An Enhanced MBMS Power Control Mechanism towards Long Term Evolution

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***Abstract*—Long Term Evolution (LTE) promises the delivery of rich multimedia services in a more power and spectral efficient way than its predecessor Universal Mobile Telecommunication System (UMTS). To this direction, the newly introduced Enhanced - Multimedia Broadcast/Multicast Service (E-MBMS) framework is envisaged to play a fundamental role during the LTE standardization. E-MBMS constitutes the successor of MBMS which was introduced in the Release 6 of UMTS in order to deliver multimedia data from a single source entity to multiple destinations. This paper proposes a novel mechanism for efficient radio bearer selection during E-MBMS transmissions in LTE networks. The proposed mechanism is based on the concept of transport channels combination (point-to-point and/or point-to-multipoint radio bearers) in any cell/sector of the network in which multicast users are residing. The mechanism is evaluated through several realistic scenarios and is compared with several radio bearer selection mechanisms in order to highlight the enhancements that it provides.**

***Index Terms*—UMTS, LTE, E-MBMS, Power Control.**

I. Introduction

TODAY we are witnesses of a rapidly increasing market for mobile multimedia applications, such as Mobile TV and Mobile Streaming. Services like these have or are expected to have high penetration in mobile multimedia communications industry. In order to confront such high requirements for multimedia content, the MBMS framework was introduced in Release 6 of the UMTS architecture [1], [2].

The main requirement during the provision of MBMS multicast services is to make an efficient overall usage of radio and network resources. This necessity mainly translates into improved power control strategies, since the base stations' transmission power is the limiting factor of downlink capacity in UMTS networks. Under this prism, a critical aspect of MBMS performance is the selection of the most efficient radio bearer for the transmission of MBMS traffic.

In the frame of MBMS power control and transport channel selection several approaches have been proposed. The 3rd Generation Partnership Project (3GPP) approaches (already included in the MBMS specifications) TS 25.346 [3] and TR 25.922 [4], as well as works [5] and [6] are representative approaches regarding the issue of MBMS power control. All these works focus on the transport channel selection for the transmission of the MBMS data over the Universal Terrestrial Radio Access Network (UTRAN) interfaces.

In this paper, we propose a power control mechanism for efficient radio bearer selection in MBMS. The proposed scheme adopts downlink transmission power as the optimum criterion for radio bearer deployment and selects the transport channel combination that minimizes the transmission power of the base station. Point-to-Point (PTP) and Point-to-Multipoint (PTM) transmission modes may be used separately or may be combined and deployed in parallel. Our approach will be compared with the aforementioned approaches in terms of both power consumption and complexity so as to highlight its enhancements and underline the necessity for its incorporation in E-MBMS framework of LTE.

The paper is structured as follows: In Section II, we present the motivation behind our study and the related work in the specific field. Section III presents the proposed power control mechanism, while Section IV is dedicated to the presentation of the results. Finally, the planned next steps as well as the concluding remarks are briefly described in Section V.

II. Motivation and Related Work

The transmission of MBMS packets over the UTRAN interfaces may be performed on common (Forward Access Channel or FACH), dedicated (Dedicated Channel or DCH) or shared channels (High Speed-Downlink Shared Channel or HS-DSCH) [2]. It is worth mentioning that the selection of the most efficient radio bearer is still an open issue in today's MBMS infrastructure mainly due to its catalytic role in Radio Resource Management (RRM). In the following paragraphs we present the main radio bearer selection approaches.

A. MBMS Counting Mechanism (TS 25.346)

The 3GPP MBMS Counting Mechanism (TS 25.346) constitutes the prevailing approach of switching between PTP (multiple DCHs) and PTM (FACH) radio bearers, mainly due to its simplicity of implementation and function [3]. According to this mechanism, a single transport channel can

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be deployed in a cell at any given time. The decision on the threshold between PTP and PTM bearers is operator dependent, although it is proposed that it should be based on the number of served MBMS users. In other words, a switch from PTP to PTM resources should occur, when the number of users in a cell exceeds a predefined threshold. However, this mechanism provides a non realistic approach because mobility and current location of the mobile users are not taken into account. Moreover, this mechanism does not support FACH dynamic power setting. When employed, FACH has to cover the whole cell area that generally leads to unnecessary power wasting. Finally, TS 25.346 does not support the High Speed Downlink Packet Access (HSDPA) technology, which could enrich MBMS with broadband characteristics [7].

