A Hybrid Unicast-Multicast Network Selection for Video Deliveries in Dense Heterogeneous Network Environments

Giuseppe Araniti, *Senior Member, IEEE,* Pasquale Scopelliti, *Student Member, IEEE,*, Gabriel-Miro Muntean *Senior Member, IEEE,* and Antonio Iera *Senior Member, IEEE*

***Abstract*—Resource management in emerging Dense Heterogeneous Network Environments (DenseNets) is a challenging issue. The employment of multicast transmissions in this scenario has potential to address the problems. On one hand, the large number of smart user mobile devices and user expectations for high-quality rich media services has determined a growing demand for network resources; in DenseNets, mobile users have to make the choice in terms of the network to connect to, in order to balance energy saving and delivery performance. On the other hand, the proliferation of user accesses to the existing and future network infrastructure will bring along with it the operators need for optimizing the radio resource usage. This paper proposes a Hybrid Unicast-Multicast utility based Network Selection algorithm (HUMANS), which offers the additional option of selecting multicast transmissions in the network selection process during video delivery. By serving users with good channel conditions via unicast transmissions and users with poor channel quality conditions via multicast, HUMANS allows outperforming other solutions in terms of outage percentage and average quality of transmission, in both low- and high-density scenarios. Most importantly, at the same time it guarantees operators a more efficient resource utilization.**

***Index Terms*—Network Selection, Video Delivery, DenseNets, Energy Saving, Multicasting, Resource Allocation.**

I. Introduction

THe growing number of smart user mobile devices and the raising demand for video-centric applications (e.g., video on demand, video games, live video streaming, video conferencing, video surveillance, etc.) accessed via existing network infrastructure make the provision of services at high quality very challenging.

Yet, providing these services at high quality and at low cost in the emerging fifth generation network realm is fundamental for its market success. For instance, LTE-A [1] helps to overcome challenges related to *edge-cell users* and *coverage holes*. The deployment of several femtocells within a macrocell area served by a Base Station (BS) can provide an improved coverage (either indoor or in the coverage holes, for example) and an increase in the system capacity through the offloading of some of the macrocell's traffic. Furthermore, edge-cell users connected to a femtocell should benefit from a higher data rate, low latency, and improved levels of Quality of Service (QoS) and Quality of Experience (QoE).

In the view of an increased capacity and improved performance of the system, recent researches push towards the deployment, within the same area, of several coverage layers (associated to macro, micro, pico, and femto cells), diverse Radio Access Technologies (RAT) (e.g. GSM, UMTS, LTE, WiFi), and multiple Point-to-Point (PtP) user links (e.g. Device-to-Device communication [2], mmWave). This massive growth of dissimilar cell deployments is leading to a high densification of networks and to the creation of the so-called Dense Heterogeneous Network (DenseNet) [3] paradigm.

Moreover, radio resources management (RRM) is stressed by the huge number of smart devices requiring video services. In this scenario, device-to-device (D2D) communications [4] and multicast services over current LTE and future 5G systems [5] have been considered as possible enabling approaches to efficiently manage the traffic load and provide a better Quality of Experience (QoE) to end-users. In particular, multicasting allows a large number of users to be simultaneously served with relatively low latency and high throughput. To support such services, the Third Generation Partnership Project (3GPP) offers basic support to the standardization of multicast services over LTE under the name of enhanced Multimedia Broadcast Multicast Services (eMBMS) [6].

One of the most important issues for multicast transmission is the management of multi-user diversity. In fact, each user within a multicast group experiences a different channel quality level. *Least channel gain* users affect the performance of the whole multicast group as they can only support a transmission with low Modulation and Coding Scheme (MCS) level, thus achieving transmissions with bad spectral efficiency. On the contrary, serving multicast users that experience high channel quality levels improves the system spectral efficiency, at the expense of users under bad channel conditions. This introduces challenging issues for the RRM in multicast transmissions.

Our research focuses on a DenseNet deployment scenario characterized by overlapping of an LTE-A macro cell and LTE-A small cells (i.e., femtocells), in the presence of multicast groups in each cell. In this scenario, mobile users want to access video content at high user QoE levels and with a low energy consumption. Indeed, energy/power management as

G. Araniti, P. Scopelliti and A. Iera are with DIIES Department, University Mediterranea of Reggio Calabria, Italy, e-mail: {araniti, pasquale.scopelliti, antonio.iera}@unirc.it

G.-M. Muntean is with the Performance Engineering Lab and School of Electronic Engineering, Dublin City University, Ireland, e-mail: gabriel.muntean@dcu.ie

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well as user mobility management are key challenges in the next generation mobile multimedia networks [7]. Innovative RAT selection [8] solutions help in managing energy issues for smart users in mobility. However, mobile users have to face the issue of the wise selection of the access network to connect to, which is made more challenging by the highly dynamic network environment [9]. In particular, in a DenseNet context, network selection should place great importance to improving the balance between QoE of the video service offered to the user and energy saving [10]. Furthermore, a proper management of network selection is needed, in order to avoid issues such as frequent and unnecessary handovers (i.e. the so-called *ping-pong effect*).

Access network selection schemes can be user-centric or network-driven. In the user-centric approaches, the focus is on maximizing user QoE levels. However, this presents several limitations as users are only aware of their link quality, and have no information about the network load, which could affect user perceived quality and induce instability due to frequent handovers. In the network-driven solutions, the objective is to maximize the network operator revenues and maintain high overall user satisfaction by avoiding network congestion and by selecting the optimum interface for each user.

In this context, there is a need for a resource allocation mechanism to provide the best available performance to the largest number of users possible. The presence of a multicast transmission helps to obtain such a requirement, but at the cost of a compromise in terms of data-rate achieved by users within the multicast group. Generally, the methodology of resource allocation is to model it as an optimization problem whose objective function and constraints are determined by user requirements and network specifications. The objective function is usually referred to as utility function, which characterizes a user satisfaction when allocated given resources [11].

This paper proposes the *Hybrid Unicast-Multicast utility based Network Selection algorithm (HUMANS)*, a network selection approach that exploits the benefits of multicast during video delivery. In such an approach both bandwidth utilization (an operator priority) and the trade-off between quality and energy consumption (a user priority) are considered in deciding how to deliver video content in a DenseNet. HUMANS, in taking access-related choices, considers the estimated energy consumption of the mobile device running a real-time video application, the estimated achievable data-rate, the utilized resources and the expected user satisfaction level.

A major contribution is, thus, a mechanism allowing for a wise network selection choice, also considering a multicast group joining option, which at the same time meets users exigencies and enables a smart bandwidth management.

The remainder of this paper is organized as follows. In Section II the major literature proposals related to our research work are discussed from the perspectives of network selection and RRM algorithms for multicast transmission. The reference system model is described in Section III, whereas the proposed HUMANS and its related utility function are presented in Section IV. Performance evaluation is performed and analysed in Section V, whereas conclusive remarks are summarized in Section VI.

