On the management of unicast and multicast services in LTE networks

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***Abstract*—Among the solutions for broadband wireless access (BWA) provisioning, Long Term Evolution (LTE) represents one the most promising technologies. In order to effectively support the tremendous growth of mobile broadband services required by the users of the fifth generation (5G) systems, LTE is claimed to efficiently manage the contemporary presence of traditional unicast and value-added multicast services. In this paper, we propose an effective strategy for joint multicast and unicast scheduling in LTE networks which distributes system resources among unicast and multicast services by taking into account the instantaneous load conditions while guaranteeing session quality improvements to both unicast and multicast services. In particular, the designed policy firstly performs the allocation of the resources required for the delivery of minimum requested data rate for both unicast and multicast services. Subsequently, unicast and multicast services equally share the remaining network resources; while resource assignment of additional resources to unicast users is accomplished through a maximum throughput approach, multicast services are managed through a *subgroup*-based resource allocation scheme. Simulations highlight the effectiveness of the proposed strategy in several scenarios and under different traffic loads.**

***Index Terms*—Networking and QoS, Traffic and performance monitoring, Multicast, Unicast, LTE.**

I. INTRODUCTION

Long Term Evolution (LTE) [1] represents one of the most accredited wireless technology that promise to support the growth of mobile broadband services expected in the next years. Indeed, LTE introduces several benefits in terms of high data rates, low latency and low cost per bit and, coupled with Multimedia Broadcast/Multicast Service (MBMS) [2], can efficiently support value-added *multicast* services (such as sport, streaming, video conferencing, IPTV) expected to be massively required by the users of 5G systems.

Nevertheless, effective multicast delivery strategies are claimed in order to overcome the limitations of the conventional multicast scheme, which suffers in terms of poor session quality and spectrum utilization. The standard approach for multicast management, the Conventional Multicast Scheme (CMS) [3], has inherent limitations. Indeed, despite it is an intrinsically fair approach that guarantees all users the same throughput, at the same time, serving the entire multicast group at the transmission conditions required by the node with the poorest channel quality reduces the overall system throughput.

In addition, the growing interest in multicast services mandates to efficiently manage the contemporary coexistence of multicast and traditional *unicast* services and this poses novel challenges due to the different requirements of unicast and multicast services also in terms of link adaptation procedures (i.e., selection of transmission parameters based on the perceived channel conditions). Indeed, unicast data is delivered to a single user and hence resource allocation is performed on a *per-user* basis, i.e., by serving each unicast terminal according to the supported Modulation and Coding Scheme (MCS). On the contrary, multicast information is simultaneously delivered to multiple users and this involves that link adaptation is accomplished on a *per-group* basis, i.e., by taking into account the channel quality of all multicast members. Furthermore, additional issues are related to the resource distribution among unicast and multicast traffic. In particular, higher network utilization can be achieved by favoring multicast traffic (since a multicast service is simultaneously received by several users) but it may cause unicast users to suffer from poor performance.

Despite a big effort has been made by the research community in the analysis of radio resource management techniques for unicast [4] and multicast traffic [5] separately, only a few research works [6]-[9] deal with the coexistence of unicast and multicast services in broadband wireless access networks. In this paper, we contribute to fill this gap by designing an effective strategy for joint multicast and unicast scheduling in LTE networks. The proposed approach, which enhances the work in [9], distributes system resources among unicast and multicast services by taking into account the instantaneous load conditions while guaranteeing session quality improvements to both unicast and multicast services. In particular, the designed policy firstly performs the allocation of the resources required for the delivery of minimum requested data rate for both unicast and multicast services. Subsequently, unicast and multicast services equally share the remaining network resources; while the assignment of additional resources for unicast users is accomplished through a maximum throughput approach, multicast services are managed through a *subgroup*-based resource allocation scheme [10], i.e., each group is split into several subgroups in order to efficiently exploit the multi-user diversity.

