Efficient MCS Selection for MBSFN Transmissions over LTE Networks

Antonios Alexiou[2], Christos Bouras[1,2], Vasileios Kokkinos[1,2], Andreas Papazois[1,2], George Tsichritzis[1,2]
[1] Research Academic Computer Technology Institute
[2] Computer Engineering and Informatics Department, University of Patras
Patras, Greece
alexiua@ceid.upatras.gr, bouras@cti.gr, kokkinos@cti.gr, papazois@ceid.upatras.gr, tsixritzis@cti.gr

***Abstract*—Long Term Evolution (LTE), the next-generation network beyond 3G, is designed to support the explosion in demand for bandwidth-hungry multimedia services that are already experienced in wired networks. To support Multimedia Broadcast/Multicast Services (MBMS), LTE offers functionality to transmit MBMS over a Single Frequency Network (MBSFN), where a time-synchronized common waveform is transmitted from multiple cells for a given duration. This significantly improves the Spectral Efficiency (SE) compared to conventional MBMS operation. The achieved SE is mainly determined by the Modulation and Coding Scheme (MCS) utilized by the LTE physical layer. In this paper we propose and evaluate four approaches for the selection of the MCS that will be utilized for the transmission of the MBSFN data. The evaluation of the approaches is performed for different users' distribution and from SE perspective. Based on the SE measurement, we determine the most suitable approach for the corresponding users' distribution.**

Keywords-long term evolution; multimedia broadcast and multicast; single frequency network; spectral efficiency;

I. INTRODUCTION

The 3rd Generation Partnership Project (3GPP) has introduced the Multimedia Broadcast/Multicast Service (MBMS) as a means to broadcast and multicast information to mobile users, with mobile TV being the main service offered. The Long Term Evolution (LTE) infrastructure offers to MBMS an option to use an uplink channel for interaction between the service and the user, which is not a straightforward issue in common broadcast networks [1], [2].

In the context of LTE systems, the MBMS will evolve into e-MBMS ("e-" stands for evolved). This will be achieved through increased performance of the air interface that will include a new transmission scheme called MBMS over a Single Frequency Network (MBSFN). In MBSFN operation, MBMS data are transmitted simultaneously over the air from multiple tightly time-synchronized cells. A group of those cells which are targeted to receive these data is called MBSFN area [2]. Since the MBSFN transmission greatly enhances the Signal to Interference Noise Ratio (SINR), the MBSFN transmission mode leads to significant improvements in Spectral Efficiency (SE) in comparison to multicasting over Universal Mobile Telecommunications System (UMTS) [1].

In general, SE refers to the data rate that can be transmitted over a given bandwidth in a communication system. Several studies such as [3], [4] and [5] have shown that SE is directly related to the Modulation and Coding Scheme (MCS) selected for the transmission. Additionally, the most suitable MCS is selected according to the measured SINR so as a certain Block Error Rate (BLER) target to be achieved. In this paper, we evaluate the performance of MBSFN in terms of SE. More specifically, we focus on a dynamic user distribution, with users distributed randomly in the MBSFN area and therefore experiencing different SINRs. Based on the measured SINRs, our goal is to select the MCS which should be used by the base stations when transmitting the MBMS data. For this purpose, we propose a 4-step procedure that calculates the most efficient MCS in terms of SE. Based on this procedure we propose and evaluate four approaches for the MCS selection during MBSFN transmissions.

The paper is structured as follows: in Section II we describe the method of calculating the SE of the MBSFN delivery scheme in a single-user case. The four different approaches for selecting the MCS of an MBSFN area are presented in detail in Section III; while the evaluation results are presented in Section IV. Finally, the conclusions and planned next steps are briefly described in Section V.

II. SINGLE-USER MCS SELECTION AND SE ESTIMATION

In order to select the MCS and calculate the SE in the case of a single receiver, we propose the following 4-step procedure.

A. Step 1: SINR Calculation

Let the MBSFN area consist of N neighboring cells. Due to multipath, the signals of the cells arrive to the receiver by M different paths, so the SINR of a single user at a given point m is expressed as in (1) [3]:

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

with:

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

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) and T_u the length of the useful signal frame.

