Combining MBSFN and PTM Transmission Schemes for Resource Efficiency in LTE Networks

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Abstract. Long Term Evolution (LTE) systems allow the transmission of rich multimedia services by utilizing the Multimedia Broadcast/Multicast Service (MBMS) over a Single Frequency Network (MBSFN). During MBSFN transmission a time-synchronized common waveform is transmitted from multiple cells. The 3rd Generation Partnership Project (3GPP) has specified that Point-to-Multipoint (PTM) transmission can be used in combination with MBSFN to provide MBMS-based services. In this paper we evaluate the combined transmission scheme in terms of Resource Efficiency (RE). The evaluation is performed through simulation experiments for various user distributions and LTE network configurations. The experiments are conducted with the aid of a proposed algorithm, which estimates the Spectral Efficiency (SE) of each cell and the RE of the network, and is also able to formulate the optimal network deployment that maximizes the network's RE. For each of the examined scenarios, we present the most efficient solution (in terms of RE) selected by our algorithm and we compare it with other transmission schemes.

Keywords: long term evolution; multimedia broadcast and multicast; single frequency network; point-to-multipoint; resource efficiency;

1 Introduction

The 3rd Generation Partnership Project (3GPP) has introduced the Multimedia Broadcast/Multicast Service (MBMS) as a means to broadcast and multicast information to mobile users, with mobile TV being the main service offered. The Long Term Evolution (LTE) infrastructure offers to MBMS an option to use an uplink channel for interaction between the service and the user, which is not a straightforward issue in common broadcast networks [1], [2].

In the context of LTE systems, the MBMS will evolve into e-MBMS ("e-" stands for evolved). This will be achieved through increased performance of 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 those cells, which are targeted to receive these data, is called MBSFN area [2]. 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 Universal Mobile Telecommunications System (UMTS) [3], [4]. The higher the SE is, the faster the transmissions get per Hz of bandwidth that is devoted to the transmission.

3GPP has also proposed Point-to-Multipoint (PTM) transmissions for individual cells. The main disadvantage of PTM when compared to MBSFN is that it has a much lower SE because nearby transmitting cells cause destructive interference. On the other hand, in PTM transmissions there is no need for complex synchronization with adjacent cells as in the MBSFN case. This means that the cost of synchronization in PTM case is lower than that of MBSFN.

Different aspects of MBSFN have been studied in previous research works. For example, in [5] and [6], the authors evaluated the SE of four different approaches when selecting the Modulation and Coding Scheme (MCS) to be utilized for MBSFN data transmission under various scenarios. The authors in [7] evaluated the SE and the Resource Efficiency (RE) under varying numbers of MBSFN assisting rings. The RE takes into account the SE of all cells and shows how well are the system resources (essentially the active cells and bandwidth) used for the transmissions. Furthermore, the authors of [8] proposed analytical approaches for the evaluation and validation of MBSFN enabled networks. Finally, there have been several studies for PTM over UMTS networks [9], [10].

To the best of our knowledge there is little to no research regarding the combination of MBSFN and PTM as a way to increase the RE of a system. In this paper, we investigate the provision of MBMS service through a new scheme that combines MBSFN and PTM transmissions. The evaluation of RE is performed through simulation experiments for various user distributions and LTE network configurations. The experiments are conducted with the aid of a proposed algorithm, which estimates the SE of each cell, the RE of the network and gradually formulates the optimal network deployment that maximizes the network's RE. The tool implementing this algorithm is available at [11]. In the first experiment, we compare different network deployments for a simple user distribution scenario, where a single interested UE drop cell is located at different distances from an extensive UE drop area. In this experiment we present how the RE changes as the distance between the two areas changes for different network deployments. In the second experiment, we re-evaluate the resulting RE of hexagonal interested UE drop areas when MBSFN is used along with a varying number of assisting rings. This experiment is similar to the one performed in [7] but in this case we use a method that provides more precise approximations of the SE of individual cells compared to the one used in [7]. In the third experiment, we try to optimize the network deployment in order to achieve the highest possible RE for different interested UE drop deployment scenarios.

The remainder of the paper is structured as follows: Section 2 presents an overview of the MBSFN area configuration. In Section 3, we describe our simulation tools and in Section 4 the experiments that we have conducted. Finally, the conclusions and the planned next steps are described in Section 5.

