Multimedia Multicast Services in 5G Networks: Subgrouping and Non-Orthogonal Multiple Access Techniques

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ABSTRACT

The expected growth in the mobile video demand over the broadband cellular networks is one of the key factors driving the wireless industry to develop fifth generation of network technology. This scenario is fueling the need for group-oriented services (i.e., multicast and broadcast) in order to efficiently manage the radio resources, and consequently, grant different groups of users simultaneous access to the same multimedia content with differentiated quality of service (QoS). The evolved Multimedia Broadcast Multicast Service (eMBMS), standardized by the Third Generation Partnership Project (3GPP), is one of the technologies likely to be extended to 5G systems with the aim of addressing Point-to-Multipoint services. In addition, Non-Orthogonal Multiplexing Access (NOMA) techniques are being also considered as a driver to increase the efficient use of the spectrum in multi-user environments with asymmetric data delivery. The present article proposes the joint use of subgrouping multicast techniques and NOMA, in an eMBMS-like scenarios. Performance is evaluated in envisaged 5G environments, where different quality video services are delivered to a group of users interested in the same contents.

INTRODUCTION

It is expected that the first 5G network based solutions will be commercially launched by 2020. The requested minimum requirements are noted into the technical performance report defined by ITU IMT-2020[1]. Following those terms and the expectations from both users and operators, one of the main challenges of future 5G wireless networks is to include the efficient provision of mass mobile multimedia services through one or several broadcast transmission modes [1]. The demand for video services in mobile networks (i.e., streaming, downloading, conferences, live social broadcasting, etc.) is rapidly increasing and it is expected that video will account for more than 80% of mobile data traffic by 2019[2]. Consequently, in order to satisfy the increasing Media and Entertainment (M&E) content distribution, the 5G ecosystem will seamlessly integrate different network technologies [2], including unicast, multicast and broadcast[3]. In 5G systems, conventional application scenarios such as mobile pedestrian, vehicular to vehicular (V2V) and vehicular to infrastructure (V2I) communications, generally referred as to V2X communications, will gain higher interest with specific focus on dense urban scenarios within the framework of Smart Cities [3].

[1] ITU, “Minimum requirements related to technical performance for IMT-2020 radio interface(s)”, ITU-R, February, 2017.

[2] Cisco, White paper: “Cisco visual networking index: Forecast and Methodology”, 2016-2021.

[3] New European Media (New), White paper, “5G and Media & Entertainment”, January, 2016.

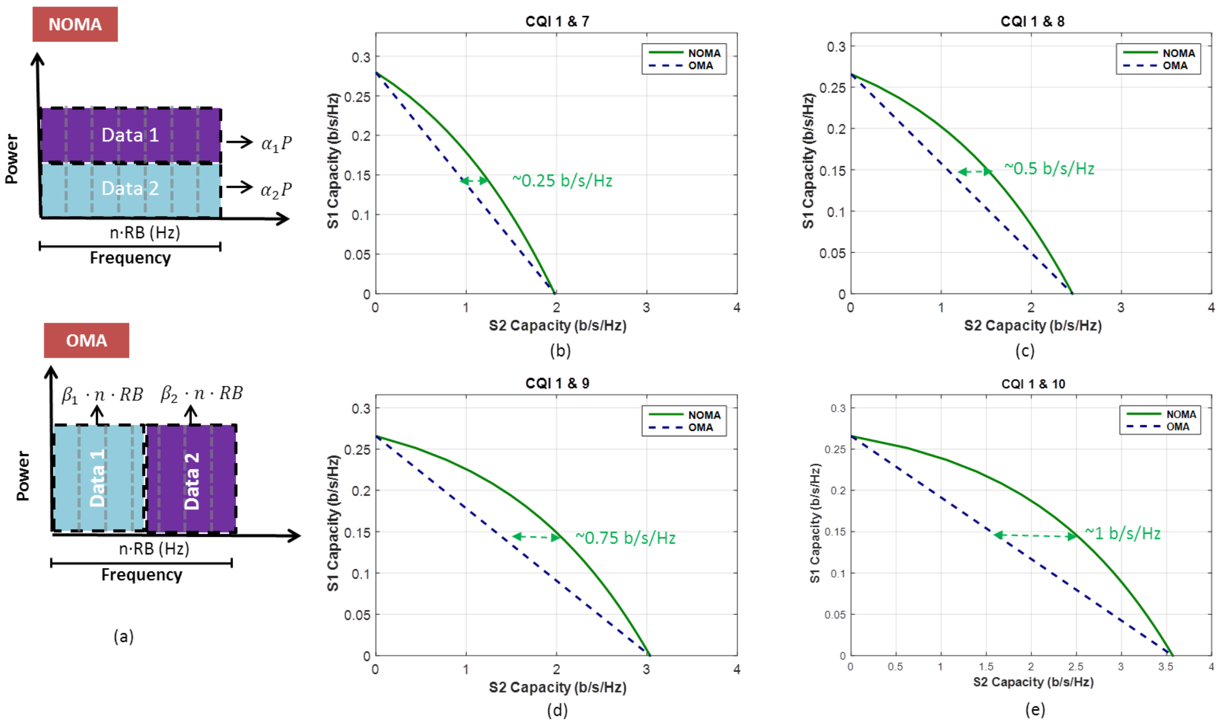

Figure 1. (a) The implementation of two different services within the same RF channel following the NOMA and OMA techniques, where α stands for the shared power value and the β for the assigned piece of bandwidth respectively. In (b), (c), (d) and (e) the theoretical capacity for different receiving conditions are depicted.

