Effective Resource Allocation in 5G-Satellite Networks

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Abstract—This paper addresses the radio resource management of multicast transmissions in the emerging fifth generation satellite systems (5G-Satellite). A subgrouping approach is exploited to provide video streaming services to satellite users by splitting any multicast group into subgroups. This allows an effective exploitation of multi-user diversity according to the experienced channel conditions and the achievement of a high throughput level. The main drawback is the high computational cost usually related to the selection of the optimal subgroup configuration. In this paper we propose a low-complexity subgrouping algorithm that achieves performance close to optimum. Our solution is suitable for implementation in practical systems, such as Satellite-Long Term Evolution (S-LTE), since the computational cost does not depend on the multicast group size and the number of available resources. Through simulation campaigns conducted in different radio propagation and multicast group environments, the effectiveness of the proposed subgroup formation scheme is assessed.

Index Terms—Satellite, LTE, 5G, OFDMA, Multicast, RRM.

I. INTRODUCTION

TODAY, 4.3% of the European population lives in areas without access to wired or mobile Internet, because the deployment of optical fiber cables is unfeasible in terms of investments. Moreover, a growing number of people expects to access to the same services they have at home even while traveling on cruise liners, flights and high-speed trains. This ubiquitous coverage is achieved by extending the emerging fifth generation (5G) networks with the satellite’s wide coverage. Furthermore, it is expected that 5G satellite systems will also provide human-to-machine and machine-to-machine communications by introducing new challenging scenarios derived from the integration of satellite networks with heterogeneous terrestrial systems.

The main contribution of satellite transmissions, thanks to their broadcast/multicast and broadband capabilities, is the off-loading of terrestrial 5G networks in different cases, such as emergency scenarios [2]. Significant advantages are expected for bandwidth hungry services such as video-based traffics, big data downloading and, in particular, for group-oriented services (e.g., multicast), considered the value-added of Satellite-Long Term Evolution (S-LTE) [3][4], that will play an important role in the 5G-Satellite standardization. Nevertheless, different issues need to be evaluated to achieve effective satellite communications. A challenge is related to the long delay of the satellite link [5][6] which requires that the link adaptation process has to be sensitive to the instantaneous variations of channel conditions of the users. For this reason, the misalignment between the channel quality feedback transmitted to the network and the channel quality experienced by the mobile users at the reception of data traffic is a key component of the S-LTE network. Therefore, new techniques of channel quality prediction have to be investigated to improve the efficiency of link adaptation. Many works in literature deal with the prediction problem [7]. Among those, in this paper we adopt the Autoagressive Integrated Moving Average Model (ARIMA) [8] which is characterized by a simple implementation and guarantees high accuracy.

The main concern investigated in this paper deals with the radio resource management (RRM) of multicast services over S-LTE, which poses several issues to be solved in order to offer adequate session quality to involved terminals while guaranteeing high spectrum utilization. In this direction, several approaches have been proposed in the literature. According to a conservative approach, the whole set of destinations is served by adapting the transmission parameters to those supported by the user experiencing the worst channel conditions. To overcome the limitations of this approach, which does not efficiently exploit the available spectrum, the opportunistic approach [9] has been proposed to allow meaningful improvements in terms of instantaneous throughput by dynamically changing the portion of served multicast members on a timeslot basis. Since the whole multicast group is not successfully served in each time slot, opportunistic multicasting requires the exploitation of rateless codes to guarantee the data stream delivery to users served in different time slots.

An effective approach overcoming the above mentioned schemes is the subgrouping [10] which is based on the idea of dividing the group members into subgroups according to the experienced channel conditions. Subgrouping allows to efficiently serve all the multicast destinations and it has the advantage to be properly tunable to perform resource allocation with different target cost functions. The high computation complexity of subgrouping still limits its effectiveness in practical systems. The contribution of this paper is to propose a novel scheme, the Low-Complexity Subgrouping (LCS), able to achieve performance close to the optimal one while handling the subgroup formation with limited computational load.