II. Related Works

On the one hand, the 5G DenseNet environment will provide increasing coverage and system capacity with respect to the current cellular networks. On the other hand, the DenseNet's associated higher complexity exacerbates problems of interference coordination, power consumption, RRM and mobility management. In such a DenseNet scenario, there is a need for proper Network selection and resource allocation in order to meet both 5G requirements and user and market expectations in terms of, high QoE levels, increased power saving, reduced cost, etc. State-of-the art related to our research is discussed next, from the perspectives of network selection solutions and RRM algorithms in multicast transmissions.

A hybrid multimedia delivery solution which balances the benefits of multimedia content adaptation and network selection in order to decrease power consumption in a heterogeneous wireless network environment, composed of UMTS and WLAN networks, was proposed in [10]. The trade-off between energy and quality has been considered via a utility function. Similar approaches have been introduced in [12] and [13]. In [12] authors propose an adaptive real-time Multi-user access network selection load balancing algorithm, taking into account not only the real-time global traffic load on each network, but also considering the different classes of traffic. Whereas, the solution proposed in [13] combines several inputs such as power of the received signal, throughput, packet delay, cost-per-user, the requested type of traffic, and type of device.

In [14], authors propose a network selection solution based on a novel algorithm, which relies on the concept of Fittingness Factor (FF). The novel solution maximizes a function that reflects the suitability of the available spectrum resources to the application requirements. The selection is carried out by taking into account specific parameters and QoS metrics. The suitability of a network is determined by using the data bit rate required by the new flow and the bit rate that the network can support.

Several other network selection criteria have been presented in literature, such as for instance the multi-criteria decision making (MCDM). In [15] authors present performance evaluation of a number of widely used multi-attribute decision making solutions. TOPSIS [16] method has been exploited in [17], where account user preferences, network conditions, QoS and energy consumption requirements have been taken into account, in order to select the optimal network which achieves the best balance between performance and energy consumption. In [18] and [19] Game theory has been used to perform network selection. The goal of [18] is maximize accommodated number of calls, minimize handoff occurrences frequency, and fulfill QoS requirements. Hence, the network that maximizes the utility value obtained through the game is selected as the most suitable network for the call request. Game theory is exploited in user-centric manner in [19]. The game-theoretic approach carried out the negotiation between users and network operators in terms of offered prices and service quality.

Furthermore, in a DenseNet scenario with several small cells deployed, users are moving near the small cells and enter and exit in/from their coverage area with high frequency. This introduces additional issues such as unnecessary handovers with consequent reductions in terms of user QoE and system capacity. Authors in [20] propose a RAT selection algorithm that efficiently manages the RAT handover procedure by *(i)* choosing the most suitable RAT that guarantees high system and user performance, and *(ii)* reducing unnecessary handover events. They introduce a parameter named *Reference Base Station Efficiency* that considers the BS transmitted power, BS traffic load and user spectral efficiency.

A different approach to avoid unnecessary handovers is a user mobility-aware technique that takes into account users' speed [21] [22]. The authors of [21] proposed a handover algorithm based on the user speed and QoS. The authors suggested that users with high speed do not need to handover, as they cross the coverage area fast and especially when avail from non-real-time services, as this is inefficient. Nevertheless, they did not consider any energy saving issue. An energy efficient handover algorithm is proposed in [22] with the aim to reduce power consumption and frequent and unnecessary handovers. Users' speed is accounted for in order to allow only slow users performing handover. On the other hand, power saving is accomplished by decreasing the femtocell power transmission in particular conditions. However, the energy management proposed in [22] is network-side only, and does not consider mobile device power consumption, a key aspect for users.

EMANS [23], instead, proposes an energy-saving network selection algorithm, which provides a good trade-off between energy consumption and perceived quality when delivering video content. EMANS includes a method to adapt the delivered video stream bitrate according to the available network resources such as maintaining good user perceived quality levels. Furthermore, it also reduces the number of handovers in comparison with other state-of-the-art approaches.

All the works presented above deals with unicast transmission. Nevertheless, a dense 5G scenario should take into account also group-oriented transmissions. In such a solution, the selection of the most proper MCS with which serve all users is a challenging issue. A typical solution is represented by the conventional multicast scheme (CMS) where all the users within a multicast group are served with the lowest level MCS, representing users with worst channel condition [24].

The opportunistic multicasting [25] has been proposed in literature as a possible solution to overcome the typical limitations of the conservative approach and to efficiently exploit multi-user diversity, thus providing a more effective selection of the MCS based on the users channel information. CMS and OMS are both single-rate transmission modes, where the BS transmits to all users in each multicast group at the same rate. In Multi-rate, instead, the BS transmits to each user at different rates exploiting users frequency diversity, according to the heterogeneity of wireless channel.

The work presented in [26] optimally forms multicast groups, based on the users data rate. Whereas, the authors of [27] propose an approach for Single-Frequency Networks aiming to increase the aggregate datarate of the multicast group by pushing out of the transmission bad channel users, which are served through unicast transmissions. Nevertheless, differently from our work, this approach does not account for resource utilization and, like some other innovative works, may cause waste of resources. In a 5G scenario, where several users require high quality services, a big issue is the limited availability of radio resources. Multicast transmissions have become a solution for both increasing network capacity and improving spectral efficiency. Hybrid unicast-multicast approaches [28] can provide an efficient radio resource exploitation.

Differently from previous works, this paper introduces a utility-based network selection algorithm, which takes into consideration hybrid unicast-multicast transmissions and balances energy consumption and quality for video deliveries in DenseNets. Besides taking into account the trade-off between throughput and estimated energy consumption of the mobile device, the selection of the network is also affected by the radio resources required by the users, in order to achieve an efficient usage of radio spectrum. In particular, the approach proposed considers that users with good channel conditions, which consequently need less resources, could be served via unicast, whereas users with bad channels can be served via multicast. This paper extends an early version of the proposed HUMANS approach in [29] by: *(i)* introducing a comparison in low and high density scenarios by adding users with higher mobility (i.e., from 3 to 60 kmph), *(ii)* presenting the proposed idea through an algorithmic approach and presenting the details of the HUMANS operation in a step-wise manner, and *(iii)* assessing the performance of HUMANS through an exhaustive simulation campaign under low and high density conditions in terms of throughput, energy consumption, user satisfaction, percentage of served users and utilized resources.

III. System Model

The reference scenario consists of a DenseNet scenario, represented by a LTE base station (eNB) and several small-range LTE femtocells (HeNB) under the same coverage area (Fig. 1). Multicast flows are activated within each cell belonging to the reference area. Users within this area access multimedia video content and pass through different cell coverages. In each overlapping point users need to select the most appropriate network to connect to.

