Efficient MCS Selection Mechanisms for Multicasting over LTE Networks

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Abstract—**In Long Term Evolution (LTE) networks, the Multimedia Broadcast/Multicast Services over Single Frequency Network (MBSFN) operation enables the delivery of the same multimedia content to a set or all the users in a cell, leading in this way to efficient utilization of the network resources. This is achieved through a time-synchronized common waveform that is transmitted from multiple cells for a given duration, which enables over-the-air combining, and therefore significantly improves the spectral efficiency. However, the performance of MBSFN is directly connected to the Modulation and Coding Scheme (MCS) and the transmission mode that will be selected for the delivery of the multimedia data. This paper proposes three different approaches for the selection of the MCS during MBSFN transmissions. Main target is to determine the most efficient approach depending on the target that the operator may set, i.e. the approach that either maximizes the spectral efficiency or achieves a target spectral efficiency for various user distributions. The performance of the approaches is evaluated for scenarios that include users' mobility and for three different transmission modes in order to also examine the effectiveness of Multiple Input Multiple Output (MIMO) techniques.**

Keywords—Long term evolution; multimedia broadcast and multicast; single frequency network; spectral efficiency; modulation and coding scheme; multiple input multiple output

I. INTRODUCTION

Multimedia Broadcast/Multicast Service (MBMS) constitutes a technology introduced by the 3rd Generation Partnership Project (3GPP) as a means to broadcast and multicast information to mobile users. In the context of Long Term Evolution (LTE) systems, the MBMS will evolve through the increased performance of the air interface that will include a new transmission scheme called MBMS over Single Frequency Network (MBSFN) [1]. In MBSFN, the data are transmitted simultaneously over the air from multiple tightly time-synchronized cells that constitute the MBSFN area [2].

MBSFN transmissions are extremely beneficial at the cell edge, where transmissions are translated into useful signal energy and hence the received signal strength is increased, while at the same time the interference power is largely reduced [1]. This may lead to significant improvements in the Signal to Interference plus Noise Ratio (SINR) and in the Spectral Efficiency (SE) compared to multicasting over Universal Mobile Telecommunications System (UMTS).

In order to fully exploit the benefits of MBSFN and to improve its performance in terms of SE, the Modulation and Coding Scheme (MCS) for the transmission of the data should be carefully selected. This relationship between MBSFN performance and MCS selection has been thoroughly studied in previous research works, such as works [3], [4] and [5]. In detail, work [3] proposes an approach, which selects the lowest MCS for the MBSFN transmission that allows an expected SE target to be achieved for 95% of users. However, focusing only on the users' side may not be sufficient. Sometimes the operator's goal may be the maximization of the SE over all users of the topology or the provision of the service to all the users irrespectively of the conditions that they experience. On the other hand, work [4] proposes an adaptive MCS based on partial feedback in order to obtain the improvement of system throughput. Work [5] determines the MCS scheme for MBSFN considering only the case of single antenna transmissions.

More recent works, such as works [6], [7] and [8], also study MCS selection techniques. In detail, work [6] proposes a framework for energy-efficient cross-layer Adaptive Modulation and Coding (AMC) scheme that captures the impact of both MAC layer and PHY layer parameters on the AMC switching criteria, instead of just switching the MCS according to signal-to-noise ratio thresholds at the PHY layer. The authors of work [7] have developed and examined several effective MCS selection schemes by using the effective packet-level SINR with main target to maximize the downlink throughput. Finally, work [8] proposes a scheduling and resource allocation mechanism for latency-constrained operation that is based on the optimization of a joint hybrid-automatic repeat-request (ARQ) and AMC policy that changes the number of physical resources used in each round. However, none of them focuses on MBSFN transmissions and moreover they do not examine the impact of Multiple Input Multiple Output (MIMO) transmissions on the overall performance.

The goal of this paper is to extend and complete the above studies and, furthermore, to tackle the problems addressed. To this direction, we first analyze a 3-step procedure that selects the MCS and calculates the SE in the case of a single user. Then, we generalize the single-user case and we propose three approaches that select the MCS for the delivery of the MBSFN data in multiple-users scenarios. The approaches are evaluated for three different transmission modes, so as to examine the impact of multiple antennas techniques on the MCS selection, and for different users' distributions. The evaluation results indicate that depending on the target that the operator may set (i.e. SE maximization or achievement of a specific SE) each approach could lead to improved performance.

