A Multi-Criteria Approach for Multicast Resource Allocation over LTE and Beyond Cellular Systems

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***Abstract*—The fast growing of multimedia applications and enhanced device (i.e., in capacity and computing) leads the network infrastructure to manage a number of users with different channel qualities, application requirements, and service constraints. In such a scenario, is evident the need to find a resource scheduling procedure able to guarantee good levels of performance not only on the network-side but also to the user-side. To this end, this paper introduces a novel approach for multicast resource allocation based on the idea of exploiting a multi-criteria decision method (i.e., namely TOPSIS) properly designed to simultaneously take into account both provider and user benefits during the spectrum allocation process. In particular, we compared a promising multicast radio resource strategy, i.e., subgrouping, tailored to exploit different cost functions represented by *(i)* local throughput, *(ii)* local fairness, and *(iii)* subgroup minimum dissatisfaction index. The obtained results, performed for the delivery of scalable multicast video flows in a Long Term Evolution (LTE) macrocell, demonstrate the effectiveness of the TOPSIS-based radio resource management scheme, which outperforms existing approaches from the literature. Indeed, it succeeds to provide higher data rate and an improved user satisfaction when considering multicast users experiencing different levels of channel and service quality.**

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

I. Introduction

THE fast diffusion of mobile devices as smartphones and tablets leads to a growing demand of high quality services like IPTV, Internet video streaming, video conferencing, telecasting of sporting events. The provisioning of these hungry-bandwidth services needing high data rates and low-latency pushes novel challenges for next-to-come fifth generation (5G) cellular systems. It is expected that the avalanche of "smart" devices and multimedia traffic will grow faster in the next years by reaches 50 billion devices and Terabites of traffic over the current cellular/wireless infrastructures [1], [2]. In this scenario, the usage of multicast services over current Long Term Evolution (LTE) and future 5G systems has been identified as a possible enabling technology to efficiently manage the traffic load and to provide a better Quality of Experience (QoE) to end-users. In particular, multicasting will allow a large amount of users to be simultaneously served with relatively low latency and higher throughput [3], [4]. As a result of these benefits, the Third Generation Partnership Project (3GPP) poses the basic for the standardization of multiast services over LTE with the name of "enhanced" Multimedia Broadcast Multicast Services (eMBMS) [5]. This standard provides the guidelines in order to support multicast transmissions over LTE-based cellular systems and covers the implementation of different functionalities related to the point-to-multipoint protocol (e.g., service announcement, joining and leaving procedures, session setup and re-configuration).

However, although multicasting aims to offer several enhancements in content delivery toward large group of users, several open issues are still under consideration over Orthogonal Frequency Division Multiple Access (OFDMA) systems, such as LTE, and also over WiFi networks [6], [7]. The most challenging issue is related to the multi-user diversity and to the different channel quality (and, consequently, supported transmission parameters) experienced by the users in a multicast group. In fact, the limited spectral efficiency provided by the group-based management, mainly caused by cell-edge users characterized by poor channel quality conditions, forces the group to be served with a robust modulation and coding scheme (MCS) to guarantee a more reliable transmission at the expense of the transmission data rate. On the contrary, serving multicast users experiencing high channel qualities improves the system spectral efficiency at the expense of users that are in bad channel conditions. Moreover, starvation may occur for users requiring videos with lower throughput constraints if, to increase the system capacity, preference is given to those asking for a higher throughput [8]. To overcome these issues, a possible idea is introducing a link-adaptation procedure, based on the channel quality feedback transmitted by multicast users. Hence, according to these feedbacks, users are grouped in subgroups thus exploiting the user-diversity and achieving benefits either at the user- and network-side.

Therefore, the aim of this work is to propose a Radio Resource Management (RRM) technique based on *subgrouping* with the joint use of *scalable video coding* (SVC) [9]. According to this technique, the video to be delivered is split into several layers and this approach could be exploited in the RRM step to allocate different layers to different subgroup of users according to their MCS. As a result, users with poor channel qualities receive only the base layer, whereas users that experience a better channel condition are served with enhancement layers (i.e., these will improve drastically the perceived video quality). In addition to subgrouping and SVC, *frequency selectivity* [3] is exploited by managing the assignment of each frequency resource to the subgroup that guarantees the highest value of a defined cost function. Then, the scheduling decision is taken through the use of a multi-criteria decision making method, namely *Technique for Order of Preference by Similarity to Ideal Solution* (TOPSIS) [10].

