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An improved mechanism for multiple MBMS sessions assignment in B3G cellular networks

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Abstract In Universal Mobile Telecommunication System (UMTS), the downlink capacity is limited by the base station transmission power. Therefore, power control plays an important role to minimize the transmitted power shared among unicast and multicast users within a cell. In Multimedia Broadcast/Multicast Service (MBMS), power control targets to the efficient utilization of radio and network resources. However, the expected high demand for such services stresses the need for an efficient scheme, capable of dynamically allocating radio resources to parallel MBMS sessions. This paper proposes a power control mechanism for efficient MBMS session assignment in next generation UMTS networks. The mechanism shares efficiently the available power resources of UMTS base stations to MBMS sessions running in the network. Furthermore, the mechanism is evaluated through several realistic scenarios and the results indicate the ability of the mechanism to utilize efficiently the radio resources and to ensure the service continuity when parallel MBMS services run in the network. Our approach is compared with current 3rd Generation Partnership Project (3GPP) approaches, such as these presented in TS 25.346 and in TR 25.922, in order to highlight the enhancements that it provides.

Keywords UMTS · MBMS · Power control · Radio resource management · HSDPA

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1 Introduction

Due to rapid growth of mobile communications technology, the demand for wireless multimedia communications thrives in consumer and corporate market. The major challenge that the mobile telecommunications industry faces today is how to offer a wide range of appealing multimedia services, such as Mobile TV and streaming video, to mobile users. The expected high penetration of such services translates into optimal resource allocation strategies and improved network performance. One of the most important areas in which these issues are being debated, is the development of standards for UMTS.

UMTS constitutes the third generation of cellular wireless networks which aims to provide high-speed data access and real time multimedia traffic to mobile users. However, despite the high capacity that UMTS networks offer, the expected demand for the delivery of rich multimedia services will certainly overcome the available resources. This is the reason why multicast transmission is one of the major goals for UMTS [1]. Actually, multicast is an efficient method for massive transmission, mainly of multimedia data, to multiple destinations. 3GPP recognized the need for the support of multicasting in UMTS networks and as a result, the MBMS framework of UMTS was introduced [2]. MBMS is a novel framework, extending the existing UMTS infrastructure and constitutes a significant step towards the so-called Mobile Broadband. MBMS is intended to efficiently use network and radio resources, both in the core network and, most importantly, in the air interface of UMTS Terrestrial Radio Access Network (UTRAN), where the bottleneck is placed to a large group of users.

One of the most important aspects of MBMS is power control. Power control aims at minimizing the transmitted power shared among unicast and multicast users within a cell [3]. Efficient power control mechanisms in MBMS should deal with two major aspects of MBMS. The first one is the selection of the appropriate transport channel for the transmission of the MBMS traffic to multicast users, while the second is the ability of the base stations to support many simultaneous MBMS sessions.

Current 3GPP approaches TS 25.346 [4] and TR 25.922 [5] as well as works [3] and [6], deal mainly, but not efficiently, with the first aspect. All these works focus on the transport channel selection for the transmission of the MBMS data over the UTRAN interfaces. However, none of these works performs optimal transport channel selection either due to the fact that some of them do not consider the power consumption as the selection criterion or because of the fact that some do not consider all the available transport channels for the transmission of the MBMS data. Our approach will be compared to the above works in terms of power consumption so as to highlight its enhancements and underline the necessity for its incorporation in MBMS framework.

Regarding the second fundamental aspect of power control in MBMS, none of the above MBMS power control mechanisms takes into account the ability of the base stations to support many simultaneous MBMS sessions. Under this prism, in this paper we present a power control mechanism, called MBMS session assignment mechanism, which shares efficiently the available power resources of UMTS base stations to all MBMS services running in the network.

The paper is structured as follows: In Sect. 2 we provide an overview of the UMTS in packet switched domain, while in Sect. 3 we present the motivation behind our study and the related work in the specific field. Section 4 is dedicated to an in depth analysis of Power Control in MBMS. Section 5 presents the proposed MBMS session assignment mechanism, while Sect. 6 is dedicated to the presentation of the results. Finally, the planned next steps and the concluding remarks are briefly described in Sects. 7 and 8 respectively.

2 Overview of UMTS and MBMS architecture

UMTS network is split in two main domains: the User Equipment (UE) domain and the Public Land Mobile Network (PLMN) domain. The UE domain consists of the equipment employed by the user to access the UMTS services. The PLMN domain consists of two land-based infrastructures: the Core Network (CN) and the UTRAN (Fig. 1). The CN is responsible for switching/routing voice and data connections, while the UTRAN handles all radio-related functionalities. The CN is logically divided into two service domains: the Circuit-Switched (CS) service domain and the Packet-Switched (PS) service domain [1, 7]. The PS portion of the CN in UMTS consists of two kinds of General Packet Radio Service (GPRS) Support Nodes (GSNs), namely Gateway GSN (GGSN) and Serving GSN (SGSN) (Fig. 1). SGSN is the centerpiece of the PS domain. It provides routing functionality interacts with databases (like Home Location Register (HLR)) and manages many Radio Network Controllers (RNCs). SGSN is connected to GGSN via the Gn interface and to RNCs via the Iu interface. GGSN provides the interconnection of UMTS network (through the Broadcast Multicast-Service Center (BM-SC)) with other Public Data Networks (PDNs), like the Internet [1].

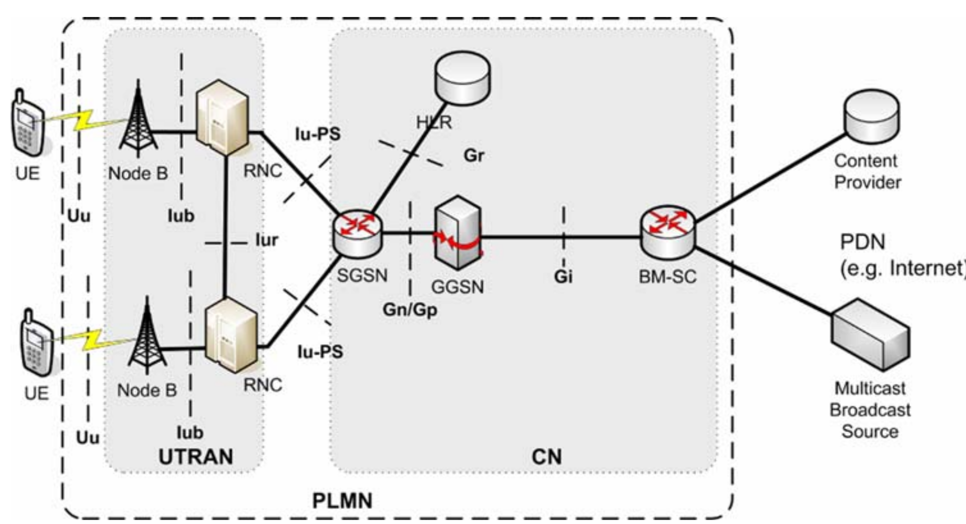

Fig. 1 UMTS and MBMS architecture

UTRAN consists of two kinds of nodes: the first is the RNC and the second is the Node B. Node B constitutes the base station and provides radio coverage to one or more cells (Fig. 1). Node B is connected to the UE via the Uu interface (based on the Wideband Code Division Multiple Access (WCDMA) technology) and to the RNC via the Iub interface.

