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Exploiting MIMO Technology for Optimal MBMS Power Allocation

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Abstract In mobile networks, the provision of rich multimedia services, such as Mobile TV, is considered of key importance. To this end, Multimedia Broadcast/Multicast Service (MBMS)—that was introduced in the Release 6 of Universal Mobile Telecommunication System (UMTS)—is envisaged to play an instrumental role in the proliferation of mobile market. The reason behind the design of MBMS was the need to provide multiple users with the same data at the same time in 3GPP (3rd Generation Partnership Project) cellular networks. Still, MBMS performance is limited by the base stations' transmission power. As an aftermath, efficient power allocation techniques should be implemented so as to ensure the mass provision of multimedia applications to mobile users. This paper proposes a novel mechanism for efficient radio bearer selection during MBMS transmissions. The proposed mechanism is based on the concept of transport channels combination in any cell of the network. Furthermore, the mechanism exploits the performance enhancements emerged from Multiple Input Multiple Output (MIMO) antennas and manages to efficiently deliver multiple MBMS sessions. The proposed mechanism is thoroughly evaluated and compared with the radio bearer selection mechanisms proposed by 3GPP.

Keywords UMTS · MBMS · HSDPA · MIMO · Power control · Radio bearer selection mechanisms

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1 Introduction

The bandwidth-hungry multimedia services that are already experienced in wired networks, will indisputably characterize tomorrow's mobile marketplace. This emerging trend motivated the 3rd Generation Partnership Project (3GPP) to launch the Multimedia Broadcast/Multicast Service (MBMS) framework so as to meet the requirements of multimedia applications for mobile users. The first MBMS services in Universal Mobile Telecommunication System (UMTS) networks were based on point-to-point (PTP) connections, but with an increasing number of user equipments (UEs) this transmission scheme becomes highly inefficient. Therefore, the first MBMS release made use of both PTP transmission for small number of served users and point-to-multipoint (PTM) transmission for larger number of MBMS users [1,2].

However, the plethora of mobile multimedia services poses the need for the deployment of a more economic and resource efficient scheme. The main requirement during the provision of MBMS 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 most limiting factor of downlink capacity in UMTS and High Speed Packet Access (HSPA) networks. Under this prism, a critical aspect of MBMS performance is the selection of the most efficient radio bearer for the transmission of multimedia traffic to mobile users.

In the frame of power control and transport channel selection during multimedia data delivery several approaches have been proposed. 3GPP specifications consider the TS 25.346 [3], TR 25.922 [4] and TSG-RAN WG1#28 R1-02-1240 [5] approaches. However, all of these works fail to take into account the latest advances in mobile communications that rely on the broadband HSPA technology and on Multiple Input Multiple Output (MIMO) systems. MIMO systems have the potential to address the unprecedented demand for wireless multimedia services and particularly for the MBMS.

In this paper, we are dealing with the critical topic of transport channel selection and we propose a novel radio bearer selection mechanism for MBMS that constitutes an advanced and a more efficient version compared to the existing 3GPP approaches. The mechanism dynamically determines the optimal MBMS radio bearer or radio bearer combination, based on the required transmission power to serve a multicast group. Therefore, PTP and PTM transmission modes may be used separately or be combined and deployed in parallel in a cell.

The proposed mechanism takes advantage of the HSPA technology (including MIMO support) and contributes to Radio Resource Management (RRM) mechanisms of mobile networks by adopting a novel framework for MBMS that efficiently utilizes power resources. However, the most remarkable advantage of the proposed mechanism, that actually differentiates it from the 3GPP approaches, is that it conforms to the requirements for simultaneous provision of multiple multimedia sessions. Our approach is compared with the 3GPP approaches in terms of power consumption and complexity so as to highlight its enhancements and underline the necessity for its incorporation in MBMS specifications.

The paper is structured as follows: Sect. 2 presents the power characteristics of the transport channels which could be used in MBMS. Section 3 presents the motivation behind our study and the related work in the specific field; while, in Sect. 4 we describe the proposed MBMS power allocation mechanism. Section 5 is dedicated to the presentation of the results. Finally, the planned next steps and the concluding remarks are briefly described in Sects. 6 and 7 respectively.

2 Power Control in Multimedia Broadcast/Multicast Service

MBMS is a service designed by 3GPP to meet the emerging requirements of multimedia applications for mobile users and can provide both broadcast and multicast services. This section presents the power consumption characteristics of the transport channels that could be used for the transmission of MBMS data packets. The transport channels that could be used in MBMS are: the Forward Access Channel (FACH), the Dedicated Channel (DCH) and the High Speed Downlink Shared Channel (HS-DSCH) [6].

