Performance Analysis of eMBMS in LTE: Dynamic MBSFN Areas

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Abstract

Mobile video is one of the most popular uses for mobile broadband networks. Based upon evolved Multimedia Broadcast Multicast Service (eMBMS) available with 3GPP Release 9, LTE can provide *broadcast/multicast* content delivery with a single-frequency network mode that sends the same multimedia content to a mass audience within a specific area. In this paper, we describe a performance analysis carried out for this type of network using OPNET Modeler.

We propose a new algorithm to create, dynamically, Multicast-Broadcast Single Frequency Network (MBSFN) areas that will optimize the efficiency of *multicast* transmissions of events to a large number of users in a limited area.

Introduction

MBMS is a point-to-multipoint service suggested in 3GPP [1], that allows data transmissions from a single source to multiple recipients. MBMS can improve the scalability of broadcast and multicast transmissions in mobile networks, using a common channel to send the same data to multiple receivers, thereby minimizing the utilization of network resources.

Furthermore, the efficiency of user terminals (UEs) can be affected by destructive interferences in the areas where the coverage overlaps, and the performance gradually decreases as UEs move away from the base station that transmits the signal to each terminal. MBSFN was proposed in order to improve the performance of MBMS [2].

In Figure 1, the architecture required for the introduction of e-MBMS in LTE is shown. The MCE entities (Multi-cell/Multicast Coordination Entity) coordinate the synchronized transmissions of signal from different cells (eNodeBs), being responsible of the allocation and configuration (election of modulation and coding schemes, MCS [3]) of radio resources used by every eNodeB in the MBSFN area during the MBMS multi-cell transmissions. The e-MBMS gateway (GW) is physically placed among the e-BM-SC (evolved Broadcast Multicast Service Center) and the eNodeBs, as its main purpose is the forwarding of MBMS packets to every eNodeB that is transmitting the service. Moreover, the e-MBMS GW performs the control signaling of an MBMS session by means of MME (Mobility Management Entity), so the gateway is divided into a control plane (CP) and a user plane (UP), with M1 and M3 interfaces, respectively. The e-BM-SC is the entity responsible for putting the multimedia content into the LTE network, serving as an entry point to content providers or any other broadcast-multicast source out of the network.

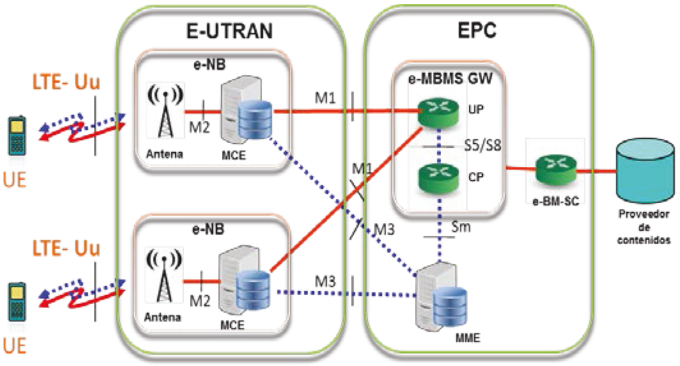

Figure 1: e-MBMS architecture

There are several works that have analyzed the performance of MBSFN [4-6], comparing it with point-to-point and point-to-multipoint traditional transmissions (performing in an individual way at each cell). These works conclude that MBSFN is the most efficient mechanism for sending multicast data, which contributed to its standardization by the 3GPP. In later works [7], the performance of MBSFN by means of the study of spectral efficiency, directly related with the modulation and coding scheme (MCS) chosen, has been analyzed. Furthermore, analytical studies to evaluate the performance of MBSFN [8] have been developed, based on a cost analysis to determine the ideal number of cells in order to optimize the global performance in the MBSFN transmission. On the other hand, OPNET Modeler has been used in another work [9] to obtain results in MBMS transmission over a single cell in order to propose a group base MBMS scheme to support moderate to high rate multicasting services over the HSDPA link.

