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Joint Multicast/Unicast Scheduling with Dynamic Optimization for LTE Multicast Service

Alejandro de la Fuente, Ana Garcia Armada, Raquel Pérez Leal
Department of Signal Theory and Communications
University Carlos III of Madrid
Email: afuente@tsc.uc3m.es, agarcia@tsc.uc3m.es, rpleal@tsc.uc3m.es

Abstract—Mobile video service is one of the most increasing uses expected in future generation cellular networks, including multicast video services. Based upon Evolved Multimedia Broadcast and Multicast Service (eMBMS) available with 3rd Generation Partnership Project (3GPP) release 9, Long Term Evolution (LTE) can provide broadcast/multicast content delivery with a single-frequency network mode. This means sending the same multimedia content to a mass audience within a specific area. However, it is not always possible to use multicast transmission to every user because of their different channel conditions, so unicast transmission should also be used to fulfill Quality of Service (QoS) requirements for multicast services. This paper proposes a Joint Multicast/Unicast Scheduling (JMUS) strategy for multicast service delivery. This method is based on dynamic optimization at each LTE frame, obtaining the optimal Modulation and Coding Scheme (MCS) for multicast transmission, the optimal number of subframes reserved for multicast transmission and allocating the remaining resources using a unicast scheduling metric for guaranteed data-rate. The goal of the scheduling technique proposed is to maximize the overall throughput, guaranteeing a target bit rate for all the users in the area. A new JMUS with dynamic optimization is presented to improve QoS performance. Finally, a fast search algorithm is evaluated to approach the optimal values for dynamic optimization with an order of magnitude fewer iterations than using exhaustive search.

I. INTRODUCTION

The growing demand for video services in mobile networks poses new challenges in the design of techniques to improve the throughput and the delays to provide those services. These techniques must guarantee the scalability for large amount of users and reliable transmission to everyone, every time and everywhere, using Long Term Evolution (LTE) coverage.

On the one hand, 3rd Generation Partnership Project (3GPP) proposed Multimedia Broadcast and Multicast Service (MBMS) [1], a point-to-multipoint service, that allows data transmissions from a single source to multiple recipients. This technique improves the scalability of broadband and multicast transmissions in mobile networks. MBMS utilizes a common channel to send the same data to multiple receivers, thereby minimizing the utilization of network resources. Furthermore, Multicast/Broadcast over Single Frequency Network (MB-SFN) was proposed to improve the performance of MBMS [1]. It avoids the destructive interferences in the areas where the coverage overlaps, and maintains the performance that would otherwise gradually decrease as User Equipment (UE) moves away from the base station. There are works that have analyzed

the performance of MBSFN [2], comparing it with point-to-point and point-to-multipoint traditional transmissions. These works conclude that MBSFN is the most efficient mechanism for sending multicast data, which contributed to its standardization by the 3GPP. In later works [3], the performance of MBSFN has been evaluated by means of a cost analysis to determine the ideal number of cells to optimize the global performance in the MBSFN transmission. Moreover, a joint delivery of unicast and multicast transmissions to repair the erroneously received files after the initial MBMS transmission using unicast service was proposed in [4].

On the other hand, while using multicast transmissions improves the efficient utilization of network resources, it requires setting equal transmission parameters to all the users in the MBSFN area. Consequently, in multicast transmissions, the Modulation and Coding Scheme (MCS) is unique and set by upper layers. Therefore, the multicast transmission throughput in the MBSFN area is jointly established by the MCS and the transmission bandwidth [5]. Differently, unicast transmissions can use link adaptation and channel dependent scheduling, based on the Channel Quality Indicator (CQI) the user sends periodically to the Evolved Node B (eNodeB). Therefore, Evolved Universal Terrestrial Radio Access (E-UTRA) can dynamically allocate resources, both Physical Resource Block (PRB) and MCS, to the UEs at each Transmission Time Interval (TTI) [5].