2 MBSFN Area Configuration

We define the MBSFN area as the group of cells that contain UEs, which requests media (the interested UE drop location cells) plus any number of assisting cells. A cell is assumed to be assisting when it broadcasts MBSFN data while it does not actually contain any users that request any media service. Although their SE is not useful (i.e. they do not contribute to the RE of the system), assisting cells may increase the SE of nearby MBSFN cells by constructive combination of their transmissions. This is the main difference between MBSFN and PTM, MBSFN transmissions are synchronized so their combination can be constructive while PTM transmissions cause interference to any other nearby transmission.

If an area is completely surrounded by assisting neighboring cells then we say that it is surrounded by an assisting ring.

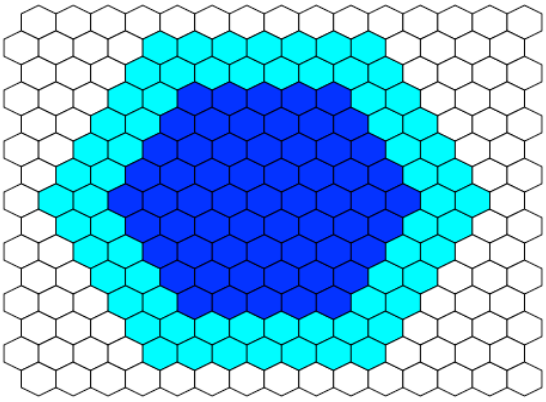

Fig. 1. Example topology with 2 assisting rings.

Fig. 1 illustrates a network topology. The dark blue cells are interested UE drop location cells that contain users requiring the MBSFN data, while the light blue cells are assisting cells, which form two assisting rings. In the remainder of the paper, we call this kind of network deployment as AAI (using the terminology from [7], meaning that two rings around the interested UE drop area are Assisting and the third one is Interfering). In the same manner we define all cases from III (three interfering rings) to AAA (three assisting rings).

3 Simulation Scheme

3.1 Spectral Efficiency in MBSFN

We define a simulation scheme that, among other parameters, uses the coordinates of interested UE drop locations and an initial MBSFN topology. After the network has been populated, the mechanism evaluates the RE and, if desired, starts optimizing the current MBSFN deployment in order to increase the RE.

In general, RE is a measure for monitoring how efficiently the resources of a system are utilized. It is tightly associated with the SE, but also considers the amount of resources that are utilized to achieve a certain SE. To calculate the RE of the system, the SE of each cell must be known. Therefore, the first step is to approximate the SE of each cell. We suppose an inter site distance of 500m and therefore we use the SE values given in [7]. The remainder of the simulation parameters are given in Table 1.

Table 1. Simulation settings.

Parameter	Units	Value
Cellular layout		Hexagonal grid, 19 cell sites
Inter Site Distance (ISD)	m	500
Carrier frequency	MHz	2000
System bandwidth	MHz	1.4
Channel model		3GPP Typical Urban
Path loss	dB	Okumura-Hata
BS transmit power	dBm	46
BS # antennas		1
UE # Rx antennas		2
UE speed	Km/h	3

If no users requesting media are resided in the cell then there is no need to calculate the SE as it does not affect the RE of the system. As suggested in [7], a cell transmitting with PTM has a spectral efficiency of 0.4bps/Hz. If the cell is transmitting with MBSFN we use the values shown in Table 2.

Table 2. SE with different number of assisting rings [7].

1st ring	2nd ring	3rd ring	Central cell SE (bps/Hz)
Assisting	Assisting	Assisting	2.4
Assisting	Assisting	Interfering	2.2
Assisting	Interfering	Interfering	1.3
Interfering	Interfering	Interfering	0.4

The performance of the MBSFN increases rapidly when rings of neighboring cells outside the interested UE drop area assist the MBSFN service and transmit the same MBSFN data. More specifically according to [7] and [12] even the presence of one assisting ring can significantly increase the overall spectral efficiency. Moreover, we assume that a maximum of 3 neighboring rings outside the interested UE drop area can transmit in the same frequency and broadcast the same MBSFN data (assisting rings), since additional rings do not offer any significant additional gain in the MBSFN transmission [7], [12]. In our case by adding one assisting ring the SE goes from 0.4bps/Hz to 1.3bps/Hz, which constitutes a difference of 0.9bps/Hz. By adding one more assisting ring, it goes up to 2.2bps/Hz and by adding the third one we can gain only 0.2bps/Hz.

For cases not matching any of the calculated data of the work presented in [7], we use the following approach for estimating the SE. We suppose that the change of the

SE when transiting between different numbers of assisting rings is approximately linear. Our method can be summarized in the following table.

