

Genetic Optimization for Spectral Efficient Multicasting in LTE Systems

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Abstract—Past research has proposed the usage of assisting cells with Multimedia Broadcast/Multicast Service (MBMS) over a Single Frequency Network (MBSFN) to increase the Spectral Efficiency (SE) of LTE. In this paper we propose and investigate a method for optimizing the power consumption of the network while retaining an acceptable SE for most users. We design an algorithm that makes use of genetic optimization and analytical estimation of the SE. The algorithm is implemented in a novel simulation tool that allows experimentation over various user distributions and LTE deployments similar to the real-world ones. This simulation tool estimates the SE of each user and is able to optimize the network deployment by adjusting the individual transmission power levels for each cell.

I. INTRODUCTION

3GPP has introduced the Multimedia Broadcast/Multicast Service (MBMS) as a means to broadcast and multicast information to mobile users. In the context of LTE, the MBMS will offer high rates that will be able to support advanced multicast and broadcast services. This will be achieved through increased performance over the air interface that will include a new transmission scheme called MBMS over a Single Frequency Network (MBSFN). In MBSFN operation, MBMS data are transmitted simultaneously over the air from multiple tightly time-synchronized cells. A group of cells that are transmitting these data, is called MBSFN area [1]. Since the MBSFN transmission greatly enhances the Signal to Interference plus Noise Ratio (SINR), the MBSFN transmission mode leads to significant improvements in Spectral Efficiency (SE) in comparison to multicasting over UMTS [2]. The higher the SE is, the faster the bit-rate becomes per Hz of bandwidth that is devoted to the transmission.

3GPP has proposed that the MBMS can also be provided through the conventional transmission scheme used in the previous generations of mobile networks, i.e., Point-to-Multipoint (PTM) transmissions for individual cells. The main disadvantage of PTM transmissions is that the neighboring transmitting cells cause destructive interference, especially at the cell edges. This leads to increased SINR and eventually to much lower SE. On the other hand, in PTM transmissions there is no need for performing complex synchronizations with adjacent cells as in the case of MBSFN.

Different aspects of MBSFN have been studied in previous research works. The authors of [3] propose analytical approaches for the evaluation and validation of MBSFN. In

[4] and [5], the authors evaluate the SE of four different approaches when selecting the Modulation and Coding Scheme (MCS) for MBSFN data transmission under various scenarios. 3GPP in [6] assesses the SE and the Resource Efficiency (RE) under varying numbers of MBSFN assisting rings. The RE is a metric that takes into account the SE of all cells and shows how efficient the system resources are used for the transmissions. To summarize, the literature review reveals that the maximization of the SE and consequently of the RE when multicasting or broadcasting over LTE systems, is an issue of major importance in mobile communications. In [7] we examined the effect of the combination of PTM and MBSFN with the help of a novel optimization algorithm. Using the simulation results presented in [6] we approximated the SE of individual cells based on the number of assisting cells around them. Furthermore, we produced some promising results regarding the usage of strategically placed MBSFN assisting cells, i.e., cells transmitting using MBSFN although no users in them are interested in the transmission.

In this paper we use an improved version of the aforementioned algorithm to examine the power consumption of the MBSFN transmission scheme and if assisting cells are actually useful and when does this happen. The improvement has been performed towards three directions:

- 1) The usage of an analytical method, which is based on the methodology presented in [8] in order to calculate the SE of cells which will provide more accurate results than our previous version.
- 2) Allowing arbitrary positioning for base stations which can form irregular grids if that is desired allowing to simulate real-world networks and not just hex grids.
- 3) The replacement of the optimization part of the previously proposed algorithm with a genetic algorithm, which is more resistant to entrapment in local optima compared to our old implementation.

