Efficient Delivery of MBMS Multicast Traffic over HSDPA

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Abstract

Multimedia Broadcast/Multicast Service (MBMS) and High-Speed Downlink Packet Access (HSDPA) are two key technologies that constitute a significant step towards the Mobile Broadband. MBMS was introduced by the third Generation Partnership Project (3GPP) in order to support broadcast and multicast communication over wireless networks and in particular over Universal Mobile Telecommunications System (UMTS). Concurrently, HSDPA aims to ensure the transmission of high peak data rates and increase system capacity. In this paper we evaluate the performance of MBMS multicast transmission over the premier transport channel used in HSDPA, named High Speed-Downlink Shared Channel (HS-DSCH). Due to the fact that downlink transmission power is the scarcest resource in UMTS networks, the evaluation is performed through an analytical dimensioning of the MBMS downlink transmission power. Furthermore, the impacts of power allocation on MBMS capacity are investigated.

1. Introduction

The plethora of emerging wireless multimedia services, which are expected to face high penetration in the near future, poses the need for the employment of a resource economic scheme in order to efficiently deliver such rich services to multiple destinations while in parallel conforming to specific QoS requirements. To this direction, the 3GPP proposed some enhancements on the UMTS Release 6 architecture that led to the definition of the MBMS framework. MBMS is a point-to-multipoint service in which data are transmitted from a single source entity to multiple destinations, allowing resources to be shared in an economical way [2], [3]. Actually, MBMS targets at efficiently using network and radio resources, mainly in the air interface of UMTS.

Transmission of MBMS multicast packets over the air may be performed over common (Forward Access Channel - FACH), shared (HS-DSCH) or dedicated (Dedicated Channel - DCH) transport channels. Although Release ’99 transport channels (FACH, DCH) have already been standardized for the delivery of MBMS multicast traffic, MBMS over HS-DSCH is a relatively novel proposal, still under investigation. HS-DSCH, introduced in the Release 5 specifications of the UMTS standard [4], is envisaged as a promising bearer for enhanced provision of MBMS multicast data, since it offers improved spectral efficiency, improved radio transmission techniques and network protocol functionality.

Despite the fact that performance enhancements HSDPA technology introduced in mobile telecommunications have already been studied extensively, HS-DSCH deployment for the delivery of multimedia applications in MBMS has not been investigated in depth. Some recent research works concerning MBMS over HSDPA mainly focus on capacity and scheduling aspects [14], [15]. However, none of these works takes into account the power aspects or any possible power improvements arising from HS-DSCH usage during MBMS transmissions.

Downlink transmission power is one of the most critical aspects in MBMS due to the fact that power budget in UMTS networks is the most limited resource and must be shared efficiently among all MBMS users. The selection of the most efficient transport channel in terms of power consumption is a key point for the MBMS performance, since a wrong channel selection could result to a significant decrease in the total capacity of the system. Several studies have been made on the power allocation of DCH and FACH bearers during MBMS transmission. In studies [7] and [8] the power consumption of FACH is extensively investigated, while in [10] the authors perform an MBMS power planning both for DCH and FACH transport channels. In this paper, we further extend the work in this research field by analyzing HS-DSCH power consumption during MBMS multicast transmission. Simulation results prove that MBMS over HS-DSCH can offer significant power savings and enhancements on total MBMS capacity, thus enabling the mass market delivery of higher bit rate multimedia services to mobile users.

The paper is structured as follows: Section 2 is devoted to the presentation of the power profiles of the three downlink radio bearers. In Section 3 the evaluation results are presented and finally in Section 4 some concluding remarks and planned next steps are briefly described.

2. Power Profiles of Downlink Transport Channels

HS-DSCH is characterized as a point-to-point (PTP) channel, as well as DCH, due to their unicast nature, while FACH is a point-to-multipoint (PTM) transport channel. MBMS Counting Mechanism [11] constitutes a mechanism that decides whether it is more economic to use PTP (multiple DCHs) or PTM (a single FACH) MBMS transmission mode. Although, the proposed threshold between PTP and PTM modes relies on the number of MBMS users, in [12] the authors proved that the optimum threshold should be based on the base station's transmission power, as in UMTS networks power is a limited resource. With the deployment of HS-DSCH as a MBMS bearer, the decision is slightly differentiated in the sense that the decision has to take into account not only the DCH and FACH but also the HS-DSCH transport channel. Therefore, it is imperative to further investigate the power profiles of all three candidate bearers for the delivery of multicast data and study their performance in order to create an overall, resource economic MBMS Counting Mechanism.