The remainder of this paper is structured as follows. Section II focuses the S-LTE systems and the related work. Section III discusses the subgroup formation problem while in Section IV we present our proposal. Section V focuses on the performance analyses. Finally, conclusive remarks are given in Section VI.
II. RESEARCH BACKGROUND

A. The Satellite-LTE Architectures

The role of satellite in 5G networks is still under discussion [11]; nevertheless, the scientific community is addressing on exploiting the emerging satellite-LTE architecture (shown in Fig. 1) as a possible starting point for the 5G-Satellite definition. The S-LTE architecture is composed by a (i) GEO satellite (36000 km far away from the Earth), equipped with a S-LTE air interface [3], [5] that communicate with the S-LTE terminals and a (ii) LTE ground component that performs the radio access procedures [12]. In our architecture, the support of group-oriented services is handled through the Multimedia Broadcast Multicast Service (MBMS) standard. The ground component hosts the Satellite eNodeB (S-eNodeB), the entry point for the satellite link, which handles the configuration of physical layer parameters, e.g., Modulation and Coding Schemes (MCSs) of the S-LTE radio interface. The Multi-Cell/Multicast Coordination Entity (MCE) is used for transmission parameters adaptation in case of a multicast transmission involving different S-eNodeB. The MBMS Gateway (MBMS-GW) is a logical entity whose principal function is to forward packets to S-eNodeBs while the Broadcast Multicast-Service Center (BM-SC) is the MBMS traffic source which also accomplishes service announcement and group membership functions. The S-eNodeB is connected to the core network by means of the S1 interface. In particular, with the S1-u link to the Serving Gateway (S-GW) and Packet Data Network Gateway (P-GW) and with the S1-c link with the Mobility Management Entity (MME) [5]. Multiple S-eNodeBs are linked each other with the X2 interface in order to support the active-mode mobility. This interface is also used for further functions, such as the interference cancellation techniques (i.e., ICIC) and to support mobility between neighboring beams.

The downlink S-LTE air interface is based on Orthogonal Frequency Division Multiple Access (OFDMA). The resource allocation is performed in terms of Resource Blocks (RBs), i.e. the basic time-frequency resource. The RRM dynamically adapts the MCSs according to the Channel Quality Indicator (CQI), an indication of the maximum supported MCS. The propagation delay between terminals and the P-GW is about 270ms in line-of-sight (LOS) conditions [5].

B. Related Work

This paper focuses on the RRM of multicast services in satellite environment, where RRM must be performed on a per-group basis since a group of users is simultaneously served by the satellite with one single radio transmission. As a consequence, the selection of transmission parameters (i.e., MCS) has to take into account the channel qualities of all involved multicast members.

As mentioned in Section I, traditional approaches like conservative and opportunistic multicasting [9] suffer from inefficiencies in terms of poor spectrum efficiency and inadequate short-term fairness, respectively [10]. Nevertheless, the former approach is robust to the long delay of satellite networks since it is aimed to select to most robust MCS among those supported by the multicast members. On the contrary, the opportunistic strategy is meaningfully influenced by the long propagation delay [10], and this limits its effectiveness.

An promising RRM scheme for multicast environments is the subgrouping [10]. It serves all multicast terminals in every time slot by splitting them into different subgroups according to their experienced channel qualities. This improves the session quality compared to other strategies. An example can be found in [10], where authors proposed a novel cost function designed to guarantee a better throughput-fairness trade-off with respect to existing policies and also demonstrated that subgrouping is robust to long propagation delays of satellite links since multicast members do not experience bit error rate increase.

The intended contribution of our paper is to handle the complexity burden of multicast subgroup formation in S-LTE systems. Indeed, the selection, based on an Exhaustive Search Scheme (ESS) or global solvers, as in [10], of the optimal subgroup configuration introduces a high load and limits the effectiveness of subgrouping in practical satellite systems. For this reason, near-optimal approaches have been designed to drastically decrease the time required for resource allocation. In the design of low-complexity schemes, the main issues to be considered are in terms of scalability (i.e., achieving a complexity which does not increase with the number of multicast members and the number of resources available in the system) and achieved performance which has to be as much as possible close to the optimal one.