Meanwhile, the mobile and broadcast industries have both developed independently several point to multipoint technologies to support large-scale consumption of mass multimedia services on mobile devices. Broadcasters have proposed Layered Division Multiplexing (LDM) to enable mobile TV on top of conventional terrestrial digital TV services [4]. LDM is a non-orthogonal multiplexing (NOM) technique, which has been included in the ATSC 3.0 standard. A similar concept was previously presented for cellular environments in [6]. Regarding the broadband industries, 3GPP introduced eMBMS within the Long Term Evolution (LTE) systems and beyond to provide data transmissions from a single source to multiple devices [7]. Efficient resource allocation, in case of multimedia delivery, is a key issue for eMBMS and the implementation of subgrouping techniques is a promising solution [8].

This work proposes to apply jointly two of the aforementioned techniques, including LDM as an additional resource allocation mechanism in the Radio Resource Management (RRM) entity and considering it in the subgrouping decision process. The article includes computer simulations that confirm the performance advantages of the LDM-based subgrouping technique and concludes with the future challenges and directions of the proposed work.

NOMA/LAYER DIVISION MULTIPLEXING

In a conventional cellular network the devices physical connection with the network architecture is handled by the radio access network (RAN). This is the entity in charge of providing resources through different channel access multiplexing techniques to the user equipments (UEs) involved in the communication process. The wide range of solutions present in the literature can be gathered in two categories: the orthogonal multiple access (OMA) techniques and the non-orthogonal multiple access techniques (NOMA) [9]. In the first case, the available frequency/time resources in the network are orthogonally assigned to the different user equipments. Thus, at the receiver site, under perfect conditions, the desired data can be unequivocally separated from the rest of the information. In the second case, the available resources, both frequency and time, are completely shared among different users, and therefore, when decoding the desired content the rest of the signals are considered an additional source of noise (See Fig.1a).

In the literature, the spectral efficiency of both proposals has been widely studied from an information theoretic point of view. In principle, NOMA based techniques had shown a higher efficiency, especially when the throughput rate among different users is asymmetric [9]. In Fig.1 there have been depicted the different achievable theoretical spectrum efficiencies when two different services are multiplexed, either with NOMA (green solid line) or OMA (blue dotted line). The reception thresholds have been obtained from the set of the signal-to-interference-plus-noise ratio (SINR) values associated to the channel quality indicators (CQI) included at the current LTE release. As shown, the NOMA always performs better than OMA, especially for asymmetric scenarios, where the gain can be up to 1.0 b/s/Hz for the high SINR service. When both services CQI values are closer (i.e., CQI 1&7), the reception threshold difference is smaller, and consequently, the maximum gain is reduced down to 0.25 b/s/Hz.

In NOMA, the content can be multiplexed either on a code-domain basis or on a power-domain basis. In this work, the proposal is oriented towards the latter approach, with a particular profile for multicast/broadcast services known as LDM. A simple representation of this particular use case for a NOMA superimposed signal is described by the following equation:

$$X(n) = \sqrt{P\alpha_1 S_1(n)} + \sqrt{P\alpha_2 S_2(n)} \quad (1)$$

Where P is the total transmitted power, $S_{1,2}$ the delivered signals and $\alpha_{1,2}$ represent the fraction of power assigned to each service, provided $\alpha_1 + \alpha_2 = 1$. In general, from the receiver point of view, the main characteristic of the NOMA techniques is the implementation of a successive interference cancellation (SIC) technique for accessing the overlaid contents. At the transmitter site, the content has been previously arranged according to the assigned portion of the total available power (See Eq.1). Therefore, at the UE the services will be processed following the same order. First, the strongest signal is decoded, remodulated and subtracted from the received signal. Consequently, the next user can access the second signal with less interference. This process should be repeated until all the users have accessed to their content.

The main disadvantages of this family of multiplexing techniques are related to both the latency in accessing the buried contents and the hardware complexity increase. As a matter of fact, the overlaid content cannot be accessed until the stronger signal is successfully decoded and subtracted from the superimposed data. Depending on the SIC strategy, this could lead to a small delay in the decoding process. However, in many use cases associated to broadcast/multicast scenarios, delay requirements are not as tough as in unicast point-to-point communications, and in any case, both complexity and latency can be greatly reduced with a synchronized data delivery approach in the transmitter part [10].

SUBGROUPING TECHNIQUE FOR MULTICASTING

eMBMS, which is likely to be exploited in the 5G networks, defines the network enhancements to support the transmission of multicast services over LTE. It introduces the point-to-multipoint (PtM) transmission mode in cellular networks and covers different functionalities related to the management of multicast services [11]. In particular, PtM simultaneously serves all users interested to a given multicast service through a shared channel, with the aim to improve the system capacity, and theoretically, serve an unlimited number of users. The main challenge for supporting multicast services in eMBMS environment is related to the efficiency of the RRM approach in optimizing the allocation of the radio resources available in the radio access network. In particular, according to the channel conditions experienced by the UEs belonging to the multicast group, the RRM is in charge of performing link adaptation procedures, i.e., the selection of the most appropriate transmission parameters for multicast content delivery, such as the Modulation and Coding Scheme (MCS).