B. MBMS PTP/PTM Switching Algorithm (TR 25.922)

3GPP TR 25.922 or MBMS PTP/PTM switching algorithm [4], assumes that a single transport channel can be deployed in a cell at any given time. Contrary to TS 25.346, it follows a power based approach when selecting the appropriate radio bearer, aiming at minimizing the Node B's (Node B constitutes the base station in UMTS terminology) power requirements during MBMS transmissions. In TR 25.922, instead of using solely DCHs, HS-DSCH can also be transmitted. However, the restricted usage of either DCH or HS-DSCH in PTP mode may result to significant power losses. In both cases, the PTP (DCH or HS-DSCH, since the switching between HS-DSCH and DCH is not supported in this mechanism) and the PTM power levels are compared and the case with the lowest power requirements is selected. Even though TR 25.922 overcomes several inefficiencies of the TS 25.346, still it does not support FACH dynamic setting.

C. MBMS Session Assignment Mechanism

The MBMS Session Assignment Mechanism [5] can be considered as an enhancement of the 3GPP TS 25.346 and TR 25.922. This is due to the fact that contrary to TS 25.346, this mechanism considers users' mobility and location and takes into account the power requirements for switching between transport channels. Contrary to TR 25.922, the switching between PTP (DCH and HS-DSCH) transmission modes is supported. Furthermore, contrary to TS 25.346 and TR 25.922, this mechanism supports FACH dynamic power allocation, reducing in this way the power requirements during PTM transmissions. Finally, the major advantage of this mechanism is its ability to ensure the service(s) continuity when multiple parallel MBMS services are delivered.

D. Mechanism proposed in 3GPP TSG RAN1 R1-02-1240

All the above mechanisms allow a single PTP or PTM transport channel deployment at any given time. On the other hand, the mechanism proposed in 3GPP TSG RAN1 R1-02-1240 [6], considers the mixed usage of DCHs and FACH, which can significantly decrease the Node B's transmission power, depending on the number and the location of the users. According to this approach, the FACH channel only covers a dynamically selected inner area of a cell and provides the MBMS service to the users that are found in this part. The rest of the users are served using DCH to cover the remaining outer cell area.

III. Proposed Mechanism for PTP and PTM Bearers Combination

This section presents the architecture and the functionality of the proposed mechanism. The block diagram of the mechanism is illustrated in Fig. 1. According to Fig. 1, the mechanism consists of four distinct operation phases. These are: the Initialization phase, the Parameter Retrieval phase, the Channels Selection phase, and the Event Scheduling phase. The Radio Network Controller (RNC) is the responsible node of the UMTS architecture for the operation of this mechanism.

The Initialization phase (Fig. 1) launches the mechanism when one user expresses its interest in receiving a MBMS service. In other words the mechanism begins when the first user requests the MBMS service and the Initialization phase is responsible for this procedure.

The Parameter Retrieval phase is responsible for retrieving the parameters of the existing MBMS users in each cell. These parameters are the distance of each User Equipment (UE) from the Node B and the signal quality requirement per UE. The MBMS service bit rate is assumed to be already known (in the Broadcast Multicast - Service Center or BM-SC).

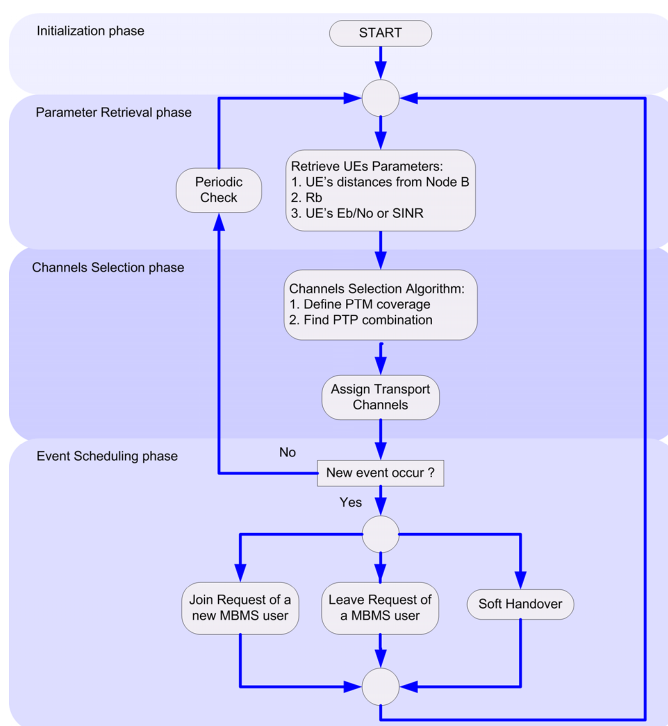

Fig. 1. Block diagram of the mechanism.