The remainder of the paper is organized as follows. In section II, the system model and research background of the work are presented. The proposed policy for concurrently handling unicast and multicast services in a cell is described in section III. Simulation results are discussed in section IV.

Conclusive remarks are given in the last section.

II. System Model and Research Background

In LTE systems [1], Orthogonal Frequency Division Multiple Access (OFDMA) and single carrier frequency division multiple access (SC-FDMA) are used to access the downlink and the uplink, respectively. The available radio spectrum is managed in terms of *resource blocks* (RBs) and, in the *frequency domain*, each RB corresponds to 12 consecutive and equally spaced sub-carriers. One RB is the smallest frequency resource that can be assigned to a user equipment (UE). The overall number of available RBs depends on the system bandwidth configuration and can vary from 6 (1.4 MHz channel bandwidth) to 100 (20 MHz).

The system architecture considered in this paper extends the MBMS standard architecture defined in [2] in order to support data communication for efficient video delivery to users in a cell. The classic MBMS architecture for the access network is composed of eNodeBs, which are the evolved network nodes which communicate directly with UE and a MultiCell/Multicast Coordination Entity (MCE), responsible for transmission parameter configuration in single- and multi-cell mode, respectively. The eNodeB manages the spectrum, by assigning the adequate number of RBs to each scheduled user and by selecting the MCS for each RB. Scheduling procedures are based on the *channel quality indicator* (CQI) feedback, transmitted by each UE to the eNodeB . The CQI-MCS mapping for the LTE standard [1] is reported In Table I. Transmission parameters (i.e., MCSs) are adapted at every *CQI feedback cycle* (CFC), which can last one or several transmission time intervals (TTIs), where one TTI is equal to 1 ms [1].

TABLE I
CQI-MCS in LTE networks.

CQI index	Modulation Scheme	Spectral Efficiency [bit/s/Hz]	Minimum Rate [kbps]
1	QPSK	0.1523	25.59
2	QPSK	0.2344	39.38
3	QPSK	0.3770	63.34
4	QPSK	0.6016	101.07
5	QPSK	0.8770	147.34
6	QPSK	1.1758	197.53
7	16-QAM	1.4766	248.07
8	16-QAM	1.9141	321.57
9	16-QAM	2.4063	404.26
10	64-QAM	2.7305	458.72
11	64-QAM	3.3223	558.72
12	64-QAM	3.9023	655.59
13	64-QAM	4.5234	759.93
14	64-QAM	5.1152	859.35
15	64-QAM	5.5547	933.19

Although the literature on resource allocation in broadband wireless access networks mainly focused on the management of unicast or multicast traffic separately, 5G networks are claimed to manage the contemporary presence of unicast and multicast services. For this reason, this research topic is of outmost importance. The issues related to the topic addressed in this paper are analyzed in [6]-[9], where main approaches for the coexistence of unicast and multicast services in Orthogonal Frequency Division Multiplexing (OFDM) based systems have been proposed and discussed. Authors in [6] and [7] propose a scheme (referred as *Unicast Maximization* (UM) in the following) which foresees to serve all multicast members with the minimal data rate and to assign the remaining resources to unicast users through a maximum throughput approach. Hence, the UM strategy aims at improving the performance of unicast users at the expense of multicast session quality. A different strategy is at the basis of the work in [8], where the authors propose to provide *all* users (i.e., both unicast and multicast) with the minimum requested data rate while extra resources are assigned according to a maximum throughput scheme. We refer to this approach as *Equal Competition* (EC). According to EC, additional resources are assigned to the services (unicast or multicast) which guarantee to maximize the system throughput. Although this strategy does not introduce limitations to the performance of unicast or multicast users, multicast services have higher probability to be scheduled with respect to unicast users since a larger number of users can be served if resources are allocated to a multicast service. A further approach, denoted in the following as *Equal Sharing* (ES), is proposed in [9] and is based on the idea that multicast and unicast services equally share the available network capacity. In details, the ES strategy exploit a maximum throughput approach to serve unicast and multicast services, each over a half portion of available resources. The aim of ES is to prevent unicast (or multicast) terminals to utilize the available resources at the expense of multicast (or unicast) users. Nevertheless, in the case of low multicast load and high number of unicast users, the bandwidth allocated to multicast flows could be oversized at the expense of the bandwidth assigned to unicast services (or vice versa).