2.1 HS-DSCH Power Profile

HS-DSCH is a rate controlled rather than a power controlled transport channel. Although there are two basic modes for allocating HS-DSCH transmission power [7], in this paper we will focus on a dynamic method in order to provide only the required, marginal amount of power so as to satisfy all the served multicast users and, in parallel, reduce interference. Two major measures for High-Speed Downlink Packet Access (HSDPA) 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) [6,7]:

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

where $P_{HS-DSCH}$ 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 ($p = 0$: perfect orthogonality), while SF_{16} is the spreading factor of 16.

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

$$G = \frac{P_{own}}{P_{other} + P_{noise}} \tag{2}$$

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 ($P_{HS-DSCH}$) can be expressed as a function of the *SINR* value and the user location (in terms of *G*) as in (3) [7]:

$$P_{HS-DSCH} \geq SINR\left[p - G^{-1}\right]\frac{P_{own}}{SF_{16}} \tag{3}$$

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 requirements consider two transmit and receive antennas (MIMO 2x2) and approximately, double data rates are obtained with the same base station 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.

Table 1 FACH Tx (transmission) power levels

Cell coverage (%)	Required Tx power (W) (64 Kbps)
10	1.4
20	1.6
30	1.8
40	2
50	2.5
60	3
70	3.6
80	4.8
90	6.4
95	7.6

2.2 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 served users, their distance 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].

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

In (4), P_T 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 ith user transmission rate, W the bandwidth, P_N the background noise, p is the orthogonality factor and x_i is the intercell interference observed by the ith 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 jth cell L_{ij}.

2.3 FACH Power Profile

A FACH essentially transmits at a fixed power level since it does not support fast power control. FACH is a PTM channel and therefore it must be received by all users throughout the cell, or the part of the cell that the users reside in. Therefore, the fixed power should be high enough to ensure the requested Quality of Service (QoS) in the desired area of the cell and serve the user with the worst path loss in the specific area [10]. Table 1 presents some indicative FACH downlink transmission power levels obtained for various cell coverage areas, without assuming diversity techniques [10].

These FACH transmission power levels correspond to a macrocell environment (site to site distance equal to 1 Km), when a 64 Kbps MBMS service is delivered. Moreover, Transmission Time Interval (TTI) is set to 80 ms, Block Error Rate (BLER) target is 1% and no Space Time Transmit Diversity (STTD) is assumed [10].

3 Motivation and Related Work

There exist two main research directions during the radio bearer selection procedure. According to the first approach, a single transport channel (PTP or PTM) can be deployed in a cell at any given time (like works [11] and [12]). In this case, a switching threshold is actually set that defines when each channel should be deployed. On the other hand, the second approach performs a simultaneous deployment of PTP and PTM modes. A combination of these modes is scheduled and both dedicated and common bearers are established in parallel in a cell. In the following paragraphs, we present the main representative 3GPP approaches of each research direction.

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 (PTP or PTM) can 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 should occur, when the number of users in a cell exceeds a predefined threshold. The mean value for the threshold proposed in the majority of research works is 8 UEs.

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. However, contrary to TS 25.346, it follows a power based approach when selecting the appropriate radio bearer, aiming at minimizing the Node B's power requirements during MBMS transmissions. In TR 25.922, instead of solely using 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. Even though TR 25.922 overcomes several inefficiencies of TS 25.346, still it does not support FACH dynamic setting and therefore FACH has to cover the whole cell area, which in turn leads to increased power consumption in PTM transmissions.

The above mechanisms allow a single PTP or PTM transport channel deployment at any given time. In [5], an alternative idea is presented, based on the combined usage of PTP and PTM bearers for MBMS transmissions. In particular, this approach considers the mixed usage of DCHs and FACH for the transmission of the MBMS data. According to this approach, the FACH channel only covers an inner area of a cell. The rest of the users are served using DCHs to cover the remaining outer cell area.

4 Mechanism for PTP and PTM Bearers Combination

At this point, it should be noted that none of the above mechanisms takes into account the ability of the Node Bs to support many simultaneous MBMS sessions. MBMS transmissions have increased power requirements and consume a large portion of the available power recourses in Node Bs. Consequently, the number of parallel MBMS sessions that a base station could support is limited and the selection of the appropriate radio bearer for a service should be done with respect to other existing MBMS sessions in the corresponding cell.