In LTE systems [1], Orthogonal Frequency Multiple Access (OFDMA) and single carrier frequency division multiple access (SC-FDMA) are used to access the downlink and the uplink, respectively. The available radio spectrum is split into several *Resource Blocks* (RBs) and, in the *frequency domain*, each RB corresponds to 12 consecutive and equally spaced sub-carriers. One RB is the smallest frequency resource that can be assigned to a user equipment (UE). The overall number of available RBs depends on the system bandwidth and can vary from 6 (1.4 MHz channel bandwidth) to 100 (20 Mhz). The eNodeB (eNB), which is the node that communicates with UEs, is in charge to assign the adequate number of RBs to each user. The packet scheduler properly manages

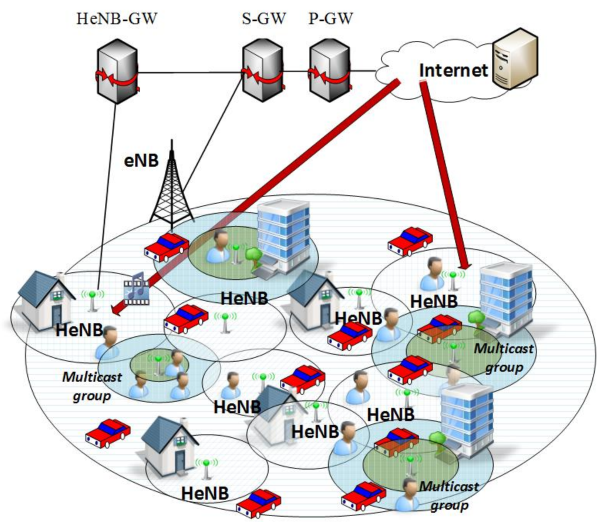


Fig. 1. Example mobile users in a DenseNet environment with the presence of multicast groups.

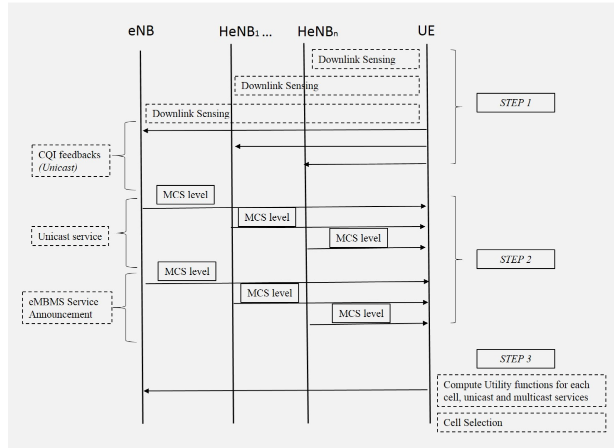


Fig. 2. HUMANS procedures.

the transmission parameters and the allocation of the $\mathcal{B}$ RBs according to the Channel Quality Indicator (CQI) feedbacks received from the users. Based on the CQI received by each user, the transmission from the BS to the user is set with a given MCS. For each MCS level, a certain spectral efficiency is achieved by the transmission. The greater is the spectral efficiency, the lower is the number of RBs required to achieve a given datarate[1].

In case of multicast service, it is typically the UE that experiences the worst CQI that drives the MCS selection for the multicast transmission. It means that the multicast flow is delivered with very low spectral efficiency. On the other hand, during a multicast session all the bandwidth dedicated for the MBMS service could be assigned to the multicast transmission. Furthermore, it is worth noting that, according to the eMBMS standard [6], at least 40% of whole available bandwidth has to be dedicated to unicast transmissions.

We consider a wireless network scenario where different types of small networks (the term *cell* is also used in this paper), e.g. femtocells, are deployed in an uncoordinated manner within a macro cellular coverage, as shown in Fig. 1.

Let $\mathcal{U} = \{u_i | i = 1, \ldots, n\}$ the set of Users and $\mathcal{C} = \{C_j | j = 1, \ldots, c\}$ is the set of all cells of the scenario, and each cell C_j can be either a eNodeB (i.e. a macrocell) or a HeNb (i.e. a small cell). Since the handover decision measurements are performed in the downlink direction, we focus on the transmission from a the generic cell C_j to a generic UE u_i.

τ is the time interval (TTI) in between regular system updates. Every τ each i-th UE u_i collects measurements from all cells which it is able to sense.

Network selection is then accomplished through computing of a utility function $\mathcal{U}$ (eq. 1) that takes into account the energy consumption of the mobile device when running real-time video applications, estimated network conditions, utilized resources and estimated user's satisfaction level.

[1]Depending on the spectral efficiency guaranteed by the MCS assigned to that transmission, the frequency scheduler has to decide how many RBs should be assigned to the user.

IV. Proposed HUMANS algorithm

The proposed approach aims to provide a very good trade-off between throughput, energy consumption and user satisfaction while allowing a high number of users to be served, hence targeting efficient resource utilization, too.

The proposed Hybrid Unicast-Multicast utility-based Network Selection algorithm (HUMANS) is designed for DenseNet scenarios and is based on appropriate network selection carried out by users. Moreover, according to the considered scenario, the proposed algorithm could be tailored for next-generation video applications. For example, the proposed HUMANS algorithm could be exploited for convergence of broadcasting and forthcoming 5G enabling technologies. Fig. 2 presents a step-wise description of the algorithm phases.

- During step 1, each user first senses the neighbor cells and send the CQI of the respective downlink channel to all of them.
- In step 2, each cell selects the most appropriate MCS level for the user according to the received CQI, and announces the multicast service (eMBMS Service announcement). In such a message is also included the MCS level of the multicast group. According to such informations the user performs the network selection as explained in the next step.
- In step 3, Network selection is executed according to the utility function defined for each Radio Access Network (RAN) j by the following equation:

$$\mathcal{U}_j = u_{q_j}^{\omega_q} * u_{e_j}^{\omega_e} * u_{s_j}^{\omega_s} * u_{b_j}^{\omega_b} \tag{1}$$

The use of a utility function together with the Multiplicative Exponential Weighted (MEW) method in the decision making mechanisms has proven to be useful in [30]. In equation (1) $\mathcal{U}_j$ is the overall score function for RAN j and u_{q_j}, u_{e_j}, u_{s_j}, u_{b_j} are the utility functions defined for video service quality, device energy consumption, user satisfaction and radio resource usage, respectively. w_q, w_e, w_s, w_b are weights for the considered criteria, representing the importance of the associated parameter in the decision algorithm, where $w_q + w_e + w_s + w_b = 1$. Such score is computed for every neighbor cells of each UE. This is done for both unicast and multicast services, which could be offered within the cell. The cell with the highest score is selected as target cell for the UE. Regarding multicast, it is considered that a multicast group is already created in the cell and, if the considered UE will join the group, its transmission will adapt to the multicast transmission (i.e., it will be served with the MCS level already selected for the multicast transmission). The novelty of the proposed approach is that it takes into account the multicast transmission as an additional option during the RAN selection. It means that, when sensing a new cell, each user exploits the opportunity to select either a unicast or a multicast transmission. Hence, a score is computed also for the multicast transmission within the cell. In such a case if a user decides to join a multicast group following the evaluation of eq. (1), then it could suffer from a lower performance in terms of throughput. This is due to the level determined by the least channel gain user in the multicast group, because it is assumed that the scheduler implements the CMS scheme. On the other hand, higher radio resource savings will be achieved since the resources for the multicast group have been already reserved. Therefore, the user joining a multicast group does not introduce additional resource waste. In such a way, the system has more resources available, i.e. more users could be served.