Table 3. The linear approximation used for calculating the spectral efficiency (X is the percentage of the ring that is assisting).

1st ring	2nd ring	3rd ring	SE of cell
X%	Any	Any	X% * 0.9 + 0.4
100%	X%	Any	X% * 0.9 + 1.3
100%	100%	X%	X% * 0.2 + 2.2

As an example, let us consider the leftmost cell in Fig. 2. It is transmitting using MBSFN. It has 6 adjacent cells and 3 of them are transmitting with MBSFN, while the transmissions of the other 3 are interfering. Therefore 50% of the cells in the 1st ring are Assisting while the other 50% are Interfering and the SE of this cell is 0.4+50%*0.9=0.85bps/Hz.

3.2 Configuration Optimization Algorithm

The RE of the system for a given service is calculated by dividing the sum of all useful SE with the number of cells transmitting data for that service via PTM or MBSFN. We consider the SE of a cell useful if there is at least one user in that cell that are interested in receiving the PTM or MBSFN transmission. For example, if there are 3 interested UE drop cells with SE 0.4, 1.4 and 1.2 respectively but only the first two cells actually contain users interested into the service then the resulting RE is (0.4 + 1.4) / 3 = 0.6bps/Hz.

The algorithm is summarized using pseudo-code in the table that follows. In brief, the algorithm starts with an arbitrary distribution of MBSFN cells (for a given interested UE drop area) and then makes random changes to it. For every change it calculates the RE of the system, if it has decreased, it rolls back to the best-known configuration. In many cases though, the changes happen to be beneficial for the RE and thus they are accepted. Gradually, this procedure leads to better configurations. The computational overhead of the algorithm is reasonably low. For example, for medium size interested UE drop areas (consisting of approximately 20 cells) the algorithm requires less than 5 seconds to find the configuration that leads to the maximum value for RE. It is theoretically impossible for the algorithm to get trapped forever in local optima because the mutation function (the one that produces the changes) has a small chance to produce so radical changes that it will overcome such problems, given adequate time. Although the algorithm cannot and does not provide any information on whether it has reached the globally optimal configuration, it is fairly obvious when the search can be safely stopped. For example the algorithm might make rapid changes for a few seconds and then stabilize for more than a minute, which almost surely indicates that this is the optimal configuration. Additionally one can perform the experiments with different starting configurations to be further reassured that the optimum found is the global one.

```
% MBSFN area optimization algorithm

Grid = create_grid()
create_rings(grid,number_of_assisting_rings)
RE = evaluate(grid)
best = RE
print("Initial SE: ",best)
While not user_requested_break
        mutations = mutate(grid)
        For each cell in grid do
                If cell.MBSFN and cell.UE_drop then
                        % MBSFN cell
                        cell.SE=calculate_MBSFN_SE(cell)
                Elseif cell.MBSFN then
                        % Assisting cell.
                        % SE=0 because it is useless
                        cell.SE=0
                Elseif cell.UE_drop then
                        % PTM cell.
                        SE=0.4
                Else
                        % Cell off
                        SE=0
                Endif
        Next
        % The SE have been calculated. We can calculate the RE.
        RE = evaluate_RE(grid)
        If RE > best then
                best = RE
                print("Current SE: ",best)
                export_grid_to_file(grid)
        Elseif RE==best then
                best = RE
        Else
                demutate(grid,mutations)
        Endif
Endwhile
```

The evaluate subroutine calculates the SE for each cell and then the RE of the system which is also returned. The mutate subroutine randomly enables and disables MBSFN cells and returns the changes that have been made so that the demutate subroutine can undo those changes later if the evaluation of the grid shows a decrease in the RE of the system because of them.

4 Experimental Evaluation

In this section, we present the experiments we have conducted along with their results. The experiments are grouped in the three following subsections.

4.1 Deployments for Moving Adjacent Cell

The first part of our simulation experiments attempts to estimate how the optimal MBSFN deployment varies as the multicast user distribution changes. Although the current 3GPP specification does not allow on-the-fly changes to the MBSFN deployment, our algorithm is fast and efficient enough to propose on-the-fly changes, if they get ever allowed by the standard. The optimal RE is estimated and compared with the RE estimated for other typical configurations. For this purpose we consider a set of adjacent cells where the multicast users are located in a way that a primary area with multicast users is formed (Fig. 2). The next step is to define a cell where multicast user(s) exist and to see how the optimal MBSFN deployment varies as the position of this cell recedes from the primary area.

