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Cost analysis and efficient radio bearer selection for multicasting over UMTS

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Summary

Along with the widespread deployment of the Third Generation (3G) cellular networks, the fast-improving capabilities of the mobile devices, content, and service providers are increasingly interested in supporting multicast communications over wireless networks and in particular over Universal Mobile Telecommunications System (UMTS). To this direction, the Third Generation Partnership Project (3GPP) is currently standardizing the Multimedia Broadcast/Multicast Service (MBMS) framework of UMTS. In this paper, we present an overview of the MBMS multicast mode of UMTS. We analytically present the multicast mode of the MBMS and analyze its performance in terms of packet delivery cost under various network topologies, cell types, and multicast users' distributions. Furthermore, for the evaluation of the scheme, we consider different transport channels for the transmission of the multicast data over the UMTS Terrestrial Radio-Access Network (UTRAN) interfaces. Finally, we propose a scheme for the efficient radio bearer selection that minimizes total packet delivery cost. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: UMTS; multicast in UMTS; MBMS; power control

1. Introduction

UMTS constitutes the third generation of cellular wireless networks which aims to provide high-speed data access along with real time voice calls. Although UMTS networks offer high capacity, the expected demand will certainly overcome the available resources. The 3GPP 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 MBMS framework. MBMS is a point-to-multipoint service which allows the networks resources to be shared [1].

A detailed cost analysis model for the evaluation of different one to many packet delivery schemes in UMTS is presented in Reference [2]. The schemes that the authors consider in the evaluation are the Broadcast scheme, the Multiple Unicast scheme, and Multicast scheme. However, in this approach the authors focus their evaluation in the Core Network of the UMTS architecture. In Reference [3], a more detailed analysis of the above-mentioned one to many delivery schemes is presented. In this work, the authors consider different transport channels for the transmission of the data over the UTRAN interfaces. Both these works do not take into account the evalua-

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tion of a number of parameters such as the different cell environments (micro, macro), the power profiles of the transport channels, and finally the selection of the most efficient transport channel for the transmission of the data over the UTRAN interfaces.

In this paper, we present an overview of the MBMS multicast mode of UMTS. We analytically present the multicast mode of the MBMS and analyze its performance in terms of packet delivery cost under various network topologies and multicast users' distributions both in macrocell and microcell environments. The analysis of total packet delivery cost takes into account the paging cost, the processing cost, and the transmission cost at nodes and links of the topology.

Furthermore, for the evaluation of the scheme, we consider different transport channels for the transmission of the multicast data over the Iub and Uu interfaces. The transport channels, in the downlink, currently existing in UMTS which could be used to an MBMS service are the Dedicated Channel (DCH), the Forward Access Channel (FACH), and the High-Speed Downlink Shared Channel (HS-DSCH). However, in our analysis we will focus on the DCH and FACH transport channels. The fundamental factor that determines the transmission cost over the air (Uu interface) is the amount of Node B's transmission power that should be allocated when using each one of these transport channels. DCH and FACH have different characteristics in terms of power control. Thus, we present an extended analysis of Node B's power consumption in order to define the exact telecommunication cost introduced by the Iub and Uu interfaces during the MBMS multicast transmission.

Finally, we propose a switching point scheme for the efficient radio bearer selection in order to minimize total packet delivery cost. This scheme actually constitutes a contribution to the MBMS Counting Mechanism [1]. MBMS counting mechanism examines whether it is more economical to transmit the multimedia services in point-to-point (PTP) or point-to-multipoint (PTM) mode. This mechanism evaluates whether it is preferable to use dedicated resources (multiple DCHs) or common resources (a single FACH). The criteria for the decision of this switching point should be based on the downlink radio resource efficiency.

This paper is structured as follows. In Section 2, we provide an overview of the UMTS in packet switched domain. Section 3 presents the MBMS framework of UMTS. In Section 4, we present a cost analysis method for the evaluation of the MBMS multicast mode. Following this, Section 5 provides important aspects of power control in MBMS, while Section 6 presents some numerical results. Finally, some concluding remarks and planned next steps are briefly described.

2. Overview of UMTS and MBMS Architecture

UMTS network is split into 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 (Figure 1). The CN is responsible for switching/routing voice and data connections, while the UTRAN handles all radio-related

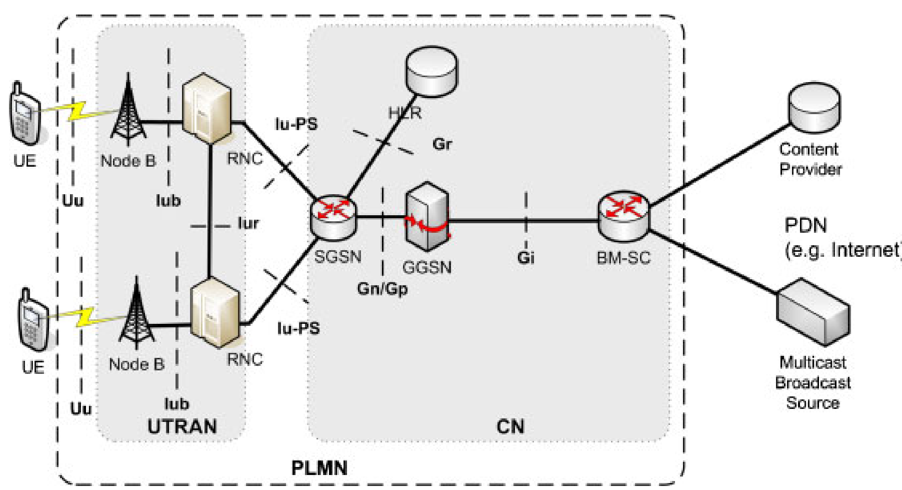

Fig. 1. UMTS and MBMS Architecture.

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functionalities. The CN is logically divided into two service domains: the Circuit-Switched (CS) service domain and the Packet-Switched (PS) service domain [4,5]. 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 which 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 [5].

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 W-CDMA technology) and to the RNC via the Iub interface. One RNC with all the Node Bs connected to it is called Radio Network Subsystem (RNS).

In the UMTS PS domain, the cells are grouped into Routing Areas (RAs), while the cells in a RA are further grouped into UTRAN Registration Areas (URAs). The mobility-management activities for a UE are characterized by two finite state machines: the Mobility Management (MM) and the Radio Resource Control (RRC). The Packet MM (PMM) state machine for the UMTS PS domain is executed between the SGSN and the UE for CN-level tracking, while the RRC state machine is executed between the UTRAN and the UE for UTRAN-level tracking. After the UE is attached to the PS service domain, the PMM state machine is in one of the two states: PMM idle and PMM connected. In the RRC state machine, there are three states: RRC idle mode, RRC cell-connected mode, and RRC URA connected mode [6].