The novelty of this work is that we exploit TOPSIS in a *real-time* way since it is commonly used *a-posteriori* to decide, for example, the approach that guarantees the best performance among a set of different approaches by considering different performance metrics. As a consequence, the novel TOPSIS-based RRM approach proposed in this paper is able to achieve a better *trade-off* between throughput, fairness [11] and user's satisfaction index. In particular, this result is also confirmed by a simulation campaign where it is shown that the proposed technique achieves higher performance compared to the different RRM approaches considered.

The remainder of this paper is organized as follows. In Section II we provide a literature review related to our research work whereas the reference system model is described in Section III. The proposed RRM technique with related cost functions is described in Section IV. In Section V we commented the obtained simulation results and conclusive remarks are summarized in Section VI.

II. Related Work

The growth of the multimedia applications and number of enhanced devices poses tremendous challenges about the increasing of the radio resource utilization and services demand over mobile systems. In such a scenario, Point-to-Multipoint (PtM) transmissions improves the resource utilization compared to Point-to-Point (PtP) transmission, and the achievable gain increases with the number of UEs. Nevertheless, the main disadvantage of PtM is that the MCS of the transmitted multicast flow should be selected to guarantee successful reception to all the multicast subscribers in the cell.

Generally speaking, two different strategies for content delivery have been proposed in literature: *(i)* single-rate and *(ii)* multi-rate schemes. In the former case, a typical solution is represented by the *conventional multicast scheme* (CMS) where all the users within a multicast group are served based on the Modulation and Coding Scheme (MCS) of the user with worst channel condition [12]. Even if this approach provides high network coverage, fairness [13], [14] and high reliability, the potentials of the LTE systems are not fully exploited when the multicast group size increases drastically (i.e, users experience low data rates due to the presence of group members with poor channel capabilities).

To overcome these issues, the *opportunistic approach* [15] has been proposed in literature. The aim of this approach is to serve, during each Transmission Time Interval (TTI), only the "best" portion of multicast members able to maximize a given cost function, e.g. spectral efficiency or throughput. Nevertheless, although it exploits the multi-user diversity in resource allocation, the multicast gain could be limited due to the lower number of users successfully served in each time slot compared to the CMS. In addition, even if opportunistic approaches can achieve long-term fairness [16] (which can be considered suitable in applications such as file delivery), they cannot achieve short-term fairness (since not all users are served within every time slot) that, on the contrary, is more important in streaming applications.

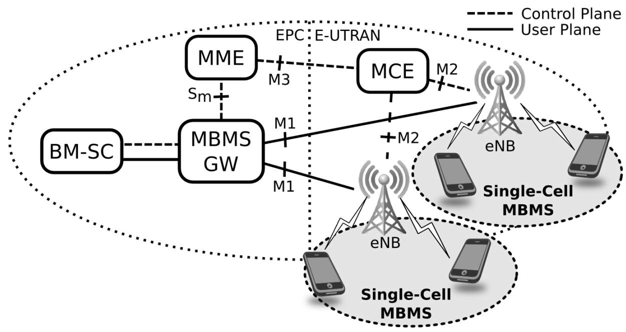


Fig. 1. Reference scenario: eMBMS architecture for LTE.

Focusing on provide a better trade-off between throughput and fairness, a promising scheme for multicast environments is represented by the *subgrouping* [17]. It divides the users into different subgroups based on perceived channel quality and serves all of them in the same TTI [18]. As a result, it is able to improve the session quality of the users by overcoming the typical issues related to the previous mentioned multicast approaches [17].

Nevertheless, since subgrouping could exploit different cost functions to assign the radio resources to the end-users, is still really challenging to state, in an effective way, which is the most performing cost function to be used [19]. According to this issue, in this paper we proposed a TOPSIS-based RRM approach that exploits a combination of the subgrouping technique and the TOPSIS[1], algorithm. This novel approach, is based on the TOPSIS concept that the most efficient solution has the shortest geometric distance from the ideal solution and the longest geometric distance from the negative solution (i.e., please refers to [10] for more detailed information). Therefore, we apply this rule in the selection of the subgroup that is able to guarantee the best trade-off among different cost functions. In particular, we use an extension of the TOPSIS method that exploits the fuzzy logic by evaluating the possible solutions with a similarity approach [20].

