Utilization of Hybrid Access Femtocells During Multicast Transmissions in Mobile Networks

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***Abstract*—Femtocells enhance indoor coverage of mobile services using the owner’s broadband connection. They were initially designed to serve a number of subscribed User Equipments within their range. This design however, resulted in underutilization of the femtocells resources, and simultaneously in high interference levels for nearby non-subscribed users. Nowadays, femtocells can support multicast transmissions, while their hybrid operation allows non-subscribed users to use a portion of their resources. In this paper we propose a novel mechanism that is based on the selection of the appropriate Modulation and Coding Scheme. The mechanism allows non-subscribed users to utilize a portion of the femtocells’ resources for multicast transmissions when located inside their coverage, without affecting the owners’ satisfaction. The simulation results show that depending on the portion of the femtocells’ resources allocated to non-subscribed users, the mechanism may significantly increase the average user throughput.**

Keywords—modulation and coding scheme; mbsfn; femtocells; hybrid access; next generation mobile networks

I. INTRODUCTION

Over the last years many mobile operators have enabled multicast services. To meet the growing demand for multicast services, the Third Generation Partnership Project (3GPP) has introduced the Multimedia Broadcast/Multicast Service (MBMS) over Single Frequency Network (MBSFN) [1]. In the multicast transmissions of MBSFN the data are delivered simultaneously to all users within a group who already subscribed for the specific content. The services are distributed solely to the macrocells that belong to the MBSFN area. However, the utilization of the macrocell infrastructure alone for the delivery of the multicast content is expensive. Heterogeneous networks are expected to conquer mobile networks in this generation and the next (i.e. the 5th Generation - 5G) and they can provide an efficient solution for the delivery of multimedia content to a large number of users at the same time [2]-[5].

Specifically femtocells which support multicast transmission present an attractive solution to exploit the available spectrum locally and provide better data rates and coverage [6]. This is in line with the main technologies proposed for the 5G mobile networks, i.e. the ultra-densification, according to which the network capacity can be increased by employing smaller cells [7].

Femtocells may be configured to operate in different access modes, open, closed and hybrid. In close access, femtocells maintain a list of User Equipments (UEs), known as Closed Subscriber Group (CSG), that may be served by the femtocell when within its range. However, it may cause severe interference to non-subscribers in the vicinity of the femto Base Station (BS) requiring frequency reuse schemes and power control for its mitigation [8]. In open access, the femtocell may serve any user, thus avoiding interference but with the drawback of the exploitation of private resources by outsiders.

Hybrid access is a compromise between the previous two modes. In this case, both macro and femto UE (MUE, FUE) are allowed to access the femtocells’ spectrum when inside their coverage area. Since subscribers are the rightfully owners of the femtocell and the backhaul connection, they usually maintain a priority on resources utilization. The decision over the allocation of resources in hybrid access is a complex task and many methods have been proposed [9]. Based on the above, the utilization of the femtocells in hybrid access mode for the delivery of MBSFN data could offer higher spectral efficiency and higher data rates especially near the macrocell edges. To fully exploit the benefits of the hybrid access of femtocells for MBSFN, the Modulation and Coding Scheme (MCS) for the transmission of the data should be carefully selected for both subscribed and non-subscribed users.

The goal of this paper is to extend and complete the above studies between MBSFN performance and MCS selection which has been studied in previous research works, such as [10], taking into account femtocell in addition to macrocell users. To this direction, we first analyze a procedure that selects the MCS and calculates the throughput in the case of a single user (femto or macro). Then, we generalize the single-user case and we propose a mechanism that selects the MCS for the delivery of the MBSFN data in multiple-users scenarios. The evaluation results indicate that the hybrid femtocells mode may lead to higher average throughput compared to the traditional multicasting by significantly improving the Signal to Interference plus Noise Ratio (SINR). Our study is based on Long Term Evolution (LTE) networks with a view to be used in 5G mobile networks.

The remainder of the paper is structured as follows: In Section II we present the methodology for selecting the MCS and calculating the throughput of the MBSFN delivery scheme in the single-user case. The procedure for the multiple-users case is presented in Section III; while the evaluation results are presented in Section IV. Finally, some conclusions and planned next steps are briefly described in Section V.

II. SINGLE-USER CASE

In order to select the MCS and calculate the SE in the case of a single user, we propose the following procedure that consists of three steps: the *SINR Calculation* step, the *MCS Selection* step and the *Throughput Calculation* step.

