Received: 26 June 2017 | Revised: 5 February 2018 | Accepted: 10 March 2018

DOI: 10.1002/dac.3585

RESEARCH ARTICLE

WILEY

MCS selection exploiting femtocell utilization in multicast transmissions

Christos Bouras[1,2] | Nikolaos Kanakis[1] | Vasileios Kokkinos[1] | Nikolaos Papachristos[2] | Demosthenes Vouyioukas[3]

[1] Computer Technology Institute and Press "Diophantus", Patras, Greece

[2] Computer Engineering and Informatics Department, University of Patras, Greece

[3] Department of Information and Communication System Engineering, University of Aegean, Greece

Correspondence
Christos Bouras, Research Academic Computer Technology Institute and Computer Engineering and Informatics Department, University of Patras, Greece.
Email: bouras@cti.gr

Summary

Multicast-Broadcast over Single Frequency Network (MBSFN) technology, as introduced by the Long Term Evolution Advanced group, is expected to be part of the upcoming cellular systems offering resource efficiency to broadcast services. MBSFN transmission is suitable to serve multicast groups searching the same content. In addition, the fast emerging technology of femtocells networks and their hybrid nature can lead to efficient resource sharing between non-subscribed users when located inside their coverage. The focus of this manuscript is 2-fold; firstly, we have contacted simulation experiments to compare the MBSFN transmission with the traditional Point-To-Point transmission for various femtocell distributions and network topology changes; secondly, a novel multicast transmissions mechanism is proposed from non-subscribed users who exploit femtocells resources for broadcast services, without limiting user's data requirements. The simulation results lead to a significant system's performance in terms of average throughput, total capacity, and energy consumption.

KEYWORDS

femtocells, hybrid access, MBSFN, modulation and coding scheme, next generation mobile network, point-to-point

1 | INTRODUCTION

Multicast services, as introduced by the Long Term Evolution Advanced group, are expected to be integrated in all cellular networks and mainly in the upcoming 5G systems. One feature that greatly enhances user experience and improves spectral efficiency in these services is Multimedia Broadcast Multicast Services (MBMS). MBMS delivers content to a group of users simultaneously with a portion of the resources required by other data network services. To cope with the increasing requirement for multicast data, the Third Generation Partnership Project (3GPP) has presented the MBMS over Single Frequency Network (MBSFN), as a method for multicast transmissions to a group of users. In MBSFN, the cells that are targeted to receive the same data consist the MBSFN area. All the cells in such area transmit the same MBMS content in reserved sub frames through MBSFN or through traditional Point-To-Point (PTP) transmissions, finely time-synchronized, so that the transmission from different cells appears to the receiving User Equipment like multipath from a single cell only. This technique increases the signal-to-interference-plus-noise ratio (SINR) and enables considerable macro diversity gain at the User Equipment.[1,2]

Multicast capabilities allow the transmission and routing of packets to multiple destinations, while minimizing the utilization of network resources. In order to meet the increasing need for resources, which can not be satisfied only with the use of existing macrocell infrastructure, it is imperative to use hybrid femtocells to provide multimedia services to non-subscribed users.

Hybrid access is a compromise between open and closed access mode. In this access scenario, both femto and macro users are compatible to access the femtocells' spectrum within their coverage area. Subscribed users, as owners of the femtocells and macrocell backhaul connections, maintain the priority of the resource use. There are several works examining the resource allocation in hybrid access, as it is a complex task.[3] MBSFN as a service delivers data simultaneously to all users in the multicast group. For this reason, Modulation and Coding Scheme (MCS) as metric for these data transmissions must be appropriately selected. The topology, user's mobility, and the deployment or type of the delivered data are some factors that influence the selection of the transmission method.[4,5]

As previously mentioned, heterogeneous networks remain an attractive solution to make the most of the available spectrum, and specifically in macrocell environments, that have the ability to integrate femtocell overlay for multicast transmissions, thus providing better coverage. This is a part of the technologies inherent in the 5G mobile network capabilities, ie, the ultra-densification paradigm, while the use of smaller cells can lead to greater capacity.[6,7]

In previous research studies, the performance of MBSFN and PTP has been studied in terms of per-cell coverage without considering the femtocell impact on MBMS transmission services. In this study, a comparison between PTP transmission and MBSFN is performed in terms of average throughput, energy consumption, and capacity gain, highlighting the increased performance and the saving of the available resources while using MBSFN. However, to the best of our knowledge, none of the studies considers the hybrid access of femtocells reuse on Long Term Evolution Advanced networks and the upcoming 5G mobile networks. In order to prove our speculation, a Matlab-based simulation tool is developed, available online,[8] and used in each experiment simulation.

The manuscript has the following structure: Section 2 examines the related work in the specific field, while Section 3 describes the MCS selection procedure in the cases of PTP and MBSFN transmissions and presents the comparison results between these 2 different methods. In Section 4, simulation results for various femtocells' densities are presented. The conclusions and future work are described in Sections 5 and 6, respectively. For better convenience, Appendix at the end of this manuscript presents a list of acronyms.