III. The Proposed Policy for Joint Unicast and Multicast Traffic Delivery

The goals of the proposed policy, namely ES^+, are *(i)* to distribute system resources among unicast and multicast services by taking into account the instantaneous load conditions while *(ii)* guaranteeing session quality improvements to both unicast and multicast services. In this paper we refer to a single-cell scenario where U unicast users and G multicast groups share the available R resources (i.e., RBs) managed by the LTE base station (i.e., eNodeB). We denote with $\mathcal{K}_g$ the set of users that join multicast group g (with $g = 1, \ldots, G$). Each user, on the basis of the experienced channel conditions, transmits utilizing one among the M different MCS defined by the LTE system. Let $c_u \in \{1, \ldots, M\}$ (with $u = 1, \ldots, U$) be the CQI value transmitted by unicast user u to the eNodeB. Similarly, we indicate with $c_{g,k} \in \{1, \ldots, M\}$ the CQI feedback of multicast user k (with $k = 1, \ldots, |\mathcal{K}_g|$) belonging to multicast group g. Each service in the cell is characterized by different QoS requirements. We denote with d_u^{uni} and D_u^{uni}, respectively, the minimum and the maximum requested data rate for unicast user u. Similarly, let d_g^{mul} and D_g^{mul} be, respectively, the minimum and the maximum requested data rate for multicast group g. Let r_u be the number of RBs assigned to unicast users u. The eNodeB assigns the available RBs at each scheduled service. Concerning the management of multicast services, in this paper we extend the approach in [10] by considering the *subgrouping* approach: each group is split into several subgroups, dynamically selected by the eNodeB to efficiently exploit the multi-user diversity with the aim to enhance the spectrum utilization. Since multicast subgroups are created according to users' channel qualities, we indicate with $\mathcal{K}_{g,m} = \{k \in \mathcal{K}_g | c_{g,k} \geq m\}$ the subset of users in group g which support the m-th MCS level. Accordingly, we denote with $r_{g,m}$ the number of RBs assigned by the eNodeB to the subgroup of group g related to the m-th MCS. If $r_{g,m} > 0$, then such a subgroup is enabled.

TABLE II
THE ES^+ SCHEME

1: $R^* = R$ ▷ *Available RBs*
2: $h^{uni} = 0$ ▷ *RBs for minimum rate assignment to unicast users*
3: **for all** $u \in \{1, \dots, U\}$ **do**
4: $\quad r_u = \lceil d_u^{uni} / f(c_u) \rceil$ ▷ *Minimum rate assignment to unicast user*
5: $\quad R^* = R^* - r_u$ ▷ *Update available RBs*
6: $\quad h^{uni} = h^{uni} + r_u$ ▷ *Update RBs assigned to unicast users*
7: **end for**
8: $h^{mul} = 0$ ▷ *RBs for minimum rate assignment to multicast services*
9: **for all** $g \in \{1, \dots, G\}$ **do**
10: $\quad \tilde{m} = \min_{k \in \mathcal{K}_m} c_{g,k}$ ▷ *Minimum CQI for multicast group*
11: $\quad r_{g,\tilde{m}} = \lceil d_g^{mul} / f(\tilde{m}) \rceil$ ▷ *Minimum rate for multicast service*
12: $\quad R^* = R^* - r_{g,\tilde{m}}$ ▷ *Update available RBs*
13: $\quad h^{mul} = h^{mul} + r_{g,\tilde{m}}$ ▷ *Update RBs assigned to multicast services*
14: **end for**
15: $\begin{cases} \arg\max_{r_u} \left\{ \sum_{u=1}^{U} r_u \cdot f(c_u) \right\} \\ \textit{s.t.} \\ \sum_{u=1}^{U} r_u \leq \lfloor R^*/2 \rfloor + h^{uni} \\ r_u \cdot f(c_u) \leq D_u^{uni}, \ \forall u \end{cases}$
16: $\begin{cases} \arg\max_{r_{g.m}} \left\{ \sum_{g=1}^{G} \sum_{m=1}^{M} r_{g,m} \cdot f(m) \cdot |\mathcal{K}_{g,m}| \right\} \\ \textit{s.t.} \\ \sum_{g=1}^{G} \sum_{m=1}^{M} r_{g,m} \leq \lceil R^*/2 \rceil + h^{mul} \\ \sum_{m=1}^{M} r_{g,m} \cdot f(m) \leq D_g^{mul}, \ \forall g \end{cases}$

