Resource Allocation Management for Broadcast/Multicast Services

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***Abstract*—Video services are expected to become more than 70% of the mobile traffic in 2020. Broadcast and multicast service is the most efficient mechanism to deliver the same content to many users. Not only focusing on venue casting, but also distributing many other media such as software updates and breaking news, 5G broadcasting is a key driver to achieve the spectral efficiency needed for the 1,000 times traffic growth that is expected for the upcoming years.**

Improvements in some areas, such as resource allocation techniques for broadcast/multicast services, are needed. The utilization of the Conventional Multicast Scheme (CMS) approach for multicast resource allocation presents intrinsic inefficiencies, because of the different channel conditions of the users which demand the service. This paper presents some resource allocation strategies based on the use of multicast subgroups. We propose a multicast resource allocation algorithm including memory, which results in improvements of the service throughput at the time a high fairness among the users is guaranteed. In addition, an algorithm of joint resource allocation among multicast and unicast transmissions is developed. This strategy allows the system to take advantage of the subframes reserved for each purpose by the Long Term Evolution (LTE) standard, looking for the best joint allocation of the available resources, and results in important improvements in the service throughput.

I. INTRODUCTION

Mobile data traffic is growing rapidly in the last few years and this growth is expected to become bigger in the upcoming years, especially in multimedia services. Of course, the growing demand of multimedia services in mobile networks poses new challenges in the way these services can be provided. New techniques must be developed to guarantee the scalability for large amount of users.

Broadcasting and multicasting are expected to be promising enablers of an easy access to the ubiquitous multimedia experience through mobile terminals [1]. Using Evolved Multimedia Broadcast and Multicast Service (eMBMS), a point-to-multipoint service that allows data transmissions from a single source to multiple recipients, the scalability of broadcast and multicast transmissions in mobile networks is improved. Furthermore, Multicast/Broadcast over Single Frequency Network (MBSFN) has been proposed as an enhancement of eMBMS [2], avoiding the destructive interferences in the areas where the coverage overlaps, and maintaining the performance that would otherwise gradually degrade as User Equipment (UE) moves away from the base station.

In multicast transmissions, the resource allocation using the Conventional Multicast Scheme (CMS) [3] is based on a conservative approach, where the data rate is restricted by the user that presents worst channel conditions. Of course, this approach maximizes the fairness among multicast users, however the throughput performance in the multicast area is highly inefficient and users with good channel conditions do not achieve as high as possible bit rates.

In this paper, we propose some resource allocation strategies based on the use of multicast subgroups. Firstly, we have used joint resource allocation techniques among multicast and unicast transmissions, that allow the system to take advantage of the subframes reserved for each purpose by the Long Term Evolution (LTE) standard, and maximize the service throughput using the optimal joint allocation of the available resources. Then, we have evaluated the introduction of memory in resource allocation algorithm, which results in improvements of the service throughput guaranteeing high fairness among the users.

The rest of the paper is organized as follows. In Section II, the state of the art for multicast resource allocation is detailed. The proposed Radio Resource Management (RRM) strategies are described in Section III. The results of the performance evaluation are presented in Section IV. Finally, in Section V, the main conclusions are explained.

II. STATE OF THE ART

A. Conventional Multicast Scheme

The first approach for resource allocation in multicast transmissions is the conservative scheme known as CMS. This scheme establishes the Modulation and Coding Scheme (MCS) used to deliver the service so that the user with the worst channel conditions can decode it correctly. In such a way, CMS approach guarantees the maximum fairness among all the multicast members, which are served at the same throughput. Nevertheless, CMS is clearly inefficient in terms of service throughput, since it does not take advantage of the users with good channel conditions. Furthermore, the use of this policy does not exploit the high potential of Orthogonal Frequency Division Multiple Access (OFDMA) spectrum management and, for that reason, it cannot guarantee a high spectral efficiency [3].

B. Opportunistic Multicast Scheme

An alternative approach, which is aimed to overcome the issues of the CMS, is the Opportunistic Multicast Scheme

(OMS) [4]. This scheme allocates the resources in a given time slot to the users with best channel conditions, and all the users are not served in every Transmission Time Interval (TTI). Consequently, the service throughput can be maximized according to the channel quality by exploiting the optimal tradeoff between multiuser diversity and multicast gain.