The Channels Selection phase is dedicated to the selection and assignment of the transport channels to the MBMS session in the corresponding cell. This phase consists of two blocks: the Channels Selection Algorithm block and the Assign Transport Channels block (Fig. 1). The algorithm executed in the former block selects the combination of PTP and PTM bearers that minimizes the downlink Node B's transmission power for the corresponding MBMS session. In particular, the algorithm is executed in two steps. In the first step (Define PTM coverage) the algorithm estimates the optimum coverage of FACH for the specific users' distribution in the cell. This coverage area is called inner part of the cell as illustrated in Fig. 2. In the second step (Find PTP combination), the mechanism decides which PTP bearer(s) will cover the rest part of the cell (outer part - Fig. 2).

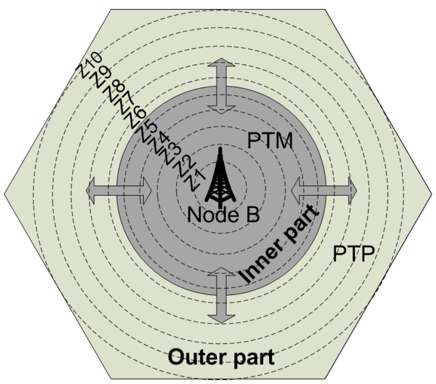

Fig. 2. Cell areas and zones.

In order to estimate the optimum coverage of FACH in Define PTM coverage step (see Fig. 1), the algorithm initially divides the cell in ten zones (Z1 to Z10). Each zone Zi refers to a circle with radius equal to 10i% of the cell radius. Afterwards, the algorithm scans all the zones and calculates the total Node B's transmission power for the following 21 transport Channel Configurations (CC):

--CC1: No FACH used. All MBMS users in the cell are covered by DCHs.

--CC2: No FACH used. All MBMS users in the cell are covered by HS-DSCHs.

--CC3: FACH for UEs up to Z1. All the rest UEs covered by DCHs.

--CC4: FACH for UEs up to Z1. All the rest UEs covered by HS-DSCHs.

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--CC19: FACH for UEs up to Z9. All the rest UEs covered by DCHs.

--CC20: FACH for UEs up to Z9. All the rest UEs covered by HS-DSCHs.

--CC21: FACH for all the MBMS UEs (up to Z10). DCHs and HS-DSCHs are not used.

The CC that consumes less power indicates the coverage of the FACH and determines the inner part of the cell. All the above procedure is presented using pseudo code in Fig. 3.

Once the appropriate FACH coverage is defined, the algorithm enters the Find PTP combination step (see Fig. 1), which determines the appropriate PTP radio bearer(s) that will cover the MBMS users residing in the outer part of the cell. The procedure is similar to the procedure described in the Define PTM coverage step. The algorithm scans all the zones in the outer part of the cell and calculates the total Node B's transmission power in order to cover all the outer part MBMS users only with PTP bearers. The first zone of the outer part is Z(inner part+1), therefore the algorithm will have to scan the following PTP transport Channel Configurations (PTP_CC):

--PTP_CC1: DCHs for outer part UEs up to Z(inner part+1). All the rest outer part UEs (up to Z10) covered by HS-DSCHs.

--PTP_CC2: DCHs for outer part UEs up to Z(inner part+2). All the rest outer part UEs (up to Z10) covered by HS-DSCHs.

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--PTP_CC(10-inner part): All MBMS users in the outer part cell are covered by DCHs. HS-DSCHs are not used.

--PTP_CC(10-inner part+1): HS-DSCHs for outer part UEs up to Z(inner part+1). All the rest outer part UEs (up to Z10) covered by DCHs.