For this paper, a performance analysis was carried out based on the signal-to-interference-plus-noise ratio (SINR) in LTE networks using MBSFN. The improvement that can be achieved, increasing the size of an MBSFN area and its dependence on cell size, was studied. Simulation results of SINR improvement are shown using OPNET Modeler, thus the results with rate improvement caused by higher SINR are also shown. Based on these results, we propose a method to create, dynamically, MBSFN areas that will optimize the efficiency of multicast transmissions of events to large numbers of users in a limited area. Finally, we use a group-based multicasting method to provide the service with different transmission characteristics, based on individual radio channel quality, to all the users in the region.

This paper is organized as follows. The first section presents an MBSFN overview, studying the influence of inter-cell distance in the optimal size of the MBSFN area and describing the studied proposal. Next, OPNET Modeler simulation scenarios with the results obtained are described. A group-based MBMS scenario is then analyzed using OPNET Modeler. Based on the simulation results, the dynamic MBSFN area clustering and multicasting group based algorithm proposals are shown. Finally, the conclusion and future work are presented.

MBSFN Overview

MBSFN was proposed to improve the performance of MBMS [2]. In SFN technology, all base stations that belong to the same MBSFN area transmit the same signal, at the same time, and in the same frequency to the UEs; therefore all base stations must be tightly synchronized. Thus, the transmissions from multiple base stations are received by the UE as a single transmission with multi-path propagation, and destructive interference becomes constructive, combining the received signals that arrive at the UE within the OFDM Cyclic Prefix (CP) so as to avoid Inter-Symbol Interference (ISI).

In order to increase the distance at which an eNodeB can be placed, MBSFN uses an extended cyclic prefix where the 0.5 ms slot can accommodate six symbols, reducing the payload. However, since in MBSFN-based transmissions the cyclic prefix should not only cover the main part of the actual channel time dispersion, but also the main part of the timing difference between the transmissions received by the UE from the eNodeBs involved in the MBSFN transmission, the performance is increased using extended cyclic prefix.

To change an eNodeB's interference from destructive to constructive, we need to calculate the maximum distance at which the eNodeB can be placed. The radio cell size is an important factor in determining how many rings of cells, around the region where the MBMS users are placed, can be included in the same MBSFN area so that the SINR in the UE can be increased.

Using extended cyclic prefix (16.7 µs) and considering the speed of signal transmissions ($3x10^8$ m/s), the number of eNodeBs that improve the performance in the UE placed in any position of the center cell is shown in Table 1, considering three different sizes for the cell radius: 200 m, 500 m, and 1000 m.

Cell radius	Results
1000 m	All the second ring and some of the third ring
500 m	All the fifth ring and some of the sixth ring
200 m	All the thirteenth ring and some of the fourteenth ring

Table 1: Number of eNodeBs improving SINR

Note that the smaller the cell is, the greater the number of eNodeBs adding their signals correctly to the UE. Thus, the performance of MBMS transmissions is higher. Therefore, it is important to choose the correct compromise between the radio cell size and the performance of the MBMS transmissions.

The proposal studied in this paper consists of a dynamic MBSFN area cluster method based on the CQI received from the UEs, increasing or decreasing the size of the area depending on the dynamic state of the users' radio channel with the goal of guaranteeing QoS requirements to a certain percentage of users. Furthermore, a multicasting group based method is used to classify the UEs depending on their radio channel state, in order to transmit the offered service with different rates to the multicast groups.

Simulation Scenarios

Different simulation scenarios using OPNET Modeler have been defined to analyze the performance of MBSFN transmissions.

The scenarios depend on the cell radius and the region size with served users, which are shown in Table 2. Using all the scenarios described in Table 2, user performance has been studied, adding different numbers of rings around the region with users demanding the MBMS service. The scenario under simulation in OPNET Modeler is shown in Figure 2, where a maximum number of 91 eNodeBs are transmitting MBMS signals.

