Multimedia Broadcasting in LTE Networks

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ABSTRACT

Long Term Evolution (LTE) constitutes the latest step before the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile communications. To support Multimedia Broadcast/Multicast Services (MBMS), LTE offers the functionality to transmit MBMS over Single Frequency Network (MBSFN), where a time-synchronized common waveform is transmitted from multiple cells for a given duration. In MBSFN transmissions, the achieved Spectral Efficiency (SE) is mainly determined by the Modulation and Coding Scheme (MCS) selected. This study proposes and evaluates 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 approach that either maximizes or achieves a target SE for the corresponding users' distribution.

INTRODUCTION

Long Term Evolution (LTE) constitutes the evolution of the 3rd Generation (3G) mobile telecommunications technologies. In order to enhance 3rd Generation Partnership Project's (3GPP) radio interface, LTE utilizes Orthogonal Frequency Division Multiple Access (OFDMA) (Holma & Toskala, 2009). Moreover, 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 (3GPP, 2010b; Holma & Toskala, 2009).

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 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 (3GPP, 2010b). Since the MBSFN transmission greatly enhances the Signal to Interference plus 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). This is extremely beneficial at the cell edge, where transmissions (which in UMTS are considered as inter-cell interference) 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 (Holma & Toskala, 2009).

In this study, we evaluate the performance of MBSFN in terms of SE. In general, SE refers to the data rate that can be transmitted over a given bandwidth in a communication system. Several studies, such as (Rong et al., 2008), 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. Taking into account the above, 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 consider four approaches with different goals set in each one of them. More specifically:

- The 1st approach selects the MCS that ensures that all users, even those with the lowest SINR, receive the MBSFN service (Bottom Up approach).
- The 2nd approach selects the MCS that ensures the maximum SE for all users in the MBSFN area (Top Down approach).
- The 3rd approach sets a predefined SE threshold for the area and selects the MCS that ensures that the average SE over the MBSFN area exceeds this threshold (Area-Oriented approach).
- The 4th approach selects the MCS that ensures that at least the 95% of the users receive the MBSFN service with a predefined target SE (User-Oriented approach).

The remaining of the manuscript is structured as follows: the background section presents the related work in the specific field, as well as an overview of MBSFN architecture. Afterwards, we describe the methodology for calculating the SE of the MBSFN delivery scheme in the single-user case. The four approaches for selecting the MCS of an MBSFN area as well as the evaluation results are presented subsequently. Finally, the last two sections present the conclusions and the planned next steps. For the reader's convenience, appendix A presents an alphabetical list of the acronyms used in the manuscript.

BACKGROUND

Long Term Evolution

Nowadays, mobile marketplace has enabled dramatic advances and changes in telecommunications by offering bandwidth-hungry, multimedia services that previously could only be experienced in wired networks. Although 3G technologies has significantly increased the bit rates of previous mobile technologies, the plethora of mobile applications and services poses the need for deploying a resource economic scheme.

LTE, the evolution of the 3G mobile telecommunications technologies, could constitute the solution to the explosion in demand for such applications and services. LTE supports scalable carrier bandwidths and provides downlink peak rates of at least 100 Mbps, an uplink of at least 50 Mbps and round-trip times of less than 10ms. In order to enhance 3GPP's radio interface, LTE utilizes OFDMA. This radio technology is optimized to enhance networks by enabling significant new high capacity mobile broadband applications and services, while providing cost efficient ubiquitous mobile coverage (Holma & Toskala, 2009).

Moreover, LTE incorporates several key features of next generation networks. It offers low latency mobile access and implements policy enforcement and decisions at the network edge in order to improve the performance of cell-edge users. Other enhancements include the support for real-time and non-real-time applications, flexible spectrum allocations, re-use of existing cell site infrastructure and high SE performance.