The major challenge that the mobile telecommunications industry faces today is how to offer a wide range of appealing multimedia group communication services, such as Mobile TV and streaming video, to mobile users. This increasing demand for communication between one sender and many receivers led to the standardization of the MBMS framework of UMTS. MBMS is a unidirectional Point-to-Multipoint (PTM) service in which data is transmitted from a single source entity to multiple destinations, allowing the network and radio resources to be shared. PTM transmission is opposed to the Point-to-Point (PTP) transmission, using the unicast technology, which is exclusively used in conventional UMTS networks (without the MBMS extension).

From the operators' point of view, the employment of MBMS framework involves both an improved network performance and a rational usage of radio resources, which in turn, leads to increased network capacity and extended service provision. In parallel, users are able to realize novel, high bit-rate services, experienced until today only by wired users. Such services include Mobile TV, weather or sports news and other streaming services.

MBMS consists of a bearer service and a user service. The latter represents applications, which offer for example multimedia content to the users, while the MBMS bearer service provides methods for user authorization, charging, Quality of Service (QoS), improvements to prevent unauthorized reception and power control. The major modification in the existing UMTS platform is the addition of a new entity called BM-SC. BM-SC communicates with the existing UMTS networks and external PDNs [2, 8].

Regarding the transmission of the MBMS packets over the Iub and Uu interfaces, it may be performed on common (Forward Access Channel or FACH), dedicated (Dedicated Channel or DCH) or shared channels (High Speed-Downlink Shared Channel or HS-DSCH) [9]. Three new logical channels are considered for PTM transmission of MBMS: MBMS point-to-multipoint Control Channel (MCCH), MBMS point-to-multipoint Scheduling Channel (MSCH) and MBMS point-to-multipoint Traffic Channel (MTCH). These logical channels are mapped on FACH. In case of PTP transmission, Dedicated Traffic Channel (DTCH) and Dedicated Control Channel (DCCH) are used and are mapped on the dedicated channel, DCH [4]. Several enhancements in High Speed Downlink Packet Access (HSDPA) technology allow DTCH and DCCH to be mapped also on the HS-DSCH [10].

3 Motivation and related work

According to 3GPP specifications, MBMS traffic can be provided in each cell by either multiple PTP channels or by a single PTM channel [9]. The FACH is the main transport channel for PTM MBMS data transmission with turbo coding and Quadrature Phase-Shift Keying (QPSK) modulation. 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. HSDPA, a broadband extension of UMTS, introduces a new transport channel, named HS-DSCH, which optimizes the air interface to support higher data rate and delay tolerant services [10]. Although Release'99 transport channels (FACH and DCH) have already been standardized for the delivery of MBMS multicast sessions, MBMS over HS-DSCH is an open research topic, still in infancy phase.

In the frame of switching between PTP and PTM radio bearers several approaches have been proposed. The 3GPP MBMS Counting Mechanism (TS 25.346) 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. Several studies and simulations have been carried out focusing on defining the appropriate threshold. In [11] is claimed that for a FACH with transmission power set to 4 W, the threshold for switching from dedicated to common resources is around 7 users per cell, while in [12] the threshold is 5 users.

However, this approach suffers from much inefficiency, mainly due to the difficulty of defining the appropriate threshold. Assuming that all 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 difficulty 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 (base station in UMTS terminology) power requirements [5]. An interesting study under these assumptions is presented in [13], where the authors propose a switching point between PTP and PTM bearers, based on power consumption. Furthermore, in work [3], the authors propose a power control scheme for the efficient radio bearer selection in MBMS.

However, all the above works and approaches assume a fixed power allocation when FACH is used for PTM transmission. Even if all users of a specific MBMS group are located near the base station, in PTM transmission the FACH will transmit at a high fixed power level so as to cover the whole cell, leading in turn to power resources waste. In our approach we consider a dynamic power setting for PTM transmission, where the FACH power is determined based on the area that needs to be covered [14]. This way, the FACH transmission power is allocated dynamically based on the desired service area, saving in this way significant power budget. Furthermore, all existing works in this research field consider only the DCH in PTP mode. However, the key characteristics that HS-DSCH comprises constitute it an ideal transport channel for the delivery of multicast content in PTP mode, due to its unicast nature.

Moreover, none of the above approaches 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 of the base stations. 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 MBMS service should be done with respect to the other existing MBMS sessions in the corresponding cell.

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 mechanism 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 mechanism contributes to Radio Resource Management (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 multiple parallel MBMS services are delivered. 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.

4 Power control in MBMS

Power control is one of the most critical aspects in MBMS due to the fact that downlink transmission power in UMTS is a limited resource and should be optimally utilized. In this paper we will present two approaches of achieving efficient power control in MBMS. The first approach is the efficient transport channel assignment, while, the second one is the efficient MBMS session assignment. As it will be shown in this paper, the combination of the above mentioned approaches results to a significant increase in the system's capacity.

4.1 Transport channel selection

In this section, we analytically present the power consumption characteristics of the transport channels that could be used in MBMS for the transmission of the data packets over the UTRAN interfaces.

4.1.1 HS-DSCH power profile

HS-DSCH is a rate controlled rather than a power controlled transport channel. In HSDPA fast power control (characterizing Release'99 channels) is replaced by the Link Adaptation (LA) functionality, including techniques such as dynamic Adaptive Modulation and Coding (AMC), multicode operation, fast scheduling, Hybrid Automatic Repeat-reQuest (HARQ) and short Transmission Time Interval (TTI) of 2 ms [1].

There are two different modes for allocating HS-DSCH transmission power. In the first power allocation mode, a fixed amount of HS-DSCH transmission power is explicitly allocated per cell and may be updated any time later, while in the second mode the Node B is allowed to use any unused power remaining after serving other, power controlled channels, for HS-DSCH transmission [10]. Obviously, setting the HS-DSCH power too high would result in excessive interference in the network without essentially achieving higher cell throughput. On the other hand, if the HS-DSCH transmission power is too low, higher data rates cannot be obtained. Next 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 serving multicast users and, in parallel, eliminate system interference.