III. System Model

The reference scenario is represented by a single-cell multicast system where a LTE base station (i.e., the eNodeB) serves all the users (though a multicast transmission) within its coverage area. Therefore, multicast services are managed with the eMBMS, illustrated in Fig. 1, which is able to guarantee optimized transmissions of multicast and broadcast sessions. The users are distribute uniformly in the eNodeB coverage and, based on the subgrouping approach, they are split into several groups, each one receiving a different video quality according to SVC.

The LTE downlink interface uses the OFDMA technique where the available radio spectrum is split into several Resource Blocks (RBs[2]). The total number $\mathcal{B}$ of available RBs

[1]We remark that, differently from the common *a posteriori* usage of TOPSIS, in our paper it is executed *a priori* within the proposed scheduling algorithm

[2]The RB corresponds to the smallest time-frequency resource (12 subcarriers) that can be allocated to a UE in LTE

depends on the system bandwidth configuration and is managed by the packet scheduler, implemented at the eNodeB side. In addition, Channel Quality Indicator (CQI) feedbacks from the multicast users are exploited by the packet scheduler to properly manage, on a *per-group* basis, the transmission parameters and the allocation of the $\mathcal{B}$ RBs. Let denote $\mathcal{N}$ the number of RBs available after each allocation.

Let us indicate with $\mathcal{G}$ the *multicast group set*, which includes all the groups served by the eNodeB. Let $\mathcal{K}_g$ be the *user set* which collects the users that joined the multicast group $g \in \mathcal{G}$, with $\sum_{g=1}^{G} \mathcal{K}_g = \mathcal{K}$, and $\mathcal{K}$ the total set of users in the system. We indicate with $u_{c,g}$ the number of users with a CQI value c corresponding to a MCS level $m = \{1, \ldots, M\}$, belonging to the group g. Let us denote with $\mathcal{S}_g = \{s_{g,1}, s_{g,2}, \ldots, s_{g,m}\}$ the *subgroups set* belonging to the group g, where $s_{g,m}$ is composed by $\mathcal{K}_{g,m} \subseteq \mathcal{K}_g$ users belonging to group g that experience a channel quality $c_{g,k} \geq c_m$. Where c_m is the CQI value that support the support the MCS level m. In addition, we define with b_m the data rate obtained by transmitting in a given RB with a MCS index m (i.e., the MCS level is set accordingly to CQI), r_m the number of RBs assigned to a MCS level m and $x_{k,m}$ the $k-th$ user with supported MCS level m. Then, we identify with $\mathcal{C}$ the *CQI set* and with $c_{g,k} \in \mathcal{C}$ the CQI value experienced by the user k belonging to the group g.

Each multicast group is served with a video flow encoded through a SVC technique. The base layer (BL), which is essential for decoding the whole video frame, is received by all the multicast group members, whereas each enhancement layer (EL) is delivered only to a subgroup of users based on the channel quality they are able to experience [3]. Let L_g be the number of layers of the video flow delivered to the group g. We define $\mathcal{K}_{g,l} \subseteq \mathcal{K}_g$ the subset of users that joined the multicast group g and that receive the $l-th$ layer (with $l = 0, 1, \ldots, L_{g-1}$), where $l = 0$ indicates the BL, $l = 1$ the first EL, $l = 2$ the second EL, and so on. Since each layer has a fixed data rate to achieve a given video quality, $d_{g,l}$ denote the number of bits related to the $l-th$ layer relevant to the multicast flow of the group g. Finally, $N_{g,l} \subseteq N$ represents the set of RBs selected for the transmission in a single layer layer l.

We want to remark that the proposed TOPSIS-based RRM technique meets the constraint that the BL shall be delivered to all the multicast receivers of a given group so that we have: $K_{g,0} = K_g, \forall g \in G$.