3GPP is currently standardizing the Multimedia Broadcast/Multicast Service. Actually, the MBMS is an IP datacast type of service, which can be offered via existing GSM and UMTS cellular networks. It consists of a MBMS bearer service and a MBMS 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, and Quality of Service improvement to prevent unauthorized reception. The major modification in the existing GPRS platform is the addition of a new entity called Broadcast Multicast–Service Center (BM-SC). Figure 1 presents the architecture of the MBMS. The BM-SC communicates with the existing UMTS GSM networks and the external Public Data Networks [7,8].

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 [1].

3. Description of the MBMS Multicast Mode

In this section, we present an overview of the multicast mode of the MBMS framework. Figure 2 shows a subset of a UMTS network. In this architecture, there are two SGSNs connected to a GGSN, four RNCs, and twelve Node Bs. Furthermore, eleven members of a multicast group are located in six cells. The BM-SC acts as the interface towards external sources of traffic [8]. In the analysis presented, we assume that a data stream that comes from an external PDN through BM-SC must be delivered to the 11 UEs as illustrated in Figure 2.

The analysis presented in the following paragraphs covers the forwarding mechanism of the data packets between the BM-SC and the UEs (Figure 2). Regarding the transmission of the packets over the Iub and Uu interfaces, it may be performed on common (e.g., Forward Access Channel–FACH) or dedicated (Dedicated Channel–DCH) channels. As presented in Reference [9], the transport channel that the 3GPP decided to use as the main transport channel for point-to-multipoint MBMS data transmission is the FACH with turbo coding and QPSK modulation at a constant transmission power. DCH is a point-to-point 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 [5,10].

With multicast, the packets are forwarded to those Node Bs that have multicast users. Therefore, in Figure 2, the Node Bs 2, 3, 5, 7, 8, 9 receive the multicast packets issued by the BM-SC. We briefly summarize the five steps occurred for the delivery of the multicast packets. Firstly, the BM-SC receives a

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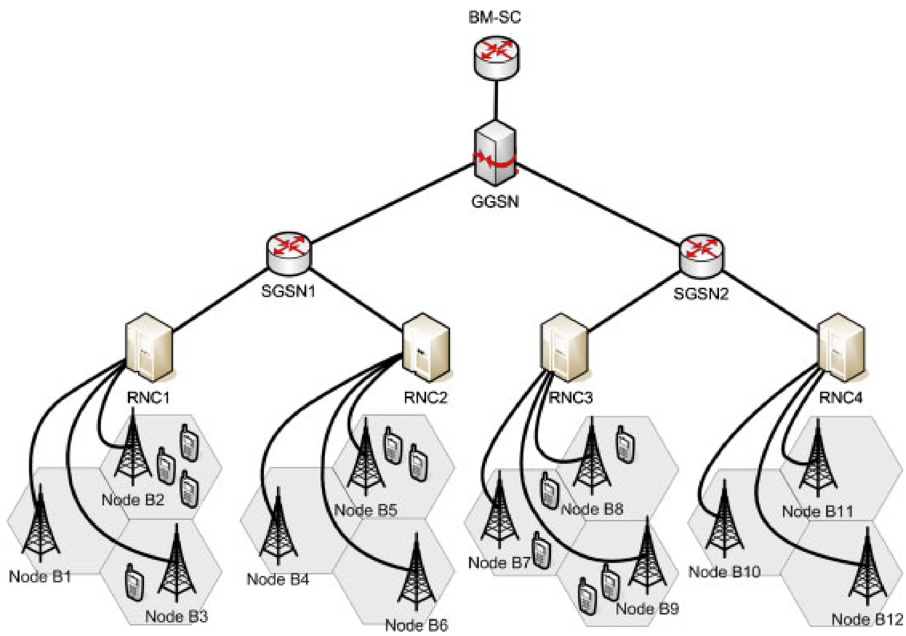

Fig. 2. Packet delivery in UMTS.

multicast packet and forwards it to the GGSN that has registered to receive the multicast traffic. Then, the GGSN receives the multicast packet and by querying its multicast routing lists, it determines which SGSNs have multicast users residing in their respective service areas. In Figure 2, the GGSN duplicates the multicast packet and forwards it to the SGSN1 and the SGSN2 [11]. Then, both destination SGSNs receive the multicast packets and, having queried their multicast routing lists, determine which RNCs are to receive the multicast packets. The destination RNCs receive the multicast packet and send it to the Node Bs that have established the appropriate radio bearers for the multicast application. In Figure 2, these are Node B2, B3, B5, B7, B8, and B9. The multicast users receive the multicast packets on the appropriate radio bearers, either by point-to-point channels transmitted to individual users separately or by common channels transmitted to all members in the cell [11].

4. Cost Analysis of the MBMS Multicast Mode

4.1. General Assumptions

We consider a subset of a UMTS network consisting of a single GGSN and N_{SGSN} SGSN nodes connected to the GGSN. Furthermore, each SGSN manages a number of N_{ra} RAs. Each RA consists of a number of N_{rnc} RNC nodes, while each RNC node manages a number of N_{ura} URAs. Finally, each URA consists of N_{nodeb} cells. The total number of RAs, RNCs, URAs and cells are:

$$N_{\mathrm{RA}} = N_{\mathrm{SGSN}} \cdot N_{\mathrm{ra}} \tag{1}$$

$$N_{\mathrm{RNC}} = N_{\mathrm{SGSN}} \cdot N_{\mathrm{ra}} \cdot N_{\mathrm{rnc}} \tag{2}$$

$$N_{\mathrm{URA}} = N_{\mathrm{SGSN}} \cdot N_{\mathrm{ra}} \cdot N_{\mathrm{rnc}} \cdot N_{\mathrm{ura}} \tag{3}$$

$$N_{\mathrm{NODEB}} = N_{\mathrm{SGSN}} \cdot N_{\mathrm{ra}} \cdot N_{\mathrm{rnc}} \cdot N_{\mathrm{ura}} \cdot N_{\mathrm{nodeb}} \tag{4}$$

The total transmission cost for packet deliveries including paging is considered as the performance metric. Furthermore, the cost for paging is differentiated from that cost for packet deliveries. We make a further distinction between the processing costs at nodes and the transmission costs on links, both for paging and packet deliveries. As presented in Reference [12] and analyzed in Reference [2], we assume that there is a cost associated with each link and each node of the network, both for paging and packet

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deliveries. For the analysis, we apply the following notations:

D_{gs}	Tx cost of packet delivery between GGSN and SGSN
D_{sr}	Tx cost of packet delivery between SGSN and RNC
D_{rb}	Tx cost of packet delivery between RNC and Node B
D_{DCH}	Tx cost of packet delivery over Uu with DCHs
D_{FACH}	Tx cost of packet delivery over Uu with FACHs
S_{sr}	Tx cost of paging between SGSN and RNC
S_{rb}	Tx cost of paging between RNC and Node B
S_{a}	Tx cost of paging over the air
p_{gM}	Processing cost of multicast packet delivery at GGSN
p_{sM}	Processing cost of multicast packet delivery at SGSN
p_{rM}	Processing cost of multicast packet delivery at RNC
p_{b}	Processing cost of packet delivery at Node B
a_{s}	Processing cost of paging at SGSN
a_{r}	Processing cost of paging at RNC
a_{b}	Processing cost of paging at Node B

The total number of the multicast UEs in the network is denoted by N_{UE}. For the cost analysis, we define the total packets per multicast session as N_{p}. Since network operators will typically deploy an IP backbone network between the GGSN, SGSN, and RNC, the links between these nodes will consist of more than one hop. Additionally, the distance between the RNC and Node B consists of a single hop ($l_{\mathrm{rb}} = 1$). In the presented analysis, we assume that the distance between GGSN and SGSN is l_{gs} hops, while the distance between the SGSN and RNC is l_{sr} hops.