Multicast transmissions are influenced by multi-users different receiving conditions, mainly due to the particular channel propagation distortion experienced by UEs. In Figure 2 an envisaged scenario is depicted, where the receivers are divided into different subgroups according to the experienced channel conditions. *Least Channel Gain* users (i.e., users with the lowest CQI) could affect the performance of the complete multicast group, since they can only support the lowest MCS level. This brings on bad spectral efficiency and very poor throughput. Traditional approaches as opportunistic multicast scheme (OMS) and conventional multicast scheme (CMS) suffer of low user fairness and weak spectral efficiency, respectively. Indeed, the former serves only the subscribers able to optimize a given objective function, for instance, it serves the multicast users, which allow maximizing the system throughput. Hence, for each time slot OMS aims to efficiently exploit the multiuser diversity by selecting the portion of multicast members to serve with the most suitable MCS. Nevertheless, OMS cannot guarantee short-term fairness among users, because only a portion of them will be served at each time slot. Vice versa, the CMS algorithm guarantees the multicast service delivery to the overall set of multicast receivers. Indeed, CMS selects the MCS parameters according to the worst CQI value collected by the RAN (e.g., eNodeB in LTE) from all the multicast subscribers in a cell. Therefore, the multicast session performance is bounded by the UEs with the worst channel conditions. CMS and OMS belong to the single-rate multicast scheme, according to which all users within the multicast group share the same resources and a single transmission with a fixed data rate is delivered to each UE. Although single-rate schemes present advantages in terms of simple implementation and low complexity, they suffer of poor spectrum efficiency or low fairness**Errore. L'origine riferimento non è stata trovata.**.

Effective approaches aiming to overcome the inefficiencies introduced above are the multi-rate schemes [11]. Such schemes allow each user device to receive multimedia traffic based on its capabilities. In particular, two techniques have been presented in literature for multi-rate multicast transmission: *(i)* the Stream Splitting and *(ii)* the Group Splitting. The Stream Splitting is based on splitting high-rate multimedia contents into multiple substreams of lower data rate. A base substream, receivable by all users, is transmitted in order to accomplish full coverage of the multicast group. Afterwards, users with good channel condition receive additional enhancements streams to improve information quality. Scalable Video Coding (SVC) technique is typically at the base of this approach.

An effective Group Splitting approach is the subgrouping [8], which is based on splitting the multicast clients into subgroups and applying subgroup-based adaptive modulation and coding schemes, which enable a more efficient exploitation of multi-user diversity. Concerning the subgroup formation, this may be performed by designing the subgroup formation according to an optimization problem [12] that can be formulated in order to achieve different goals, for instance, the maximization of the system throughput, the spectral efficiency, or the energy efficiency. In doing this, the most suitable subgroup configuration (i.e., number of subgroups with the related MCS, portion of users, assigned resources, and data rate for each enabled subgroup) is dynamically selected by the base station based on the minimization (maximization) of a given cost (utility) function. The main issue faced by the subgrouping approach is the computational complexity.

LDM APPLIED TO SUBGROUPING TECHNIQUES ON 5G

3GPP has divided the 5G normative work into two phases. Phase-1 (Rel-15) will address the more urgent subset for commercial deployments, whereas Phase-2 (Rel-16) will address all the identified use cases and requirements. According to the preliminary technical reports, 5G RAN will keep the LTE principles, with the same Orthogonal Frequency Division Multiple Access (OFDMA) technology for the downlink for both cases, either New Radio (NR) or Rel-16 [14]. What is more, this new radio access should cover mainly the enhanced mobile broadband (eMBB) using mmWave frequencies, where the multicast and point to multipoint services will be a key for empowering vertical industries. Consequently, the subgrouping and NOMA techniques, which independently proved to be valuable for previous releases and standards, are jointly proposed as a cutting edge joint technology for facing the challenge of satisfying the mass media video consumption in the point-to-multipoint scenarios.

SUBGROUPING WITH NOMA RESOURCE ALLOCATION STRATEGIES

It is expected that in NR-5G, the Resource Block (RB), which corresponds to twelve consecutive subcarriers, will be also the smallest frequency resource, which can be assigned to a terminal. The set of available RBs is managed by the packet scheduler to efficiently handle resource allocation to mobile users in both frequency and time domain. Our proposal mainly focus on the frequency domain packet scheduler (FDPS), which is in charge of executing the fast link adaptation procedures by selecting the most appropriate MCS level and number of RBs for each multicast service. The NR-5G Base Station carries out such selection every Transmission Time Interval (TTI), which lasts 1 ms, by considering the CQI feedbacks received by all multicast users. According to the CQI value, each user will support a given MCS. In principle, a higher MCS level does not guarantee a better quality transmission for the user, whereas a lower MCS implies inefficient use of the spectral resources.

Therefore, subgrouping techniques in [8] are proposed as a valid solution to increase the efficiency splitting multicast users in different subgroups according to their capabilities. The main challenge is the formation of the optimal subgroup configuration, which is tackled as an optimization problem, aiming at maximizing (or minimizing) a given objective function. The potential of using subgrouping techniques relies on the independency of the optimization from the objective function considered (e.g. throughput maximization, fairness optimization, minimum dissatisfaction index, etc. [10]).

Considering the conventional time and frequency resource allocation techniques, the best subgroup analytical configuration was found in [11], when Maximum Throughput (MT) was set as cost function. Authors demonstrated that the optimal solution can be found within 1 TTI; that the optimal number of subgroup is no greater than two; and that the number of RBs to assign to the lowest subgroup is 1 or 2, whereas remaining RBs are assigned to the highest level subgroup. Starting from this result, this proposal aims to exploit the LDM technique as an alternative to optimize the resource allocation in the subgrouping process. In such a way, the FDPS also considers the NOM multiplexation in order to assign the different resources to the groups. In particular, in the case of LDM every subgroup will access to the whole frequency band the 100% of the time. The FDPS will assign a different weighted power to each service, performing a layered delivery, which in most cases is more efficient than the classical multiplexing schemes.