To this direction, this section presents a power control mechanism that considers the Node B's transmission power level as the key criterion for the selection of the appropriate MBMS radio bearer. The goal achieved by this approach is threefold: At a first level, our mechanism proposes a more realistic and adaptive to dynamic wireless environments approach, by employing a power based switching criterion and allowing the combined usage

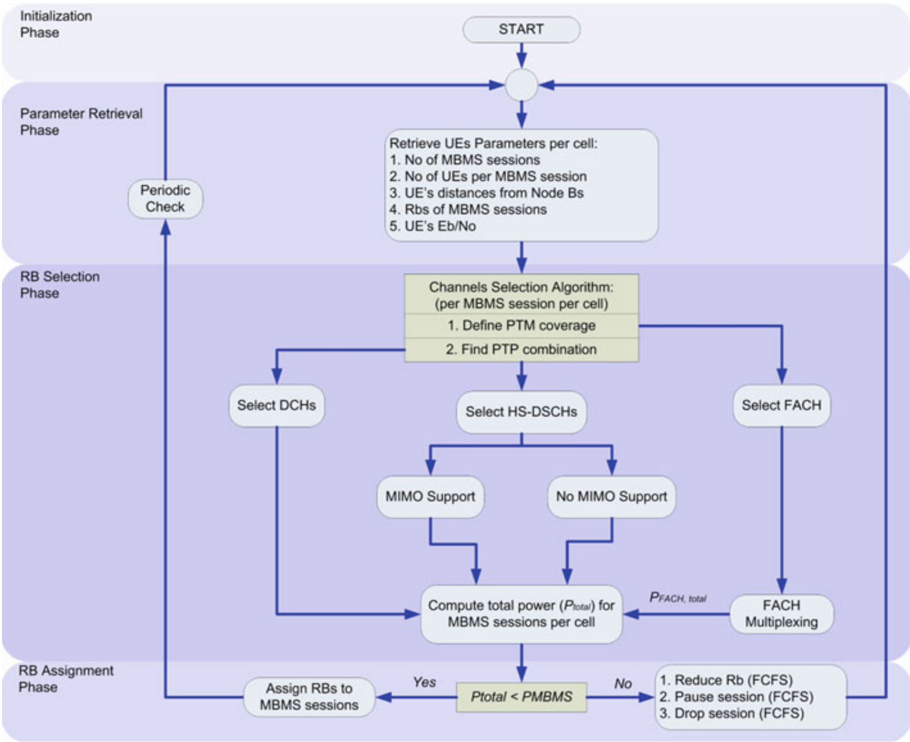


Fig. 1 Block diagram of the mechanism

of transport channels. At a second level, our mechanism contributes to RRM mechanisms of UMTS by presenting a novel framework for MBMS that optimally utilizes power resources. At a third level, a major advantage of our mechanism is its ability to ensure the service continuity in the system when parallel MBMS services are delivered in a single cell.

It is worth mentioning that the number of parallel MBMS sessions that a Node B could support depends on many parameters. We could classify these parameters in three categories: user related parameters, MBMS session related parameters and provider related parameters.

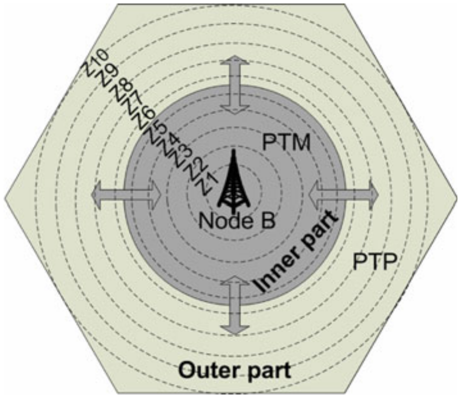
User related parameters are parameters such as UEs' distances from the base stations and parameters related to the received signal quality. The number of active MBMS sessions per cell, the number of UEs per MBMS session per cell and the bit rates of the MBMS services are some of the MBMS session related parameters. Finally, the portion of the available power recourses of base stations that could be used for MBMS is a provider related parameter.

The block diagram of the proposed mechanism is illustrated in Fig. 1. The mechanism consists of four distinct operation phases. These are: the initialization phase, the parameter retrieval phase, the radio bearer (RB) selection phase and the RB assignment phase.

4.1 Initialization and Parameter Retrieval phases

The **initialization phase** launches the mechanism when one user expresses his interest in receiving a MBMS service. The **parameter retrieval phase** is responsible for retrieving the parameters of the existing MBMS users and services in each cell. In this phase, the

Fig. 2 Cell areas and zones



mechanism requires the two of the three types of parameters, mentioned previously: the user related parameters and the MBMS session related parameters. Regarding the latter type of parameters, the mechanism requires information about the number of active sessions per cell, the number of UEs per session per cell and the bit rates of the MBMS sessions.

4.2 Radio Bearer Selection phase

The **RB selection phase** is dedicated to the selection of the transport channels for the MBMS sessions in any cell of the network. The most critical operations of the phase are executed by the Channels Selection Algorithm block (Fig. 1). This algorithm selects the combination of PTP and PTM bearers that minimizes the downlink base station's transmission power in any cell of the network that contains multicast users. 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 users' distribution of any MBMS session 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). It has to be mentioned that the above cell characterization is done for every MBMS session of the corresponding cell.

