Optimal MBMS Power Allocation Exploiting MIMO in LTE Networks

Antonios Alexiou, Christos Bouras, Vasileios Kokkinos, Evangelos Rekkas
Research Academic Computer Technology Institute, Patras, Greece and
Computer Engineering and Informatics Dept., Univ. of Patras, Greece
alexiua@cti.gr, bouras@cti.gr, kokkinos@cti.gr, rekkas@cti.gr

Abstract— **In the frame of the Long Term Evolution (LTE) of mobile networks, the provision of rich multimedia services, such as Mobile TV, is considered of key importance for the LTE proliferation in mobile market. To this end, Multimedia Broadcast/Multicast Service (MBMS) is envisaged to play an instrumental role during LTE standardization process. MBMS was introduced in the Release 6 of Universal Mobile Telecommunication System (UMTS) in order to deliver multimedia data from a single source entity to multiple destinations. However, downlink capacity in such networks is limited by base station transmission power. As an aftermath, in MBMS efficient power allocation techniques should be implemented so as to ensure the mass provision of multimedia applications to mobile users. In this paper we propose a power control scheme for efficient selection of MBMS bearers. The proposed mechanism on the one hand manages to economically utilize power resources during MBMS transmissions, while on the other hand exploits the performance enhancements emerged from Multiple Input Multiple Output (MIMO) antennas used in LTE networks. Simulation results indicate that the proposed scheme results to significant power and capacity improvements.**

Keywords— LTE, HSPA, UMTS, MBMS, MIMO, Power Control

I. INTRODUCTION

Indisputably, tomorrow's mobile marketplace will be characterized by bandwidth-hungry, multimedia services that are already experienced in wired networks. LTE, the evolutionary successor of UMTS and High Speed Packet Access (HSPA) networks, addresses this emerging trend, by shaping the future mobile broadband landscape. LTE promises a richer, more immersive environment that significantly increases peak data rates and spectral efficiency. However, the plethora of mobile multimedia services that are expected to face high penetration, poses the need for the deployment of a resource economic scheme. MBMS, also called enhanced MBMS (e-MBMS) in LTE terminology, constitutes an efficient way to compensate for this necessity since it allows resources' sharing during data transmission [1], [2].

The main requirement during the provision of MBMS multicast services is to make an efficient overall usage of radio and network resources. The system should conceive and adapt to continuous changes that occur in such dynamic wireless environments and optimally allocate resources. Under this prism, a critical aspect of MBMS performance is the selection of the most efficient transport channel for the transmission of MBMS multicast data. In the frame of switching between different channels, MBMS specifications consider the so-called Counting Mechanism which decides whether it is more efficient to deploy Point-to-Point (PTP) or Point-to-Multipoint (PTM) bearers [3]. Counting Mechanism is an open issue in today's MBMS infrastructure mainly due to its catalytic role in Radio Resource Management (RRM).

Current specifications of Counting Mechanism consider a static switching point between PTP and PTM modes, based on the number of serving MBMS users in a cell [3]. However, this pre-defined threshold suffers from the inefficiency to waste significant power resources due to the lack of any adaptive functionality (no mobility or users' location is considered). Furthermore, existing Counting Mechanism fails to take into account advances in mobile communications that rely on the broadband HSPA technology and on MIMO systems. MIMO systems are a prerequisite for LTE networks and have the potential to address the unprecedented demand for wireless multimedia services and particularly for the MBMS.

In this paper, we deal with this contemporary topic and propose an advanced version of Counting Mechanism that performs optimal power allocation during MBMS transmissions. Actually, in this paper we further optimize our previous work presented in [4]. Relative works are also presented in [5] and [6] but all of these works focus on UMTS networks without taking into account HSPA or LTE standards. The mechanism dynamically determines the optimal MBMS radio bearer, based on the required transmission power to serve a multicast group. The proposed scheme takes advantage of the HSPA technology (including MIMO support) and contributes to RRM mechanisms of LTE by adopting a novel framework for MBMS that efficiently utilizes power resources. Our research motivation is reducing MBMS power consumption, which translates into improved capacity, thus enabling the mass delivery of rich multimedia services in LTE networks.