Moreover, different unicast scheduling mechanisms are developed to improve the system performance. Most of the current scheduling proposals provide a good trade-off between spectral efficiency and fairness for unicast transmissions [6]. Multi-user scheduling is a crucial feature in an LTE system, because it is in charge of distributing available resources among active users to satisfy their needs. Packet schedulers are deployed at the eNodeB. They work with a granularity of one TTI and one PRB, in the time and frequency domain, respectively. The scheduler performs the resource allocation decision every TTI and sends such information to the UEs. The characteristics of the fast fading in the channel, being independent for different users, can be exploited by allocation procedures. This allows to obtain "multi-user diversity" gain, that takes advantage of serving more than one user [7]. Different allocation strategies have been introduced for LTE systems, being channel-aware schedulers the most suitable for wireless networks, in particular those with Quality of Service

(QoS) support [6].

Furthermore, the adoption of advanced Radio Resource Management (RRM) procedures is critical to distribute radio resources among different users, taking into account channel conditions and QoS requirements. The procedure of CQI reporting is a fundamental feature of LTE networks, since it enables the estimation of the downlink channel quality at the eNodeB. The CQI reporting procedure is strictly related to the MCS chosen for the transmission, maximizing the supported throughput with a given Block Error Rate (BLER). Note that multicast transmissions cannot directly adapt the MCS to the CQI of each user, because the transmitted signal must be the same to all the users in the MBSFN area. Hence, high order MCS means high data rate multicast transmission, but at the cost of many users having a high BLER. Therefore, a good trade-off between high multicast data rate and the number of users receiving the service with the required BLER is needed.

Multicasting is emerging as an enabling technology for multimedia transmissions over wireless networks to support several groups of users with flexible QoS requirements. In [9] a survey of multicast scheduling an resource allocation algorithms for LTE systems is presented, in which various challenges and drawbacks associated with the algorithm design are described.

In this paper, a new Joint Multicast/Unicast Scheduling (JMUS) to maximize the overall throughput in the MBSFN area is developed. The proposed technique combines unicast and multicast transmissions to guarantee a target bit rate for all the users demanding a multicast service. By multicast service we refer to a streaming or downloading service delivered to all the users in the system model, while we denote by multicast transmission when the eNodeB uses the Physical Multicast Channel (PMCH) to send the same data to all the users and by unicast transmissions when eNodeB uses Physical Downlink Shared Channel (PDSCH) to send the data to each UE [5]. The optimal MCS and the optimal number of subframes reserved for multicast transmission are obtained each LTE frame; furthermore, the unicast scheduling metric for guaranteed data-rate proposed in [8] is used to allocate the remaining resources. The JMUS with dynamic optimization achieves better QoS performance than pure unicast, pure multicast, or JMUS without dynamic optimization scheduling techniques. In addition, an evaluation of a proposed fast search algorithm to obtain close to optimal multicast transmission parameters is developed. The proposed fast search algorithm achieves the dynamic optimization with an order of magnitude fewer iterations than an exhaustive search.

The rest of the paper is organized as follows. In Section II, the system model used is described. The proposed JMUS with dynamic optimization is detailed in Section III. The performance evaluation results are presented in Section IV. Finally, in Section V, the conclusions and future works are explained.
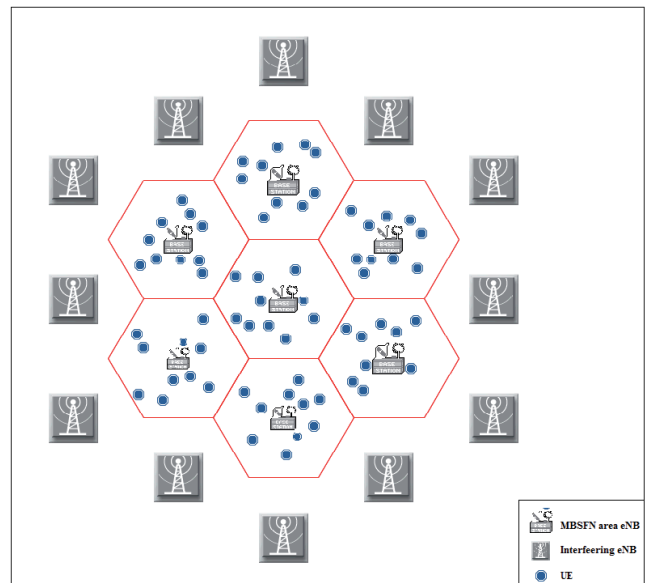

