An Efficient Mechanism for Power Control Optimization in MBMS Enabled UTRAN

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***Abstract*—This paper proposes a power control mechanism for the efficient radio bearer selection in the Multimedia Broadcast/Multicast Service (MBMS) framework of Universal Mobile Telecommunications System (UMTS). The selection of the most efficient transport channel in terms of power consumption is a key point for MBMS enabled UMTS networks, since a wrong transport channel selection for the transmission of the MBMS data could result to a significant decrease in the total capacity of the network. Different UMTS transport channels and power saving techniques are examined and an algorithm that selects the most efficient combination of the above parameters is proposed. The proposed MBMS power control mechanism selects the transport channel that minimizes the base station's transmission power in every cell of the network that serves multicast users.**

Keywords-UMTS, MBMS, Power Control, Radio Resource Management

I. INTRODUCTION

Universal Mobile Telecommunications System (UMTS) constitutes the 3rd generation (3G) of cellular wireless networks which aims to provide high-speed data access along with real time voice and video calls. Wireless data is one of the major boosters of wireless communications and one of the main motivations of the next generation standards [1].

At first, UMTS offered tele-services (e.g. voice and SMS) and Bearer Services for point-to-point (PTP) transmission. Later, with the introduction of new services, such as IP Video Conferencing and Streaming Video, there was an increasing need for communication between one sender and many receivers, leading to the need of point-to-multipoint (PTM) transmission [1]. One efficient way to implement this type of transmission is the use of broadcast and multicast technologies. The 3rd Generation Partnership Project (3GPP) realized the need for broadcasting and multicasting in UMTS and proposed some enhancements on the UMTS Release 6 architecture that led to the definition of the Multimedia Broadcast/Multicast Service (MBMS) framework. MBMS is a point-to-multipoint service in which data is transmitted from a single source entity to multiple destinations, allowing networks resources to be shared [2], [3].

Power control is one of the most important aspects in MBMS due to the fact that the base stations' transmission power is a limited resource and must be shared among all MBMS users in a cell. The main purpose of power control is to minimize the transmitted power, thus avoiding unnecessary high power levels and eliminating intercell interference. As transmission power plays a fundamental role in the process of planning and optimization of UMTS radio access networks, its analysis is of great importance. This analysis is the main objective of this paper. In particular, this paper proposes a power control mechanism for the efficient radio bearer selection in MBMS enabled UTRAN (UMTS Terrestrial Radio Access Network). Different UMTS transport channels and power saving techniques are examined and an algorithm that selects the most efficient combination of these parameters is proposed.

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 constitutes an introduction of power control in MBMS; Section IV analyzes the proposed power control mechanism, while the results of the analysis are presented in Section V. Finally, some concluding remarks and planned next steps are briefly described in Section VI.

II. MOTIVATION AND RELATED WORK

According to 3GPP specifications, the transmission of MBMS packets over the UTRAN interfaces may be performed on PTM or PTP radio bearers [4]. The Forward Access Channel (FACH) is the main transport channel for PTM MBMS data transmission with turbo coding and Quadrature Phase-Shift Keying (QPSK) modulation. Dedicated Channel (DCH) is a PTP channel and hence, it suffers from the inefficiencies of requiring multiple DCHs to carry the data to a group of users. However, DCH can employ fast closed-loop power control and soft handover mechanisms and generally is a highly reliable channel. 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 frame of switching between PTP and PTM transmissions several approaches have been proposed. The 3GPP MBMS Counting Mechanism was the prevailing approach mainly due to its simplicity of implementation and function [4]. According to this mechanism, 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 serving 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 approach suffered from much inefficiency, mainly due to the difficulty of defining the appropriate threshold.

Assuming that all User Equipments (UEs) are distributed uniformly across the cell, the MBMS Counting Mechanism provides a non realistic approach because mobility and current location of the mobile users are not taken into account. On the other hand, assuming that all UEs are found near the cell borders (worst case scenario), this mechanism may lead to misleading results, and thus to an inappropriate threshold, resulting in inefficient utilization of network resources. This way, the advantage of simplicity of implementation is overshadowed by the disadvantage generated from the impossibility of determining the appropriate switching point.