The paper is structured as follows: Section II is dedicated to an extended power profile analysis of the available bearers in MBMS, while Section III describes the proposed MBMS power allocation mechanism. Section IV is dedicated to the presentation of the results. Finally, concluding remarks and planned next steps are briefly described in Section V.

II. POWER PROFILES OF DOWNLINK TRANSPORT CHANNELS

The transport channels that could be used in MBMS for the transmission of the data packets over the Universal Terrestrial Radio Access Network (UTRAN) interfaces are: the High Speed Downlink Shared Channel (HS-DSCH), the Dedicated Channel (DCH) and the Forward Access Channel (FACH). In this section, we analytically present their power consumption characteristics during MBMS multicast transmissions.

A. HS-DSCH Power Profile

HS-DSCH is a rate controlled rather than a power controlled transport channel. In this paper we will focus on a dynamic method for allocating HS-DSCH transmission power that provides only the required, marginal amount of power so as to satisfy all the serving multicast users and, in parallel, eliminate system interference. Two major measures for HSPA power planning are the HS-DSCH Signal-to-Interference-plus-Noise Ratio (*SINR*) metric and the Geometry factor (*G*). *SINR* for a single-antenna Rake receiver is calculated as in (1) [7]:

$$SINR = SF_{16}\frac{P_{HS-DSCH}}{pP_{own} + P_{other} + P_{noise}} \quad (1)$$

where $P_{HS\text{-}DSCH}$ is the HS-DSCH transmission power, P_{own} is the own cell interference experienced by the mobile user, P_{other} the interference from neighboring cells and P_{noise} the Additive White Gaussian Noise. Parameter p is the orthogonality factor, while SF_{16} is the spreading factor of 16.

Geometry factor is another major measure that indicates the users' location throughout a cell. A lower *G* is expected when a user is located at the cell edge. *G* is calculated as in (2) [7]:

$$G = \frac{P_{own}}{P_{other} + P_{noise}} \quad (2)$$

There is a strong relationship between the HS-DSCH allocated power and the obtained MBMS cell throughput. This relationship can be disclosed in the three following steps. Initially, we have to define the target MBMS cell throughput. Once the target cell throughput is set, the next step is to define the way that this throughput relates to the *SINR* [7]. Finally, we can describe how the required HS-DSCH transmission power ($P_{HS\text{-}DSCH}$) can be expressed as a function of the SINR value and the user location (in terms of *G*) as in (3) [7]:

$$P_{HS-DSCH} \geq SINR[p - G^{-1}]\frac{P_{own}}{SF_{16}} \quad (3)$$

When MIMO is supported in HS-DSCH, multiple transmit antennas and receive antennas are used (different data streams are transmitted simultaneously over each antenna) and *SINR* is further improved [8]. Early LTE requirements consider two transmit and receive antennas (MIMO 2x2) and approximately, double data rates are obtained with the same base station transmission power. Therefore, without loss of generality, half power is required, compared to conventional HS-DSCH single antenna systems, for the delivery of the same MBMS session. In other words, MIMO further contributes in saving significant power resources and, in parallel, maximizing system capacity.

B. DCH Power Profile

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 serving users, their distances from the base station, the bit rate of the MBMS session and the experienced signal quality E_b/N_0 for each user. Equation (4) calculates the base station's total DCH transmission power required for the transmission of the data to *n* users in a specific cell [9].

$$P_{DCH} = \frac{P_P + \sum_{i=1}^{n}\frac{(P_N + x_i)}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p}L_{p,i}}{1 - \sum_{i=1}^{n}\frac{p}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p}} \quad (4)$$

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 ($p = 0$ for 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}, $j=1,\ldots K$ and the path loss from this user to the j^{th} cell L_{ij}.