A. Step 1: SINR Calculation

In MBSFN operation, due to multipath, the signals of the cells arrive to the receiver by M different paths and the SINR of a single user at a given point m of the MBSFN area is expressed as in Eq. 1, assuming that the area consists of N neighboring cells [11]:

$$SINR(m) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{w\left(\tau_i(m)+\delta_j\right)P_j}{q_i(m)}}{\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{\left(1-w\left(\tau_i(m)+\delta_j\right)\right)P_j}{q_i(m)}+N_0} \tag{1}$$

with:

$$w(\tau)=\left\{\begin{array}{cc} 1 & 0\le\tau<T_{CP} \\ 1-\dfrac{\tau-T_{CP}}{T_u} & T_{CP}\le\tau<T_{CP}+T_u \\ 0 & otherwise \end{array}\right\} \tag{2}$$

where P_j is the average power associated with the j path, $\tau_i(m)$ the propagation delay from the macro or femtocell i, δ_j the additional delay added by path j, $q_i(m)$ the path loss from base station i, T_{cp} the length of the cyclic prefix (CP), T_u the length of the useful signal frame and N_0 the noise power.

The path loss for a macro user roaming outdoor can be determined as follows, where R, is the transceiver receiver distance in meters [12], [13]:

$$q_i(m)=15.3+37.6\cdot log_{10}(R) \tag{3}$$

Similarly, for a macro user roaming indoor the path loss is evaluated by Eq. 4 [12], [13]:

$$q_i(m)=15.3+37.6\cdot log_{10}(R)+L_{ext} \tag{4}$$

with L_{ext} representing the penetration loss of an external wall.

On the other hand, $q_i(m)$ between a femto BS and a UE roaming indoor is given by Eq. 5 [12], [13]:

$$q_i(m)=38.46+20\cdot log_{10}(R)+L_{int} \tag{5}$$

with L_{int} representing the penetration of an interceded internal wall.

Finally, Eq. 6 calculates the path loss for a femto UE roaming outdoor [12], [13].

$$q_i(m)=38.46+20\cdot log_{10}(R) \tag{6}$$

B. Step 2: MCS Selection

Next step is to select the most suitable MCS for the transmission of the MBSFN data to a single fetmo or macro user. To achieve this, after calculating the SINR in Step 1, we use the SINR - Channel Quality Indicator (CQI) mapping presented in Table I so as to match the SINR with the MCS which must be selected in order, all users, to receive the MBSFN service [14].

TABLE I. SINR-CQI MAPPING TO FACILITATE MBSFN TRANSMISSIONS

SINR (dB)	CQI	Modulation Scheme	Coding Rate
-5.6	1	QPSK	0.076
-3,85	2	QPSK	0.117
-2,1	3	QPSK	0.188
-0,35	4	QPSK	0.300
1,4	5	QPSK	0.438
3,15	6	QPSK	0.587
4,9	7	16QAM	0.369
6,65	8	16QAM	0.478
8,4	9	16QAM	0.601
10,15	10	64QAM	0.455
11,9	11	64QAM	0.533
13,65	12	64QAM	0.650
15,4	13	64QAM	0.753
17,15	14	64QAM	0.852
18,9	15	64QAM	0.925

C. Step 3: Throughput Calculation

In order to estimate the achieved throughput for the selected MCS we use the equation below [15]:

$$Throughput = BW\cdot e(SINR)\cdot\left(1-BLER(SINR)\right) \tag{7}$$

where BW is the total bandwidth offered by the system, $e(SINR)$ is the effective code rate of the selected MCS and $BLER(SINR)$ the block error rate.

III. MULTIPLE-USERS CASE

The MCS selection and the throughput evaluation in the multiple-users case are deduced from the single-user approach described in the previous section. In detail, we follow an approach that ensures that all users, even those with the lowest SINR, will receive the MBSFN service. In order to achieve this goal the algorithm:

i. Calculates the SINR for all users in the topology (Step 1 in the previous section),

ii. Finds the minimum SINR,

iii. Selects the MCS that corresponds to the minimum SINR (Step 2 in the previous section) and

iv. Calculates the average throughput based on Eq. 7.

The procedure for obtaining the MCS and the average throughput is presented below using pseudo code.