A major measure for HSDPA link budget planning is the HS-DSCH Signal-to-Interference-plus-Noise Ratio (SINR) metric. SINR actually constitutes a new evaluation metric that slightly differentiates HSDPA from that traditionally used in Release'99 bearers. Release '99 typically uses E_b/N_0 that corresponds uniquely to a certain Block Error Rate (BLER) for a given data rate. E_b/N_0 metric is not an attractive measure for HSDPA because the bit rate on the HS-DSCH is varied every TTI using different modulation schemes, effective code rates and a number of High Speed-Physical Downlink Shared Channel (HS-PDSCH) codes [10]. SINR for a single-antenna Rake receiver is calculated as in (1) [10]:

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

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 (AWGN). Parameter p is the orthogonality factor ($p = 0$ for perfect orthogonality), while SF_{16} is the spreading factor of 16.

Moreover, 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. For instance, if a 64 Kbps MBMS service should be delivered to a multicast group of 10 users, then the target throughput will be equal to 640 Kbps. Once the target cell throughput is set, the next step is to define the way that this throughput relates to the SINR (Fig. 2). At this point, it is worth mentioning that as the number HS-PDSCH codes increases, a lower SINR value is required to obtain a target MBMS data rate (Fig. 2).

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 Geometry factor—G) through Eq. 2 [10]:

$$P_{HS-DSCH} \geq SINR\left[p - G^{-1}\right]\frac{P_{own}}{SF_{16}} \tag{2}$$

The Geometry factor (G) is given by the relationship between P_{own}, P_{other} and P_{noise} and is defined from Eq. 3, while the Geometry CDF function values obtained for the macro cell environment is depicted in Fig. 3 [1]:

$$G = \frac{P_{own}}{P_{other} + P_{noise}} \tag{3}$$

The Geometry factor is another major measure that indicates the users' position in a cell (distance from the base station). A lower G is expected when a user is located at the cell edge (where interference received from the neighboring cell is higher than the interference experienced in its own cell).

4.1.2 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 serving 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 [15].

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

where 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

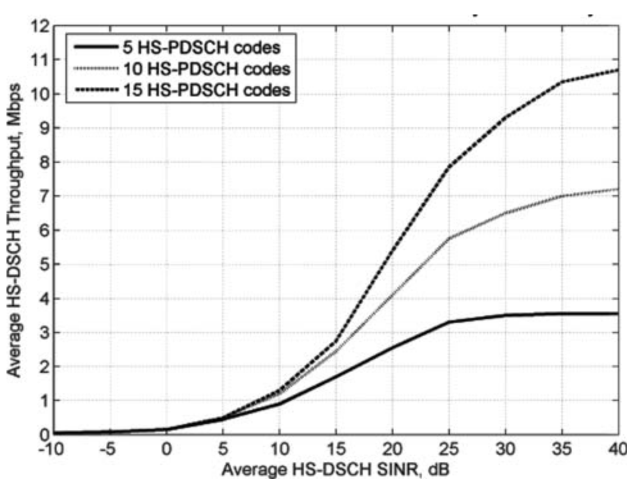

Fig. 2 Actual cell throughput versus SINR

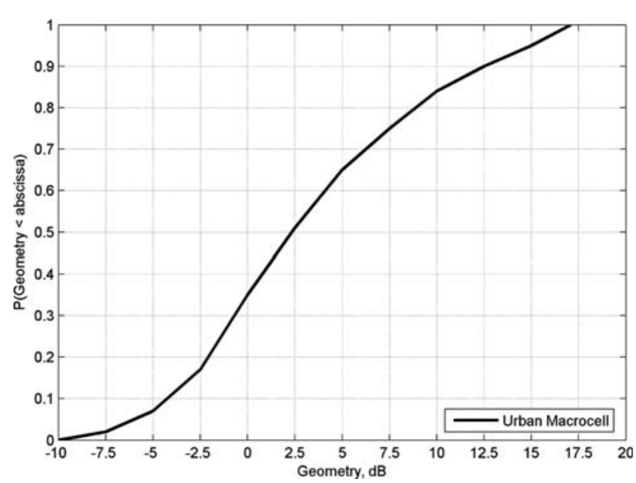

Fig. 3 Geometry CDF for macro cell

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 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}. More specifically [15]:

$$x_i = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{ij}} \tag{5}$$

DCH may be used for the delivery of PTP MBMS services, while can not be used to serve large multicast populations, since high downlink transmission power would be required.

4.1.3 FACH power profile

A FACH essentially transmits at a fixed power level since fast power control is not supported in this channel. FACH is a PTM channel and must be received by all UEs throughout the part of the cell that the users are found. 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 QoS in the desired area of the cell [16]. FACH power efficiency depends on maximizing diversity. Diversity can be obtained by the use of a longer TTI, e.g. 80 ms instead of 20 ms, to provide time diversity against fast fading. The bit rate of the MBMS service also affects the FACH transmission power [17].

Table 1 provides the FACH transmission power levels when dynamic power setting is utilized [14]. According to this technique, the FACH transmission power can be determined based on the user with the worst path loss. Depending on the distance between the user with the worst path loss and Node B, the RNC adjusts the FACH transmission power in one of the ten levels presented in Table 1, so as to ensure a reliable reception of the MBMS data. The FACH transmission power levels presented in Table 1 correspond to the case where no Space Time Transmit Diversity (STTD) is assumed. In addition, TTI is set to 80 ms and BLER target is 1% [17].

4.2 MBMS session assignment

The increased power requirements of MBMS transmissions place a restriction on the number of parallel MBMS sessions that a base station could support. This number depends on many parameters. We could classify these parameters in three categories:

- User related parameters.
- MBMS session related parameters.
- Provider related parameters.

Table 1 Fach Tx 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	7.6	–

User related parameters are parameters such as UEs' distances from the base stations and UEs' QoS parameters. 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 transmissions is a provider related parameter. All these parameters should be taken into account in the RRM of MBMS so as to have efficient power control.

5 MBMS session assignment mechanism

This section presents the architecture and the functionality of the MBMS session assignment mechanism that is used for the efficient data transmission of parallel MBMS services in UMTS. The proposed mechanism incorporates all the basic functionalities of the standardized by the 3GPP MBMS Counting Mechanism and furthermore, it integrates several enhancements. These are:

- Power based transport channel selection and not number of UEs based channel selection as the MBMS Counting Mechanism.
- Parallel MBMS sessions support.
- Consideration of users' mobility.

The block diagram of the mechanism is illustrated in Fig. 4. According to Fig. 4, the mechanism consists of five distinct operation phases. These are: the initialization phase, the parameter retrieval phase, the power computation phase, the radio bearer (RB) selection phase and the RB assignment phase. The RNC is the responsible node of the MBMS architecture for the operation of this algorithm and the decision of the most efficient transport channel.