2 | RELATED WORK

In previous research works, the system performance of MBSFN transmissions was examined in length. Existing literature provides mainly simulation results for the evolved MBMS (eMBMS) from 3GPP Long Term Evolution standard system based on theoretical assumptions for simultaneously deliver of multimedia services. The radio solution for eMBMS is known as Multicast Broadcast SFN (MBSFN), and each one of the receiver's antennas results in improved SINR.[9] However, the existing models are trying to estimate the spectral efficiency and coverage area, while improving the performance because of higher and more flexible LTE bit rates, without exploiting the femtocells' infrastructure. Nevertheless, works like Bochrini et al and Bouras et al[10,11] compare the performance of PTP and Point-to-Multipoint transmissions, where PTP or Point-to-Multipoint transport channels serve the users, with the help of MBSFN transmission. The goal of the previous works does not consider the utilization of the femtocell's resources in order to achieve better performance of MBSFN transmission. More specific, the authors in Bouras et al[11] calculate the throughput performance of specific scenarios in order to select the most suitable MCS to be used for the MBSFN service. The current study extends and completes the aforementioned studies and comparisons of PTP and MBSFN transmissions over multicast services. It proposes a novel mechanism allowing non-subscribed users to utilize femtocells' resources when they are within the MBSFN area, without affecting the owners' data requirements. The total throughput evaluation is extracted using simulations for different user and LTE network configuration rates.

Moreover, the authors in Talarico and Valenti[12] propose an approach for modeling and analyzing the performance of MBSFN, combining the outage probability expression with a constrained random spatial model, to show the improvement of the total performance for different network topologies. The aforementioned analysis examines the impact of the nearest base-station, thus providing information regarding the MBSFN area. In addition to Talarico and Valenti[12] the proposed study focuses on the probability of serving users with the help of the femtocells, as the number of femtocells increases for different network topologies. Taking advantage of the hybrid access of the femtocells resources, as the number of the femtocells per cell increases, an improvement in total performance appears, achieving higher throughput values for both macro and femto users.

On the other hand, the authors in Wibowo and Bangun[13] study users' spectrum efficiency and transmission bearer mechanisms inside a MBSFN area. The experiments analyze and simulate the transmission of eMBMS in the femtocell network and review the spectrum efficiency of the related transmission. Moreover, they show promising performance of eMBMS in femtocells, which hopefully can lead to better multimedia service delivery for the femtocells. Compared with Wibowo and Bangun[13] the results of the experiments of the proposed study using the efficient mechanism via the simulation tool, by comparing the traditional PTP with the MBSFN transmission, provide an improvement in the system performance for the subsequent user distribution and suggest the best MCS for all users, because in MBSFN all users receive the same MBSFN data.

3 | METHODOLOGY AND CONTRIBUTIONS OF MCS SELECTION

The delivery of MBSFN data, as introduced in Bouras et al,[14,15] is served using the hybrid access property of femtocells that could offer higher data rates and throughput optimization, especially for users close to the macrocell edges. However, to benefit from the hybrid access, the MCS for the data transmission must be carefully selected for both registered and unregistered users. Therefore, the study starts by improving the system's total performance, selecting the most suitable MCS for the data transmission. Due to this reason, the MCS should be chosen based on the users that have the worst channel conditions. In this section, the MCS procedure is described for the case of MBSFN transmissions and the traditional PTP transmissions, where finally a comparison is accomplished. The main goal is to highlight which method stands out in terms of average throughput and energy consumption.

3.1 | PTP transmission

In the case of PTP transmissions (Figure 1), the SINR of each user is mapped into a Channel Quality Indicator (CQI), and the total throughput is calculated based on each user's throughput. Each user reports its conditions as CQI to the base station that serves him, and the base station translates the CQI as MCS with different rate. Therefore, each user may have a different MCS depending on the distance between this user and the macro or femto BS and its conditions. For multicast transmissions, in order to reach all the subscribed users, the base station initially chooses the appropriate MCS.

For the calculation of SINR in PTP transmission, Equation 1 is used:

$$SINR(r) = \frac{P/q_0}{\sum_{i=1}^{n} X_i \frac{P}{q_i} + N_0} \tag{1}$$

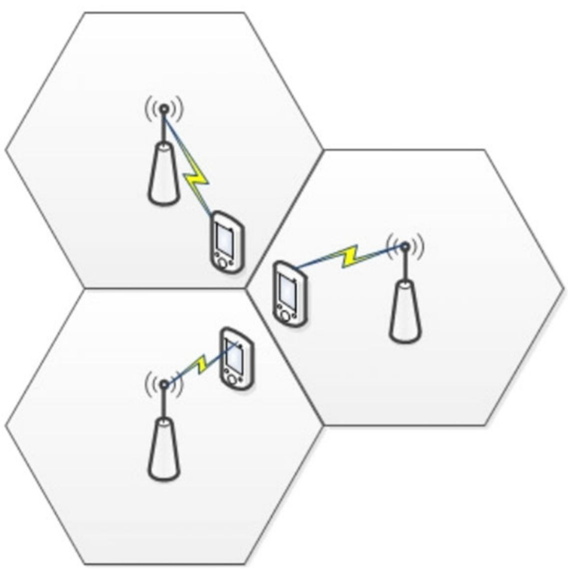

FIGURE 1 Point-to-point transmission

where P is the base station transmit power (constant value), r is the distance of the user from the base station, variable No is the background noise, q_i denotes the pathloss between the corresponding receiver and the base station i, while X_i is equal to 1 or 0 depending on whether there is interference between the user and the base station or not.