In this paper we design the Low-Complexity Subgrouping (LCS) algorithm, tailored to effectively perform subgroup formation in S-LTE systems. Our proposal enhances the work in [10] since it proposes an effective low-complexity scheme which reduces the burden of subgroup formation. The LCS scheme is based on a merging approach [4] which aims

1 An example of this technique can be found in [13], where authors proposed a near-optimal scheme for terrestrial OFDMA-based systems. This solution is not suitable for satellite networks since it strongly suffers in terms of scalability when the number of multicast destinations becomes large.
at iteratively reducing the number of enabled subgroups to improve the target cost function. The goals of the proposed LCS are: (i) high scalability since the computational cost does not depend on the number of multicast terminals and available resources; (ii) close to optimum performance through a novel resource allocation strategy tailored for S-LTE subgrouping; (iii) near-optimal performance which are demonstrated in different multicast scenarios and radio propagation conditions.

III. SUBGROUP BASED RRM ALGORITHM

A. Subgroup formation

We consider a satellite stream transmitted towards one multicast group, denoted by the $K$ set. The subgroup formation is performed by the S-eNodeB according to the CQI values of multicast terminals and the available RBs, indicated by $N$.

Each S-LTE terminal belonging to $K$ transmits the CQI $c_k$ (with $k \in K$) to the S-eNodeB. We assume that $c_k$ is represented by an integer value which varies from 1 to $M$ (where $M$ are the MCS levels defined in S-LTE).

At the reception of CQI values, the S-eNodeB creates the $U = \{u_1, u_2, \ldots, u_M\}$ vector, where $u_m = \{|k \in K|c_k = m\}$ is the number of terminals having a CQI equal to $m$.

According to $U$, the S-eNodeB selects the subgroup configuration to enable by computing the number of subgroups with the relevant MCSs and assigned resources. In detail, the S-eNodeB creates the resource distribution vector $R = \{r_1, \ldots, r_M\}$, which lists the number of RBs assigned to each subgroup. If $r_m \neq 0$, then the subgroup associated to the MCS $m$ is enabled and $r_m$ represents the amount of RBs assigned to such a subgroup (i.e., $0 \leq r_m \leq N$).

According to $R$, all users with the same CQI will be gathered in the same subgroup, while a given subgroup may include S-LTE terminals with different CQI values. The S-LTE terminals experiencing a CQI value equal to $m$ will be served with the following data rate:

$$d_m = \{\max(b_ir_i), \ i = 1, 2, \ldots, m\}$$

where $b_i$ the minimum attainable data rate for the $i$-th MCS, i.e., the data rate obtained when one RB is transmitted with a MCS equal to $i$. According to (1), each multicast terminal is associated to the subgroup relevant to the closest supported MCS among those enabled by the S-eNodeB.

The vector $R$ is computed by the S-eNodeB to optimize a target cost function. To overcome the throughput limitation due to the presence of users with poor channel capabilities, in this paper we consider that subgroups are created with the aim to maximize the Aggregate Data Rate (ADR), i.e., the sum of data rate experienced by multicast members. This choice allows to improve the channel utilization and introduces benefits for both provider (i.e., higher spectrum efficiency) and user (i.e., higher data rate) sides.

B. The exhaustive search scheme

The S-eNodeB can exploit different schemes to compute the vector $R$. With the aim to achieve the optimal subgroup configuration, i.e., the configuration which maximizes the ADR, the S-eNodeB may exploit the exhaustive search scheme (ESS). The ESS is based on the idea of solving the following optimization problem:

$$R = \arg \max_{R} \sum_{m=1}^{M} d_m u_m$$

where, constraint (3a) shows that all the available resources are exploited by the subgrouping algorithm and constraint (3c) guarantees that all multicast destinations are served. Finally, constraint (3d) indicates that each enabled subgroup must be served with at least one resource.

To obtain the optimal $R$ vector, the ESS creates a set containing all the admissible configurations to be assumed by $R$ (denoted by $\mathcal{R}$ in the optimization problem) and, among those, selects the one which maximizes the target cost function (i.e., the ADR in our scenario). The main concern of ESS is related to the massive load in creating the search space $\mathcal{R}$. Indeed, with $M$ potential subgroups to enable and $N$ resources to share among such subgroups, the computational complexity related to the ESS policy is given by $O(M^N)$ [13]. Consequently, although ESS finds the subgroup configuration with the highest cost function value, the number of feasible solutions to evaluate exponentially increases with the number of available resources. This high complexity cost reduces the effectiveness of ESS-based approaches in satellite systems, where the long execution time jointly with long propagation delay may involve drastic channel variations of multicast users and this asks for low-complexity near-optimal algorithms. This key challenge will be the focus of the next Section, which describes the proposed low-complexity scheme.

