies based in the method used in this paper are performed inBasque Country (Spain) and Sardinia island (Italy) based on compare the coverage and throughput that DVB-T2 may achieve with various modes in different HTHP network configurations such as MFNs, regional SFNs and national SFNs. Referring on these examples this paper is an effort to analyze how much a specific SFN can be extended.

III. SFN Network Simulation Model

In purpose to optimize the expansion of the network without changing the physical location and transmission power of the transmitters (set in GE-06 Agreement plan), two real existing SFNs (Fier SFN and Berat SFN) are taken in reference. A propagation prediction loss model provides a database which contains a contribution of delay and power received for each location within area of interest. The network simulation model includes the terrain height database, determined generally by a grid 100 ×100 m accuracy.

In digital broadcasting systems based on COFDM modulation and statistical models, the QoS is estimated as a function of carrier to interference *(C/I)* ratio. In this paper, the QoS is determined in terms of the threshold value *C/I* required for the correct operation of the DVB-T/T2 system.

According to the COFDM properties the signals with relative propagation delay shorter than the GI contributes constructively to the useful part of combined signals, *C*, while the signals which arrive outside the GI are treated as interference, *I* . If it considered a SFN with *N* transmitters distributed over a certain region for which the 3D digital terrain maps are known:

$$\frac{C}{I} = \frac{\sum_{i \in \Omega} c_i \cdot w_i \cdot (\delta_i - \delta_0)}{\sum_{i \in \Omega} c_i \cdot [1 - w_i \cdot (\delta_i - \delta_0)]} \quad [dB] \qquad (1)$$

where, ci [dBm] denotes the power received from the *i*- th transmitter, wi[0,1] is the fast Fourier transform (FFT) receiver mask weighting value of *i*-th echo, δi[μs] the *i*–th echo delay relative to the synchronization reference $\delta 0$ [μs] selected among δi. The set of transmitters is represented by $\Omega = \{1, . . . , N\}$.

$$w_i = \begin{cases} 0 & if \quad t \leq \Delta - T_p \\ \left(\frac{T_u + t}{T_u}\right)^2 & if \quad \Delta - T_p < t \leq 0 \\ 1 & if \quad 0 \leq t \leq \Delta \\ \left[\frac{(T_u + \Delta) - t}{T_u}\right]^2 & if \quad \Delta < t \leq T_p \\ 0 & if \quad T_p < t \end{cases}$$

Several studies provide a model of FFT weighting function, which considers the effect of possible signal paths that arrive faster or slower than the current symbol synchronization time reference, i.e., pre-echoes and post-echoes respectively. These echoes are partially contributing and partially interfering. In this work we consider the weighting function where Tudenotes the useful symbol length, Δ is the GI length and $Tp$the interval during which signals contribute constructively.

Another crucial issue in COFDM-based broadcasting network planning is the FFT synchronization at receiver side. In this work we rely on Centre of Gravity (CoG) strategy.CoG locates the FFT window on:

$$t_c = \frac{\sum_i p_i t_i}{\sum_i p_i}$$

where$ti$is the arrival time of the *i*-th signal and pi represents its corresponding power level. The CoG approach responds well to pre-echoes and delayed signals of similar amplitude.

It does not fix the FFT window to a particular signal, but takes into account the average behavior of the impulse response of the transmission channel.

IV. Heuristic Approach

Simulated annealing (SA) and advanced simulated annealing (ASA)

Simulated annealing is an algorithm implemented in this paper simulates the cooling of material in a heat bath. This is a process known as annealing, in metallurgy a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. The heat causes the atoms to become unstuck from their initial positions (a local minimum of the internal energy) and wander randomly through states of higher energy; the slow cooling gives them more chances of finding configurations with lower internal energy than the initial one.

In SA, the fitness function establishes the only relationship between the physical problem and the SA algorithm, so the performance of the approach is directly related to the fitness function used. In fact the algorithm works by representing the parameters of the fitness function as continuous numbers, and as dimensions of a hypercube (*N* dimensional space).

