Supporting Group Communication in WCDMA Networks

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Abstract. It is known that multicast is an efficient method of supporting group communication as it allows the transmission of the packets to multiple destinations using fewer network resources. Along with the widespread deployment of the third generation cellular networks and 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). In this paper, a multicast scheme for UMTS is analyzed. We analytically present the multicast routing mechanism behind our scheme as well as the multicast group management functionality of the scheme. Furthermore, we present an evaluation of our scheme in terms of its performance. The critical parameters for the evaluation of the scheme are the number of users within the multicast group, the amount of data sent to the multicast users, the density of the multicast users within the cells and finally the type of transport channel used for the transmission of the multicast data over the air.

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. Wireless data is one of the major boosters of wireless communications and one of the main motivations of the next generation standards [9]. The multicast transmission of real time multimedia data is an important component of many current and future emerging Internet applications, such as videoconference, distance learning and video distribution. It offers efficient multidestination delivery, since data is transmitted in an optimal manner with minimal packet duplication [10], [11].

Compared with multicast routing in the Internet, mobile networks such as UMTS pose a very different set of challenges for multicast. First, multicast receivers are nonstationary and consequently may change their point of attachment to the network at any given time. Second, mobile networks are generally based on a well-defined tree topology, with the nonstationary multicast receivers being located at the leaves of the network tree. It is therefore not appropriate to apply conventional IP multicast routing mechanisms in UMTS, since they cannot manage the mobility of the mobile users [2].

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Several multicast mechanisms for UMTS have been proposed in the literature. In [1], the authors discuss the use of commonly deployed IP multicast protocols in UMTS networks. However, in [2] the authors do not adopt the use of IP multicast protocols for multicast routing in UMTS and present an alternative solution. More specifically, in order to overcome the one-to-one relationship between a single subscriber and a GPRS Tunneling Protocol (GTP) tunnel that is inherent to the hierarchical routing in UMTS, they implement a Multicast-Packet Data Protocol (M-PDP) context for each multicast group in the GGSN and SGSN. Furthermore in [3], a multicast mechanism for circuit-switched GSM and UMTS networks is outlined, while in [4] an end-to-end multicast mechanism for software upgrades in UMTS is analyzed. Additionally, the 3rd Generation Partnership Project (3GPP) is currently standardizing the Multimedia Broadcast/Multicast Service (MBMS) [5], [12].

In this paper, we analytically present a multicast scheme for UMTS. The multicast routing mechanism behind our scheme is analyzed as well as the multicast group management functionality of our mechanism. Additionally, we analyze the performance of the scheme, in terms of the packet delivery cost and the scalability of the scheme, considering different transport channels for the transmission of the multicast data over the air. These channels include the Dedicated Channel (DCH) and a common transport channel such as the Forward Access Channel (FACH). Furthermore, we propose methods that may reduce the packet delivery cost of the multicast data and improve the performance of the delivery scheme. A preliminary version of this paper has been presented in [13] as a poster.

The paper is structured as follows. In Section 2 we provide an overview of the UMTS. Section 3 presents a multicast scheme for UMTS. Following this, Section 4 analyzes the cost of this scheme in function of a number of parameters, while Section 5 presents some numerical results that characterize the multicast scheme. Finally, some concluding remarks and planned next steps are briefly described.

2 Overview of the UMTS in the Packet Switched Domain

A UMTS network consists of two land-based network segments: the core network (CN) and the UMTS Terrestrial Radio-Access Network (UTRAN) (Fig. 1). The CN is responsible for the routing of the calls and the data connections to the external networks, 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 CS domain provides access to the PSTN/ISDN, while the PS domain provides access to the IP-based networks. In the remainder of this paper, we will focus on the UMTS packet-switching mechanism. The Packet-Switched (PS) portion of the CN in UMTS consists of two General Packet Radio Service (GPRS) support nodes (GSNs), namely the gateway GPRS support node (GGSN) and the Serving GPRS Support Node (SGSN) (Fig. 1). An SGSN is connected to the GGSN via the Gn interface and to UTRAN via the Iu interface. The UTRAN consists of the Radio Network Controller (RNC) and Node B, which constitutes the base station and provides radio coverage to a cell. Node B is connected to the User Equipment (UE) via the Uu interface (based on the WCDMA technology) and to the RNC via the Iub interface. The GGSN interacts with external Packet Data