In addition to the above, LTE may efficiently deliver unicast, multicast and broadcast media to the mobile users. To this direction, 3GPP has introduced the MBMS as a means to broadcast and multicast information to mobile users, with mobile TV being the main service offered. 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 usual broadcast networks (3GPP, 2010b; Holma & Toskala, 2009).

Overview of E-MBMS LTE Architecture

As depicted in Figure 1, the e-MBMS architecture is split into three domains: the User Equipment (UE) domain, the evolved UMTS Terrestrial Radio Access Network (e-UTRAN) and the Evolved Packet Core (EPC). The UE domain consists of the equipment employed by the user to access the MBSFN services. Within e-UTRAN, the evolved Node Bs (e-NBs or base stations) are the collectors of the information that has to be transmitted to users over the air-interface. The Multi-cell/multicast Coordination Entity (MCE) coordinates the transmission of synchronized signals from different cells and is responsible for the allocation of the same radio resources, used by all e-NBs in the MBSFN area for multi-cell MBMS transmissions. Besides allocation of the time / frequency radio resources, MCE is also responsible for the radio configuration e.g. the selection of the MCS (3GPP, 2010c; Holma & Toskala, 2009).

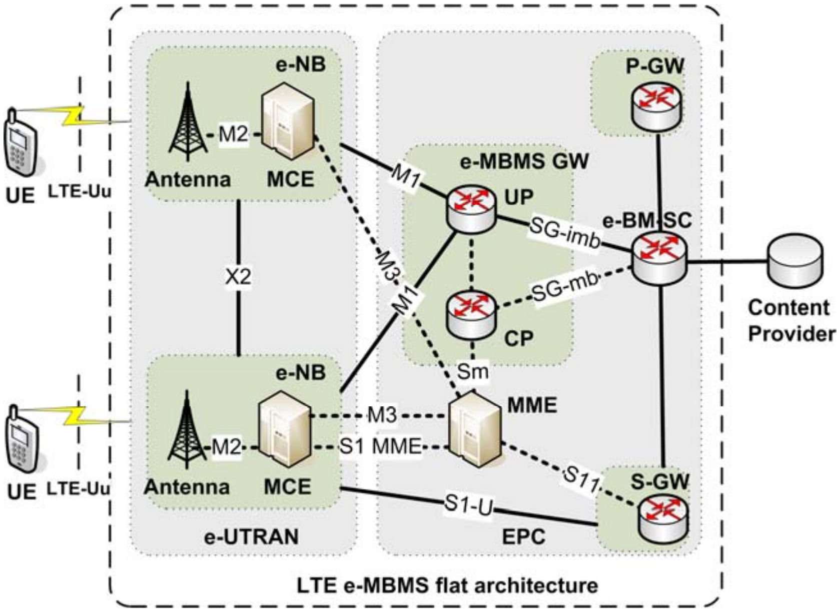

Figure 1. LTE e-MBMS flat architecture.

The EPC consists of five main nodes. These are the Mobility Management Entity (MME), the Serving Gateway (S-GW), the PDN Gateway (P-GW), the e-MBMS Gateway (e-MBMS GW) and the evolved Broadcast Multicast Service Center (e-BM-SC). The last two nodes are associated only to e-MBMS. The MME is the key control-node for the LTE access-network. All major control functionalities of LTE are executed and coordinated by this node. Among all MME functionalities the most indicative are presented below. At first, MME is responsible for the secure signaling procedure of LTE which is called Non Access Stratum (NAS) signaling. Secondly, MME controls the UE handover procedures. Furthermore, it coordinates the UE tracking, paging and polling procedures of LTE. Additionally, MME handles the UE reachabillity procedures (CONNECTED, IDLE). MME is also responsible for the authentication and authorization functions both for UEs as well as for authentication of the interconnection of LTE with external Packet Data Networks (PDNs). Another basic functionality of MME is that it controls the roaming procedures. A warning message transfer function is also implemented in MME providing in that way a more optimized selection of appropriate eNodeBs for the transmission of the data. Last but not least, MME is responsible for controlling the radio bearer management functions including dedicated bearer establishment (3GPP, 2010b; 3GPP, 2010c).