The initialization phase (Fig. 4) launches the mechanism when one user expresses his interest in receiving a

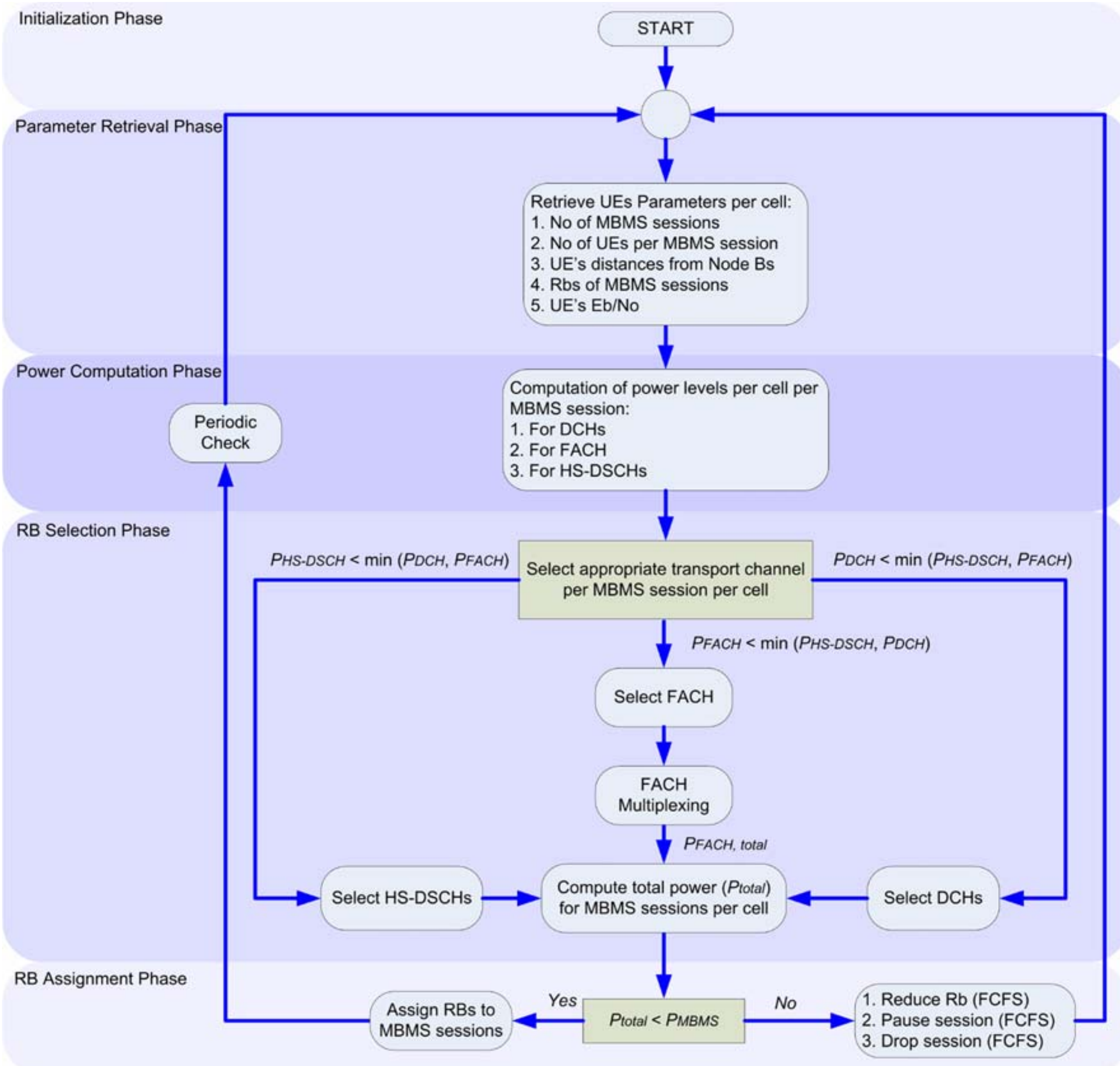

Fig. 4 MBMS session assignment mechanism

MBMS service. In other words, the mechanism begins when the first user requests the first 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 mechanism requires the two of the three types of parameters, mentioned in the previous section: 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 MBMS sessions per cell, the number of UEs per MBMS session per cell and the bit rates of the MBMS sessions. This information is retrieved from the BM-SC. On the other hand, the user related parameters are retrieved from the UEs through uplink channels. 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 power computation phase substantially processes the data received from the parameter retrieval phase. During this phase, the required power to be allocated for any MBMS session in each cell is computed. The computation is based on the assumption that the transmission of the multicast data over the UTRAN interfaces can be performed with:

- Multiple DCHs (DCHs case).
- FACH with such power so as to serve the UE with the worst path loss (FACH Dynamic case).
- HS-DSCHs (HS-DSCHs case).

In other words, the Node B's transmission power for any active MBMS session per cell is computed, assuming that all the UEs of each session in a cell could be served with the above three possible ways. The computation of the required power for the DCHs case takes into account the parameters defined in the parameter retrieval phase and calculates the required power (P_{DCH}) as in (4). For the FACH Dynamic case, the total required power (P_{FACH}) is computed depending on the user with the worst path loss as described in detail in the previous section. Finally, for the HS-DSCH case, the mechanism computes the required power ($P_{HS\text{-}DSCH}$) as in (2).

In the RB selection phase, the P_{DCH}, the P_{FACH} and the $P_{HS\text{-}DSCHs}$ are compared in order to select the most efficient transmission method for any MBMS session in a cell. Thus, for any MBMS session, the algorithm decides which case consumes less power and consequently, chooses the corresponding radio bearer for this session.

In the FACH Dynamic case there is another block in the mechanism's block diagram named FACH multiplexing. When the number of MBMS sessions requiring FACH in a cell is greater than one, these FACHs should be multiplexed onto a Secondary Common Control Physical Channel (S-CCPCH) as in Fig. 5 [18–20]. After the multiplexing procedure, the capacity of the S-CCPCH is calculated and based on this calculation, the total power required for the common channels ($P_{FACH,\ total}$) in the corresponding Node B is estimated. In this paper we consider two different channel multiplexing procedures. The first one is called single level channel multiplexing (Fig. 5(a)) and is based on an one to one mapping between MBMS sessions (MBMS point-to-multipoint Traffic Channels—MTCHs) and FACHs. The second procedure, which is called 2-level channel multiplexing (Fig. 5(b)), has as main target to further optimize the channel multiplexing procedure. In the 2-level channel multiplexing, several MTCHs could be multiplexed in a single FACH as shown in (Fig. 5(b)). The output of the FACH Multiplexing block is the multiplexing procedure that produces the minimum residual capacity in FACHs, which in turn means lower power requirements. In case the residual capacity in FACHs that produce the two procedures is the same, the single level multiplexing procedure is chosen, since it has lower complexity than the 2-level multiplexing procedure, as shown clearly in (Fig. 5).

