

A Low Computational-Cost Subgrouping Multicast Scheme for Emerging 5G-Satellite Networks

Giuseppe Araniti¹, Antonino Orsino¹, John Cosmas², Antonella Molinaro¹, Antonio Iera¹

¹DIIES Dep., University Mediterranea of Reggio Calabria, Italy
e-mail: {araniti, antonino.orsino, antonella.molinaro, antonio.iera}@unirc.it.

²WNCC, Brunel University, London, UK
e-mail: john.cosmas@brunel.ac.uk.

Abstract—Multimedia content delivery over satellite system is considered as a promising service in the future fifth generation (5G) cellular systems. The aim of this work is to design a low-computational radio resource management (RRM) multicast algorithm, named Near-Optimal Subgroup Solution (NOSS), for efficiently managing multimedia video content delivery over satellite network. The idea is to perform the radio spectrum allocation on a per-group basis, thus splitting all the multicast members into different subgroups according to the experienced channel quality. Simulation results demonstrate that the proposed approach is able to overcome the limitation of the previous techniques proposed in literature in terms of user throughput. As a further result, the proposed NOSS approach resulted to be also efficient in terms of fairness and robust to the long propagation delay of satellite links.

Index Terms—5G-Satellite, Satellite-LTE, Multicast, Networking and QoS, Resource allocation, Performance evaluation.

I. INTRODUCTION

SATELLITE networks experienced a rebirth with the coming 5G cellular systems and have been identified as a promising candidate for off-loading the terrestrial 5G networks traffic. In the future 5G vision [1] [2], it is expected that transmissions over satellite link will bring significant advantages for those bandwidth-hungry services such as video, 3D multimedia, and real-time applications, where the current broadcast and multicast capabilities may be not sufficient to provide an suitable Quality of Experience (QoE) to the end-users [3]. In particular, video content delivery services are gaining momentum especially over satellite networks [4] where it is expected that by 2018 11 exabytes of video data traffic (8 times larger than it is in 2014) will be carried out over wireless networks [5].

Given the fast growing of such multimedia application where the same content has to be forwarded to a multitude of destinations, the 3rd Generation Partnership Project (3GPP) started in 2002 with a new standardization of multicast and broadcast services solutions know as Multimedia Broadcast Multicast Service (MBMS) [6]. Afterwards, the MBMS has been extended to the Long Term Evolution (LTE) standard and it is now called evolved MBMS (eMBMS) [6]. Nowadays, the scientific community is addressing to exploit the eMBMS in the emerging Satellite-Long Term Evolution (S-LTE) architecture [2] that has been taken into account as a potential starting

point for the 5G-Satellite definition [1].

To cope to the ongoing research activities in such field, in this paper we focuses on LTE-Satellite environments where the Radio Resource Management (RRM) of multicast services is performed on a per-group basis with the aim to deliver video multimedia contents to a large amount of users with one single radio transmission. As a consequence, the selection of transmission parameters (i.e., modulation and coding scheme, MCS) has to take into account the channel qualities of all involved multicast members.

Many works in literature addresses the content delivery through multicast solutions. However, traditional approaches like *conservative* and *opportunistic* multicasting schemes [8] suffer from inefficiencies in terms of poor spectrum efficiency and inadequate short-term fairness, respectively, whereas subgrouping technique [9] (exploited in this paper) can noticeably improves the multicast session performance. The subgrouping technique, indeed, serves all multicast terminals in every time slot by splitting them into different subgroups according to the experienced channel qualities. This improves the video session quality compared to other strategies [10], although it can be characterized by a higher computation complexity than conventional schemes. In fact, the need for selecting an adequate number of subgroups, with their relevant transmission parameters and assigned resources, introduces complexity in the subgroup creation, and makes the exhaustive search scheme (ESS) not suitable for real implementations in satellite environment. In addition, execution time is critical in any wireless system wherein multicast members may experience channel variations during the time interval needed by the Satellite eNodeB (S-eNodeB) to form the subgroups according to the collected CQIs.