The remainder of the paper is structured as follows: In Section II we describe the methodology for calculating the SE of the MBSFN delivery scheme in the single-user case. The three approaches for selecting the MCS of an MBSFN area are 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. Modulation and Coding Scheme Selection

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 and SE Estimation* 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 [3]:

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

with:

$$w(\tau)=\begin{cases}1 & 0\le\tau<T_{CP}\\ 1-\frac{\tau-T_{CP}}{T_u} & T_{CP}\le\tau<T_{CP}+T_u\\ 0 & otherwise\end{cases} \quad (2)$$

where P_j is the average power associated with the j path, $\tau_i(m)$ the propagation delay from base station 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.

B. Step 2: MCS Selection

In order to select the MCS for the transmission of the MBSFN data to a single user, first the SINR should be mapped to the available Channel Quality Indicators (CQI, i.e. MCS) [10]. After taking into account that in LTE networks an acceptable Block Error Rate (BLER) target value should be smaller than 10% [9], this mapping is obtained by plotting the 10% BLER values over SNR of the curves in Fig. 1. Using the obtained line, the SNR can be mapped to a CQI value that should be signaled to the base stations so as to ensure the 10% BLER target.

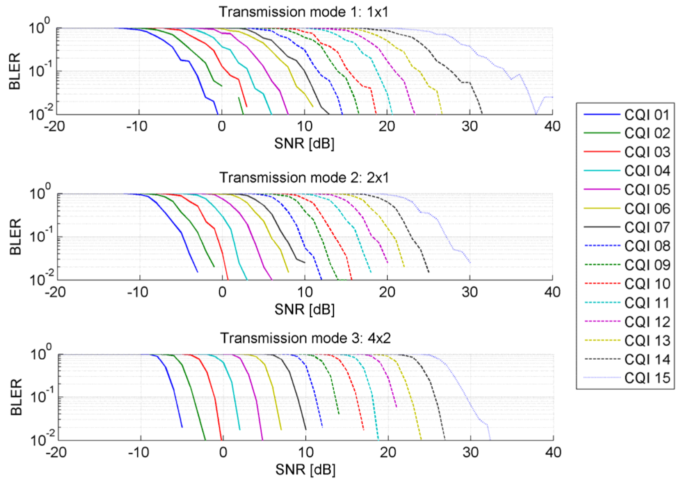

Fig. 1. SNR-BLER curves for the three transmission modes.

The results in Fig. 1 have been obtained from the link level simulator introduced in [9], assuming a system bandwidth equal to 5.0 MHz. Our intention is also to examine the impact of multiple antennas techniques on the MCS selection and therefore each plot of Fig. 1 corresponds to a different transmission mode. In detail, this paper examines the following three transmission modes:

- Transmission mode 1: 1x1. Corresponds to Single Input Single Output (SISO) transmissions with one antenna at both the transmitter and receiver.
- Transmission mode 2: 2x1. Multiple Input Single Output (MISO) transmissions with two antennas at the transmitter and one antenna at the receiver.
- Transmission mode 3: 4x2. Multiple Input Multiple Output (MIMO) transmissions with four antennas at the transmitter and two antennas at the receiver.

C. Step 3: Throughput and SE Estimation

In order to estimate the achieved throughput for the selected MCS, Eq. 3 is used. In Eq. 3, 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 [11].

$$Throughput=BW\cdot e(SINR)\cdot\left(1-BLER(SINR)\right) \quad (3)$$

Therefore, by utilizing the SINR and MCS obtained by Steps 1 and 2 respectively, the achieved throughput can be calculated. Fig. 2 depicts the relationship between the achieved throughput and the SNR for all MCSs and for the examined transmission modes, as calculated from Eq. 3.

After the throughput calculation, the SE of each MCS can be easily obtained by Eq. 4:

$$SE=\frac{Throughput}{BW} \quad (4)$$

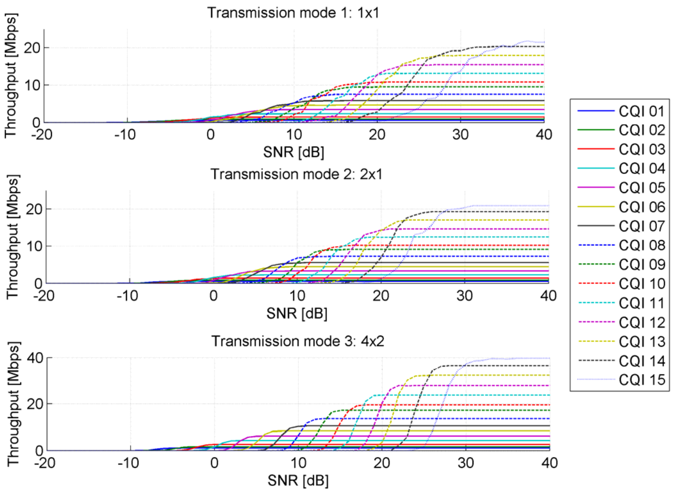

Fig. 2. Throughput for all CQIs for the three transmission modes.

