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EVALUATION OF THE MULTICAST MODE OF MBMS

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ABSTRACT

Multicasting is an efficient way for delivering rich multimedia applications to large user groups as it allows the transmission of packets to multiple destinations using fewer network resources. 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 environments and multicast users' distributions. Furthermore, for the evaluation of the scheme, we consider different transport channels for the transmission of the data over the UTRAN interfaces and propose a cost based scheme for the efficient radio bearer selection that minimizes the packet delivery cost.

I. INTRODUCTION

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 [8].

A detailed cost analysis model for the evaluation of different one-to-many packet delivery schemes (including the multicast scheme) in UMTS is presented in [1]. However, in this approach the authors focus their evaluation in the Core Network (CN) of the UMTS architecture. In [2], the authors analyse several one-to-many delivery schemes both in the CN and in the Radio Access Network (RAN) of UMTS and in particular they consider different transport channels for the transmission of the data over the RAN interfaces. However, both works do not take into account in the evaluation a number of parameters such as the different cell environments and the power profiles of the transport channels.

In this paper, 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 macro cell and micro cell 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 of the UMTS architecture.

II. OVERVIEW OF RELEASE 6 UMTS ARCHITECTURE

A UMTS network consists of two land-based network segments: 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 consists of two service domains: the Circuit-Switched (CS) service domain and the Packet-Switched (PS) service domain. 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). An SGSN is connected to GGSN via the Gn interface and to UTRAN via the Iu interface. UTRAN consists of the Radio Network Controller (RNC) and the Node B. Node B constitutes the base station and provides radio coverage to one or more cells. Node B is connected to the User Equipment (UE) via the Uu interface and to the RNC via the Iub interface [8].

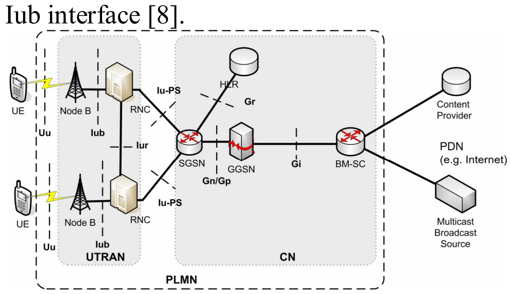

Figure 1: Release 6 UMTS Architecture.

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 [7].

3GPP is currently standardizing the MBMS. Actually, the MBMS is an IP datacast 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). Figure 1 presents the architecture of the MBMS. The BM-SC communicates with the existing UMTS-GSM networks and the external Packet Data Networks (PDNs) [4][5].

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III. Cost Analysis of the MBMS Multicast Mode

A. 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:

$$N_{RA} = N_{SGSN} \cdot N_{ra} \quad (1)$$

$$N_{RNC} = N_{SGSN} \cdot N_{ra} \cdot N_{rnc} \quad (2)$$

$$N_{URA} = N_{SGSN} \cdot N_{ra} \cdot N_{rnc} \cdot N_{ura} \quad (3)$$

$$N_{NODEB} = N_{SGSN} \cdot N_{ra} \cdot N_{rnc} \cdot N_{ura} \cdot N_{nodeb} \quad (4)$$

The total transmission cost for packet deliveries including paging is considered as the performance metric. Furthermore, the cost for paging is differentiated from the 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 [6] and analyzed in [1], we assume that there is a cost associated with each link and each node of the network, both for paging and packet deliveries.

The transport channels in the downlink, 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). Due to the fact that power is the most scarce downlink transmission resource, the fundamental factor that determines the transmission cost over the Iub and Uu interfaces is the amount of Node B's transmission power when using each one of these transport channels. Thus, we present an analysis of Node B's power consumption, separately for each channel, in order to define the exact cost introduced by the Iub and Uu interfaces during the MBMS multicast transmission. 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
$D_{HS\text{-}DSCH}$	Tx cost of packet delivery over Uu with HS-DSCHs
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_{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.

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

B. 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. Obviously, the cost of a single packet delivery to a multicast user depends on its MM and RRC state.