To tackle this issue, previous works proposed low-complexity sub-optimal schemes to solve the formation problem in a reasonable time. Among them, the Low-Complexity Subgrouping (LCS) [11] iteratively computes the subgroup configuration that maximizes the satellite system throughput by starting with an initial unicast configuration with a number of subgroups equal to the number of multicast users. LCS iteratively tries to reduce by one the number of subgroups to activate, by merging two of the enabled subgroups with the aim of finding a new configuration that provides a higher

overall system throughput with respect to the previous step. Subgroup merging continues until no further improvement can be obtained (or a single subgroup configuration is reached). Further, the Multicast Grouping Genetic Algorithm (MGGA) [12][13] uses an evolutionary approach by computing different generations (iterations) in order to select the population (subgroup configuration) with the highest fitness (i.e., throughput). It is worth noticing that this approach is referred to a terrestrial multicast transmission.

In this paper we propose a new multicast RRM approach based on a low complexity greedy algorithm which exploits an iterative smart search scheme of the most suitable subgroup configuration according to the channel qualities of users involved in the multicast session. We named this approach Near-Optimal Subgroup Scheme (NOSS).

The remainder of the paper is organized as follows. In Section II the reference S-LTE scenario with service configuration is described. The alternative RRM strategies policies for multicast services are described in Section III, whereas the proposed Near-Optimal Subgroup Scheme is illustrated in sections IV. Finally, performance evaluation and obtained results are summarized in Section V whereas conclusive remarks are given in Section VI.

II. SYSTEM MODEL

A. The Reference LTE-Satellite Scenario

A possible architecture of the reference LTE-Satellite scenario is depicted in Fig. 1. In such architecture, a GEO satellite equipped with a S-LTE air interface communicates on one side with an LTE ground component (i.e., S-eNodeB) and on the other side with the S-LTE terminals. The former handles the the radio access procedures, the radio resource management, and the configuration of physical layer parameters, e.g., the modulation and coding scheme (MCS); whereas, the latter have in charge for transmitting every transmission time interval (TTI) the user signalling information, e.g., the channel quality indicator (CQI), like an indication of the maximum MCS that guarantees a successful data reception according to the channel conditions experienced by the satellite terminal.

Since in our work we are interested in multicasting transmission, group-oriented services are handled through the evolved-Multimedia Broadcast Multicast Service (eMBMS) standard [7]. For describing how the eMBMS standard is integrated in the S-LTE networks, the MultiCell/Multicast Coordination Entity (MCE) is used for the adaptation of transmission parameters in case of multicast transmission involving different S-eNodeBs. In addition, the MBMS Gateway (MBMS-GW) is a logical entity whose principal function is data packets' forwarding 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-LTE air interface, instead, exploits OFDMA in down-link direction, where the resource allocation is performed in terms of *Resource Blocks* (RBs), each one spanning 12 adjacent sub-carriers and lasting 0.5 ms. The RRM is in

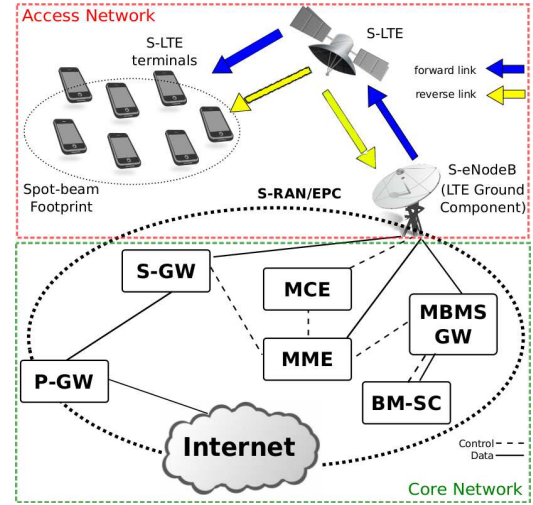


Fig. 1. The Satellite-LTE reference scenario

charge for performing the link adaptation procedures in order to dynamically adapt the transmission parameters [14], i.e., MCSs, with the aim of exploiting the greatest potential of OFDMA. Even if normally the RRM allocates the resources on a RB-pair basis according to the CQI feedback sent by the S-LTE terminals, in our work RBs are allocated 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.