IV. Subgroup Formation Problem and Considered Cost Functions

A. Subgrouping Formulation

As discussed above, in our approach we use TOPSIS in order to select the best group/subgroup to serve based on certain cost functions of interest. In this subsection, indeed, we provide a brief analytical discussion about the subgrouping analytical formulation and the different cost functions we take into consideration for our problem. In particular, the subgroup formation problem can be written, in a general form, as follows:

$$\mathbf{\Pi} = \arg\max_{r_m, x_{k,m}} \left\{ \sum_{m=1}^{M} \phi(b_m, r_m) \sum_{k=1}^{K} x_{k,m} \right\} \quad (1)$$

$$\text{s.t.} \sum_{m=1}^{M} r_m = N \quad (2a)$$

$$r_m \in \{0, 1, \ldots, N\}, \quad m = 1, \ldots, M \quad (2b)$$

$$\sum_{m=1}^{\ell_k} x_{k,m} = 1, \quad \sum_{m=\ell_k+1}^{M} x_{k,m} = 0, \quad k = 1, \ldots, K \quad (2c)$$

$$x_{k,m} \in \{0, 1\}, \quad k = 1, \ldots, K, \; m = 1, \ldots, M \quad (2d)$$

$$\frac{1}{K} \sum_{k=1}^{K} x_{k,m} \leq r_m \leq N \sum_{k=1}^{K} x_{k,m}, \; m = 1, \ldots, M \quad (2e)$$

where $x_{k,m}$, $k = 1, \ldots, K$, $m = 1, \ldots, M$, is equal to "1" if a given multicast member has the $m-th$ MCS level, and "0" otherwise. Further, Eq. (1), $\phi(b_m, r_m)$ indicates a generic cost function P, whereas the constraint (2a) guarantees that the whole RB set is exploited for serving the subgroups. Then, the constraints (2c) take into account the initial configuration, with the requirement that the MCS level must be in accordance to the MCS level corresponding to the CQI initially reported. Finally, all considered constraints (2a)-(2e) involve that:

$$\begin{cases} r_m = 0, & \text{if } \sum_{k=1}^{K} x_{k,m} = 0 \\ 1 \leq r_m \leq N, & \text{if } \sum_{k=1}^{K} x_{k,m} \geq 1 \end{cases} \quad (3)$$

i.e., a nonzero RB value is assigned only to subgroups with at least one user.

B. Cost Functions

1) Local Throughput Maximization: The Local Throughput Maximization (LTM) cost function is based on the maximization of a cost function *P* defined as the Aggregate Data Rate (ADR), that is the sum of data rate values obtained by all the multicast members. In particular, the aim of this function is to serve the subgroups (among all the possible combinations) that is able to maximize the ADR within a given group. We remark that, maximizing the local ADR does not translates in achieving the maximum overall ADR. Indeed, the cost function related to the LTM problem can be written as:

$$\mathbf{\Pi^{LTM}} = \arg\max_{\mathbf{R} \in \mathcal{R}} \left\{ \sum_{c=1}^{C} d_c^{\mathbf{R}} u_c \right\} \quad (4)$$

2) Local Fairness: The Local Fairness (LF) scheduling aims to improve the fairness while increasing the multicast throughput for a given combination of subgroups. In particular, Local Fairness resource allocation can be achieved through the maximization of the sum of the logarithm of the data rate [21] belonging to the different users of the subgroup:

$$\mathbf{\Pi^{LF}} = \arg\max_{\mathbf{R} \in \mathcal{R}} \left\{ \sum_{c=1}^{C} (\log d_c^{\mathbf{R}}) u_c \right\} \quad (5)$$

3) Subgroup Minimum Dissatisfaction Index: The Subgroup Minimum Dissatisfaction Index (SMDI) is based on the optimization of a cost function conceived to guarantee an increased throughput with respect to the PF policy without meaningfully affecting the fairness among the multicast members.

In particular, this new metric is based on the *"dissatisfaction"* experienced by users within a subgroup, computed as the weighted difference between the maximum data rate supported by a UE B_c^{MAX} and its effective achieved data rate:

$$w_c^{\mathbf{R}} = \frac{B_c^{MAX} - d_c^{\mathbf{R}}}{B_c^{MAX}} \tag{6}$$

The minimum dissatisfaction ($w_c^{\mathbf{R}} = 0$) is achieved when the assigned data rate is equal to the maximum allowable one ($d_c^{\mathbf{R}} = B_c^{MAX}$) within a given group. The considered cost function is defined as the average dissatisfaction index over the set of K_g users, named *Subgroup Dissatisfaction Index* (SDI), while the SMDI resource allocation policy aims to select the subgroup configuration $\mathcal{S}_g$ that minimizes the SDI and meets both fairness and throughput requirements :

$$\mathbf{\Pi^{SDI}} = \arg\min_{\mathbf{R} \in \mathcal{R}} \left\{ \frac{1}{K_g} \sum_{c=1}^{C} w_c^{\mathbf{R}} u_c \right\} \tag{7}$$

V. Proposed TOPSIS-based RRM Strategy

The idea behind our proposed approach is to guarantee a high trade-off among throughput, fairness and user's satisfaction index to all the multicast members in the network coverage. We assume that data are grouped on a per-layer basis, i.e., bits relevant to a given video layer are managed by the packet scheduler as a single data unit. According to this model, the data unit corresponding to a given layer is scheduled only if the units associated to the previous layers have been already scheduled.