The algorithm is implemented in a graphical tool (AccuGra-CovO [9]) written in LÖVE [10], a framework for writing 2D applications using Lua [11]. The remainder of the paper is structured as follows: Section II presents the fundamental aspects of the MBSFN transmission as well as the analysis that consists the basis for the design and implementation of our simulation tool. In Section III, we explain in detail the proposed genetic algorithm. Section IV describes the exper-

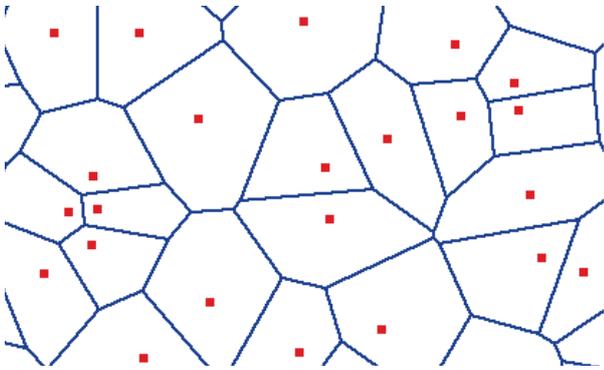


Fig. 1. The simulated network topologies are, essentially, Voronoi diagrams.

iments that we have conducted and, finally, the conclusions and some possible next steps are described in Section V.

II. MODELING & ANALYSIS

In this section we present the modeling and the analysis that we have conducted for the design and implementation of our simulation tool.

A. MBSFN Transmission

One of the basic notions in this work is that of the MBSFN area. The MBSFN area is defined as the group of time-synchronized cells that participate in the MBSFN operation. It should be noted that each cell in this group may or may not contain UEs (User Equipment) that have subscribed in the MBMS service. The cells containing UEs are called interested UE drop location cells, whereas the rest are called assisting cells. The assisting cells broadcast the MBSFN data while they do not actually contain any users that request that MBMS service. Instead, those cells assist the UEs of neighboring cells to constructively combine their transmissions. This is the main difference between MBSFN and PTM transmission; MBSFN transmissions are synchronized so their combination can be constructive, while PTM transmissions cause interference to any other nearby transmission.

B. SE Estimation

Since our goal is the optimization of the network deployment, our simulation tool is able to estimate the SE for any user utilizing the network based on the positions of the nearby cellular antennae. The input of this lower level calculation is the 2D coordinates of the antennae and the users in double precision floating point arithmetic. In that way, our simulation tool can process any arbitrary network topology even those that are not composed of regular hexagons unlike all the previous works, e.g., [6] and [7], where the examined networks were simplified topologies consisted by regular hexagonal cells. The first step is to assign the user to a cell that will be considered his primary cell. Our simulator chooses the link with the highest power for the user. That creates areas around each cell in which every user has the same primary cell. Those areas get bigger as the transmission power of the cell increases since a user will then have to move much further away from

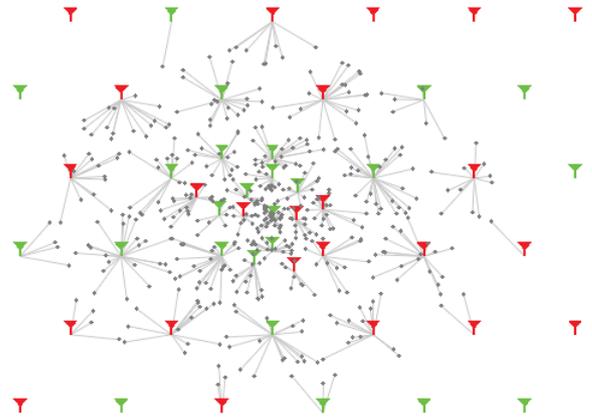


Fig. 2. A network topology with users connected to their primary cell.

his primary cell in order for the signal of a neighbouring cell to surpass the power of the primary signal. That makes the network topology similar to a weighted Voronoi diagram like this depicted in Figure 1, with the weights being each base station's transmitting power. This operation associates all the users to their primary cells as seen in Figure 2. After this operation the simulator proceeds with estimating the SE of the communication over each user's primary link. To calculate the SE for each user, we use the Shannon theoretical limit multiplied by an attenuation factor:

$$SE = 0.6 \log_2 \left(1 - \frac{S}{N+I} \right) \quad (1)$$

For each of the cells we have to calculate the power that arrives to the user (using the COST 231 path-loss model). Additionally for cells other than the primary we have to take into account the timing of the signal arrivals because according to [8] the exact timing of the secondary signals determine the portion of the signals power that will count as signal (S) in the above formula, or interference (I). Since in our simulator cells can transmit using different power different cell characteristics, like base station power and antenna height, can be used, a user's primary cell is not necessarily the one closest to him. As a result, some of the secondary signals can arrive earlier than the primary signal. To achieve maximum constructive interference the two signals have to be received in sync. Otherwise the overlapping portion of their cyclic prefixes will determine what portion of the interference is considered constructive as given by the formula in (2) [8] where τ is the time shift between the neighbouring signal and that of the primary cell and T_{CP} is the duration of the cyclic prefix.

$$w(\tau) = \begin{cases} 0, & \text{if } \tau < -T_u \\ 1 + \frac{\tau}{T_u}, & \text{if } -T_u \leq \tau < 0 \\ 1, & \text{if } 0 \leq \tau < T_{CP} \\ 1 + \frac{\tau - T_{CP}}{T_u}, & \text{if } T_{CP} \leq \tau < T_{CP} + T_u \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

After the SE for every user is calculated, it is trivial to check if at least 95% of the users have $SE > 1$.

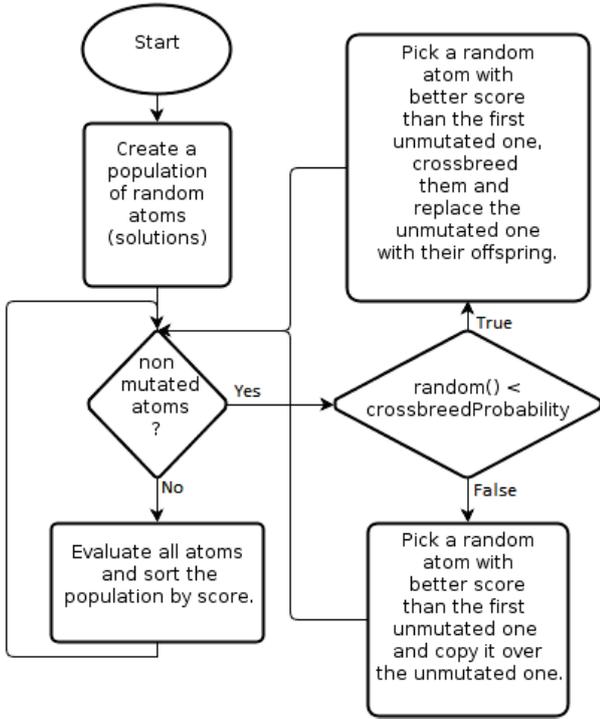


Fig. 3. Simplified flowchart of the genetic algorithm.

III. PROPOSED GENETIC ALGORITHM

The genetic algorithm that we propose for the power consumption optimization uses mutations and crossbreeding over the atoms of a population of possible network configurations. It receives the following four parameters as input:

- The population size: typically 50.
- The protected population size: these will be some of the best atoms in the populations that will survive unchanged in the next generation. Typically 10.
- The mutation factor: this parameter controls how strong the mutations (random changes on an atom) will be.
- The crossbreeding probability: typically 50%.
- The network topology. this includes all the constant characteristics of the network like cell and user coordinates.

The procedure that creates a new generation of solutions from the older one can be seen in Algorithm 1 or more simplified in Flowchart 3. It guarantees that the best atoms of the population do not vanish from generation to generation while slowly spreading their “genes”, which are partial solutions, to other atoms of the population. This spreading is achieved in two ways. First of all, some solutions are replaced by a mutated copy of a better solution. Secondly some solutions are crossbred with a better solution and then replaced by the offspring, which is also mutated.