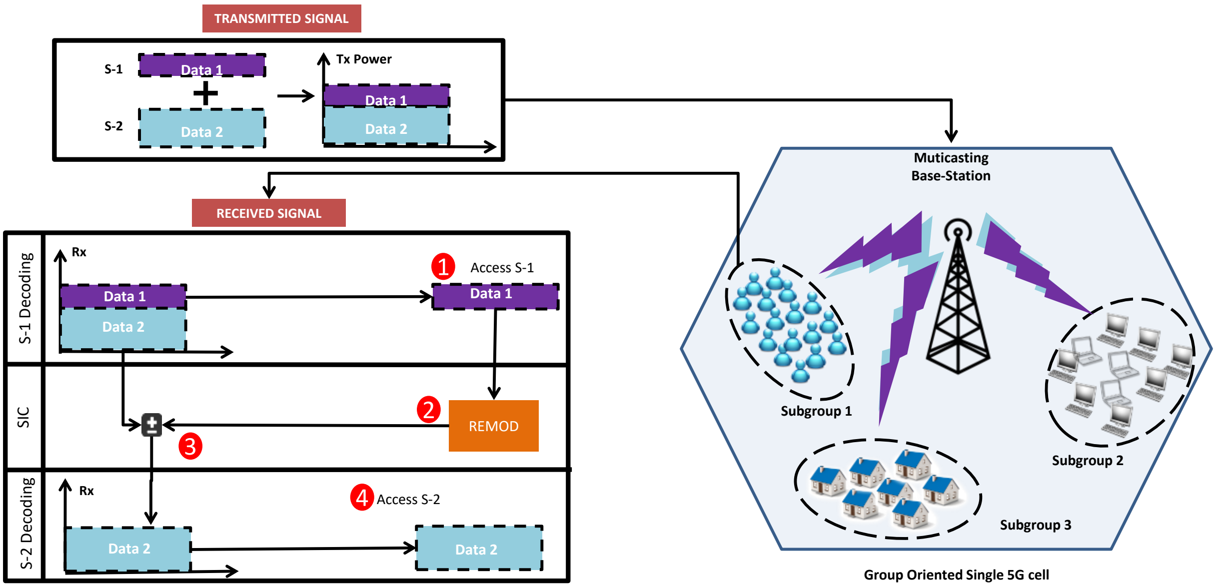

Figure 2. Proposed solution application scenario and simplified receiver architecture.

Our proposal is to exploit the LDM concept of splitting the total available power for multicast subgrouping. In such an approach, the different layers defined through the LDM technique are matched with the subgroups derived by the multicast subgrouping approach. Furthermore, the performances of the proposed technique have been evaluated according to three different objective functions: Maximum Throughput (MT), Proportional Fairness (PF) and Minimum Dissatisfaction Index (MDI) [10]. Maximum Throughput is based on the maximization of a cost function defined as the Aggregate Data Rate (ADR), which is the sum of the data rate obtained by all the multicast members. The Proportional Fairness scheduling can be accomplished by maximizing the sum of the logarithm of the data rate. Finally, MDI is defined as the weighted difference between the data rate achieved by the UE and the maximum possible value of data rate achieved by a UE when all RBs are assigned to the user [8].

NOMA RECEIVER ARCHITECTURE

In this subsection the main implications regarding the LDM implementation from the receiver perspective are given. In principle, each layer will have its own coverage footprint depending on the targeted subgroup and assigned MCS. Classically, the upper layer will be assigned to the most SNR demanding subgroup (UEs with lower CQI values), whereas the overlaid layer will be assigned to the less demanding SNR with higher CQIs. This way the multicast problem of bandwidth exploitation explained in the previous sections is avoided and the throughput asymmetry is better exploited.

The transmission approach presented in this solution aims at reducing the complexity at the receiver part. The proposed receiving mechanism is displayed in Figure 2. The architecture assumes that in the transmitter part, in each delivered multicast frame, both layers/services share the majority of the communication blocks: OFDM framing, interleaving and packet scheduling. This architecture enables to use a simplified SIC approach at the receiver. Provided both layers are fully synchronized, the first modules at the receiever (synchronization, channel estimation, equalization, OFDM de-framing and de-interleaving) are common for both layers/services. Cancellation is performed at the modulation level, and thus, the memory requirements will not be significantly increased [10].

The upper layer service can be decoded as usual. Afterwards, the upper signal is coded and modulated again and the obtained data is subtracted from the equalized signal. Once the upper service has been removed from the superimposed signal, the second layer content can be accessed. The accuracy of the signal cancellation process is closely related to the channel estimation accuracy.

IDENTIFIED MULTICAST/BROADCAST USE CASES IN 5G

Taking into account the evolution of the technology and the expected user media consumption, four potential use cases have been identified within the 5G eMBB scenario framework where the presented technical solution can be considered as a very promising tool (See Fig. 3).

STANDARD BROADCAST LDM (DYNAMIC)

NOMA techniques, especially LDM, have been identified as a driver technology for multiplexing different contents in classical broadcasting or point to multipoint applications. They maximize the spectrum efficiency when the different mixed services throughput is asymmetric. What is more, its efficiency combined with the dynamic resource allocation will increase the performance shown in classical unidirectional broadcasting scenarios. The eventual number of multicasted services/layers will strongly depend on the user CQIs and the required number of groups to maximize the throughput. An interesting use case for this group could be the implementation of multiple services with Scalable Video Coding (SVC).