C. Multicast Subgrouping Policy

The creation of different multicast subgroups to deliver one multicast service has been adopted to overcome the limitations of both CMS and OMS [5]. This strategy allocates the available resources into different subgroups, minimizing the negative effects of users with poor channel conditions and serving all multicast members in the same time slot. Thus, the service throughput is maximized. Unfortunately, a drawback of these approaches is the lack of fairness among the members of the multicast service.

The utilization of different cost functions to allocate the available resources into the different subgroups allows the system to focus on maximizing the service throughput, e.g. using Maximum Throughput (MT) algorithm, or improving the fairness among the users at the time a high service throughput is achieved, e.g. using Proportional Fairness (PF) algorithm.

The multicast subgrouping strategy can be splitted into different phases.

- **Channel Quality Indicator (CQI) collection:** the first step consists of the collection by the Evolved Node B (eNodeB)s of the CQI feedback from the UEs placed in their MBSFN area, and which are demanding the multicast service. For each CQI Feedback Cycle (CFC), the eNodeB creates a vector with all the UEs CQI.
- **Subgroup creation:** the multicast members are splitted into different multicast subgroups. Each multicast subgroup delivers the service using different MCS, and consequently, serving the users that support the decoding of this scheme with a Block Error Rate (BLER) less than 10% [6].
- **Resource allocation:** the resource allocation algorithm works such as a UE that reports a CQI will be served by the multicast subgroup closer to the CQI reported and whose MCS can be decoded by the user. Resources must be allocated in such a way that every user is served by a multicast subgroup whose MCS can correctly decode.

III. Proposed Radio Resource Management strategies

This section details the proposed RRM strategies based on the creation of multicast subgroups. Firstly, the strategy is based on the joint allocation of multicast and unicast transmissions. Then, the use of strategies with memory has been included in the resource allocation.

A. RRM strategies based on joint allocation of multicast and unicast transmissions

The proposed RRM strategy uses a Joint Multicast Subgrouping and Unicast Transmissions (JMSUT) scheme. The RRM algorithm searches the optimal allocation of the resources in the multicast subframes, splitting them into multicast subgroups that deliver the service using different MCS. Furthermore, the RRM uses the unicast Quality of Service (QoS)-aware scheduling, proposed in [7], to deliver the service using unicast transmissions to the UEs with worst channel conditions. Consequently, the JMSUT aims to maximize the service throughput and, at the same time, guarantee the QoS requirements for all the users demanding the service.

Therefore, this algorithm is based on a service throughput maximization problem that is given as

$$\underset{R}{\text{maximize}} \qquad \sum_{i=1}^{n} d_{c_i}^{R} \tag{1}$$

$$\text{subject to} \qquad M_{max} = 6 \tag{1a}$$

$$M + U = 10 \tag{1b}$$

$$d_{c_i}^{R} \geq b_{min} \qquad \forall i \tag{1c}$$

$$\sum_{i=1}^{G} r_i = K \tag{1d}$$

where $R = \{r_1, ..., r_G\}$ is the distribution vector which allocates the Resource Block (RB)s into the different multicast subgroups, $d_{c_i}^{R}$ denotes the bit rate achieved to deliver the service to user i when the distribution vector R is used to allocate the RBs among the multicast subgroups, and n is the total number of users demanding the multicast service in the MBSFN area. In (1a), M_{max} denotes the maximum number of subframes that can be reserved for multicast transmissions [2]. In (1b), M and U denote the number of subframes reserved by the standard for multicast and unicast transmissions in an LTE frame, respectively. In (1c), the minimum bit rate that must be guaranteed for all the users is denoted as b_{min}. In (1d), the maximum number of RBs to allocate is established, so to that end, G denotes the maximum number of multicast subgroups (in LTE there are 15 different CQI sublevels), and K denotes the number of available RBs to deliver the service.

B. RRM strategies with memory

In practical systems, not only throughput is considered in resource allocation procedures but also the fairness among users must be taken into account. For that reason, cost functions such as PF are used to guarantee a good trade-off between the service throughput and the fairness among the users. Another option to achieve a good compromise between throughput and fairness is proposed in [5], and consists of the minimization of the Minimum Dissatisfaction Index (MDI).