B. Step 2: MCS Selection

In order to obtain the MCS that should be used for the transmission of the MBSFN data to a single user, Additive White Gaussian Noise (AWGN) simulations have been performed. In general, the MCS determines both the modulation alphabet and the Effective Code Rate (ECR) of the channel encoder. Figure 1 shows the BLER results for Channel Quality Indicators (CQI) 1-15, without using Hybrid Automatic Repeat Request (HARQ) and for 1.4 MHz and 5.0 MHz bandwidth. The results have been obtained from the link level simulator introduced in [6]. Each MCS is mapped to a predefined CQI value. The 15 different sets of CQIs and the corresponding MCSs are defined in [7].

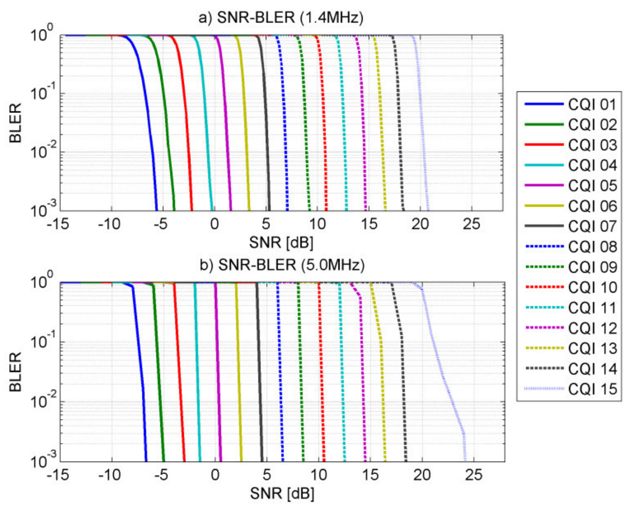

Figure 1. SNR-BLER curves obtained for: a) 1.4 MHz, b) 5.0 MHz.

In LTE networks, an acceptable BLER target value should be smaller than 10% [6]. The SINR to CQI mapping required to achieve this goal can thus be obtained by plotting the 10% BLER values over SNR of the curves in Figure 1. Using the obtained line, the SNR can be mapped to a CQI value (i.e. MCS) that should be signaled to the base stations so as to ensure the 10% BLER target.

C. Step 3: Throughput Estimation

In order to estimate the achieved throughput for the selected MCS, (3) is used. In (3), *BW* is the total bandwidth offered by LTE, *e(SINR)* is the effective code rate of the selected modulation scheme and *BLER(SINR)* the block error rate [8].

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

Therefore, by utilizing the SINR and MCS obtained by the SINR Calculation and MCS Selection steps respectively, the achieved throughput can be calculated. Figure 2a and Figure 2b depict the relationship between the achieved throughput and the SNR for all MCSs, as calculated from (3) for the cases of 1.4 MHz and 5.0 MHz respectively.

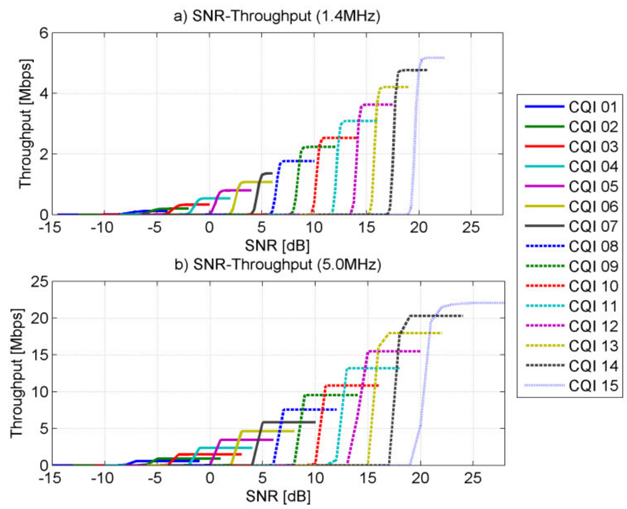

Figure 2. Throughput for all CQIs obtained for: a) 1.4 MHz, b) 5.0 MHz.