Pseudo code of the MCS selection and Average Throughput Calculation

```
1:  % SINR calculation for all users
2:  for i = 1:total_users
3:      Calculate SINR(i)
4:  end
5:  min_SINR = min(SINR)      % find the lowest SINR among all users
6:  % choose the MCS that corresponds to the minimum SINR
7:  selected_MCS = $f_{MCS}$ (min_SINR)
8:  % calculate the users' throughput for the selected MCS
9:  for i = 1:total_users
10:     user_throughput(i) = $f_{throughput}$(BW, selected_MCS, min_SINR)
11: end
12: %calculate the average throughput
13: average_throughput = sum(user_throughput) / total_users
14: topology_changes go to line 1
```

Looking the pseudo code above we observe that there are three points that need further explanation:

- *Line 5:* The fact that the proposed mechanism determines the MCS based on the minimum SINR indicates that the randomly located users, part of a multicast group, in the MBSFN area will receive the MBMS service irrespectively of the conditions they experience in terms of SINR. However, this has a negative impact on users that are located near the base stations, since these users will not be able to use a higher MCS and therefore achieve higher throughput.
- *Line 13:* In order to calculate the average throughput, we consider three different scenarios for the portion of the femtocells' resources dedicated to non-authorised users: 0%, 10% and 20% respectively. The first scenario refers to the case where the femtocells do not contribute at all in the MBSFN transmissions and the delivery of the service is performed only by the macrocell infrastructure. The other two scenarios aim at highlighting the femtocells influence during the multicast transmissions.
- *Line 14:* The MBSFN area consists of a dynamic and constantly changing topology. In detail, the number and the location of the users that receive the MBSFN service may change, while simultaneously the number of cells that contribute in the MBSFN transmissions may also be modified. The proposed mechanism is periodically triggered in order to be able to adapt to such changes.

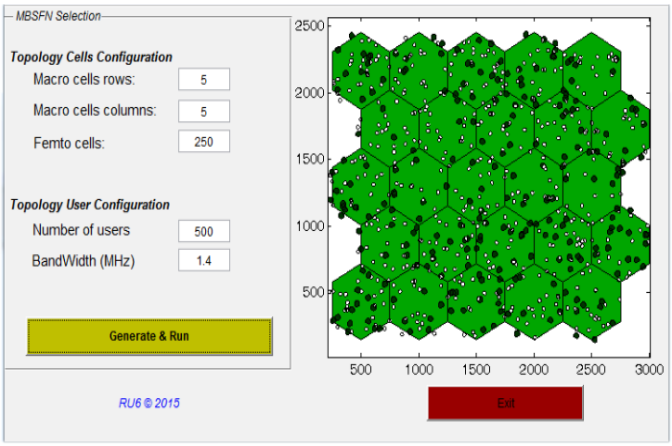
IV. PERFORMANCE EVALUATION

This section provides simulation results regarding the operation and performance of the proposed mechanism. The parameters used in the performed simulations are presented in the following table.

TABLE II. SIMULATION SETTINGS

Parameter	Value
Cellular Layout	5 x 5
Femtocells Density	Max 100 femtocells per cell
Users Density	Max 100 users per cell
Inter Site Distance	500m
Carrier Frequency	2.000MHz
System Bandwidth	1.4MHz
Femtocells Transmission Power	2Watt
Macrocells Transmission Power	20Watt
Channel Mode	3GPP Typical Urban
Propagation model	Cost Hata
Cyclic prefix	16.67μsec
Useful signal frame length	66.67μsec
Modulation and Coding Schemes	15 different sets as defined in Table I

In order to facilitate the simulations, we have developed a Matlab-based simulation tool, a screenshot of which is depicted in Fig. 1. The tool enables the user to configure the topology (i.e. number of macrocells rows and columns, number of femtocells and users, system bandwidth) and calculates the average user throughput based on this configuration. The calculations are updated periodically in order to adapt to possible topology changes. The results take into account the three different scenarios for the portion of the femtocells' resources dedicated to non-subscribed users mentioned in the previous section. The tool is available for download at [16].



MBSFN Selection

Topology Cells Configuration

Macro cells rows: 5

Macro cells columns: 5

Femto cells: 250

Topology User Configuration

Number of users: 500

BandWidth (MHz): 1.4

Fig. 1. Graphical user interface of the simulation tool.