IV. THE LCS POLICY

In this paper we propose the Low-Complexity Subgrouping (LCS) algorithm, to the aim of achieving close to optimum subgroup configurations with a very low computational burden for the S-eNodeB and, consequently, a drastic execution time reduction. The idea at the basis of LCS is to (i) iteratively select the configuration that guarantees the highest ADR increase compared to the previous step and (ii) repeat this process until no further improvements are achieved (or no more iterations can be performed).

The proposed LCS is summarized in Table I. In the initialization step, LCS collects all the users reporting the same CQI value in the same subgroup (line 1) and, as a consequence, enables as many subgroups as the different CQI values reported by the S-LTE terminals. Each subgroup enabled in this iteration is denoted by $u_m$ and collects, for a generic value $m$, the subset of users which reported a CQI value equal to $m$. As
TABLE I
THE LCS APPROACH

1: Define $u_m = \{k \in K \mid c_k = m\}$, $m = \{1, \ldots, M\}$
2: Define $M = \{m \mid u_m > 0\}$
3: Define $R = \{0, \ldots, 0\}$, $|R| = M$
4: Compute $r_m$ according to eq. (6), with $\sum_{m=1}^{M} r_m = N$
5: Compute $d_m$ according to eq. (4)
6: Compute $\Omega^t = \sum_{m=1}^{M} d_m u_m$
7: $t = 2$
8: while $t \leq |M|$ do
9:   Find $i, j \in M$ that maximize $\Omega^t$
10:  where $n = \min(b_i, b_j)$, $r_m^* = r_i + r_j$, and $u_m^* = u_i + u_j$
11:  if $\Omega^t > \Omega^{t-1}$ then
12:     Update $M = M \setminus \{i, j\} \cup \{n\}$
13:     $r_m = r_i + r_j$, with $n = \min(b_i, b_j)$
14:       $r_i = 0$, $r_j = 0$
15:     $u_m = u_i + u_j$
16:     $u_i = 0$, $u_j = 0$
17:     $t = t + 1$
18:   else
19:       Stop
20:   end if
21: end while
22: end

a consequence, the maximum number of subgroups enabled in the first iteration is bounded by the maximum number of CQI levels defined by S-LTE system, i.e., $M$ (line 2).

After the initialization step, the S-eNodeB allocates the resources (line 4) according to the following weight:

$$\alpha_m = \frac{b_m u_m}{\sum_{i=1}^{M} b_i u_i}$$

(5)

where the higher the number of users and the MCS of a given subgroup, the higher the value of $\alpha_m$. Once $\alpha_m$ is calculated, the resources are then assigned as follows:

$$r_m = 1 + \left[ \frac{\alpha_m}{\sum_{i=1}^{M} \alpha_i} (N - |M|) \right], \forall m \in M$$

(6)
i.e., with the aim to assign at least one RB to each subgroup while guaranteeing higher number of resources to subgroups related to higher $\alpha_m$ values.

Once the $R$ vector is calculated, the S-eNodeB computes the data rate $d_m$ of each subgroup as in eq. (1) and, finally, the initial ADR value, i.e., $\Omega^1$ (line 6).

After the initialization phase, LCS starts the iterations (lines 8-23) by searching through all the combinations of two subgroups to merge with the aim to increase the ADR compared to the previous iteration. The subgroup merging step is performed as follows. For example, let $M = \{m_1, m_2, m_3\}$ (with $m_1 < m_2 < m_3$) be the MCSs relevant to the subgroup configuration enabled in a generic iteration. A possible subgroup configuration should be equal to $m_1, m_3$, achieved by merging the subgroups related to MCS $m_1$ and $m_2$. In this case, the novel subgroup associated to $m_1$ will have an amount of assigned resources equal to $r_{m_1}^* = r_{m_1} + r_{m_2}$, i.e., the MCS relevant to $m_2$ is disabled and the new enabled subgroup will be served with the lowest MCS among the merged ones (i.e., $m_1$). Similarly, another possible subgroup configuration should be equal to $m_1, m_2$, obtained by merging the subgroups related to MCS $m_2$ and $m_3$. After the creation of all admissible merging configurations, the S-eNodeB computes the novel data rate for each subgroup and consequently the novel ADR value.