The crossbreeding mechanism is described in Algorithm 2 and is also depicted in Figure 4 as a visual example. A separation grid of random density and placement is decided in lines 1 to 4 and is overlaid on the network deployment. This breaks both parents into blocks, i.e., partial solutions, and then

Algorithm 1 Genetic algorithm

Require: $atoms$, $crossbreedProbability$, $mutationFactor$

Require: $protectedPopulation$, $population$

```

1: {Create the starting population.}
2: for  $i = 1$  to  $population$  do
3:    $atoms_i \leftarrow createRandomAtom()$ 
4: end for
5: loop
6:    $sortByCriterion(atoms,$ 
    $\%OfUsersWithAcceptableSE,$ 
    $\%PowerConsumption)$  {Sorts the atoms using
   the two criteria in order.}
7:   for  $i = 1$  to  $population - protectedPopulation$  do
8:     {The protected population is ignored and will survive
     unchanged to the next generation.}
9:     if  $random() < crossbreedProbability$  then
10:      {This atom will be crossbred with someone better
      and get replaced by their child.}
11:       $j \leftarrow random(i + 1, population)$ 
12:       $atoms_i \leftarrow crossbreed(atoms_i, atoms_j)$ 
13:     else
14:      {This atom will be replaced by a replica of some-
      one better.}
15:       $j \leftarrow random(i + 1, population)$ 
16:       $atoms_i \leftarrow atoms_j$ 
17:     end if
18:     {Perform mutations on this atom, whether it is a child
     or a replica, to introduce variety in the population.}
19:      $mutate(atoms_i, mutationFactor)$ 
20:   end for
21: end loop
  
```

half of those blocks are copied to the child from each parent, alternating between the two as the condition in line 7 dictates. This results in about 50% of each parent solution to be present in the offspring.