Furthermore, in this work we assume that the satellite channel is not affected by nonlinear distortions. We believe that this can be considered as a realistic assumption for two main reasons: (i) the transmission band of interest is relatively low (i.e. S-band) therefore current power amplifiers in this band can be driven in a fully linear region at the expense of a low power efficiency, and (ii) several variants of OFDMA exist which have a low sensitivity to non-linear distortions because of a lower Peak-to-Average Power Ratio (PAPR), such as Single Carrier FDMA (SC-FDMA) and Constant Envelope SC-FDMA (CE-SC-FDMA) [15].

B. LTE Multicast Assumptions

Let R be the number of RBs available for the transmission of a satellite multicast stream and K multicast members, denoted with $e_1, e_2, \dots, e_K$, to whom the multicast stream is transmitted. The channel quality is estimated by each user through the CQI value, which is transmitted at the S-eNodeB in order to perform the RRM procedures. We indicate with M the number of admissible CQI levels and with $\ell_k \in \{1, 2, \dots, M\}$ the CQI reported by member e_k , for $k = 1, 2, \dots, K$. Accordingly, the minimum data rate achieved, according to the MCS corresponding to the m -th CQI, when at least one RB is used is indicated with b_m^{MIN} (where $m = 1, \dots, M$). On the other hand, B_m^{MAX} is the

maximum data rate for the m -th MCS level by considering that all N RBs are assigned. Since in this work we consider a scalable video coding technique in order to guarantee a minimum data rate to all the multicast members, we define with b_{video}^{MIN} and B_{video}^{MAX} the minimum and the maximum data rate requested by the video application, respectively.

Going further in our system configuration, we denote with $\mathcal{U} = \{u_1, u_2, \dots, u_M\}$ the final subgroup configuration, where u_m represents the number of S-LTE terminals assigned to an MCS corresponding to the m -th CQI, and with $\mathcal{R} = \{r_1, r_2, \dots, r_m\}$ the distribution of the resources assigned to the subgroup configuration. In case $r_m \in \mathcal{R}$ is greater than zero, the subgroup related to the m -th CQI level is considered as suitable for the transmission and a certain number of resources (i.e., r_m) are allocated to the subgroup. On the contrary, when $r_m = 0$ such a subgroup is not enabled. Noteworthy, the number S of enabled subgroups is thus given by the sum of items $r_m \in \mathcal{R}$ greater than zero. Depending on the amount of the RBs given to a subgroup, all the S-LTE terminals of the subgroup m will be served with a data rate given by:

$$b_m^{TH} = \{max(b_i^{MIN} r_i), i = 1, 2, \dots, m\} \quad (1)$$

As discussed in the introduction, *subgrouping* represents a valid approach to increase the overall performance on the network- and user-side. In particular, we consider a subgrouping scheme that divide the entire multicast groups in different subgroups with the aim to maximize a given cost function. Regarding the subgroup formation problem, in a general form it can be written as follows:

$$\Pi = \arg \max_{r_m, x_{k,m}} \left\{ \sum_{m=1}^M \phi(b_m^{TH}) \sum_{k=1}^K x_{k,m} \right\} \quad (2)$$

$$\text{s.t. } \sum_{m=1}^M r_m = N \quad (3a)$$

$$r_m \in \{0, 1, \dots, N\}, \quad m = 1, \dots, M \quad (3b)$$

$$\sum_{m=1}^{\ell_k} x_{k,m} = 1, \quad \sum_{m=\ell_k+1}^M x_{k,m} = 0, \quad k = 1, \dots, K \quad (3c)$$

$$x_{k,m} \in \{0, 1\}, \quad k = 1, \dots, K, \quad m = 1, \dots, M \quad (3d)$$