The utility function for the estimated video quality received by each RAN is defined by the following sigmoid utility function introduced in [31]:

$$u_q = \begin{cases} 0, & \text{for } Th < Th_{min} \\ 1 - e^{\dfrac{-\alpha * Th^2}{\beta + Th}}, & \text{for } Th_{min} \leq Th < Th_{max} \\ 1, & \text{otherwise} \end{cases} \quad (2)$$

The minimum throughput (Th_{min}) is a threshold to maintain the multimedia service at a minimum acceptable quality level. Values below this threshold result in unacceptable quality levels. Th_{req} is the required throughput in order to ensure high quality levels for the multimedia service. Whereas values above the maximum throughput (Th_{max}) threshold will not add any noticeable improvements in the user perceived quality. The quality utility has values in the [0,1] interval and no unit. In order to determine the exact shape of the utility function the values of α and β need to be calculated. Knowing that: (1) for $Th_{max} = 3500$ kbps the utility has its maximum value; (2) $Th_{req} = 250$ kpbs; α and β are determined by performing some mathematical computations of [31] and their values are 1.64 and 0.86, respectively.

The estimated energy consumption for a real-time application is computed using equation (3), as defined in [32]:

$$E = t(r_t + Th_{rec} * r_d) \quad (3)$$

where t represents the transaction time, which can be estimated from the duration of the video stream; r_t is the mobile device energy consumption per unit of time (W), Th_{rec} is the received throughput (kbps), r_d is energy consumption rate for data/received stream (J/Kbyte), and E is the total energy consumed (J). The two parameters, r_t and r_d, are device specific and differ for each network interface (e.g., LTE, WiFi) [33]. They were determined by running different simulations for various amounts of multimedia data (i.e., quality levels) while measuring the corresponding energy levels and then used to define the energy consumption pattern for each interface/scenario. The device power consumption depends on receive (Rx) and transmit (Tx) power levels, uplink (UL) and downlink (DL) data rate, and RRC mode [34]. Uplink transmit power and downlink data rate greatly affect the power consumption, while uplink data rate and downlink receive power have little affect. In this work, we deal with the downlink side, so we focus only on the power consumption contribution related to the down link datarate. Therefore, the energy consumption defined by eq. (3) refers only to the downlink datarate energy consumption. Based on the estimated energy consumption E, the utility for the energy criteria u_e is computed by using eq. (4) [15]:

$$u_e = \begin{cases} 1, & \text{for } E < E_{min} \\ \dfrac{E_{max} - E}{E_{max} - E_{min}}, & \text{for } E_{min} \leq E < E_{max} \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

where E_{min} and E_{max} are computed considering Th_{min} and Th_{max}, respectively.

The user satisfaction utility function u_s is defined as the ratio between the datarate received and the datarate required by the user.

$$u_s = \frac{Th_{rec}}{Th_{req}} \quad (5)$$

Obviously, the satisfaction achieved by users connected via unicast is, on average, closer to the value of 1 since the eNB tries to assign users all RBs they need. Oppositely, the satisfaction of users connected via multicast is affected by users with worse channel gain. Finally, the bandwidth utilization utility reflects the amount of resources used by the user in the context of the total amount of available resources. The utility is calculated as the ratio between the new RBs used by the user and the number of available RBs in the cell for the corresponding type of transmission (i.e. unicast or multicast).

$$u_b = 1 - \frac{RB_{used}}{RB_{avail}} \quad (6)$$

In case of a multicast transmission such a percentage is equal to zero. Indeed, if a user joins a multicast group, no more resources are used by the cell. In such a way, radio resources could be saved and, therefore, also the capacity of the system could be increased. The greater is u_b, the higher is the efficiency of the bandwidth utilization.

Eq. (5) and eq. (6) together represent the two factors that differentiate the selection between unicast and multicast transmission within a cell.

TABLE I
MAIN SIMULATION PARAMETERS

Parameter	Value
MacroCell Radius	500 m
Frame Structure	Type 2 (TDD) [1]
TTI	1 ms
Cyclic prefix/Useful signal frame length	16.67 μs/66.67 μs
Macrocell TX Power	46 dBm
Femtocell TX Power	20 dBm
Macrocell Downlink Channel Bandwidth	10 Mhz
Femtocell Downlink Channel Bandwidth	5 Mhz
Noise power	-174 dBm/Hz
Path loss (macrocell)	15.6 + 35 log(d), dB
Path loss (femtocell)	38.46 + 20 log(d), dB
Target Bit Error Rate	10 x 10^{-5}
Simulation Time	3 mins
Number of Macrocells	1
Number of Femtocells	*[10,20,30,40,50,60]*
Number of Users	*[20 - 1000]*
Users' speed	3 - 60 km/h

V. Performance Evaluation

An extensive numerical evaluation is conducted by using Matlab. The performance analysis is performed following the guidelines for the LTE system model in [35]. The main simulation parameters are listed in Table I. The parameters for the LTE system are set according to [1]. The transmission powers of the cells have been such chosen in order to guarantee a coverage area of about 500x500 m and 100x100 m for macrocell and femtocells, respectively. The bandwidth of 10 Mhz has been chosen in order to provide enough resources (i.e., 50 RBs) for efficient support of high-quality video multimedia services (well known hungry-bandwidth applications). The number of femtocells has been varied from 10 to 60 in order to simulate variable environment conditions, from a low-density scenario to a high-density one, whereas the variation of number of users (i.e., from 20 to 1000) allows us to validate the proposed approach under different traffic load conditions.

Simulations have considered a reference scenario where several LTE femtocells are deployed within the coverage of a LTE macrocell. It is assumed that a multicast group delivering the service required by the user is already formed in each cell and that such transmission is carried out with the minimum MCS level. This assumption guarantees that the users could always support such multicast transmission. A dense urban scenario was considered where users are free to move according to Random Waypoint Mobility model [36]. Users' speed values are uniformly distributed within the interval from 3 km/h to 60 km/h. The simulations are carried out in a time interval of 3 minutes, with users downloading a real-time video. HUMANS algorithm performance is compared with that of E-PoFANS [10] and EMANS [23]. Furthermore, in the presented simulation campaign, the weights of all four utility functions are considered the same (i.e., equal to 0,25). The algorithms' performance has been computed every TTI, i.e., the throughput Th_{rec} at the users and the relative energy consumption have been recorded at every TTI in the simulation.