BROADCAST FOR INFOTAINMENT SERVICES

In this case, the transmission station performs multicast LDM transmissions to stream multimedia broadcast contents for infotainment services towards vehicles in a specific area. In a typical urban scenario, different types of vehicles can be identified in terms of their dimensions, speed, constrained routes, etc. Infotainment services, and subsequently multicast subgroups, can be diversified in terms of class of users and type of contents. In such a heterogeneous scenario multicast subgrouping technique performed standalone (i.e., without LDM) may result inadequate for streaming of different broadcast multimedia contents to different users/vehicles classes. LDM can improve flexibility to create subgroups by adding resources.

INFRASTRUCTURE TO VEHICULAR SERVICES

A new advanced driver assistance system (ADAS) in which vehicular users in a determined area can cooperate for generating 3D video contents to increase safety is considered. Using 3D video for intelligent safety procedures involves the necessity to guarantee a good quality of the content in order to avoid failed interpretation by onboard intelligent systems. The BS is in charge of transmitting the new video content to all vehicles through multicast LDM subgrouping transmissions. The main challenge is to guarantee a minimum quality level of the video content to users that belong to a subgroup characterized by low CQIs. In this way, adequate performance of intelligent systems could be reinforced. LDM could be used to improve the quality of the video content experienced by users that perceive worse channel conditions (i.e., lower CQIs) adding extra content to enhance 3D video quality.

IoT MULTICAST MESSAGE BASED SERVICES

Machine-Type Communications (MTC) for Internet of Things (IoT) forecast the involvement of a huge number of devices. Indeed, 5G will have the capability to manage simultaneously multiple MTC devices and to support different multicast machine-oriented applications. The main multicast MTC applications for 5G scenarios are Smart Environments and Software Upgrades.

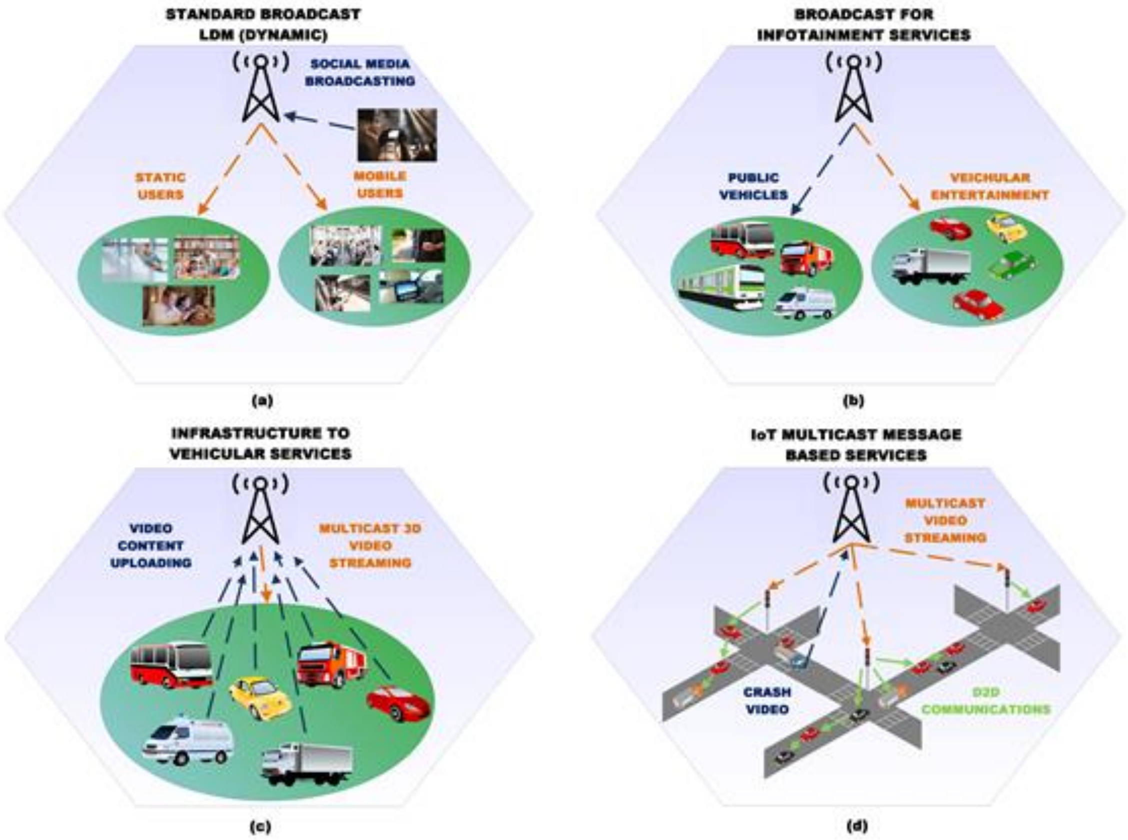

Figure 3. Proposed 5G use cases: standard broadcast LDM (dynamic) (a), broadcast for infotainment services (b), infrastructure to vehicular services (c), and IoT multicast message based services (d).

The former gathers all those application beneficial for smart homes/offices/cities/industries. In such applications, groups of devices receive simultaneously the content in order to act some kind of smart action.

Furthermore, smart devices could need either periodical or sparse software upgrades for bug fixation and functionality upgrades. LDM could enhance the device capabilities enabling them to download data content. The higher SNR asymmetry, the greater will be the gain provided by LDM-based approach.