The inefficiencies of the MBMS Counting Mechanism and the power limitations motivated novel approaches, indicating that there is no need for a priori information and predefined switching thresholds; while, the assignment of the radio bearer should be performed in order to minimize the Node B's (Node B constitutes the base station in UMTS terminology) power requirements [5]. An interesting study under these assumptions is presented in [6], where the authors propose a switching point between PTP and PTM bearers, based on power consumption; while, in [7] the authors propose a power control scheme for efficient radio bearer selection in MBMS enabled UMTS networks.

However, none of these works and approaches considers the power saving techniques that have been proposed [8], [9]. Techniques, such as Dynamic Power Setting and mixed usage of multiple DCHs and FACH, are proven to reduce the power requirements during MBMS transmissions and are considered in our approach.

The goal achieved by this work is threefold. At a first level, due to the fact that the MBMS Counting Mechanism is an open issue for 3GPP, our approach constitutes a more realistic and adaptive to dynamic wireless environments approach, by employing a power-based switching criterion when selecting transport channel for MBMS transmissions. At a second level, our approach contributes to RRM mechanism of UMTS by presenting a novel framework for MBMS that optimally utilizes the available power resources of UMTS base stations to MBMS sessions running in the network, resulting in that way to an extensive increase on the system's capacity. At a third level, our approach meets and extends the current requirements of 3GPP for reducing power requirements by incorporating several power saving techniques. Therefore, our approach does not only take into consideration all the basic functionalities of the 3GPP MBMS Counting Mechanism and the other power-based approaches but furthermore, it incorporates several basic and compulsory enhancements.

III. POWER PLANNING OF MBMS IN UTRAN

The Radio Network Controller (RNC) for radio efficiency reasons, can either use dedicated resources (one DCH for each UE in the cell), common resources (one FACH for all the UEs) or mixed resources (one FACH for the UEs that are close to the base station and multiple DCHs for the other UEs in the cell) to distribute the same content in a cell.

The total downlink transmission power allocated for all MBMS users in a cell that are served by multiple DCHs is variable. It mainly depends on the number of UEs, their location, the required bit rate of the MBMS session and the experienced signal quality, E_b/N_0, for each user. The Node B's total transmission power required for the transmission of the data to n users in a specific cell is calculated as in (1) [10].

$$P_{DCH} = \frac{P_P + \sum_{i=1}^{n} \frac{(P_N + x_i)}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p} L_{p,i}}{1 - \sum_{i=1}^{n} \frac{p}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p}} \tag{1}$$

where P_{DCH} is the base station's total transmitted power, P_P is the power devoted to common control channels, $L_{p,i}$ is the path loss, $R_{b,i}$ the i^{th} user transmission rate, W the bandwidth, P_N the background noise, p is the orthogonality factor (p=0: perfect orthogonality) and x_i is the intercell interference observed by the i^{th} user given as a function of the transmitted power by the neighboring cells P_{Tj}, j=1,…K and the path loss from this user to the j^{th} cell L_{ij}.

On the other hand, a FACH channel essentially transmits at a fixed power level since fast power control is not supported in this channel. A FACH channel must be received by all UEs throughout the cell (or the part of the cell that the users are residing). The RNC establishes and adjusts the FACH transmission power so as to cover only the specific area of the cell. In other words, the fixed power should be high enough so as to ensure the requested Quality of Service (QoS) in the desired area of the cell [11]. FACH power efficiency depends on maximizing diversity. Diversity can be obtained by the use of a longer Transmission Time Interval (TTI), e.g. 80ms instead of 20ms, to provide time diversity against fast fading. The bit rate of the MBMS service also affects the FACH transmission power.

Table I provides the FACH transmission power levels when Dynamic Power Setting is utilized [11]. In this case, the FACH transmission power can be determined based on the worst user's path loss. Depending on the distance between this user and the Node B, the RNC adjusts the FACH transmission power in one of the levels presented in Table I, so as to ensure a reliable reception of MBMS data. This way, the FACH transmission power will need to cover the whole cell only if one (or more) user is at the cell boundary. The power levels presented in Table I correspond to the case where no Space Time Transmit Diversity (STTD) is assumed. In addition, TTI is set to 80ms and Block Error Rate (BLER) target is 1% [11].

Nevertheless, the mixed usage of DCHs and FACH in a cell presents special interest as it can significantly decrease the Node B's transmission power [8]. In this approach, the FACH channel only covers the inner part of the cell (50% of the cell area) 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. The total downlink power consumption obviously depends on the number of users who are served by DCHs and their location [9].