C. FACH Power Profile

FACH is a PTM channel and must be received by all users throughout the MBMS service area of a cell. A FACH essentially transmits at a fixed power level that should be high enough to serve the user with the worst path loss, i.e. the user with the higher distance from the base station. The following table presents some indicative FACH downlink transmission power levels obtained for various cell coverage areas, without assuming diversity techniques [10].

TABLE I FACH TX POWER LEVELS

Cell coverage	Required Tx power (W) 64Kbps
60 %	3.0
80 %	4.8
100 %	7.6

The dynamic FACH power setting constitutes another major difference between our mechanism and the current Counting Mechanism, since the latter is not scalable and transmits at a power level so as to provide full cell coverage, irrespective of users' location.

III. PROPOSED MBMS MECHANISM

As presented in Section I, the improved performance of the proposed MBMS mechanism relies on the maximization of power efficiency and on the exploitation of the HSPA and MIMO technologies.

More specifically, the transport channel with less power requirements is selected for the delivery of the multicast traffic. In this way, due to the fact that any changes in such dynamic environments are directly reflected to the base station transmission power, our mechanism is highly adaptive. Furthermore, the proposed scheme incorporates the premier HS-DSCH transport channel used in HSPA, in contradiction to the existing Counting Mechanism which considers only Release '99 bearers (DCH and FACH). HS-DSCH in many cases is less power consuming, which combined to the power-based bearer switching criterion further improves MBMS power efficiency. However, even more power resources can be saved when MIMO is supported (which is highly expected to occur in LTE networks).

Next in this section, we present the architecture and the functionality of the proposed scheme, the block diagram of which is illustrated in Figure 1. More specifically, the mechanism comprises three distinct operation phases: the parameter retrieval phase, the power level computation phase and the transport channel selection phase. Additionally, a periodic check is performed at regular time intervals. The Radio Network Controller (RNC) is the responsible node of the MBMS architecture for the operation of this algorithm and the final decision on the most efficient transport channel for the delivery of MBMS multicast data.

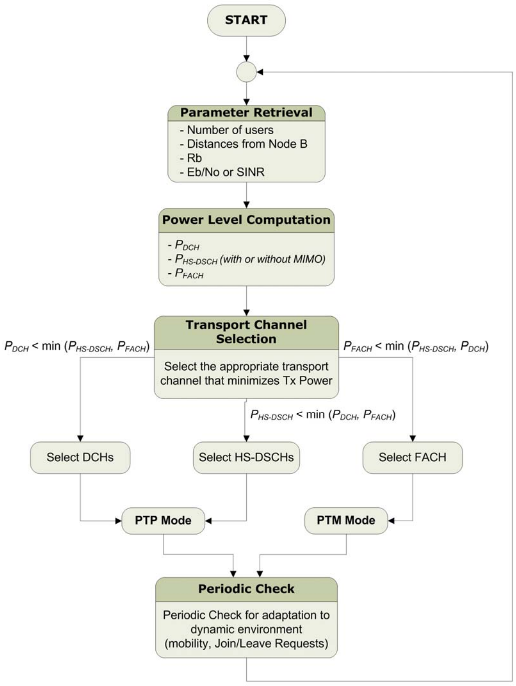

Figure 1. Power Counting Scheme with MIMO functionality

During the parameter retrieval phase (Figure 1) the mechanism retrieves parameters of the existing MBMS users and services in each cell. User related parameters, such as the number of users requesting a specific MBMS session; their distances from the base station and their QoS requirements are received from the RNC through appropriate uplink channels. Moreover, the MBMS bit rate service is retrieved from the Broadcast Multicast-Service Center (BM-SC) node.