Fig. 1. System model

II. SYSTEM MODEL

We target an LTE system where a 7-cell MBSFN area has been configured. A multicast service is delivered to all the UEs placed in the region. Around the 7-cell MBSFN area, we consider one tier of 12 eNodeBs operating on the same frequency and transmission power as the 7 eNodeBs in the MBSFN area. The system model is depicted in Fig. 1. The values of the main parameters are shown in Table I.

TABLE I
SYSTEM PARAMETERS

Parameter	Value
MBSFN area size	7 eNodeBs
Interference model	1 tier (12 eNodeBs)
eNodeBs geographical overlay	Hexagonal
Cell radius	1 Km
Transmission power	42 dBm
Cyclic prefix	Extended ($16.7\mu s$)
Bandwidth	10 MHz (dedicated)
Downlink base frequency	2110 MHz
Pathloss model	3GPP Urban Macrocell
Multipath channel model	ITU Pedestrian A
eNodeB transmission antennas	1
UEs per eNodeBs	10
UEs distribution	Fixed UEs with uniform distribution
Target GBR per UE	500 kbps

In LTE systems, radio resources are allocated into the time/frequency domain [6]. In the time domain, they are distributed every TTI of 1 ms. Time is organized in frames, each one composed of 10 consecutive TTIs or subframes. In addition, each TTI is made of two time slots with 0.5 ms length. Each time slot corresponds to 7 Orthogonal Frequency Division Multiplexing (OFDM) symbols with normal cyclic

prefix (default configuration for unicast transmissions), or 6 OFDM symbols with extended cyclic prefix (recommended for MBSFN configuration for multicast transmissions). In the frequency domain, the total bandwidth is divided in sub-channels of 180 kHz, each one with 12 consecutive 15 kHz OFDM sub-carriers. A PRB is the smallest radio resource unit that can be assigned to a UE for data transmission, it consists of a 2D radio resource, over two time slots in the time domain, and one sub-channel in the frequency domain. As the sub-channel size is fixed, the number of PRBs varies according to the system bandwidth configuration (e.g. 50 PRBs for system bandwidth of 10 MHz).

To implement channel-aware JMUS, UEs' CQI are assumed to be known at the eNodeB [9]. CQI is estimated at each UE from the Signal to Interference plus Noise Ratio (SINR) measurement of its radio channel and sent to the eNodeB using feedback. The eNodeB utilizes this information to allocate the resources among the users, determining the MCS used for each unicast transmission. Furthermore, in the case of the proposed JMUS with dynamic optimization, the eNodeB utilizes this information to determine the optimal MCS and the optimal number of subframes assigned to the multicast group transmissions. The JMUS goal is to maximize the overall throughput of the multicast group, guaranteeing a target bit rate per UE.

III. JOINT MULTICAST/UNICAST SCHEDULING (JMUS)

A multicast service is delivered in an MBSFN area using a dedicated LTE bandwidth. An LTE system can use multicast or unicast transmissions to provide the service to all the users. This proposal finds the optimal compromise between unicast and multicast transmissions to maximize the overall through-put of the multicast group, guaranteeing QoS requirements. To this end, the MCS and the number of subframes used in multicast transmissions must be optimized, allocating the remaining resources using the unicast QoS-aware scheduling proposed in [8].

A. Problem Formulation

On the one hand, for all the users with the capability of receiving the multicast service using the multicast transmission (BLER $< 10\%$), the bit rate r_m is given as

$$r_m = \frac{n_s \times \Omega}{T} \quad (1)$$

where n_s denotes the number of multicast subframes, Ω is the transport block size utilized in multicast transmission and T denotes the frame length of 10 ms. Note that Ω depends on the MCS used and the number of PRBs available for the transmission [10].