To compare the three algorithms and to simulate the dense scenario of the emerging 5G systems, simulation campaigns have been carried out in different network load conditions. Simulation results, indeed, have been evaluated in *High density* or *Low density* conditions (i.e. both users density and femtocells density). The number of users has been varied from 20 to 1000. The following simulation metrics have been considered:

- *Average Throughput*: the average quality of transmission accomplished to users;
- *Aggregate Data rate (ADR)*: the sum of the throughput of the users among overall system;
- estimated *Energy Consumption:* the estimated energy consumption of the devices when downloading a video flow;
- *User Satisfaction:* the satisfaction perceived by users in terms of the ratio between the datarate received and the datarate required by each user;
- *Percentage of served users*: the measure of how efficiently the algorithms work in terms of system capacity;
- *Percentage of resource usage:* the measure of the efficiency of the algorithms in order to save resources. The lower is this metrics, the higher the performance;
- *CQI variation*: the distribution of users with different CQIs among multicast and unicast transmissions. This metric is measured in terms of percentage of users served with a given CQI.

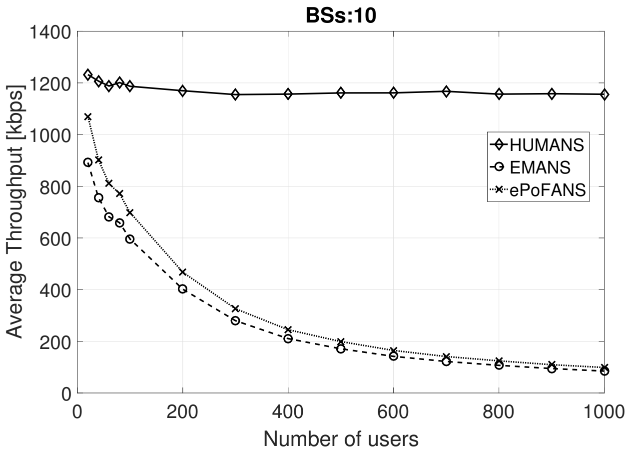
It is worth noting that the energy consumption of each user has been calculated according to eq. (3) at every TTI. Th_{rec} is the throughput received by users in the given TTI and t is the duration of the TTI.

A. Low Density

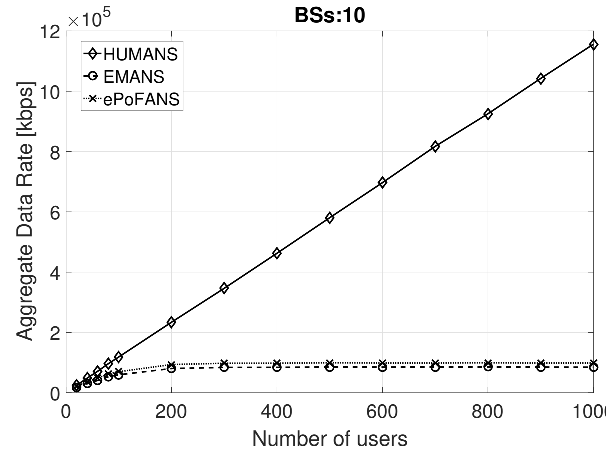
In this Section the performance of the three algorithms in low density conditions are presented. Simulation results are shown in the case of 10 small cells within the macrocell. The analysis has been carried out with users moving at different speeds from pedestrian (i.e. 3 kmph) to low vehicular speed (i.e., from 30 to 60 kmph) in a dense urban scenario.

Fig. 3(a) shows the average throughput received by users. The proposed HUMANS algorithm outperforms the other ones, guaranteeing a relatively constant trend even when increasing the number of users within the reference area. This is due to the presence of the multicast groups, whose users are always served with the same number of RBs and with the minimum CQI experienced by group members. At the same time both E-PoFANS and EMANS experience a decrease in their performance with an increasing number of users, as these two algorithms use only unicast transmissions. This is expected because the availability of resources decreases when increasing the network load. The system ADR achieved by the algorithms is shown in fig. 3(b). Exploiting multicast communications allows HUMANS algorithm to increase the ADR of the system when increasing the number of users. Indeed, each new user contribute to add rate to the system ADR. Whereas the other two algorithms saturate after around 200 users within the system.

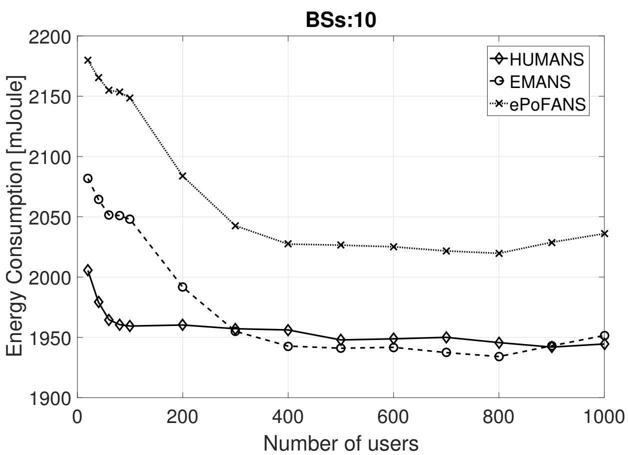
According to (1), also the estimated device energy consumption has to be taken into account (fig. 3(c)). For all algorithms the highest energy consumption is met with few users in the system. That is because there are enough resources to serve users requiring higher datarate and greater resources,