2.1 HS-DSCH Power Profile

HS-DSCH is a rate controlled rather than a power controlled transport channel. In HSDPA fast power control and variable spreading factor principles (characterizing Release '99 channels) are replaced by the Link Adaptation functionality, including techniques such as dynamic Adaptive Modulation and Coding (AMC), multicode operation, fast scheduling, Hybrid ARQ (HARQ) and short transmission time interval (TTI) of 2ms.

There are two different modes for allocating the HS-DSCH's 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 base station is allowed to use any unused power remaining after serving other power controlled channels, for HS-DSCH transmission [9]. Obviously, setting the HS-DSCH power too high would result to excessive interference in the network without essentially achieving higher HSDPA cell throughput. Similarly, if the HS-DSCH transmission power is too low, the highest data rates cannot be achieved. 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 serving MBMS multicast users and, in parallel, eliminate system interference.

An important measure for HS-DSCH power budget planning is the HS-DSCH Signal-to-Interference-plus-Noise Ratio (SINR) metric. SINR actually constitutes an evaluation metric that slightly differentiates HSDPA from that traditionally used in Release '99 bearers. Release '99 typically uses E_b/N_0 (received-energy-per-bit-to-noise ratio) that corresponds uniquely to a certain Block Error Rate (BLER) for a given data rate. However, the 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. SINR for a single-antenna Rake receiver is calculated from equation (1) [9]:

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

where $P_{HS\text{-}DSCH}$ is the HS-DSCH transmission power, P_{own} the own cell interference experienced by the mobile user, P_{other} the interference from neighboring cells and P_{noise} the Additive Gaussian White Noise – AGWN. Parameter p represents 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 power allocation and the average MBMS cell throughput. This relationship can be disclosed in the two following steps. Firstly, we have to define the way that the target MBMS cell throughput relates to the SINR (Figure 1). Next, once the SINR value is set, we can describe how the SINR can be expressed as a function of HS-DSCH transmission power and user location (in terms of Geometry factor - G) through equation (2):

$$P_{HS-DSCH} \geq SINR[p + G^{-1}] \frac{P_{own}}{SF_{16}} \qquad (2)$$

Figure 1 depicts the actual cell throughput for different HS-PDSCH codes as a function of the average HS-DSCH SINR experienced. As the number of HS-PDSCH codes increases, a lower SINR value is required to obtain a target MBMS cell throughput.

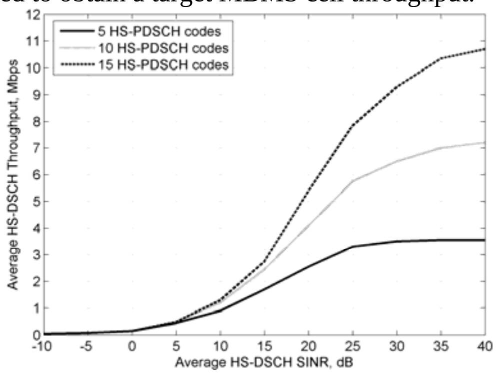

Figure 1. Actual Cell Throughput vs. SINR

The Geometry factor (G) indicates the users' location throughout a cell (i.e. distance from the base station). G is given by the relationship between P_{own}, P_{other} and P_{noise} and is defined from equation (3) as follows [1]:

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

Figure 2 depicts the Geometry CDF function values obtained for the macrocell and microcell environments. A lower G value 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). Moreover, in microcells MBMS users experience a better (higher) G due to the better environment isolation that leads, in turn, to lower intercell interference (P_{other}).