We assume that the probability that a UE is in the PMM detached state is P_{DET}, the probability that a UE is in the PMM idle/RRC idle state is P_{RA}, the probability that a UE is in the PMM connected/RRC URA connected state is P_{URA}, and finally the probability that a UE is in the PMM connected/RRC cell-connected state is P_{cell}.

In the remainder of this section, we describe a method that models the multicast user distribution in the network. In particular, we present a probabilistic method that calculates the number of multicast users in the network (N_{UE}), the number of SGSNs that serve multicast users (n_{SGSN}), the number of RNCs that serve multicast users (n_{RNC}), and finally the number of Node Bs that serve multicast members (n_{NODEB}).

As introduced in Reference [13] and analyzed in Reference [2], we classify the RAs into L_{RA} categories in order to create an asymmetric topology. For $1 \leq i \leq L_{\mathrm{RA}}$ there are $N_i^{(\mathrm{RA})}$ RAs of class i. Therefore, the total number of RAs within the network is $N_{\mathrm{RA}} = \sum_{i=1}^{L_{\mathrm{RA}}} N_i^{(\mathrm{RA})}$.

Suppose that the distribution of the multicast users among the classes of RAs follows the Poisson distribution with $\lambda = \theta_i^{(\mathrm{RA})}$ where $1 \leq i \leq L_{\mathrm{RA}}$. In general, the probability that exactly k multicast users reside in the RAs of class i is calculated from the following equation:

$$p\left(k, \theta_i^{(\mathrm{RA})}\right) = \frac{\mathrm{e}^{-\theta_i^{(\mathrm{RA})}} \cdot \left(\theta_i^{(\mathrm{RA})}\right)^k}{k!} \tag{5}$$

Thus, the probability none of the RAs of class i serves multicast users is $p(0, \theta_i^{(\mathrm{RA})}) = \mathrm{e}^{-\theta_i^{(\mathrm{RA})}}$, which in turn means that the probability at least one multicast user is served by the RAs of class i is $p = 1 - p(0, \theta_i^{(\mathrm{RA})}) = 1 - \mathrm{e}^{-\theta_i^{(\mathrm{RA})}}$.

Since every class i consists of $N_i^{(\mathrm{RA})}$ RAs, the total number of the RAs in the class i, that serve multicast users is $N_i^{(\mathrm{RA})}(1 - \mathrm{e}^{-\theta_i^{(\mathrm{RA})}})$. Thus, the total number of the RAs of every class that serve multicast users is

$$n_{\mathrm{RA}} = \sum_{i=1}^{L_{\mathrm{RA}}} N_i^{(\mathrm{RA})} \left(1 - \mathrm{e}^{-\theta_i^{(\mathrm{RA})}}\right) \tag{6}$$

where $\theta_i^{(\mathrm{RA})}$ represents the number of multicast users for the $N_i^{(\mathrm{RA})}$ RAs of class i.

If there are n_{RA} RAs that are serving multicast users, the probability that an SGSN does not have any such RA is

$$p_{\mathrm{SGSN}} = \begin{cases} \binom{N_{\mathrm{RA}} - N_{\mathrm{ra}}}{n_{\mathrm{RA}}} \Big/ \binom{N_{\mathrm{RA}}}{n_{\mathrm{RA}}}, & n_{\mathrm{RA}} \leq N_{\mathrm{RA}} - N_{\mathrm{ra}} \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Based on Equation (7), the total number of SGSNs that are serving multicast users can be calculated as follows: $n_{\mathrm{SGSN}} = N_{\mathrm{SGSN}}(1 - p_{\mathrm{SGSN}})$.

The total number of multicast users in the network is

$$N_{\mathrm{UE}} = \sum_{i=1}^{L_{\mathrm{RA}}} N_i^{(\mathrm{RA})} \theta_i \tag{8}$$

where θ_i is the number of multicast users in a RA of class i.

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As in Reference [2], we assume that all RNCs within a service area of class i have the same multicast population distribution density as in the RA case. Based on a uniform density distribution within a single RA, the multicast population of an RNC within the service area of a class i RA is $\theta_i^{(\mathrm{RNC})} = \theta_i^{(\mathrm{RA})}/N_{\mathrm{rnc}}$. The total number of RNCs of class i is $N_i^{(\mathrm{RNC})} = N_i^{(\mathrm{RA})} \cdot N_{\mathrm{rnc}}$.

Assuming that the number of RA categories is equal to the number of RNC categories ($L_{\mathrm{RNC}} = L_{\mathrm{RA}}$), the total number of RNCs that serve multicast users is

$$n_{\mathrm{RNC}} = \sum_{i=1}^{L_{\mathrm{RNC}}} N_i^{(\mathrm{RNC})}\left(1 - \mathrm{e}^{-\theta_i^{(\mathrm{RNC})}}\right) \tag{9}$$

The same are applied to the cells within the service area of an RNC. The average number of multicast users for a single cell of class i is $\theta_i^{(\mathrm{B})} = \theta_i^{(\mathrm{RNC})}/(N_{\mathrm{ura}} \cdot N_{\mathrm{nodeb}})$.

The number of Node Bs belonging to class i is $N_i^{(\mathrm{B})} = N_i^{(\mathrm{RNC})} \cdot N_{\mathrm{ura}} \cdot N_{\mathrm{nodeb}}$. Assuming that the number of the RNC categories is equal to the number of the Node B categories ($L_{\mathrm{RNC}} = L_{\mathrm{NODEB}}$), the total number of Node Bs that serve multicast users is

$$n_{\mathrm{NODEB}} = \sum_{i=1}^{L_{\mathrm{NODEB}}} N_i^{(\mathrm{B})}\left(1 - \mathrm{e}^{-\theta_i^{(\mathrm{B})}}\right) \tag{10}$$

4.2. Cost Analysis of the Multicast Mode

In the multicast scheme, the multicast group management is performed at the BM-SC, GGSN, SGSN, and RNC and multicast tunnels are established over the Gn and Iu interfaces. It is obvious that the cost of a single packet delivery to a multicast user depends on its MM and RRC state.