D. Step 4: Single-User Spectral Efficiency

Spectral efficiency (SE) refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It constitutes a measure of how efficiently a limited frequency spectrum is utilized. The formula from which the SE can be obtained is:

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

III. Multiple-Users MCS Selection and SE Estimation

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 four approaches for the selection of the MCS during MBSFN transmissions.

A. 1st Approach - Bottom Up Approach

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 finds the minimum SINR and the MCS that corresponds to the minimum SINR is obtained from the MCS Selection step. Then, from (3) or Figure 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 greater

SINR values will not make use of a MCS that would ensure a greater throughput. The procedure for obtaining the MCS and the SE is presented using pseudo code in the table below.

```
% Algorithm for 1st Approach - Bottom Up

Define MBSFN topology
FOR i = 1:total_users
    Calculate SINR(i)
END
%find the lowest SINR
min_SINR = min(SINR)
% choose the MCS that corresponds to the min SINR
selected_MCS = f_MCS (min_SINR)
%Calculate the throughput for the selected MCS
throughput = f_throughput(selected_MCS, min_SINR)
Calculate SE
```

B. 2nd Approach - Top Down Approach

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 (1). Then, the algorithm scans all the MCSs in Figure 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 following table presents the algorithm of the 2nd approach using pseudo code.

```
% Algorithm for 2nd Approach - Top Down

Define MBSFN topology
FOR i = 1:total_users
    Calculate SINR(i)
END
% for each MCS calculate the
% average throughput over all users
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
SE = max(SE(:))
```

C. 3rd Approach - Area-Oriented Approach

The goal of the 3rd approach is to find the lowest MCS that achieves a target SE for an area. This target usually equals to 1 (bit/s)/Hz [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 area target SE, the operation stops without scanning all the MCSs of Figure 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 Figure 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 using pseudo code in the table below.

```
% Algorithm for 3rd Approach - Area-Oriented

Define MBSFN topology
Define area_target_SE
FOR i = 1:total_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 area target SE is achieved
    IF SE(MCS) >= area_target_SE THEN      % target is achieved
        BREAK;
    ELSE      % target is not achieved
        SE = max(SE(:))
    END
END
SE = SE(MCS)
```

D. 4th Approach - User-Oriented Approach

The difference between the 4th and the 3rd approach is that in spite of defining an area-specific target SE such as the 3rd approach, the 4th approach defines a user-oriented target SE (usually equal to 1 (bit/s)/Hz [3]). More specifically, the algorithm initially calculates the SINR value for each user. Then, starting from the lowest MCS, the algorithm calculates the per-user throughput and per-user SE of each MCS. If during the scanning procedure one MCS ensures that at least 95% of the users reach or exceed the target SE, the operation stops and the algorithm selects this MCS for the delivery of the MBMS data. Similar to the 3rd approach, this approach locates the lowest MCS that allows a user-specific target SE to be achieved for the 95% of the users' population. If the target SE cannot be achieved for the 95% of the users, the MCS that ensures the maximum total SE is selected. This procedure is presented using pseudo code in the following table.

```
% Algorithm for 4th Approach - User-Oriented

Define MBSFN topology
Define user_target_SE
FOR i = 1:total_users
    Calculate SINR(i)
END
Scan the MCSs so as to calculate the per-user SE
FOR MCS = 1:15 %
    FOR j = 1:total_users
        % Calculate the per user throughput and spectral efficiency
        throughput(MCS, j) = f_throughput (MCS, SINR(j))
        SE(MCS, j) = throughput(MCS, j) / bandwidth
    END
    % examine if user target SE is achieved for 95% of users
    IF SE(MCS, j) >= user_target_SE FOR 95% of users THEN
        BREAK;      % target achieved
    ELSE      % target is not achieved
        SE = max(SE(:, j))
    END
END
SE = SE(MCS, j)
```

IV. Performance Evaluation

This section provides simulation results regarding the operation and performance of the aforementioned approaches. For the purpose of our experiments we have extended the link level simulator introduced in [6]. In particular, two different scenarios are investigated. Scenario 1 assumes that a constant number of 100 users are randomly distributed in the MBSFN area; while Scenario 2 investigates the case of variable number of users. The parameters used in the performed simulations are presented in the following table.