Parameters of SA algorithm are delineated as follows: *T*k is a control variable called *temperature* gradually decreased along the process, *k* is the index of steps during which the temperature is fixed, *fk*denotes the current function value, *fk*+1 is the new function value and *fval*the final function value. The temperature is decreased at each step *k* according to *T*k+1 = *α* ・ *T*k. The choice of α is crucial. Several simulations have been needed to verify the optimal value.

The detected value is *α* = 0.89. Compared to other values, *α* = 0.89 proves the best convergence performance in term of capability to avoid local minimum. Each step of the SA algorithm replaces the current solution by a random "nearby" solution, chosen with a probability

$$P\,(k, k+1, T_k) = \begin{cases} 1 & if\ E(T_{k+1}) \le E(T_k),\ f_{k+1} \le f_k \\ \exp\left(-\frac{\Delta E}{K_B T_K}\right) & if\ E(T_{k+1}) > E(T_k),\ f_{k+1} > f_k \end{cases}$$

that depends both on the difference between the corresponding function values and also on the global parameter *T*k; for a negative difference of energy

$$\Delta E = E(T_k) - E(T_{k+1})$$

the new solution is accepted with a probability defined by Boltzmann distribution whereas for a positive difference of energy, the new solution is always accepted.

The dependency is such that the current solution changes almost randomly when *T*k is large, but increasingly "downhill" as *T*k goes to zero. The allowance for "uphill" moves saves the method from becoming stuck at local optima which are the bane of greedier methods.

The advanced simulated annealing (ASA) configuration is also considered. In ASA the algorithm parameters that control temperature schedule and random step selection are automatically adjusted according to algorithm progress. This makes the algorithm more efficient and less sensitive to user defined parameters than canonical SA.

The temperature and the step size are adjusted so that all of the search space is sampled to a coarse resolution in the early stages, whilst the state is directed to favorable areas in the late stages. For these reasons is not possible to consider the parameter *α* as a constant for each step as considered in general SA.

ASA responds well to different configurations of hilly terrain and different density of transmitters introduced in the second network; results obtained shown effects of amendments. The increase of the computational complexity does not affect the effectiveness of the method and the quality of the solution.

I. SFN NETWORK HEURISTIC OPTIMIZATION

As to our optimization, let us define the fitness function *F* as follows:

$$F\left(C, \frac{C}{I}\right) = \frac{L}{\sum_{l=1}^{L} COV_l}$$

$$COV_l = \begin{cases} 1, & if\ C > C_{\min}\ and\ \frac{C}{I} > \left(\frac{C}{I}\right)_{\min} \\ 0, & otherwise \end{cases}$$

where*l* is a generic receiver location within area of interest, *L* is the total receiver locations and *COVl*is the coverage in the *l*-th location. The optimization process identifies the parameter *δ*0 among the *δi*which minimizes (6) by means of (1) to achieve the highest percentage of coverage for fixed QoS requirements. QoS requirements are fulfilled when the total power *C* of the useful signals and the *C/I* ratio at the receiver antenna concurrently are above the threshold values *C*min and *(C/I)* min respectively.

For this optimization have been considered at the receiver side a typical directive antenna pattern with a beam width of 60◦ and 20◦ in azimuth and elevation, respectively, a gain of 13 dBi and −12 dB side lobes level. Omnidirectional antennas are considered at the transmitters;

The optimization method proposed shows different blocks which interact in order to obtain the optimum configuration for the transmitters of the SFN network. For the network infrastructure, the prediction of the propagation is used to estimate the contribution in terms of power, Ci and delays $\delta i$for all the transmitters and receivers.