Shannon's capacity is used in order to calculate the system's throughput of user i on a subcarrier n, according to Equation 2:

$$C_{i,n} = W \cdot \log_2\left(1 + aSINR_{i,n}\right) \tag{2}$$

where W is the available bandwidth for subcarrier n divided by the number of users that share this bandwidth and α is a constant for a target Bit Error Rate (BER) defined by $\alpha = -1.5 / \ln(5BER)$. It is noted that the BER has constant value of 10^{-6}.

The throughput expression of the multicast service is summarized as follows:

$$T_M = \sum_i \sum_n p_{i,n} C_{i,n} \tag{3}$$

where $p_{i,n}$ declares an index variable. When the subcarrier n is assigned to user i, $p_{i,n}$ equals to 1; otherwise, it is equal to 0.

On the other hand, in MBSFN, the throughput is calculated on the basis of a different approach. Because all users are served with the same MCS, this MCS should be appropriate so as to serve all the users within the cell.[16,17] Therefore, the main goal in our research is to choose the most suitable MCS that simultaneously allows a target system throughput achieved for more than 95% of users.

3.2 | Multicast transmission

The main goal of this research study is to provide a coordinated mechanism suitable to provide the best MCS for multicast transmissions. The MCS defines the encoding alphabet and the channel encoder code rate. The different sets of CQIs - MCSs that are defined in 3GPP TS 36.213,[18] match the SINR calculated in Equation 1 with the MCS that fits every user in the MBSFN area who requests the MBSFN service, thus allocating the available bandwidth to all the users within the MBSFN area. However, we assume that each Resource Block assigned to MBSFN has the same CQI value to transmit the MBSFN content.

In detail, the approach that we follow ensures that the selected MCS fits every user's demands for the MBSFN services, even those with the lowest SINR. The following algorithm describes the analytical model in which the 2 transmissions are studied.

Pseudo code of the MCS selection in MBSFN case

```
% SINR calculation for subscribed and non-subscribed   users
int i = 0;
while (i<number_of_users)
  SINR(i) calculation using the suitable formula from (1) and (4)
  i++;
end;
% SINR - CQI mapping based on minimum SINR
selected_MCS = f_MCS (min_SINR)
% calculate throughput for this MCS
 i = 0;
 while (i<number_of_users)
       user_throughput(i) = f_throughput(BW, selected_MCS, min_SINR)
    capacity(i) = f_energy(BW,α,SINR)
 end
 %Average throughput calculation
 average_throughput = sum(user_throughput) / number_of_users
```

```
17:  %Comparison of the 2 different use cases
18:  if there are changes in topology go to line 1
```

There are some points in the pseudocode that need further explanation:

- *Line 4*: The algorithm selects the MCS of the user's minimum SINR, which shows that users randomly located in the MBSFN area will be served the MBMS content regardless of their SINR value. However, this condition could be a problem for the subscribed users located in the area of the base stations' coverage, because they will not use a higher MCS rate to achieve better system performance.
- *Line 16*: Three different scenarios have been developed for a variety of femtocells' data accessed by users that are not-subscribed: the 0% scenario, the 10% scenario, and the 20% scenario. In the 0% scenario, the femtocells have no effect whatsoever in the MBSFN service transmission, and only the macrocells are responsible for the delivery of the requested content. The other 2 cases aim at revealing the benefits when the femtocells contribute in the multicast transmissions.
- *Line 18*: Because the MBSFN topology is dynamic, the proposed mechanism and the developed simulator may adopt any changes regarding the topology. In detail, the number of users receiving the MBSFN data may change, as well as the number of the cells that affect the MBSFN transmission.

In MBSFN operation, taking into account signals arriving to the receiver from N interfering cells, by M different path, in Equation 4, the SINR per user is calculated as follows:

$$SINR(m) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{w(\tau_i(m)+\delta_j)P_j}{q_i(m)}}{\sum_{i=1}^{N}\sum_{j=1}^{M}\frac{(1-w(\tau_i(m)+\delta_j))P_j}{q_i(m)}+N_0} \tag{4}$$

where

$$w(\tau) = \left\{\begin{array}{cc} 1 & 0 \le \tau < T_{CP} \\ 1-\frac{\tau-T_{CP}}{T_u} & T_{CP} \le \tau < T_{CP}+T_u \\ 0 & otherwise \end{array}\right\} \tag{5}$$

P_j is the average power of the j-th path, $\tau_i(m)$ is the propagation delay from the femto or macrocell i, δ_j is the delay added by j-th path, $q_i(m)$ is the path loss from the base station i, T_{cp} is the length of the cyclic prefix (CP), T_u is the length of the useful signal frame, and N_0 is the noise power.[19,20]

The macro user's path loss in case of outdoor roaming can be determined as follows:

$$q_i(m) = 15.3 + 37.6\cdot \log_{10}(R) \tag{6}$$

where R is the distance (in meters) between the transceiver and receiver. The macro user's roaming path loss is estimated by Equation 7:

$$q_i(m) = 15.3 + 37.6\cdot \log_{10}(R) + L_{ext} \tag{7}$$

where L_{ext} is the penetration loss of an external wall.

Besides, in case of indoor roaming, $q_i(m)$ can be calculated as follows:

$$q_i(m) = 38.46 + 20\cdot \log_{10}(R) + L_{int} \tag{8}$$

where L_{int} is the penetration of an internal wall.