The S-GW routes and forwards user data packets, while also acting as the mobility anchor for the user plane during inter-e-NB handovers and as the anchor for mobility between LTE and other 3GPP technologies. For idle state UEs, the S-GW terminates the downlink (DL) data path and triggers paging when DL data arrives for the UE. It manages and stores UE contexts, e.g. parameters of the IP bearer service, network internal routing information. It also performs replication of the user traffic in case of lawful interception (3GPP, 2010b; 3GPP, 2010c).

The P-GW provides connectivity from the UE to external packet data networks by being the point of exit and entry of traffic for the UE. A UE may have simultaneous connectivity with more than one PGW for accessing multiple PDNs. The P-GW performs policy enforcement, packet filtering for each user, charging support, lawful Interception and packet screening. Another key role of the PGW is to act as the anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX and 3GPP2 (3GPP, 2010b; 3GPP, 2010c).

The e-MBMS GW is physically located between the e-BM-SC and e-NBs and its principal functionality is to forward the MBMS packets to each e-NB transmitting the service. Furthermore, e-MBMS GW performs MBMS Session Control Signaling (Session start/stop) towards the e-UTRAN via the MME. The e-MBMS GW is logically split into two domains. The first one is related to control plane, while the other one is related to user plane. Likewise, two distinct interfaces have been defined between e-MBMS GW and e-UTRAN namely M1 for user plane and M3 for control plane. M1 interface makes use of IP multicast protocol for the delivery of packets to e-NBs. M3 interface supports the MBMS session control signaling, e.g. for session initiation and termination. The e-BM-SC is the entity that is in charge of introducing multimedia content into the LTE network. For that purpose, the e-BM-SC serves as an entry point for content providers or any other broadcast/multicast source, which is external to the network. An e-BM-SC serves all the e-MBMS GWs in a network (3GPP, 2010b; Holma & Toskala, 2009).

Regarding the air (or LTE-Uu) interface, in MBSFN the transmission takes place from a time-synchronized set of e-NBs using the same resource block. The OFDM symbols in MBSFN contain a Cyclic Prefix (CP), which however is slightly longer than the CP used in conventional transmissions. This enables the UE to combine transmissions from different e-NBs located far away from each other (3GPP, 2007b). Moreover, MBSFN uses two logical channels (in downlink), namely Multicast Traffic Channel (MTCH) and Multicast Control Channel (MCCH). MTCH is a Point-to-Multipoint (PTM) downlink channel for transmitting data traffic to the UEs residing to the service area. On the other hand, MCCH is a PTM downlink channel used for transmitting MBMS control information from the network to UEs and is associated to one or several MTCHs. MCCH and MTCH are only used by UEs that receive MBMS traffic. Additionally, both MCCH and MTCH are mapped on the Multicast Channel (MCH), which is a transport channel at the Medium Access Control (MAC) layer. MCH is a broadcast channel that supports semi-static resource allocation e.g. with a time frame of a long CP. MCH is mapped to the Physical Multicast Channel of the physical layer (3GPP, 2009; 3GPP, 2010b).

The introduction of the MBSFN feature in the set of LTE transmission techniques has triggered a set of experiments that have been performed in the context of 3GPP and have investigated the efficiency of the radio techniques that can be employed in order to provide the MBMS services (3GPP, 2007a; 3GPP, 2007c; 3GPP, 2007d). These experiments have been conducted through network simulations and have provided useful information about the relative efficiency of different approaches for the provisioning of MBMS services. Different means to provide MBMS services have been evaluated including the following techniques:

- Point-to-Point (PTP) provisioning of MBMS services: this corresponds to mapping the MBMS service to Downlink Shared Chanel (DL-SCH) and includes the possibility to apply link adaptation and Hybrid Automatic Repeat-reQuest (ARQ).
- MBSFN-based multi-cell transmission using MCH.
- PTM provisioning of MBMS services on a per-cell basis with no UE Layer 1 feedback. RAN1 has, at this stage, not made any specific assumptions whether this corresponds to DL-SCH transmission addressing multiple UEs or single-cell MCH transmission.
- PTM provisioning of MBMS services on a per-cell basis with a possibility for Hybrid ARQ UE feedback also for point-to-multipoint transmission.
- PTM provisioning of MBMS services with interference reduction by not transmitting on neighboring cells.
- PTM provisioning of MBMS services on a per-cell basis with a possibility for UE feedback, thus enabling link adaptation and Hybrid ARQ also for point-to-multipoint transmission.

The simulation experiments have been conducted for various UE densities and geometries of the UE drop locations in the examined LTE network topology. The performance evaluation results have proved that the PTP and MBSFN-based techniques provide significant benefits over the PTM techniques in terms of spectral and resource efficiency, coverage and complexity of specification (3GPP, 2007a; 3GPP, 2007d). Additionally, the MBSFN-based multi-cell technique is able to deliver the highest data rate in the central cells of the deployments (3GPP, 2007a). It should be noted that the PTM transmission techniques have been proved efficient only in cases of low UE densities (less than 1.3 UEs/sector) (3GPP, 2007d) or when the UE's subscribing to the MBMS service in question are restricted to occupy only a single cell or a very small number of cells (3GPP, 2007a).

It is obvious that the MBSFN transmission configuration augmented by single-cell PTP or PTM configurations could provide a sufficient basis for the provision of MBMS services in LTE networks by preserving optimum spectral and resource efficiency. Therefore, in the rest of this chapter we focus on the MBSFN transmission technique, which turns to be the most popular for the provision of MBMS services. More specifically we examine the very challenging issue of MCS selection during MBSFN transmission.

RELATED WORK

The performance of MBSFN has been thoroughly examined in previous research works. However, most of these works, such as (3GPP, 2007a; 3GPP, 2007b; 3GPP, 2007d), compare the performance of MBSFN transmissions with classic PTP and PTM transmissions, in which the users are served with PTP or PTM transport channels respectively and the transmissions are executed in a per-cell basis. Additionally, these works do not consider Adaptive Modulation and Coding (AMC) in order to further improve the performance of MBSFN transmission. These works performed by 3GPP have been extended by in (Alexiou et al., 2010b) where the authors focus on the MBSFN transmission scheme and evaluate techniques for the selection of the MCS that can be utilized for the transmission of the MBSFN data. The evaluation of the techniques is performed for different users' distributions and from SE perspective. Based on the SE measurements, the most suitable technique for the corresponding users' distribution is determined.

Transmission techniques, which do not adapt to the fading channel, require a fixed link margin or coding to maintain acceptable performance in deep fades. Thus, these techniques are effectively designed for the worst-case channel conditions, resulting in insufficient utilization of the full channel capacity (Goldsmith & Chua, 1998). For better utilization of the channel capacity, AMC has been proposed in a variety of publications. For example, an adaptive variable rate variable-power transmission scheme using un-coded M-ary Quadrature Amplitude Modulation (M-QAM) was proposed in (Goldsmith & Chua, 1997). This adaptive technique is more power efficient than non-adaptive modulation in fading.

Adaptive algorithms for the OFDM system are also proposed in (Wong et al., 1999). In (Wong et al., 1999) a multi-cell, multi-user OFDM system with adaptive subcarrier allocation and adaptive modulation is considered. The specific study describes an adaptive sub-carrier, bit and power allocation algorithm to maximize the total throughput of the multi-cell system in the presence of Co-Channel Interference (CCI), frequency selective Rayleigh fading and Additive White Gaussian Noise (AWGN). For the unicast system, link adaptation is possible because the Channel Status Information (CSI) can be reported to the base-station by the terminal. Our work expands (Wong et al., 1999), by focusing on the MBSFN service, which utilizes OFDM technology.