The utilization of cost functions using memory, which allow the system to take into account the bit rate achieved in previous LTE subframes, may increase the service capacity and a high fairness among users in a given interval of time.

Based on PF and MDI, we have proposed the following variations in the cost functions to include the use of memory.

- **PF algorithm with memory:** it uses PF policy as cost function including the logarithm of the average bit rate in a given interval of time. The resulting maximization problem is modeled as

$$\Pi^{PF} = \arg\max_{R} \left\{ \sum_{i=1}^{n} \log \overline{d_{c_i}^{R}} \right\} \quad (2)$$

where R is the distribution vector which allocates the RBs into the different multicast subgroups, $\overline{d_{c_i}^{R}}$ denotes the average bit rate achieved to deliver the service to user i in a given interval of time when the distribution vector R is used, and n is the total number of users demanding the multicast service in the MBSFN area.
- **MDI algorithm with memory:** it uses MDI policy as the cost function to minimize. A variation is included in the weight calculation using the average user bit rate in a given interval. The optimization problem is given as

$$\Pi^{MDI} = \arg\min_{R} \left\{ \sum_{i=1}^{n} \omega_i^{R} \right\} \quad (3)$$

The proposed ω_i^R can be calculated as

$$\omega_i^R = \frac{\overline{R_i^{MAX} - r_i}}{\overline{r_i}} \quad (4)$$

where $\overline{r_i}$ denotes the average bit rate of the user i in a given interval of time, and R_i^{MAX} represents the maximum bit rate that this user would achieve if all the resources were allocated to the close multicast group the user can decode correctly.

IV. Performance Evaluation

The performance evaluation has been carried out using the reference scenarios for single-cell and multi-cell multicast systems, based on the LTE standard. These scenarios use 3 MHz bandwidth, thus 15 RBs are available to deliver the service. A deployment of 100 users, which are multicast members of the service, has been used with a uniform distribution in each cell. A combination of users has been evaluated, using static (40%), pedestrian (40%) and vehicular (20%) UEs. Main simulation parameters are listed in Table I.

TABLE I
System Parameters

Parameter	Value
Multi-cell system size	7 eNodeBs
Interference model	1 tier of eNodeBs
eNodeBs geographical overlay	Hexagonal
Inter site distance	500 m
Transmission power	43 dBm
Antenna gain	11.5
Bandwidth	3 MHz
Number of PRBs	15
Downlink base frequency	2110 MHz
Pathloss model	3GPP Urban Macrocell
Multipath channel model	ITU Pedestrian B
eNodeB transmission antennas	1
UEs per eNodeBs	100
UEs distribution	Uniform distribution
Guaranteed bit rate per user UE	20-200 kbps
Pedestrian user speed	3 Km/h
Vehicular user speed	50 Km/h

A. Results of RRM strategies based on joint allocation of multicast and unicast transmissions

The first evaluation illustrates the service throughput achieved using different resource allocation strategies both in a single-cell and in a multi-cell multicast scenario, where users with different mobility features are placed.

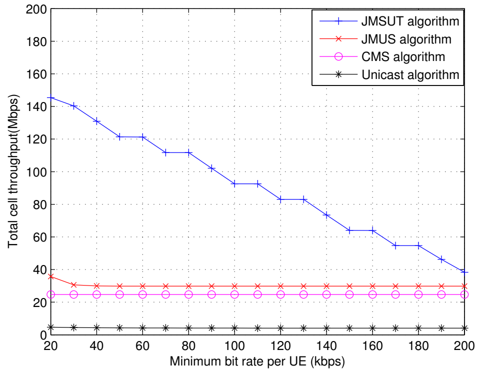
Fig. 1(a) shows the total service throughput as a function of the minimum bit rate required for every user. It can be noticed that the use of multicast transmissions highly improves the performance of using only unicast transmissions. Nonetheless, the application of joint resource allocation techniques enhances the throughput results with respect of the most conservative multicast scheduling scheme (CMS). Especially with the utilization of multicast subgrouping, since we can observe how the JMSUT strategy results in important improvements in service throughput over the use of Joint Multicast/Unicast Scheduling (JMUS) strategy, that is not using multicast subgroups, proposed in [8]. However, as the minimum bit rate per user is increased, this gain in total throughput is decreasing. This is because the resource allocation strategy must ensure that users with worst channel conditions reach this minimum bit rate, allocating more resources to the groups that are less efficient in terms of throughput.