$$\frac{1}{K} \sum_{k=1}^K x_{k,m} \leq r_m \leq N \sum_{k=1}^K x_{k,m}, \quad m = 1, \dots, M \quad (3e)$$

where $x_{k,m}$, $k = 1, \dots, K$, $m = 1, \dots, M$, is equal to "1" if a given multicast member has the m -th MCS level, and "0" otherwise. Then, in Eq. (2) the function $\phi(b_m^{TH})$ indicates a generic cost function P (e.g., the ADR), whereas the constraint (3a) guarantees that the whole RBs set are used in the RRM process. Further, the constraints present in (3c) assure that the MCS level have to be assigned in accordance to the CQI initially reported by the users. Finally, all considered

constraints (3a)-(3e) involve that:

$$\begin{cases} r_m = 0, & \text{if } \sum_{k=1}^K x_{k,m} = 0 \\ 1 \leq r_m \leq N, & \text{if } \sum_{k=1}^K x_{k,m} \geq 1 \end{cases} \quad (4)$$

i.e., a nonzero RB value is assigned only to subgroups with at least one user. In addition, the data rate b_m^{TH} is properly set according to the QoS requirements of the multicast service and is bounded by:

$$b_{video}^{MIN} \leq b_m^{TH} \leq B_{video}^{MAX}, \quad (5)$$

in order to guarantee the minimum data rate to all the multicast members. In particular, when $B_{video}^{MAX} < B_m^{MAX}$ the saved bandwidth could be used for providing further services.

Concerning the generic cost function P took into account in the problem formulation this is represented by the aggregate data rate (ADR). Such a metric can be described as the sum of data rate values obtained by all the multicast members. The aim of using this function, indeed, is to serve only the subgroups that are able to guarantee the highest value of ADR. Hence, the cost function related to the our problem can be written as:

$$\Pi^{ADR} = \arg \max_{r_m, x_{k,m}} \left\{ \sum_{m=1}^M b_m^{TH} \sum_{k=1}^K x_{k,m} \right\} \quad (6)$$

subject to constraints (3a)-(3e), (4), and (5).

III. ALTERNATIVE RRM STRATEGIES FOR MULTICAST SERVICES

In this Section we provide a brief discussion of the alternative RRM strategies, known in literature, we took into account to compare our proposed low complexity greedy algorithm.

A. Exhaustive Search Scheme (ESS)

Given an RRM problem for multicast services, the search space definition is a key aspect for the computational cost analysis in assigning the radio resources in an efficient way. Generally speaking, the computational time for achieving the best combination among the users to serve and the amount of RBs that has to be used for the multicast transmission is tightly related to the number of possible configurations, among those available, to be analysed. According to the Exhaustive Search Scheme (ESS) [16] definition, the optimal solution for maximizing the ADR consists of systematically enumerating all possible candidates for the solution and checking whether each candidate satisfies the problem's statement. Referring to our work, the number of possible configurations in distributing the available RBs R among a given number of subgroups S (worst case) is bounded by $O(S^R)$, with a consequent prohibitive computational cost.

B. Multicast Grouping Genetic Algorithm (MGGA)

To overcome the limitation in term of computational costs we have by using the ESS policy, we considered a solution based on a genetic algorithm know as MGGA [12], which allows to provide a sub-optimal solution for maximizing the

ADR. In particular, the MGGA policy is a clustering method which uses a special coding scheme where the grouping problem and its relevant structures are characterized as genes in chromosomes.

Briefly, an initial group of individuals consisting of F chromosomes is first created by mapping a multicast clustering solution to a chromosome structure. Then, after generating the initial population (group of clustering solutions) randomly, at each iteration (i.e., generation of a new population) the chromosomes are evaluated using a measure of their fitness that in our case is represented by the Aggregate Data Rate (ADR). Finally, all the possible combinations are ranked from the best to the worst and, for each one of them, a probability of selection is assigned according to their normalized geometric distribution.