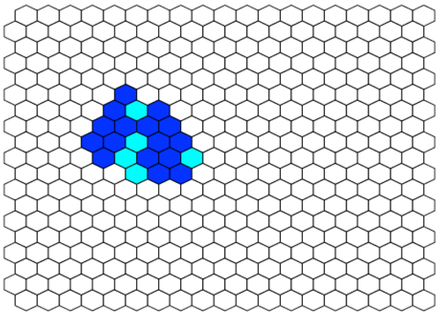

Fig. 2. The primary interested UE drop area is the one covered by dark blue cell cells.

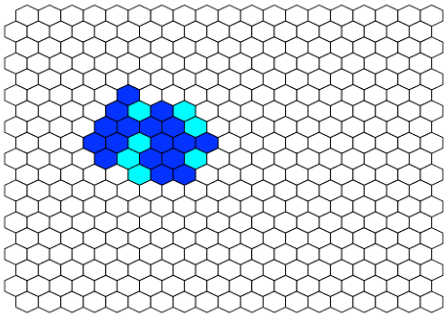

Fig. 3. A new single-cell interested UE drop location at distance 1 from the initial area.

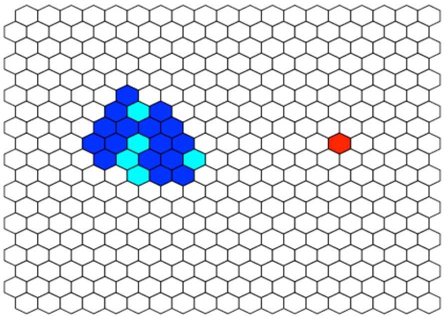

Fig. 4. The last step evaluated.
The single-cell interested UE drop location at a distance equal to 7.

In this experiment, we use a randomly shaped area of 16 cells as primary area and a single cell at different distances from the primary area are used as a base for this scenario. For example, in Fig. 2, the primary interested UE drop area is visible with dark blue color. In the same picture, the optimal coverage proposed by our algorithm is also shown. All interested UE drop location cells are covered with MBSFN transmissions along with some assisting cells (light blue).

Fig. 3 presents the second step of our experiment, where users appear in a new cell at a distance of 1 from the initial area. Our optimization algorithm proposes that the new cell should be covered with MBSFN while its addition triggers the activation of two more assisting cells.

We continue moving the new users' location to the right until distance 7 (a further increase in the distance would not change the RE of any of the transmission schemes). That last step of our experiment can be seen in Fig. 4 along with the proposed coverage configuration. What is worth mentioning is that our algorithm selects the combination of MBSFN and PTM transmissions (blue and red colored cells respectively) as the optimal network configuration.

In order to give an overview of the improved performance of our algorithm we compare the optimal RE with the RE estimated for the five typical configurations 2-6 listed below. It should be noted that the configurations 3-6 are proposed in work [7].

1. **MBSFN+PTM**: This is the configuration using MBSFN and/or PTM as proposed by our optimization algorithm. Assisting rings or MBSFN area are not predefined.
2. **III (MBSFN only)**
3. **AII (MBSFN only)**
4. **AAI (MBSFN only)**
5. **AAA (MBSFN only)**
6. **PTM**: All interested UE drop cells are covered by PTM. MBSFN is not used at all and therefore no assisting rings exist either.

The results of the aforementioned experiments are presented in Fig. 5.

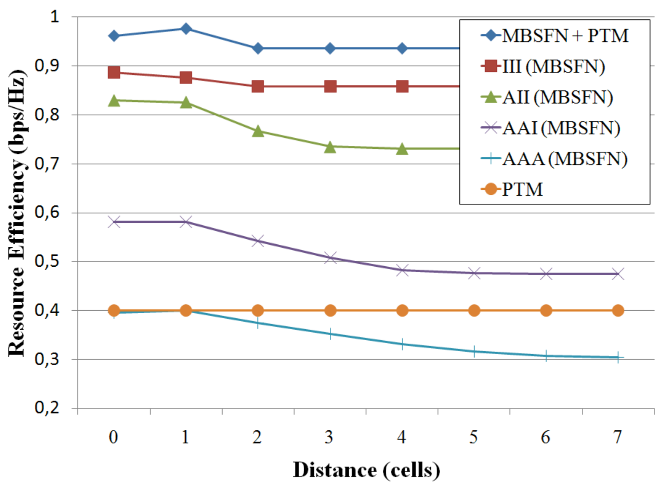

Fig. 5. The RE for different distances and coverage schemes.