--PTP_CC(10-inner part+2): HS-DSCHs for outer part UEs up to Z(inner part+2). All the rest outer part UEs (up to Z10) covered by DCHs.

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--PTP_CC(2*(10-inner part)): All MBMS users in the outer part cell are covered by HS-DSCHs. DCHs are not used.

% Mechanism for PTP and PTM Bearers Combination

% **Define PTM coverage (Estimate FACH coverage)**

Define **cell radius**
% *Divide the cell in 10 zones and calculate their radius*
For **i**=1 to 10
    Calculate **Radius Zi**
% *Compute the less power demanding CC*
Min Power = P(CC1)
Selected Zone = Z0
For **j**=2 to 21
    Calculate **P(CCj)**
    if **P(CCj)** < **Min Power** then
        Min Power = P(CCj)
        % *Find FACH coverage*
        Selected Zone = $\mathbf{Z}\left\lceil \frac{j}{2} - 1 \right\rceil$
Return **Min Power**, **Selected Zone**
%---
% **Find PTP combination (PTP bearers for outer part)**

% *Compute the less power demanding PTP_CC*
Outer Part Min Power = P(PTP_CC1)
Selected PTP_CC = 1
For **i**= 2 to 2*(10- **Selected Zone**)
    Calculate **P(PTP_CCi)**
    if **P(PTP_CCi)** < **Outer Part Min Power** then
        Outer Part Min Power = P(PTP_CCi)
        % *Find the PTP_CC with min power*
        Selected PTP_CC =i
Return **Outer Part Min Power, Selected PTP CC**

Fig. 3. Pseudo code of the Channels Selection Algorithm.

After these calculations, the different PTP_CCs are compared and the PTP_CC with the lowest power requirements determines the PTP transport channel configuration for the outer part MBMS UEs (Fig. 3).

Generally, the output of the Channels Selection Algorithm block is the combination of PTM and PTP transport channels that consumes the lowest power resources between all possible combinations in the corresponding cell. This information is given as input in the Assign Transport Channels block (Fig. 1), which is the responsible block of the mechanism for assigning the selected transport channels to the MBMS session in the corresponding cell.

The last phase of the mechanism is the Event Scheduling phase. The mechanism enters this phase, only if one of the following events occurs during a MBMS session: a join/leave request from a MBMS user or handover. The algorithm handles these events with the absolutely same way, since the parameters of all users are updated in regular time intervals.

The Parameter Retrieval phase is triggered at regular time intervals so as to take into account the users' mobility and the events of the Event Scheduling phase. This periodic computation inserts a further complexity for RNC as this information is carried in an uplink channel. This entails that a certain bandwidth fraction must be allocated for the transmission of this information in the uplink channel, thus resulting to a capacity reduction.

IV. Performance Evaluation

In this section, analytical simulation results for the evaluation of the proposed mechanism are presented. The main assumptions that are used in our simulations are presented in the Table I and refer to a macrocell environment [8], [9]. In addition, Transmission Time Interval (TTI) is set to 80ms, Block Error Rate (BLER) target is 1% and no Space Time Transmit Diversity (STTD) is assumed.

TABLE I
Simulation Parameters

Parameter	Value
Cellular layout	18 hexagonal grid cells
Sectorization	3 sectors/cell
Site-to-site distance / Cell radius	1 Km / 0.577 Km
Maximum BS Tx power	20 W
Other BS Tx power	5 W
CPICH Power	2 W
Common channel power	1 W
Propagation model	Okumura Hata
Multipath channel	Vehicular A (3km/h)
Orthogonality factor	0.5
E_b/N_0 target	5 dB

A. *Scenario 1: Fixed UE number*

The first scenario lasts for 200 sec and can be divided into four time periods, depending on the number of MBMS users. According to this scenario, a 64 Kbps service should be delivered to a group of users, whose initial position at each time period is presented in Table II. For example, for the time period 0 to 50 sec, 25 UEs receive the 64 Kbps service at distance 50% of the cell radius and 7 UEs at distance 80% of the cell radius.