If the multicast member is in the PMM connected/RRC cell-connected state, then there is no need for any paging procedure either from the SGSN or from the serving RNC. In this case, the packet delivery cost is derived from Equation (11). It has to be mentioned that this quantity does not include the cost for the transmission of the packets over the Iub and Uu interfaces, since this cost depends firstly on the number of multicast users and secondly on the transport channel used for data transmission.

$$C_{\mathrm{cell}} = p_{\mathrm{gM}} + D_{\mathrm{gs}} + p_{\mathrm{sM}} + D_{\mathrm{sr}} + p_{\mathrm{rM}} \tag{11}$$

If the multicast member is in the PMM connected/RRC URA connected state, then the RNC must first page all the cells within the URA in which mobile users reside and then proceed to the data transfer. After the subscriber receives the paging message from the RNC, it returns to the RNC its cell ID. The cost for paging such a multicast member is

$$C_{\mathrm{URA}} = N_{\mathrm{nodeb}}(S_{\mathrm{rb}} + a_{\mathrm{b}} + S_{\mathrm{a}}) + S_{\mathrm{a}} + a_{\mathrm{b}} + S_{\mathrm{rb}} + a_{\mathrm{r}} \tag{12}$$

If the multicast member is in the PMM idle/RRC idle state, the SGSN only stores the identity of the RA in which the user is located. Therefore, all cells in the RA must be paged. The cost for paging such a multicast member is

$$\begin{aligned} C_{\mathrm{RA}} = {} & N_{\mathrm{rnc}}(S_{\mathrm{sr}} + a_{\mathrm{r}}) + (N_{\mathrm{rnc}} \cdot N_{\mathrm{ura}} \cdot N_{\mathrm{nodeb}}) \\ & \times (S_{\mathrm{rb}} + a_{\mathrm{b}} + S_{\mathrm{a}}) + S_{\mathrm{a}} + a_{\mathrm{b}} + S_{\mathrm{rb}} + a_{\mathrm{r}} + S_{\mathrm{sr}} + a_{\mathrm{s}} \end{aligned} \tag{13}$$

After the paging procedure, the RNC stores the location of any UE at a cell level. In multicast, the SGSN and the RNC forward a single copy of each multicast packet to those RNCs or Node Bs respectively that are serving multicast users. After the correct multicast packet reception at the Node Bs that serve multicast users, the Node Bs transmit the multicast packets to the multicast users via common or dedicated transport channels. The total cost for the multicast scheme is derived from the following equation where n_{SGSN}, n_{RNC}, n_{NODEB} represent the number of SGSNs, RNCs, Node Bs respectively that serve multicast users.

$$\begin{aligned} Ms = {} & [p_{\mathrm{gM}} + n_{\mathrm{SGSN}}(D_{\mathrm{gs}} + p_{\mathrm{sM}}) + n_{\mathrm{RNC}}(D_{\mathrm{sr}} + p_{\mathrm{rM}}) + Y]N_{\mathrm{p}} \\ & +(P_{\mathrm{RA}} \cdot C_{\mathrm{RA}} + P_{\mathrm{URA}} \cdot C_{\mathrm{URA}})N_{\mathrm{UE}} = D_{\mathrm{packet\_delivery}} + D_{\mathrm{paging}} \end{aligned} \tag{14}$$

where

$$Y = \begin{cases} n_{\mathrm{NODEB}} \cdot (D_{\mathrm{rb}} + p_{\mathrm{b}} + D_{\mathrm{FACH}}), & \text{if} \quad \text{channel} = \text{FACH} \\ N_{\mathrm{UE}} \cdot (D_{\mathrm{rb}} + p_{\mathrm{b}} + D_{\mathrm{DCH}}), & \text{if} \quad \text{channel} = \text{DCH} \end{cases}$$

$$D_{\mathrm{packet\_delivery}} = [p_{\mathrm{gM}} + n_{\mathrm{SGSN}}(D_{\mathrm{gs}} + p_{\mathrm{sM}}) + n_{\mathrm{RNC}}(D_{\mathrm{sr}} + p_{\mathrm{rM}}) + Y]N_{\mathrm{p}}$$

$$D_{\mathrm{paging}} = (P_{\mathrm{RA}} \cdot C_{\mathrm{RA}} + P_{\mathrm{URA}} \cdot C_{\mathrm{URA}})N_{\mathrm{UE}}$$

Parameter Y represents the multicast cost for the transmission of the multicast data over the Iub and Uu interfaces. This cost depends mainly on the distribution of the multicast group within the UMTS network and secondly on the transport channel that is used.

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D_{DCH} and D_{FACH} represent the cost over the Uu interface. More specifically, D_{FACH} represents the cost of using a FACH channel to serve all the multicast users residing in a specific cell while D_{DCH} represents the cost of using a single DCH to transmit the multicast data to a single multicast user of the network. Regarding the cost over the Iub interface, in case we use the FACH as transport channel, each multicast packet send once over the Iub interface and then the packet is transmitted to the UEs that are served by the corresponding Node B. On the other hand, in case we use DCHs for the transmission of the multicast packets over the Iub each packet is replicated over the Iub as many times as the number of multicast users that the corresponding Node B serves.

5. Power Control in MBMS

In this section, some important issues regarding the power control of the downlink transport channels (DCH and FACH) are analyzed. This analysis is performed in order to determine, as will be presented in the next section, the exact values of parameters D_{DCH} and D_{FACH}, appearing in Equation (14). It is recalled that the main factor that determines the MBMS transmission cost over the Uu interface is the amount of Node B's transmission power that should be allocated when using one of these transport channels.

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. Power control is essential in order to minimize the transmitted power, thus avoiding unnecessary high power levels and eliminating intercell interference. The main requirement is to make an efficient overall usage of the radio resources: this makes the common channel, FACH, the favorite choice, since many users can access the same resource at the same time. However, other crucial factors such as the number of users belonging to the multicast group and their distance from the serving Node B, the type of service provided, and the QoS requirements (represented by E_b/N_0 targets) affect the choice of the most efficient transport channel in terms of power consumption.

On the point-to-point downlink transmissions, where multiple DCHs are used, fast power control is used to maintain the quality of the each 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. 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 UEs, their location in the cell (close to the Node B or at cell edge), the required bit rate of the MBMS session, and the experienced signal quality E_b/N_0 for each user. Equation (15) calculates the Node B's total transmission power required for the transmission of the data to n users when multiple DCHs are used [14].

$$P_T = \frac{P_P + \sum_{i=1}^{n} \frac{(P_N + x_i)}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p} L_{p,i}}{1 - \sum_{i=1}^{n} \frac{p}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p}} \tag{15}$$

where P_T the total transmission power for all the DCH users in the cell, P_P the power devoted to common control channels, $L_{p,i}$ refers to the path loss for user i, $R_{b,i}$ the bit rate for user i, W the bandwidth, P_N the background noise, p the orthogonality factor (0:perfect orthogonality), and $(E_b/N_0)_i$ is the signal energy per bit divided by noise spectral density. Parameter x_i is the intercell interference observed by user i 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 [14]:

$$x_i = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{ij}} \tag{16}$$

In contrast, in point-to-multipoint downlink transmissions, a single FACH is established and 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, irrespective of the UEs location. FACH power efficiency depends on maximizing diversity as power resources are limited. Diversity can be obtained by using a longer TTI, e.g., 80 ms instead of 20 ms, 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 [15].