If there exists a novel subgroup configuration which increases the ADR compared to the previous iteration, then LCS will select this configuration as the input of the next iteration, otherwise it stops and the final output of LCS will be the subgroup configuration of the previous iteration. Hence, the LCS algorithm every step tries to reduce by one the number of subgroups to activate. This process is iterated until there is no further improvement in data rate or no subgroups to merge (i.e., the BS reaches a single-subgroup configuration).

A. Computational cost analysis

From Table I, the LCS has an overall complexity of $O(M^2)$. For each iteration, $M(M - 1)/2$ function evaluations of $\alpha$ are needed for subgroup merging and the complexity reduces at every iteration. Therefore, the LCS is more feasible for implementation compared to the ESS which requires $O(M^N)$. It is worth noticing that the complexity of LCS does not depend on the multicast group size and the number of RBs.

V. PERFORMANCE ANALYSIS

A. Simulation Settings

Simulation campaigns are carried out to assess the effectiveness of the proposed LCS. According to the guidelines in [4], we considered an application scenario consisting of two-way communications. The system deployment is based on a multi-spot coverage with frequency reuse and Frequency Division Duplexing (FDD) scheme. Main simulative parameters of S-LTE system are listed in Table II.

TABLE II
MAIN SIMULATION ASSUMPTION

| Parameter                  | Value    |
|----------------------------|----------|
| Channel Bandwidth          | 3 MHz    |
| Number of RBs              | 25       |
| FFT size                   | 2048     |
| Sub-carrier Spacing        | 15 kHz   |
| Carrier Frequency          | 2.6 GHz  |
| TTI                        | 1 ms     |
| OFDM symbol duration       | 83.33 µs |
| Sampling interval           | 32.55 ns |
| Cyclic Prefix Length       | 16.67 µs |
| Elevation                  | 40°      |
| S-LTE terminal speed       | 30 km/h  |

According to [4], we exploited a land-mobile satellite (LMS) channel simulator based on the Pérez-Fontán model [14] with three propagation conditions: (i) LOS, (ii) moderate shadowing and (iii) deep shadowing. A Loo distribution is assumed for shadowing and multipath variations relevant to each state. The transitions between the propagation conditions.
and are ruled by a 3-state Markov chain. The initial probability vector [W] and the transition probability matrix [P], listed in Table III are set according to [14]. The signal to noise ratio experienced by each S-LTE terminal is mapped onto the CQI level according to [4]. Channel conditions are assumed to be stationary within a single TTI [12].

We considered three environments: (i) Intermediate Tree Shadowed; (ii) Suburban; (iii) Open. We set the mobility speed of S-LTE terminals to 30km/h. Each simulation run has been repeated several times to get 95% confidence intervals.

### B. Simulation Results

In our first analysis we consider the performance in terms of the ADR computed by the S-eNodeB. The performance of the proposed LCS is compared with the ESS, exploited to achieve the optimal subgroup configuration which maximizes the ADR. The conservative multicast scheme (CMS) is also evaluated as a benchmark. To clearly testify the effectiveness of the proposed LCS in achieving close to optimum performance, we conducted different analyses by varying the number of multicast users from 10 to 100.

From the achieved results, shown in Fig. 2 it clearly emerges that radio channel environments drastically influence the quality perceived by multicast members (and, consequently the ADR). Indeed, for all the considered schemes, the lowest ADR performance obtained in the Intermediate Tree Shadowed scenario while the highest ADR is reached in the Open case. In the Intermediate Tree Shadowed environment, the ADR of CMS ranges from 6 to 62 Mbps; the ADR of ESS varies from 8.1 to 73.5 Mbps; finally, the performance of the proposed LCS is from 8 to 68.5 Mbps. In the Suburban case, the CMS achieves the same results as in the previous environment. This behavior demonstrates that conventional schemes are strongly influenced by the presence of users with poor channel conditions which limits the quality of the overall multicast group. The ESS ranges from 27.75 up to 164.2 Mbps, while the LCS varies from 26.7 up to 146.5 Mbps. Finally, in the Open scenario we observe a general increase in the ADR of considered schemes. In detail, the CMS shown an ADR from 48 to 482.3 Mbps, the ESS varies from 48.2 to 514 Mbps and the LCS ranges from 48.2 to 495 Mbps.

