A Power Control Scheme for Efficient Radio Bearer Selection in MBMS

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Abstract

This paper proposes a power control scheme for the efficient radio bearer selection in the Multimedia Broadcast/Multicast Service (MBMS) framework of Universal Mobile Telecommunications System (UMTS). The choice of the most efficient transport channel in terms of power consumption is a key point for the MBMS since a wrong transport channel selection for the transmission of the MBMS data could result to a significant decrease in the total capacity of the system. Different UMTS transport channels are examined and an algorithm that defines the switching point between dedicated and common radio bearers is proposed. The proposed MBMS power control scheme selects the transport channel that reduces the Node B's transmission power in every cell of the network with multicast users.

1. Introduction

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

At first, UMTS offered tele-services (e.g voice and SMS) and Bearer Services for point-to-point (PTP) transmission using the Unicast technology. Later, with the introduction of new services, such as IP Video Conferencing, Streaming Video and others, there was an increasing need for communication between one sender and many receivers, leading to the need of point-to-multipoint (PTM) transmission. One efficient way to implement this type of transmission is the use of broadcast and multicast technologies [12]. The 3rd Generation Partnership Project realized the need for broadcasting and multicasting in UMTS and proposed some enhancements on the UMTS Release 6 architecture that led to the definition of the Multimedia Broadcast Multicast Service (MBMS) framework. MBMS is a point-to-multipoint service in which data is transmitted from a single source entity to multiple destinations, allowing the networks resources to be shared [2], [3].

Power control is one of the most important aspects in MBMS due to the fact that Node B's transmission power is a limited resource and must be shared among all MBMS users in a cell. The main purpose of power control is to minimize the transmitted power, thus avoiding unnecessary high power levels and eliminating inter-cell interference. Moreover, with the introduction of MBMS Services in UMTS networks, the Radio Network Controller (RNC) for radio efficiency reasons, can use either Dedicated resources (one Dedicated Channel (DCH) for each User Equipment (UE) in the cell) or Common resources (one Forward Access Channel (FACH) shared by all the UEs in a cell) to distribute the same content in a cell.

This paper proposes a power control scheme for the efficient transport channel selection in the MBMS framework of UMTS. The choice of the most efficient transport channel in terms of power consumption is a key point for the MBMS, since a wrong transport channel selection for the transmission of the MBMS data could result to a significant decrease in the total capacity of the system. The algorithm proposed in order to define the switching point between dedicated and common radio bearers aims to ensure that Node B transmits in a non-excessive power level but high enough to satisfy all multicast users.

Several studies and simulations have been carried out focusing on the threshold for switching between dedicated and common resources in terms of transmission power. In [8] is claimed that for a FACH with transmission power set to 4W, the threshold for switching from dedicated to common resources is around 7 UEs per cell, while in [13] the threshold is 5 UEs. However, only the information on the number of users in a cell may be not sufficient so as to select the appropriate radio bearer (PTP or PTM) for the specific cell. The decision has to take into account the total power required for the transmission of the multicast data in the PTP and PTM cases. An interesting study under this assumption is presented in [14] where the authors propose a switching point (based on power consumption) of 5 UEs between dedicated and common resources. Finally, the above switching points are expected to increase with the use of HSDPA on PTM links [4].

The paper is structured as follows. Section 2 provides an overview of the UMTS and MBMS architecture. In Section 3, we present an analysis of the power control in MBMS, while Section 4 presents a proposed power control scheme for the efficient radio bearer selection in MBMS. Section 5 presents the results of the evaluation of the power control scheme. Finally, some concluding remarks and planned next steps are briefly described.

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 UMTS Terrestrial Radio-Access Network (UTRAN) (Figure 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]. The CS domain handles the voice-related traffic, while the PS domain handles the packet transfer. In the remainder of this paper, we will focus on the UMTS packet-switching mechanism.

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) (Figure 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) with other Packet Data Networks (PDNs) like the Internet.