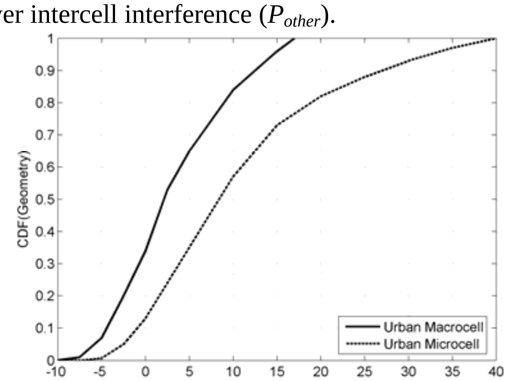

Figure 2. Geometry CDF Macrocell - Microcell

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 serving users, their location in the cell, the bit rate of the MBMS session and the experienced signal quality E_b/N_0 for each user. Equation (4) calculates the Node B's total DCH transmission power required for the transmission of the data to n users in a specific cell [5].

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

where P_T is the base station total transmitted power, P_P is the power devoted to common control channels $L_{p,i}$ is the path loss, $R_{b,i}$ the i^{th} user transmission rate, W the bandwidth, P_N the background noise, p is the orthogonality factor (p=0: perfect orthogonality), $(E_b/N_0)_i$ is the signal energy per bit divided by noise spectral density. Parameter x_i is the intercell interference observed by the i^{th} user given as a function of the transmitted power by the neighboring cells P_{Tj}, j=1,…K and the path loss from this user to the j^{th} cell L_{ij}. More specifically [5]:

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

DCH may used for the delivery of PTP MBMS services, while cannot be used to serve large multicast populations since high downlink transmission power would be required. Figure 3 depicts the downlink transmission power when MBMS multicast data are delivered over multiple DCHs (one separate DCH per user). It is obvious that higher power is required to deliver higher MBMS data rates. In addition, increased cell coverage area and larger multicast groups result to higher power consumption levels.

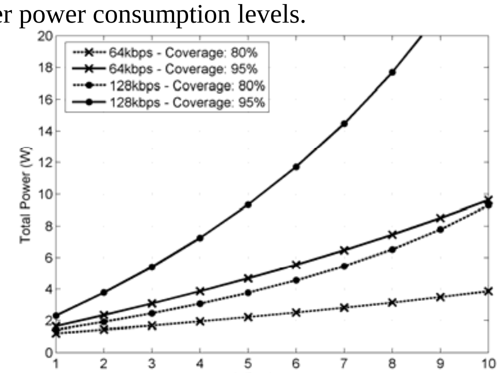

Figure 3. DCH Transmission Power

2.3. FACH Power Profile

A FACH essentially transmits at a fixed power level since fast power control is not supported in this common channel. FACH is a PTM channel and must be received by all users throughout the cell, thus, the fixed power should be high enough to ensure the requested QoS in the whole coverage area of the cell, irrespective of users' location. FACH power efficiency strongly depends on maximizing diversity as power resources are limited. Diversity can be obtained by the use of a longer TTI in order to provide time diversity against fast fading (fortunately, MBMS services are not delay sensitive) and the use of combining transmissions from multiple cells to obtain macro diversity [6].

Table 1 presents some indicative FACH downlink transmission power levels obtained for various cell coverage areas and MBMS bit rates, without assuming diversity techniques [7], [8]. A basic constraint is that the delivery of high data rate MBMS services over FACH is not feasible, since excessive downlink transmission power would be required (overcoming the maximum available base station power of 20W). High bit rates can only be offered to users located very close to Node B.

Table 1. FACH Transmission Power Levels Macrocell Environment

Cell Coverage	MBMS Service Bit Rate (Kbps)	Required Tx Power (W)
60%	64	3
	128	6.4
80%	64	4.8
	128	9.8
95 %	64	7.6
	128	15.8

3. Evaluation Results

In this section some evaluation results are presented. Actually, the following figures depict MBMS power allocation for DCH, FACH and HS-DSCH transport channels when delivering the multicast traffic in a macrocellular environment. The power consumption of each channel type is derived from the analysis presented in the previous section. Additionally, all simulations assumptions used in our evaluation procedure are presented in Table 2 [1], [13].

From these figures a decision on the most power efficient radio bearer for the delivery of MBMS multicast data can be extracted. The transport channel that requires less power resources is thus selected leading, in turn, to an advanced and resource economic MBMS delivery scheme. For the purpose of the evaluation, 64Kbps and 128Kbps MBMS services for varying cell coverage areas (60%, 80% and 95%) are assumed. Moreover, it should be mentioned that for the HS-DSCH transmission 15 HS-PDSCH codes are considered.