From above results, it emerges that the ADR is drastically improved with the subgrouping technique. As it is expected, the best ADR performance is obtained with the ESS, tailored to select the subgroup configuration with the highest ADR among all the admissible solutions. The proposed LCS achieves results close to optimum. As analyzed in Fig. 3 the ADR mismatch (namely, $\Delta_{ADR}$) between LCS and ESS is lower than 4% when the multicast group is composed by few members, while it becomes lower than 9% for scenarios with higher number of destinations. The $\Delta_{ADR}$ increases with the multicast members for the Intermediate Tree Shadowed and

### Fig. 2. ADR values for CMS, ESS and LCS as function of the multicast group size.

### TABLE III

| Environment          | $W$         | $P$          |
|----------------------|-------------|--------------|
| Intermediate Tree Shadowed | 0.3929 0.7193 0.1865 0.0942 | 0.3571 0.1848 0.7269 0.0883 |
|                      | 0.25 0.1771 0.0971 0.7258 | 0.4545 0.8177 0.1715 0.0108 |
| Suburban             | 0.4545 0.1544 0.7997 0.0459 | 0.091 0.1400 0.1433 0.7167 |
| Open                 | 0.5 0.9530 0.0431 0.0039 | 0.375 0.0515 0.9347 0.0138 |
|                      | 0.125 0.0334 0.0238 0.9428 | 0.375 0.0515 0.9347 0.0138 |

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### Fig. 3. ADR variation for LCS compared to ESS.
the Suburban environments, while it is constant in the Open case (in this case, it is always lower than 4%). These results underline the effectiveness of the proposed LCS in achieving performance close to the ESS under different radio channel environments and multicast group scenarios.

| TABLE IV | COMPARISON OF LCS AND ESS |
|----------------------|-------------------------|
|                        | ESS | LCS |
| Execution time [min/avg/max] | 5.4/14.3/25.5s | 1.4/3.5/4.2ms |
| ∆CQI Intermediate Tree Shaded | 75.4 % | 14.6 % |
| ∆CQI Suburban           | 16.8 % | 3.2 % |
| ∆CQI Open               | 4.2 %  | 0.6 % |
| ∆THR Intermediate Tree Shaded | 79.4 % | 11.8 % |
| ∆THR Suburban           | 19.4 % | 2.1 % |
| ∆THR Open               | 2.1 %  | 0.3 % |

A further comparison between the proposed LCS and ESS can be found in Table IV. Focusing on the execution time (i.e., the time needed by the S-eNodeB to perform subgroup formation), it emerges that LCS introduces drastic benefits compared to ESS. Indeed, the execution time of LCS is lower than 4.2 ms, while that of ESS ranges from 5.4 up to 25.5 s and this demonstrates that the proposed LCS is able to reduce the computation load at the S-eNodeB. The decrease in the execution time also allows benefits in terms of radio channel exploitation since it guarantees to better fulfill the users’ channel variation. This can be noted by analyzing the ∆CQI, i.e., the percentage of multicast members which experienced a CQI variation during the time interval between the CQI transmission towards the S-eNodeB and the reception of multicast stream (i.e., after propagation delays and subgroup execution time). We can note that ∆CQI is higher for the ESS, whose percentages vary from 4.2% up to 75.4%. This analysis shows that the long execution time of ESS has a strong impact on the users’ channel variation: a large percentage of multicast members experiences a CQI variation during the time needed by the S-eNodeB for achieving the subgroup configuration. This involves that the subgroup configuration selected by ESS should be no longer the most effective one in the instant of multicast stream reception. On the contrary, the proposed LCS shows the most interesting results, with ∆CQI varying from 0.6% up to 14.6%. Consequently, the ESS is not suitable to guarantee an effective link adaptation, since it is not able to quickly fulfill the channel variations of group members. On the contrary, our proposal is able to perform link adaptation in satellite scenarios with large round trip time.