It is worth noticing that the computational complexity by using the MGGA for each generation is $O(F \cdot S \cdot R \cdot K_g)$, where F is the number of chromosomes, S is number of subgroups, R the available RBs, and K_g the amount of the users within a given multicast group. However, a possible method to improve the efficiency of the genetic engine could be to use the best settings so that the overall computational time of the MGGA is less than the channel coherence time.

C. Low-Complexity Subgrouping (LCS)

In the first step of the Low-Complexity Subgrouping scheme (LCS) [11], K subgroups are created (where K is the number of multicast destinations), i.e., LCS adopts a traditional unicast scheme for the initial subgroup formation and enables a number of subgroups equal to the number of multicast members (i.e., each user is considered as a single subgroup). In the initialization phase, resources are randomly assigned among the K enabled subgroups. Finally, the initial ADR is evaluated by computing the data rate of each subgroup according to the assigned resources and the MCS relevant to each user. Next, the base station initiates an iterative process and, at each iteration, the base station searches the best subgroups to merge to increase the ADR. At each iteration, it is created a novel candidate subgroup configuration starting from the target subgroups to merge, and such a configuration is composed as follows: (i) the assigned resources are computed as the sum of resources of the target subgroups; (ii) the users are those which were served in the target subgroups; (iii) the MCS is selected as the minimum between those of the target subgroups. At each iteration, the base station selects the novel subgroup configuration which allows the highest ADR increase and this novel configuration is the input of the next iteration. This process is iterated until there is no further improvement in data rate or no subgroups to merge (i.e., the base station reaches a single-subgroup configuration).

IV. THE NEAR-OPTIMAL SUBGROUP SCHEME (NOSS)

The proposed low computational RRM strategy, named NOSS, aims to deliver the multimedia content with high data rate without affecting, strongly, the fairness and the CQI misalignment experienced by the users due to (i) the mobility

with which they are moving, and (ii) the long propagation delay that is typical of the satellite systems.

In doing this, the proposed scheme adopts a subgroup splitting approach: it starts from a single-group configuration where all resources are assigned to one subgroup served with the lowest MCS among those supported by the multicast users. At every iteration, the proposed NOSS scheme increases the number of enabled subgroups by splitting one of the subgroups enabled in the previous iteration. Then, NOSS searches the most suitable subgroup configuration to enable (i.e., the novel MCS and the resources to assign at the novel subgroup), that allows the ADR to be higher than in the previous iteration. In particular, during the first iteration, NOSS performs the conventional multicast scheme resource allocation by scheduling all the frequency resources with the MCS supported by the user with the worst channel conditions. Once this step is performed, the enabled MCS in a given set are stored and the ADR value related to the enabled configuration are evaluated. At the second iteration, NOSS verifies if there exists a subgroup configuration formed by two subgroups, which allows to increase the ADR value compared to the previous iteration. The new candidate configuration considers the case when another subgroup is enabled in addition to the subgroup enabled at the first iteration. In each configuration the new enabled subgroup will be related to a MCS among the feasible ones not already enabled. Among all candidate solutions, NOSS selects the configuration which guarantees the highest ADR, then the target subgroup configuration formed by two subgroups is selected by NOSS as input for the next iteration. More generally, at the generic t -th iteration, the NOSS approach evaluates all possible configurations $\mathcal{R}$ made up of s subgroups associated to the m -th MCS level plus those selected in the previous iterations. As a result, the algorithm ends when no further improvements of the cost function (i.e., the ADR) can be achieved or all the admissible subgroup combinations have been selected. Thus, a suitable candidate solution at the generic t -th iteration is represented by $\mathcal{R}$, with $|\mathcal{R}| = \mathcal{M}$. In particular, r_m represents the number of resources allocated to the subgroup and when $r_m \in \mathcal{R}$ is greater than zero denote the enabled subgroups with the related number of assigned resources.

Generally speaking about the computational cost of NOSS, this is equal to $\mathcal{O}(S^4)$, where S is the maximum number of subgroups to enable. It represents a reasonable burden for practical systems compared to the ESS which requires $\mathcal{O}(S^R)$, where R is the maximum number of available RBs to enable the subgroups. In addition, it is worth noticing that the complexity of NOSS does not depend on the multicast group size and the number of RBs.