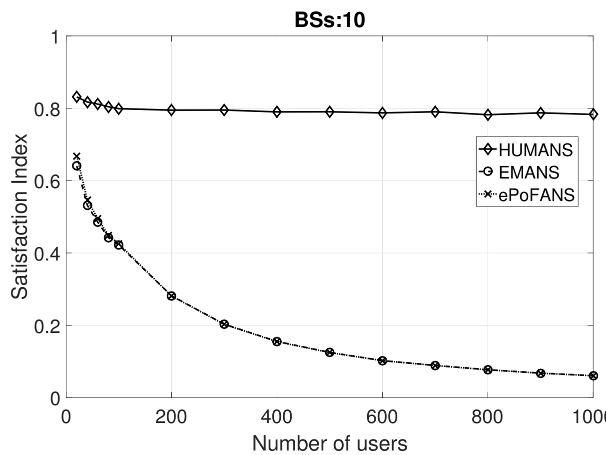
(a) Average throughput



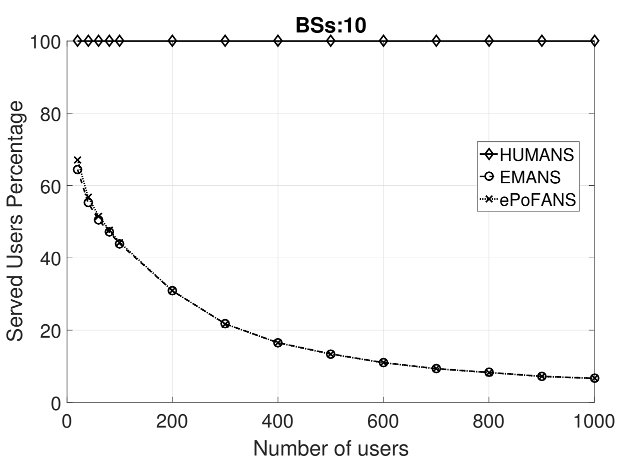
(b) ADR



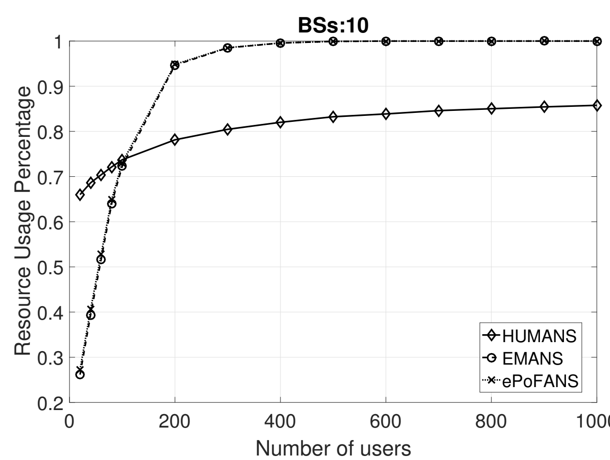
(c) Devices Energy Consumption



(d) Users Satisfaction



(e) Users served expressed as percentage



(f) Resource usage expressed as percentage

Fig. 3. Low Density Scenario.

consequently consuming more energy. Compared to other algorithms, HUMANS achieves a gain ranging from 4% to 9% with respect to ePoFANS, whereas it gains up to 4% against EMANS with a few users in the system.

Following the average throughput trend, the user satisfaction (fig. 3(d)) achieved by HUMANS is always high (i.e., around 80%), whereas the users satisfaction decreases with the number of users when adopting the two other algorithms.

This is due to the limited amount of resources for unicast transmissions considered in both EMANS and ePoFANS.

However, the strength of HUMANS is illustrated in both figures 3(e) and 3(f). The former shows how the proposed solution is able to serve all users requiring access to the video flow. This is due to the intrinsic behaviour of the multicast approach, which can serve all users. Whereas, the two other algorithms have a limited capacity as they serve users via unicast only. At the same time, HUMANS also achieves resource utilization savings between 25% and 15% compared to both EMANS and ePoFANS when increasing the density of the network in terms of number of users.

B. High Density

The performance of the proposed algorithm has been evaluated also in a high density scenario, when the number of small cells within the macrocell increases to 60.

Fig. 4(a) shows the average throughput received by users in this high density scenario. Similar to the low density case, HUMANS outperforms the other solutions it is compared against. Nevertheless, with few users ePoFans has still a very good performance as, in these conditions, the high number of cells deployed provides enough resources to satisfy all user requests. However, E-PoFANS and EMANS decrease their performance with the increasing number of users. This happens as these algorithms employ unicast transmissions only and an increase in the offered load adversely affects their performance.

Fig. 4(b) shows the ADR of the whole system for users in *High density* scenarios. At a certain point (500 users) EMANS and E-PoFANS do not bring any additional improvements, whereas HUMANS continues to follow the growing ADR. This is due to the fact that multicast transmissions allow all users requiring the service to receive it with no additional resource requirements. Indeed, as shown in Fig. 4(e) HUMANS provides overall coverage to all users in the system. On the contrary, EMANS and E-PoFANS suffer from high user outage when increasing the overall number of users.

In the High density scenario, the performance of HUMANS in terms of energy consumption (Fig. 4(c)) shows a degradation with respect to the other algorithms. Since there are many more resource available for users, both EMANS and ePoFANS are able to serve more users with lower datarate, and consequently low energy consumption, with respect to the low density scenario. On the other hand, in HUMANS case, the unicast component is more prominent just because more resources are available, thus consuming more energy.

Whereas, as for users satisfaction (Fig. 4(e)), HUMANS maintains the same trend of the low density scenario, as expected, with higher achievable values (i.e., around and 95%). Increasing the available resources in the system allows the other two algorithms to achieve a performance closer to HUMANS, but only with a few users in the system. When increasing the number of users, simulation results show that HUMANS gains up to 65% (with 1000 users).

All the above considerations are the result of a different behaviour of the algorithms in terms of resource usage (Fig. 4(f)). Since multicast transmission consumes many RBs, resource utilization is better for EMANS and E-PoFANS algorithms with a few users in the system. On the other hand, when increasing the number of users, these two algorithms use all the available resources, thus reaching saturation, which leads to the high outage percentage illustrated in Fig. 4(e). Furthermore, as expected, in a high density scenario the increasing number of cells leads to a consequent overall improvement in the performance of all algorithms thanks to the greater number of resources available.

C. Users' CQI Distribution

The final discussion is about the distribution of user CQI levels between multicast and unicast transmissions. Results are presented in Fig. 5, where the percentage of users served for each value of CQI is shown, for each kind of transmission (multicast and unicast). Each bar related to the values on x-axis represents the percentage of users served with the CQI value associated. In all cases unicast transmission is activated to users with high CQI levels (i.e., in good channel condition) only. This is because users in good channel condition require a few RBs, whereas users experiencing bad channel conditions need more resources to obtain the required datarate. In HUMANS, the users with lower CQI levels are served via multicast transmissions and this has a double advantage: *(i)* they do not waste additional resources and *(ii)* make use of multicast flows (i.e. they receive all the RBs dedicated to the multicast group). Therefore, thanks to this approach, users requiring many resources that cannot be served if an only-unicast oriented algorithm is implemented, can always receive the video service, especially when the system is in high load conditions.

Fig. 5 best depict the objective of the proposed HUMANS, that is to guarantee an increasing user capacity either by using the multicast or by saving resources.