PERFORMANCE

MOBILITY MODELS AND PERFORMANCE

A dense urban scenario is the typical environment for characterizing 5G communications in a Smart City context, with different types of users (i.e., pedestrian, vehicular, mixed, and fixed). Several mobility models can be used to describe the activity pattern of users changing position, speed, and similar location related characteristics. In this work, in order to compare the performance between the classical multicast subgrouping and the multicast LDM subgrouping methods, and taking into account the use cases presented in previous section, the *Random Way Point* model has been implemented. In this model, the users are uniformly distributed over the environment at the initial stage. At every iteration they move along line segments toward a random destination position, with a fixed speed. When the user reaches the target position, waits for a predetermined time interval and then a new random target position is assigned. In our simulations, users are allowed to change direction every second. This allowed to realistic reproduce pedestrians and slow vehicles moving behavior in dense urban environments, where pedestrians walk in crowd spaces (e.g., sidewalk, square, mall, etc.), whereas vehicles often circulate in severe traffic condition (e.g., traffic jam, peak hours).

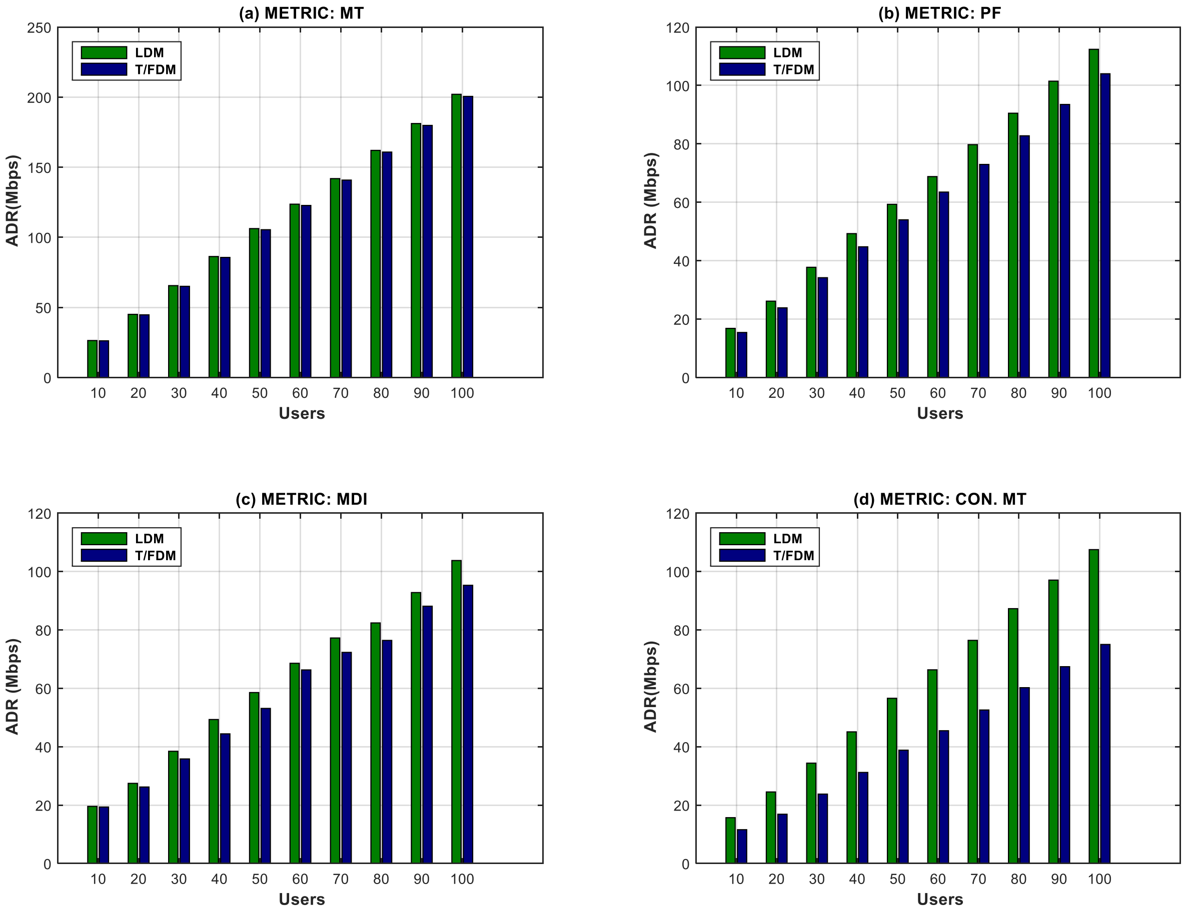

Figure 4. Obtained Aggregated Data Rate (ADR) for the Random Way Point mobility scenario at 3 km/h with different metrics.

Afterwards, the channel conditions for each UE are evaluated in terms of the experienced SINR, which results on an effective CQI level assuring a Block Error Rate less than 10%. Then, these results are fed to a simulation model, where the LTE scheduler RRM procedures are simulated, and the resources are shared among the different created subgroups with ideal MCSs. Eventually, the final output parameters for evaluation are the Aggregated Data Rate (ADR) and Throughput per User (TU), which are obtained in order to evaluate and compare the proposed methodologies.