Moreover, studies such as (Ball et al., 2008; Phan et al., 2008; Rong et al., 2008; Sheng et al., 2008) have shown that SE is directly related to the MCS selected for the transmission. In (Rong et al., 2008) the authors propose 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 the users face. On the other hand, in (Sheng et al., 2008) an adaptive MCS based on partial feedback is proposed in order to obtain the improvement of system throughput. Our work extends and completes the above studies and, furthermore, tackles the addressed problems by proposing four approaches, each one of them fulfilling different goals in terms of SE.

Finally, a cost-based approach for the evaluation of the MBSFN delivery scheme is examined in (Alexiou et al., 2010a). For the evaluation, the packet delivery cost, cost for control procedures (synchronization, polling) and scalability of the scheme are taken into account. Based on these telecommunication cost parameters, the authors calculate the total telecommunication cost required for the transmission of the MBSFN data to mobile users of a given MBSFN service. Finally, this work estimates how many neighboring cell rings should be included in the same MBSFN area and thus transmitting in the same frequency with the cells that actually contain users, in order to achieve high SFN gains with the lowest possible cost with respect to users' distribution in the topology.

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 use the following 4-step procedure (Alexiou et al., 2010c).

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 average SINR of a single user at a given point *m* is expressed as in (1) (Rong et al., 2008):

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

with:

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

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 and T_u the length of the useful signal frame.

SINR is usually calculated in OFDMA for each subcarrier and all the SINRs are combined in order to find a non-linear average SINR (effective SINR or γ_{eff}), using the Exponential Effective SIR Mapping (EESM) (Mehlfhrer et al., 2009).

$$\gamma_{eff}=EESM\left(\gamma_i,\beta\right)=-\beta\cdot\ln\left(\frac{1}{N}\cdot\sum_{i=1}^{N}e^{-\frac{SINR_i}{\beta}}\right) \tag{3}$$

where *N* is the number of subcarriers and *β* is calibrated by means of link level simulations to fit the compression function to the AWGN (Mehlfhrer et al., 2009).

However, in 3GPP LTE systems, adjacent subcarriers allocation is considered, making subcarriers allocated to one channel experiencing similar fading conditions. All subcarriers allocated to a given channel will thus experience the same fast fading and their SINR will be equal (Rong et al., 2008).

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, 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 2 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

(Mehlfhrer et al., 2009). Each MCS is mapped to a predefined CQI value. The 15 different sets of CQIs and the corresponding MCSs are defined in (3GPP, 2010a).

In LTE networks, an acceptable BLER target value should be smaller than 10% (Mehlfhrer et al., 2009). 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 2. The 10% BLER values for each CQI are depicted in Figure 3. Using the obtained line, the γ_{eff} can be mapped to a CQI value (i.e. MCS) that should be signaled to the e-NB so as to ensure the 10% BLER target.