TABLE I. FACH TRANSMISSION POWER LEVELS

Cell coverage	*Required Tx power (W) (64 Kbps)*	*Required Tx power (W) (128 Kbps)*
10 %	1.4	2.6
20 %	1.6	3
30 %	1.8	3.6
40 %	2	4.2
50 %	2.5	5
60 %	3	6.2
70 %	3.6	7.8
80 %	4.8	10
90 %	6.4	13
100 %	12	-

IV. PROPOSED POWER CONTROL MECHANISM

The block diagram of the proposed mechanism is illustrated in Fig. 1. According to Fig. 1, the mechanism consists of five distinct operation phases: the initialization phase, the parameter retrieval phase, the power computation phase, the radio bearer selection phase and the event scheduling phase. The algorithm runs at the RNC, which is the responsible node for selecting of the most efficient transport channel.

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.

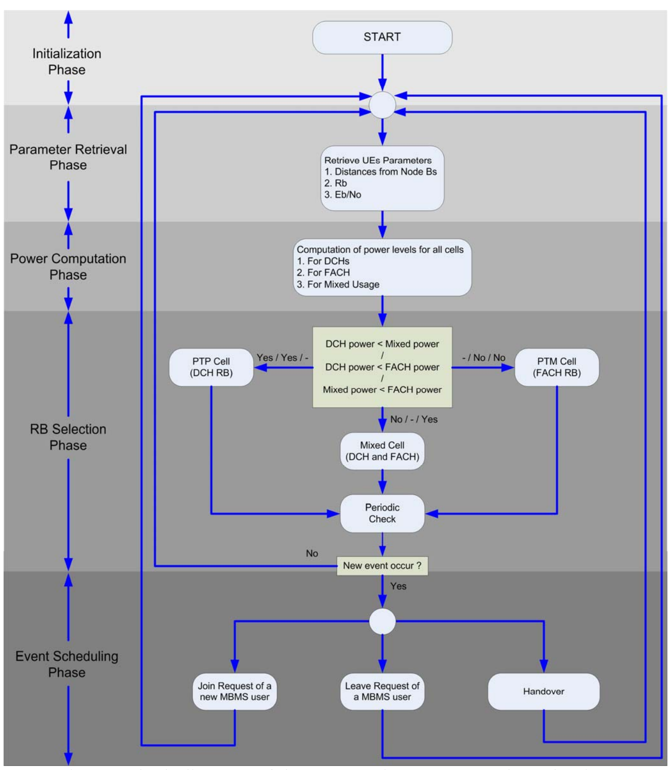

Fig. 1. Block diagram of the proposed power control mechanism

The parameter retrieval phase is responsible for retrieving the parameters of the existing MBMS users (through uplink channels) in each cell. These parameters are the distance of each UE from the Node B and the E_b/N_0 requirement per UE. In order to retrieve this information, the RNC broadcasts a message to the UEs belonging to a specific MBMS group and each user of the group responds to this message by indicating its location and its experienced signal quality. The MBMS bit rate service is assumed to be already known (in the Broadcast Multicast–Service Center or BM-SC).

During power computation phase, the required power to be allocated for each cell is computed. The computation is based on the assumption that the transmission of the multicast data can be performed with:

- Multiple DCHs (DCHs case).
- One FACH with such power so as to serve the UE with the worst path loss (FACH Dynamic case).
- One FACH with such power so as to serve the UEs that reside in 50% of the cell area, while the rest UEs are served with DCHs (Mixed case).

The total Node B's transmission power per cell for the MBMS session is computed as follows. For the DCHs case, the computation considers the parameters defined in the parameter retrieval phase and calculates the total required power (P_{DCH}) as in (1). For the FACH Dynamic case, the total required power (P_{FACH}) is computed depending on the user with the worst path loss and according to Table I, as described in section III. Finally, the Mixed case assumes that if there are UEs in 50% of the cell area, they are served with one FACH (requiring 2.5 W for a 64 Kbps service according to Table I), while the power required for the rest of the UEs is calculated as in (1). The total required power for this case (P_{Mixed}) is the sum of the two mentioned power levels.

In the radio bearer selection phase, the P_{DCH}, P_{FACH} and P_{Mixed} are compared in order to select the most efficient transmission method for the specific MBMS session. Thus, the algorithm decides which case consumes less power and chooses the radio bearer that minimizes the Node B's transmission power. Therefore, a cell can be characterized as a PTP cell (data is carried through multiple DCHs), as a PTM cell (data is carried through FACH channel) or as a Mixed cell (data is carried through FACH and DCHs). The categorization of the cells is done for each cell in the network separately.