The power level computation phase substantially processes the information received from the parameter retrieval phase. In this phase, the required power to be allocated for MBMS session delivery in each cell is computed. The computation is based on the assumption that the transmission of the multicast data can be performed over multiple DCHs, HS-DSCHs or over a single FACH. Consecutively, P_{DCH}, $P_{HS\text{-}DSCH}$ (with or without MIMO) and P_{FACH} power levels are computed respectively for each type of transport channel, according to the analysis presented in Section II.

During the transport channel selection phase, the appropriate transport channel for the transmission of the MBMS multicast content is selected. P_{DCH}, $P_{HS\text{-}DSCH}$ and P_{FACH} values are compared in order to select the most power efficient bearer for an MBMS session in a cell. The algorithm dynamically (as opposed to current Counting Mechanism) decides which case requires less power and consequently, chooses the corresponding transport channel for the session.

Finally, the mechanism performs a periodic check and re-retrieves user and service parameters in order to adapt to any changes during the service provision. This periodic check is triggered at a predetermined frequency rate and ensures that the mechanism is able to conceive changes, such as users' mobility, join/leave requests or any fading phenomena and configure its functionality so as to maintain resource efficiency at a high level.

IV. PERFORMANCE EVALUATION

In this section, analytical results for the evaluation of the proposed mechanism are presented. The main simulation assumptions used in our simulations are presented in Table II and refer to a macro cell environment [10], [11]. In addition, no Space Time Transmit Diversity (STTD) is assumed, while the Block Error Rate (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)
maximum BS power allocated to MBMS (P_{MBMS})	10 W (40 dBm)
propagation model	Okumura Hata
multipath channel	vehicular A (3km/h)
orthogonality factor (0 : perfect orthogonality)	0.5
E_b/N_0 target	5 dB

A. Efficient MBMS Transport Channel Selection

This subsection presents performance results concerning the most critical aspect of our scheme: the transport channel selection phase. This power efficient channel deployment is illustrated in Figures 2-4, for 60%, 80% and 100% cell coverage areas respectively. In these figures, transmission power levels (overall output of the power level computation phase) for DCH, HS-DSCH (with and without MIMO support) and FACH channels are depicted. The simulation scenario considers a 64 Kbps MBMS session delivery in a cell, whose users are assumed to be in groups (of varying population), located at the bounds of the above coverage areas each time.

Regarding the 60% cell coverage case (Figure 2) we observe that for a multicast group with 10 or fewer users DCH is the optimal transport channel. For a multicast population of 10-17 users HS-DSCH (without MIMO) is less power consuming and, thus, it should be preferred for MBMS content transmission (PTP mode). When MIMO 2x2 is supported the above upper threshold is further increased to 20 users. For more than 17 users (or 20 users with MIMO support), FACH is more power efficient and should be deployed (PTM mode).

Similar results can be extracted for the cases of 80% and 100% cell coverage from Figure 3 and Figure 4 respectively. However, from these figures we may additionally conclude that for higher cell coverage areas HS-DSCH is prevailing over the DCH even for a small multicast group and should be exclusively used instead of DCH in PTP mode.