Networks (PDNs) through the Gi interface. The GGSN is like an edge IP router providing connectivity with IP networks. The Broadcast/Multicast Service Center (BM-SC) serves as the entry point of data delivery for internal sources and it is introduced in Release 6 of UMTS [9]. In the UMTS PS domain, the cells are grouped into Routing Areas (RAs), while the cells in an RA are further grouped into UTRAN Registration Areas (URAs) [7].

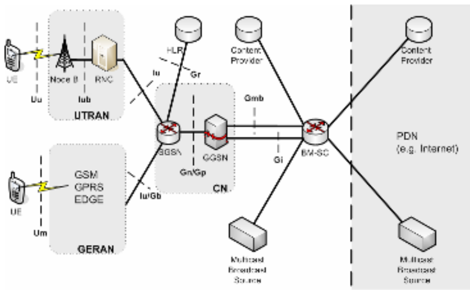


Fig. 1. UMTS architecture

Before a UE can exchange data with an external PDN, the UE must first establish a virtual connection with this PDN. Once the UE is known to the network, packets are transferred between the UE and the network, based on the Packet Data Protocol (PDP), the network-layer protocol carried by UMTS. An instance of a PDP type is called a PDP context and contains all the parameters describing the characteristics of the connection to an external network by means of end-point addresses and QoS. A PDP context is established for all the application traffic sourced from and destined for one IP address. A PDP context activation is a request–reply procedure between a UE and the GGSN. A successful context activation leads to the creation of two GPRS Tunneling Protocol (GTP) sessions, specific to the subscriber: between the GGSN and SGSN over the Gn interface and between the SGSN and RNC over the Iu interface. IP packets destined for an application using a particular PDP context are augmented with UE- and PDP-specific fields and are tunneled using GTP to the appropriate SGSN. The SGSN recovers the IP packets, queries the appropriate PDP context based on the UE- and PDP-specific fields and forwards the packets to the appropriate RNC. The RNC maintains Radio-Access Bearer (RAB) contexts. Equivalently to PDP contexts, a RAB context allows the RNC to resolve the subscriber identity associated with a GTP-tunneled network packet data unit. The RNC recovers the GTP-tunneled packet and forwards the packet to the appropriate Node B [2], [8].

In the remainder of this section, we present a short description of the MBMS framework of the UMTS. 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 means for user authorization, charging and QoS improvement to prevent unauthorized reception [12]. The major modification in the existing GPRS platform is the addition of a new entity called BM-SC (Fig. 1). As the term Multimedia Broadcast/Multicast Service indicates, there are two types of service modes: the broadcast and the multicast mode. Since the multicast mode is more complicated than the broadcast mode, it is more useful to present the operation of the MBMS multicast mode and the way that the mobile user receives the multicast data of a service. Thus, the actual procedure of the reception of an MBMS multicast service is enabled by certain procedures that are illustrated in Fig. 2. The phases Subscription, Joining and Leaving are performed individually per user. The other phases are performed for a service, i.e. for all users interested in the related service. The sequence of the phases may be repeated, depending on the need to transfer data. Also Subscription, Joining, Leaving, Service Announcement, as well as MBMS notification may run in parallel to other phases [12].

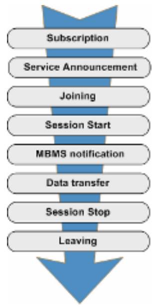


Fig. 2. Phases of MBMS multicast service provision

3 A Multicast Approach for UMTS

In this section we present an overview of a multicast scheme for UMTS. More specifically, it is presented in detail the way that the multicast packets are delivered to a group of mobile users. Additionally, we analyze the packet forwarding / routing mechanism behind the multicast scheme as well as the multicast group management functionality of the scheme.