The last action performed in the RB selection phase is the computation of the total Node B's power (P_{total}) required so as to support all the 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.

During the RB assignment phase, P_{total} is compared to 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. In case when P_{total} is bigger than P_{MBMS}, a session reconfiguration procedure should occur due to the fact that there are no available radio resources to the Node B so as to serve all the MBMS sessions. In this paper, we propose three possible reconfiguration events that could be used in such a case. The first is the reduction of the transmission rate of a MBMS session, the second is the pause of a MBMS session for a short period of time and the last is the cancellation of the service.

The simplest policy that RNC could adopt in order to perform the three above reconfiguration events, is a First Come First Served (FCFS) policy. Following the FCFS policy and considering the available power, the RNC performs the optimum event to the most recent MBMS sessions.

The above description refers to a dynamic model, in the sense that the UEs are assumed to be moving throughout the topology; while, 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 and the MBMS session related parameters. Therefore, the P_{DCH}, P_{FACH} and $P_{HS\text{-}DSCH}$ 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

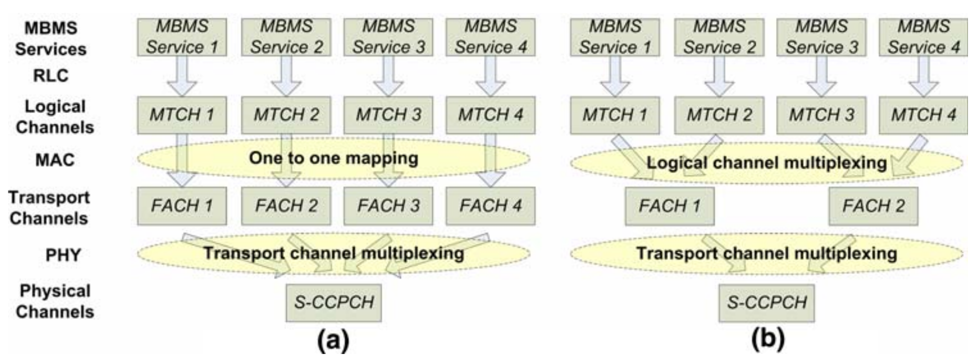

Fig. 5 FACH multiplexing **a** single level **b** 2-level

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. A further complexity is inserted in RNC due to the fact that the mechanism is executed many times in each RNC. In particular, if we suppose that a RNC serves N Node Bs with multicast users, while each of these Node Bs serves M_i ($i = 1 \ldots N$) parallel MBMS sessions, then the number of executions of the mechanism is computed as in (6):

$$K = \sum_{i=1}^{N} M_i \quad (6)$$

6 Performance evaluation

In this section, analytical simulation results for the evaluation of the mechanism are presented. In particular, we examine the following key aspects of the mechanism:

- Selection of the transport channel with the minimum power requirements for a given MBMS session.
- Handling of multiple parallel MBMS sessions in a cell and users' mobility.
- Comparison with other approaches.

The main assumptions that are used in our simulations are presented in the following table and refer to a macro cell environment [17, 21, 22]. In addition, no STTD is assumed, while the BLER target is set to 1% (Table 2).

Our goal is to demonstrate the advantages of our mechanism through a mathematical analysis, which however totally simulates the macro cell environment. We 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, certain scenarios are examined, indicative of the way our mechanism functions and of the advantages offered in comparison with current 3GPP approaches.

Table 2 Simulation parameters

Parameter	Value
Cellular layout	18 hexagonal grid cells
Sectorization	3 sectors/cell
Site to site distance	1 Km
Cell radius	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	10 W (40 dBm)
Propagation model	Okumura Hata
Multipath channel	Vehicular A (3 km/h)
Orthogonality factor	0.5
E_b/N_0 target	5 dB

6.1 Efficient transport channel selection

In this section we will present simulation results regarding the operation of the main phase of our mechanism, the RB selection phase. More specifically, we evaluate the ability of our mechanism to select the most efficient transport channel for the transmission of a single MBMS session. To this direction, transmission power levels of the different types of transport channels are presented.

The simulation scenario considers a 64 Kbps MBMS service transmitted to a multicast group in a cell/sector. The UEs appear in random initial positions and then move randomly throughout the cell. Moreover, the number of users receiving the service gradually increases, reaching 32 UEs at the end of the simulation time, as shown in Fig. 6.

In Fig. 6, the transmission power levels when using DCHs, FACH or HS-DSCH are depicted. These power levels constitute the overall output of the power computation phase of the mechanism. In the next phase, the mechanism will force the RNC to select, at each instant, the radio bearer that ensures the lowest power consumption, thus saving the expensive and limited power resources. Therefore, in the beginning of the simulation, when the number of UEs is small, the most efficient channel is DCH. The increase in the number of UEs and the continuous users' movement throughout the cell causes a switch from DCHs to HS-DSCH at simulation time 34 s, when the UE population is 7. An additional increase in the number of UEs results to a switch from HS-DSCH to a single FACH (at simulation time 83 s when the UE population is 17) with transmission power high enough to cover the UE with the worst path loss. A further increase in the UE number does not involve any change, unless the user with the worst path loss moves towards the cell edge, forcing the FACH to transmit at a higher power level (simulation time 103 s).

Generally, in cases where the number of users is small, PTP transmissions are preferred. DCH and HS-DSCH are both PTP channels; however, the results have shown that for very small multicast user population DCH is preferred, while for relatively more users, HS-DSCH is the most appropriate channel. Therefore, our mechanism does not only decide to use PTP or PTM transmissions (as the MBMS Counting Mechanism 3GPP—TS 25.346), but it makes a further distinction between DCH and HS-DSCH in PTP mode.