V. PERFORMANCE EVALUATION

The simulation campaign has been carried out according to the guidelines defined in [17]. We addressed an application scenario consisting of two-way communications using multi-spot coverage with frequency reuse and Frequency Division Duplexing (FDD) scheme. According to [17], we developed

TABLE I
MAIN SIMULATION ASSUMPTIONS

Parameters	Value
Frequency Bandwidth	S-2.618 GHz (S-Band)
Channel Bandwidth	5 MHz
Number of RBs	25
FFT size	2048
Sub-carrier Spacing	15 kHz
TTI	1 ms
OFDM symbol duration	83.33 μ s
Sampling interval	32.55 ns
Cyclic Prefix Length	16.67 μ s
UE distribuion	Uniform
Elevation	40°
S-LTE terminal speed	60 kmph

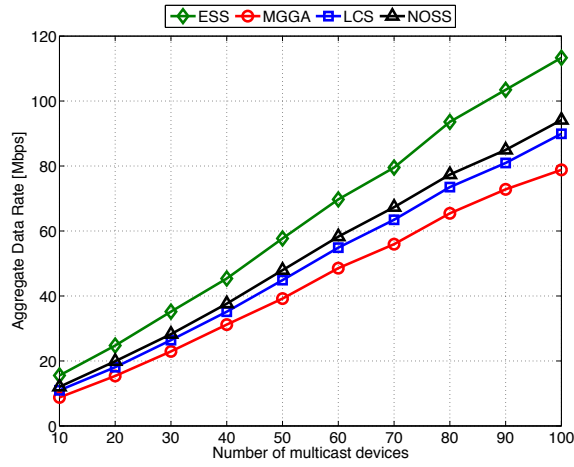


Fig. 2. Aggregate data rate.

a land-mobile satellite (LMS) channel simulator based on the Pérez-Fontán model [18]. This model considers a data set for the S-Band provided by Bradford University, U.K. [19].

In our simulation campaign we assumed $K = 100$ multicast members joined in the multicast group and to assess the effectiveness of the proposed NOSS algorithm, the environment *Intermediate Tree Shadowed* with a mobility speed for the S-LTE terminals equal to 60 km/h is considered. In addition, the following system-level metrics are considered: (i) the ADR, indicating the sum of throughput values experienced by multicast users, (ii) the Jain's fairness index (JFI), that is measured according to the well known formula reported in [20] and indicates the "fairness" in the distribution of throughput experienced by multicast users, and (iii) CQI variation, that represents the misalignment between the channel quality feedback transmitted to the S-eNodeB (i.e., CQI) and the channel quality experienced by the mobile users at the reception of data traffic; such a misalignment is due to the typical round trip time related to the geostationary satellite. For additional details, the main parameters related to the S-LTE scenarios are listed in Table I.

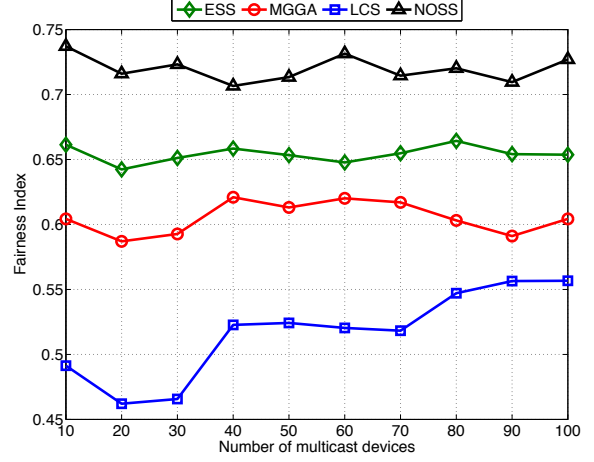


Fig. 3. Jain's fairness index.