Fig. 3 shows a subset of a UMTS network. In this architecture, there are two SGSNs connected to an 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 [5]. In the presented analysis, we assume that a data stream coming from an external PDN through BM-SC, must be delivered to the eleven UEs as illustrated in Fig. 3.

For the efficient multicast packet forwarding mechanism, every node of the network (except the UEs) maintains a Routing List (Fig.4a). In this list of each node, we record the nodes of the next level that the messages for every multicast group should be forwarded. Additionally, we keep information regarding the QoS profile of the specific multicast group. This information is useful for congestion avoidance and rate control. Obviously, the BM-SC that organizes the multicast mechanism, ought to keep an additional list with the multicast groups (Multicast group id) and the correspondent UEs that have joined them. This information is kept in the Multicast Groups List (Fig.4b) and the BM-SC has the opportunity to retrieve the UEs belonging to a specific multicast group. It is essential that these lists are fully updated at every moment for the correct transmission of the packets to the UEs that have joined a multicast group. Obviously, there is a possibility that a multicast group has no members, which in turn means that the correspondent record in the Multicast Group List in the BM-SC does not contain any UEs.

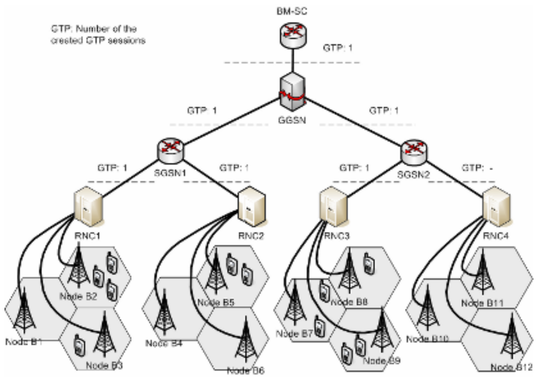
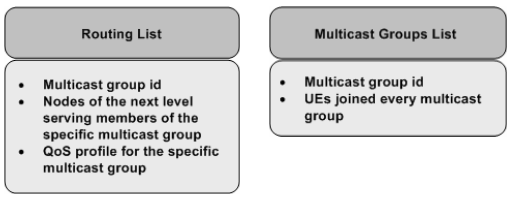


Fig. 3. Packet delivery in UMTS



a) **b)**

Fig. 4. Routing List and Multicast Groups List

Additionally, the phases that the multicast mechanism follows are these that have been presented above in the MBMS service provision (Fig. 2). In the following, we briefly describe the main steps of the multicast packet forwarding mechanism. Firstly, we consider that the UEs are known to the network, thus the Subscription phase is completed. In the Service Announcement phase, the routing lists of the nodes are filled with the useful information. This procedure can be initialized either from the UEs or from the BM-SC (i.e. Software upgrades). In the former case, consider a UE that decides to become a member of a multicast service. Thus, it sends an appropriate message to the BM-SC requesting this service. Then, every node located in the path between this UE and the BM-SC, when it receives the message from the UE, it updates its routing list and forwards the message to the next node. In the second case, the BM-SC initializes the Service Announcement phase. Since the BM-SC does not have any information regarding the location of the multicast members, a paging procedure at RA and URA level is necessary for the updating of the routing lists of the nodes. The phases that follow are Session Start, MBMS Notification, Data Transfer and Session Stop, where the data are transferred from the BM-SC to the UEs. In these phases, each node of the network that receives a multicast packet, searches its routing list and decides the nodes of the next level that the packet should be forwarded. Finally, the packet reaches the UEs that are members of the multicast group.

With multicast, the packets are forwarded to those Node Bs that have multicast users. Therefore, in Fig. 3, the Nodes B2, B3, B5, B7, B8, B9 will 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 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 routing list, it determines which SGSCs in its service area have multicast users residing in their respective service areas. In Fig. 3, the GGSN duplicates the packet and forwards it to the SGSN1 and the SGSN2.