In order to estimate the optimum coverage of FACH (for any MBMS session in the cell) in Define PTM coverage step, the algorithm initially divides the cell in ten zones (Z1–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 base station's transmission power for the following 21 transport Channel Configurations (CC):

- CC1: No FACH used. All users of the specific MBMS session in the cell are covered by DCHs.
- CC2: No FACH used. All users of the specific MBMS session in the cell are covered by HS-DSCHs (with or without MIMO, depending on whether the mechanism supports MIMO or not).
- 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 (with or without MIMO).
- ………..
- 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 (with or without MIMO).
- CC21: FACH for all UEs (up to Z10) for the specific session. 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. The same procedure is executed simultaneously for any MBMS session in the cell. The output of the Define PTM coverage step is the coverage of the FACH for any MBMS session in the cell.

Once the appropriate FACH coverage for any MBMS session in the cell is defined, the algorithm enters the Find PTP combination step, which determines the appropriate PTP radio bearer(s) that will cover the MBMS users residing in the outer part of the cell for any MBMS session. 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 base station'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 (with or without MIMO).
- 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 (with or without MIMO).
- ………..
- 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 (with or without MIMO) 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 (with or without MIMO) for outer part UEs up to Z(inner part+2). All the rest outer part UEs (up to Z10) covered by DCHs.
- ………..
- PTP_CC(2*(10-inner part)): All MBMS users in the outer part cell for the specific session are covered by HS-DSCHs (with or without MIMO). DCHs are not used.

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 of the specific MBMS session in the cell.

In the case of FACH, there is another block in the mechanism's block diagram named FACH Multiplexing. When the number of MBMS sessions requiring FACH in cell is greater than one, these FACHs should be multiplexed onto a Secondary Common Control Physical Channel (S-CCPCH) [13,14]. After the multiplexing procedure, the capacity of the S-CCPCH is calculated and based on this, the total power required for the common channels ($P_{FACH,total}$) in the corresponding base station is estimated. In this paper we consider a one to one mapping between sessions and FACHs.

The last action performed in the RB selection phase is the computation of the total base station's power (P_{total}) required so as to support all MBMS sessions in each cell of the network. However, at this point we have to mention that the selected radio bearers are not yet assigned to the MBMS sessions. This action is performed in the following phase.

Table 2 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 (3 km/h)
Orthogonality factor	0.5
E_b/N_0 target	5 dB

4.3 Radio Bearer Assignment phase

During the **RB assignment phase**, the P_{total} is compared with the available power assigned by the network provider to MBMS sessions in each base station (P_{MBMS}). Obviously, P_{MBMS} constitutes the third type of parameters mentioned in the previous section, known as provider related parameter. If P_{total} is smaller than P_{MBMS} then the selected from the RB selection phase transport channels are assigned to MBMS sessions and the MBMS data transfer phase begins. If P_{total} is bigger than P_{MBMS}, a session reconfiguration procedure should occur as shown in Fig. 1. The simplest policy that the mechanism could adopt during the session reconfiguration procedure is the First Come First Served (FCFS) policy.

The above description refers to a dynamic model, in the sense that the UEs are assumed to be moving throughout the topology and the number of MBMS sessions varies. The parameter retrieval phase is triggered at regular time intervals so as to take into account the user related parameters, the MBMS session related parameters and the operator related parameters. Therefore, the Channels Selection Algorithm must be periodically executed at a predetermined frequency rate. This periodic computation inserts a further complexity for the Radio Network Controller (RNC) as this information is carried in through uplink channels. This entails that a certain bandwidth fraction must be allocated for the transmission of this information in uplink channels, thus resulting to a system's capacity reduction. Moreover, further complexity is inserted in RNC due to the fact that the mechanism is executed many times in each RNC.

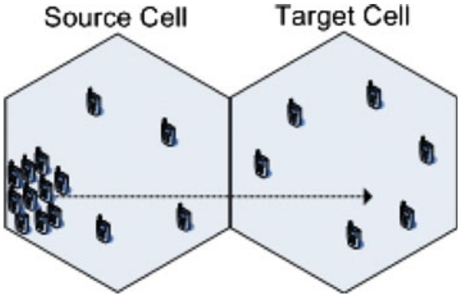
5 Performance Evaluation

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 Table 2 and refer to a macrocell environment [10]. In addition, TTI is set to 80 ms, BLER target is 1% and no STTD is assumed.