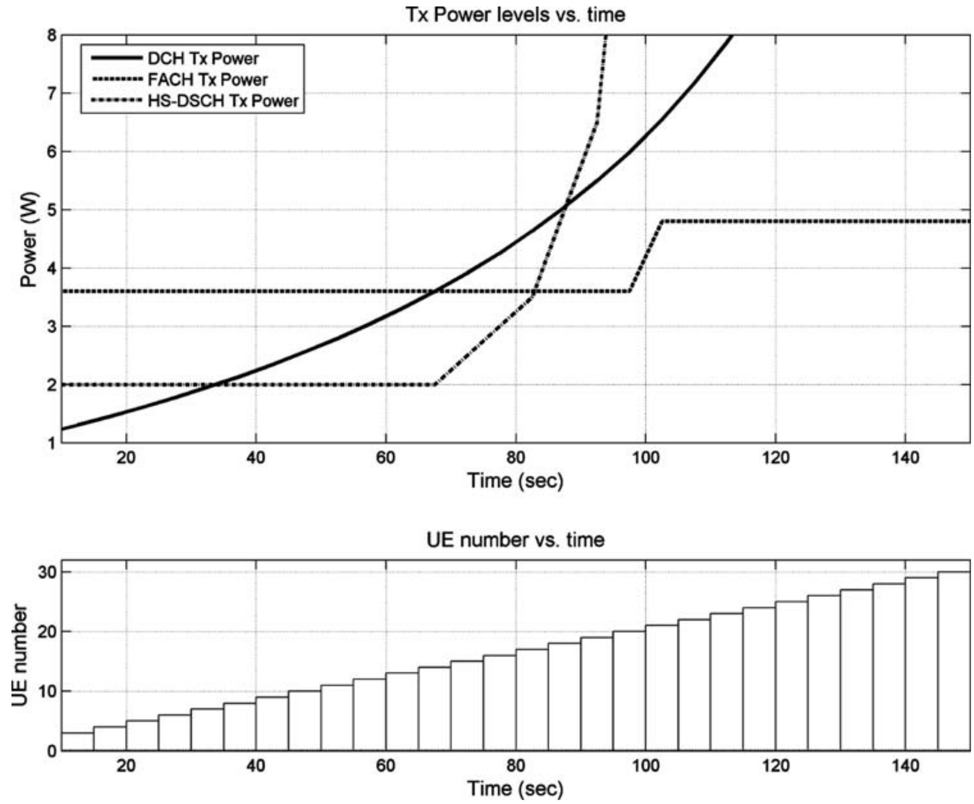

Fig. 6 Transport channel selection

6.2 Comparison with current 3GPP approaches

Based on the above scenario, we will make a comparison between our approach and the current 3GPP approaches: TS 25.346 [4] and TR 25.922 [5]. For comparison reasons, we will examine the power requirements of our mechanism and the two mechanisms proposed by 3GPP (Fig. 7).

According to MBMS Counting Mechanism (3GPP TS 25.346), the decision for switching between PTP and PTM bearers should be based on the number of serving MBMS users. Assuming that the threshold is 7 UEs (a mean value for the threshold proposed in the majority of research works mentioned in this paper), the MBMS Counting Mechanism will command the Node B to switch from DCH to FACH (HS-DSCH is not supported) when the number of users exceeds this predefined threshold. The inefficiency of the MBMS Counting Mechanism is obvious as this mechanism follows a fixed, predefined scheme that does not consider mobility and current location of the users. This scheme results in a sharp increase of the power level from 2 to 7.6 W when the number of users exceeds the threshold (Fig. 7).

The MBMS Power Counting Mechanism (3GPP TR 25.922) overcomes several inefficiencies of the MBMS Counting Mechanism. The reduction of the power requirements is the main goal behind this approach and to this direction, a dynamic switching scheme is proposed that takes into account mobility and current location of the users. However, as depicted in Fig. 7 the power requirements of this mechanism are increased compared to our approach. The increased power consumption is caused by two reasons. Firstly, TR 25.922 allows the use of PTP transmissions (DCH or HS-DSCH); however, it does not support both PTP channels in the same MBMS session. Thus, in Fig. 7 we consider that only the use of DCH is allowed for PTP transmissions. In this case the advantages from the use of HS-DSCH are eliminated. On the other hand, if only the use of HS-DSCH is allowed, the advantages from the use of DCH are eliminated. Secondly, dynamic power allocation for the FACH is not supported, in other words when FACH is used, it should obligatorily cover the whole cell area. The above two reasons induce increased power consumption in MBMS Power Counting Mechanism.

In Fig. 7 the power requirements of our approach remain lower than the power requirements of the other two approaches. The lower power consumption is derived from three different reasons. Firstly, contrary to TS 25.346 our approach considers users' mobility and location and utilizes a power based scheme for switching between the transport channels. Secondly, contrary to TR 25.922 both PTP transmission modes are supported. Therefore, our approach does not only allow PTP transmissions, but it makes a further distinction between DCH and HS-DSCH

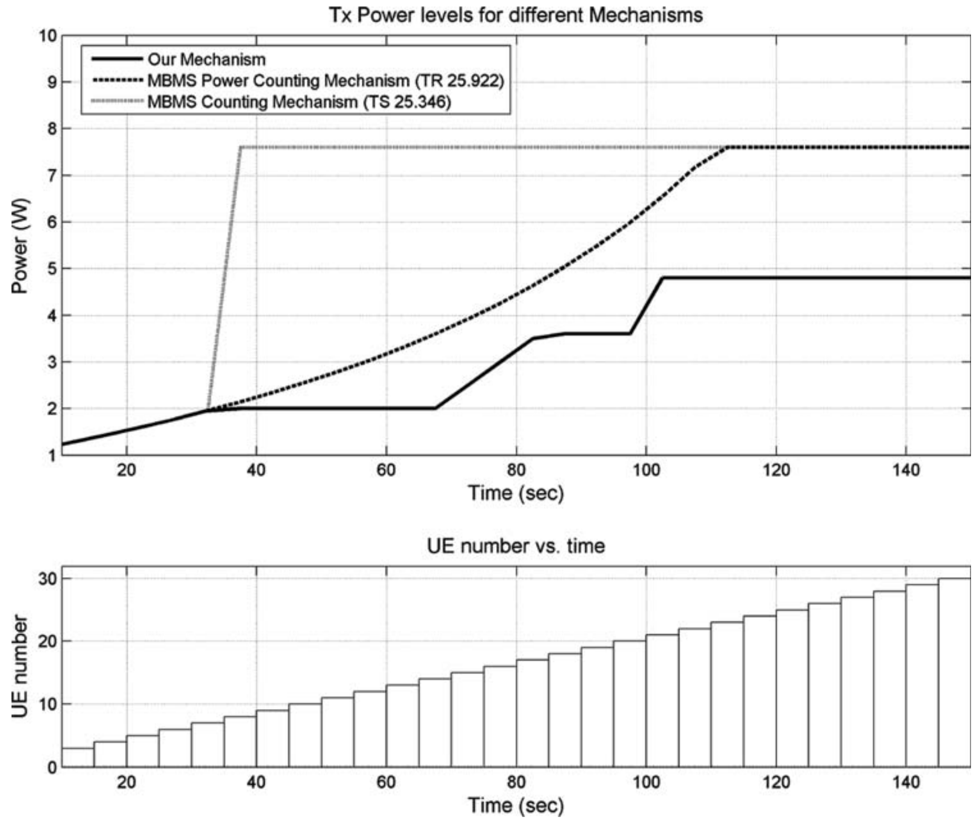

Fig. 7 Comparison between different mechanisms

transmissions. Thirdly, contrary to TS 25.346 and TR 25.922 our approach supports FACH dynamic power allocation, reducing in this way the power requirements during PTM transmissions. Finally, our mechanism provides multiple MBMS session assignment functionality for efficient capacity allocation during MBMS transmissions.