Equation 9 calculates the macro user's outdoor pathloss roaming:

$$q_i(m) = 38.46 + 20 \cdot \log_{10}(R). \tag{9}$$

Equation 10 estimates the throughput that the selected MCS achieves:

$$Throughput = BW \cdot e(SINR) \cdot (1 - BLER(SINR)) \tag{10}$$

where BW represents the system bandwidth, $e(SINR)$ is the effective code rate of the selected MCS, and $BLER(SINR)$ is the block error rate. Based on the aforementioned analysis, the best method that can be used for delivering the multicast transmissions is evaluated.[21,22]

3.3 | Comparison results between PTP and MBSFN

In this section, the performance results arising from the comparison between PTP and MBSFN in case of heterogeneous environments are provided. In general, throughput and energy efficiency are metrics that can provide a better perspective for monitoring the performance of each transmission method. The values throughput and energy efficiency can be extracted after calculating the SINR in each case.[23]

Table 1 presents the parameters that we used for our simulations. According to this table, the Inter-Site Distance of macrocells is 500 m, and the femtocells density varies from 0 to 300 femtocells per macrocell, depending on the experiment. A total of 300 femtocells per macrocell seems too high for a realistic scenario; however, we examined such extreme cases in order to reveal the femtocell impact on MBMS transmissions even for ultra-dense cases.

The initial step is to calculate the path loss for each user from both macrocells and femtocells stations. Then, the propagation delay is calculated for each user to be used in Equation 4 for the calculation of SINR. As already mentioned, in case of PTP transmission the propagation delay is not taken into consideration, because the interference value is equal to 0 or 1.

Having calculated the SINR for each user, this value is used as a metric for the selection of the MCS that supports all the users' requests in PTP and Multicast Transmission.[24]

3.3.1 | Average throughput scenario

The experiment starts by analyzing the average throughput achieved by the 2 different transmission methods.

The simulation utilizes an initial MBSFN topology that consists of 100 users per macrocell, 25 macrocells, and 0 femtocells. Subsequently, targeting at revealing the femtocell impact on MBMS transmissions for dense environments, the number of hybrid femtocells is gradually increased to a maximum of 20 femtocells per macrocell.

In Figure 2, we can see the average throughput while the number of femtocells increases. In addition, we examine cases where the bandwidth of the femtocells allocated to MBSFN users is 0% (PTP case) 10% and 30% of their available bandwidth. The results indicate that the offered average throughput in the case of Multicast Transmissions (or MBSFN)

TABLE 1 Simulation settings

Parameter	Value
Layout	5 × 5 cells
Femtocells density	0-300 femtocells per macrocell (depending on the experiment)
Users density	0-100 users per macrocell (depending on the experiment)
ISD	500 m
Frequency	2 GHz
System bandwidth	1.4 MHz
Transmission power	2 W for femtocells, 20 W for macrocells
Channel mode	3GPP typical urban
Cyclic prefix	16.67 μsec
Useful signal frame length	66.67 μsec

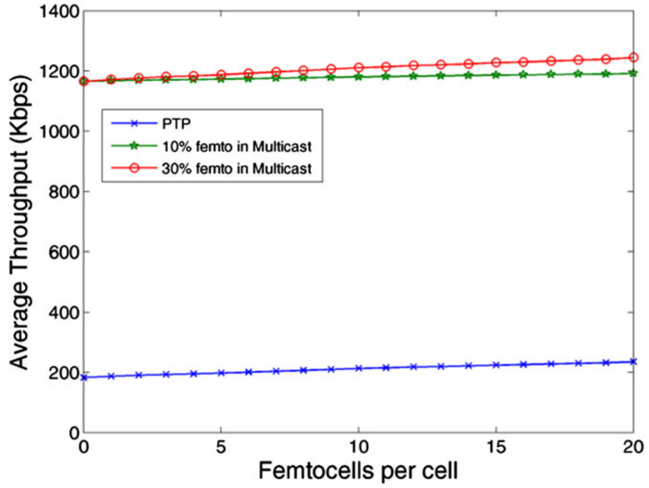

FIGURE 2 Average throughput for increasing number of femtocells

is more beneficial compared with PTP transmissions. From Figure 2, one may also observe the femto impact to the system's throughput, as the use of 10% and 30% of femtocells' bandwidth to assist MBSFN provides higher average throughput.[25]

3.3.2 | System capacity

The bit rate between the transmitter and the receiver is based on the Shannon theoretical capacity for a PTP Gaussian channel. The channel capacity, as a metric, applies to the maximum number of users that contribute to the system. We start our research by studying and integrating the theoretical expression of Shannon's Capacity that has been described in Section 3.1 in our experiments. Based on this, the scenario consists of a MBSFN area that includes 25 macrocells, 100 users, and 50 femtocells per macrocell. The scenario starts with the transmission of 100000 frames. During the next step, the total capacity is calculated for each transmitted packet for all the users within the MBSFN topology for 2 different transmission scenarios (PTP and Multicast).