5.1 Power Gains Through MIMO Technology

The superiority of MIMO transmissions can be better illustrated if we compare the performance of our approach with the MBMS Counting Mechanism (TS 25.346). For a more

Fig. 3 Simulation topology



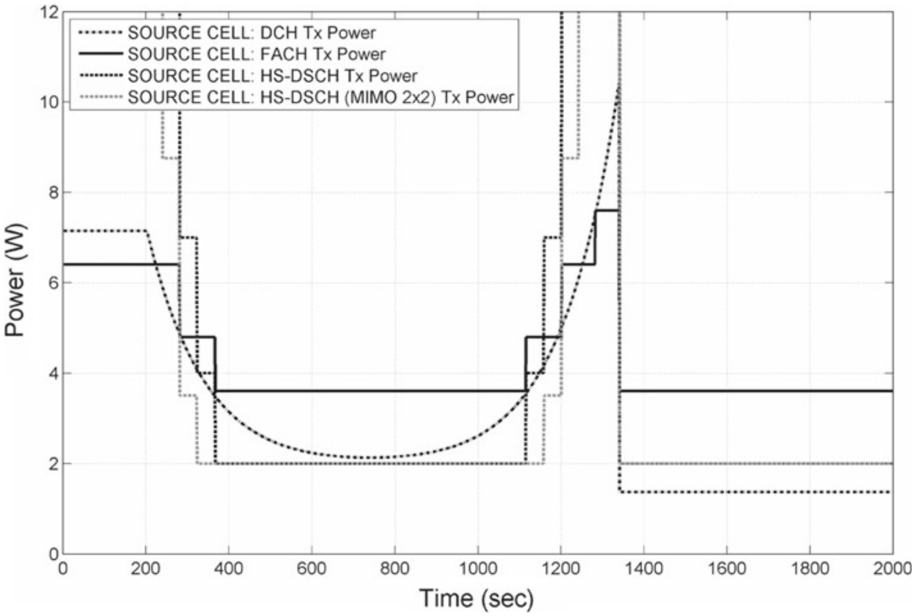


Fig. 4 Source cell: output of RB selection phase for all transport channels

realistic performance comparison, one MBMS service is delivered to the users; while, both mobility issues and varying number of served users are taken into consideration.

The simulation scenario considers the provision of one 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 Fig. 3. The same 64 Kbps MBMS session with 2000 s time duration is delivered in both cells.

Figures 4 and 5 depict the downlink power of the available transport channels, as extracted from the RB selection phase, in source and target cells respectively. Figure 6 depicts the transmission power of the transport channel that is actually deployed by our mechanism and the TS 25.346 mechanism, in source and target cells. In our approach, this transmission power level represents the power consumed by the channel selected in the RB selection phase (the combination of transport channels is not applied since the moving users are assumed to be in one group). The selected channel for each cell can be easily extracted from Figs. 4 and 5 (the one with less power requirements at each time instance). Regarding TS 25.346, this power