On the other hand, the remaining resources available in the LTE frame are allocated using unicast transmissions. The bit rate r_{u_i} for the unicast transmission of user i is given as

$$r_{u_i} = \frac{z_i \times \Omega_i}{T} \quad (2)$$

where z_i is the number of transport blocks allocated to user i and Ω_i is the transport block size per PRB when the MCS required for user i is used [10].

The optimization problem results in maximizing the multi-cast service capacity C_T given as

$$C_T = M \times r_m + \sum_{i=1}^{U} r_{u_i} \quad (3)$$

where M and U are the number of UEs making use of multicast and unicast transmissions, respectively. Both M and U depend on the MCS, denoted as μ, chosen for multicast transmission.

The JMUS strategy must take into account several con-straints. The maximization problem with its constraints is detailed in Equations (4-9).

$$\begin{aligned}
\underset{\mu, n_s, z_i}{\text{maximize}} \quad & C_T & (4) \\
\text{subject to} \quad & M + U = K & (5) \\
& n_s \in \{1...6\} & (6) \\
& r_m \geq \Gamma & (7) \\
& r_{u_i} \geq \Gamma \quad \forall i & (8) \\
& \sum_{i=1}^{U} z_i \leq (10 - n_s) \times \Psi & (9)
\end{aligned}$$

The goal is to find the optimal values of μ and n_s that max-imize the system capacity C_T at each LTE frame transmission. The unicast QoS-aware scheduling must guarantee the optimal z_i allocation each frame transmission too. In (5), K is the total number of UEs. The multicast subframes number constraint is given as Equation (6). In (7) and (8), the target bit rate constraint for multicast and unicast transmissions, respectively, is presented. Finally, Equation (9) limits the resources used for unicast transmissions, and depends on Ψ that is the total number of PRBs for the system bandwidth.

B. Exhaustive Search Algorithm

An exhaustive search algorithm can be used to obtain the optimal values for the maximization problem. JMUS with dynamic optimization uses the knowledge of the UEs' CQI in the eNodeB, and therefore the optimal MCS to each UE transmission. The exhaustive search algorithm computes the bit rates of the UEs using both all MCS values (29 alternatives) and all possibilities of subframes reserved for multicast (6 alternatives). Consequently, the exhaustive search used for JMUS with dynamic optimization requires 174 (29×6) iterations each LTE frame to find the optimal values. Each combination gives a number of UEs using multicast transmis-sion (UEs that can receive the MCS used with the required BLER) and the remaining unicast transmissions for receiving the multicast service. When all the combinations are checked, the one which maximizes the multicast service capacity and fulfills the target bit rate for all the users is selected.

Algorithm 1 Fast Search Algorithm

```
1:  t = {1...1000} ∈ ℤ              ▷ Number of LTE frames
2:  m = {0...28} ∈ ℤ               ▷ Available MCS indexes
3:  s = {1...6} ∈ ℤ                ▷ Multicast subframes options
4:  l = {1...10} ∈ ℤ               ▷ Total number of LTE subframes
5:  Input CQI₁ₜ...CQI_Kₜ           ▷ CQI for each UE/frame
6:  for all t do
7:      Compute MCS₁...MCS_K = f(CQI₁ₜ...CQI_Kₜ)
8:      m = 0
9:      s = 6
10:     repeat
11:         repeat
12:             Calculate M        ▷ UEs using multicast
13:             for all l do
14:                 if multicast subframe then
15:                     Compute multicast bit rate as (1)
16:                     Update r_m for multicast UEs
17:                 else
18:                     Compute unicast bit rate as (2)
19:                     Update r_{uᵢ} for unicast UEs
20:                 end if
21:             end for
22:             m ← m + 1
23:         until [unfeasible] or [sum bit rate ↓] or [m > 28]
24:         s ← s − 1
25:     until [unfeasible] or [sum bit rate ↓] or [s < 1]
26:     μ(t) ← m − 1
27:     n_s(t) ← s + 1
28:     Update rᵢ                   ▷ UE i bit rate
29: end for
```

C. Fast Search Algorithm

To reduce the computation complexity in the eNodeB we propose a faster search algorithm that can obtain these values with a much reduced number of iterations.