Figure 3 shows that MBSFN provides larger capacity compared with PTP transmissions. Furthermore, the difference in the capacity increases linearly as the number of users increases. This is due to the fact that in PTP transmission, the users are forced to consume all available bandwidth even if they do not use it. On the other hand, in multicast transmission, the losses seem to be minimal without affecting the total capacity.[26]

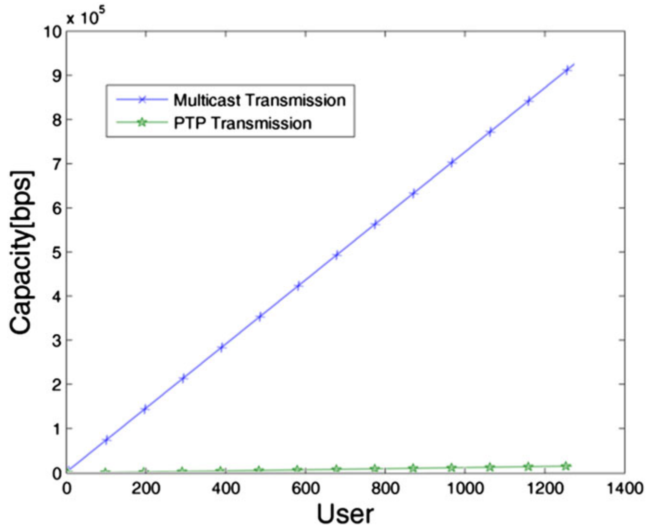

FIGURE 3 Capacity vs user density

3.3.3 | Energy consumption

For this scenario, we use the same MBSFN topology, consisting of 25 macrocells, 100 users, and 50 femtocells per macrocell. Our target is to calculate the total energy consumed, by using the statistical method of sum of the power losses for all the transmitted frames in Joule. The total power can be determined as follows:

$$\Sigma_{k=1}^{n} P_{\mathrm{k}} \tag{11}$$

where n is the number of frames transmitted during the simulation and P_k is the power loss in each PTP and multicast transmission, respectively.

For comparison reasons, the values in Figure 4 are normalized to the maximum power. It is clear, that the multicast transmission requires less total energy in comparison with the traditional PTP transmission. In fact, the use of MBSFN may save almost 15% energy compared with PTP transmissions.

4 | PROPOSED MECHANISM FOR MCS SELECTION IN MBSFN

To validate the study, a simulation tool is developed,[8] a User Interface implementation of which is depicted in Figure 5. This tool enables the topology configuration, ie, it alters the number of macrocells, the total number of femtocells, the number of users, and finally the system bandwidth. After that, based on the topology changes, it calculates the average throughput per user. The calculations are refreshed periodically, as the simulations are repeated in order to adapt to the user's topology changes. During the simulation experiments, 3 scenarios were used for different femtocells' resources, ie, assisting to MBSFN by contributing 0%, 10%, and 20% of their resources.

4.1 | Average throughput for increased number of users

The simulation in this section shows the effect of the user density on the average throughput. Initially, a MBSFN area is utilized consisting of 250 users, 25 macrocells, and 1250 femtocells (ie, approximately 50 femtocells and approximately 10 users per macrocell). Afterwards, the existing users in the macrocell are increased from 10 up to 100, while keeping all other parameters constant during the simulation.

More analytically, Figure 6 indicates the total average throughput compared with the users in the cell for a variety of femtocell values distributed to non-authorized users. It is obvious from the figure that as the femtocells do not have any impact in the MBSFN transmissions scenario of 0%, the average throughput is kept stable during the simulation. This is an anticipated result, because the value of MCS is chosen based on the user with the worst channel conditions. The minimum SINR as calculated by the simulation tool is 10.8 dB, and therefore the mechanism chooses MCS 10 value to transmit the MBSFN content.