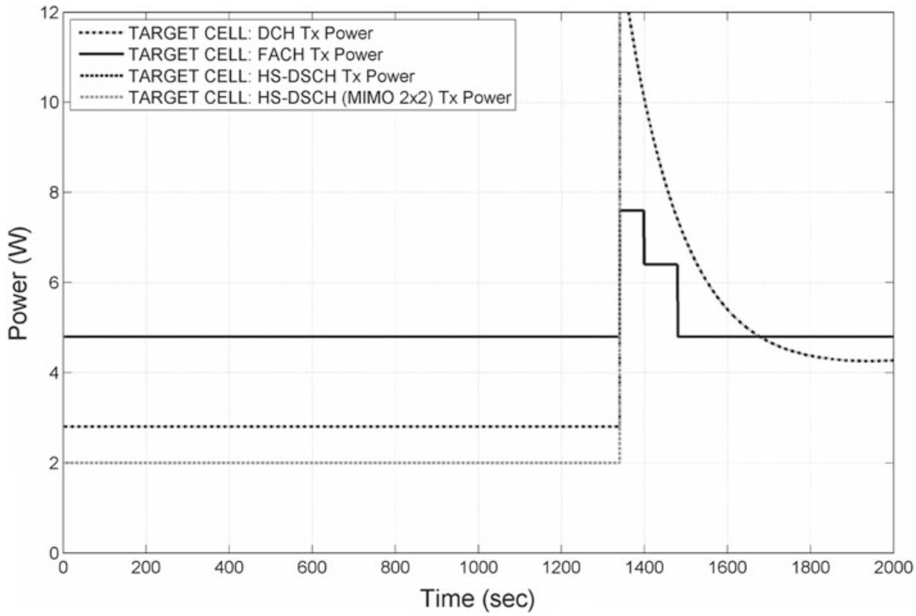


Fig. 5 Target cell: output of RB selection phase for all transport channels

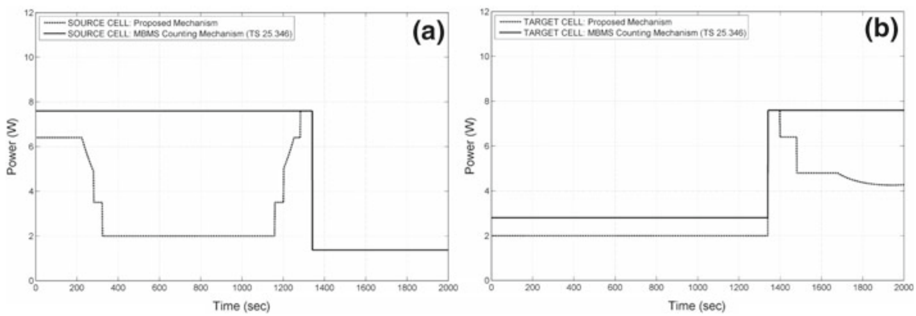


Fig. 6 Proposed mechanism versus MBMS counting mechanism: (**a**) source cell and (**b**) target cell

level is either the total DCH power for less than 8 users, or the fixed FACH power, equal to 7.6 W (from Table 1, to essentially provide 95% 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, TS 25.346 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 (Fig. 6a). 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 1 W power saving (Fig. 6b). Thus, the proposed scheme performs better than TS 25.346 in target cell, too.

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 s towards the target cell, according to the

Table 3 Users' number and coverage per time period

Time (s)	UEs number	Coverage (%)	Best performance
0–50	25	50	Our mechanism
	7	80	
51–100	25	50	R1-02-1240 and our mechanism
	2	80	
101–150	17	50	TR 25.922 (HS-DSCH) and our mechanism
151–200	4	50	All except TR 25.922 (HS-DSCH)

trajectory depicted in Fig. 3, while the rest users remain static. This group enters the target cell at time instance 1341 s. During the time period 201–1341 s, 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 are less power consuming than PTM bearer (FACH) even for a large number of served users. Similarly, when users reside near the cell edge FACH is more efficient. On the other hand, TS 25.346 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 (Fig. 6a). 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 the first 200sec of simulation (Fig. 6b).

Finally, at time instance 1341 s, the group of 10 moving users enters the service area of the target cell. At this point, according to TS 25.346, the source cell switches to PTP mode (multiple DCHs) since it has to serve only 4 users. The proposed mechanism also uses DCHs and, thus, both approaches have similar performance. At the same time, the target cell serves 16 users and switches to PTM mode (a single FACH). However, as the moving group reaches the target cell's 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 3 W.

5.2 Comparison with 3GPP Approaches

This scenario lasts for 200 s 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 3. For example, for the time period 0 to 50 s, 25 UEs receive the service at distance 50% of the cell radius and 7 UEs at distance 80% of the cell radius.

Figure 7a depicts the power levels of the examined radio bearer selection mechanisms. The proposed mechanism and the mechanism presented in 3GPP R1-02-1240 have the best performance in general. 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 in TS 25.346 is 8 UEs (a value proposed in the majority of research works), TS 25.346 will deploy a FACH with 95% cell coverage (7.6 W).

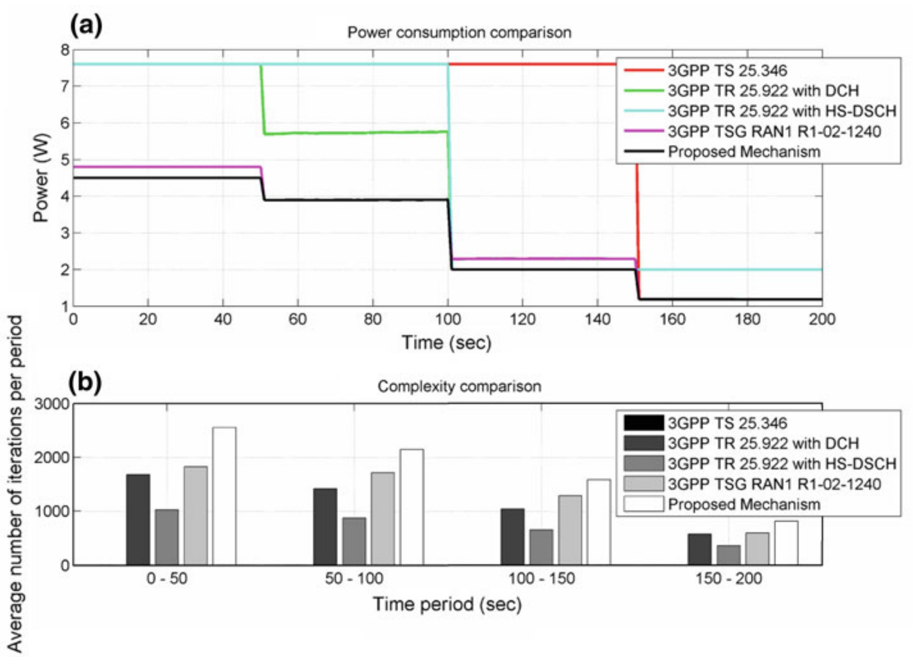


Fig. 7 (**a**) Power consumption and (**b**) complexity comparison between the different approaches

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 that 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 s.