Fig. 1(b) illustrates the service throughput achieved in the central cell and a peripheral one of the multi-cell multicast scenario, using both JMSUT and JMUS strategies. Furthermore, these results are compared with the ones achieved using the single-cell multicast scenario. It can be noticed an important throughput gain obtained in multi-cell scenario, especially in the central cell. The utilization of coordinated transmissions among 7-cells in an MBSFN area improves the channel conditions of the users in the cell edge, especially in central cell. In addition, this improvement in the channel conditions of the users leads to a higher gain using JMSUT instead of JMUS.

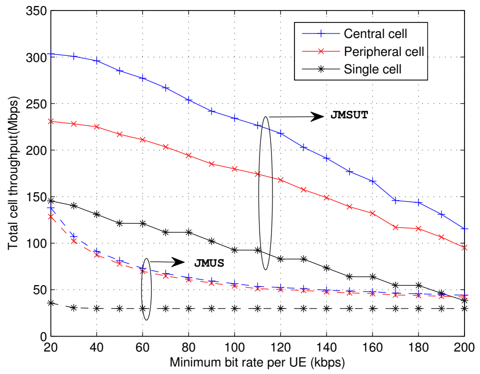
B. Results of RRM strategies based on memory utilization

The second evaluation shows the results obtained using cost functions with memory to allocate the multicast resources.

Fig. 2(a) and Fig. 2(b) show the service throughput and the fairness index achieved using PF and MDI algorithms as a function of the memory used. It can be noticed that the trade-off between throughput and fairness is improved using memory in the resource allocation algorithms. Consequently, the service throughput can be enhanced, at the time a high fairnes among the users in a given time interval is achieved.

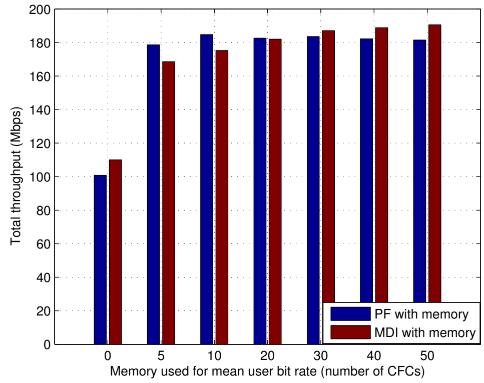


(a) Single-cell multicast scenario

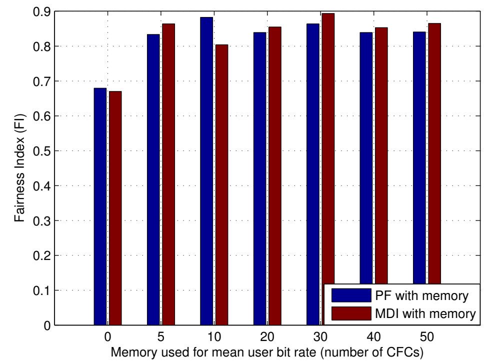


(b) Multi-cell multicast scenario

Fig. 1. Performance evaluation of JMSUT



(a) Service throughput



(b) Fairness Index

Fig. 2. Performance of resource allocation strategies with memory

V. Conclusions

This work studies some enhancements to resource allocation management in multicast services.

Firstly, the performance evaluation of a joint resource allocation strategy between unicast and multicast transmissions has been shown. This strategy is based on the creation of different multicast subgroups to allocate the available RBs among them, and combines it with transmissions in unicast subframes to serve the users with worst channel conditions. JMSUT strategy can greatly improve, in terms of service throughput, the results achieved using CMS or JMUS strategy proposed in [8].

Secondly, the evaluation of resource allocation strategies for multicast services using memory has been presented. The results bring out the improvements in the trade-off between service throughput and fairness when memory is introduced in the algorithms for multicast resource allocation. Thus, focusing on maximization of service throughput in a given time interval, a high fairness among users can also be achieved.

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