Cell radius	Number of cells in studied region
1000 m	1 cell
500 m	1 cell
200 m	1 cell
1000 m	7 cells
500 m	7 cells
200 m	7 cells

Table 2: Tested scenarios

The simulations are carried out using different numbers of rings included in the same MBSFN area as the region under study (these rings are identified with the letter A) and a ring transmitting in the same frequency in another MBSFN area (identified with the letter I). Using this nomenclature, we carry out the simulations in the following scenarios in order to evaluate the user performance in each one: II, AI, AAI, AAAI, AAAAI, and AAAAA. For example, the scenario named AI represents the configuration with the cells in the first ring (eNodeB_2 to eNodeB_7) belonging to the same MBSFN area as eNodeB_1, and including a second ring of cells (eNodeB_8 to eNodeB_19) transmitting in the same frequency in another MBSFN area, interfering with the first one.

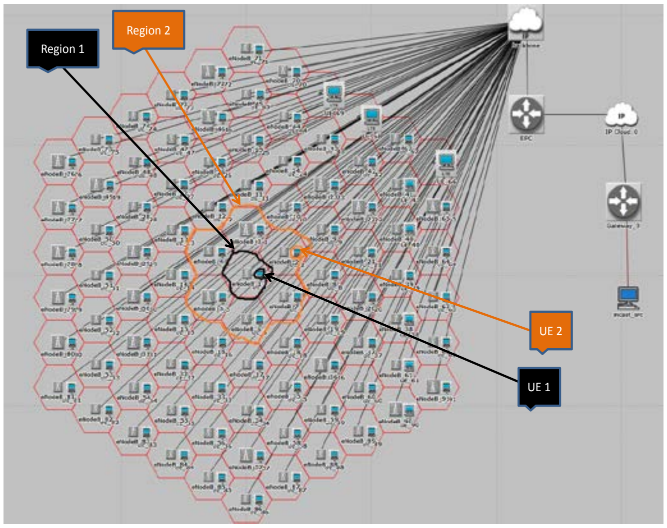

Figure 2: Simulation scenario with 91 cells

Using OPNET Modeler, it is possible to evaluate the SINR for a UE, as well as the associated BLER and the throughput using different Modulation and Coding schemes (MCS).

Table 3 shows the main parameters used in the LTE scenario simulated with OPNET Modeler.

Parameter	Value
Maximum number of eNodeB	91
BS antenna gain + cable loss	15 dBi
BS total transmit power	1 W
BS number of receive antennas	1
BS number of transmit antennas	1
Pathloss model	Macrocell suburban based on COST231 Hata Urban model
Uplink base frequency	2.500 MHz
Downlink base frequency	2.620 MHz
Bandwidth	10 MHz
Cyclic prefix type	Extended
UE antenna gain	-1 dBi
Multipath channel model	ITU pedestrian B
UE number of receive antennas	1
UE number of transmit antennas	1
Fixed/Mobile user	Fixed
Simulation time	180 sec

Table 3: Simulation parameters

Simulation Results

This section shows the results obtained in the simulation of the scenarios defined in Table 2. First, we perform the scenario with one cell containing users demanding the MBMS service under study (Region 1 and UE1 in Figure 2) and with different numbers of rings around this cell with the same or different MBSFN area. Figure 3 shows how the performance increases with the number of cells included in the same MBSFN area around the user (this user is placed around the 55% of the cell radius), when the cell radius is 200 m.