III. Proposed Mechanisms

The MCS selection and the SE evaluation in the multiple-users case are deduced from the single-user approach described in the previous section. This section examines three approaches for the selection of the MCS during MBSFN transmissions.

A. 1st Approach - Guaranteed Service Provision

The 1st approach ensures that all users, even those with the lowest SINR, will receive the MBSFN service. In order to achieve this goal the algorithm locates the user with the minimum SINR and the MCS that corresponds to the minimum SINR is obtained from the *MCS Selection* step. Then, from Eq. 3 or Fig. 2 the corresponding average throughput and SE are obtained. The operation of this approach indicates that all the users in the MBSFN area will uninterruptedly receive the MBMS service, irrespectively of the conditions they experience in terms of SINR. However, the fact that the user with the minimum SINR determines the MCS indicates that users with higher SINR values will not make use of a MCS that would ensure a higher throughput. The procedure for obtaining the MCS and the SE is presented below using pseudo code.

Algorithm of the 1st Approach

```
Define MBSFN topology
for i = 1:total_users              % SINR calculation for all users
    Calculate SINR(i)
end
min_SINR = min(SINR)               % find the lowest SINR among all users
% choose the MCS that corresponds to the minimum SINR
selected_MCS = f_MCS (min_SINR)
% calculate the throughput for the selected MCS
throughput = f_throughput(selected_MCS, min_SINR)
Calculate SE                       % spectral efficiency calculation
```

B. 2nd Approach - Maximum Spectral Efficiency

The 2nd approach selects the MCS that ensures the maximum average throughput and SE over all users in the MBSFN area. At first the algorithm calculates the SINR value for each user using Eq. 1. Then, the algorithm scans all the MCSs in Fig. 2. For each MCS, the algorithm calculates the per-user throughput depending on the calculated SINRs and obtains the average throughput and total SE. The MCS that ensures the maximum average throughput - and therefore the maximum total SE - is selected. The pseudo code of the 2nd approach is presented below.

Algorithm of the 2nd Approach

```
Define MBSFN topology
for i = 1:total_users              % SINR calculation for all users
    Calculate SINR(i)
end
% for each MCS calculate the average throughput and SE
for MCS = 1:15
    for j = 1:total_users
        throughput(MCS, j) = f_throughput (MCS, SINR(j))
    end
    avg_throughput(MCS) = average(throughput(MCS, :))
    Calculate SE(MCS)
end
% find the max spectral efficiency that can be achieved and select
% the corresponding MCS
SE = max(SE(:))
```

C. 3rd Approach - Target Spectral Efficiency

The goal of the 3rd approach is to find the lowest MCS that achieves a target SE (usually equal to 1 (bit/s)/Hz) for an MBSFN area [3]. Initially the algorithm calculates the SINR value for each user. Then it proceeds with the scanning of the MCSs to calculate the per-user throughput. Starting from the lowest MCS, the algorithm calculates the per-user throughput and obtains the average throughput and the total SE for each MCS. If during the scanning procedure one MCS ensures that the total SE is equal or higher than the target SE, the operation stops without scanning the remaining MCSs of Fig. 2 and the algorithm selects this MCS for the delivery of the MBMS data. In other words, the aim of this approach is to find the lowest MCS that allows a target SE to be achieved. The scanning procedure starts from the lowest MCS in order to serve as many users as possible. If the scanning procedure starts from the highest MCS, then the SE target is achieved very quickly by utilizing a high MCS, and therefore only the users that experience high SINRs receive the MBSFN service as depicted in Fig. 2. In the case the target SE cannot be achieved, this approach has identical operation with the 2nd approach (i.e. selects the MCS that ensures the maximum total SE). This procedure is presented below using pseudo code.

