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Abstract — Focus of the present paper is the integration between High Altitude Platforms (HAPs) and terrestrial UMTS system to support Multimedia Broadcast/Multicast Services. HAPs are characterised by a wide coverage area, which makes them a very attractive solution to support broadcast and multicast applications, while increasing both resource capacity and Grade of Services. In the depicted scenario, we propose to enhance the system efficiency by envisaging a novel Radio Resource Management (RRM) protocol based on the evaluation of the Power Consumption relevant to users belonging to each multicast group. We will demonstrate that the use of the proposed RRM policy, coupled to a wise selection of transport channels, leads to the effective management of multiple multicast groups.

Keywords: Cellular systems (3G/4G); Resource allocation; Next generation services; High Altitude Platform; Multicast services.

I. INTRODUCTION

Nowadays, video streaming, mobile TV, and file downloading are considered by network operators as key applications in 3G/4G systems. In this view, Multimedia Broadcast/Multicast Services (MBMS) [1] has been introduced by 3GPP as a means to provide opportunities for triple-play mobile services (a combination of mobile telephone, broadband internet, and mobile TV). Nevertheless, according to the MBMS system, the capacity for novel point-to-multipoint (p-t-m) services is provided within the same spectrum used by point-to-point (p-t-p) transmissions, with a consequent prospective decrease in the overall system Grade of Service (GoS). An interesting way to overcome MBMS limitations consists in integrating HAPs [2] into the UMTS system [3] with the aim of improving the UMTS efficiency in terms of resources capacity, coverage area, and number of simultaneously active users. In the reference scenario of our research, HAPs are located at an altitude of about 17-22 Km, equipped with Base Stations (BSs) similar to terrestrial ones, and play the roles of: (i) a complementary/alternative solution to the terrestrial-satellite system for multimedia service provisioning; (ii) a viable solution to provide coverage to metropolitan regions and rural areas; (iii) a buffer of extra-resources for multicast users.

In this paper, we define a new RRM policy based on the evaluation of the Power Consumption of users belonging to each multicast group. The choice of the most efficient transport channel, together with the adoption of the proposed RRM policy, allows to efficiently support MBMS traffic and to increase the integrated UMTS/HAP system performance.

The paper is structured as follows. Section II provides a brief overview of the integrated UMTS/HAP architecture for MBMS services. Section III introduces channel assignment procedures to deliver multicast traffic in the reference scenario. RRM policies proposed by the authors are described in Section IV. The main results of simulation campaigns conducted to test the robustness of the proposed approach are the focus of Section V. Conclusive remarks are given in Section VI.

II. ENVISIONED UMTS/HAP INTEGRATED ARCHITECTURE

In an early work [4], we have already analyzed the impact on MBMS services deriving from the presence of HAP platforms in hybrid wireless communications systems. A possible integration of HAP platform into MBMS architecture to enhance the delivery of multicast/broadcast services over 3G/4G cellular networks is illustrated in Figure 1.

Let’s term this hybrid architecture TH-MBMS (Terrestrial-HAP integrated system for MBMS services). More specifically, the proposed hybrid scenario foresees:

• CP (Content Provider) that deliver multicast/ broadcast multimedia contents to User Equipments (UE) by means of either terrestrial or HAP links, through the UMTS Core Network;

• BM-SC (Broadcast-Multicast Service Centre), authenticating and authorizing the content providers and checking the integrity of received data;

This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE "GLOBECOM" 2008 proceedings.
• **UTRAN** (UMTS Terrestrial Radio Access Network), including several **NodeBs** (the UMTS Base Stations) and **Radio Network Controller** (RNC), which is in charge of the MBMS service distribution across the multicast service area. It also identifies MBMS users within a cell, chooses the most suitable channel type, supports UE mobility and transmits MBMS service announcements and paging information.

The inclusion of a HAP into the system implies the add-on of a **U-HCS** (UMTS-HAP Control System) module into the MBMS architecture (an UMTS device that includes the RNC functionality to control the Node-Bs on board the HAP; more details are available in [4]).

### III. CHANNEL ALLOCATION IN THE TH-MBMS SYSTEM

In this section we will address the main features of the MBMS protocol and analyze the transport channel management policies proposed to support multicast traffic with the aim of optimizing the system capacity. Weak points of the proposed policies, emerging when in the presence of **multiple multicast groups**, are highlighted and motivations are given to the introduction of an integrated UMTS/HAP system to improve the overall system performance.

#### A. Transport Channel Selection in Terrestrial MBMS

In the MBMS standard [1], two different transport modalities are defined to support multicast traffic on the radio interface: (i) by using a p-t-p transmission, i.e. by assigning a dedicated channel (DCH, Dedicated CHannel) to each multicast user; (ii) by using a p-t-m transmission, i.e. by assigning a common channel (FACH, Forward Access CHannel) to all multicast users in the same cell.