Algorithm 2 crossbreed routine

Require: $A, B \in atoms$

Require: $gridWidth$, $gridHeight$

```

1:  $widthDivider \leftarrow random() * gridWidth$ 
2:  $heightDivider \leftarrow random() * gridHeight$ 
3:  $widthOffset \leftarrow random() * gridWidth$ 
4:  $heightOffset \leftarrow random() * gridHeight$ 
5: for  $index, cell \in A.cells$  do
6:   if  $2 \lfloor [(cell.x + widthOffset)/widthDivider] +$ 
    $[(cell.y + heightOffset)/heightDivider] \rfloor$  then
7:      $insert(child.cells, A.cells_{index})$ 
8:   else
9:      $insert(child.cells, B.cells_{index})$ 
10:  end if
11: end for
12: return  $child$ 
  
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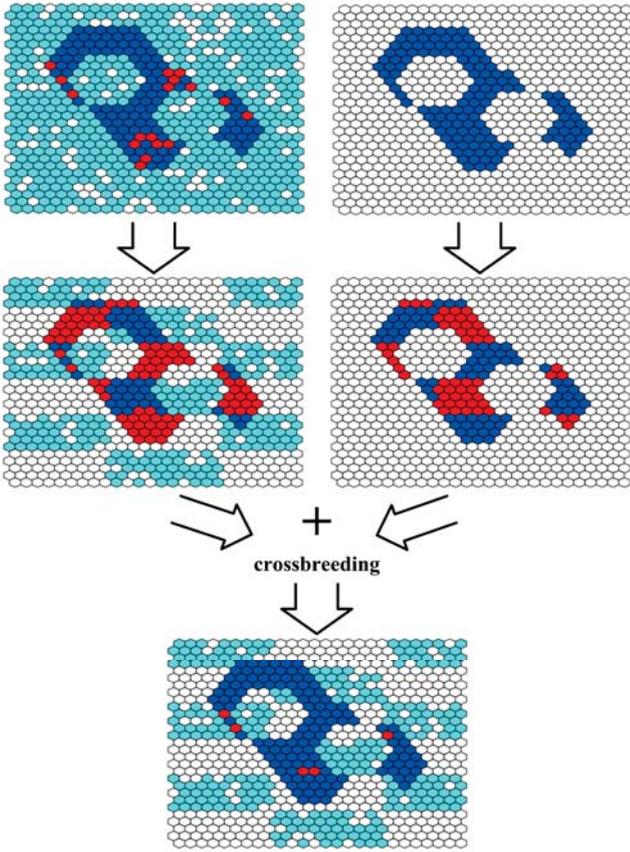


Fig. 4. Example crossbreeding of two atoms.

The *mutate* function is applied to each atom at the end of every round, making random changes to it, like changing the transmission schemes randomly and all cell transmission powers are multiplied by a random factor in $(0.5, 1.5]$ without ever exceeding a power of 20W. The cell selection works by starting at a random cell and picking up a random radius around it within which all cell parameters are altered as described.

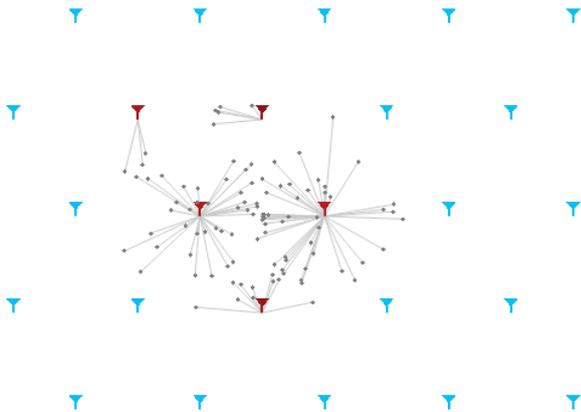


Fig. 5. A grid-like network topology and the proposed coverage.

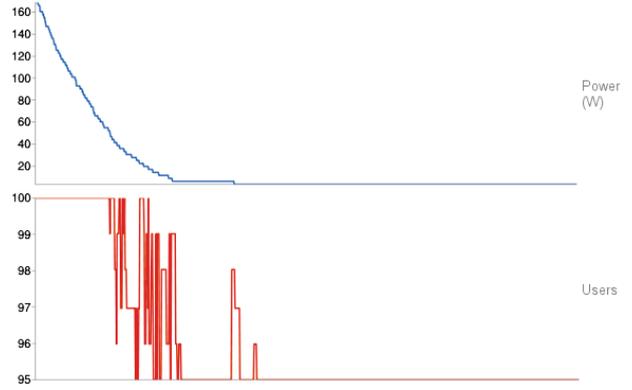


Fig. 6. Power consumption and satisfied users (out of 100) during the optimization.

IV. EXPERIMENTAL EVALUATION

In the next two subsections we present the results of our experiments on both realistic and hex grid topologies. For each experiment we present the proposed deployment and a graph of the algorithm's progress towards the proposed deployment.

A. Simulations of Typical Topologies

The first experiment is performed over a grid-like topology as illustrated in Figure 5. The antennae are placed with horizontal and vertical distance between them equal to 1000m. 100 users are placed around an almost central point with uniform distribution over a fixed radius equal to 1200m. This leads to higher user concentrations near the center where the radii are more "dense". As we can see in Figure 5, the algorithm turned off all cells that were away from the users therefore using the expected deployment while minimizing the power consumption. In Figure 6 the progress (which took 1000 generations of the genetic algorithm) towards the proposed coverage can be seen in terms of power consumption and number of satisfied users. Initially the power consumption was huge and every user was satisfied but while the power consumption was reduced, a total of 5 users were left out of satisfactory coverage.

The second experiment is the same network topology with 63 users placed in a ring like formation as illustrated in Figure 7. This is the first case where we expected that the algorithm would suggest that the central cells should assist. Contrary to our past research, we now see that filling the central user-less area with assisting cells is not the optimal strategy as long as no users are in the proximity of the central cells. We notice though a few cells that only serve a single user or even a couple of users. Although not assisting by definition, these cells are the closest thing we saw to purely assisting cells. The progress of the algorithm over 2000 generations can be seen in Figure 8.