In order to evaluate the optimization algorithm the ITUR P.1812 propagation prediction loss has been used in this paper. The use of heuristic algorithms and a propagation prediction tool allows estimating and increasing the power received at each location according to the ITU–R recommendation P.1812. This information consists of couples $(CL, N, \delta L, N)$ and represents the input to the SA algorithms.

V. Simulation Results

In this section we consider two SFNs for DVB-T2.The SFN topology analyzed for SA and ASA, concerns two geographic regions (Fier and Vlora) in Albania.

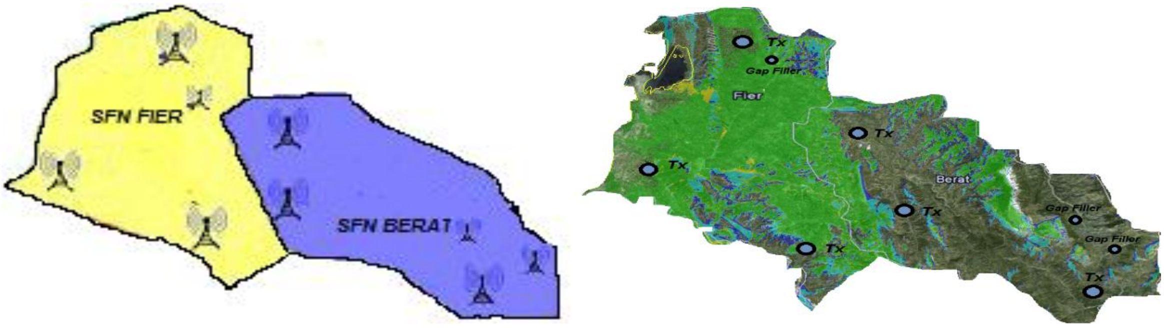

Fig.1Fier SFN and Berat SFN

Two SFN areas exhibits a very complex orography. These SFNs are shown in Fig. 1. There are three transmitters in each SFN, as well as one Gap Filler in SFN Fier and two Gap Fillers in SFN Berat Within the simulation area is considered a grid of 100 × 100 m resolution corresponding to a set of L = 1.173 × 106 receiver locations. The power transmitted by one of the transmittersin each SFN is equal to 1Kw EIRP and the rest of transmitters transmit with the power equal to 500 w EIRP.

The frequency band used in these SFNs is the Ultra High Frequency (UHF) for DVB-T2 with DVB-T2 8K mode for a simplified version of the approach, considering omnidirectional antennas and antennas far-field pattern for transmitters and receivers.

Any receiver location, l, is considered to be served only if both conditions $C > C$min and $C/I > (C/I)$ min are satisfied. See threshold levels in Table 1.

DVB-T2 - 573 MHz		Coverage (%) −CoG	
DVB-T2 8K (Fier)	SFN without optimization	$C > C$min	78.0
		$(C/I) > (C/I\,)$min	99.75
		Coverage	77.85
DVB-T2 - 567MHz		Coverage (%) −CoG	
DVB-T2 8K (Berat)	SFN without optimization	$C > C$min	78.0
		$(C/I) > (C/I\,)$min	99.75
		Coverage	77.85

Table 1: Threshold values for DVB-T2

VI. Conclusion

The optimization of SFN network coverageis applied for Fier SFN (DVB- T2) and the Berat SFN (DVB-T2) using a planning tool combining the heuristics SA, ASA and a propagation prediction tool and considering effectively as well synchronization strategies. The purpose of the optimization isto reduce self-interfered areas and to increase the size of SFN,Results showed that coverage was increased by up to 16.8% in Fier SFN and up to 10.7% in Berat SFN.

Whiles SA has improved the DVB- T2 service of two existing networks without changing the physical location of the transmitters the ASA approach responded well to different configurations of terrain of two SFN areas.

The simulation has shown that in order to improve the managing of self-interfered SFNs, each broadcaster need to amendment independently via software the radio planning engineer done manually iterative adjustments to have for each SFN network operates its own static mapping of delays.

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