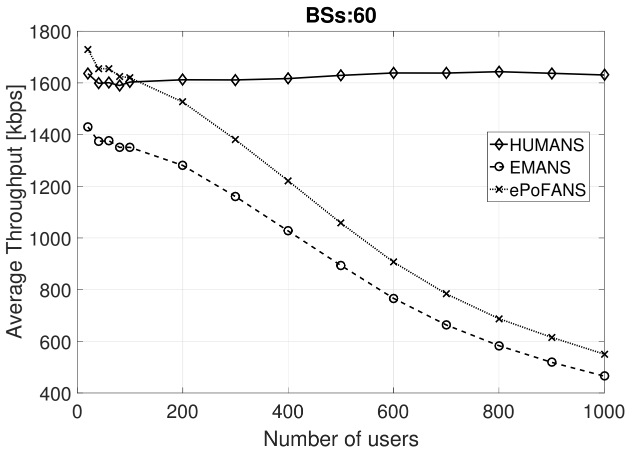
VI. Conclusions

This paper proposes the Hybrid Unicast-Multicast utility-based Network Selection algorithm (HUMANS), a network selection approach that exploits the benefits of co-existing unicast and multicast transmissions during video deliveries.

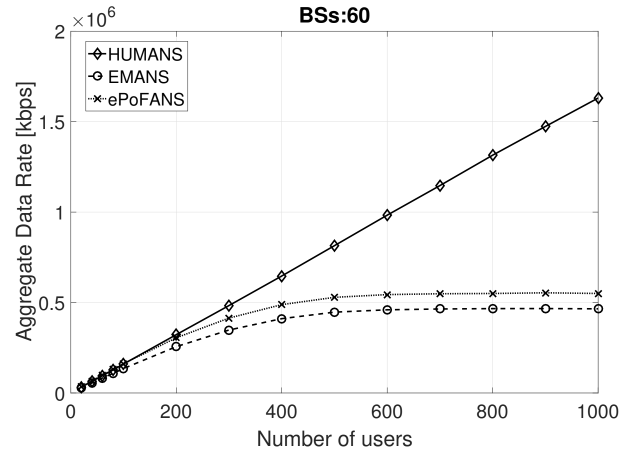
HUMANS considers bandwidth utilization and the trade-off between quality and energy consumption when delivering video in DenseNet scenarios.

A major contribution of HUMANS is the consideration of joining a multicast group as a possible option in the network selection process, thus allowing for smart bandwidth management. HUMANS serves users with good channel conditions via unicast transmissions and the remaining users via multicast.

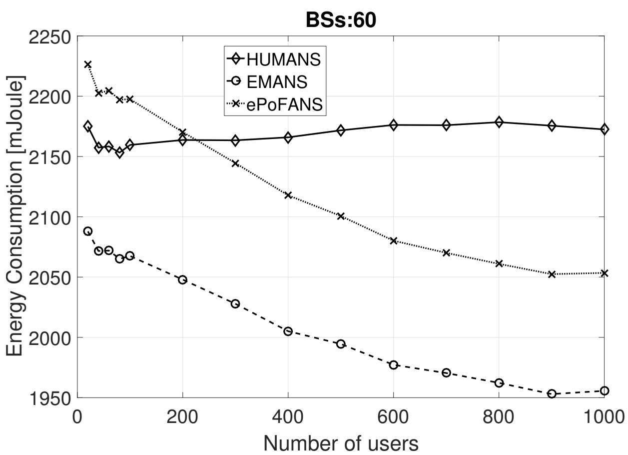
Performance evaluation carried out in low- and high-density scenarios, demonstrate how the proposed hybrid unicast-multicast approach provides a significant improvement in terms of capacity and radio resource utilization in comparison with other unicast-only solutions. The performance gain is much higher when user density increases within a system, thus providing an interesting solution for the future *dense* networks.