A. *Average Throughput vs User Density*

In this experiment we examine how the average user throughput is affected by the user density. For the conducted evaluation we utilize an MBSFN area that initially consists of 25 macrocells, 250 users and 1250 femtocells (i.e. about 10 users and 50 femtocells per macrocell). During our simulation, we gradually increase the number of users per macrocell from 10 up to 100 users per macrocell; while the other parameters remain the same.

Fig. 2 displays the average throughput in comparison with the number of users per cell for different portions of femtocell bandwidth allocated to non-authorized users.

As we can see from Fig. 2, when femtocells do not contribute in the MBSFN transmissions (0% case) the average throughput remains constant throughout the simulation. This was expected since the MCS is selected based on the user with the minimum SINR. In our experiment, the minimum SINR value calculated is 10.8 and therefore according to the SINR-CQI mapping in Table I, the mechanism selects the MCS 10 (64QAM with coding rate 0.455) for the delivery of the MBSFN data.

Increasing the portion of femtocell bandwidth allocated for MBSFN to 10% and 20% respectively, we observe that the average throughput is high for low users' densities; while the increase of the users' number causes the average throughput to significantly decrease.

In every case, it is obvious that users who receive the MBSFN service by femtocells (in addition to the macrocells) have significant improvement in comparison to the users that receive the service only by the macrocell infrastructure. This is achieved since the cells that transmit the MBSFN data are tightly time-synchronized and therefore the transmissions from neighboring cells (independently of the fact they are macro or femtocells) are translated into useful signal energy instead of interference, thus leading in significant improvements in SINR.

In our experiment, we observe that for 10 users per macrocell the average throughput increases from 1165 Kbps to 1710 Kbps and 2254 Kbps when the femtocells portion for MBSFN increases from 0% to 10% and 20% respectively. This means that the average throughput may increase by up to 46.78% and 93.48% compared to pure macrocell transmissions when femtocells contribute to the delivery of the MBSFN data with 10% and 20% of their resources respectively.

B. *Average Throughput vs Femtocell Density*

The second experiment targets at highlighting the impact of the femtocells density on the average throughput achieved. In general, as the femtocells density increases, the number of users that are found inside the femtocell coverage area increases. These users receive the MBSFN service both from the femto and macrocells, thus they achieve higher throughput values.

Initially, we examine the cumulative probability of a user to be located inside the femtocells coverage area as their density increases from 0 to 300 femtocells per macrocell (Fig. 3). The number of users is kept constant to 100 users.

According to Fig. 3, the more dense the topology is, the higher the probability is the user to be served by femtocells. For the ISD that we used in our experiments (500m) the results indicate that about 300 femto per macrocell should be installed in order to cover the whole area.

Finally, we have calculated the average throughput for different values of femtocell bandwidth allocated to non-authorized users when the number of femtocells per macrocell increases (Fig. 4). The initial topology consists of 25 macrocells, 10 users per macrocell. The number of femtocells gradually increases from 0 to 100 femtocells per macrocell; while the other parameters remain the same. Thus, according to Fig. 3 the probability the user to be served by femtocells increases from 0 to 0.72 throughout the simulation. It is worth mentioning that the mechanism selects MCS 10 for the delivery of the MBSFN data throughout the simulation.

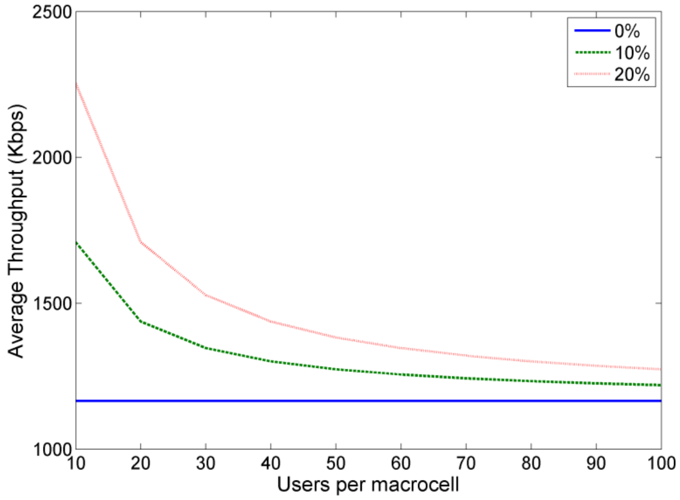


Fig. 2. Average throughput vs number of users per macrocell for different values of femtocell bandwidth allocated to non-authorized users.