Power aspects of MBMS are investigated separately for macro and microcell environments. The amount of intercell interference is lower in microcells where street corners isolate the cells more strictly than

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Table I. 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)
Other BS Tx power	5 W (37 dBm)
Common channel power	1 W (30 dBm)
Propagation model	Okumura Hata
Multipath channel	Vehicular A (3 km/h)
Orthogonality factor (0: perfect orthogonality)	0.5
E_b/N_0 target	5 dB
FACH Tx power (no STTD, 95% coverage)	4 W (32 kbps service) 7.6 W (64 kbps service) 15.8 W (128 kbps service)

in macrocells. Moreover, in microcells there is less multipath propagation, and thus a better orthogonality of the downlink codes. On the other hand, less multipath propagation gives less multipath diversity, and therefore a higher E_b/N_0 requirement in the downlink in micro than in macrocells is assumed [5]. The basic simulation parameters are presented in Tables I and II [16–19].

6. Results

6.1. Simulation and Evaluation Parameters

In this section, we present the evaluation parameters regarding the MBMS multicast mode. We consider different cell configurations, different user distributions, and finally, different transport channels for the transmission of the multicast data over the UTRAN interfaces. Therefore, we assume a general network topology, with $N_{SGSN} = 10$, $N_{ra} = 10$, $N_{rnc} = 10$, $N_{ura} = 5$, and $N_{nodeb} = 5$.

Table II. Microcell simulation assumptions.

Parameter	Value
Cellular layout	Manhattan grid
Number of cells	72
Block width: Road width: Building to building distance	75 m: 15 m: 90 m
Straight line distance between transmitters	360 m (four blocks)
Maximum BS Tx power	2 W (33 dBm)
Other BS Tx power	0.5 W (27 dBm)
Common channel power	0.1 W (20 dBm)
Propagation model	Walfish-Ikegami
Multipath channel	Pedestrian A 3 km/h
Orthogonality factor (0: perfect orthogonality)	0.1
E_b/N_0 target	6 dB
FACH Tx power (no STTD, 95% coverage)	0.36 W (64 kbps service)

The packet transmission cost (D_{xx}) in any segment of the UMTS network depends on two parameters: the number of hops between the edge nodes of this network segment and the capacity of the link of the network segment. This means that $D_{gs} = l_{gs}/k_{gs}$, $D_{sr} = l_{sr}/k_{sr}$, and $D_{rb} = l_{rb}/k_{rb}$. Parameter k_{xx} represents the profile of the corresponding link between two UMTS network nodes. More specifically, in the high capacity links at the CN, the values of k_{xx} are greater than the corresponding values in the low capacity links at UTRAN. For the cost analysis and without loss of generality, we assume that the distance between the GGSN and SGSN is 8 hops, the distance between SGSN and RNC is 4 hops, and the distance between RNC and Node B is 1 hop. The above parameters as well as the values of the k_{xx} are presented in detail in Table III. Regarding the transmission cost of paging (S_{xx}) in the segments of the UMTS network, it is calculated in a similar way as the packet transmission cost (D_{xx}). More specifically, S_{xx} is a fraction of the calculated transmission cost (D_{xx}) and in our case we assume that it is three times smaller than D_{xx}.

As we can observe from the equations of the previous section, the costs of the schemes depend on a number of other parameters. Thus, we have to estimate the value of these parameters. The chosen values of the parameters are presented in Table IV.

At this point, we have to mention that since the nodes that are responsible for the forwarding of the multicast packets are the GGSN, SGSN, and the RNC, we consider a lower packet processing cost in the Node B than the corresponding costs in the GGSN, SGSN, and RNC since some overhead is needed in the above-mentioned three nodes in order to maintain the routing lists required for the packet forwarding in the multicast scheme (Table IV).

Table III. Chosen values for the calculation of transmission costs in the links.

Link	Link Capacity factor (k)	Number of hops (l)	Transmission cost (D)
GGSN-SGSN	$k_{gs} = 0.8$	$l_{gs} = 8$	$D_{gs} = 10$
SGSN-RNC	$k_{sr} = 0.7$	$l_{sr} = 4$	$D_{sr} = 4/0.7$
RNC–Node B	$k_{rb} = 0.5$	$l_{rb} = 1$	$D_{rb} = 2$

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Table IV. Chosen parameters' values.

S_{sr}	S_{rb}	S_a	p_{gM}	p_{sM}	p_{rM}	p_b	a_s	a_r	a_b	P_{RA}	P_{URA}	P_{cell}
4/2.1	2/3	4/3	2	2	2	1	1	1	1	0.6	0.2	0.1

Furthermore, we have appropriately chosen the probabilities P_{RA}, P_{URA}, and P_{cell} More specifically, the probability that a UE is in the PMM idle/RRC idle state is $P_{RA} = 0.6$. The probability that a UE is in the PMM connected/RRC URA connected state is $P_{URA} = 0.2$, and the probability that a UE is in the PMM connected/RRC cell-connected state is $P_{cell} = 0.1$. Additionally, there is a probability that the UE is not reachable by the network and we consider it to be 0.1.

Regarding the transmission over the Iub and Uu, DCH and FACH channels are examined. Some important aspects concerning the power consumption for these two transport channels were presented analytically in Section 5. It is recalled that the amount of Node B's transmission power that must be allocated for these two channels is the main parameter that defines the transmission cost over the air (Uu interface). Parameter D_{FACH} represents the cost, over the Uu interface, of using a FACH channel to serve all the multicast users. Similarly, parameter D_{DCH} represents the cost, over the Uu interface, of using a single DCH channel to serve one multicast user.

In our analysis, we calculate in each cell of the network topology the Node B's power in the case of using DCHs or FACH. Then, by comparing these power values with the total available Node B's transmission power, we select the appropriate values for D_{DCH} and D_{FACH} Obviously the values D_{DCH} and D_{FACH} are proportional to the percentage of the Node B's transmission power allocated to DCH or FACH in any cell. The D_{DCH} and D_{FACH} values are then used in Equation (14) that calculates the total telecommunication cost of the MBMS multicast mode. Furthermore, we assume that the minimum value that the total D_{DCH} per cell and the D_{FACH} could take is the value of 10 since this value is the cost of the data transmission in the wired link between the GGSN and the SGSN (D_{gs}), and generally the transmission cost in a wired link is assumed to be lower than that in a wireless link.