The algorithm enters the event scheduling phase, only if one of the following events occurs during a MBMS session: a join request from a new MBMS user, a leave request from an existing MBMS user or handover. The algorithm handles these three events with the absolutely same way, since the parameters of all the users are updated in regular time intervals. The only difference is that a join and a leave request influence the power of only one cell, while handover influences the power of two different cells (the source and the destination cell).

The above description refers to a dynamic model, in the sense that the UEs are assumed to be moving throughout the topology. The parameter retrieval phase is triggered at regular time intervals so as to take into account the users' mobility and the three events of the event scheduling phase. Therefore, the P_{DCH}, P_{FACH} and P_{Mixed} power levels must be computed periodically at a predetermined frequency rate. 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 capacity reduction. The computation frequency is beyond the scope of this paper and should be further studied.

V. PERFORMANCE EVALUATION

In this section, analytical simulation results for the performance evaluation of the proposed mechanism are presented. The main assumptions that are used in our simulations are presented in the following table and refer to a macro cell environment [12]. In addition, no STTD is assumed, while the BLER target is set to 1%.

TABLE II. 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 (43 dBm)
other BS Tx power	5 W (37 dBm)
common channel power	1 W (30 dBm)
propagation model	Okumura Hata
multipath channel	vehicular A (3km/h)
orthogonality factor	0.5
E_b/N_0 target	5 dB

Our goal is to illustrate how the Node B's transmission power could be reduced by selecting different transport channels for the transmission of the MBMS data over the UTRAN interfaces. To this direction, three scenarios are examined, indicative of the way our mechanism works (appropriate channel assignment, handling of join and leave requests, users movement and handover consideration).

Transmission power levels when using DCH, FACH or mixed channels are depicted in the figures of the two first scenarios. These power levels constitute the overall output of the power computation phase. In the next phase, the mechanism will force the RNC to select at each instant the radio bearer that ensures the lowest power requirements.

A. Scenario 1: PTM, PTP, Mixed cell

The first scenario examines three cases where the users' initial locations are selected so as to favor the transmission of the MBMS data through FACH, DCHs and the combination of these channels respectively. During the simulation each UE is moving randomly throughout the topology. Without loss of generality, these three cases constitute possible circumstances during a MBMS session in a real world scenario.

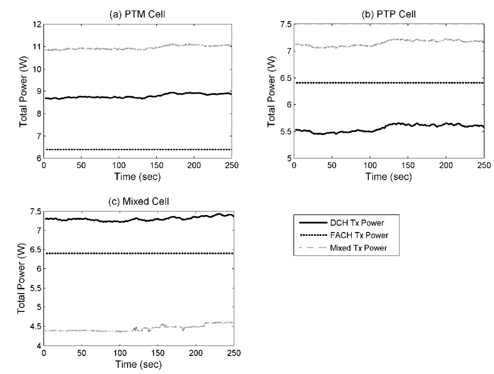

Fig. 2. Transmission power levels and cell categorization

According to the first case, 12 UEs near the cell borders and 2 UEs close to Node B receive a 64 Kbps MBMS service. This scenario favors the deployment of FACH for the transmission of the MBMS data. Indeed, as presented in Fig. 2a, the FACH transmission power level is lower throughout the whole simulation. More specifically, 6.4 W are required in order to cover 90% of the cell area with a FACH and provide the MBMS service to all UEs. This power level is independent of the UE population and remains constant, since the user with the worst path loss remains between 80 and 90% of cell area.

In the second case (Fig. 2b), 7 UEs with random initial positions are moving throughout the cell while receiving a 64 Kbps service. The fact that the UE population is small favors the deployment of multiple DCHs. The fact that the UEs are moving explains why the power level does not remain constant. However, even if it not constant, the DCH power level is always lower than the other two cases.

Regarding the third case, 16 UEs in total receive a 64 Kbps MBMS service. 14 of these UEs are found inside the 50% of the cell area ("inner part" UEs), while only 2 UEs are outside this area ("outer part" UEs). As Fig. 2c presents, the best way to serve all the UEs is to serve the "inner part" UEs with one FACH with such power so as to cover only the 50% of the cell area (2.5 W according to Table I). On the other hand, each "outer part" UEs is served with one DCH, increasing in this way the total power. The mixed usage transmission power remains lower that the other two cases (Fig. 2c), indicating that this is the most efficient method to serve all the MBMS users.