The mechanism proposed in 3GPP R1-02-1240 allows the mixed usage of DCHs and FACH and supports FACH dynamic power setting. As shown in Fig. 7a, this mechanism requires 4.8 W in order to serve all the users in the cell, for the first time period. This derives from the fact that for the specific scenario, this mechanism will deploy only a FACH with 80% coverage, while the user with the worst path loss resides in the borders of zone Z8.

Figure 7a depicts the power requirements of the proposed mechanism for the examined scenario. For the time period 0–50 s, the output of the Channels Selection Algorithm block specifies that the users up to Z5 should be server 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 (incorporating MIMO technology). Therefore, 4.4 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 gain, ranging from 0.4 to 3.2 W, may be saved for the period 0–50 s compared to the other approaches.

Figure 7b presents the computational overhead that each mechanism inserts (number of iterations required 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

Table 4 Scenario parameters

MBMS No.	Duration (s)	Rb (Kbps)	UEs number	Maximum coverage	Channel
1	0–600	64	10	80%	HS-DSCH
2	50–600	64	22 + 6	20%+50%	FACH and DCH
3	100–150	64	2–13	60%	DCH
	151–300	64	14–19	60%	HS-DSCH
	301–600	64	20–27	60%	FACH
4	150–560	64	7	70%	DCH
	561–600	32	7	80%	DCH

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 and examines all possible transport channels configurations explains why the number of iterations in this case is higher than the other approaches.

5.3 Managing Parallel MBMS Sessions

The major advantage of the proposed mechanism is its ability to manage multiple parallel MBMS sessions. In order to evaluate this ability, we setup a simulation scenario where multiple MBMS services are transmitted in parallel to several user groups residing in a cell. In particular, we suppose that four user groups receive four distinct MBMS services with characteristics presented in Table 4. Moreover, Table 4 presents the appropriate transport channel (with respect to power consumption as presented in previous sections) to serve each group at each time interval.

Figure 8 depicts the power consumption of each MBMS session as well as the total, aggregative power required to support the transmission of all services to the multicast users in the corresponding cell. Users of the 1st MBMS session are served with a HS-DSCH channel (that supports MIMO), due to the small population, throughout the whole service time. At simulation time 50 s, MBMS service 2 is initiated (Fig. 8). At this time instant, the mechanism, through the RB selection phase, selects FACH (for the 22 inner part users) and DCHs (for the 6 outer part users) as the most efficient transport channel combination.

MBMS service 3 starts at simulation time 100 s. At this time the 3rd group consists of only two UEs; thus, the mechanism selects multiple DCHs for this MBMS service. The number of users receiving the service successively increases (join requests), reaching 13 UEs at simulation time 150 s, 19 at simulation time 300 s and 27 at the end of the simulation time. The increasing number of users forces the mechanism to perform a channel switching from DCH to HS-DSCH at simulation time 151 s and another one from HS-DSCH to FACH at simulation time 301 s, securing, in this way, the efficient resource utilization.

At this point we have to mention that from simulation time 300 s until the end of the simulation, MBMS services 2 and 3 employ FACHs for the transmission of the MBMS data (see Table 4). The deployment of two parallel FACHs forces the mechanism to perform a FACH multiplexing procedure in the RB selection phase. Consequently, a single S-CCPCH with bit rate of 128 Kbps is used to deliver MBMS services 2 and 3. Moreover, P_{total} is lower than P_{MBMS}, which means that the three parallel sessions are efficiently served.

At simulation time 150 s, the MBMS service 4 is initiated and is targeted to a multicast group consisting of seven members. Multiple DCHs are selected by the mechanism to deliver