Algorithm of the 3rd Approach

```
Define MBSFN topology
Define target_SE
for i = 1:total_users                 % SINR calculation for all users
    Calculate SINR(i)
end
% Scan the MCSs so as calculate the SE over the MBSFN area
for MCS = 1:15
    for j = 1:total_users
        throughput(MCS, j) = f_throughput (MCS, SINR(j))
    end
    avg_throughput(MCS) = average(throughput(MCS, :))
    Calculate SE(MCS)
    % examine if target SE is achieved
    if SE(MCS) >= target_SE  then      % target is achieved
        break;
    else                               % target is not achieved
        SE = max(SE(:))
    end
end
% select the MCS that achieves the target SE or that maximizes
% the SE (if target SE is not achieved)
SE = SE(MCS)
```

IV. Performance Evaluation

This section provides simulation results regarding the operation and performance of the three approaches. For the purpose of our experiments we have extended the link level simulator introduced in [9]. In particular, three different scenarios are investigated. Scenario 1 assumes that a constant number of 300 users are randomly distributed in the MBSFN area; Scenario 2 investigates the case of increasing number of users and Scenario 3 investigates the case of 300 randomly moving users. The parameters used in the performed simulations are presented in the following table.

TABLE I. Simulation Parameters

Parameter	Value
Cellular layout	Hexagonal grid, 19 cell sites
Inter Site Distance (ISD)	1732 m
Carrier frequency	2.0 GHz
System bandwidth	5.0 MHz
Channel model	3GPP Typical Urban
Propagation model	Cost Hata
Cyclic prefix	16.67μsec
Useful signal frame length	66.67μsec
Transmission modes	SISO 1x1, MISO 2x1, MIMO 4x2
Modulation and Coding Schemes	15 different sets as defined in [10]

A. *Scenario 1: Constant Number of Users*

This section presents the way that each approach selects the appropriate MCS, while simultaneously it makes a comparison between them and between the transmission modes for each approach. The scenario assumes a fixed number of 300 users randomly distributed in an MBSFN area.

Specifically, Fig. 3 illustrates how the 1st approach selects the MCS for the transmission of the MBSFN data. Initially, it calculates the SINR of all users in the cell according to the procedure described in Section II and detects the user with the lowest SINR, which in this scenario is -0.204 dB. Then, it selects the CQI that maximizes the throughput of the "worst" user. Thus, in the case of transmission mode 1, i.e. SISO 1x1, the CQI that provides the lowest-SINR user with the maximum throughput (equal to 1.505 Mbps) is CQI 4. For the case of transmission mode 2 (MISO 2x1), the selected CQI is CQI 4 which achieves a throughput equal to 1.585 Mbps. Finally, the transmission mode 3 (MIMO 4x2) leads to significantly higher throughput (2.635 Mbps) and selection of lower modulation scheme, which in this case is CQI 3.

Fig. 4 evaluates the 2nd approach by presenting the SE that each MCS achieves for each transmission mode. In this approach, as described in Section III.B, the MCS that ensures the maximum SE is selected after the algorithm scans all the available MCSs. Transmission mode 1 provides a maximum SE equal to 1.218 (bit/s)/Hz for CQI 10. The same CQI is also assigned in the case of transmission mode 2, providing a SE equal to 1.241 (bit/s)/Hz. Finally, Fig. 4c shows that transmission mode 3 provides a maximum SE equal to 1.887 (bit/s)/Hz) for CQI 9.

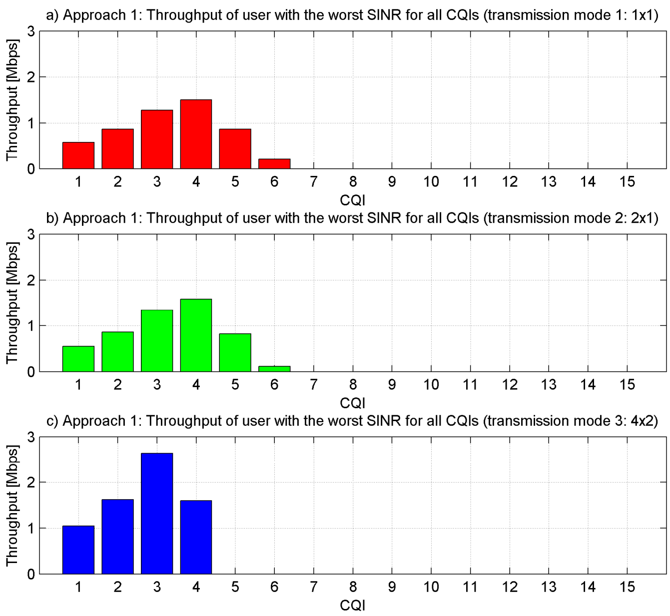

Fig. 3. Throughput of user with worst SINR for all CQIs and all transmission modes (approach 1).