Terrestrial DCHs are radio bearers supporting power control, through DCH return channels. As a result, a variation in the transmitted power according the user position within the cell is foreseen to maintain the interference level at acceptable values [5], [6]. Main disadvantage of using DCHs for multicast transmission consists in the inefficient radio resource exploitation deriving from the “single channel per active user” allocation. This way, an increase in the number of multicast users per cell may cause a severe performance degradation to unicast traffics in the same cell. Hence, DCHs channels may be efficiently utilized only when the number of active multicast users in a given cell is low.

**Terrestrial FACH** is considered the best candidate for p-t-m transmission in MBMS system. Nevertheless, since a FACH does not support power control (a feedback channel does not exist), transmission power has to be set at an adequately high level to allow users at the cell borders to receive the service with an acceptable QoS [1],[5]. Once the power level is set, group members simply need to “listen to” the FACH channel to receive MBMS data traffic without the BS awareness [6]. Hence, FACH channel is efficiently utilized when in a given cell there is a large number of multicast users.

MBMS standard foresees the joint use of DCH and FACH channels; but, as discussed above, there are situations in which the use of DCH channels is more convenient (in terms of radio resources utilization, system capacity, Grade of Services, and so on) with respect to FACH channel and vice-versa [5]. Thus, several studies have been conducted to identify the conditions under which is advisable to switch from dedicated to common channels (and vice-versa), when in the presence of a single multicast group [5-7], [9]. As an example, in [7] and [9] the computation of a **Channel Switching Threshold** is based only on the number of users utilizing dedicated channels in a given cell. While, subsequent studies conducted in [5] demonstrate that the **Channel Switching Threshold** cannot be only based on the number of the user in a cell. Differently, it is also needed to account for the total power required by multicast users; this parameter being related to several features such as MBMS bit rate, user position within the cell coverage, $E_b/N_0$ requirement per UE, interference from neighboring cells. In fact, authors of [5] conclude that the computation of the total downlink power allocated for DCHs in a given cell (named $P_{DCH}^X$ in this paper) is a key aspect for the evaluation of a p-t-p to p-t-m switching threshold to handle generic multicast group $X$.

The results obtained in [5] are interesting although they cannot be directly extended to the case of multiple multicast groups. In this latter case (which is the focus of the present paper), decision policies simply based on a mere switching threshold are surely inefficient. In fact, before applying the switching threshold policy, when in presence of more than one multicast group, it is necessary to define a RRM strategy able to choose which multicast group is more convenient to switch from p-t-p to p-t-m channels (and vice-versa). Furthermore, as it will be demonstrated in section V, whatever the RRM policy implemented, the only UMTS terrestrial system doesn’t permit to greatly improve the system performance if multiple multicast groups are active. The reason is that in UMTS system, only one FACH per cell is available. If several multicast group are active in the same cell, then one of them will be served by the FACH channel, while the remaining groups must exploit dedicated terrestrial channels.

#### B. Transport Channel Selection in TH-MBMS

To manage multiple multicast groups, we propose to introduce a HAP segment into UMTS system as an additional resource for multicast users assuming that the HAP FACH channel (FACHHAP) is utilized to support multicast traffic. Differently from the terrestrial segment, we assume that HAP Dedicated Channels (DCHHAP) are allowed only to support unicast services (i.e. to provide a buffer capacity to already established unicast connections).

The policy implemented into the integrated UMTS/HAP system is based on the following principles. When a new user belonging to a Multicast Group enters a new cell, the system checks if other users belonging to the same group are already active on a FACH channel (either the FACHHAP in the current cell or a FACHHAP). In a such situation, the new user shares the FACH channel with other members of the same group. Differently, if a new user enters in a new cell and the requested Multicast Group is not active on any UMTS/HAP FACH channel, then the system checks the availability of a DCH channel for the incoming new user. Subsequently, the total number of users associated to DCH channels in the current cell and belonging to the same Multicast Group needs
to be computed to check if the cited “Channel Switch Threshold” is crossed and a p-t-p to p-t-m channel switching is requested. When a DCH-to-FACH switching is required, the policy followed by our system consists in always trying to first use the terrestrial FACH channels. The further possibility of activating a FACH over the HAP to support one multicast group is contemplated only when in the presence of more than one single multicast group. This is due to the fact that each HAP has a single $FACH_{HAP}$ and it is a precious resource to be used with parsimony. For that reason, when more than one multicast group is present in the system, an efficient RRM policy has to be triggered to decide which group has to be served through DCH channels, which one through the $FACH_{Terral}$, and which one through the $FACH_{HAP}$.