B. Scenario 2: Handover

This scenario presents the operation of the mechanism during handover. The UEs' initial positions according to the scenario are presented in Fig. 3. Each Node B in the topology has to serve a number of randomly moving UEs. However, Node B1 is initially serving 8 UEs, 4 of which will follow a predefined route so that handover will take place. More specifically, as shown in Fig. 3, UE1 and UE2 will move towards Node B2, while UE3 and UE4 towards Node B3.

The simulation lasts for 300 sec, time interval capable in order the process of handover to be completed. Fig. 4 depicts the power levels of the Node Bs under study when DCH, FACH or mixed channels are used. The three Node Bs under study, in other words, the three Node Bs that participate in the process of handover are: Node B1, Node B2, Node B3 (Fig. 3).

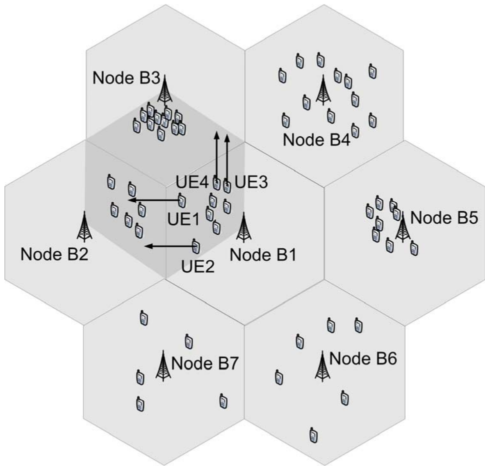

Fig. 3. UEs' initial locations and routes

More specifically, regarding Node B1, we observe that 4 UEs in total leave its coverage area. In Fig. 4a, this is presented by the 4 abrupt decrements in DCHs and mixed power level. The FACH power level remains high, until the 4 UEs leave the cell (about 255 sec after the simulation starts), when an abrupt decrement in its power level is observed. This happens because after the UEs leave the cell; the FACH will only have to serve UEs that are found in a small distance from Node B1 (Fig. 3). Nevertheless, even if the 4 UEs leave the cell area, multiple DCHs should be deployed as the power level in this case remains the lowest (Fig. 4a).

On the other hand, a decrement in Node B1 power levels is followed by a simultaneous increment in another Node B power levels. For example, at simulation time 205 sec, UE4 leaves the coverage area of Node B1 and enters the coverage area of Node B3 (Fig. 3). The FACH power level in Node B3 simultaneously increases because the new user (UE4) is the user with the worst path loss. The DCH and mixed power levels are also increased, because in both cases, Node B3 will have to serve one more user with DCH.

However, it is worth mentioning, that during the simulation, the efficient channel was selected independently of the UE's number and location. The corresponding power levels were compared and the channel with the lowest power requirements was selected at each instant. This fact makes the mechanism more powerful and resistant in changes.

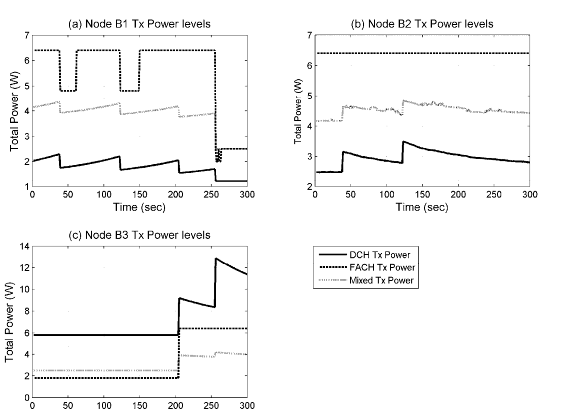

Fig. 4. Transmission power levels of cells under study during handover

C. *Scenario 3: Comparison with 3GPP approaches*

In order to further evaluate the proposed mechanism, we will make a comparison between our approach and the following approaches that were presented in Section II:

- MBMS Counting Mechanism (3GPP TS 25.346 [4]).
- MBMS PTP/PTM switching algorithm (3GPP TR 25.922 [5]).

According to this scenario, the UEs appear in random initial positions and then move randomly throughout the cell 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 (successive join requests by MBMS users). Fig. 5 presents the comparison of the above mentioned mechanisms in terms of power consumption (Fig. 5a) and complexity (Fig. 5b). Fig. 5a depicts the power levels of the examined radio bearer selection mechanisms. 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.