TABLE I. Simulation Settings

Parameter	Value
Cellular layout	Hexagonal grid, 19 cell sites
Inter Site Distance (ISD)	1732 m
Carrier frequency	2.0 GHz
System bandwidth	1.4 MHz / 5.0 MHz
Channel model	3GPP Typical Urban
Propagation model	Cost Hata
Cyclic prefix / Useful signal frame length	16.67μsec / 66.67μsec
Modulation and Coding Schemes	15 different sets defined in [7]

A. *Scenario 1: Predefined Number of Users*

Scenario 1 attempts to make a direct comparison of the proposed approaches when the MBSFN area consists of a constant number of users. More specifically, the MBSFN area - which consists of four neighboring cells - contains 100 randomly distributed users. For comparison reasons the evaluation is performed for 1.4 MHz and 5.0 MHz bandwidth.

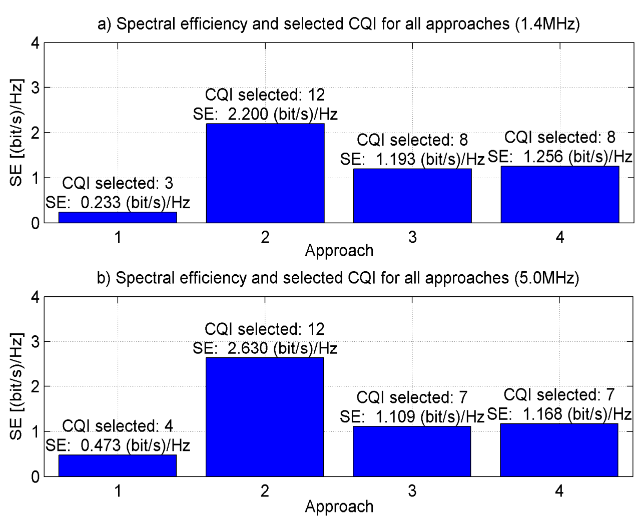

Figure 3. SE evaluation and CQI selection for predefined number of users. Bandwidth: a) 1.4 MHz, b) 5.0 MHz.

Let us first consider the case of 1.4 MHz bandwidth presented in Figure 3a. According to the procedure of the 1st approach, initially the users' SINRs are obtained and the lowest SINR value is selected for the determination of the MCS. In the examined scenario, the lowest SINR is -1.952dB. Therefore, from Figure 2 the CQI 3 is selected. Indeed, Figure 3a confirms that the 1st approach may provide a SE value of 0.233 (bit/s)/Hz by deploying CQI 3 for the transmission of the MBSFN data. On the other hand, the 2nd approach after the scanning procedure selects CQI 12 for the transmission of the MBSFN data. The selection of CQI 12 increases the SE drastically to 2.200 (bit/s)/Hz. As expected, this is the maximum SE that can be achieved for the specific user distribution in the case of 1.4 MHz bandwidth (Figure 3a).

Finally, the performance of the 3rd and 4th approach in Figure 3a confirms that the specific approaches have similar operation. Indeed, both approaches select CQI 8; however the 4th approach may provide a slightly increased level of SE. This is caused due to the fact that the 4th approach does not take into account the 5% of the users that experience worse network conditions (in terms of SINR). Nevertheless, it is worth mentioning that both approaches reach the target SE that was set. More specifically, the 3rd approach ensures that the total SE exceeds the SE target over the MBSFN area; while in the 4th approach the per-user SE for the 95% of the users exceeds the predefined threshold. The examination of Figure 3b that corresponds to the case of 5.0 MHz leads to similar results.