IV. RADIO RESOURCE MANAGEMENT IN THE TH-MBMS

In this section we introduce a Radio Resource Management (RRM) policy able to handle more than two multicast groups in the integrated UMTS/HAP system. To design an effective RRM policy we need to focus on those parameters that significantly limit the performance of the UMTS system. One of them is surely the transmission power, being UMTS a power limited systems on the downlink.

UMTS system. One of them is surely the transmission power, parameters that significantly limit the performance of the system. In order to have a clear understanding of the improvement deriving from the implementation of the proposed policy, we will compare its behavior with the one of the simplest policy RNC may adopt, named “First In First Served” (FIFS) policy [10]. This latter assigns channels depending on the time instant a multicast group starts a communication session. More specifically, the first multicast group appearing in the system will be preferably served over terrestrial network channels ($FACH_{Terral}$), the second one over the HAP common channel ($FACH_{HAP}$), and the subsequent groups (if any) over dedicated power level associated to the relevant FACH channel).

Hence, $N_{fach\_cell}$ is either equal to or a subset of $N_{cell}\cdot \prod_{X}$ gives information on the whole power level UMTS uses to support multicast group $X$. Moving a group, which is currently using a high $\prod_{X}$, to the $FACH_{HAP}$ allows to free a significant amount of resources on the terrestrial segment. Freed resources can be used by unicast users, which will consequently experience an improvement in the QoS and GoS. Hence, the PMU algorithm can be envisaged as a three-phase procedure:

**Phase I**: the transmitted power in each cell $(P_{DCH}^{X})$ is computed. The obtained value of $P_{fach\_X}$ with the aim of choosing, on a cell-by-cell basis, the most efficient transport channel that minimizes the Node B transmitted power [5].

**Phase II**: the Load Controller in the RNC is aware of the current network load and has the capacity of monitoring and controlling the so called Load Factor (LF) of the terrestrial radio access network. Obviously, whenever multicast connections are activated, the LF increases. If this value becomes greater than 75%, then the PMU algorithm is triggered to reduce the Load Factor of the terrestrial segment, with a consequent improvement of the overall system GoS. In this situation, the total power emitted by the terrestrial segment $(\prod_{DCH}^{X})$ for each MBMS session is computed with the aim of always moving the multicast group characterized by the highest value of $\prod_{DCH}^{X}$ to the $FACH_{HAP}$. The only requirement for the RNC is to track the total power emitted by the terrestrial segment to serve any active multicast group $X$ and to store the identifier of the currently group that is consuming the greatest amount of power in the terrestrial segment.

**Phase III**: logically, as soon as the multicast session served by the HAP ends, a different terrestrial multicast group can be assigned to the $FACH_{HAP}$, according to the described PMU policy described in Phase II.

The novel RRM approach is investigated under the following assumptions: if a multicast group is active in the terrestrial network, it cannot be also active over the HAP, and vice-versa; priority is given to active unicast users in the cells; FACH channel over the HAP air interface is used only if strictly necessary (i.e., when the Load Factor in the terrestrial segment is greater than 75%). Moreover, the RRM algorithm is executed when more than one multicast group is operating in our reference scenario.

In order to have a clear understanding of the improvement deriving from the implementation of the proposed policy, we will compare its behavior with the one of the simplest policy RNC may adopt, named “First In First Served” (FIFS) policy [10]. This latter assigns channels depending on the time instant a multicast group starts a communication session. More specifically, the first multicast group appearing in the system will be preferably served over terrestrial network channels ($FACH_{Terral}$), the second one over the HAP common channel ($FACH_{HAP}$), and the subsequent groups (if any) over dedicated
terrestrial channels (DCH_{TERN}). From the comparison it will clearly emerge that the presence of a HAP segment in the systems is sufficient by itself to improve the performance compared to the case of a pure UMTS based MBMS. The need for an alternative policy with a performance level beyond the one already assessed for FIFS policy derives from the observation that the value of blocking and dropping probabilities, even if significantly improved, are, sometimes, still unsatisfactory.

V. SIMULATION RESULTS

In this section the results of a thorough assessment study, conducted to verify the performance of the proposed RRM policy and its impact on the system GoS, are illustrated. The most interesting results are reported in term of system blocking and dropping probabilities when in the presence of unicast and multicast connections. Simulations have been carried out by means of an ad hoc implemented C++ simulator; each simulation is composed of 20 runs and averaged measures are reported within the 95% confidence intervals. Table I depicts the main assumptions of our simulation campaign.