Firstly, an analysis of the problem feasibility has to be made to look for a good starting point. This problem can be guaranteed to be feasible, when the target bit rate constraint is less than the bit rate generated using the most robust MCS (all the UEs can receive the multicast transmission) and the maximum number of subframes available for multicast transmissions. In a 10 MHz bandwidth LTE system, using $\mu = 0$ and $n_s = 6$, a multicast bit rate of 830 kbps is guaranteed to all the UEs [10].

Given that the target condition makes the problem has a solution, i.e. $\Gamma = 500$ kbps, the algorithm should define a feasible starting point for the fast search [11]. Choose $\mu = 0$ and $n_s = 6$ as the starting point. Next, the search algorithm looks for suboptimal values. First, the MCS index is increased looking for maximizing the capacity in the feasibility region. The feasibility region of this problem consists of the solutions that fulfill the bit rate requirements of all the UEs. Afterwards, the number of multicast subframes is decreased and the algorithm checks if the capacity is increased in the feasibility
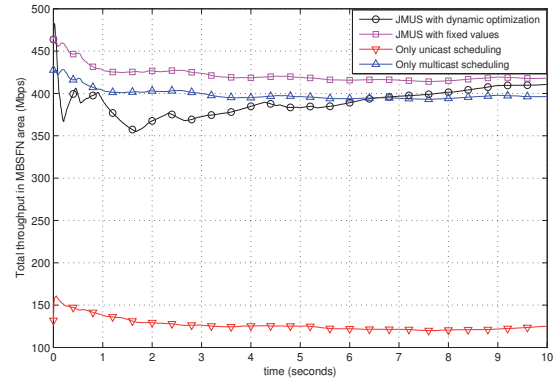

Fig. 2. Sum of all UEs bit rate using accumulated throughput constraint

region. If it is indeed increased, the MCS index is increased looking for maximizing the capacity again. The new search starts with the MCS value that maximizes the capacity with the subframe number checked before. The search algorithm stops when the multicast subframe number is decreased and the capacity is not increased in the feasibility region.

The JMUS with dynamic optimization using a fast search algorithm to find close to optimal values of multicast MCS and number of subframes is shown in Algorithm 1 using pseudo code. The average number of iterations needed to compute the fast search algorithm each LTE frame is presented in the following section.

IV. PERFORMANCE EVALUATION

Performance evaluation has been carried out during a simulation time of 10 seconds (1000 frames), with 10 fixed UEs uniformly distributed in each cell of the 7 eNodeBs MBSFN area. The following scheduling techniques have been used:

1) Pure unicast transmission with generic QoS-aware scheduling as proposed in [8].
2) Pure multicast transmission scheduling allocating fixed MCS and subframes values ($\mu = 14$ and $n_s = 6$).
3) JMUS using fixed MCS and subframes values ($\mu = 14$ and $n_s = 6$).
4) JMUS with dynamic optimization of the multicast MCS index and the number of subframes allocated for multicast transmissions.

Two different ways to evaluate the fulfillment of the constraints have been used. On the one hand, in Fig. 2, the UE bit rate constraint used is the accumulated throughput received since the beginning of the simulation. On the other hand, in Fig. 3, the bit rate constraint is required to be fulfilled instantaneously, every frame transmission.