It is true that the performance of the multicast scheme depends mainly on the configuration of the UMTS network that is under investigation. In our analysis, we assume that we have two classes of RAs. A class $i = 1$ RA has multicast user population of $\theta_1 = 1/\delta$ and a class $i = 2$ RA has a multicast user population of $\theta_2 = \delta$. If $\delta \gg 1$, the class $i = 1$ RA has a small multicast user population and the class $i = 2$ RA has a large multicast user population. Let α be the proportion of the class $i = 1$ RAs and $(1 - \alpha)$ be the proportion of the class $i = 2$ RAs [13]. Thus, the number of class $i = 1$ RAs is $N_1^{(RA)} = \alpha N_{RA}$ and the number of class $i = 2$ RAs is $N_2^{(RA)} = (1 - \alpha) N_{RA}$. Each RA of class $i \in \{1, 2\}$ is in turn sub-divided into N_{rnc} RNCs of the same class i and similarly, each RNC of class $i \in \{1, 2\}$ is sub-divided into $N_{ura} \cdot N_{nodeb}$ Node Bs of the same class i. Taking into consideration the above-mentioned parameters, Equation (8) can be transformed to Equation (17). It is obvious from Equation (17) that as α decreases and δ increases the number of multicast users increases rapidly:

$$
\begin{aligned}
N_{UE} &= \sum_{i=1}^{2} N_i^{(RA)} \cdot \theta_i = N_1^{(RA)} \cdot \theta_1 + N_2^{(RA)} \cdot \theta_2 \\
&= N_{RA} \left(\frac{\alpha}{\delta} + \delta - \alpha\delta \right)
\end{aligned}
\tag{17}
$$

6.2. Telecommunications Cost of the Data Transmission Over the Uu Interface

In this section, analytical simulation results, distinctly for the cases of macro and microcell environments, are presented. Node B's transmission power levels when using DCH or FACH channels, for different simulation parameters, are depicted in each of the following figures. The aim for this parallel plotting is to determine the most efficient transport channel, in terms of power consumption, for the transmission of the MBMS data.

The effect of UEs location (distance from Node B) is presented in Figure 3. UEs are assumed to be in groups, located at the same distance from Node B each time. When multiple DCHs are used, it is obvious that the further a UE is from the Node B the more power is required for the successful delivery of the MBMS service, both for macrocell and microcell environments. On the other hand, when a FACH

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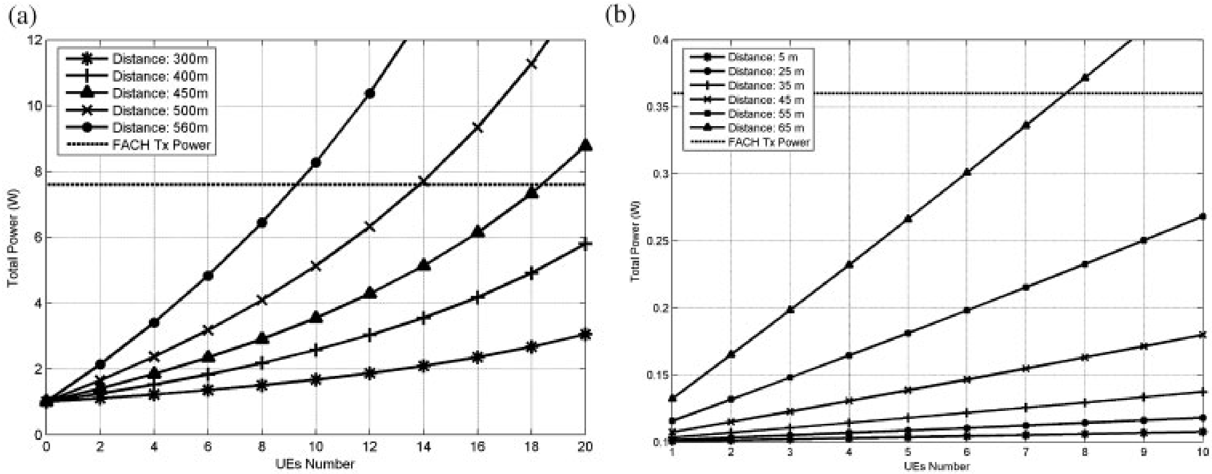

Fig. 3. Tx power versus. distance (a) Macrocell, (b) Microcell.

channel is used, transmission power is kept constant (irrespective of UEs' location) at a power level that is high enough to serve the UE with the greater distance from Node B. In Figure 3, FACH Tx power is set to a value that provides 95% coverage (cell edge). For smaller coverage areas FACH Tx power could be set in lower levels.

Figure 4 reflects the impact of QoS requirements (E_b/N_0) on Node B transmission power. As expected, the higher the E_b/N_0 parameter is the more power is required when transmitting multicast data with multiple DCHs.

Figure 5 depicts the impact of the MBMS bit rate on Node B transmission power. When multiple DCHs are used, increased MBMS bit rates result in higher Node B transmission power. Similarly, in the case of a FACH channel, more power needs to be transmitted when providing higher MBMS bit rates. FACH transmission power levels for various bit rates are depicted for a macrocell environment (Figure 5a), while for a microcell environment (Figure 5b) we consider only a 64 kbps service.

Another crucial factor that has to be taken into account when selecting the most efficient transport channel is the transmission power of neighboring cells, expressed by the parameter P_{Tj} in Equation (16). Figure 6 depicts the impact of this factor under the simplifying assumption that all neighboring Node Bs transmit at the same power levels. Of course, it is rather impossible that all neighboring Node Bs transmit at the same power level, but this is assumed here for better understanding of this parameter's significant

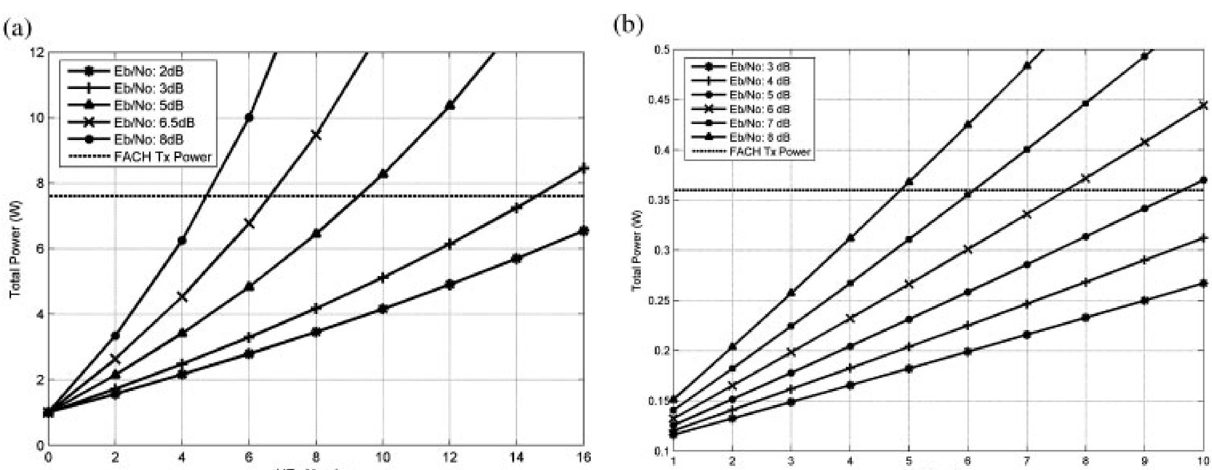

Fig. 4. Tx power versus. Eb/No (a) Macrocell, (b) Microcell.