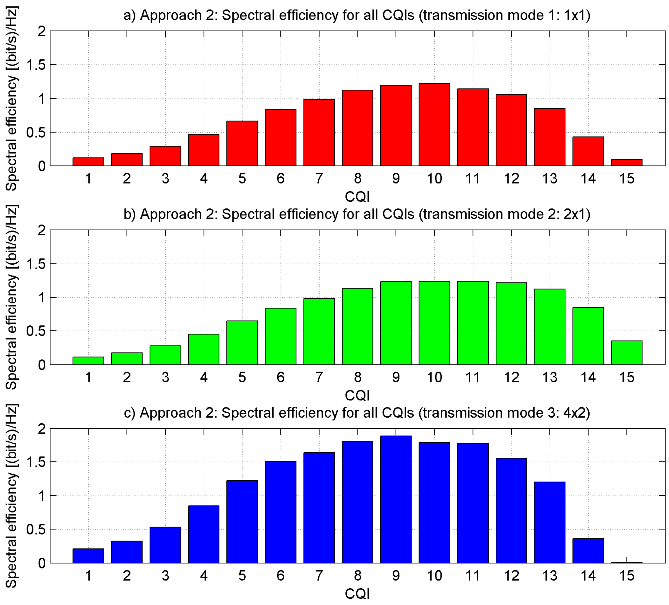

Fig. 4. Spectral efficiency for all CQIs and all transmission modes (approach 2).

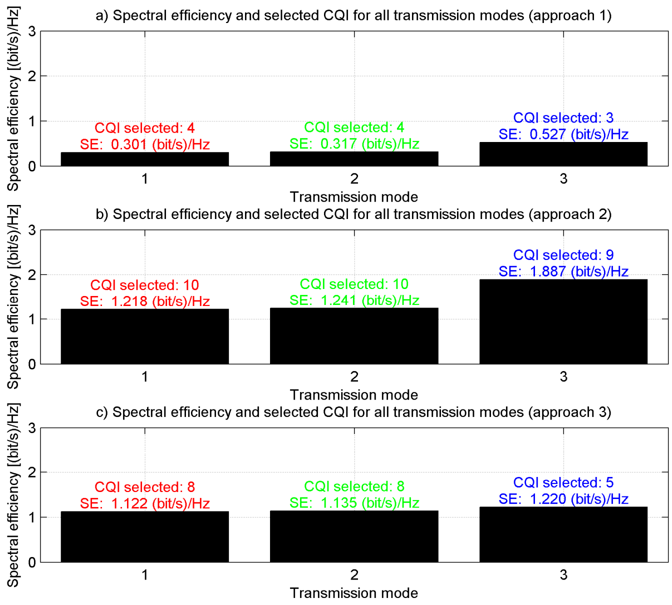

Fig. 6. Spectral efficiency and selected CQI for all approaches and all transmission modes.

Fig. 5 depicts how the 3rd approach assigns the MCS for each transmission mode. Recall that the goal of this approach is to select the lowest CQI meeting the target SE of 1 (bit/s)/Hz. Therefore in the case of transmission modes 1 and 2 the lowest CQI that achieves the target SE is CQI 8, while for transmission mode 3 the CQI meeting the target SE is CQI 5.

To conclude, Fig. 6 summarizes the results by presenting the selected CQI and the SE obtained for the three approaches and for each transmission mode. It is clear that the 1st approach achieves the smallest SE while trying to satisfy the lowest-SINR user. Despite the low per-user throughput, this approach ensures that all users will receive the MBSFN data. The 2nd approach offers the maximum SE; however, it uses higher CQI compared with the other two approaches. This results in favoring users close to the base stations, whereas the users in the cell boundaries cannot receive the MBSFN data. Finally, the 3rd approach makes a trade-off between the SE and the coverage by choosing an intermediate CQI.