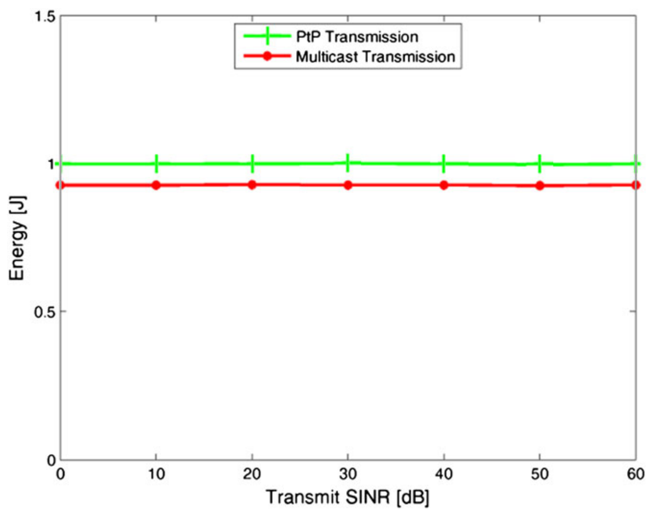

FIGURE 4 Energy consumption vs transmit SINR

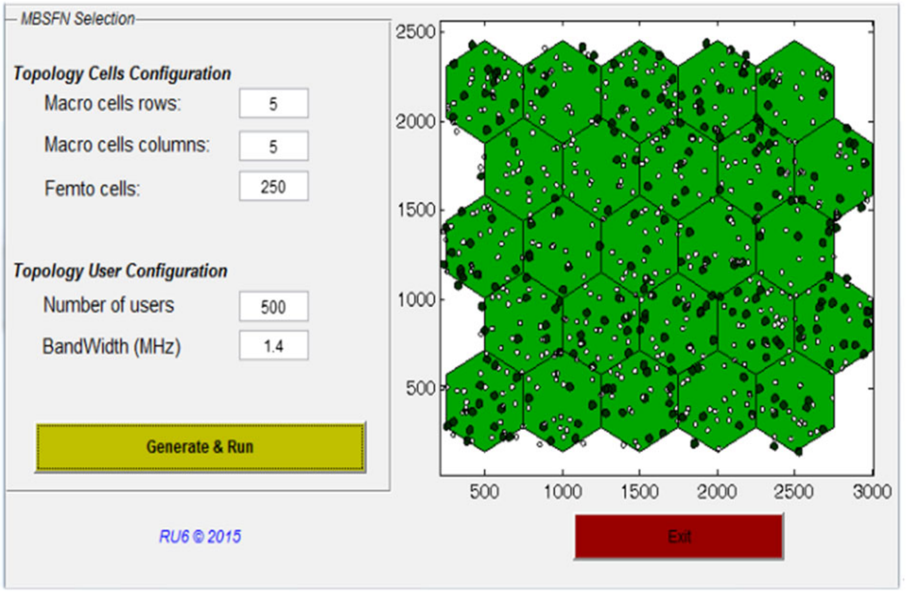

FIGURE 5 Simulation tool user interface

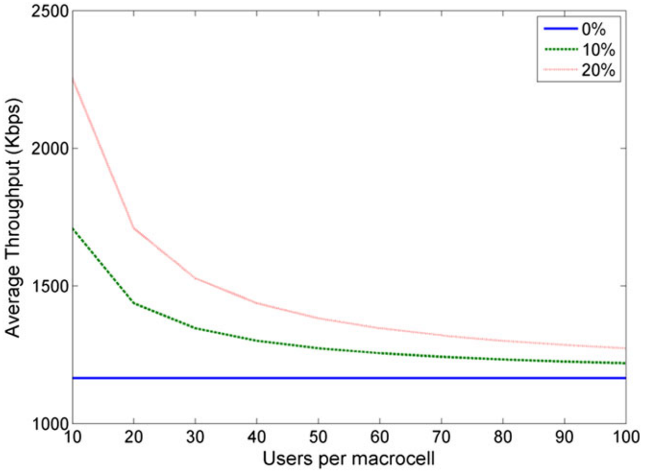

FIGURE 6 Average throughput for increased number of users per macrocell

During the scenario, we also examined the impact to the average throughput when femtocells contribute to MBSFN by allocating a portion of their bandwidth to non-subscribed users that receive the MBSFN content (ie, 10% and 20%). As Figure 6 shows, when the number of users in the topology is small, the average throughput is high. The increment of the number of users leads to the significant decrement of the average throughput. The simulated experiment ensures that even users with low SINR values and poor transmission conditions will receive the MBSFN content.

In general, non-subscribed users that receive MBSFN content from a portion of femtocells' bandwidth experience improved performance in comparison with users receiving MBSFN data only by the macrocells. The previous deduction is inferred because cells transmitting MBSFN content are briefly time synchronized, and for this reason these transmissions are converted into useful energy signal, instead of interference.

For 10 users per macrocell (Figure 6), the average throughput is 1165 kbps when the femtocells do not contribute in MBSFN (0% case). On the other hand, when the femtocells allocate the 10% and 20% of their bandwidth to MBSFN, the average throughput increases to 1710 and 2254 kbps, respectively. These results show that the average throughput may increase by up to almost 94% when the femtocells contribute to the delivery of the MBSFN content.

4.2 | Average throughput for increased number of femtocells

The simulation that follows our study is placing emphasis on the effect of the femtocells' density on the total average throughput. It is obvious that, as the number of femtocells increases, the number of users that are served by femtocells increase as well. At this point, let us note that the increase of femtocells in the case of MBSFN does not increase the interference, because the signal from adjacent base stations and/of femtocells is beneficial. Non-subscribed users will benefit from the MBSFN content received both from macro and femtocells, achieving higher throughput rates.

The scenario studies the probability of users to be served by femtocells as their density changes from 0 to 300 per cell. As Figure 7 shows, when the topology is dense, the probability is high. The results show that when 300 femto are placed inside the macrocell, the probability of the users to be assisted by femtocells when receiving the MBSFN content (ie, receiving the MBSFN content from the macrocell and the serving femtocell) approaches 1.

Our goal is to calculate the average throughput for a changing portion of femtocell bandwidth, when the femtocells density increases. The topology includes 25 macrocells and 250 users in total, while the number of femtocells increases from 0 to 100 per macrocell. Figure 7 shows that the probability of each user to be served by the femtocells increases from 0 to 0.72 during the simulation when MCS 10 is selected for the delivery of the MBSFN content.

It is clear from Figure 8 that a change in the femtocells' topology leads to an increase in the average reached throughput. In the first case (0%), the femtocells do not actually contribute to the delivery of the MBSFN content; therefore, their density has no effect on the overall performance. As derived from Figure 8, the average system throughput of this scenario is kept constant to 1165 kbps. However, while the femtocells affect the MBSFN transmission, the average throughput changes from 1248 to 1333 kbps (7.12% and 14.42% increase) for the cases of 10% and 20%, respectively. The