An interesting aspect regarding the performance evaluation of the examined mechanisms is the computational overhead inserted in RNC. Figure 8 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 above scenario. The main purpose of Fig. 8 is to demonstrate the number of operations performed in RNC so as to compute the transport channels' power levels (except for TS 25.346 that does not require this information during the RB assignment phase) and assign the appropriate bearer.

In general, the MBMS Counting Mechanism (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, TR 25.922 and our approach have higher computational overhead due to the fact that both mechanisms have to periodically retrieve the parameters of existing MBMS users. Moreover, these two approaches have to calculate the power consumption of the transport channels that each mechanism supports; and based on this calculation to assign the ideal radio bearer. As depicted in Fig. 8, the number of iterations in both cases increases as the number of users increases, leading to higher computational overhead. The fact that our approach supports both DCH and HS-DSCH in PTP mode (therefore, both power levels have to be computed) explains why the number of iterations in this case is higher that TR 25.922.

To sum up, Table 3 presents a direct comparison between the mechanisms analyzed in this paper. The main conclusion is that the MBMS Session Assignment Mechanism outperforms the 3GPP standardized approaches (TS 25.346 and TR 25.922) in terms of power consumption. However, this approach inserts high complexity for RNC due to its dynamic and periodic nature. Nevertheless, due to the fact that Node B's transmission power is a limited resource, the disadvantages caused by the inserted complexity seem minor compared to the advantages of the power consumption reduction.

6.3 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

Fig. 8 Complexity comparison between different mechanisms

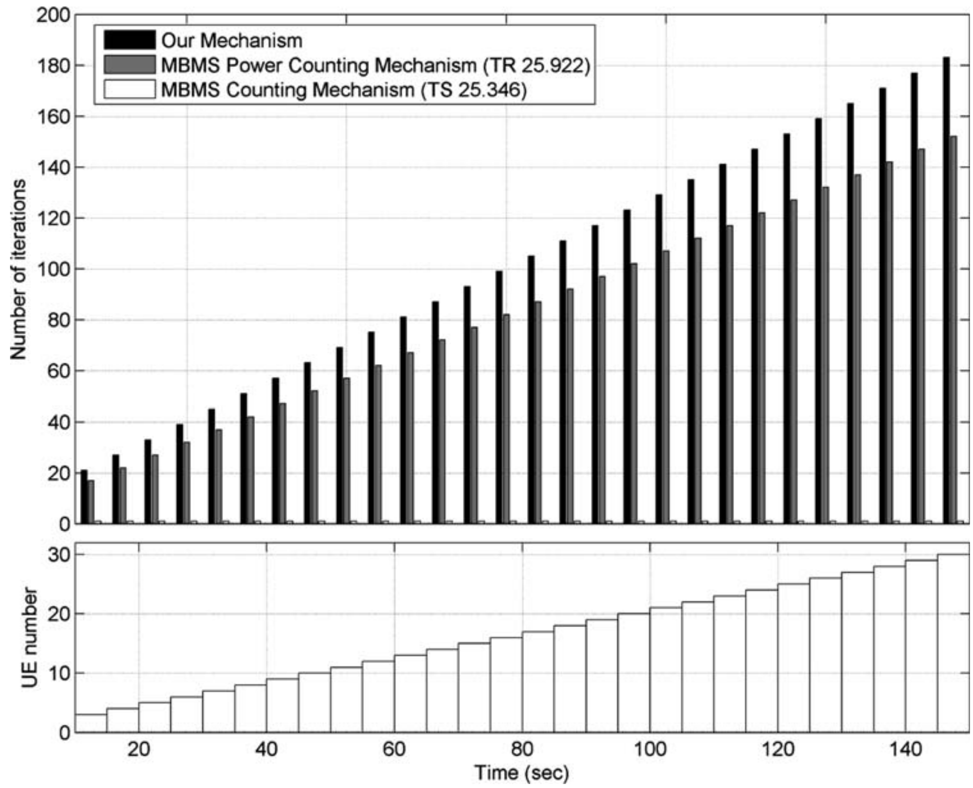

Table 3 Comparison of the mechanisms

Mechanism	Advantages	Disadvantages
TS 25.346	Low complexity	High power requirements
	Easy to implement	No mobility support
	3GPP standardized	Not support HS-DSCH in PTP mode
		Not support dynamic FACH in PTM mode
TR 25.922	Support all transport channels	High power requirements
	3GPP standardized	Not support switching between HS-DSCH and DCH in PTP mode
		Not support dynamic FACH in PTM mode
MBMS session assignment mechanism	Support all transport channels	No standardized
	Support switching between HS-DSCH and DCH	High complexity due to multiple session support
	Support multiple MBMS sessions	
	Support dynamic FACH and FACH multiplexing in PTM mode	

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. Figure 9 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. It is worth mentioning that Table 4 presents, apart from service related aspects, the appropriate transport channel (with respect to power consumption as presented in previous section) to serve each group at each time interval.

Users of the 1st MBMS session are served with a HS-DSCH channel, due to the small population, throughout the whole service time. At simulation time 50 s, MBMS service 2 is initiated (Fig. 9). At this time instant, the mechanism, through the RB selection phase, selects FACH as the most efficient transport channel for the transmission of the MBMS traffic, since MBMS session 2 is delivered to a large number of users (22 UEs).

MBMS service 3 starts at simulation time 100 s. At this time the 3rd multicast group consists of only two UEs and thus the mechanism selects multiple DCHs for this MBMS service. The number of users that receive this service successively increases, 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 in the group 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). During this time interval, 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 translates into efficient provision of the three parallel MBMS sessions.

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 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 until the end of the simulation, four parallel MBMS sessions running in the system and our mechanism handles them in an efficient way.

The increase in P_{total} occurs because the users of the 4th multicast group are moving towards the cell edge. Due to this movement P_{total} exceeds P_{MBMS} value at simulation time 560 s (Fig. 9). 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.

The transmission rate reduction of the MBMS service 4 is considered as a drastic action/policy; however, it is necessary for the uninterrupted provision of this service.