As we can observe in Fig. 2, the ADR increases linearly with the number of multicast devices. In particular, it emerges that the best ADR is obtained with the ESS as it selects the subgroup configuration with the highest ADR among all the admissible solutions. The proposed NOSS, instead, achieves the results closest to optimum. This represents a good result as with our proposed scheme we are able to guarantee to the end-users a considerable ADR that is close to the one achieved with the ESS scheme, but with a lower computational costs.

The results in term of fairness are, instead, shown in Fig. 3. Even if the fairness maximization is not the main target of this paper, it is interesting to note that LCS and MGGA perform the worst behaviour with respect to the NOSS and ESS schemes. This means that they do not guarantee high levels of intra-user fairness though they achieve a considerable data rate. Instead, as depicted in Fig. 3 the proposed NOSS scheme provides an interesting throughput-fairness trade-off since it is able to assure high values in terms of fairness and ADR.

In Fig. 4 the misalignment between the channel quality feedback transmitted to the S-eNodeB (i.e., CQI) and the channel quality experienced by the mobile users at the reception of data traffic (hereinafter named CQI misalignment) is reported. Therefore, Fig. 4 provides an example of CQI variation during one round trip time (RTT, approximately 0.54sec) for a generic user for each considered approach. As expected, in intermediate tree shadowed environments the delay introduced by satellite link heavily influences the CQI misalignment. However, the NOSS scheme is robust to long propagation delays, because with these approach, in each multicast subgroup users are managed with a conservative approach where, inside every subgroup, users are served by exploiting a transmission parameters experienced by the user with the worst channel conditions.

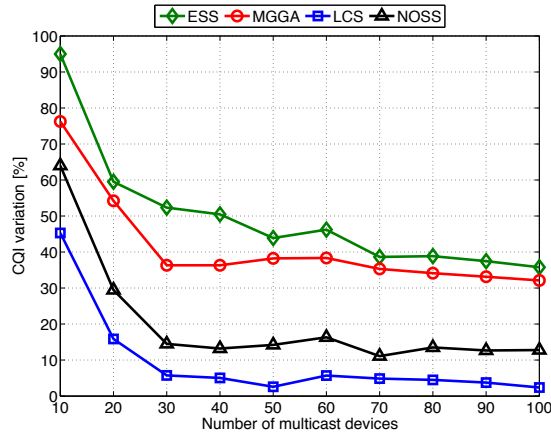


Fig. 4. CQI misalignment for the considered approaches.

VI. CONCLUSIONS

In this paper, we focused on RRM techniques for providing video multimedia content in emerging satellite 5G networks. A novel low-computational multicast approach, named Near-Optimal Subgroup Solution, has been proposed with the aim of delivering high data rate multimedia video contents to a larger number of users. In doing this, in the NOSS approach we took into account a subgroup formation process that is able to reduce sensibly the complexity burden that represents a huge limitation in achieving the best performance (e.g., by using the ESS approach). Further, we compared the NOSS approach with multicast RRM strategies already present in literature and an exhaustive simulation campaign has been performed to demonstrate the goodness of the proposed solution. The obtained results, showed that the NOSS scheme overcomes the compared multicast RRM scheme in terms of fairness by providing, at the same time, an ADR that is close to the theoretical solution (i.e., represented by the ESS scheme). In addition to this, our approach results also a suitable solution to tackle the robustness to the long propagation delays that in satellite environments play an important role.