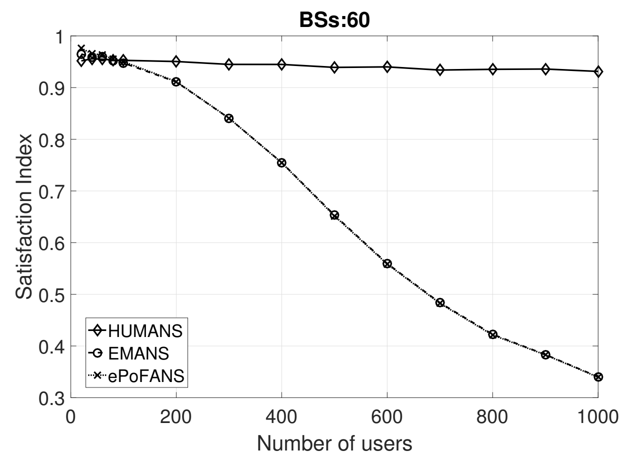
(a) Average throughput



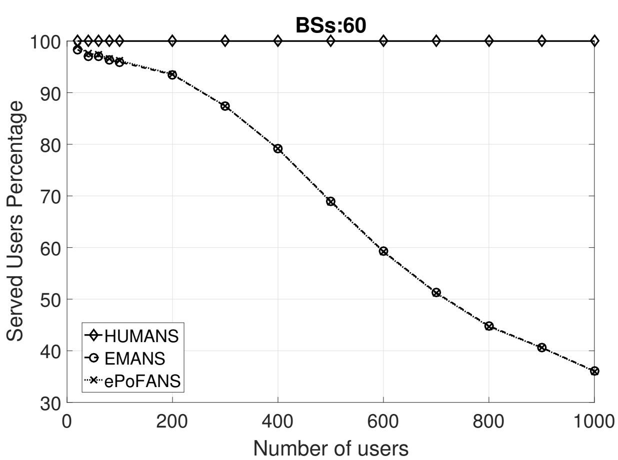
(b) ADR



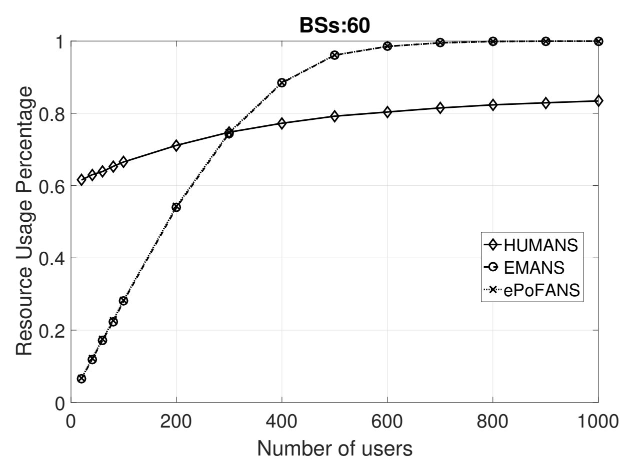
(c) Devices Energy Consumption



(d) Users Satisfaction



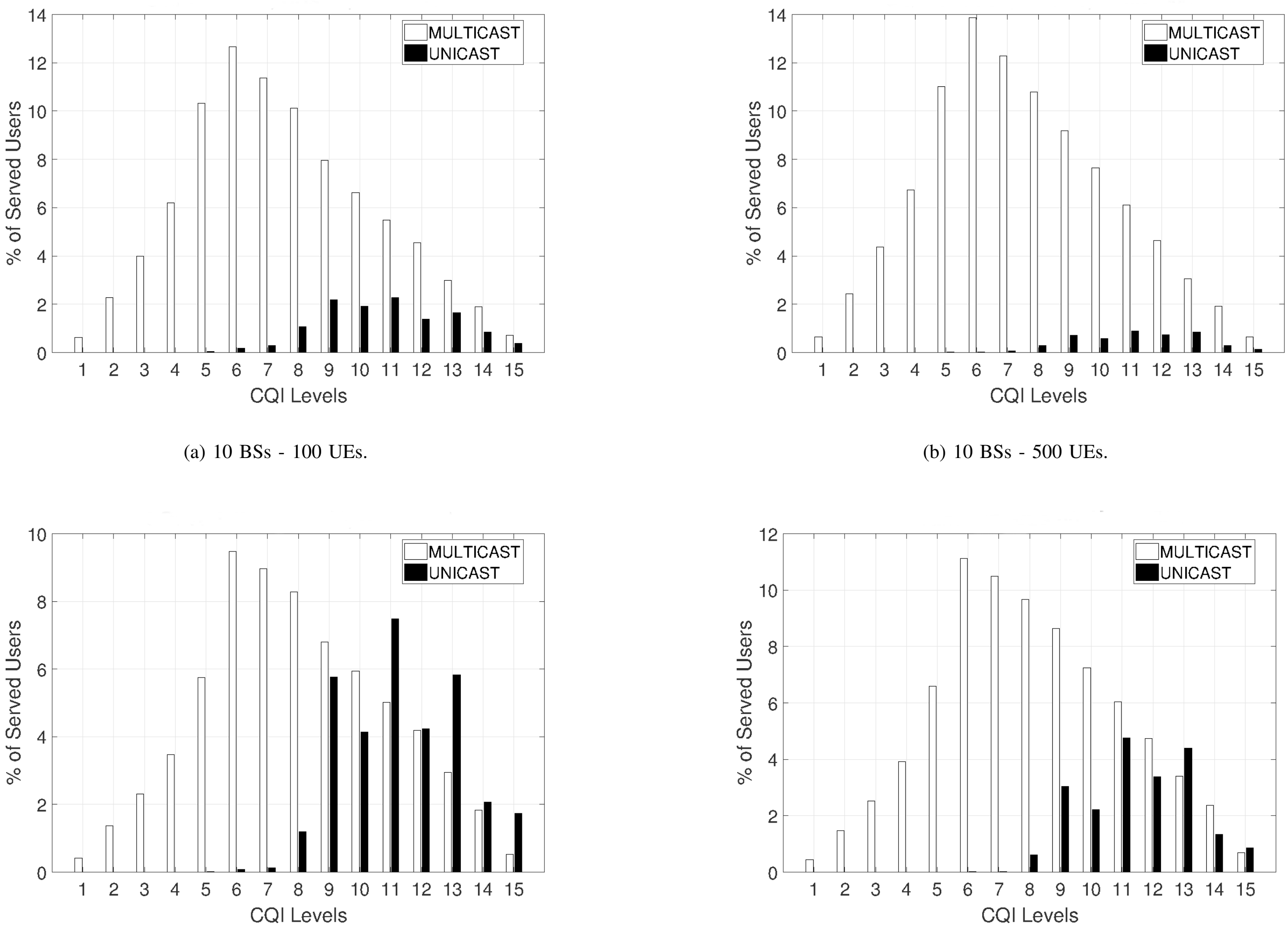
(e) Users served expressed as percentage



(f) Resource usage expressed as percentage

Fig. 4. High Density Scenario.

Future extensions of this work will account for the variation of both the background traffic in the network and the weights assigned to each utility. Finally, the proposed algorithm will be deployed in future dense wireless networks scenarios that will be one of the enabling technologies of the forthcoming 5G system. It could also exploiting other solutions, such as Device-to-Device (D2D) communications for network traffic overloading and innovative management of the least channel



(a) 10 BSs - 100 UEs.

(b) 10 BSs - 500 UEs.

(c) 60 BSs - 100 UEs.

(d) 60 BSs - 500 UEs.

Fig. 5. Users' CQI distribution

gain users. Furthermore, an actual hot-topic is the convergence of broadcasting and diverse 5G enabling technologies. HUMANS approach, based on group-oriented communications could be a suitable solution for the support of broadcast video transmission over cellular networks.

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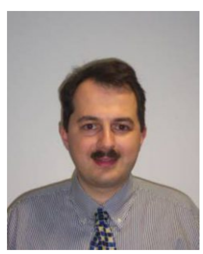
Giuseppe Araniti (S'03, M'05, SM'15) is an Assistant Professor of Telecommunications at the University Mediterranea of Reggio Calabria, Italy. From the same University he received the Laurea (2000) and the Ph.D. degree (2004) in Electronic Engineering. His major area of research includes personal communications systems, enhanced wireless and satellite systems, traffic and radio resource management, multicast and broadcast services, device-to-device (D2D) and machine-type communications (M2M/MTC) over 5G cellular networks.

Pasquale Scopelliti (S'15) received the M.Sc. in Telecommunications Engineering in 2013 from the University Mediterranea of Reggio Calabria, Italy. He is currently a Ph.D. student with the same University. His current research interests include cellular systems, radio resource management, multicast and broadcast services over 5G cellular networks and heterogeneous networks.



Gabriel-Miro Muntean (S'02, M'04, SM'17) is Associate Professor with the School of Electronic Engineering, Dublin City University (DCU), Ireland and co-Director of the DCU Performance Engineering Laboratory. Assoc. Prof. Muntean received a Ph.D. degree from DCU in 2003. He has published over 300 papers in prestigious international journals and conferences, has authored three books and has edited six other books. His current research interests include quality-oriented and performance-related issues of adaptive multimedia delivery, performance of wired and wireless communications, and personalized technology-enhanced learning. He is Associate Editor for the IEEE Transactions on Broadcasting, Multimedia Communications Area Editor for the IEEE Communications Surveys and Tutorials, and reviewer for other top international journals, conferences, and funding agencies. He coordinates the EU Horizon 2020 project NEWTON and member of the IEEE Broadcast Technology Society.

Antonio Iera (SM'07) graduated Computer Engineering at the University of Calabria, Italy in 1991, received a Master Diploma in Information Technology from CEFRIEL at Politecnico di Milano Italy, in 1992 and was awarded a Ph.D. degree from the University of Calabria in 1996. Since 1997, he has been with the University of Reggio Calabria and currently holds the position of Full Professor of Telecommunications and Director of the Laboratory for Advanced Research into Telecommunication Systems (www.arts.unirc.it). His research interests include next generation mobile and wireless systems, RFID systems, and IoT.