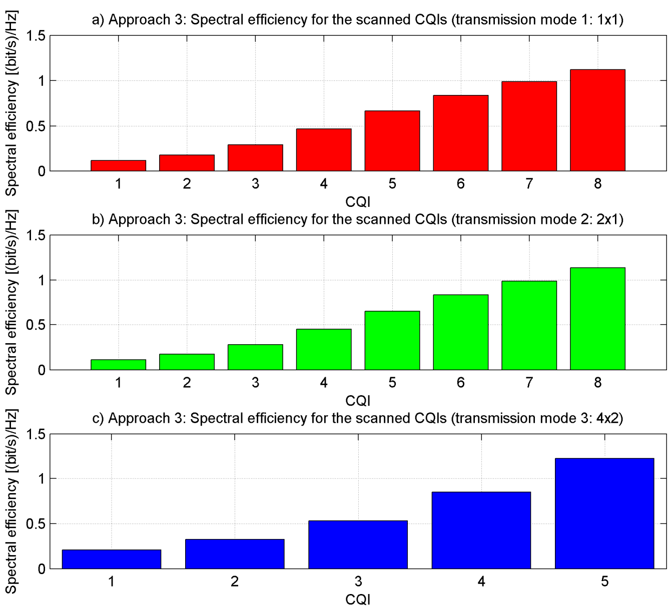

Fig. 5. Spectral efficiency for the scanned CQIs and all transmission modes (approach 3).

Fig. 6 also shows the impact of MIMO transmissions on the overall performance of the system. It is clear that transmission mode 3 (MIMO 4x2) not only provides a better SE in comparison with the other two modes but also selects a lower CQI, and therefore can serve users that are located at a big distance from the base station. Additionally, transmission mode 2 (MISO 2x1) selects the same CQI with transmission mode 1 (SISO 1x1); however, the use of two transmitting antennas leads to slightly higher values of SE.

B. Scenario 2: Increasing Number of Users

Having studied the way that the three approaches choose the MCS for a fixed number of users, this section attempts to make a comparison between them when the number of users in the MBSFN area increases from 0 to 300 users. The comparison is based on the achieved SE and the MCS selected.

Fig. 7 illustrates the way that the SE changes with respect to the number of users for each approach and for the three different transmission modes. Irrespectively of the transmission mode, the application of the 1st approach leads to a small decrease in the SE when the number of users is small; however, the SE remains constant for larger number of users (Fig. 7a). In addition, the achieved SE is low compared to the other two approaches. The 2nd approach on the other hand leads to the highest SE values as depicted in Fig. 7b, especially for the case of transmission mode 2. Regarding the 3rd approach, Fig. 7c shows that irrespectively of the transmission mode and the number of users, the target SE is achieved.

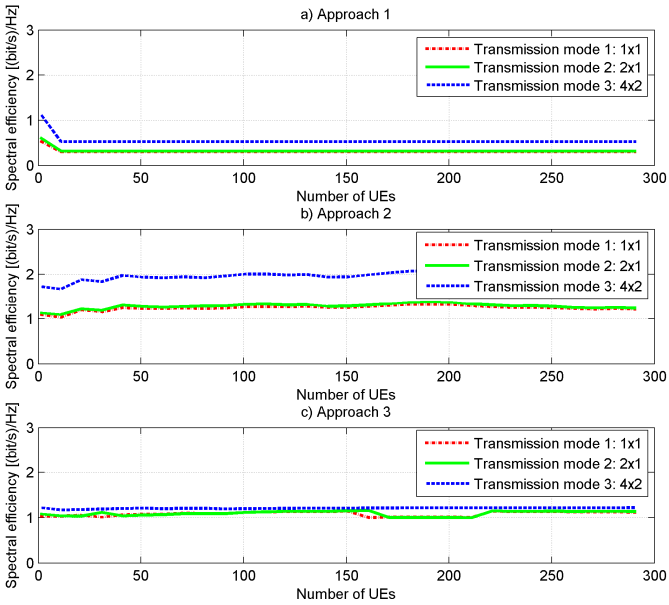

Fig. 7. Increasing number of users scenario: Spectral efficiency for all transmission modes and all approaches.

Fig. 8 depicts the performance of each approach in terms of CQI selection. The 1st approach initially selects CQI 5 for all transmission modes until the 16th user appears in the MBSFN area and causes the selection of a smaller CQI (CQI 4 for transmission modes 1 and 2 and CQI 3 for transmission mode 3), which is maintained until the end of the simulation. This happens because the 16th user is the worst-SINR user throughout the simulation and therefore is the user that determines the MCS. Fig. 8b reveals that the 2nd approach selects higher CQIs compared to the other two approaches as a result of trying to maximize the SE throughout the simulation; while, Fig. 8c shows the way that the 3rd approach changes the CQI in order to achieve the target SE. Fig. 8b and Fig. 8c also show that the application of the 2nd and 3rd approach leads to successive changes in the selected CQIs, especially when transmission modes 1 and 2 are used. These changes also explain the fluctuations in the SE values of Fig. 7b and Fig. 7c respectively.