EFFICIENCY RESULTS AND DISCUSSIONS

The mobility model simulations follow 3GPP standards. The values presented are an average of 50 different realizations covering 180 seconds. The RandomWayPoint mobility scenario metrics have been obtained for an assumed UE speed of 3km/h. In this case, among all the use cases explained previously, we are focusing our research on low speed mobility scenarios. Nevertheless, the results can be extended to other mobility models and different speed values. Performance analysis has been carried out comparing the proposed solution with the LTE-based multicast subgroup technique [8] (i.e., labeled with T/FDM in the next figures).

The first evaluated parameter is the aggregated data rate of the cell, which depends on the assigned optimization cost function of the subgrouping process (See Fig. 4). The first important outcome is that the maximum throughput metric does not provide meaningful difference between the different multiplexing methods (Fig. 4 (a)). That is because, for both approaches, the best solution is obtained offering the maximum number of possible resources to the subgroup with best reception conditions, while the

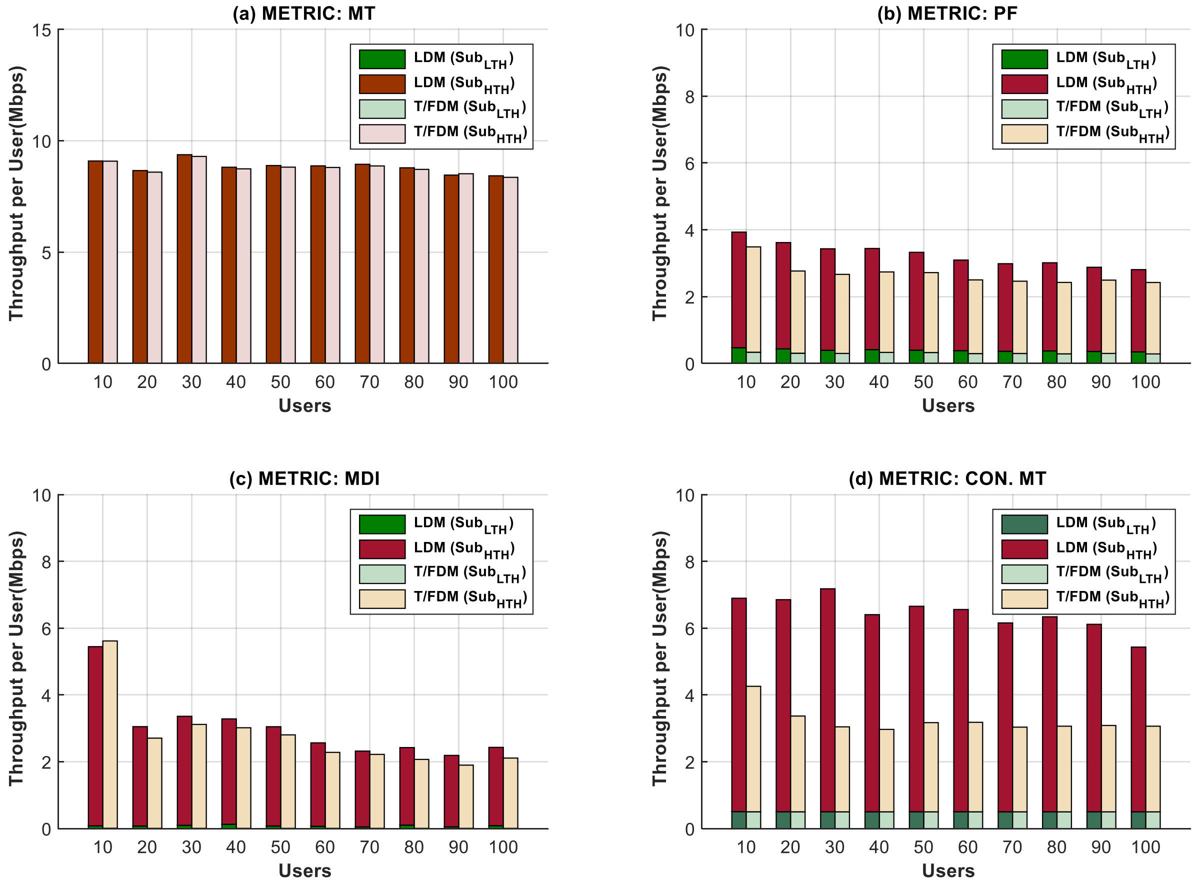

Figure 5. Throughput per User for the Random Way Point mobility scenario at 3 km/h with different metrics.

users dealing with more challenging conditions are poorly satisfied. In the case that PF or MDI are used (Fig. 4 (b) and (c)), it can be clearly noticed how LDM offers a significate gain (about ~10 Mbps in the best case) with respect to the OMA subgrouping technique (i.e., T/FDM in the figures). This means that LDM achieves higher performance in terms of ADR, when exploiting such "fair" metrics.

Finally, the maximum throughput metric is modified, adding a minimum bit rate constraint of 0.5 Mbps (Fig. 4 (d), i.e. Constrained MT (CON.MT)) to one of the services. In this case, it is easily shown that the gain is much higher for NOMA subgrouping, because in OMA subgrouping approach, according to this constraint, many RBs must be assigned to the low-level subgroups. On the contrary, with LDM both subgroups exploit the whole bandwidth. This assumption represents those use cases, which need to guarantee a minimum data rate to all users.