Above mentioned considerations are further testified by investigating ∆THR, designed to measure the impact of propagation delays and long execution time on the user throughput. For any instant time, ∆THR is the difference between the throughput of multicast members in that instant (which is related to an “old” subgroup configuration since the multicast stream is received with a delay compared to the transmission of CQI feedback due to propagation delays and execution time of subgroup formation) and the “ideal” throughput that they should experience if subgroups should be performed with the channel qualities experienced by the members in that instant time. From the results in Table IV it emerges that ESS has a ∆THR which varies from 2.1% to 79.4% while the performance of the proposed LCS ranges from 0.3% to 11.8%. These results demonstrate that the proposed LCS guarantees a better link adaptation compared to ESS.

VI. CONCLUSIONS

In this paper we proposed a subgrouping RRM scheme for multicast services in 5G-Satellite systems which enhances the Aggregate Data Rate (ADR) to introduce benefits for both provider and user sides. We designed the LCS algorithm, suitable for the implementation in practical systems such as S-LTE, which does not suffer in terms of scalability since its computational cost does not depend on the multicast group size and the number of available resources. We compared the proposed algorithm with an exhaustive search in different radio channel environments and multicast group configurations. The achieved results underlined the effectiveness of our solution in guaranteeing performance close to the optimal one with a mismatch in terms of ADR less than 9%.

REFERENCES

[1] N. Celandroni, at al., “A survey of architectures and scenarios in satellite-based wireless sensor networks: system design aspects,” Int. Journal of Satellite Comm. and Networking, vol. 31, no. 1, pp. 1-38, 2013.
[2] E. Del Re, et al., “SALICE Project: Satellite-Assisted Localization and Communication Systems for Emergency Services,” IEEE Aerospace and Electronic Systems Magazine, vol. 28, no. 9, pp. 2-13, Sep. 2013.
[3] R. Khan. “System and method for Satellite-Long Term Evolution (S-LTE) air interface;” U.S. Patent Application 12/209, 436.
[4] ETSI, “Satellite Earth Stations and Systems (SES); Advanced satellite based scenarios and architectures for beyond 3G systems,” Tech. Rep. 102 662, v.1.1.1, March 2010.
[5] S. Liu, F. Qin, Z. Gao, Y. Zhang, and Y. He, “LTE-satellite: Chinese proposal for satellite component of IMT-Advanced system,” China Communications, vol. 10, no. 10, pp. 47-64, Oct. 2013.
[6] G. Aiyetoro, G. Giambene, and F. Takawira, “Link Adaptation in Satellite LTE Networks,” Journal Of Advances In Information Technology, vol. 5, no. 1, pp. 37-43, Feb. 2014.
[7] “Channel Quality Indicator (CQI) Correcting Method and Device in LTE Emission Mode 7,” China Patent CN101753190A, Jun. 2010.
[8] Z. Yadan, et al., “A modified ARIMA model for CQI prediction in LTE-based mobile satellite communications,” ICIST, pp.822-826, Mar. 2012.
[9] A. Sali, H. A. Karim, G. Acar, B. Evans, and G. Giambene, “Multicast Link Adaptation in Reliable Transmission Over Geostationary Satellite Networks,” Wireless Personal Commm., vol. 62, no. 4, pp. 759-782, 2012.
[10] G. Araniti, M. Condoluci, and A. Petrolino, “Efficient Resource Allocation for Multicast Transmissions in Satellite-LTE Networks,” IEEE GLOBECOM, pp. 3045-3050, Dec. 2013.
[11] NetWorld2020’s - SatCom WG The role of satellites in 5G, Jul. 2014 http://networld2020.eu/wp-content/uploads/2014/02/SatCom-in-5G_v5.pdf
[12] M. Amadeo, G. Araniti, A. Iera, and A. Molinaro, “A Satellite-LTE network with delay-tolerant capabilities: design and performance evaluation,” IEEE VTC-FALL, pp. 1-5, September 2011.
[13] C. K. Tan, T. C. Chua, and S. W. Tan, “Adaptive multicast scheme for OFDMA-based multicast wireless systems,” Electronics Letters, vol. 47, no. 9, pp. 570-572, April 2011.
[14] F. P. Fontán, et al., “Statistical Modeling of the LMS Channel,” IEEE Transaction on Vehicular Technology, vol. 50, no. 6, pp. 1549-1567, November 2001.