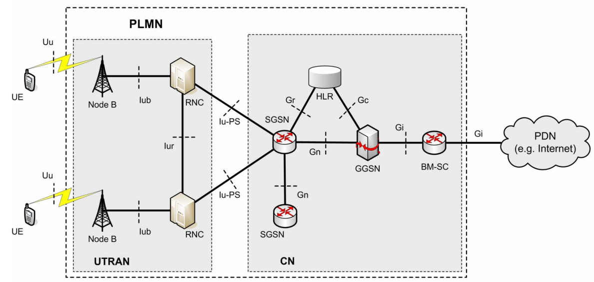

Figure 1. UMTS and MBMS architecture

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 (Figure 1). Node B is connected to the User Equipment (UE) via the Uu interface (based on the Wideband Code Division Multiple Access, WCDMA technology) and to the RNC via the Iub interface. One RNC with all the connected to it Node Bs is called Radio Network Subsystem (RNS) [1].

The 3rd Generation Partnership Project (3GPP) is currently standardizing the Multimedia Broadcast/Multicast Service (MBMS) [2], [3]. Actually, the MBMS is an IP datacast (IPDC) type of service, which can be offered via existing GSM and UMTS cellular networks. The major modification in the existing GPRS platform is the addition of a new entity called Broadcast Multicast–Service Center (BM-SC). The function of the BM-SC can be separated into five categories: Membership, Session and Transmission, Proxy and Transport, Service Announcement and Security function. As Figure 1 depicts, BM-SC communicates with both the existing UMTS network and external PDNs.

Regarding the transmission of the packets over the Iub and Uu interfaces, it may be performed on common (ex. Forward Access Channel – FACH, High Speed Downlink Shared Channel - HS-DSCH) or dedicated transport channels (ex. Dedicated Channel - DCH). As presented in [11], the transport channel that the 3GPP decided to use as the main transport channel for PTM MBMS data transmission is the FACH with turbo coding and QPSK modulation at a constant transmission power. 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. Furthermore, a new transport channel named HS-DSCH has been introduced as the primary radio bearer in Release 5 of UMTS. The HS-DSCH resources can be shared between all users in a particular sector.

3. Power control in MBMS

Power control is one of the most important aspects in MBMS due to the fact that Node B's transmission power is a limited resource and must be shared among all MBMS users in a cell. It is essential to combat fading and minimize interference in the system. However, when misused, the use of power control may lead to a high level of wasted power and worse performance results.

On the unicast (PTP) downlink transmissions, fast power control is used to maintain the quality of the link and thus to provide a reliable connection for the receiver to obtain the data with acceptable error rates. Transmitting with just enough power to maintain the required quality for the link also ensures that there is minimum interference affecting the neighboring cells. However, when a user consumes a high portion of power, more than actually is required, the remaining power allocated for the rest of the users is eliminated, which may lead to a significant capacity loss in the system.

In multicast (PTM) downlink transmissions, Node B transmits at a power level that is high enough to support the connection to the receiver with the highest power requirement among all receivers in the multicast group. This would still be efficient because the receiver with the highest power requirement would still need the same amount of power in a unicast link, and by satisfying that particular receiver's requirement, the transmission power will be enough for all the other receivers in the multicast group. Consequently, the transmitted power is kept at a relatively high level most of the time, which in turn, increases the signal quality at each receiver in the multicast group. On the other hand, a significant amount of power is wasted and moreover inter-cell interference is increased.

Yet no decision has been made within 3GPP on how to optimize the MBMS data flow over the Iub. It is proposed in the literature to avoid the duplication of Iub data flows and hence, only one Iub data flow per MBMS service should be used [4], [5]. However, the selection of the appropriate radio bearer for the transmission of the multicast data over the Iub is not only based on the data duplication over the Iub or not but also on the efficient usage of the available power resources in the Node B.

The transport channels, in the downlink, currently existing in UMTS which could be used to serve MBMS are the Dedicated Channel (DCH), the Forward Access Channel (FACH) and the High Speed DSCH (HS-DSCH). Each channel has different characteristics in terms of power control. In this paper we will focus on the FACH and DCH channels.