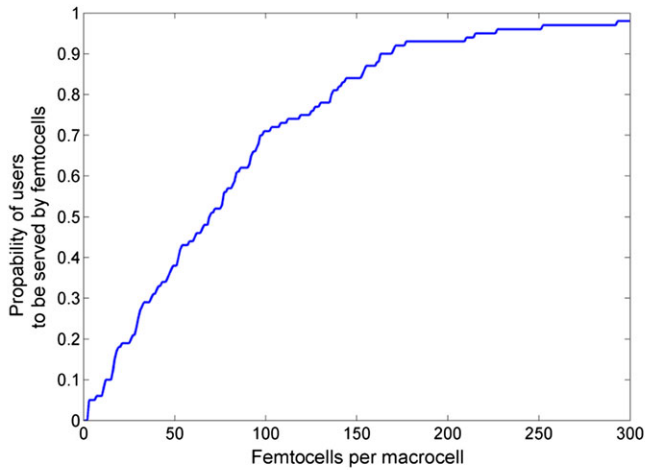

FIGURE 7 Probability of users to be served by femtocells for increased number of femtocells

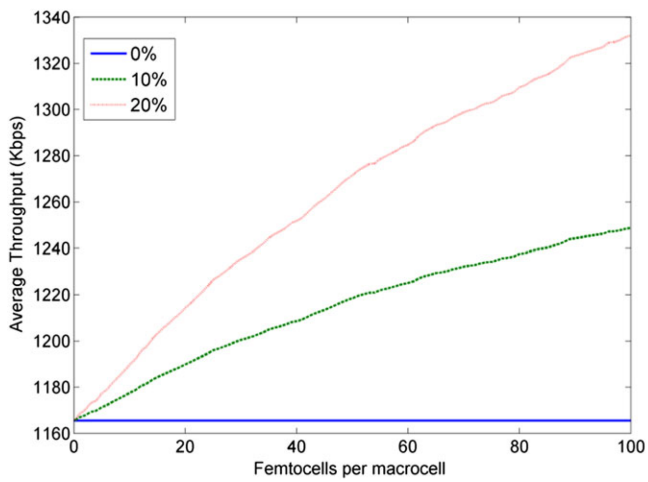

FIGURE 8 Average throughput for increased number of femtocells

improvement in the throughput optimization could be further enhanced by increasing the femtocells density in the whole topology. The results are indicative, as topology changes could lead to higher average user throughput and total performance generally.

5 | CONCLUSIONS

This study considered the use of adaptive MCSs to allow improved performance for non-subscribers inside femtocells. Initially, we compared the PTP transmissions with MBSFN transmissions. The obtained results reveal that MBSFN transmission exploiting hybrid femtocell access guarantees better system performance, increased average throughput, better energy efficiency, and a significant increase in the system capacity, as the femtocell density increases, in comparison with the PTP transmissions. Then, we proposed a mechanism which can select the most suitable MCS for the multicast transmissions, so as to serve all the users in a MBSFN area. In addition, numerical results verify that the mechanism changing the number of users and femtocells densities may lead to an enhancement of increased average system throughput, mainly as femtocells increase.

To sum up, it is worth mentioning that the analysis underlines that a suitable selection of MCS and the proposed algorithm for MBFSN transmissions is a valuable requirement for the network operators, so as to achieve high quality broadcast networks, with real-time delivery of multimedia applications to the end users, while using a small portion of the femtocells bandwidth.

6 | FUTURE WORK

In the future, the next steps of our research could be an improved version of the proposed algorithm that selects the most suitable MCS even for the user experiencing the worst transmission condition or based on the maximization of the average throughput. In addition, it is aimed to prove that, depending on the users' distribution, a higher MCS could lead users that are close to the base stations to higher throughput cases.

For further research, the study of different (higher) percentages of femtocells' resources, in cases where the authorized users do not use them, could be of high interest. In such cases, the mechanism will use all the resources for non-authorized users, achieving even higher performance.

As a final step, it is planned to extend the proposed mechanism, so as to include more metrics in the PTP and MBSFN transmission comparison, such as the power consumption and total efficiency of the network. These metrics could further highlight the efficient operation of MBSFN compared with the traditional PTP transmissions, as well as to fully exploit the femtocells utilization.

ORCID

Christos Bouras http://orcid.org/0000-0001-9160-2274

REFERENCES

1. Bouras C, Alexiou A, Papazois A, Kokkinos V, Tsichritzis G. Multimedia broadcasting in LTE networks. In: *Access Environments and Quality of Service Provisioning: Solutions and Applications*. IGI Global; 2012:269-289.
2. Xylomenos G, Katsaros K, Tsakanikas V. Support of multiple content variants in the multimedia broadcast/multicast service. *Int J Commun Syst*. 2011;24(6):691-708.
3. Bouras C, Diles G, Kokkinos V, Papazois A. Optimizing hybrid access femtocell clusters in 5G networks. in Proceedings of 2015 10th International Conference on Broadband and Wireless Computing, Communication and Applications (BWCCA), 2015;220-226.
4. 3GPP TS 25.346, Introduction of the Multimedia Broadcast Multicast Service (MBMS) in the Radio Access Network (RAN); Stage 2 (Release 7),V7.6.0,December, 2007.
5. Chandrasekhar V, Andrews J, Gatherer A. Femtocell networks: a survey. *IEEE Communications Magazine*. 2008;46(9):59-67.
6. Andrews JG, Buzzi S, Choi W, et al. What will 5G be?. IEEE JSAC Special Issue on 5G Wireless Communication Systems, 2014;1-17.
7. Bouras C, Diles G, Kokkinos V, Papazois A. Evaluation of femtocells interference mitigation techniques over ICIC coordinated LTE-a networks. in Proceedings of 2013 IFIP Wireless Days (WD), 2013;1-3.