The aim of this work is to exploit, during the scheduling procedures, the TOPSIS algorithm as a real-time decision maker in order to efficiently deliver data among the users and improve the perceived QoE. The resource allocation algorithm relies on TOPSIS decision [20] to select which subgroup has to be served in a give time slot in order to guarantee a better trade-off with respect to a set of cost functions (as described in more details in the next section, we consider the *maximum throughput*, *proportional fairness*, and *minimum dissatisfaction index*).

Our proposed approach can be divided into three on three main phases. The three steps are shown in Fig. 2 and described in the following.

Step 1. CQI collection: the eNodeB collects the CQI feedback from each UE belonging to each multicast group (i.e., $c_{g,k} \forall k \in \mathcal{K}_g$). Subsequently, it creates the *user CQI distribution* vectors $\mathbf{U_g} = \{u_{g,1}, u_{g,2}, \ldots, u_{g,C}\}$, where $u_{g,c}$ is the number of UEs with a CQI value equal to c for each $g-th$ group; thus $\sum_{c=1}^{C} u_{g,c} = K_g$.

Step 2. BL assignment: during this phase the BL is allocated to all users of each group. Therefore, each $g-th$ flow is transmitted with MCS m, that is the minimum MCS among those supported by the users of multicast group g. Once m_g is computed for each group, then the iterations for BL assignment start. In particular, the resource allocation is accomplished depending on the cost function computed by TOPSIS for each group. The G groups are the *attributes* (i.e., in [10] identified as $A = A_1, A_2, \ldots, A_g$) to be classified, and these ones are ranked according to a set of *criteria* (i.e., $C = C_1, C_2, ..., C_n$). The criteria set $\mathcal{C}$ consists of three different cost functions: *(i)* maximum throughput (MT), *(ii)* proportional fairness (PF), and *(iii)* minimum dissatisfaction index (MDI). Hence, through the TOPSIS approach, during this phase we have all the groups ranked based on the criteria considered. The g^* group with the highest rank is served and $\mathcal{N}_{g^*,0} \subseteq \mathcal{N}$ RBs are allocated to g^*. In particular, $\mathcal{N}_{g^*,0}$ depends on $d_{g^*,0}$ and m_{g^*}. If $\mathcal{N}_{g^*,0} > \mathcal{N}$, then g^* is deleted from the $\mathcal{G}$ set. Once the group g^* is selected, the set $\mathcal{N}$ of available resources is updated and the parameter l_g (i.e., the index value of the next layer to be delivered to the multicast group) is set to 1. Iterations stop either when all groups are served or when no more RBs are available.

Step 3. EL assignment: in the last phase, remaining RBs are used to assign ELs to the multicast users. From the previous phase, the $\mathcal{G}$ set includes the groups served with the BL, and $\mathcal{N}$ indicates the resources still available after the BL assignment. In order to assign the ELs, the algorithm check if the RBs needed by each subgroup $s_{g,m}$ are available and if $\mathcal{N}_{s_{g,m},l_g} > \mathcal{N}$, then $s_{g,m}$ is deleted from the the $\mathcal{S}_g$ set. Furthermore, if $\mathcal{S}_g = \varnothing$, g is deleted from the $\mathcal{G}$ set. After that, the algorithm computes the TOPSIS algorithm (i.e. as already explained in the BL assignment phase) for each subgroup $s_{g,m} \in \mathcal{S}_g$, $\forall g$. We want to remark that in this case the set of attributes to be classified are not the groups anymore, but consists on the subgroups (i.e., $A_g = A_{g,1}, A_{g,2}, \ldots, A_{g,m}$). Once TOPSIS has computed the rank value $\mathcal{T}$ for each subgroup, the result could be identified as the best subgroup s^* that assure the best trade-off among the considered cost function:

$$s^* = \arg\max_{s_{g,m} \in \mathcal{S}} \{\mathcal{T}\} \qquad , \ \mathcal{S} = \bigcup_g \mathcal{S}_g. \tag{8}$$

Hence, layer l_{g^*} is scheduled for the group g^* with MCS m[3] and $\mathcal{N}_{s_{g,m},l_g}$ RBs are assigned to s^*. Then $\mathcal{N}$ is updated and l_{g^*} is increased by 1. Finally, the group g is deleted by the $\mathcal{G}$ set if all its enhancement layers have been assigned. As for the BL assignment, the iterations stop either when no more resources are available or when all layers have been transmitted towards all multicast groups.