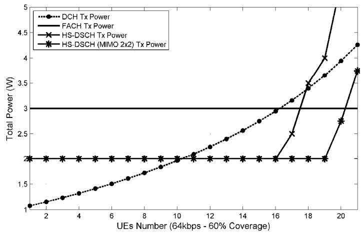

Figure 2. MBMS Power Allocation, 64Kbps, 60% coverage

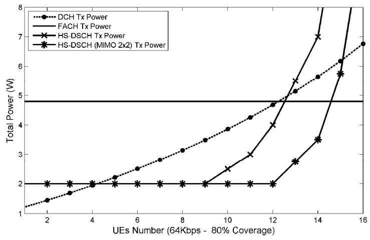

Figure 3. MBMS Power Allocation, 64Kbps, 80% coverage

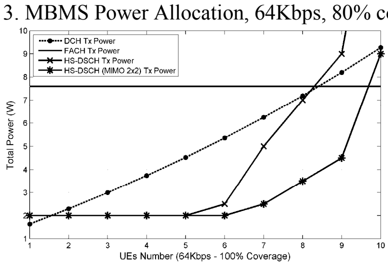

Figure 4. MBMS Power Allocation, 64Kbps, 100% coverage

In general, in cases where the number of users is small, PTP transmissions are preferred, while PTM transmissions are favored for large multicast population. However, our mechanism does not only decide to use PTP or PTM transmissions, but it makes a further distinction between DCH and HS-DSCH in PTP mode. This is an important notice since HS-DSCH appears to be less power consuming than DCH in most cases, especially when MIMO is supported. MIMO schemes significantly reduce MBMS power consumption compared to other radio bearers and further maximize power efficiency. This power gain, in turn, leads to a major gain in capacity and enables the provision of multimedia services to a greater number of MBMS users in future mobile networks.

B. Comparison with existing Counting Mechanism

The superiority of the mechanism can be better illustrated if we compare the performance of our approach with the current Counting Mechanism. For a more realistic performance comparison, both mobility issues and varying number of serving users are taken into consideration and investigated.

At this point, it should be reminded that existing Counting Mechanism considers a static switching point between PTP and PTM modes (or else between DCH and FACH), based on the number of MBMS serving users. Such a reasonable threshold for a macro cell environment would be 8 multicast users; for less than 8 users in PTP mode, multiple DCHs (and no HS-DSCH) would be transmitted, while for more than 8 multicast users in PTM mode, a single FACH with such power so as to provide full (100%) coverage would be deployed.

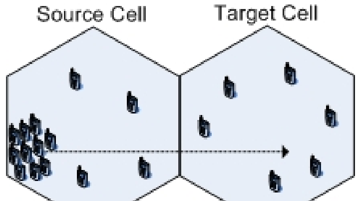

Figure 5. Simulation Topology

The simulation scenario considers the provision of a MBMS multicast session in a segment of a UMTS macrocellular environment. We examine the performance of both approaches for two neighboring cells (called source cell and target cell) as depicted in Figure 5. A 64 Kbps MBMS session with 2000 sec time duration is delivered in both cells.

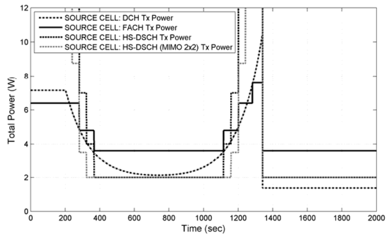

Figure 6. Source Cell: Output of power level computation phase

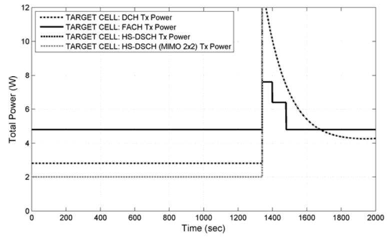

Figure 7. Target Cell: Output of power level computation phase

Figure 6 and Figure 7 depict the downlink power of the available transport channels, as extracted from the power level computation phase, in source and target cells respectively. Figure 8 and Figure 9 depict the transmission power of the transport channel that is actually deployed both for the proposed mechanism and the existing Counting Mechanism, in source and target cell respectively. In our approach, this transmission power level represents the power consumed by the channel selected in the transport channel selection phase. The selected channel for each cell can be easily extracted from Figure 6 and Figure 7 (the one with less power requirements for each time instance). Regarding the existing Counting Mechanism this power level is either the total DCH power for less than 8 users, or the fixed FACH power, equal to 7.6 W (from Table I, to essentially provide 100% coverage), for more than 8 users.

Source cell initially consists of 14 multicast users, while 6 users reside in target cell. During the first 200 sec of the simulation time, all users in both cells are static. In source cell, the proposed mechanism favors the transmission of MBMS content over FACH with power set to 6.4 W in order to serve users with the worst path loss, located at a distance of 90% cell coverage. On the other hand, current Counting Mechanism uses a FACH with power set to 7.6 W to provide full cell coverage, resulting in a power wasting of 1.2 W in the source cell (Figure 8). Target cell is a PTP cell, since it serves less than 8 users. However, we observe that HS-DSCH has better performance than DCH, with almost 1W power saving (Figure 9). Thus, our scheme performs better than the existing Counting Mechanism in target cell, too.