The operation of the proposed ES^+ policy is shown in Table II. Firstly, the proposed scheme performs the allocation of the RBs required for the delivery of minimum requested data rate for both unicast and multicast services.[1] As it can be noticed from *lines 3-7*, the resource assignment for unicast users is accomplished on a per-user basis, i.e., by serving each unicast terminal with the supported MCS. On the contrary, the minimum data rate assignment to multicast services (*lines 9-14*) is performed on a per-group basis. In particular, the RBs are allocated according to the most robust MCS among those supported by the group members (*line 10*) in order to guarantee that each multicast user can obtain the minimum data rate. After the allocation of the minimum required data rates, the eNodeB is aware of the resources still available, i.e., R^*. A portion equal to $\lfloor R^*/2 \rfloor$ RBs is dedicated for unicast services (*line 15*). In particular, the assignment of additional resources for unicast users is accomplished through a maximum throughput approach in order to efficiently exploits the available resources. Similarly, a portion equal to $\lceil R^*/2 \rceil$ RBs is reserved for multicast services (*line 16*). This step is performed by selecting the subgroups to enable (with the related RBs) for each group, according to the technique proposed in [10].

[1]The function $f(m)$ in Table II indicates the data rate when one RB is transmitted with the m-th MCS.

IV. PERFORMANCE EVALUATION

The performance evaluation of the proposed resource allocation algorithm has been run in Matlab. In order to evaluate the performance of the proposed ES^+ policy, we consider an LTE cell coverage area where $R = 100$ RBs are available for unicast and multicast content delivery.

Simulations have been carried out in the two following scenarios with different distributions of unicast and multicast users:

- *Scenario A*, where the overall number of users (x-axis) is equally divided into unicast and multicast terminals (multicast members are gathered in one multicast group);
- *Scenario B*, where we set the number of unicast users and the number of multicast group members to 20 and we varied the number of multicast services from 1 to 8.

We assume that both unicast and multicast services have the same minimum (i.e., 121 kbps) and maximum (i.e., 564 kbps) data rate requirements. Outputs are achieved by averaging a sufficient number of simulation results to obtain 95% confidence intervals.

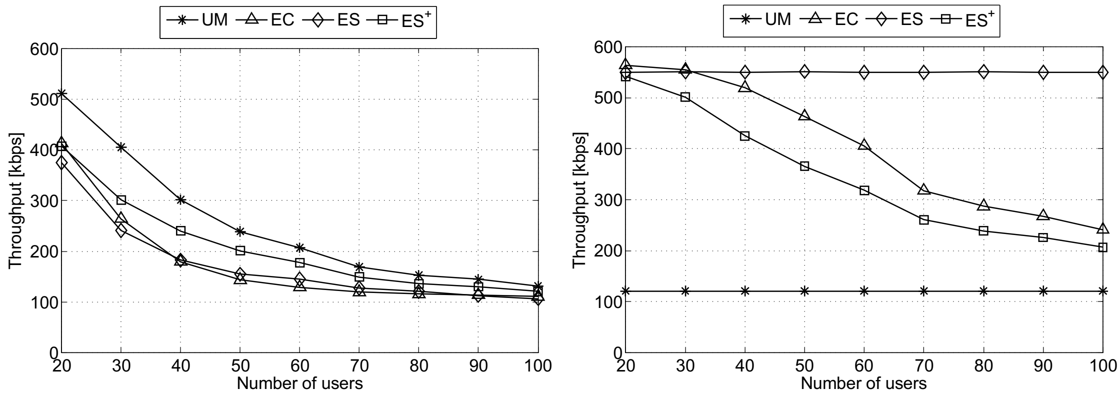
Table III presents the main simulation parameters.