If the multicast member is in PMM connected/RRC cell-connected state, then there is no need for any paging procedure neither from the SGSN nor from the serving RNC. The packet delivery cost is derived from eqn(5). This quantity does not include the cost for the transmission of the packets over the Iub and Uu interfaces.

$$C_{cell} = p_{gM} + D_{gs} + p_{sM} + D_{sr} + p_{rM} \quad (5)$$

If the multicast member is in 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 proceeds 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:

$$C_{URA} = N_{nodeb}\left(S_{rb} + a_b + S_a\right) + S_a + a_b + S_{rb} + a_r \quad (6)$$

If the multicast member is in 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:

$$\begin{aligned} C_{RA} = {} & N_{rnc}\left(S_{sr} + a_r\right) + \left(N_{rnc} \cdot N_{ura} \cdot N_{nodeb}\right) \times \left(S_{rb} + a_b + S_a\right) + \\ & + S_a + a_b + S_{rb} + a_r + S_{sr} + a_s \end{aligned} \quad (7)$$

After the paging procedure, the RNC stores the location of any UE at a cell level. The SGSN and the RNC forward a single copy of each multicast packet to those RNCs or Node Bs respectively that serve multicast users. After the correct packet reception at the Node Bs that serve multicast users, the Node Bs, in turn, transmit the multicast packets to the multicast users via common, shared or dedicated transport channels. The total cost for the multicast scheme is derived from eqn(8) where n_{SGSN}, n_{RNC}, n_{NODEB} represent the number of SGSNs, RNCs, Node Bs respectively that serve multicast users.

$$Ms = \left[p_{gM} + n_{SGSN}\left(D_{gs} + p_{sM}\right) + n_{RNC}\left(D_{sr} + p_{rM}\right) + Y \right] N_p + \\ + \left(P_{RA}\cdot C_{RA} + P_{URA}\cdot C_{URA}\right) N_{UE} = D_{packet\_delivery} + D_{paging} \quad (8)$$

$$where \;\; Y = \begin{cases} n_{NODEB}\cdot\left(D_{rb} + p_b + D_{FACH}\right), & if \quad channel = FACH \\ N_{UE}\cdot\left(D_{rb} + p_b + D_{DCH}\right), & if \quad channel = DCH \\ \frac{N_{UE}}{2}\cdot\left(D_{rb} + p_b\right) + n_{NODEB}\cdot D_{HS-DSCH}, & if \quad channel = HS-DSCH \end{cases}$$

$$D_{packet\_delivery} = \left[p_{gM} + n_{SGSN}\left(D_{gs} + p_{sM}\right) + n_{RNC}\left(D_{sr} + p_{rM}\right) + Y \right] N_p$$

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

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. Parameters D_{DCH}, D_{FACH} and $D_{HS\text{-}DSCH}$ represent the cost over the Uu. 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. Moreover, $D_{HS\text{-}DSCH}$ represents the cost of using a HS-DSCH, shared by all multicast users. Regarding the cost over the Iub, when we use a FACH, each multicast packet is sent once over the Iub. In the case we use DCHs for the transmission of the multicast packets each packet is replicated over the Iub as many times as the number of multicast users that the corresponding Node B serves. Finally, when a HS-DSCH is established, there is an improved Iub efficiency by a factor of 2 compared to that on WCDMA in which the Iub bandwidth is typically allocated separately per user. This improvement mainly comes from fast dynamic sharing of the HSDPA Iub bandwidth allocated between active HSDPA users [13].

IV. Evaluation of the MBMS Multicast Mode

In this section we present some evaluation results 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.

A. Evaluations Parameters

The packet transmission cost (D_{xx}) in any segment of the UMTS network depends on the number of hops between the edge nodes of this network segment and on 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 (Table 1). 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}.

Table 1: 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

As we can observe from the equations of the previous section, the cost of the multicast scheme depends also on a number of other parameters. The chosen values of these parameters are presented in Table 2.

Table 2: 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

It is reminded that the fundamental parameter that defines the transmission cost over the air (D_{DCH}, D_{FACH} and $D_{HS\text{-}DSCH}$) is the amount of allocated Node B's transmission power when transmitting multicast data with these transport channels.

More specifically, a FACH channel 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 UEs location. For the purpose of our analysis, no diversity techniques are assumed when a FACH is used.