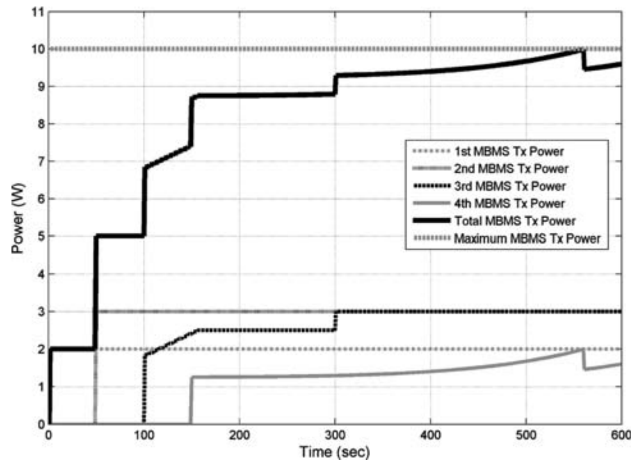

Fig. 9 Power levels of the MBMS sessions

The users of this service will observe a relatively small reduction of the quality, which nevertheless will allow them to keep enjoying the service.

If a user expressed its interest for a new MBMS service, the user would have waited until the appropriate power resources were released. According to the session reconfiguration procedure, initially the mechanism would have paused and finally would have cancelled the new service (if the pause period became too long) as long as these power resources could not be ensured. These drastic actions during the session reconfiguration procedure stress the importance and the efficiency of the proposed mechanism.

Another aspect of the mechanism that we want to highlight is the evaluation of the FACH multiplexing block of the RB Selection Phase. To this direction, we consider the simulation scenario presented in Table 5. Furthermore, we suppose that the number of users as well as their location in the cell favor the deployment of FACHs as transport channels for the three MBMS sessions.

For the specific scenario the performance of the single and 2-level multiplexing procedures is presented in Fig. 10. In Fig. 10 we can see how the three MBMS services are mapped on S-CCPCHs using single level (Fig. 10(a)) and 2-level (Fig. 10(b)) multiplexing. Initially, the three MBMS services are mapped on three MTCHs with the same bit rates as the corresponding MBMS

Table 4 Simulation scenario

MBMS No.	Duration (s)	Bit rate (Kbps)	UEs number	Maximum coverage (%)	Channel selected
1	0–600	64	10	80	HS-DSCH
2	50–600	64	22	60	FACH
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

Table 5 Simulation scenario

MBMS No.	Duration (s)	MTCH bit rate (Kbps)	Channel selected
1	0–500	64	FACH
2	0–500	32	FACH
3	0–500	32	FACH

services. The next step is the mapping of logical channel (MTCHs) onto transport channels (FACHs). In an one to one mapping of MTCHs on FACHs (single level FACH multiplexing—Fig. 10(a)), if the bit rates of the MTCHs does not exactly match the corresponding bit rate of the FACHs, residual capacity occurs in FACHs as shown in Fig. 10(a). On the other hand, in 2-level FACH multiplexing procedure (Fig. 10(b)), we can eliminate this residual capacity by multiplexing several MTCHs on a single FACH of appropriate bit rate. Finally, supposing that the available S-CCPCHs transmission capacity is 128 Kbps, the FACHs are multiplexed on S-CCPCH on the physical layer. This mapping is shown in Fig. 10 for the two different multiplexing procedures.

Figure 10 shows clearly that 2-level multiplexing requires half capacity (i.e. bandwidth) and power resources than the single level multiplexing in order to transmit the same MBMS data of the specific scenario to mobile users. To sum up, the problem with the single level channel multiplexing is that there exists residual capacity (i.e. bandwidth) on the transport channel when the bit rate of the logical channel does not exactly match the corresponding bit rate of the transport channel, which in turn leads to inefficient usage of radio resources.

7 Future work

The steps that follow this work could be at a first level the evaluation of the mechanism through additional simulation scenarios. The scenarios could be simulated in the ns-2 simulator, 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 UTRAN interfaces during MBMS transmissions. At a second level, the complexity that the mechanism inserts in RNCs due to its dynamic and periodic nature is of critical importance and should be further studied. Furthermore, several power saving techniques such as rate splitting and macro diversity combining could be integrated in the MBMS session assignment mechanism. The use of these techniques will 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, we plan to improve the capacity and functionality of our mechanism by incorporating the enhancements that could be obtained from the use of multiple-input multiple-output (MIMO) antenna techniques in HSDPA.

8 Conclusions

In this paper we presented a novel power control mechanism for efficient MBMS session assignment in next generation UMTS networks. The mechanism shares efficiently the available power resources of UMTS base stations to MBMS sessions running in the network. Furthermore, the mechanism supports all the available transport channels which could be used for transmission of the MBMS traffic to mobile users. The mechanism is evaluated through several realistic scenarios and the results indicated the ability of the mechanism to handle efficiently multiple MBMS sessions, increasing in this way the total capacity of UMTS networks. Our approach considers all the basic functionalities of the two 3GPP approaches (TS 25.346 and TR 25.922) and incorporates several enhancements. In order to highlight these enhancements, we provided a comparison of our mechanism with the above mentioned approaches. The main conclusion is that our

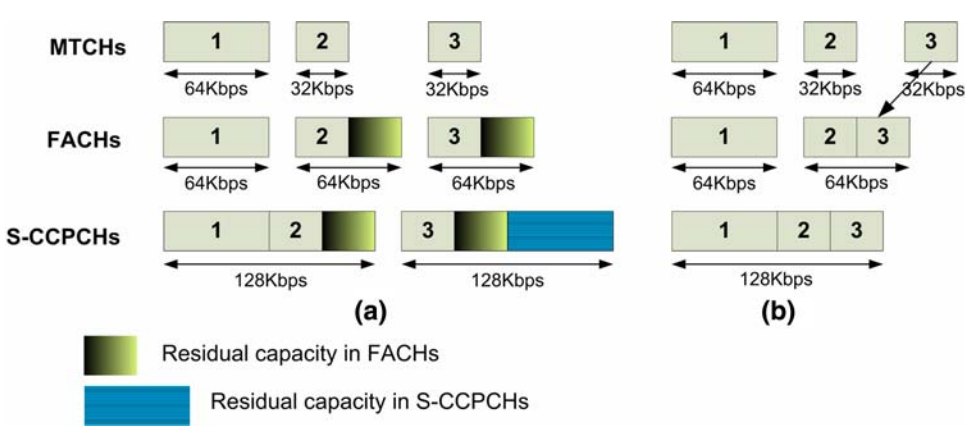

Fig. 10 FACH multiplexing performance evaluation **a** single level **b** 2-level

mechanism outperforms them, underlining in this way the necessity for its incorporation in MBMS. In particular, contrary to TS 25.346 our approach considers users' mobility and location and utilizes a power based scheme for switching between the transport channels. Secondly, contrary to TR 25.922 both PTP transmission modes are supported. Thirdly, contrary to TS 25.346 and TR 25.922, our approach supports FACH dynamic power allocation. Finally and most importantly, our approach provides multiple MBMS session assignment functionality for efficient capacity allocation during MBMS transmissions.

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