The main requirement is to make an efficient overall usage of the radio resources: this makes a common channel, such as FACH or HS-DSCH, the favorite choice, since many users can access the same resource at the same time, but this depends also on the number of users belonging to the multicast group, on the type of service provided and the QoS that it can guarantee. Therefore, the determination of the switching point between PTP channels and PTM channels becomes of great importance for the insurance of the system's efficient operation.

In the following two paragraphs we present the power profiles of the DCHs (PTP bearers) and the FACHs (PTM bearers).

3.1. DCH power allocation

DCH is the main radio bearer that is used for the PTP case and supports fast power control. Transmission power allocated for dedicated resources is variable and depends on the distribution of UEs in a cell and on the requirements of the service provided.

When only few users are receiving the same MBMS service it could be more efficient to use DCHs for each user in order to reduce the total transmitted power and the system interference. However, only the information on the number of users in a cell may not be sufficient so as to select the appropriate radio bearer for the specific cell. The decision has to take into account the total power required for the transmission of the multicast data in the PTP and PTM case.

The total downlink transmission power allocated for DCHs is variable and mainly depends on the number of UEs, their locations throughout the cell, the required bit rate of the MBMS service and the experienced signal quality (E_b/N_0) for each user. Equation(1) calculates the total Node B's transmission power required for the transmission of the multicast data to n users in a specific cell. Actually, the total Node B's transmission power is the sum of Node B's power allocated to each DCH user in the cell.

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

where P_T is the base station total transmitted power, P_{Ti} is the power devoted to the ith user , 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 (p=0: perfect orthogonality),

$(E_b/N_0)_i$ is the signal energy per bit divided by noise spectral density. Parameter 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,…K and the path loss from this user to the j^{th} cell L_{ij}. More specifically [6]:

$$x_i = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{ij}} \quad (2)$$

From the above equations it is observed that Node B's transmission power, for the PTP case, increases when the distance between the Node B and the UEs increases. The same occurs when the bit rate of the MBMS service increases. The above behavior of the transmission power is illustrated in Figure 3 and Figure 2.

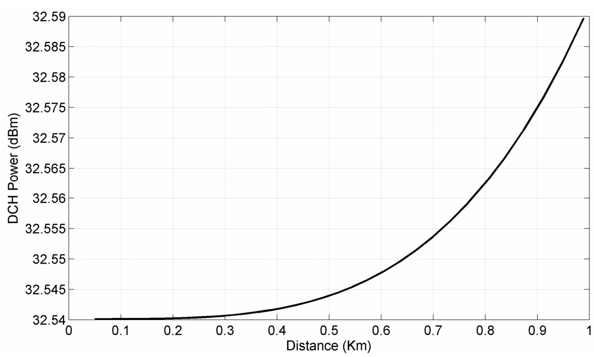

Figure 2. DCH power for different distances

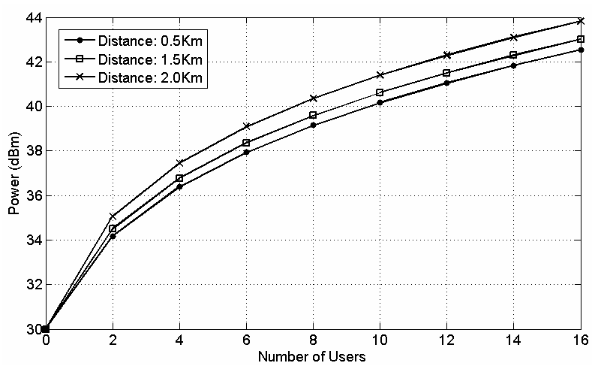

Figure 3. DCH power against the number of users

For instance, in Figure 2 we can see that as the distance between the mobile user and the Node B increases the DCH power allocated for the specific user increases too. Figure 3 depicts the behavior of the total Node B's transmission power for various groups of UEs served by DCHs.