The total downlink transmission power allocated for DCHs is variable and mainly depends on the number of UEs, their location throughout the cell, the required bit rate of the MBMS service and the experienced signal quality (E_b/N_0) for each user. Eqn(9) calculates the total Node B's transmission power required for the transmission of the data to n users in a specific cell [9]. The total Node B's transmission power is the sum of the Node B's power allocated to each DCH user in the cell.

$$P_T = \sum_{i=1}^{n} P_{Ti} = \frac{P_P + \sum_{i=1}^{n} \frac{(P_N + x_i)}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p} L_{p,i}}{1 - \sum_{i=1}^{n} \frac{p}{\frac{W}{(E_b/N_0)_i R_{b,i}} + p}} \quad (9)$$

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) and

x_i is the intercell interference observed by the ith user given as a function of the transmitted power by the neighboring cells P_{Tj}, j=1,…K and the path loss from this user to the j^{th} cell L_{ij}. More specifically:

$$x_i = \sum_{j=1}^{K} \frac{P_{Tj}}{L_{ij}} \tag{10}$$

The HS-DSCH is not power controlled but rate controlled channel. There are mainly two different modes for allocating HS-DSCH transmission power to each Node B. In the first power allocation mode, the controlling RNC explicitly allocates a fixed amount of HS-DSCH transmission power per cell, while in the second mode the remaining power (after serving other, power controlled channels) may be used for HS-DSCH transmission. In this paper, we assume a fixed power allocation mode. More specifically, 35% of total Node B power is allocated to HS-DSCH [13].

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

$$\begin{aligned} N_{UE} &= \sum_{i=1}^{2} N_i^{(RA)} \cdot \theta_i = N_1^{(RA)} \cdot \theta_1 + N_2^{(RA)} \cdot \theta_2 = \\ &= N_{RA} \left(\frac{\alpha}{\delta} + \delta - \alpha\delta \right) \end{aligned} \tag{11}$$

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 that has multicast user population of $\theta_1 = 1/\delta$ and a class i=2 RA that has a multicast user population of $\theta_2 = \delta$. If $\delta >> 1$, 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-α) be the proportion of the class i=2 RAs [3]. 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 subdivided into N_{rnc} RNCs of the same class i and similarly, each RNC of class $i \in \{1,2\}$ is subdivided into $N_{ura} \cdot N_{nodeb}$ Node Bs of the same class i. It is obvious from eqn(11) that as α decreases and δ increases the number of multicast users increases rapidly.

For the cost analysis of the MBMS multicast mode, we consider the cases of urban macrocell (hexagonal grid, 19 3-sector cells, 1000m site-to-site distance) and urban microcell (Manhattan grid with 360m base station spacing) environments. Moreover, a 64Kbps MBMS service is assumed. The basic simulation parameters are presented in Table 3 [10][11][12].

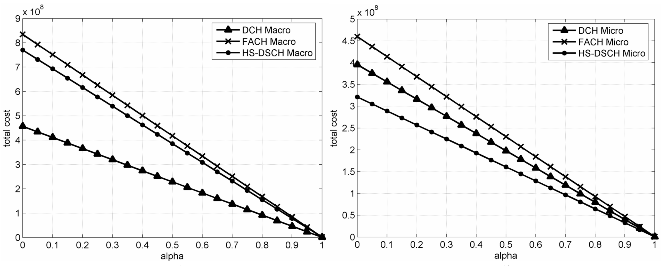
For the purpose of our analysis, we calculate each Node B's transmission power when using each transport channel separately. Then, by comparing these power values with the total available Node B's power, we select the appropriate values for parameters D_{DCH}, D_{FACH} and $D_{HS\text{-}DSCH}$. Finally, we assume that the minimum value that the above parameters can 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 and generally the transmission cost in a wired link is assumed to be lower than the transmission cost in a wireless link.

Table 3: Simulation Parameters.

Parameters	Macro Cell	Micro Cell
BS Max Tx Power	43dBm	33dBm
Common channel power	30dBm	20dBm
Orthogonality factor (0:perferct orthogonality)	0.5	0.1
Downlink E_b/N_0	5dB	6.5dB
Other-to-own cell interference ratio i	0.65	0.4
Multipath channel	Vehicular A (3km/h)	Pedestrian A (3km/h)
Propagation model	Okumura Hata	Walfisch-Ikegami
FACH Tx Power (64Kbps, no STTD, 95% coverage)	7.6 W (38% of BS Tx Power)	0.36 W (18% of BS Tx Power)

B. Results

In Figure 2, total costs for the multicast mode when using different transport channels in function of α, for macrocell and microcell are presented. From these plots, we can see that the costs decrease as α increases, 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.