8. HybridAccess femtocells for MBSFN (HAF4MBSFN) simulator: http://ru6.cti.gr/ru6/system/files/tools_and_mechanisms/HAF4MBSFN.zip
9. Urie A, Rudrapatna AN, Raman C, Hanriot J-M. Evolved multimedia broadcast multicast service in LTE: an assessment of system performance under realistic radio network engineering conditions. *Bell Labs Tech J*. 2013;18(2):57-76. https://doi.org/10.1002/bltj.21605
10. Bochrini S, Bouras C., Kokkinos V. Efficient MCS selection mechanisms for multicasting over LTE networks. in Proceedings of 6th Joint IFIP Wireless and Mobile Networking Conference (WMNC 2013), 2013;1-8.
11. Bouras C, Alexiou A, Papazois A, Kokkinos V, Asimakis K. Combining MBSFN and PTM transmissions schemes for resource efficiency in LTE networks. in Proceedings of 9th International Conference on Wired/Wireless Internet Communications. 2011;56-67.
12. Talarico S, Valenti MC. An accurate and efficient analysis of a MBSFN network. in Proceedings of 2014 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP). 2014;6994-6998.
13. Wibowo FXA, Bangun AAP. Study on transmission bearer mechanisms for e-MBMS in LTE based femtocells. in Proceedings of Future Network & Mobile Summit (FutureNetw). 2011;1-10.
14. Bouras C, Kanakis N, Kokkinos V, Papachristos N, Vouyioukas D. Utilization of hybrid access femtocells during multicast transmissions in mobile networks. in Proceedings of 2016 European Conference on Networks and Communications (EuCNC). 2016;190-194.
15. Bouras C, Kanakis N, Kokkinos V, Papachristos N, Vouyioukas D. Comparison of point to point and MBSFN transmissions in next generation mobile networks. in Proceedings of 14th ACM International Symposium on Mobility Management and Wireless Access (MobiWac '16). 2016;169-172.
16. Rong L, Haddada O, Elayoubi S. Analytical analysis of the coverage of a MBSFN OFDMA network. in Proceedings of IEEE Global Communication Conference 2008 (Globecom 2008). 2008;1-5.
17. Bouras C, Kokkinos V, Kontodimas K, Papazois A. A simulation framework for LTE-A systems with femtocell overlays. in Proceedings of 7th ACM workshop on Performance monitoring and measurement of heterogeneous wireless and wired networks (PM2HW2N 2012). 2012;85-90.
18. 3GPP TS 36.213, V9.1.0, Technical specification group radio access network; evolved universal terrestrial radio access; physical layer procedures (release 9). 2010.
19. 3GPP TR 25.942, v13.0.0 3rd generation partnership project; technical specification group radio access networks; radio frequency (RF) system scenarios (Release 13). 2016.
20. Longfei Li C, Chen X, Xiang X. An intelligent optimization algorithm for joint MCS and resource block allocation in LTE femtocell downlink with QoS guarantees. in Proceedings of 5th International Conference on Game Theory for Networks (GAMENETS), 2014;1-6.
21. Muntean GM. *Wireless Multi-Access Environments and Quality of Service Provisioning: Solutions and Application: Solutions and Application*. IGI Global; 2012:1-428.
22. Elayoubi S-E, Ben Haddada O, Fouresti'E B. Performance evaluation of frequency planning schemes in OFDMA-based networks. *IEEE Transactions on Wireless Communications*. 2008;7(5):1623-1633.
23. Alexiou A, Bouras C, Kokkinos V, Papazois A, Tsichritzis G. Modulation and coding scheme selection in multimedia broadcast over a single frequency network-enabled long-term evolution networks. *Int J Commun Syst*. 2012;25(12):1603-1619.
24. Wibowo FXA, Bangun AAP, Kurniawan A, Hendrawan H. Multimedia broadcast multicast service over single frequency network (MBSFN) in LTE based femtocell. in Proceedings of 2011 International Conference on, Bandung Electrical Engineering and Informatics (ICEEI). 2011;1-5.
25. Rong L, Elayoubi SE, Haddada OB. Performance evaluation of cellular networks offering TV services. *IEEE Transactions on Vehicular Technology*. 2011;60(2):644-655.
26. Panayides A, Christophorou C, Antoniou J, Pitsillides A, Vassiliou V. Power counting for optimized capacity in MBMS enabled UTRAN. in Proceedings of 2008 IEEE Symposium on Computers and Communications, (ISCC), 2008;368-373.

How to cite this article: Bouras C, Kanakis N, Kokkinos V, Papachristos N, Vouyioukas D. MCS selection exploiting femtocell utilization in multicast transmissions. *Int J Commun Syst*. 2018;31:e3585. https://doi.org/10.1002/dac.3585

APPENDIX: ACRONYMS

Acronym	Description
3GPP	3rd generation partnership project
BS	Base station
BER	Bit error rate
BLER	Block error rate
CQI	Channel quality indicators
CP	Cyclic prefix
e-MBMS	Evolved MBMS
ISD	Inter-site distance
LTE	Long-term evolution
LTE - A	Long-term evolution advanced
MBMS	Multimedia broadcast/multicast service
MBSFN	MBMS over single frequency network
MCS	Modulation and coding scheme
PTP	Point-to-point
PTM	Point-to-multipoint
SE	Spectral efficiency
SINR	Signal to interference plus noise ratio
UE	User equipment
UI	User interface