3.2. FACH Power Allocation

FACH (PTM bearer) essentially transmits at a fixed power level since fast power control is not supported in this channel. A FACH channel must be received by all UEs throughout the cell. Consequently, the fixed power should be high enough to ensure the requested QoS in the whole coverage area of the cell and independently of the location of UEs.

However, it should be mentioned that allocating a high portion of the available Node B's power to a FACH channel results to a waste of resources, both from efficiency and interference point of view. On the other hand, allocating insufficient power may lead to a high BLER experienced by MBMS users, leading in turn to either a reduction of the cell coverage area or to an overload of the repair mechanism [7].

A FACH channel may be used to serve a PTM cell, as it is a common channel. UEs in a multicast group receive data but cannot send back packets in the uplink. Due to fact that there is need to cover the whole PTM cell, the power setting for the multicast channel depends on the trade off between cell coverage, QoS of UEs and interference caused to other UEs in the cell [8].

FACH power efficiency strongly depends on maximizing diversity as power resources are limited. Diversity can be obtained by the use of a longer TTI, e.g. 80ms instead of 20ms, to provide time diversity against fast fading (fortunately, MBMS services are not delay sensitive) and the use of combining transmissions (soft and selection combining) from multiple cells to obtain macro diversity [9]. In [10] the above statement is confirmed through analytical investigations. Simulation results regarding the fraction of Node B's transmit power for a cell served by a FACH for various channels are presented. An average 20% - 25% fraction of total Node B power (equal to 4W – 5W) must be allocated for a 64Kbps MBMS service. Such power levels are also illustrated in [8].

However it should be mentioned that a PTM channel, such as FACH, transmitting at fixed power, results to a decrease of available power for dedicated channels and increases both inter-cell and intra-cell interference.

4. A Power control scheme for efficient radio bearer selection in MBMS

In this section, we present the architecture and the functionality of a proposed power control scheme that is used for the efficient data transmission during an MBMS service. The block diagram of the scheme is illustrated in Figure 4.

More specifically, the scheme consists of four distinct operation phases. These are: the initialization phase, the power computation phase, the radio bearer selection phase and the event scheduling phase. RNC is the responsible node of the MBMS architecture for the operation of this algorithm and the decision of the most efficient transport channel.

Regarding the initialization phase (Figure 4), at first, the scheme retrieves the parameters of the existing MBMS users (through uplink channels) in each cell. These parameters are the distance of each UE from the Node B and the Eb/N_0 requirement per UE. In addition, we assume that the MBMS bit rate service is already known (in the BM-SC). This information is later used as an input in the power computation phase.