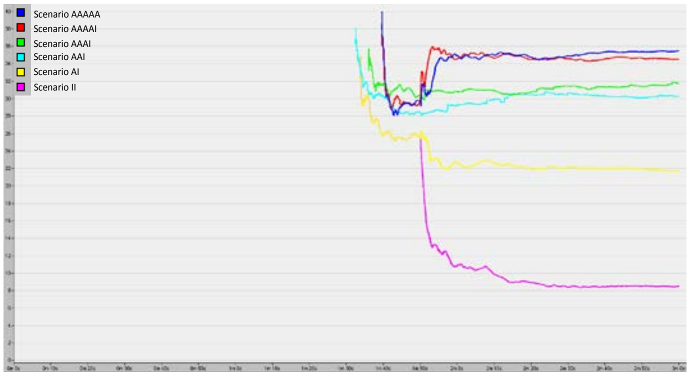

Figure 3: UE SINR with 200 m cell radius

The SINR in the UE is greatly increased with the use of a higher MBSFN area around the UE. When there is no cell in the same MBSFN area, the SINR in the UE is around 8 dB; however, in a 61 cell MBSFN area (scenario AAAAI), the SINR in the UE is around 35 dB, a similar result obtained in a 91 cell MBSFN area without interference cells (scenario AAAAA), which is considered an ideal scenario.

Figure 4 shows the SINR in the UE when the cell radius is 500 m. A great improvement is shown in the UE SINR, from 10 dB without any cooperating eNodeB in the same MBSFN area (scenario II), to 22.5 dB in a 37 cell MBSFN area (scenario AAAI). The scenarios with higher number of cells in the MBSFN area (scenarios AAAAI and AAAAA) do not increase the performance in the users of the central cell.

Figure 4: UE SINR with 500 m cell radius

Figure 5 shows the SINR in the UE when the cell radius is 1000 m. A great improvement is shown in the UE SINR from 5 dB without any cooperating eNodeB in the same MBSFN area (scenario II) to 11.5 dB in a 19 cell MBSFN area (scenario AAI). Observe that there is no additional effect by including one or more cooperative rings, 37, 61, or 91 cell MBSFN area (scenarios AAAI, AAAAI, or AAAAA, respectively), due to the large size of the cells, which causes only the first two rings' signals to reach the UE inside the extended cyclic prefix duration (see Table 1). In this scenario, the capacity of cooperation is limited for the distance; thus it is not efficient to create a cluster larger than 19 cells with a cell radius of 1000 m.

Figure 5: UE SINR with 1000 m cell radius

Next, we analyze the performance of scenarios with users demanding the MBMS service in a larger region. In this case, seven cells is the region of interest (Region 2 and UE2 in Figure 2). The following figures show the performance of a UE placed in the 85% of a seven cell region radius.

The results obtained using 200 m cell radius are shown in Figure 6. As the region with UEs demanding the service consists of seven cells, adding three additional rings creates a 61 cell MBSFN area, resulting in a UE SINR of 35 dB. Thus, in a 61 cell MBSFN area, UE 2 has the same performance as UE 1 in Region 1.

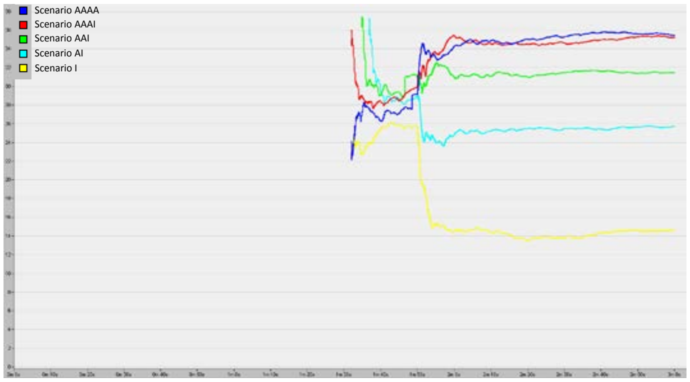

Figure 6: UE SINR with 7 cell (200 m) MBSFN area

Figure 7 and 8 show the results using 500 m and 1000 m cell radius, respectively.