Table 2. Macrocell simulation assumptions

Parameter	Value
Cellular layout	Hexagonal grid
Number of neighboring cells	18
Sectorization	3 sectors/cell
Site to site distance	1 Km
Cell radius	0,577 Km
Maximum BS Tx power	20 W (43 dBm)
Common channel power	1 W (30 dBm)
Propagation model	Okumura Hata
Multipath channel	Vehicular A (3km/h)
Orthogonality factor p (0 : perfect orthogonality)	0.5
E_b/N_0 target	5 dB

Figures 4-6 depict power consumption of all transport channel types, when delivering a 64Kbps MBMS service for 60%, 80% and 95% cell coverage respectively. More specifically, in Figure 4 (60% coverage) it can be seen that for less than 10 multicast users, multiple DCHs could be used for the MBMS multicast transmission, since less power is required for this type of radio bearer. On the other hand, for a multicast group of 10-19 users HS-DSCH is the optimal transport channel. For even larger MBMS population FACH should be employed.

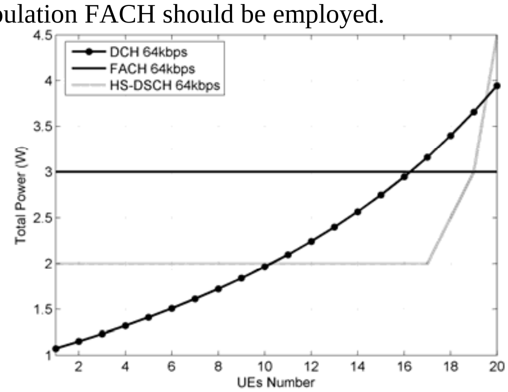

Figure 4. MBMS Transmission Power 64Kbps, 60% Coverage

The power gain emerging from the HS-DSCH deployment as a MBMS bearer can be extracted at this point. Current MBMS specifications, even when considering a power based criterion for selecting the appropriate transport channel as proposed in [12], would use DCHs for up to 16 users and a FACH for more users (and no HS-DSCH at all). However, if HS-DSCH is taken into account, a significant power gain could be obtained when transmitting to a multicast group of 10-19 users, reaching up to 1 W (when serving 16 users) since HS-DSCH is less power consuming than DCH.

For increased coverage areas, in the cases of 80% and 95% cell coverage (Figure 5 and Figure 6 respectively), HS-DSCH is prevailing over the DCH for small MBMS population and should be used instead of DCHs in the PTP MBMS multicast transmission mode. For instance, when examining the 80% cell coverage (Figure 5), power saving could reach a maximum value of 2 W when serving 10 multicast users (for this number of users DCH would require 4 W, while HS-DSCH would require only 2 W).

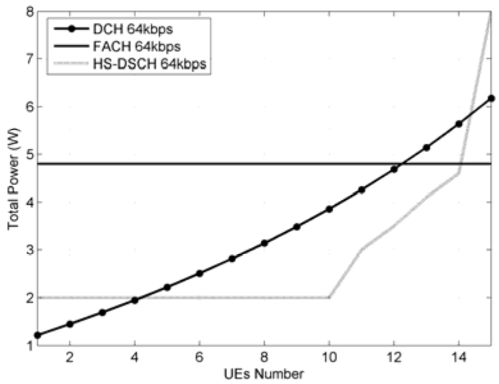

Figure 5. MBMS Transmission Power 64Kbps, 80% Coverage

Even higher power gains can be obtained when serving multicast users residing at the cell edge (95% cell coverage - Figure 6). In this case, HS-DSCH should be exclusively used, instead of DCH, when transmitting MBMS traffic to a multicast group of less than 8 users (i.e. in the PTP transmission mode). A maximum power budget of around 2.5 W can be saved in this case.