After both destination SGSNs have received the multicast packet and having queried their routing list, they determine which RNCs must receive the multicast packet. 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 Fig. 3, these are Node B2, B3, B5, B7, B8, and B9. The multicast users receive the multicast packet on the appropriate radio bearers, either by point-to-point channels transmitted to individual users separately or by point-to-multipoint channels transmitted to all group members in the cell.

In this approach, each multicast packet is initially transmitted from the BM-SC to the GGSN. This procedure implies that the first GTP session is created between the BM-SC and the GGSN. The GGSN forwards exactly one copy of the multicast packet to each SGSN that serves multicast users. This leads to the creation of one GTP session between the GGSN and the SGSN1 and one GTP session between the GGSN and SGSN2 (Fig. 3). Having received the multicast packets, the SGSN1 forwards exactly one copy of the multicast packet to the RNCs that serve multicast users, which are the RNC1 and the RNC2. In parallel, the SGSN2 forwards the multicast packets to the RNC3, which is the only RNC, covered by the SGSN2 that serves multicast users. Regarding the edges between the SGSNs and the RNCs in Fig. 3, the first GTP session is created between the SGSN1 and RNC1, the second between the SGSN1 and RNC2 and the third one between the SGSN2 and RNC3. Finally, the RNCs forward the multicast packets to those Node Bs that multicast users reside in and have established the appropriate radio bearers. Additionally, Fig. 3 shows the exact number of the GTP sessions created in edges of the network for the multicast scheme.

The analysis presented in the above paragraphs, covers the forwarding of the data packets between the BM-SC and the Node Bs (Fig. 3). Therefore, the transmission of the packets over Uu and Iub interfaces may be performed on dedicated (Dedicated Channel - DCH) or common transport channels (FACH). DCH is a point-to-point channel and hence, it suffers from the inefficiencies of requiring multiple DCH to carry common data to a group of users. However, DCH can employ fast closed-loop power control and soft handover mechanisms to achieve a highly reliable channel. As presented in [12], point-to-multipoint MBMS data transmission uses the forward access channel (FACH) with turbo coding and QPSK modulation at a constant transmission power. Multiple services can be configured in a cell, either time multiplexed on one FACH or transmitted on separate channels, although in the latter case a single UE may not be able to receive multiple services. Control information, for example, available services, neighboring cell information indicating which of the neighboring cells that transmit the same content and so forth, is transmitted on a separate FACH.

4 Evaluation of the Multicast Scheme

In this section we present an evaluation, in terms of the telecommunication costs, of the multicast scheme presented in the previous section. We consider a more general UMTS network topology and different transport channels for the transmission of the multicast data.

In particular, 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 RNCs and cells are:

$$N_{RNC} = N_{SGSN} \cdot N_{ra} \cdot N_{rnc} \tag{1}$$

$$N_{NODEB} = N_{SGSN} \cdot N_{ra} \cdot N_{rnc} \cdot N_{ura} \cdot N_{nodeb} \tag{2}$$

The total transmission cost for packet deliveries is considered as the performance metric. We make a further distinction between processing costs at nodes and transmission costs on links. Similar to [6] and [2], we assume that there is a cost associated with each link and each node of the network for the packet deliveries. We apply the following notations:

D_{gs}	Transmission cost of packet delivery between GGSN and SGSG
D_{sr}	Transmission cost of packet delivery between SGSN and RNC
D_{rb}	Transmission cost of packet delivery between RNC and Node B
D_{DCH}	Transmission cost of packet delivery over the air with DCHs
D_{FACH}	Transmission cost of packet delivery over the air with FACH
p_g	Processing cost of packet delivery at GGSN
p_s	Processing cost of packet delivery at SGSN
p_r	Processing cost of packet delivery at RNC
p_b	Processing cost of packet delivery 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. Furthermore, network operators will typically deploy an IP backbone network between the GGSN, SGSN and RNC. Therefore, 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 multicast, the SGSNs forward a single copy of each multicast packet to those RNCs serve multicast users. After the correct multicast packet reception at the RNCs the RNCs forward the multicast packets to those Node Bs that have established the appropriate radio bearers via Dedicated or Common 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.