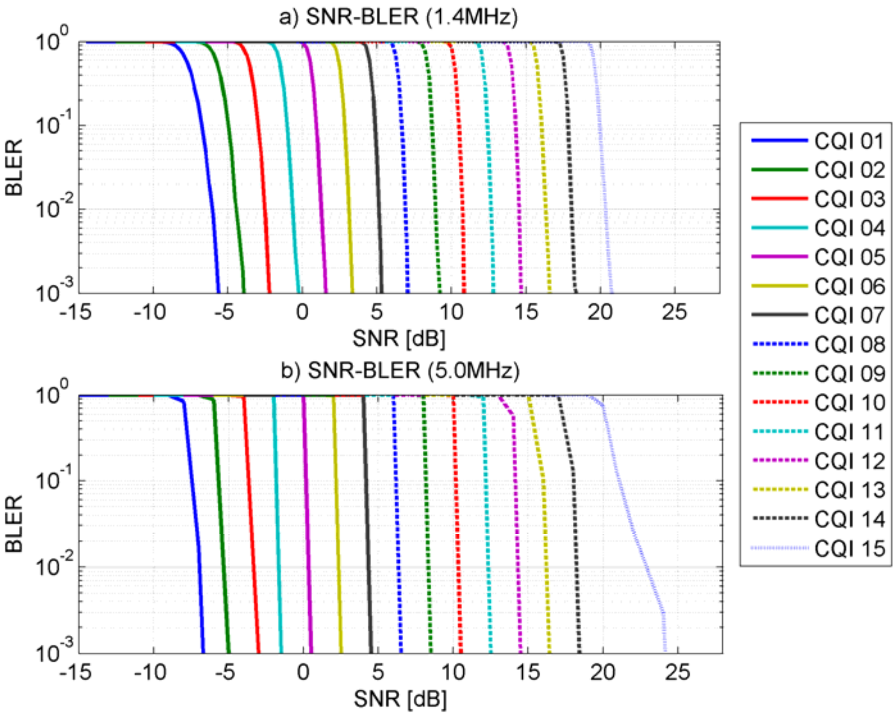

Figure 2. SNR-BLER curves obtained for: a) 1.4 MHz, b) 5.0 MHz.

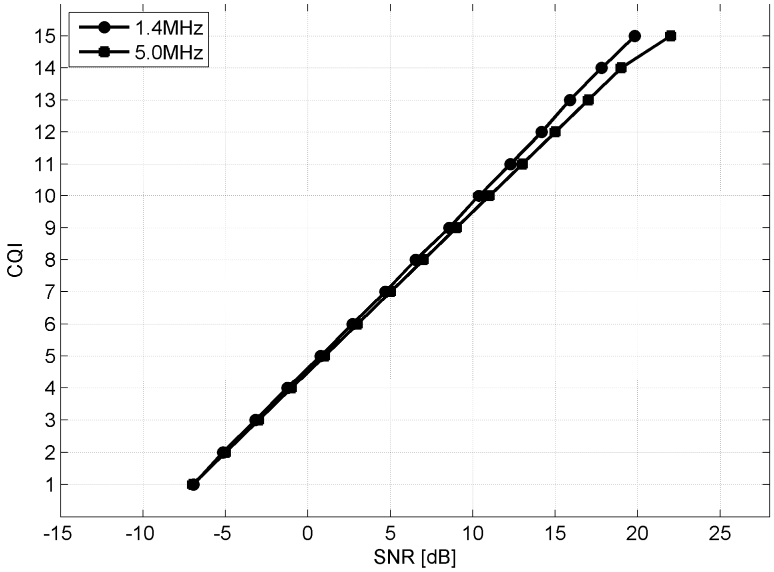

Figure 3. SINR to CQI mapping.

Step 3: Throughput Estimation

In order to estimate the achieved throughput for the selected MCS, (4) is used. In (4), *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 (Elayoubi et al., 2008).