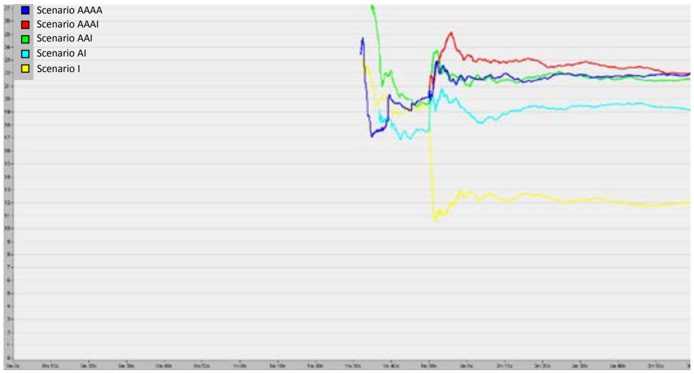

Figure 7: UE SINR with 7 cell (500 m) MBSFN area

Figure 8: UE SINR with 7 cell (1000 m) MBSFN area

These results show that the lower the cell radius, the higher the performance in the UEs, and the greater the improvement that the MBSFN technique introduces. In order to offer high data rates using MBMS transmissions, you must use cells with a small size and create clusters using the same MBSFN around the region of the UEs.

Group based MBMS scenario

Below, a 19 cell MBSFN area scenario has been analyzed. First, the performance of four different UE locations has been studied. Figure 9 shows UE1, UE2, and UE3 placed in the edge of the central cell, first ring, and second ring, respectively, and UE4 placed around the 55% of the cell radius in a first ring cell.

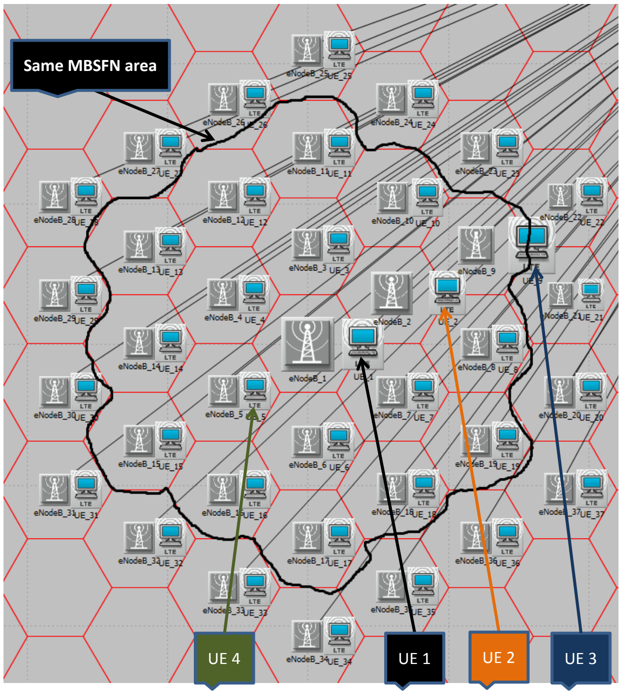

Figure 9: Group based MBMS scenario with 19 cells

Figure 10 shows the SINR for each UE. Observe that the SINR for the UEs placed in the edge of the central cell and first ring (UE1 and UE2) is very similar. However, the SINR for the UE placed in the edge of the second and last rings (UE3) is more than 8 dB down. On the other hand, the SINR of the UE placed in the 55% of the cell radius in the first ring (UE4) is around 10 dB up.

Figure 10: UE SINR with 19 cell MBSFN area

An example of MBMS group classification for a multicast service transmission is shown in Table 4, based on the CQI reported from each UE that is representative of the SINR observed by the UE over a sub-band. Based on the SINR of the UEs (sent to the eNodeB like the CQI), they are classified into the three MBMS groups (multicasting groups) shown in Table 4. Depending on the MBMS group a UE belongs to, it joins the corresponding multicast group that transmits the multimedia content using the assigned MCS, and therefore with different bit rates.