VI. Performance Evaluation

In order to investigate and provide the goodness of the proposed TOPSIS-based approach, for our simulation campaign we considered a reference scenario where the member of the multicast group are randomly distributed in a given area of interest within a LTE macrocell coverage. In particular, we want to focus on small-scale scenario where a high density

[3]We wish to remark that if the flow is transmitted with MCS = m, all users with CQI corresponding to a MCS level less than m are not able to receive the content.

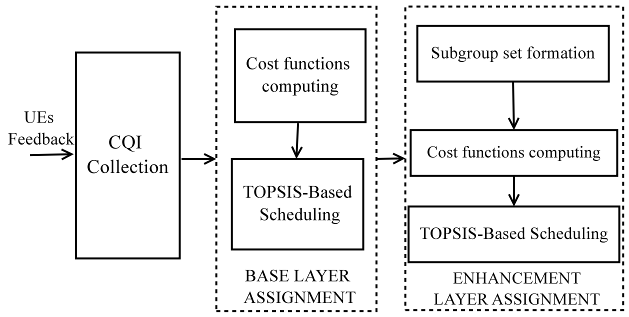
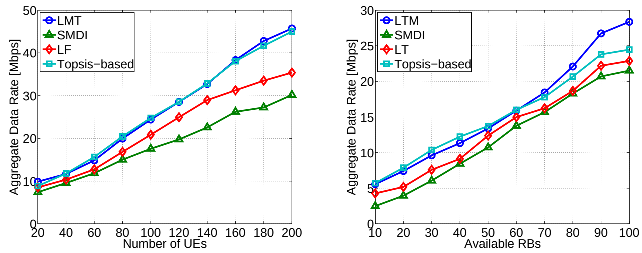


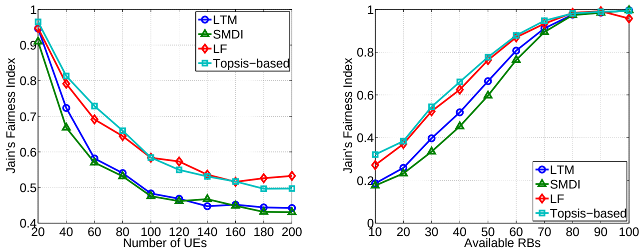
Fig. 2. Reference scenario: The three phases of the proposed RRM strategy.



(a) Varying number of UEs (RBs are set to 100).

(b) Varying available RBs (number of UEs is 100).

Fig. 3. Aggregate data rate.



(a) Varying number of UEs (RBs are set to 100).

(b) Varying available RBs (number of UEs is 100).

Fig. 4. Jain's fairness index.

of users is distributed is a relatively concentrated area, such as stadiums, theaters, fares, or shopping malls. Different video multicast video sessions are activated for each multicast groups (i.e., in our case we consider 10 multicast group) in the simulated cell; the source data rate settings of the base layer (BL) and enhancement layers (E1, E2, and E3) are generated according to [22]. In addition, we simulated a video delivery period of 1s, i.e., 1000 TTIs. Each simulation run has been repeated several times to get 95% confidence intervals for the most relevant results. Main system parameters can be found in Table I.

TABLE I
MAIN SIMULATION PARAMETERS

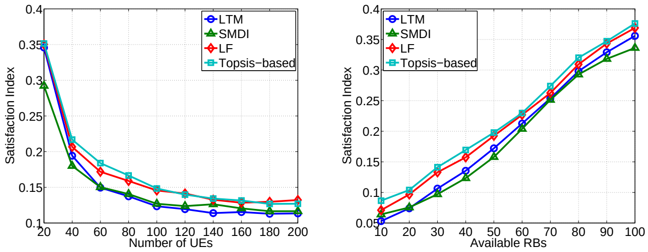
Parameter	Value
Cell radius	500 m
Frame Structure	Type 2 (TDD)
TTI	1 ms
Number of Groups	10
Carrier Frequency	2.1 GHz
eNodeB Tx power	46 dBm
Noise power	-174 dBm/Hz
Path loss	128.1 + 37.6 log(d), d[km]
Shadowing standard deviation	10 dB;
Sub-carrier spacing	15 kHz
BLER target	10%
# of Runs	500