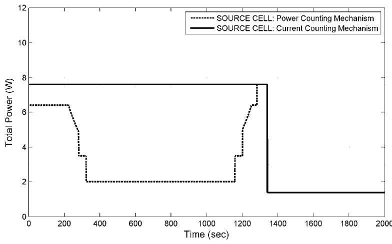

Figure 8. Source Cell: Proposed mechanism vs. current Counting Mechanism

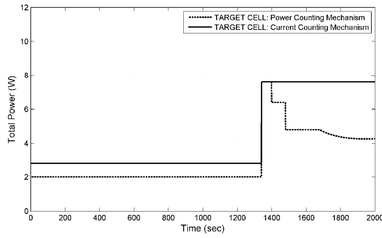

Figure 9. Target Cell: Proposed mechanism vs. current Counting Mechanism

A group of 10 users in the source cell, which is located near the cell edge (90% cell coverage), starts moving at time instance 201 sec towards the target cell, according to the trajectory depicted in Figure 5, while the rest users remain static. This group enters the target cell at time instance 1341 sec. During the time period 201-1341 sec we can make the following observations for the source cell. The proposed mechanism is able to track users' mobility and further improve power efficiency. When multicast users get close to the source cell's base station, PTP bearers (DCH and HS-DSCH) are less power consuming than PTM bearer (FACH) even for a large number of serving users. Similarly, when users reside near the cell edge FACH is more efficient. On the other hand, existing Counting Mechanism fails to deal efficiently with users' mobility, in the absence of any adaptive procedure, and uses exclusively FACH since simultaneous users receiving the MBMS service exceed the threshold of 8 users. As a result, we observe that a significant power budget, approaching 5.6 W, is wasted (Figure 8). Both mechanisms have identical performance (FACH deployment) only when moving users are on the cell border. Moreover, we observe that HS-DSCH with MIMO support requires less power compared to pure HS-DSCH for some time instances. Target cell still remains in PTP mode with the same power gains emerged from our scheme as during the first 200sec of simulation (Figure 9).

Finally, at time instance 1341 sec, the group of 10 moving users enters the service area of the target cell. At this point, according to current Counting Mechanism, the source cell switches to PTP mode (multiple DCHs) since it serves only 4 users. Our mechanism also uses DCHs and, thus, both approaches have similar performance. At the same time, the target cell switches to PTM mode (a single FACH) and serves 16 users. However, as the moving group reaches base station, the proposed scheme appropriately adapts its functionality and results to better utilization of power resources in contradiction to the static FACH channel assignment of the existing MBMS specifications. Power gains approach almost 3W.

Conclusively, from Figure 8 and Figure 9 it is obvious that the proposed approach is prevailing over the current Counting Mechanism. The power based criterion for switching between transport channels as well as the deployment of the HS-DSCH, especially when MIMO is supported, strongly optimizes resource allocation and enhances MBMS performance.

V. Conclusions and Future Work

In this paper we proposed a novel mechanism for efficient transport channel selection during MBMS transmissions in LTE networks. The proposed mechanism defines downlink power as the switching criterion between different radio bearers and is capable of conceiving any dynamic changes and, therefore, optimally adapting its functionality. Furthermore, the proposed mechanism conforms to LTE requirements and takes advantages of MIMO antennas to further improve resource efficiency. Simulation results prove that our scheme strongly outperforms current Counting Mechanism of MBMS specifications, by maximizing power and capacity efficiency. The step that follows this work is to further optimize the provision of MBMS over LTE, MIMO enabled networks and investigate power saving techniques that can further enhance MBMS performance.

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