One more observation of Fig. 8 is that the use of transmission mode 4x2 leads generally to the selection of a lower CQI compared to the other two modes, which in turn means that the specific mode can serve users that experience worse conditions in terms of SINR. To sum up, the application of MIMO schemes may increase the overall performance of MBSFN.

C. *Scenario 3: Moving Users*

The last experiment investigates the performance of the proposed approaches through a scenario that includes users' mobility. In detail, the scenario assumes 300 users randomly distributed in the MBSFN area that move randomly with speed 3 km/h. Fig. 9 and Fig. 10 present the results of the experiment for the first 100 seconds (or steps) of the simulation.

Let us first consider Fig. 9, which illustrates the SE of each approach for the three transmission modes. To begin with, Fig. 9a reveals that the 1st approach has many fluctuations in the achieved SE because it tries to adjust to the users' mobility while simultaneously ensures that even the users with low SINRs will receive the MBSFN data. In detail, the SE decreases gradually and finally reaches 0.1 (bit/s)/Hz. This happens because of the worst-SINR user's mobility, who in our experiment moves towards the borders of the MBSFN area. This is actually the user who determines the MCS selection and thus affects directly the overall throughput and SE. It is also important to notice that the utilization of MIMO techniques can improve the system's performance. Indeed, transmission mode 3 leads to higher SE compared to the other two modes.

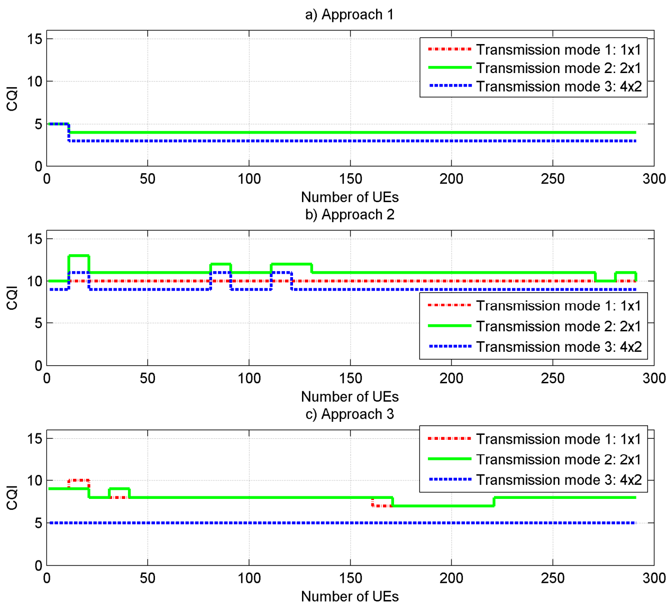

Fig. 8. Increasing number of users scenario: Selected CQI for all transmission modes and all approaches.

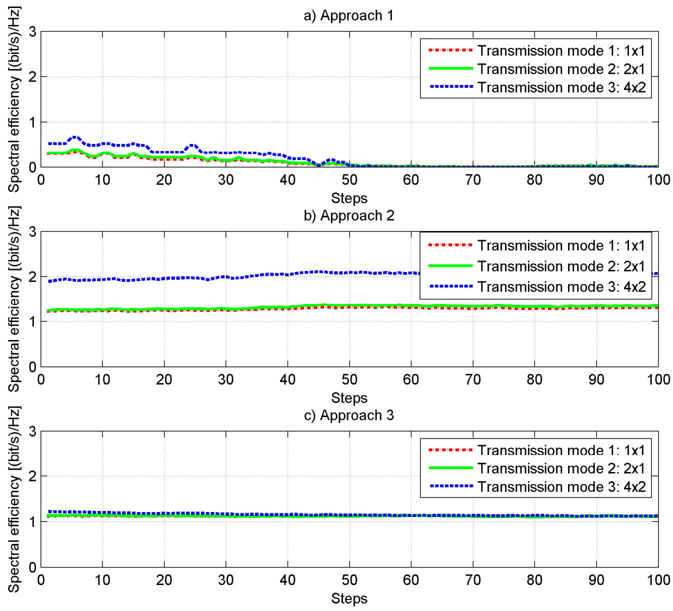

Fig. 9. Moving users scenario: Spectral efficiency for all transmission modes and all approaches.