From the results we can conclude that the best would be to use a few assisting cells (as shown in the previous figures). If this is not possible the second best solution is to use pure MBSFN without any assisting rings. Adding assisting rings only dropped the RE of the system in our scenarios to the point that, with three assisting rings, it was lower than that of pure PTM.

4.2 Optimal Configuration for Hexagonal Areas

In this paragraph we re-evaluate some of the experiments conducted in [7]. We aim to provide more accurate results using the linear approximation of SE presented in Section 3. The central area in all cases is one cell plus a number of rings around it. Around that area we apply 0 to 3 assisting rings (deployments III to AAA). As an example, in Fig. 1 we can see an area with 4 inner rings and 2 assisting ones.

We found results that differ considerably from those presented in [7] which are listed in Table 4. The underlined values of RE correspond to the highest value and therefore to the optimal MBSFN deployment. In contrast to [7], our approximation algorithm supposes that cells are also assisted by other MBSFN cells that contain users and not just by cells in assisting rings. For example in the case of 15 inner rings, we suppose that the inner 12 rings form an area already surrounded by 3 "assisting" rings, therefore their SE is already maximal and adding additional rings will not improve the RE as much as the authors of [7] suggest. Therefore out of a total of 721 interested UE drop location cells, 469 have a SE of 2.4bps/Hz (that of a fully assisted cell). Moreover, if our linear approximation is accurate enough, then using assisting rings around hexagonal areas is only lowering the RE of the system. Indeed, the assisting rings just increase the SE of the outmost rings of the interested UE drop area while the majority of cells already have a high SE because they assist each other. Our results are presented in Table 5.

Table 4. RE (in bps/Hz) for hexagonal areas of different sizes and different numbers of assisting rings, as presented in [7].

Assisting rings	0 inner rings	1 inner rings	2 inner rings	3 inner rings	4 inner rings	5 inner rings	15 inner rings	Infinite inner rings
AAA	0.06	0.28	0.50	0.70	0.87	1.01	1.68	2.4
AAI	0.12	0.42	0.69	0.89	1.11	1.18	1.73	2.2
AII	0.19	0.48	0.67	0.79	0.87	0.93	1.15	1.3
III	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Table 5. RE (in bps/Hz) for hexagonal areas of different sizes and different numbers of assisting rings.

Assisting rings	0 inner rings	1 inner rings	2 inner rings	3 inner rings	4 inner rings	5 inner rings	15 inner rings	Infinite inner rings
AAA	0.06	0.28	0.5	0.7	0.87	1.01	1.68	2.4
AAI	0.12	0.44	0.74	0.96	1.14	1.28	1.88	2.4
AII	0.19	0.69	1.06	1.3	1.48	1.6	2.07	2.4
III	0.4	0.91	1.28	1.52	1.68	1.8	2.17	2.4

From Table 5, it is clear that the addition of assisting rings does not improve the overall performance in terms of RE. Irrespectively of the number of inner rings, the RE when adding assisting rings decreases. However, this difference decreases with the number of inner rings and for an infinite area the RE for all deployments equals to 2.4bps/Hz.

4.3 Examination of Typical Cases

The third part of our simulation experiments determines the optimal network configuration and the corresponding RE for some indicative typical examples of user distribution. As in the previous figures, we use dark and light blue colors to indicate the area where MBMS is provided with MBSFN transmission scheme. Dark blue color is used for MBSFN transmissions in interested UE drop locations while light blue is used to indicate the assisting cells that are added to the MBSFN area and transmit the same MBSFN data as in interested UE drop locations. Finally, red color is used for the cells where for PTM transmission scheme is used.

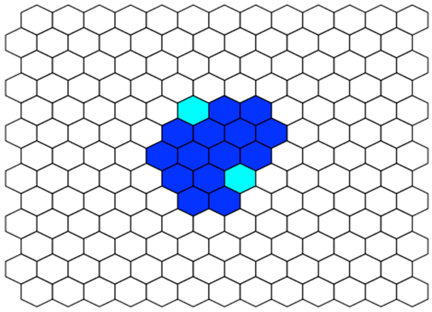

Fig. 6. A random interested UE drop area and the optimal coverage.

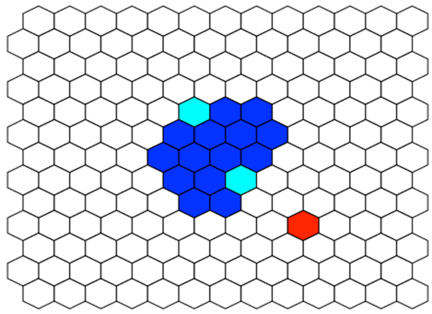

Fig. 7. A random interested UE drop area with one distant cell and the optimal coverage.