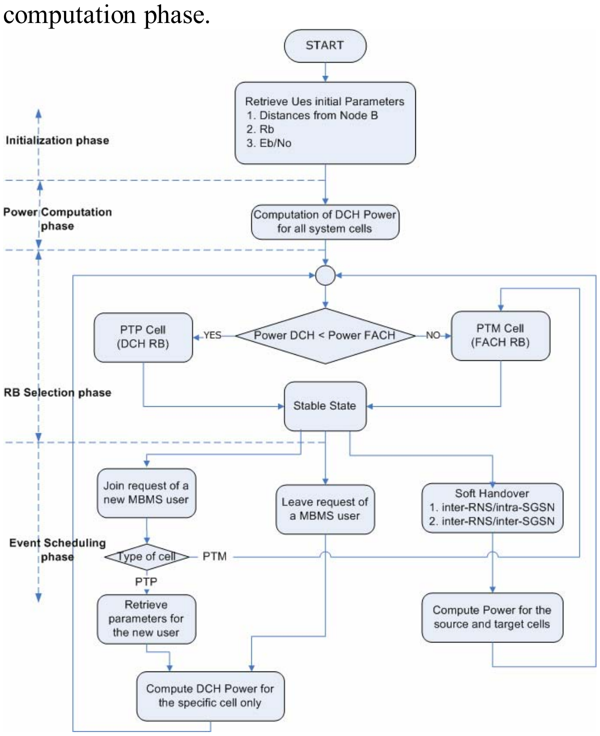

Figure 4. Block diagram of the power control scheme

In the power computation phase (Figure 4), the required power to be allocated for each cell is computed. The computation is based on the assumption that: DCHs are used for the transmission of the multicast data (of a MBMS session) over the Iub. In other words, we compute the total Node B's transmission power (P_{DCH}) per cell for the given MBMS session, assuming that all UEs of the session are served by PTP bearers. This computation is taking into account the parameters defined in initialization phase, according to equation (1).

Before continuing the description of the radio bearer selection phase, it has to be reminded that the power allocated to FACH channel (P_{FACH}) is fixed at a level that was discussed previously in section 3.2.

In the radio bearer selection phase, the P_{DCH} and the P_{FACH} are compared in order to select the most efficient transport channel for the specific MBMS session. Thus, for each cell separately, we can decide which transport channel consumes less power and consequently, choose the radio bearer that minimizes the Node B transmission power per cell. A cell can be characterized as a PTP cell (data is carried through multiple DCHs) or as a PTM cell (data is carried through FACH channel). If $P_{DCH} < P_{FACH}$ then MBMS users are served through multiple DCHs while, if $P_{DCH} > P_{FACH}$ then MBMS users are served through a FACH channel. As it has already been mentioned, the categorization of the cells is done for each MBMS session in the system.

Regarding the event scheduling phase, three different events could be occurred during an MBMS session:

1. Join Request from a new MBMS user. Initially, the new user's parameters are retrieved as in initialisation phase. Later, we make a distinction between PTP and PTM modes.
   If a UE requesting for an MBMS service is located in the coverage area of a PTM cell the computation of the new P_{DCH} value is useless. Cell is already in PTM mode which means that $P_{DCH} > P_{FACH}$ before the join request. Thus, the new P_{DCH} value will be essentially higher than that of P_{FACH}, thought a UE join in the multicast group increases transmission power. Consequently, it is certain that the cell would still be in PTM mode after the join request and the radio bearer would still be a FACH channel.
   In case of a PTP cell, the new UE join may lead to a power increase that exceeds the P_{FACH} value and the cell must be characterized as PTM. Thus, it is obligatory to compute the new DCH power for this specific cell only.
2. Leave request from an existing MBMS user. In this case, a currently existing MBMS user makes a leave request. As in join request case, the computation of the DCH power for this specific cell only is taking place.
3. Soft Handover. In this case, a MBMS user moves along different cells and Soft Handover is emerged. We examine the cases of inter-Node B/inter-RNS/intra-SGSN and inter-Node B/inter-RNS/inter-SGSN by investigating the changes, in terms of power consumption, that occur in the source and target cells. Thus, we compute the

DCH power for source and target cells only. An efficient MBMS handover mechanism is presented in [12].

The above description refers to a static model in the sense that only static UEs are assumed. Power computation phase is triggered whenever one of the three events of event scheduling phase is emerged. However, in a real world scenario, UEs are characterized by mobility. Consequently, P_{DCH} must be computed periodically every a predetermined frequency rate (f_{power}). This periodic computation inserts a further complexity for RNC as this information is carried in an uplink channel. This entails that a certain bandwidth fraction must be allocated for the transmission of this information in the uplink channel thus resulting to a capacity reduction. However, it should be mentioned that the P_{DCH} computation frequency (f_{power}) is beyond the scope of this paper and should be further studied.