$$M_S = \left[p_g + n_{SGSN} \left(D_{gs} + p_s \right) + n_{RNC} \left(D_{sr} + p_r \right) + n_{NODEB} \cdot p_b + X \right] N_p \quad (3)$$

$$X = \begin{cases} n_{NODEB} \cdot N_{UE} \cdot D_{rb} + D_{DCH} \cdot N_{UE}, if \quad channel = DCH \\ n_{NODEB} \cdot D_{rb} + D_{FACH} \cdot n_{NODEB}, if \quad channel = FACH \end{cases} \quad (4)$$

The parameter X represents the multicast cost for the transmission of the multicast data over the Iub and Uu interfaces. This cost of the multicast scheme depends mainly on the distribution of the multicast group within the UMTS network and secondly on the transport channel that is used. In cells that the multicast users' density is high, the use of common channels such as FACH is preferable to the use of a DCH since the latter is reserved only for a single user.

An issue that should be noticed regarding the eqn(4) is that the first term in each of the two legs of the eqn(4) represents the packet delivery cost over the Iub interface which depends on the radio bearer used for the transmission of the data over the Iub. 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 served by the corresponding Node B. However, 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 Results

Having analyzed the costs of the multicast scheme, we try to evaluate the cost in function of a number of parameters. The first parameter is the number of the total packets per multicast session (N_p) and the second one is the number of the multicast users (N_{UE}). We assume a more general network configuration than that illustrated in Fig. 3, with N_{SGSN} =10, N_{ra} =10, N_{rnc} =5, N_{ura} =5 and N_{nodeb} =5. As we can observe from the equations in the previous section, the cost of the scheme depends on a number of other parameters. Thus, we have to estimate the value of these parameters appropriately, taking into consideration the relations between them. The chosen values of the parameters are presented in Table 1.

Table 1. Chosen parameters' values

D_{gs}	D_{sr}	D_{rb}	p_g	p_s	p_r	p_b	D_{DCH}	D_{FACH}	l_{gs}	l_{sr}	l_{rb}
36	18	6	1	1	1	1	3	5	6	3	1

The packet transmission cost (D_{xx}) in any segment of the UMTS network is proportional to the number hops between the edge nodes of this network segment. This means that $D_{gs} = \lambda\, l_{gs}$,$D_{sr} = \lambda\, l_{sr}$ and $D_{rb} = \lambda\, l_{rb}$. For the cost analysis and without loss of generality, we assume that the distance between the GGSN and SGSN is 6 hops (l_{gs} = 6), while the distance between SGSN and RNC is 3 hops (l_{sr} = 3).

In our analysis, the values for the transmission costs of the packet delivery over the air with each of the two transport channels are different. More specifically, the transmission cost over the air with Dedicated Channels (D_{DCH}=3), is smaller than the cost of the packet delivery over the air with FACH (D_{FACH}=5). The main difference between the Dedicated and Common resources is that FACH does not allow the use of fast power control. In particular, as presented in [13] the MBMS service can take significant portion of the sector power if FACH is used to carry the MBMS traffic. As a Common Channel (FACH) needs to be received by all the UEs in the cell, also those near the cell's border, it requires more radio resources (power) than a DCH.