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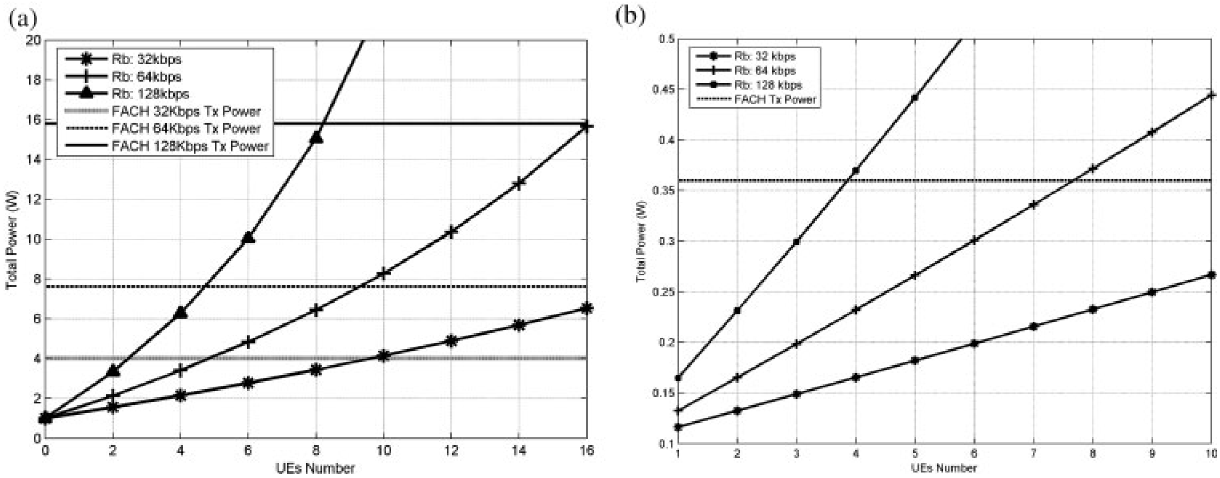

Fig. 5. Tx power versus. bit rate (a) Macrocell, (b) Microcell.

impact. Higher transmission power of neighboring Node Bs increases intercell interference, leading in turn the examined Node B to increase its transmission power in order to meet the MBMS service demands.

From the above figures that present the cost of MBMS transmission over the Uu interface, useful information about the switching point between point-to-point transmission (multiple DCHs) and point-to-multipoint transmission (a single FACH) can be extracted. Actually, a power-based switching point scheme can be employed in order to minimize Node B's transmission power, thus minimizing the cost for the transmission of the multicast data over the air. The transport channel that requires less power resources is selected. For instance, from Figure 3a in the case of a macrocell, it can be seen that for a 64 kbps MBMS service, E_b/N_0 target 5 dB, 95% coverage and neighboring Node Bs transmitting at 5 W an efficient switching point should be 9 UEs. Furthermore, in the case of a microcell, for a 64 kbps MBMS service, E_b/N_0 target 6 dB, 95% coverage and neighboring Node Bs transmitting at 0.5 W the switching point should be 7 UEs (Figure 3b). This means that, e.g., for a macrocell environment, for 9 UEs and above a FACH should be used, while for less than 9 UEs the use of multiple DCHs is the most efficient choice.

6.3. Total Telecommunication Cost

In Figure 7 the total costs for the multicast mode using different transport channels and cell environments in function of α are presented. From these plots, we can see that the costs decrease as α increases. This occurs

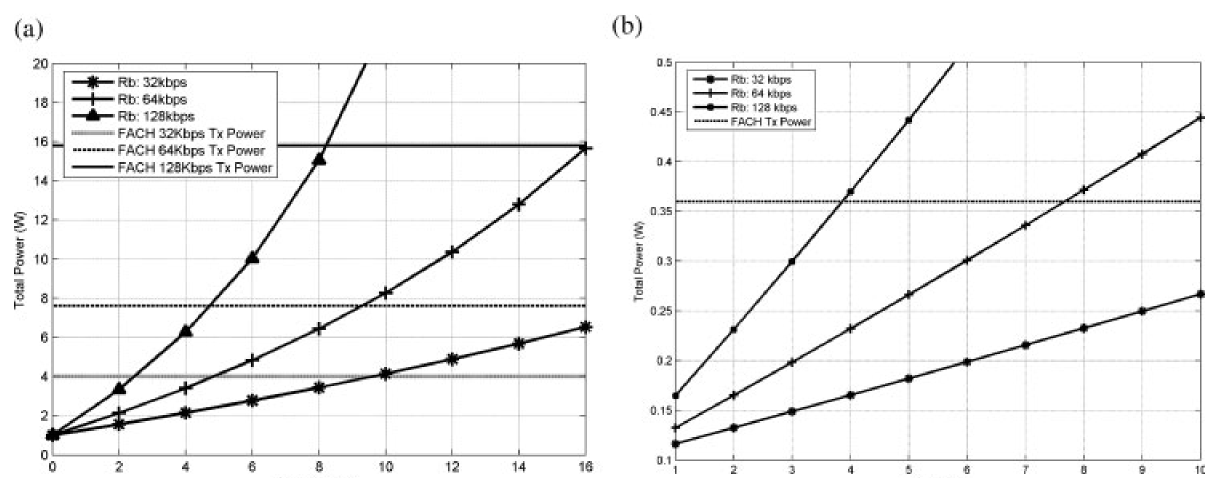

Fig. 6. Tx power versus. neighboring cells Tx power (a) Macrocell, (b) Microcell.