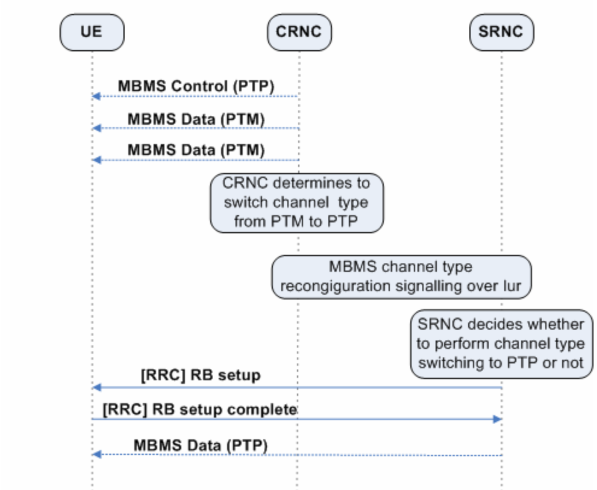

Figure 5. Channel type switching procedure

The channel type switching procedure between PTP and PTM bearers is depicted in Figure 5 [11]. The CRNC is responsible for the decision regarding the type of transmission channel in a cell for a specific MBMS service. Moreover, the CRNC informs all the SRNCs having UEs in that cell about its decision. The SRNC is the RNC that controls the RRC connection and RBs to a specific UE.

More specifically, in Figure 5 the switch from PTM to PTP bearer is described. The CRNC has decided to no longer use PTM, then the SRNC decides to perform channel type switching to deliver the MBMS service. However, it should be mentioned that the matter of whether the SRNC always follows the CRNC's request or not is for further study.

5. Results

In this section some simulation results for the performance evaluation of the proposed scheme are presented. In the simulation results we show how Node B's transmission power for an MBMS session could be reduced by selecting different transport channels for the transmission of the MBMS data over the Iub and Uu interfaces. Our study focuses on an urban macrocellular environment with parameters presented in Table 1 [10]. The topology examined consists of 1 central cell and 18 neighboring cells as shown in Figure 6. Figure 6 also depicts the simulation scenario.

Table 1. System level simulation assumptions, macrocell

Parameter	Value
cellular layout	hexagonal grid
sectorisation	yes, 3 sectors/site
cell radius	1000 m
number of neighbouring cells	18
Node B antenna gain + cable loss	14 dBi
antenna front to back ratio	20 dB
horizontal antenna pattern	Gaussian
antenna beamwidth, -3 dB	70 degrees
propagation model	PL = 128.1 + 37.6*log(R) dB
orthogonality factor	0.5
Node B total transmission power	43 dBm
thermal noise	-174 dBm/Hz

In this scenario we examine two specific cells, considered to be the source and the target cell, covered by the BS0 and the BS1 respectively. All UEs (8 UEs in the source cell and 6 UEs in the target cell as illustrated in Figure 6) are receiving an 64Kbps MBMS service. Two UEs perform a handover procedure from the source cell to the target cell. The cell path loss model used in the simulation is the Vehicular A 3Km/h [15]. For the users' distribution used in the simulation, we use the equation (1) in order to characterize the type of the source and target cells (as PTP or PTM) given the assumption that the FACH transmission power is set to 4W (or equivalently 36dBm). The results of the power consumption for the source and target cells are depicted in Figure 7 and Figure 8 respectively.

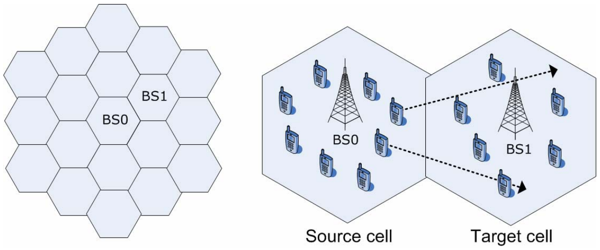

Figure 6. Simulation topology

At the beginning of the simulation, the initialization phase (Figure 4) is taking place and all the needed information about the MBMS users is retrieved. Later, the power consumption and the RB selection phases are performed. From Figure 7, it is observed that, initially, the source cell is a PTM cell as $P_{DCH} > P_{FACH}$, while from Figure 8 the target cell is a PTP cell as $P_{DCH} < P_{FACH}$. The event scheduling phase is next performed and one of the three possible events (join request, leave request and soft handover) may occur. Due to the fact that UEs are not static in our simulation scenario, power consumption and RB selection phases are performed periodically (f_{power}).