CQI	MBMS group	MCS
> 10	1	7
6-10	2	4
< 6	3	1

Table 4: Example of MBMS groups

Figure 11 shows the throughput received by the UE. Note that UE4 joins MBMS group 1, which transmits using MCS 7; UE1 and UE2 join MBMS group 2, which transmits using MCS 4; and UE3 joins MBMS group 3, which transmits using MCS 1.

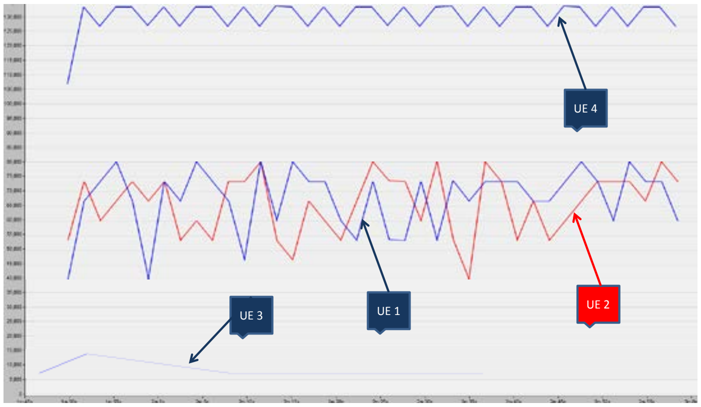

Figure 11: UE throughput using 3 different MCS

New proposals for MBSFN area transmissions

Dynamic MBSFN area clustering:
MBMS transmissions of events need to satisfy the QoS restrictions in order to offer the user a satisfying experience. With the aim of developing a method that optimizes the average performance, our proposal creates dynamic MBSFN area clusters, based on the location of the UEs (eNodeB serving each UE) and the Channel Quality Indicator (CQI) received from each UE.

First of all, place the MBSFN transmission in a determined area in order to cover a multicast event for a large number of users. Next, determine the size of the LTE cells in the given area, the Guaranteed Bit Rate (GBR) of the service to be provided with MBSFN, and the percentage of users to which the system will guarantee this GBR. With this knowledge, you can calculate the number of rings required for the served region, in the same MBSFN area, to obtain a high enough SINR to satisfy the requirements. Furthermore, based on the CQI received from the UEs dynamically, you can adapt the size of this area, increasing or decreasing the number of cells required to satisfy the QoS requirements to a certain percentage of users, whose radio channel conditions are changing dynamically.

Group-based multicasting:
Moreover, with the goal of providing the service to all UEs in the region, different multicasting groups in MBSFN area have been built. The multicast transmission algorithm proposed in [9] has been used, based on the CQI received from each UE, and the MBMS system classifies the users in a number of groups. The first group is created with the UEs that satisfy the transmission conditions to receive the GBR. Then one or more additional groups are created with the rest of the UEs that will receive the service according to their transmission conditions.

Conclusion

We demonstrate in this paper that by using MBSFN with smaller radio cells, the performance in UEs and the improvement achieved by increasing the MBSFN area is higher than when using larger radio cells.

By means of the simulations, we have been able to observe that SINR in a UE placed in the cell edge of an inner ring is highly increased, and only the users placed in the cell edge of the outer ring has a poor value of SINR. Therefore, our proposal to dynamically create and modify the MBSFN area, according to the location of the users demanding the service, adding or removing cells to or from the original MBSFN area, allows the system to optimize the resources used to meet the QoS requirements.

On the other hand, using group-based MBMS classification based on CQI received from the UEs, it is possible to adapt the MCS used for the transmission to a group of users with similar channel conditions.

Our simulations have been performed using static users. Future research will be based on the stability of the system with high mobility users, when the channel conditions are changing rapidly. This high mobility will increase the times a user changes MBMS group.

Our research continues, working on building an OPNET model that automatically performs the *dynamic MBSFN area clustering* and *the multicasting group based* on LTE.

Acknowledgment

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