REFERENCES

- [1] NetWorld2020 White Paper, "SatCom WG The role of satellites in 5G", Jul. 2014.
- [2] 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.
- [3] S. Frattasi, R. L. Olsen, M. De Sanctis, F. H. P. Fitzek and R. Prasad, "Heterogeneous services and architectures for next-generation wireless networks," *2005 2nd International Symposium on Wireless Communication Systems*, 2005, pp. 213-217.
- [4] A. Hava, Y. Ghamri-Doudane, Gabriel-Miro Muntean, J. Murphy, "Increasing User Perceived Quality by Selective Load Balancing of Video Traffic in Wireless Networks", in *Broadcasting, IEEE Transactions on*, vol.61, no.2, pp.238-250, June 2015.
- [5] Cisco, "Cisco Visual Networking Index: Forecast and Methodology, 2013-2018, June 2014.
- [6] 3GPP, "3GPP, TS 36.440, General aspects and principles for interfaces supporting Multimedia Broadcast Multicast Service (MBMS) within E-UTRAN, Rel. 11, Tech. Rep., 2012.
- [7] L. Carla, F. Chiti, R. Fantacci, C. Khirallah, and A. Tassi, "Power efficient resource allocation strategies for layered video delivery over eMBMS networks", in *Communications (ICC), 2014 IEEE International Conference on*, vol., no., pp.3505-3510, 10-14 June 2014.
- [8] A. Sali, H. A. Karim, G. Acar, B. Evans, and G. Giambene, "Multicast Link Adaptation in Reliable Transmission Over Geostationary Satellite Networks", *Wireless Personal Comm.*, vol. 62, no. 4, pp. 759-782, 2012.
- [9] G. Araniti, I. Bisio, M. De Sanctis, A. Orsino, J. Cosmas, "Multimedia Content Delivery for Emerging 5G-Satellite Networks," in *IEEE Transactions on Broadcasting*, vol. 62, no. 1, pp. 10-23, March 2016.
- [10] G. Aiyetoro, G. Giambene, and F. Takawira, "Link Adaptation in Satellite LTE Networks", *textitJournal Of Advances In Information Technology*, 5(1), 37-43.
- [11] G. Araniti, M. Condoluci, A. Orsino, A. Iera, A. Molinaro, "Effective resource allocation in 5G-satellite networks," in *Communications (ICC), 2015 IEEE International Conference on*, vol., no., pp.844-849, 8-12 June 2015.
- [12] C.K. Tan, T.C. Chuah, S.W. Tan, and M.L. Sim, "Efficient clustering scheme for OFDMA-based multicast wireless systems using grouping genetic algorithm," *Electronics Letters*, vol. 48, no.3, pp. 184-186, Feb. 2012.
- [13] M. Lixia, M. Murrone and V. Popescu, "PAPR reduction in multicarrier modulations using Genetic Algorithms," *Optimization of Electrical and Electronic Equipment (OPTIM), 2010 12th International Conference on*, Basov, 2010, pp. 938-942.
- [14] Igor Bisio, Mario Marchese, "Performance evaluation of bandwidth allocation methods in a geostationary satellite channel in the presence of internet traffic", *Computer Networks*, Volume 52, Issue 1, Pages 275-291, 18 January 2008.
- [15] M. De Sanctis, E. Cianca, T. Rossi, C. Sacchi, L. Mucchi, R. Prasad, "Waveform design solutions for EHF broadband satellite communications," in *Communications Magazine, IEEE*, vol.53, no.3, pp.18-23, March 2015.
- [16] G. Araniti, V. Scordamaglia, M. Condoluci, A. Molinaro, and A. Iera, "Efficient Frequency Domain Packet Scheduler for Point-to-Multipoint Transmissions in LTE Networks", in *Proc. IEEE International Conference on Communications (ICC)*, pp. 4405-4409, Jun. 2012.
- [17] 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.
- [18] F. P. Fontán, M. Vázquez-Castro, C. E. Cabado, J. P. García, E. Kubista, "Statistical Modeling of the LMS Channel," in *Vehicular Technology, IEEE Transactions on*, vol.50, no.6, pp.1549-1567, Nov 2001.
- [19] H. Smith, S. K. Barton, J. G. Gardiner, and M. Sforza, "Characterization of the land mobile-satellite (LMS) channel at L and S bands: Narrow-band measurements," *Bradford, ESA AOPs* 104(433), 1992.
- [20] C. Suh, J. Mo, "Resource allocation for multicast services in multicarrier wireless communications, in *Wireless Communications, IEEE Transactions on*, vol.7, no.1, pp.27-31, Jan. 2008