113 sec after the beginning of the simulation, the first UE performs a handover procedure (soft handover event). The UE leaves the coverage area of the source cell and enters the coverage area of the target cell. This results to a reduction of the source cell power consumption (Figure 7) and simultaneously to an increase of the target cell power consumption (Figure 8). At this time, the new computed value of P_{DCH} for the source cell is lower than the constant P_{FACH} value, leading the RB selection phase to perform a channel type switching (from a FACH channel to multiple DCHs). The source cell is therefore characterized as a PTP cell. Regarding the target cell, it still remains a PTP cell because, despite the addition of the new UE in the cell, the computed P_{DCH} value is still lower than the P_{FACH} value.

Later, at the time instance of 276 sec, the second UE performs a handover procedure, leading to a further reduction of the source cell's power consumption and to a further increase of the target cell's power consumption. At this time, the new P_{DCH} value for the target cell (computed at the power computation phase) is greater that the P_{FACH} value. Consequently, in the RB selection phase a FACH channel is furthermore assigned to carry the MBMS data and the target cell is characterized as a PTM cell. The source cell remains a PTP cell.

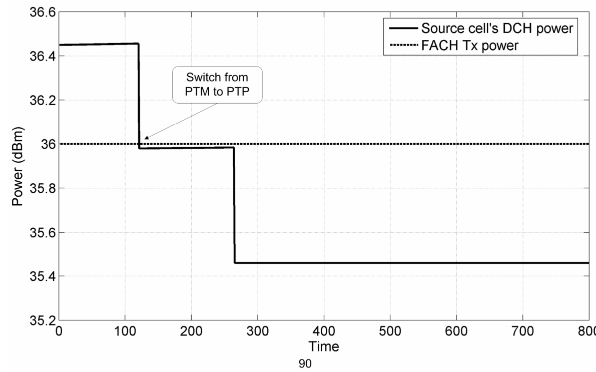

Figure 7. Power profile of the source cell

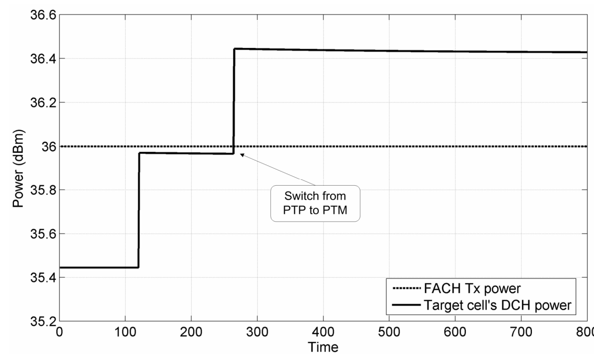

Figure 8. Power profile of the target cell

Conclusively, at the end of simulation time, the source cell (finally 6 UEs are residing) is a PTP cell and the target cell (finally 8 UEs are residing) is a PTM cell. For the scenario described above the switching point between dedicated and common resources is 8 UEs. That means that for less than 8 UEs a cell is characterized as a PTP cell, while for 8 UEs and above a cell is characterized as a PTM cell.

6. Conclusions and future work

In this paper we showed that power consumption of transport channels is a critical parameter and plays an important role for the overall efficiency of a UMTS network. Moreover, we highlighted the importance of this parameter which should be always taken into account when selecting a radio bearer, since the choice of the most efficient transport channel in terms of power consumption is a key point for the efficient operation of an MBMS session. For the above reasons, we presented a power control scheme for the efficient radio bearer selection in MBMS, in terms of power consumption, by providing a switching point between dedicated and common resources. Our study was focused in a macrocellular environment and the radio bearers examined were DCH and FACH channels.

The step that follows this work is to examine the use of HS-DSCH introduced in the Release 5 of UMTS as the transport channel for the transmission of the MBMS data in Iub and Uu interfaces.

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