The performance parameters analyzed in these comparative evaluation tests are:

- **Average User Throughput**: is the achieved bit rate per user, accounting for the packets successfully delivered to the target users during the simulation time.
- **Channel Data Rate (CDR)**: accounts for the total amount of user data transmitted by the eNodeB over the air interface.

We firstly focus on the results for the Scenario A (Fig. 1) in terms of average users throughput. As expected, the UM policy achieves the best performance for unicast users and the worst for multicast members. Compared to UM, the proposed ES^+ reduces the unicast throughput of about 21%, on average, but it allows to increase the multicast throughput by a factor equal to 200%, on average. Focusing on the comparison with respect to EC, the ES^+ introduces a gain in terms of unicast throughput equal to 33%, on average, while the multicast performance is reduced by a factor equal to 21%. Finally, with respect to ES, the proposed policy improves the performance of unicast users by a factor of about 31% while, by focusing on the multicast throughput, the mismatch between ES^+ and ES increases as the number of users becomes larger.

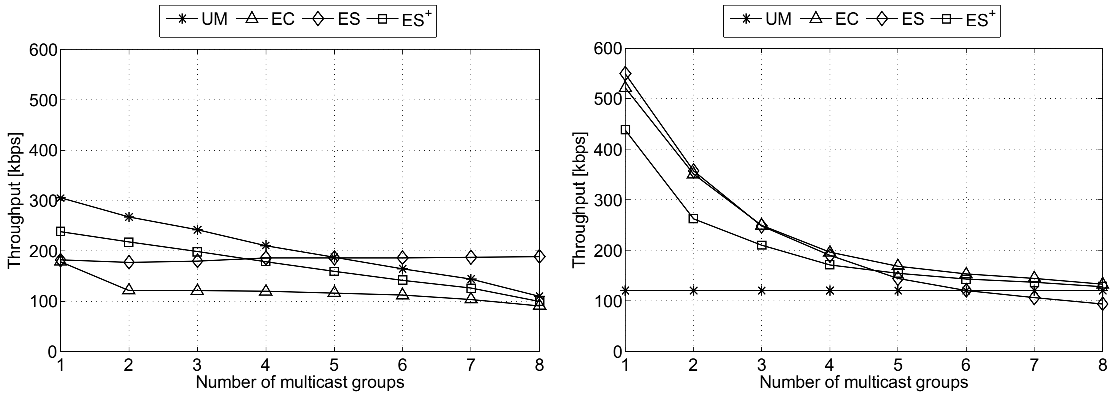
In Fig. 2 is depicted the performance for Scenario B. It emerges that the ES is not effective since it does not