These results show the sum of all UEs bit rates which are demanding the multicast service in the MBSFN area. The overall throughput achieved using JMUS with dynamic optimization considering the bit rate per frame constraint (Fig. 3) is lower than using the accumulated throughput constraint (Fig. 2). The use of JMUS with dynamic optimization improves the
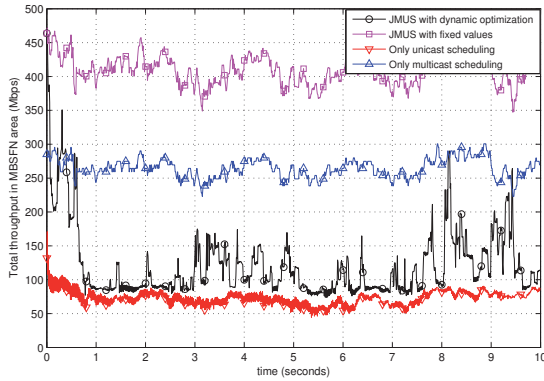
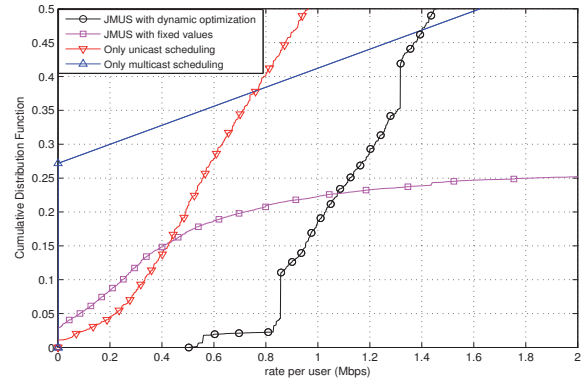Fig. 3. Sum of all UEs bit rate using bit rate per frame constraint

Fig. 5. CDF of UEs bit rate using bit rate per frame constraint
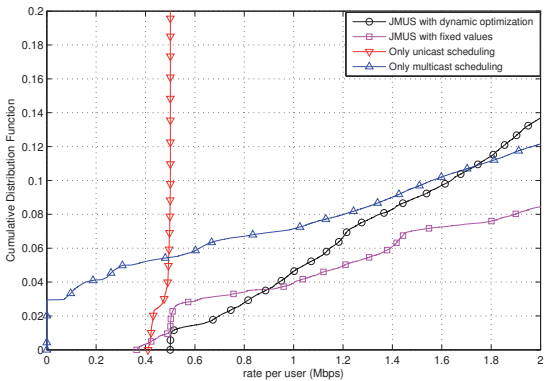

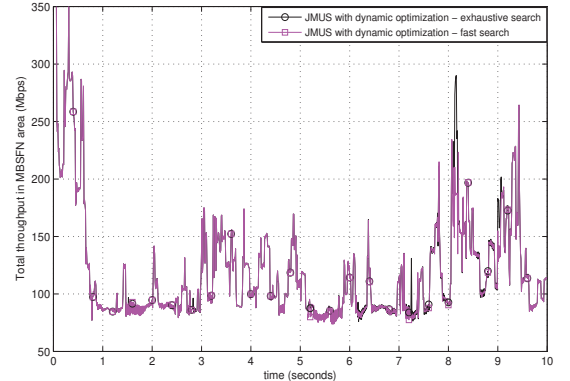Fig. 4. CDF of UEs bit rate using accumulated throughput constraint

Fig. 6. Sum of all UEs bit rate with different search algorithms

overall bit rate of using pure unicast scheduling. However, using JMUS and pure multicast scheduling with fixed values of the MCS and the multicast subframes results in higher overall bit rate. Note that the use of scheduling methods with fixed values cannot fulfill the QoS constraints as is depicted in the Cumulative Distribution Function (CDF) both in Fig. 4 and Fig. 5. Nevertheless, using JMUS with dynamic optimization the constraint requirements are fulfilled.

Thereby, only by using JMUS with dynamic optimization allows to get 100% of the bit rate constraint requirements fulfillment. The goal of the scheduling technique to achieve all UEs bit rate higher than the target (500 kbps) at every frame can only be fulfilled using JMUS. This goal cannot be ensured with the other scheduling techniques used in this paper for the performance evaluation comparison.

Next, the evaluation of using the proposed fast search algorithm compared to an exhaustive search for the dynamic optimization is presented. Fig. 6 illustrates the sum of all UEs bit rate using both searching algorithms. We can see that the use of both algorithms implies to achieve almost the same results each frame. These results are confirmed in Fig. 7, where the CDF of UEs bit rate is depicted using both exhaustive and fast search algorithms, when the constraint requirements are

applied per LTE frame.

Moreover, the use of the proposed fast search algorithm highly reduces the number of iterations needed to obtain the optimal values of the parameters each LTE frame. While using the exhaustive search algorithm, 174 iterations are needed each frame. However, with the proposed fast search algorithm, an average of 16.46 iterations are needed, using the bit rate per frame constraint, and 20.32 iterations when the accumulated throughput constraint is used.