TABLE II
Scenario 1

Time (sec)	UEs Number	Coverage (%)	Best Performance
0-50	25 7	50 80	Proposed Mechanism
51-100	25 2	50 80	R1-02-1240 and Proposed Mechanism
101-150	17	50	TR 25.922 (HS-DSCH), Work [6] and Proposed Mechanism
151-200	4	50	All except TR 25.922 (HS-DSCH)

Fig. 4a depicts the power levels of the examined radio bearer selection mechanisms. For example, for the period 0-50 sec, the total number of users in the cell is 32. By assuming that the threshold for switching between DCH and FACH (HS-DSCH is not supported) in TS 25.346 is 8 UEs (a value proposed in the majority of research works), TS 25.346 will deploy a FACH with 100% cell coverage (requiring 7.6 W).

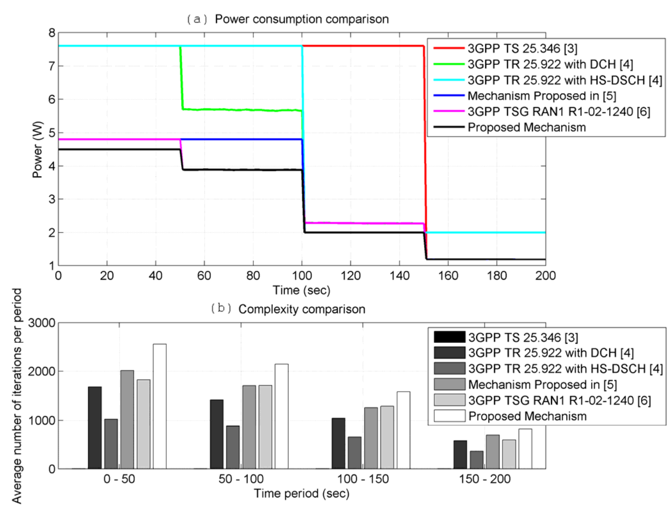

Fig. 4. (a) Power consumption and (b) complexity comparison (scenario 1).

The high initial users' population favors the deployment of FACH in order to serve all the UEs in 3GPP TR 25.922. However, as TS 25.346, TR 25.922 does not support FACH dynamic setting. This is the reason why TR 25.922 (with DCH or HS-DSCH) has the same power requirements with TS 25.346 (7.6 W) for the time period 0-50 sec.

FACH dynamic power setting is supported by the MBMS Session Assignment mechanism. Therefore, a FACH with such power so as to cover the MBMS user with the worst path loss is deployed. For the time period 0-50 sec, this user resides in the borders of zone Z8, which means that this mechanism will deploy a FACH with 80% coverage (requiring 4.8 W).

The mechanism proposed in [6] allows the mixed usage of DCHs and FACH and supports FACH dynamic power setting. As shown in Fig. 4a, this mechanism requires the same power as the MBMS Session Assignment mechanism in order to serve all the users in the cell, for the first time period.

Finally, Fig. 4a depicts the power requirements of the proposed mechanism for the examined scenario. For the time period 0-50 sec, the output of the Channels Selection Algorithm block (Fig. 1) specifies that the users up to Z5 should be served by a FACH. Moreover, the most efficient combination of PTP bearers for the outer part MBMS users is to serve the remaining 7 users in zone Z8 with HS-DSCH. Therefore, 4.5 W in total are required in order to serve all the MBMS users with this mechanism.

Obviously, the proposed mechanism ensures minimized power consumption. A significant power budget, ranging from 0.3 to 3.1 W, may be saved for the period 0-50 sec compared with the other approaches. However, the major disadvantage of the proposed mechanism is its increased complexity compared with the other approaches (Fig. 4b). The complexity comparison will be analyzed in depth through the scenario 2.

B. Scenario 2: Variable UE number

According to the second scenario, the UEs appear in random positions throughout the cell and move randomly with speed 3Km/h. Initially, the number of UEs that constitute the multicast group is 4; and 2 UEs join the MBMS session every 10 seconds. Fig. 5 presents the comparison of all the above mentioned mechanisms. As shown in Fig. 5a, the proposed mechanism has the best performance in terms of power consumption, since its power requirements remain lower (or same) than the other approaches throughout the simulation.