We compared the performance of the proposed algorithm with three RRM techniques exploiting the cost functions (i.e., in a separate manner) already presented in Section IV-B: *(i)* LTM, *(ii)* LF and *(iii)* SMDI. The application considered is modelled to characterize different video flows, delivered through the SVC technique, divided into four layers ($L = 4$) each one with its own bitrate (i.e., refers to [22] for the values of each layer). Further we analize the performance by varying two system level parameters represented by *(i)* the number of users within a multicast group (i.e., from 20 to 200) and the number of RBs available to perform the multicast transmissions (i.e., from 10 to 100). Then, the metric used to compare the different multicast RRM approach are: *(i)* the aggregate data rate, *(ii)* the Jain's fairnes index, and *(iii)* the satisfaction index (i.e., described in Section IV-B.

The first metric we evaluated in our simulation campaign is represented by the ADR, shown in Fig. 3, either by varying the number of users and the available RBs. Generally, the ADR achieved by the users grows linearly increasing with the number of users and when the radio spectrum available become higher. As we can notice, LMT achieves the best performance compared to the other approach on average. However, the proposed TOPSIS-based approach is able to provide ad ADR close to that one of the LMT algorithm to the multicast members.

In Fig. 4 the Jain's fairness is presented for the four RRM approach considered. The result shows that when the available bandwidth is low (i.e, around 5 MHz) the theoretical throughput is unfairly distributed among the users whereas if we have a full bandwidth available (i.e., 20 MHz) we are able to deliver efficiently the data rate only when the number of user is relatively low (i.e., between 40 and 60 UEs). As for the ADR, also in such a case the proposed approach reaches performance that are close to the algorithm that is expected to achieve the better performance (i.e, the LF scheme). The motivation is related to the fact the TOPSIS helps the scheduler to select instantaneously (i.e., during the RBs assignment procedures) which subgroup has to be served in order to achieve, on average, a better trade-off among ADR, Jain's fairness index, and satisfaction index.

The last result we provide is represented by the satisfaction index (i.e., shown in Fig. 5). As we can observe, then trend of Fig. 3 and Fig. 4 is confirmed also for the satisfaction index case. In fact, the TOPSIS-based RRM algorithm is able to guarantee a high satisfaction among the system users so that the users download the requested video session with a data rate that is close to the theoretical capacity given by their channel



(a) Varying number of UEs (RBs are set to 100).

(b) Varying available RBs (number of UEs is 100).

Fig. 5. Satisfaction index.

quality (i.e., CQI). In addition, it is interesting to notice that the SMDI approach, that was expected to provide the better results, actually is the one among the other that perform the worst. The reason for this behavior can be explained by the fact that the cost functions described in Section IV-B aim to maximize a certain metric by considering a set of subgroups thus not taking into account the overall system performance.

In conclusion, with this work we want to claim that using a multi-decision maker as TOPSIS for delivery multicast services in 4G and future 5G systems, can be useful for the packet schedule to manage in a effective and efficient way the increasingly few radio resources available. Indeed, using the proposed TOPSIS-based approach, we are able to deliver a multicast video session to the end user with high data rate by assuring, in addition, high levels of fairness (i.e., on the operator-side) and user satisfaction (i.e., on the user-side).

VII. Conclusions

In this paper we propose a novel multicast resource allocation policy based of the well-know multi-criteria decision maker TOPSIS. In particular, we evaluate the effectiveness of the proposed RRM scheme by taking into consideration system level metric such as ADR, Jain's fairness index and user satisfaction. The idea behind this work has been, indeed, to demonstrate how the usage of a decision maker during the resource assignment can increase the performance by providing a better trade-off among the delivered data rate, the radio resource distribution and the QoE experienced by the multicast users. In particular, obtained results show that the TOPSIS-based algorithm is able to deliver high levels of fairness among the users by guaranteeing, as the same time, their satisfaction (i.e., expressed as the gap between the capacity and throughput averaged for the number of users) and without strongly affecting the throughput performance among the users belonging to the same multicast group.

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