The reason for this behavior can be found in Fig. 5. In this case, each subplot indicates the throughput per user, differentiating the average throughput of each of the two subgroups. In this case, the good SNR condition service is marked as HTH (High Throughput) and the poor SNR condition group is tagged as LTH (Low Throughput). As expected, according to the theoretical facts explained before, the higher the required bitrate assigned to most challenging group the bigger is the gain offered by LDM. It can be noticed that in the MT and MDI cases the LTH subgroup receives a very poor rate (Fig. 5 (a), (c)). In Fig. 5 (b) with PF and in Fig. 5 (d) when the MT is modified, the gain can be up to 2 Mbps per user for the high capacity subgroup. It is expected that this trend will be maintained in the newly designed 5G environments, where the available bandwidths will be bigger and the required minimum bitrates will be higher due to the fact of the user expectations.

RESEARCH DIRECTIONS AND CHALLENGES

NOMA is considered a strong candidate to be included in the 5G ecosystem. Consequently, the challenges associated with its efficient integration in the RAN architecture have drawn a lot of attention. Some of them, will also be useful for the technical solution proposed in this paper. For instance, there are studies analyzing the impact of the path loss in the NOMA performance or the feasibility to combine non-orthogonal multiplexing techniques with cooperative communications. In addition, NOMA is also considered a very powerful tool for massive MIMO technologies. What is more, recently there has been also proposed in one of the most promising communication paradigms: the visible light communications (VLC) 0. Finally, regarding the LDM implementation, the error cancelation impact on the overlaid layers and the low complexity implementations should also be studied.

In the case of the subgrouping techniques, the main challenge is to adapt the current metrics to the requirements expected on the 5G ecosystem, for supporting not only bandwidth hungry services but also machine/IoT group oriented applications. That is to say, new architectures, protocols and metrics will be needed in order to guarantee high quality services to the different groups of receivers.

REFERENCES

[1] J. Calabuig, J. Monserrat, D. Gómez-Barquero, "5th generation of mobile networks: a new opportunity for the convergence of mobile broadband and broadcast services", IEEE Commun. Mag., vol. 53, no. 2, pp. 198-205, 2015.

[2] G. Araniti, M. Condoluci, P. Scopelliti, A. Molinaro and A. Iera, "Multicasting over Emerging 5G Networks: Challenges and Perspectives," in IEEE Network, vol. 31, no. 2, pp. 80-89, March/April 2017.

[3] M. Fadda, M. Murroni, and V. Popescu, "Interference Issues for VANET Communications in the TVWS in Urban Environments," IEEE Transactions on Vehicular Technology, vol. 65, no. 7, pp, 4952-4958, July 2016.

[4] J. Montalban, L. Zhang, U. Gil, Y. Wu, I. Angulo, K. Salehian, S.I. Park, B. Rong, W. Li, H.M. Kim, P. Angueira, and M. Velez, "Cloud Transmission: System Performance and Application Scenarios," IEEE Transactions on Broadcasting, vol.60, no.2, pp.170-184, June 2014.

[5] L. Zhang et al., "Layered-Division-Multiplexing: Theory and Practice," IEEE Transactions on Broadcasting, vol. 62, no. 1, pp. 216-232, March 2016.

[6] Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li and K. Higuchi, "Non-Orthogonal Multiple Access (NOMA) for Cellular Future Radio Access," 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), Dresden, 2013, pp. 1-5.

[7] D. Lecompte, and F. Gabin "Evolved multimedia broadcast/multicast service (eMBMS) in LTE-advanced: overview and Rel-11 enhancements", IEEE Communications Magazine, Vol. 50(11), pp. 68-74, Nov. 2012.

[8] G. Araniti, M. Condoluci, L. Militano, A. Iera, "Adaptive resource allocation to multicast services in LTE systems, IEEE Trans. on Broadcasting, vol. 59, no. 4, 2013.

[9] M. R. Islam, N. Avazov, O. A. Dobre and K. s. Kwak, "Power-Domain Non-Orthogonal Multiple Access (NOMA) in 5G Systems: Potentials and Challenges," in IEEE Communications Surveys & Tutorials, vol. 19, no. 2, pp. 721-742, Second quarter 2017. doi: 10.1109/COMST.2016.2621116.

[10] S. I. Park et al., "Low Complexity Layered Division Multiplexing for ATSC 3.0," in IEEE Transactions on Broadcasting, vol. 62, no. 1, pp. 233-243, March 2016.

[11] 3GPP, TS 36.440, "General aspects and principles for interfaces supporting Multimedia Broadcast Multicast Service (MBMS) within EUTRAN," Rel. 11, September 2012.R. O. Afolabi, A. Dadlani and K. Kim, "Multicast Scheduling and Resource Allocation Algorithms for OFDMA-Based Systems: A Survey," in IEEE Communications Surveys & Tutorials, vol. 15, no. 1, pp. 240-254, First Quarter 2013.

[12] R. O. Afolabi, A. Dadlani, and K. Kim, "Multicast Scheduling and Resource Allocation Algorithms for OFDMA-Based Systems: A Survey," IEEE Commun.Surveys & Tutorials, vol. 15, no. 1, 2013, pp. 240–54.

[13] G. Araniti, M. Condoluci, M. Cotronei, A. Iera, A. Molinaro, "A Solution to the Multicast Subgroup Formation Problem in LTE Systems, in Wireless Communications Letters, IEEE , vol.4, no.2, pp.149-152, April 2015.

[14] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on New Radio (NR) Access Technology; Physical Layer Aspects v (Release 14).

[15] H. Marshoud, V. M. Kapinas, G. K. Karagiannidis and S. Muhaidat, "Non-Orthogonal Multiple Access for Visible Light Communications," in IEEE Photonics Technology Letters, vol. 28, no. 1, pp. 51-54, Jan.1, 1 2016.