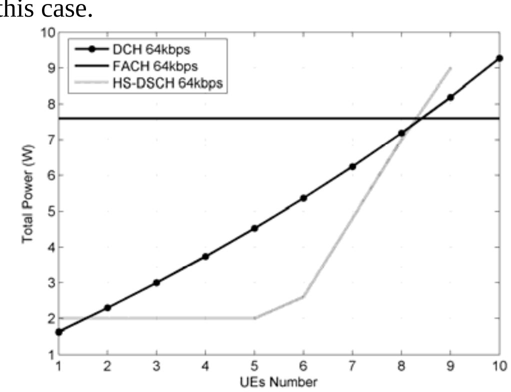

Figure 6. MBMS Transmission Power 64Kbps, 95% Coverage

Similar results can be obtained for 128Kbps MBMS services in Figures 7 and 8, for 60% and 80% cell coverage respectively. For instance, for 60% cell coverage HS-DSCH should be preferred instead of DCH when serving 5-9 multicast users (Figure 7), while for 80% cell coverage HS-DSCH should be used for up to 7 users (Figure 8). However, it can be observed that the average power saving emerging from the HS-DSCH deployment, is lower compared to that obtained for the 64Kbps MBMS service, although this improvement is not negligible.

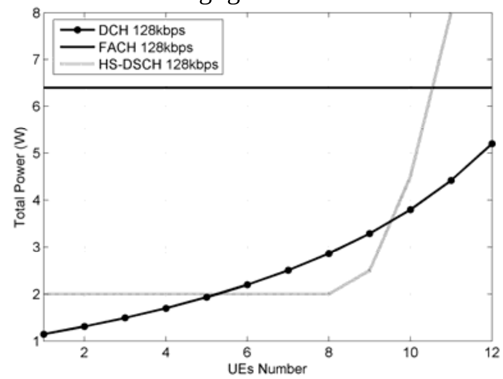

Figure 7. MBMS Transmission Power 128Kbps, 60% Coverage

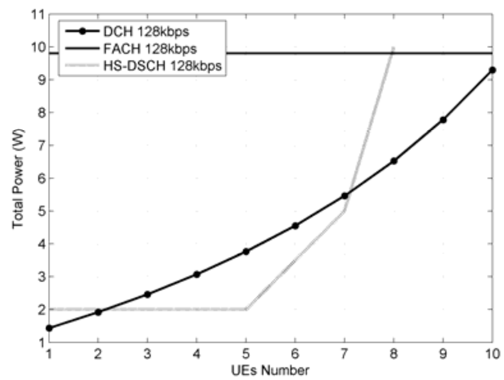

Figure 8. MBMS Transmission Power 128Kbps, 80% Coverage

In general, from the above figures it is obvious that the HS-DSCH usage in MBMS multicast provides a significant enhancement when serving a relatively small number of users. More specifically, in the PTP mode, only HS-DSCH usage (Figure 6) or a combination of HS-DSCH and DCH (Figure 4 and Figure 5) can be used, instead of an exclusive DCH usage. Obviously, as it was previously described, this could lead to significant gains in power resources since HS-DSCH requires less power compared to other types of transport channels in these cases. By taking into account that power budget is the most limited resource in UMTS networks it becomes clear that the HSDPA adoption during MBMS transmissions contributes to a more economic and optimal management of the available power resources.

Another important conclusion deriving from these figures is that power gain can lead to a significant capacity improvement for MBMS service providers. Current MBMS specifications ensure the delivery of 64-128 Kbps multicast content (such as streaming video) with a very good coverage probability using only Release ‘99 (DCH and FACH) channels. From the multicast user point of view no significant improvement is expected from HS-DSCH usage at first glance. However, as can be extracted from the above figures, HS-DSCH brings more capacity which, in turn, enables the mass-market delivery of more and higher bit rate streaming services to end users. Finally, such enhancements examined in the macrocell case are expected to be even higher in microcell environment, since higher cell isolation (which entails better G distribution as depicted in Figure 2) and less multipath propagation ensure the provision of higher MBMS data rate services.

4. Conclusions and Future Work

In this paper we underlined the importance of the analysis of downlink transmission power when delivering MBMS multicast traffic. Moreover, we investigated and highlighted the performance improvements in MBMS power resources and capacity, emerging from the employment of HS-DSCH for the MBMS multicast transmission. More specifically, through an analytical comparison between Release ’99 and HSDPA bearers it was revealed that HS-DSCH can significantly reduce power consumption during MBMS transmission and thus bring more capacity in MBMS enabled UMTS networks.

The step that follows this work is to further extend this analysis by investigating MBMS performance over HS-DSCH in microcellular environments. Moreover, power saving techniques that can further enhance MBMS performance over HSDPA will be investigated.

5. References

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