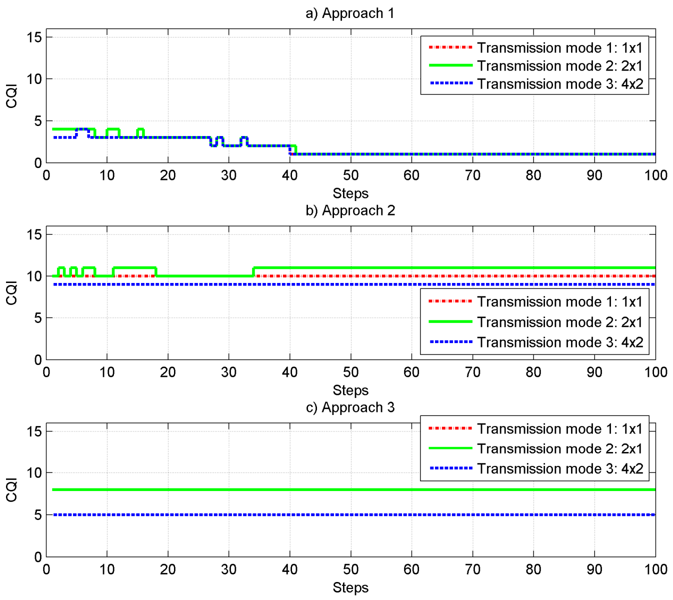

Fig. 10. Moving users scenario: Selected CQI for all transmission modes and all approaches.

On the other hand, the 2nd approach and 3rd approach adjust better to the users' mobility since the fluctuations in the SE are smoother. As expected, the 2nd approach provides the highest SE, especially for the case of transmission mode 3 (MIMO 4x2); while, the 3rd approach manages to meet the SE target throughout the simulation and irrespectively of the transmission mode (Fig. 9c).

Fig. 10 depicts how the users' mobility affects the selection of the MCS for the three approaches. Regarding the 1st approach, the figure confirms that the worst-SINR user's random movement forces the base station to constantly change the transmission MCS (ping-pong phenomena). In detail, for the simulation time 0 - 41 steps that the "worst" user moves closer and further from the MBSFN area borders (due to its random movement) the selected CQI varies from CQI 2 to CQI 4 for all transmission modes. For the remaining time, the worst-SINR user moves near the borders of the MBSFN area and therefore CQI 1 is selected. This also explains the low SE value in Fig. 9a. On the other hand, Fig. 10b shows that the 2nd approach selects a CQI between CQI 9 and CQI 11 for the transmission of the MBSFN data with main target to maximize the SE. In combination with Fig. 9b, it is clear that the utilization of MIMO techniques offers higher SE values with a simultaneous deployment of a lower CQI, increasing in this way the service coverage. Finally, Fig. 10c makes clear that the 3rd approach minimizes the ping-pong phenomena in MCS selection. During the whole simulation the selected CQI for all transmission modes was kept constant, i.e. CQI 8 was selected for transmission modes 1 and 2 and CQI 5 for transmission mode 3.

V. Conclusions and Future Work

In this paper, we proposed three different approaches for the efficient MCS selection during MBSFN transmissions. The main conclusion is that the selection of the most efficient MCS is an operator dependent parameter. Therefore, the uninterrupted service provision irrespectively of the users' conditions would make the 1st approach the most efficient approach. However, this approach could not provide any guarantee for the throughput and the achieved SE. On the other hand, for maximum SE the most efficient approach would be the 2nd approach. The 3rd approach constitutes the most efficient approach when the operator targets at a specific SE and minimizes the ping-pong phenomena in MCS selection. In order to explore the effectiveness of multiple antennas techniques, this paper also examined scenarios for three different transmission modes. As a conclusion, we can say that the utilization of MIMO schemes may increase the overall performance of MBSFN by increasing both the throughput and coverage of the MBSFN service.

The step that follows this work could be the design, the implementation and the evaluation of an algorithm responsible for choosing the most efficient MCS selection approach according to the users' distribution and the operator needs each time. In addition, we also plan to make the specific algorithm more robust by minimizing the ping phenomena in MCS switching.

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