In order to calculate the number of the UMTS nodes that serve multicast users, we define the following probabilities:

P_{SGSN}: The probability that an SGSN serve multicast users

P_{RNC}: The probability that an RNC (served by an SGSN with multicast users), serves multicast users

P_{NODEB}: The probability that a Nobe B (served by an RNC with multicast users), serves multicast users

For the cost analysis, we assume that P_{SGSN}=0.4, P_{RNC}=0.3 and P_{NODEB}=0.4. Consequently, the number of the SGSNs, the RNCs and the Node Bs that serve multicast users is derived from the following equations:

$$n_{SGSN} = N_{SGSN} \cdot P_{SGSN} = 4 \quad (5)$$

$$n_{RNC} = N_{RNC} \cdot P_{SGSN} \cdot P_{RNC} = 60 \quad (6)$$

$$n_{NODEB} = N_{NOBEB} \cdot P_{SGSN} \cdot P_{RNC} \cdot P_{NODEB} = 600 \quad (7)$$

Fig. 5 presents the cost of the multicast scheme in function of the N_p for different transport channels (DCH and FACH) used for the transmission of the multicast data over the air. The y-axis presents the total cost of the multicast scheme, while the x-axis shows the total packets per multicast session.

Regarding the use of DCHs, in Fig. 5, we have calculated the costs for three different values of the number of multicast users. Fig. 5 indicates that the multicast cost increases rapidly when the amount of the multicast data increases. Furthermore, for a given N_p, the multicast cost increases as the members of the multicast group increase. This is because the greater the number of multicast users is, the greater the number of DCHs needed for the transmission of the multicast data over the air and finally the greater the multicast cost is according to eqn (3) and eqn (4). Additionally, eqn (3) shows that in case we use FACH for the transmission of the multicast data over the air, the cost of the multicast scheme depends only on the number of packets per multicast session and not on the number of multicast users. This can be shown in Fig. 5 where we can observe that the greater the N_p is, the greater the multicast cost becomes.

Another interesting observation that comes out from Fig.5 is that for small numbers of multicast users the use of DCHs is preferable to the FACHs. One of the key assumptions in MBMS is that if the number of UEs within a cell using a particular

MBMS service is high enough, it will be advantageous to broadcast the MBMS data stream over the whole cell. If the number of UEs is low, serving each UE through DCHs means might be more efficient. A reasonable threshold for switching from point to point radio bearers to point to multipoint radio bearers in the multicast case is the number of 7-15 active MBMS users per cell [14].

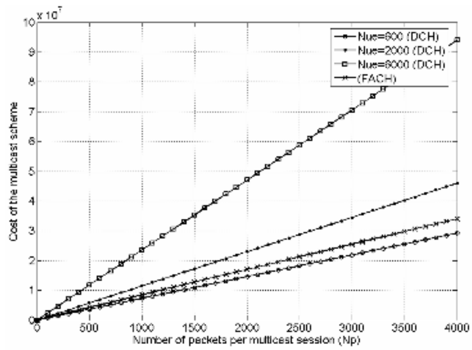
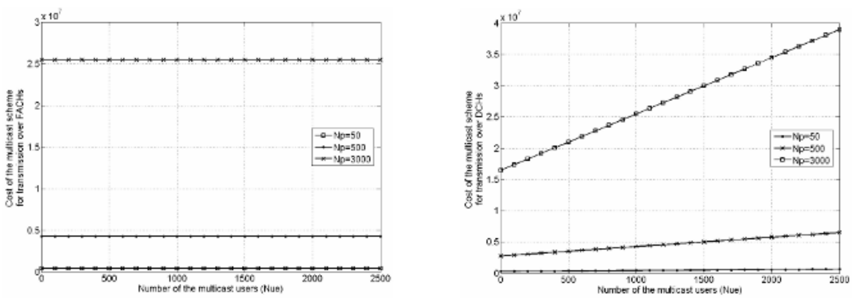


Fig. 5. Cost of the multicast scheme against *Np* for different transport channels