B. *Scenario 2: Variable Number of Users*

Figure 4 and Figure 5 depict the performance of each approach in terms of SE and MCS selection, when the users' population in the MBSFN area varies from 1 to 1000 users (for 1.4 MHz and 5.0 MHz bandwidth respectively). All the users that receive the MBMS service appear in random initial positions throughout the MBSFN area, which consists of four neighboring and tightly time synchronized cells.

As both figures present, the 1st approach achieves the lowest SE for a given user population. On the other hand, this approach takes into account the lowest SINR in order to obtain the corresponding MCS. This fact ensures that even the users that experience low SINRs will receive the MBMS service. As a result, the users with better conditions will not receive the service with the highest possible throughput. Another disadvantage of this approach is that users who enter the MBSFN area could force the base station to continuously change the transmission MCS (ping-pong effect).

As depicted in Figure 4a and Figure 5a, the 2nd approach ensures the maximum SE irrespectively of the users population in the examined network topology. This is reasonable since the 2nd approach selects the MCS that ensures the maximum average throughput and SE over all users in the topology. It is also worth mentioning that in certain scenarios where the majority of users are distributed near the base station, the 2nd approach could achieve even higher values of SE. Indeed, the users near the base station experience high SINRs and as consequence higher values of MCS may be utilized in order for a high average throughput to be achieved. Based on the above, it is worth mentioning that the 2nd approach tends to utilize a high MCS. As stated in [9], this fact has the advantage of decreasing the users' transmit power. However, the users experiencing bad network conditions will not receive the MBMS service (see Figure 2).

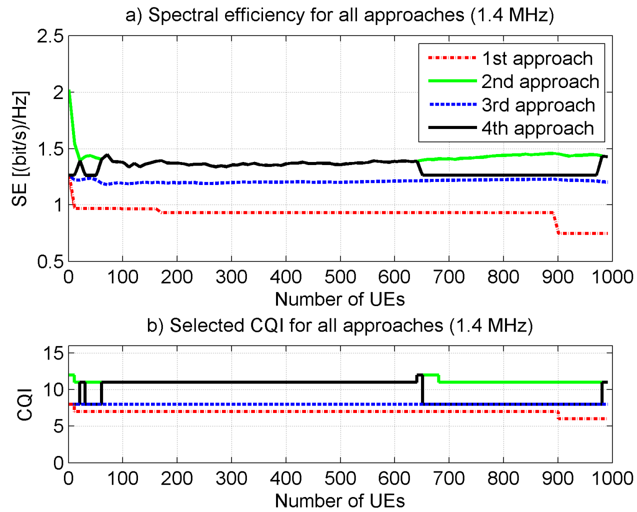

Figure 4. SE evaluation and CQI selection for variable number of users (bandwidth: 1.4 MHz).

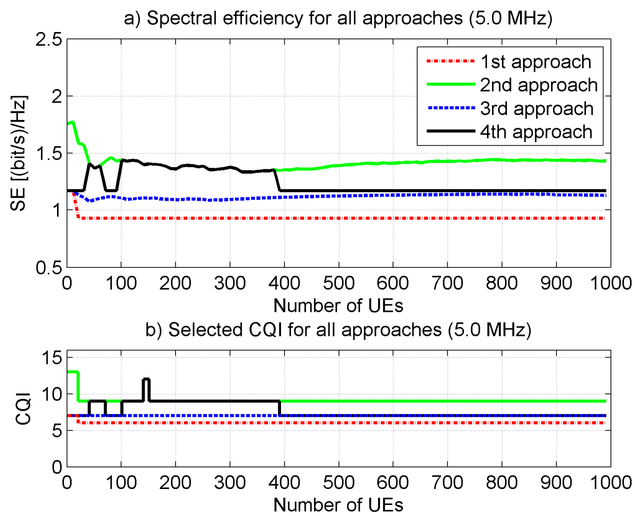

Figure 5. SE evaluation and CQI selection for variable number of users (bandwidth: 5.0 MHz).