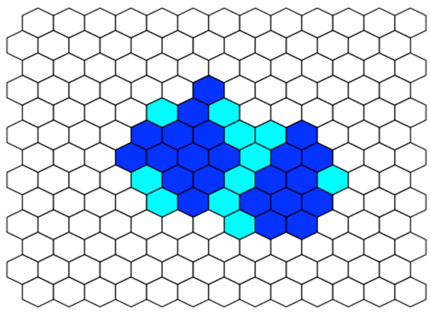

Fig. 8. Two random nearby interested UE drop areas and the optimal coverage.

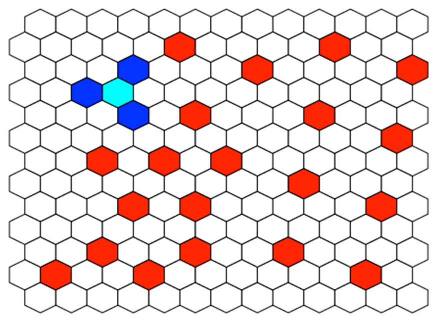

Fig. 9. Scattered interested UE drop cells and the optimal coverage.

The first case is the randomly shaped interested UE drop area shown in Fig. 6 with blue cells. The algorithm stabilizes at the proposed coverage, which covers all interested UE drop locations with MBSFN transmissions. Also two cells (light blue) transmit with MBSFN in order to increase the SE of the interested UE drop cells (these are the assisting cells). Both assisting cells fill alcoves in the initial area and therefore adding them to the MBSFN area makes it more rounded. The proposed coverage results in a RE of 1.0766bps/Hz while if we did cover that area with PTM the RE would be 0.4bps/Hz (which is the case for any PTM only coverage).

The second case considers that the majority of the multicast users are located in a set of adjacent cells formulating a primary area, while a small minority roams to a single-cell area. The optimal network configuration is depicted in Fig. 7. The optimization algorithm selects the combination of MBSFN and PTM, which provides a RE of 1.0368bps/Hz.

In third case there are two nearby, randomly shaped, interested UE drop areas. The optimization algorithm selects the network configuration shown in Fig. 8. All interested UE drop locations are covered with MBSFN transmissions and there are a lot of assisting cells especially between the two interested UE drop areas. It is clear that the algorithm tries to make the MBSFN area more rounded and achieves a RE of 0.9999bps/Hz.

In the last case, which is depicted in Fig. 9, we consider the case where the multicast user population is sparsely distributed. In more detail, 23 cells are randomly scattered throughout the LTE network topology. The algorithm selects PTM for the majority of the interested UE drop cells while only the three interested UE drop cells (and the one assisting) at the top left of the grid are covered with MBFSN because of their proximity. The selected configuration achieves a RE slightly above 0.4bps/Hz (specifically 0.4021bps/Hz).

5 Conclusions and Future Work

From our results we concluded that using a combination of MBSFN and PTM yields much higher RE than using any of the other coverage schemes described in this paper. We also concluded that on the contrary of the claims in [7] using even one assisting ring usually lowers the RE of the system. Instead in our experiments, while covering all interested UE drop locations with MBSFN and nothing more than them, yields a RE higher than not using MBSFN at all, adding a few more strategically placed assisting cells can increase the RE even more. In most cases those assisting cells tend to make the MBSFN area more round. In the current release of 3GPP LTE the definition of the MBSFN area is static and operator dependent. Therefore the results of this work can be used by LTE network operators for the definition of the MBSFN area in an optimal way. At a later stage, these results could constitute a basis for dynamic MBSFN area configuration.

In the future the current algorithm could be extended to support more metrics (for example air interface costs), with minimal changes. During our experimentation we found a minor flaw in RE as a metric. Specifically, one would expect that if the optimal coverage scheme for two different interested UE drop areas is known, putting those two areas along with their coverage scheme on the same grid at a big distance (so that there is no interference between the two) would also be optimal. This is not always the case. We observed two cases where the optimal coverage scheme of an area changed when we added another area at a great distance from the first.

The algorithm could also be extended to support more transmission schemes in addition to MBSFN and PTM. Finally replacing the optimization part of the algorithm with a genetic algorithm might be more efficient when optimizing huge network topologies as well as less prone to local optima in the network topology space (the search space).

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