Analytically, in the beginning of the simulation where the UE population is small, all mechanisms have the same performance in terms of power consumption. As the number of UEs increases, by assuming that the threshold for switching between DCH and FACH 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 since this mechanism does not support FACH Dynamic Power Setting) when the number exceeds this predefined threshold.

Like TS 25.346, TR 25.922 does not support FACH Dynamic Power Setting. This is the reason why TR 25.922 has increased power requirements compared with the proposed mechanism as the UE population increases. On the other hand, the proposed mechanism allows the mixed usage of DCHs and FACH and supports FACH Dynamic Power Setting, ensuring in this way minimized power consumption. In particular, at the end of the simulation 2.1 W may be saved compared with TR 25.922 and 4 W compared with TS 25.346. By taking into account that 3GPP specifications consider a maximum MBMS power allocation equal to 10 W, the proposed mechanism significantly relaxes the transmission power requirements and improves network capacity, which in turn, enable the mass market delivery of multimedia services to mobile users.

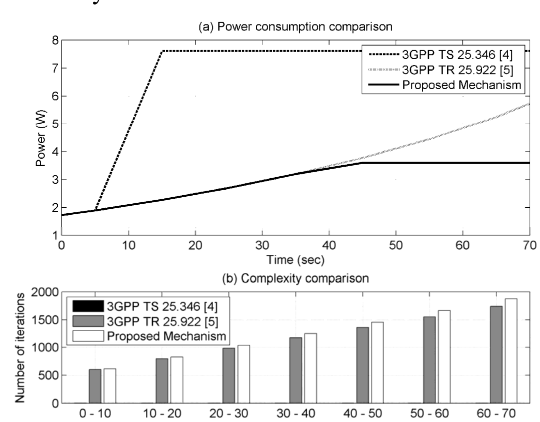

Fig. 5. (a) Power consumption and (b) complexity comparison

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 mobility support 3) Not support dynamic FACH in PTM mode
TR 25.922	1) Support all transport channels 2) 3GPP standardized	1) High power requirements 2) Not support dynamic FACH in PTM mode
Proposed Mechanism	1) Power efficient 2) Support combined usage of transport channels 3) Support dynamic FACH in PTM mode	1) High complexity 2) No standardized

An interesting aspect regarding the performance evaluation of the examined mechanisms is the computational overhead inserted in RNC. Fig. 5b presents the number of iterations that the RNC requires for each mechanism in order to calculate the power of the available transport channels and assign the ideal channel, based on the specific scenario.

In general, TS 25.346 inserts the lowest computational overhead. This derives from the fact that TS 25.346 requires only the number of served MBMS users; and by taking into account the predetermined switching threshold assigns the appropriate transport channel (DCH or FACH). Therefore, the number of iterations for this mechanism is constant and equal to one. 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 in order to calculate the power consumption of the transport channels and assign the ideal radio bearer. As depicted in Fig. 5b, the number of iterations in these mechanisms increases as the number of users increases, leading to higher computational overhead. The fact that our approach supports the mixed usage of DCHs and FACH explains why the number of iterations in this case is higher than the other approaches.

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.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we highlighted the importance of selecting the appropriate radio bearer, for the overall efficiency of a UMTS network. We underlined problems and limitation that other channel selection mechanisms have encountered. A dynamic power control mechanism was introduced, where the transmission power is the main parameter for selecting the appropriate transport channel. Our mechanism considers all the basic functionalities of the two 3GPP approaches (TS 25.346 [4] and TR 25.922 [5]) and incorporates several enhancements. Contrary to TS 25.346, our approach considers users' mobility and location and utilizes a power based scheme for switching between transport channels. Contrary to TR 25.922, the simultaneous utilization of PTP and PTM transmissions is supported. Finally, contrary to TS 25.346 and TR 25.922, our approach supports FACH dynamic power allocation in order to reduce power consumption during PTM transmissions.

The step that follows this work is to examine the use of High Speed-Downlink Shared Channel (HS-DSCH) as the transport channel for the transmission of the MBMS data over the UTRAN interfaces. Moreover, we will investigate several power saving techniques such as Rate Splitting, Macro Diversity Combining and Handover Control. An ambitious future step is to upgrade the mechanism (and mainly the Radio Bearer Selection Phase) so as to take into account the above mentioned transport channel and power saving techniques.

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