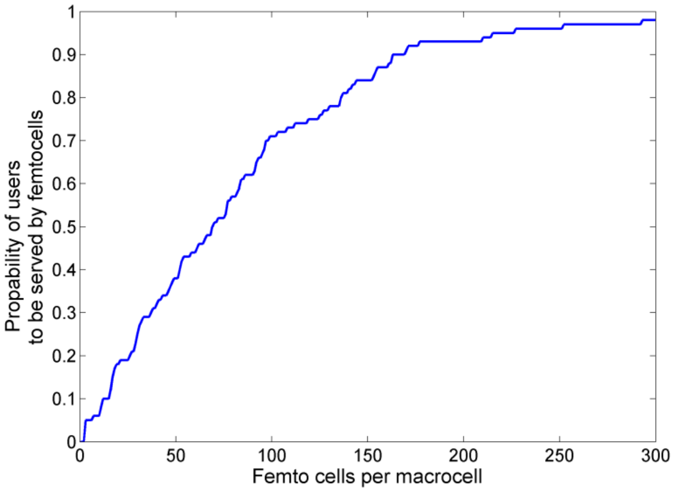


Fig. 3. Probability of users to be served by femtocells vs number of femtocells per macrocell.

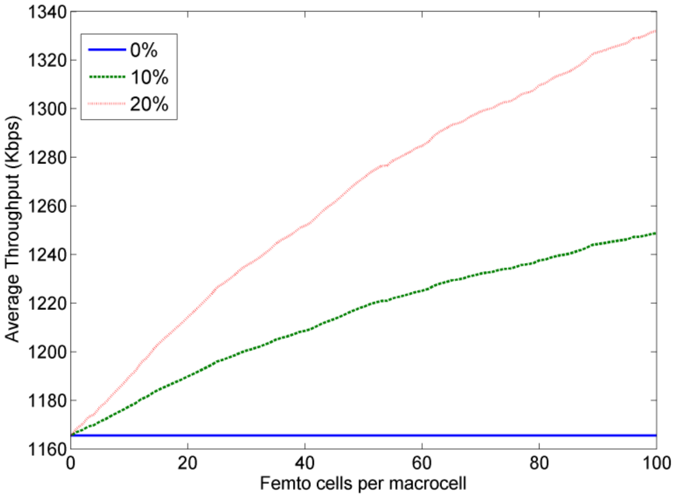


Fig. 4. Average throughput vs number of femtocells per cell for different values of femtocell bandwidth allocated to non-authorized users.

From Fig. 4 it is clear that an increase in the femtocells' density leads to an increase in the average throughput achieved. In the 0% scenario, the femtocells density has no affect on the overall performance since the femtocells do not actually contribute in the delivery of the MBSFN service. Therefore the average throughput of this scenario is constant to 1165 Kbps. On the other hand, when femtocells contribute to the MBSFN transmission, the average throughput increases up to 1248 and 1333 Kbps (7.12% and 14.42% increase) for the cases of 10% and 20% of their resources allocated to non-authorized users respectively. The above results are indicative, since a further increase in the femtocells density would result in higher average user throughput.

V. CONCLUSIONS AND FUTURE WORK

In this work we proposed a mechanism (extension from our previous works) that is able to select the Modulation and Coding Scheme that should be used for the delivery of the multicast data in order to serve all the users in an MBSFN area consisting of macrocells and also of femtocells. The mechanism exploits the hybrid operation of the femtocells in order to improve the overall performance in terms of average user throughput. In addition, we have evaluated the performance of the proposed mechanism for different user densities, femtocells densities and portions of the femtocells' resources allocated to non-subscribed users. The results indicate that the allocation of a small portion of the femtocells bandwidth (in order not to affect the owners' satisfaction) may lead to increased average throughput values, especially when the femtocells density is high.

The step that follows this work could be the design, the implementation and the evaluation of an enhanced version of the mechanism that depending on the operator's need could select the most efficient MCS either based on the user with the lowest SINR (as the current version) or based on the maximization of the average throughput. The latter approach -depending on the users' distribution- could select a higher MCS and allow the users close to the base stations to achieve high throughput, whereas the users in the cell boundaries will not be able to receive the MBSFN data.

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