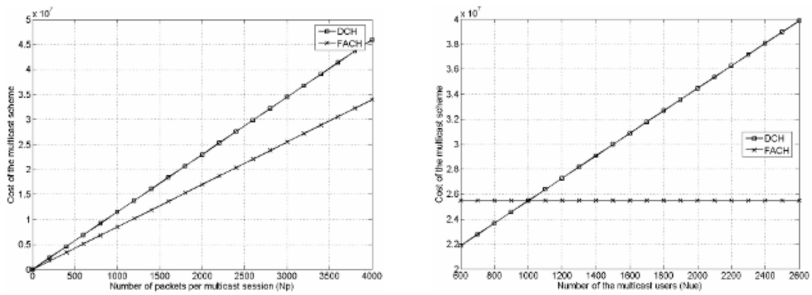
Furthermore, we try to estimate the cost of the multicast scheme in function of the N_{UE} (Fig. 6). As we observe, three different values of the number of the total packets per multicast session (N_p) have been calculated. Fig. 6a presents the cost of the multicast scheme against N_{UE} in case we use FACH for the transmission of the multicast data over the air. According to Fig. 6a, the cost of the multicast scheme is independent from the number of multicast users in case we use FACH for the transmission of the multicast data over the air. The cost of the multicast scheme in this case depends mainly on the number of Node Bs that serve multicast users. Only one FACH per cell is established and it is capable of supporting a great number of multicast users in this cell. Regarding the multicast cost against N_{UE} in case of the DCHs, the relation between them is predictable, since the greater the number of the multicast UEs is, the greater the cost becomes (Fig. 6b).



a) **b)**

Fig. 6. Costs of the multicast scheme against N_{UE} using different transport channels

Fig. 7 indicates that with multicast, the total transmission cost if we use common channels such as FACH is lower than the cost if we use DCHs. More specifically, Fig. 7a presents the costs of the multicast scheme in function of the N_p (for N_{UE}=2000) using different transport channels, while Fig. 7b presents the costs of the multicast scheme in function of the N_{UE} (for N_p=3000) using different transport channels.



a) **b)**

Fig. 7. Costs of the multicast scheme against N_p and N_{UE} using different transport channels

Another interesting parameter is the P_{NODEB}, which is the probability that a Node B, served by an RNC with multicast users, serves multicast users. Obviously, this probability takes values from 0 to 1. In case that P_{NODEB} converges to zero, the multicast users are located to a limited number of cells. On the other hand, when the P_{NODEB} converges to the value 1, then the multicast users are spread to many cells. Assuming that N_{UE}=1500, N_p=500, we can calculate the cost for the multicast scheme from the eqn(3) and eqn(4).

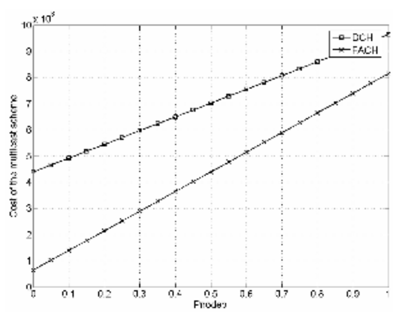


Fig. 8. Cost of the multicast scheme against P_{NODEB} for different transport channels

Fig. 8 presents the cost of the multicast scheme in function of P_{NODEB} for different transport channels. It is obvious from Fig. 8 that the cost of the multicast scheme is decreased as P_{NODEB} converges to zero. This means that the greater the number of multicast users per cell is, the lower the cost of the multicast scheme is. Furthermore, regarding the use of different transport channels for the transmission of the multicast data through the air, the use of FACHs is absolutely preferable to the use of DCHs as Fig. 8 indicates.

6 Conclusions and Future Work

In this paper, we have presented a multicast scheme for UMTS and the delivery of the multicast packets to a group of mobile users and have analyzed the performance of such a delivery in terms of the telecommunication cost. Considering a general network configuration, we have analyzed the cost of a multicast scheme in function of a number of parameters. Such parameters are the number of multicast users within the multicast group, the amount of data sent to the multicast users and finally the density of the multicast users within the cells. Additionally, we have evaluated the performance of the multicast scheme considering different transport channels for the transmission of the multicast data over the air. The step that follows this work is to carry out experiments using the NS-2 simulator.

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