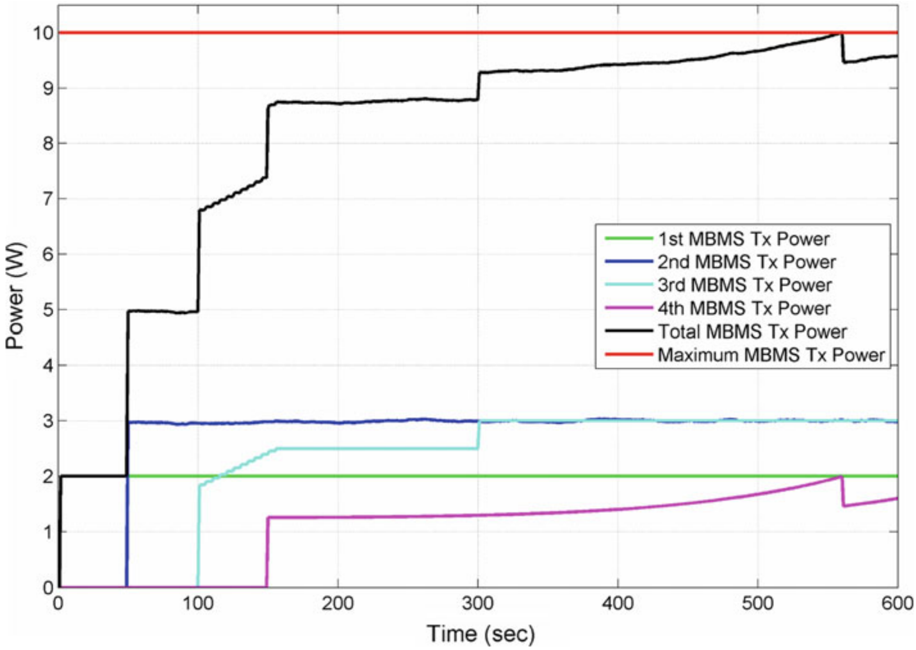


Fig. 8 Power levels of the MBMS sessions

the MBMS content to the 4th multicast group. Additionally, at the same time instance, P_{total} still remains smaller than P_{MBMS}, which means that the MBMS service 4 is accepted for transmission in the system. From simulation time 150 sec until the end of the simulation, four parallel sessions are running in the system and our mechanism handles them efficiently.

Due to the fact that the users of the 4th multicast group are moving towards the cell edge an increase in P_{total} occurs and at simulation time 560 s; P_{total} exceeds P_{MBMS} value (Fig. 8). Thus, a session reconfiguration procedure is performed, forcing the MBMS service 4 to reduce its bit rate from 64 to 32 Kbps in order to ensure the efficient service of four parallel MBMS sessions without any interruption.

To sum up, Table 5 presents a cumulative, direct comparison between all mechanisms analyzed in this paper. The main conclusion extracted is that the proposed mechanism outperforms the other approaches in terms of power consumption, since it may save a significant power budget. 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 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. This fact is strongly enhanced mainly due to the power limited mobile networks, which entails that power strategies are of key importance in order to obtain high capacity.

6 Future Work

The steps that follow this work could be at first the evaluation of the mechanism through additional simulation scenarios. The scenarios could be simulated in the ns-2 simulator,

Table 5 Comparison of the mechanisms

Mechanism	Advantages	Disadvantages
TS 25.346	Low complexity	High power requirements
	Easy to implement	No mobility support
	3GPP standardized	No HS-DSCH support
		No MIMO support
		No dynamic FACH support
TR 25.922	Support all transport channels	High power requirements
	3GPP standardized	No switching between HS-DSCH and DCH
		No MIMO support
		No dynamic FACH support
3GPP R1-02-1240	Power efficient	High complexity
	Support combined FACH and DCH	No standardized
	Support dynamic FACH	No HS-DSCH support
		No MIMO support
Proposed mechanism	Power efficient	High complexity
	Support combined channels usage	No standardized
	Support dynamic FACH	
	Support MIMO	
	Support multiple MBMS sessions	

in which the proposed mechanism could be implemented. In that way, we could measure, except from the performance of our mechanism, other parameters such as delays in Universal Terrestrial Radio Access Network (UTRAN) interfaces during MBMS transmissions. At a second level, we plan to further optimize the provision of MBMS over MIMO-enabled networks and investigate power saving techniques that can further enhance MBMS performance. Techniques such as rate splitting and macro diversity combining could be integrated in the proposed mechanism and further improve the overall performance of our mechanism, which in turn means that a better utilization of radio and network resources could be achieved. Finally, it may be examined whether the Multicast/Broadcast Single Frequency Network (MBSFN) transmission mode, included in the evolved UTRAN technologies of the Long Term Evolution (LTE), could be used as an alternative PTM mode for MBMS.

7 Conclusions

In this paper we proposed a novel mechanism for efficient transport channel selection during MBMS transmissions in MIMO-enabled networks that considers power consumption as the switching criterion between different radio bearers. The proposed mechanism is capable of conceiving any dynamic changes, since it adopts the concept of radio bearer combination so as to reduce the power requirements of the base stations. Moreover, the mechanism shares efficiently the available power resources of the base stations to several parallel MBMS sessions running in the network, conforms to 3GPP requirements and takes advantages of MIMO antennas to further improve resource efficiency. Simulation results prove that our scheme strongly outperforms current 3GPP approaches by utilizing optimally the available power resources, thus increasing the capacity of MBMS-enabled UMTS networks.

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