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<th>TABLE I. SIMULATION ASSUMPTIONS</th>
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<td>HAP Sector Coverage Area</td>
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<td>HAP propagation model</td>
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We assume Poisson distributed call interarrival times. Both multicast interarrival time ($T_{multicast}=1/\lambda_{multicast}$) and geographical distribution of multicast users vary during the simulations, while the unicast interarrival time ($T_{unicast}=1/\lambda_{unicast}$) does not change. Different sets of simulations have been performed for different values of $\lambda_{unicast}$ and always the same behavior has been observed. This is why, without any loss in generality, curves shown in the present paper only refer to the sample value of $\lambda_{unicast}=1.25$ calls/s (a value guaranteeing blocking and dropping probabilities below the target values of 5% and 1%, respectively).

Let us define $D_X = n/m$ as the Group Distribution Index of group $X$, where $n$ is the number of cells occupied by users of the group (in the simulated test scenario $n \in \{1-16\}$), and $m$ is the total number of cells in the system ($m=16$ in the simulated case). Furthermore, $N_X$ (called Group User Number Index) represents the percentage of users (with respect to the total number of multicast users in the system) which is associated to the multicast group $X$.

To demonstrate that the improvement in the system GoS favored by the proposed RRM technique does not depend on the percentage and spatial distribution of multicast users, we conduct our simulation campaign by varying both the Group Distribution Index and the Group User Number Index. Due to lack of space, we reported in this paper curves only referring to two significant cases. Obviously, obtained result can be generalized for all other cases.

A. Case 1 - Multicast groups equally distributed and one group more numerous than any other

Curves reported in Figure 2 depict the average total power used by the terrestrial segment per cell to support three multicast groups, active at the same time, with the following characteristics: (i) each multicast group uniformly scattered across the whole system (i.e. $D_X=1$ for each $X$); (ii) multicast users partitioned among three groups, as follows: $N_A=60; N_B=20; N_C=20$; (iii) multicast inter-arrival time equal to $\lambda_{unicast}=1.25$.

Figure 2 is just an example (it represents a snapshot of a simulation campaign) that clearly shows the goodness of our proposed RRM algorithm in terms of terrestrial resource utilization (in our case, in terms of terrestrial average total power consumption per cell). Initially, the three multicast groups are served by the terrestrial network only. The point of discontinuity in the graph is the time instant in which the terrestrial segment is experiencing a Load Factor greater than 75%; as a consequence of this event, the RNC decides to select a multicast group and transfer it from the terrestrial to the HAP segment, according to the proposed RRM algorithms. The two curves highlights the different effects that the choices of selecting the transferred multicast group according to PMU (in this particular case the Group A is switched to the HAP) and to FIFS (in this particular case the Group B or C is switched to the HAP) have on the overall consumed power. It is straightforward that switching the most power consuming group to the HAP segment is the most effective solution also in terms of freed power in the terrestrial segment; beneficial consequences are manifest also in term of GoS, as shown in figure 3 and 4.

![Figure 2](image_url)
Obtained results confirm that: (i) the presence of an HAP coverage is able to increase the overall system performance; (ii) when using PMU policy, the achievable gain in performance is manifestly superior than in case of FIFS. A subsequent step aims at demonstrating that the proposed technique improves the system GoS whatever the spatial distribution of multicast user.

B. Case 2 - Multicast groups equally numerous and one group more scattered than any others

In figure 5 blocking and dropping probabilities in the integrated UMTS/HAP system are evaluated under the following hypothesis: (i) the number of users per group is the same (i.e. \( N_x = 33.3 \) for each \( X \)); (ii) multicast groups are scattered across the whole system as follows: \( D_A = 1; D_B = 0.5; D_C = 0.5 \); (iii) multicast interarrival time is variable.

By analyzing the results depicted in figure 2-5, it clearly emerges that, through the monitoring of the power consumption of each active multicast group, the proposed PMU policy allows a better channels allocation strategy with respect to FIFS policy, independently of the percentage and spatial distribution of multicast user. In fact, the figures respect to FIFS policy, independently of the percentage and multicast interarrival time is variable.

![Figure 3. Overall System Blocking Probability (\( D_X = 1; N_A = 60; N_D = N_C = 20 \))](image1)

![Figure 4. Overall System Dropping Probability (\( D_X = 1; N_A = 60; N_D = N_C = 20 \))](image2)

![Figure 5. Overall System Blocking and Dropping Probability (\( N_x = 33.3; D_A = 1; D_B = D_C = 0.5 \)).](image3)

VI. CONCLUSIONS

Objective of this paper has been the performance assessment of a novel criteria for resource allocation to multicast traffic in TH-MBMS. Through a simulation study it has been proven that the exploitation of the HAP resources and the introduction of more intelligence in the RNC for multicast group management is a viable solution to deliver multicast services to mobile UMTS users. The introduction of multicast traffic obviously leads to a lower system GoS. Nonetheless, when implementing the novel PMU policy, the worsening can be sensibly reduced. In the future research activities multicast users mobility will be introduced in our reference scenario and the proposed PMU algorithm will be tested in a mobile environment.

REFERENCES