B. Simulation of Existing Topology

The third experiment is performed over a real map. Cells have been manually placed at probable positions and 137

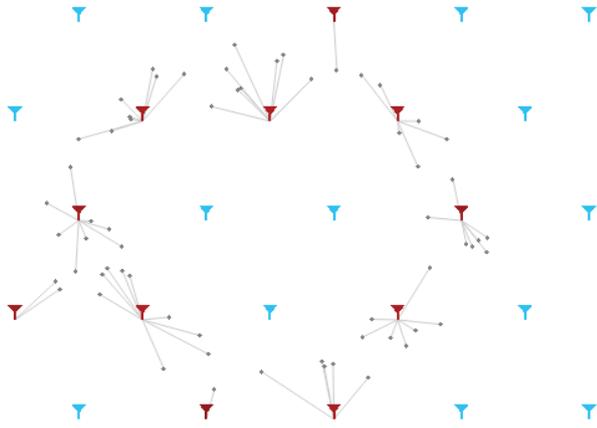


Fig. 7. A topology with users placed on a ring formation.

users have been placed on roads, villages and public transport stations. We can see the resulting coverage that the algorithm proposes in order to use minimal power in Figure 9 while retaining a SE over 1bps/Hz for at least 95% of the users. The black, red, orange and yellow cells are those that are transmitting MBSFN with increasingly higher power for each color tone. The cyan cells are completely turned off (meaning they are considered unnecessary by the algorithm). The total power used by the network is 82.5W and 95.62% of the users yield a SE over 1bps/Hz. The progress towards that network coverage over the course of 1000 generations of the genetic algorithm can be seen in Figure 10. The red line is the number of users that have a SE over 1. The algorithm first tries to get that number over 95% of the total user and until it manages that it will not start optimizing the power consumption of the network. That is the cause of the upward spike in the total power when the optimization starts.

V. CONCLUSIONS & FUTURE WORK

During our experiments we saw that the usage of assisting cells was never suggested by the genetic algorithm. The closest thing we saw was cells with a single user transmitting with MBSFN. That means that the algorithm avoided to increase



Fig. 9. The proposed deployment for the existing topology.

the power of a further cell so that it covers that user and instead decided to serve the user using the closest cell to him. Perhaps a reason for this lack of assisting cells is the usage of simplified models for the path-loss and the relationship between signal, interference and SE. More realistic formulas could provide the necessary inflection points that are currently missing. Without those inflection points, putting more power to an assisting cell doesn't increase the SE more than putting the same extra power to the cell closest to the user. Another disadvantage of devoting power to assisting cells compared to the main user cell is that signals from assisting cells are always somewhat out of sync and therefore strengthening them is not as good as strengthening the main signal.

Possible future work could examine the possibility of on purpose delayed, MBSFN transmitting, assisting cells. Those cells will delay their transmissions and be on purpose out of sync with the other cells. This delay will make the MBSFN transmissions of those cells more useful at a longer distance where the users are expected to be.

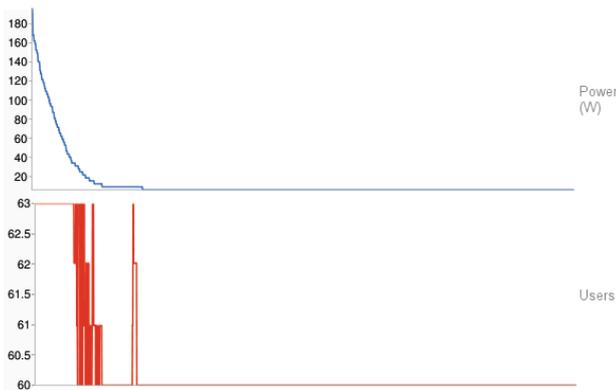


Fig. 8. Power consumption and number of satisfied users (out of 63) during the optimization.

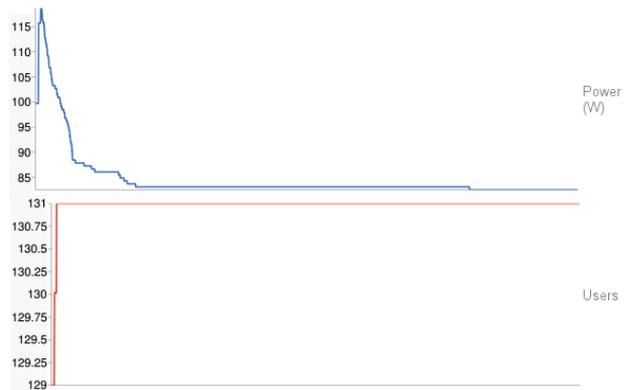


Fig. 10. Power consumption and number of satisfied users (out of 137) during the optimization.

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