Finally, the evaluation has been performed for a UE target bit rate higher than 500 kbps, as both Fig. 8 and Fig. 9 depict, obtaining interesting results. When the UEs target bit rate is increased higher than 830 kbps, the feasibility of the maximization problem cannot be guaranteed to be fulfilled, and the search starting point may be not feasible. However, as it can be observed in Fig. 9, using JMUS with dynamic optimization and bit rate per frame constraint, a 3 Mbps target bit rate can be fulfilled for more than 90% of the cases.

V. CONCLUSIONS

The results of the performance analysis show that using JMUS with dynamic optimization of the MCS and the number of subframes reserved for multicast transmissions can im-
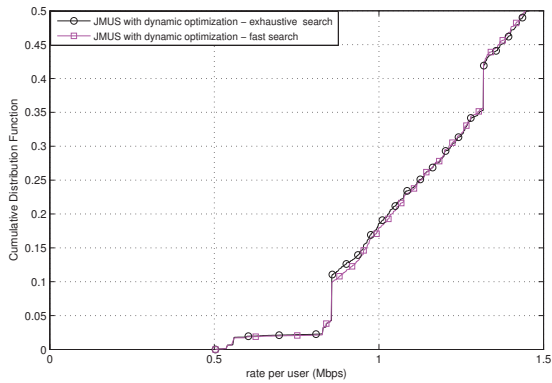
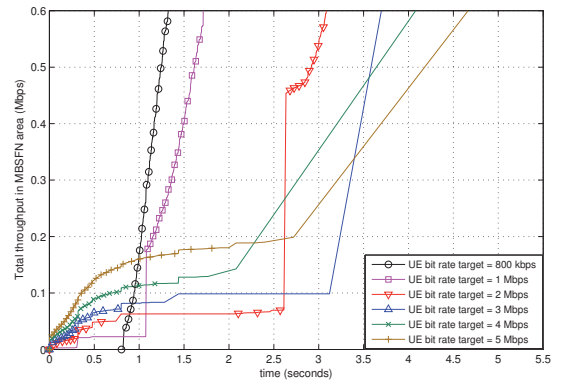Fig. 7. CDF of UEs bit rate with different search algorithms

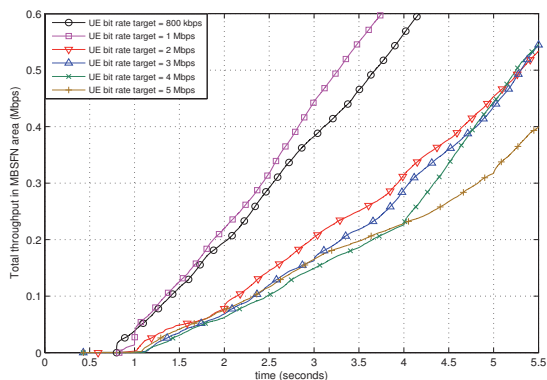Fig. 9. CDF of UEs bit rate using bit rate per frame constraint

Fig. 8. CDF of UEs bit rate using accumulated throughput constraint

prove the performance of multicast services (downloading and streaming multicast services). In order to guarantee the QoS requirements, this technique shows an important advantage over pure unicast or multicast techniques and JMUS with fixed values. While pure unicast techniques can be used to guarantee a target bit rate per UE, but the bit rate achieved is remarkably lower as compared to the use of the multicast techniques. On the other hand, using pure multicast techniques the overall bit rate achieved is high and using JMUS with fixed values it can be maximized. Nevertheless, these techniques cannot guarantee a minimum target bit rate. We have demonstrated that the use of JMUS with dynamic optimization allows the system to maximize the overall throughput taking into account the constraint requirements, so the fulfillment of QoS requirements is improved as compared to the other techniques.

In addition, a proposed fast search algorithm is performed and evaluated. This algorithm uses an order of magnitude fewer iterations to obtain close to optimal values than an exhaustive search.

Finally, this mechanism still presents a high degree of fulfillment when the target requirements are increased upto 3 Mbps.

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