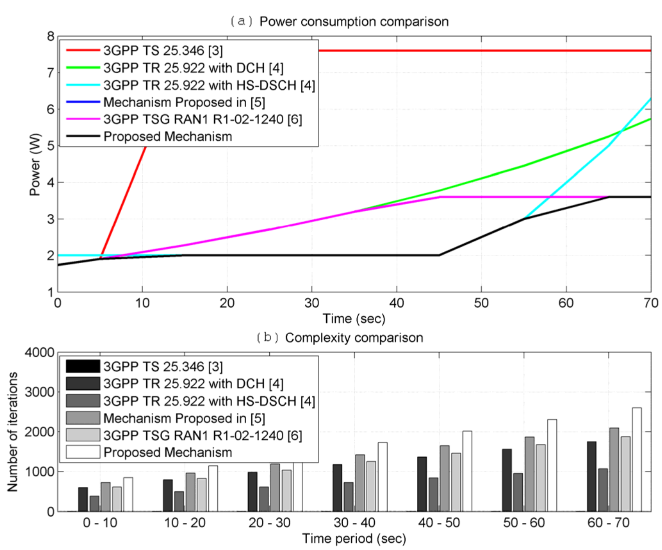

Fig. 5. (a) Power consumption and (b) complexity comparison (scenario 2).

Fig. 5b presents the computational overhead that each mechanisms inserts in RNC (number of iterations required so as to calculate the power of the available transport channels and assign the ideal channel), based on the above scenario.

In general, TS 25.346 inserts the lowest computational overhead (number of iterations constant and equal to one), because TS 25.346 requires only the number of served MBMS users in order to assign the appropriate transport channel. On the other hand, the other approaches have higher computational overhead due to the fact that these mechanisms have to periodically retrieve the parameters of existing MBMS users. Moreover, these approaches have to calculate the power consumption of the transport channels that each mechanism supports; and based on this calculation to assign the ideal radio bearer. The fact that the proposed mechanism supports all the available transport channels explains why the number of iterations in this case is higher than the other approaches.

TABLE III
COMPARISON OF THE MECHANISMS

Mechanism	Advantages	Disadvantages
TS 25.346	1) Low complexity 2) Easy to implement 3) 3GPP standardized	1) High power requirements 2) No support for mobility 3) No support for HS-DSCH in PTP mode 4) No support for dynamic FACH in PTM mode
TR 25.922	1) Supports all transport channels 2) 3GPP standardized	1) High power requirements 2) No support for switching between HS-DSCH and DCH in PTP mode 3) No support for dynamic FACH in PTM mode
MBMS Session Assignment Mechanism	1) Supports all transport channels 2) Supports switching between HS-DSCH and DCH 3) Supports multiple MBMS sessions 4) Supports dynamic FACH in PTM mode	1) No support for combined usage of transport channels 2) Not standardized 3) High complexity due to multiple session support
3GPP R1-02-1240	1) Power efficient 2) Supports combined usage of FACH and DCH 3) Supports dynamic FACH in PTM mode	1) High complexity 2) Not standardized 3) No support for HS-DSCH in PTP mode
Proposed Mechanism	1) Power efficient 2) Supports combined usage of all transport channels 3) Supports dynamic FACH in PTM mode	1) High complexity 2) Not standardized

To sum up, Table III presents a direct comparison between the mechanisms analyzed in this paper. The main conclusion is that the proposed mechanism outperforms the other approaches in terms of power consumption. It puts together the benefits of all mechanisms by providing a scheme that is based on the concept of transport channels combination; and performs an optimal power resource allocation in UMTS base stations. And even if the complexity of the proposed mechanism is higher than the complexity of the other mechanisms, the benefits from the optimal power planning counterbalance the complexity issues raised.

V. CONCLUSIONS AND FUTURE WORK

In this paper we presented a novel power control mechanism for efficient radio bearer selection in MBMS enabled UMTS networks. The proposed mechanism adopts the concept of radio bearer combination (PTP and/or PTM) so as to reduce the power requirements of the base stations. In order to highlight the enhancements obtained by the proposed mechanism, we provided a comparison of the mechanism with several approaches, including the 3GPP approaches. The main conclusion is that our mechanism outperforms them, underlining in this way the necessity for its incorporation in MBMS.

The steps that follow this work could be at a first level the evaluation of the mechanism through additional simulation scenarios in the ns-2 simulator so as to measure, except from the performance of our mechanism, other parameters such as delays in UTRAN interfaces during MBMS transmissions. At a second level, we plan to improve the capacity and functionality of our mechanism by incorporating the enhancements that could be obtained from the use of multiple-input multiple-output (MIMO) antenna techniques in HSDPA.

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