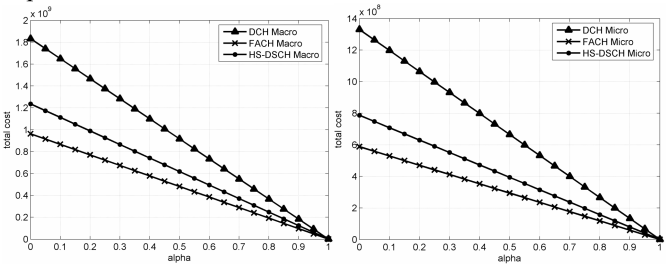


(a) (b)

Figure 2: Total cost in function of α, δ=300 for (a) macrocell, (b) microcell.

More specifically, in both environments the FACH results to the highest cost, due to the fact that a FACH is a common channel (and mainly serves large groups of users) while the value of δ is small (limited number of multicast users). Thus, the common channel is not efficient for small multicast users' population. For a macro cell environment, the lowest cost occurs in the case we use multiple DCHs, while for a micro cell environment, the HS-DSCH is the most efficient transport channel in terms of total cost. This occurs because HS-DSCH performance in microcells is significantly higher compared to that of macrocells (30-50% cell throughput improvement), since micro-cellular setup is characterized by higher isolation between neighboring cells [13].

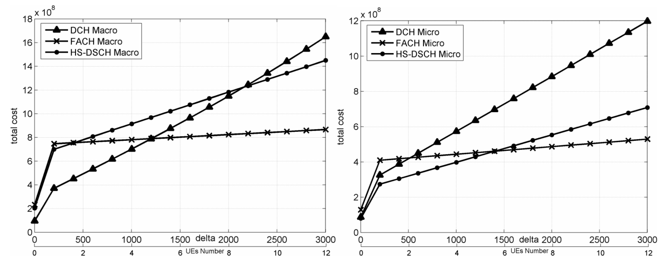
In Figure 3, the value of δ is increased, which means that the number of UEs is also increased. Therefore, FACH, as a common channel, results to the lowest cost and it is more efficient for the transmission of the multicast data than DCH or HS-DSCH channels. Additionally, DCH has a significant high cost as it is a point-to-point channel and strongly depends on the number of multicast users.



(a) (b)

Figure 3: Total cost in function of α, δ=3000 for (a) macrocell, (b) microcell.

In Figure 4, the total costs when using different transport channels in function of δ are presented. We choose a small value for the parameter α (α=0.1) because the multicast mode becomes efficient when there is an increased density of UEs in the network. A small value of parameter α means that there are many RAs in the network with a great number of multicast users in these. From these figures, 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 and HS-DSCH is greater than that of FACH due to the fact that FACH is a point-to-multipoint channel and does not depend on the number of multicast users.



(a) (b)

Figure 4: Total cost in function of δ, α=0.1 for (a) macrocell, (b) microcell.

An important notice regarding the switching point, in terms of total transmission cost, between dedicated (multiple DCHs) and common (FACH) or shared (HS-DSCH) resources can be derived from Figure 4. The determination of the switching point between different transport channels is of great importance, since the channel that requires fewer resources should be established, thus minimizing total multicast transmission cost.

More specifically, it is obvious that for a macrocell environment the switching point from multiple DCHs to a single FACH is 5 UEs (or δ=1250). This means that for 5 UEs and above a FACH should be used, while for less than 5 UEs the use of multiple DCHs is the most efficient choice. This switching point is further increased to 9 UEs (or δ=2250) when switching between DCHs and HS-DSCH because of the improved Iub efficiency of the HS-DSCH. Similarly, for a microcell environment, the switching point from multiple DCHs to a FACH is 2 UEs (or δ=500), while the HS-DSCH always has lower cost compared to that of DCH.

V. 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. The investigations were made assuming various network topologies, cell environments and multicast users' distributions. In addition, we examined the DCH, FACH and HS-DSCH transport channels in terms of data transmission cost over the Iub and Uu interfaces. Finally, we presented a total cost based switching scheme between these transport channels in order to make an efficient overall usage of the radio resources and minimize transmission cost.

The step that follows this work is to analytically examine the impact of the HS-DSCH power allocation on achievable throughput. HSDPA is a key technology for MBMS as it improves performance and increases bit rate speeds. Experiments using the NS-2 simulator will be carried out for the purpose of this investigation.

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