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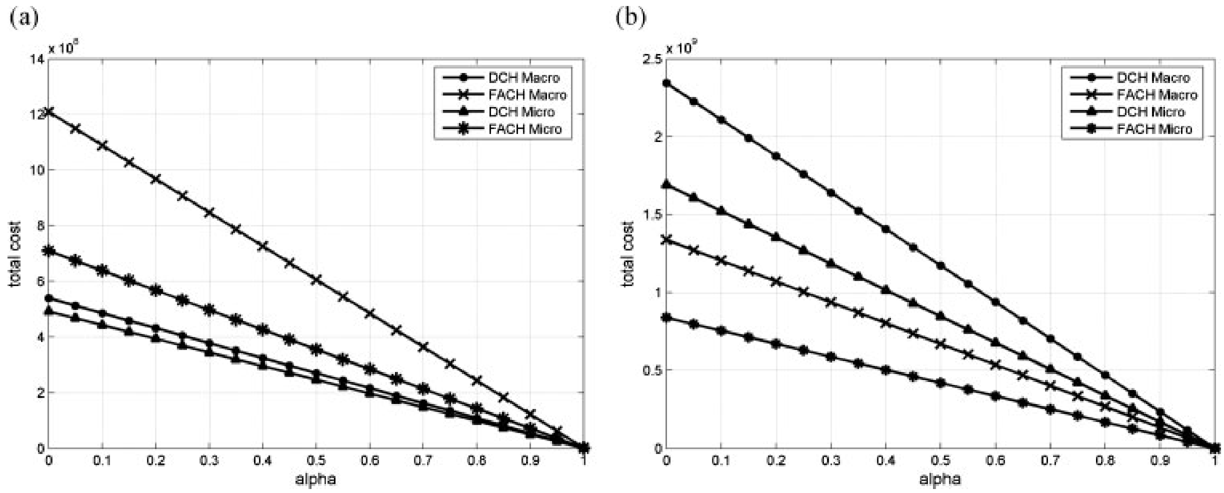

Fig. 7. Total cost in function of α with (a) $\delta = 300$, (b) $\delta = 3000$.

because as α increases the number of RAs with no multicast users increases and hence the multicast users are located in a small number of RAs.

More specifically, in Figure 7a, the cost in case we use multiple DCHs is smaller than the cost in case we use a FACH channel both in macro and microenvironments. This occurs because the small value of δ results in a reduced number of UEs in the network and hence the DCH is more efficient for the data transmission in terms of total cost. The opposite occurs in Figure 7b where the value of δ is increased, which means that the number of UEs is also increased. Therefore, the use of DCHs is inefficient for the transmission of the data over the Iub and Uu interfaces while the FACH is the most suitable transport channel in terms of total cost.

In Figure 8, the total costs using different transport channels and cell environments in the function of δ are presented. We choose a small value for the parameter α because the multicast mode becomes efficient when there is an increased density of UEs in the network [3]. Therefore, a value of $\alpha = 0.1$ is chosen which means that there are many RAs in the network with a great number of multicast users in these. From Figure 8, it is clear that as parameter δ increases (which means that the number of multicast users increases), the total cost for all cases increases too. However, the increase in total cost for DCHs is greater than that of FACH due to the fact that a DCH is a point-to-point channel and strongly depends on the number of multicast users.

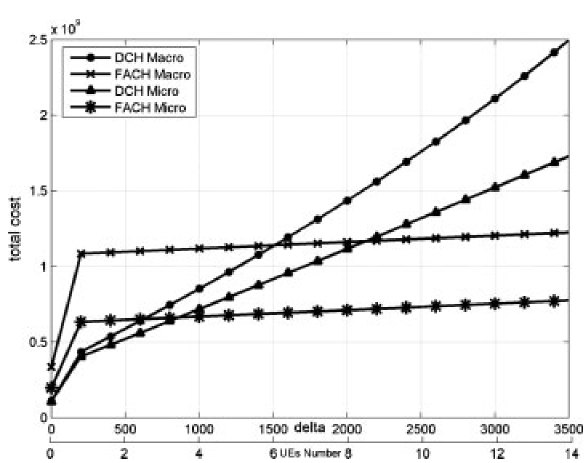

Fig. 8. Total cost in function of δ, $\alpha = 0.1$.

More specifically, in Figure 8, we observe that for small values of δ, the total cost using DCHs is small because there is a small number of UEs in the network, while for bigger values of δ, which implies bigger number of UEs, the total cost using DCHs overcomes the cost of using FACH. Thus, for small values of δ the use of DCHs is more efficient while for bigger values of δ, the use of FACH is more appropriate. The simulation parameters for DCH and FACH transport channels used for the plotting of Figures 7 and 8 are taken from the previous section. More specifically, a 64 kbps MBMS service and 95% cell coverage are assumed.

An important notice regarding the switching point between point-to-point and point-to-multipoint transport channels should be mentioned at this point. From Figure 8 the switching point between multiple DCHs and a single FACH, in terms of total transmission cost, is 6 UEs (or $\delta = 1500$) for a macrocell and 3 UEs (or $\delta = 750$) for a microcell. However, from the previous section, when only the cost over the Uu interface

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(Node Bs' total transmission power) was taken into account, it was shown that for the same simulation parameters, the switching point should be 9 UEs for a macrocell and 7 UEs for a microcell. Consequently, it is obvious that a reduction in the switching point levels is taking place when considering the total transmission cost of an MBMS session. This reduction is caused by the additional cost introduced by the Iub interface, representing the transmission cost of packet delivery between RNC and Node B. Recall from Equation (14) that computes the total cost of the multicast scheme, that the parameter Y represents the multicast cost for the transmission of the multicast data over the Iub and Uu interfaces. When a FACH transport channel is used each multicast packet is sent once over the Iub, while when multiple DCHs are used each packet is replicated over the Iub as many times as the number of multicast users. The cost added from Iub is not negligible and depends on the link capacity which is, however, operator dependent. For the simulations presented above, the link capacity factor was set to $k_{\mathrm{rb}} = 0.5$. For greater values of k_{rb}, the switching points converge to the values presented in Figures 3–6.

From the above observation, it is clear that the selection of the appropriate radio bearer for the multicast data transmission strongly depends on the cost added by the Iub interface. The Node B's transmission power should not be the only criterion for the selection of an efficient transport channel, but the total transmission cost (including the Iub cost) should always be taken into account.

7. Conclusions and Future Work

In this paper we presented an overview of the MBMS multicast mode of UMTS. We investigated the performance of the multicast mode of the MBMS in terms of packet delivery cost through an analytic theoretical model and by simulations based on this model. The investigations were made assuming various network topologies, cell environments, and multicast users' distributions. In addition, we examined the DCH and FACH transport channels in terms of data transmission cost over the Iub and Uu interfaces. Finally, we presented a scheme for the efficient selection of a switching point between point-to-point (multiple DCHs) and point-to-multipoint (a single FACH) transmissions that minimizes the total transmission cost of multicast data.

The step that follows this work is to examine the impact of the HS-DSCH on the total transmission cost of the multicast mode of MBMS. HS-DSCH is a shared channel, introduced in the Release 5 of UMTS, and can be used as a transport channel for the transmission of the MBMS data over the Iub and Uu interfaces. HSDPA is a key technology for MBMS as it improves the MBMS performance and increases bit rate speeds to support new MBMS services [20].

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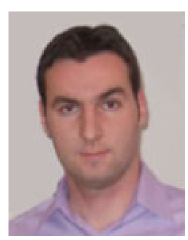

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