The 3rd approach selects the MCS that ensures that the average SE calculated over all users in the topology achieves the SE target. Therefore, as depicted in Figure 4 (1.4 MHz) the 3rd approach utilizes CQI 8, while in Figure 5 (5.0 MHz) the selected CQI is CQI 7. The specific MCSs achieve a SE value over the MBSFN area higher than the SE target during the whole simulation (Figure 4a and Figure 5a).

One of the most important advantages of the 3rd approach is that it minimizes the ping-pong effect in MCS selection. Indeed, this approach ensures that the MCS will not necessarily change when the users' population changes. This leads to the avoidance of the ping-pong effect when new users enter the MBSFN topology or when users stop requiring the MBSFN service. However, it should be noted that the 3rd approach does not achieve the maximum possible SE, since the algorithm scans the different MCS beginning from the lowest value of MCS and stops when the selected MCS achieves the SE target.

Finally, the 4th approach selects the MCS that satisfies the SE target for the 95% of users. As depicted in Figure 4a and Figure 5a, the specific MCSs achieve a SE value higher than the per-user SE target. Moreover, the SE achieved with this approach is higher than that of the 3rd approach since the 95% of the users receive the MBSFN service with a data rate that satisfies the SE target. This implies that the remaining 5% of the users who experience bad conditions are not taken into account, in opposition to the 3rd approach in which all the users in the MBSFN area are considered for the MCS selection.

V. Conclusions and Future Work

The main enhancement that the adoption of MBSFN brings in e-MBMS is the improvement of over the air SE. The achieved SE is mainly determined by the selected MCS in the physical layer. In this paper we proposed four different approaches for the efficient selection of the appropriate MCS and we evaluated the impact of this selection to the achieved SE. The parameters that have been taken into account in the evaluation are the number of served users and their position in the topology. Based on the above two parameters the service provider can choose the most efficient MCS selection approach for the active MBSFN sessions. The approaches cover different needs that could exist in real world like the assurance of service continuity for the user with lowest SINR value, the selection of the MCS that maximizes the SE, the selection of the MCS based on the covered area or the percentage of the users that receive the service in an acceptable quality.

The step that follows this work could be the design and the evaluation of an algorithm responsible for choosing the most efficient MCS selection approach.

References

[1] H. Holma, and A. Toskala, "LTE for UMTS – OFDMA and SC-FDMA based radio access", John Wiley & Sons: Chichester, 2009.

[2] 3GPP TS 36.300, V9.3.0, "Technical specification group radio access network; Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN); Overall description; Stage 2 (Release 9)", 2010.

[3] L. Rong, O. Haddada, and S. Elayoubi, "Analytical analysis of the coverage of a MBSFN OFDMA network", Globecom 2008, USA, 2008

[4] C. Ball, T. Hindelang, I. Kambourov, and S. Eder, "Spectral efficiency assessment and radio performance comparison between LTE and WiMAX", PIMRC 2008, Cannes, France, 2008

[5] D.T. Phan Huy, R. Legouable, D. Ktenas, L. Brunel, and M. Assaad, "Downlink B3G MIMO OFDMA link and system level performance", IEEE VTC Spring 2008, Singapore, May, 2008

[6] C. Mehlfhrer, M. Wrulich, J. C. Ikuno, D. Bosanska, and M. Rupp, "Simulating the Long Term Evolution Physical Layer", 17th European Signal Processing Conference (EUSIPCO 2009), Glasgow, Scotland, 2009. Available: http://publik.tuwien.ac.at/files/PubDat_175708.pdf

[7] 3GPP TS 36.213, V9.1.0, "Technical specification group radio access network; Evolved Universal Terrestrial Radio Access; Physical Layer Procedures (Release 9)", 2010.

[8] S.-E. Elayoubi, O. Ben Haddada, and B. Fouresti´e, "Performance evaluation of frequency planning schemes in OFDMA-based networks," IEEE Transactions on Wireless Communications, vol. 7, no. 5, pp. 1623–1633, 2008.

[9] M. Rumney (ed.), "LTE and the Evolution to 4G Wireless: Design and Measurement Challenges", Agilent Technologies, 2009.