(a) Unicast users

(b) Multicast users

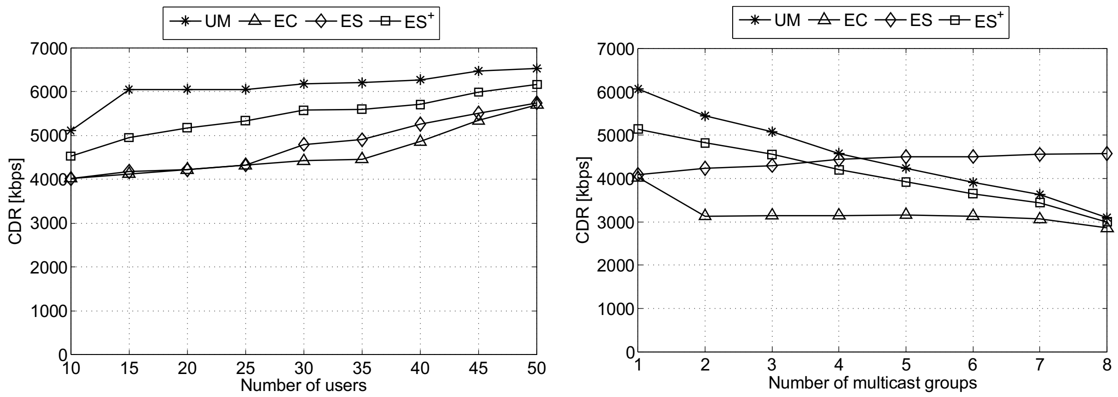
Fig. 1. Throughput performance in Scenario A.



(a) Unicast users

(b) Multicast users

Fig. 2. Throughput performance in Scenario B.



(a) Scenario A

(b) Scenario B

Fig. 3. Performance in terms of Channel Data Rate.

TABLE III
SIMULATION PARAMETERS

Cell radius	500 m
Frame Structure	Type 2 (TDD) [1]
TTI	1 ms (11 OFDM data symbols plus 3 control symbols)
Cyclic prefix/Useful signal frame length	16.67 μs / 66.67 μs
Duplexing mode	TDD
Carrier Frequency	2.4 GHz
eNodeB Tx power	46 dBm
Noise power	-174 dBm/Hz
Path loss	128.1 + 37.6 log(d), d[km]
Shadowing standard deviation	10 dB
RB size	12 sub-carriers, 0.5 ms
Sub-carrier spacing	15 kHz
BLER target	1%
Users Distribution	Uniform unicast, edge multicast
Traffic Type	Layered video - (121, 138, 113, 192) kbps
Number of Unicast Users	10-50
Number of Multicast Groups	1-8
Frame duration	10 ms
Simulation duration	5s (500 frames)

accomplish the minimum data rate requirement for multicast users when more than 6 groups require service in the cell. The EC always shows the poorest behavior for unicast throughput, while it shows a gain compared to ES^+ equal to 13%, on average, for the multicast throughput. Finally, by comparing the proposed scheme with UM, the difference in the unicast throughput is close 19% and the gain introduced by ES^+ in terms of multicast throughput is equal to 100%, on average.

Results in terms of channel date rate are presented in Fig. 3, both in Scenario A (Fig. 1(a)) and in Scenario B (Fig.1(b)). We can appreciate that, also in terms of CDR, the proposed ES^+ is able to substantially improve the performance of ES in both scenarios.

From above mentioned results, we underlined the effectiveness of the proposed ES^+ scheme which guarantees the delivery of minimum requested data rate to all involved services in the cell while achieving, compared to other polices, an improvement in the performance of unicast (or multicast) services without meaningfully reducing the performance of multicast (or unicast) services.

V. CONCLUSIONS

In this paper we have analyzed the problem of fairly distributing radio resources between unicast and multicast traffics in LTE networks. We have proposed a radio resource management policy which distributes system resources among unicast and multicast services by taking into account the instantaneous load conditions with the goal to improve session quality to both unicast and multicast services. In particular, the proposed approach works in two steps: it firstly performs the allocation of the resources required for the delivery of minimum requested data rate for both unicast and multicast services; then, unicast and multicast services equally share the remaining network resources. While resource assignment of additional resources to unicast users is accomplished through a maximum throughput approach, multicast services are managed through a *subgroup*-based resource allocation scheme. The presented results showed that, under different scenarios and traffic conditions, the proposed scheme is able to guarantee the delivery of minimum requested data rate to all involved services in the cell while achieving, compared to other polices, a performance improvement to unicast (or multicast) services without meaningfully reducing the performance of multicast (or unicast) services.

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