$$Throughput = BW \cdot e(SINR) \cdot (1 - BLER(SINR)) \qquad (4)$$

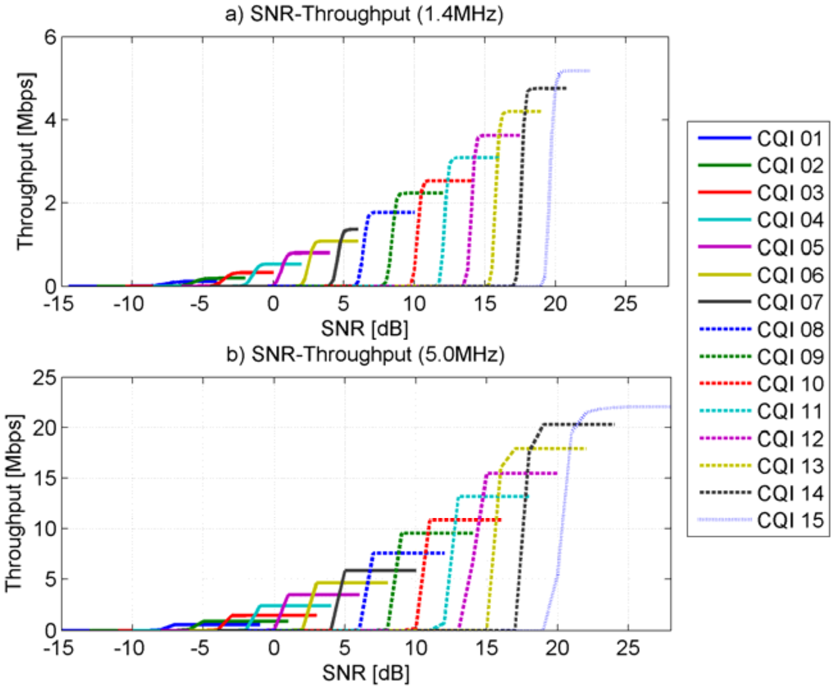

Figure 4. Throughput for all CQIs obtained for: a) 1.4 MHz, b) 5.0 MHz.

Therefore, by utilizing the SINR and MCS obtained by the SINR Calculation (Step 1) and MCS Selection (Step 2) steps respectively, the achieved throughput can be calculated. Figure 4a and Figure 4b depict the relationship between the achieved throughput and the SNR for all MCSs, as calculated from (4) for the cases of 1.4 MHz and 5.0 MHz respectively.

Step 4: Single-User 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:

$$SE = \frac{Throughput}{BW} \qquad (5)$$

To sum up, for a single user γ_{eff} is calculated from (1), (2) and (3); while the achieved SE may be obtained from (4) and (5). If, for example, the effective SINR for a random user in the topology is 5dB and the bandwidth 5.0 MHz, from Figure 3 we obtain the equivalent CQI (CQI = 7). For the specific CQI and SINR value, the throughput as obtained from Figure 4 is 6 Mbps. Therefore, the SE as calculated from (5) is 1.2 (bit/s)/Hz.

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. In general, when multiple users are located in the MBSFN area, the value of the total SE depends on the selected MCS. This section examines four approaches for the selection of the MCS during MBSFN transmissions.

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 (Figure 3). Then, from (4) or Figure 4 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 Algorithm 1 that follows:

```
Define MBSFN topology
% calculate the SINRs for all the users in the topology
FOR i = 1:total_users
    Calculate SINR(i)
END
min_SINR = min(SINR) %find the lowest 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 the obtained spectral efficiency
Calculate SE
```

Algorithm 1. Pseudo code of 1st approach.

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 4. 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. Algorithm 2 presents the operation of the 2nd approach using pseudo code.

```
Define MBSFN topology
% calculate the SINRs for all the users in the 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(:))
```

Algorithm 2. Pseudo code of 2nd approach.

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 (Rong et al., 2008). 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 4 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 4. 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 Algorithm 3:

```
Define MBSFN topology
Define area_target_SE
% calculate the SINRs for all the users in the topology
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
    % Calculate average throughput and spectral efficiency
    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
% obtained spectral efficiency
SE = SE(MCS)
```

Algorithm 3. Pseudo code of 3rd approach.

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 (Rong et al., 2008). 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 Algorithm 4.

```
Define MBSFN topology
Define user_target_SE
% calculate the SINRs for all the users in the topology
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
        % target achieved
        BREAK;
    ELSE      % target is not achieved
        SE = max(SE(:, j))
    END
END
% obtained spectral efficiency
SE = SE(MCS, j)
```

Algorithm 4. Pseudo code of 4th approach.

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 (Mehlfhrer et al., 2009). 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 Table 1.

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 (3GPP, 2010a)

Table 1. Simulation settings.

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.

Let us first consider the case of 1.4 MHz bandwidth presented in Figure 5a. 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 4 the CQI 3 is selected. Indeed, Figure 5a 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 5a).

Finally, the performance of the 3rd and 4th approach in Figure 5a 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 5b that corresponds to the case of 5.0 MHz leads to similar results.

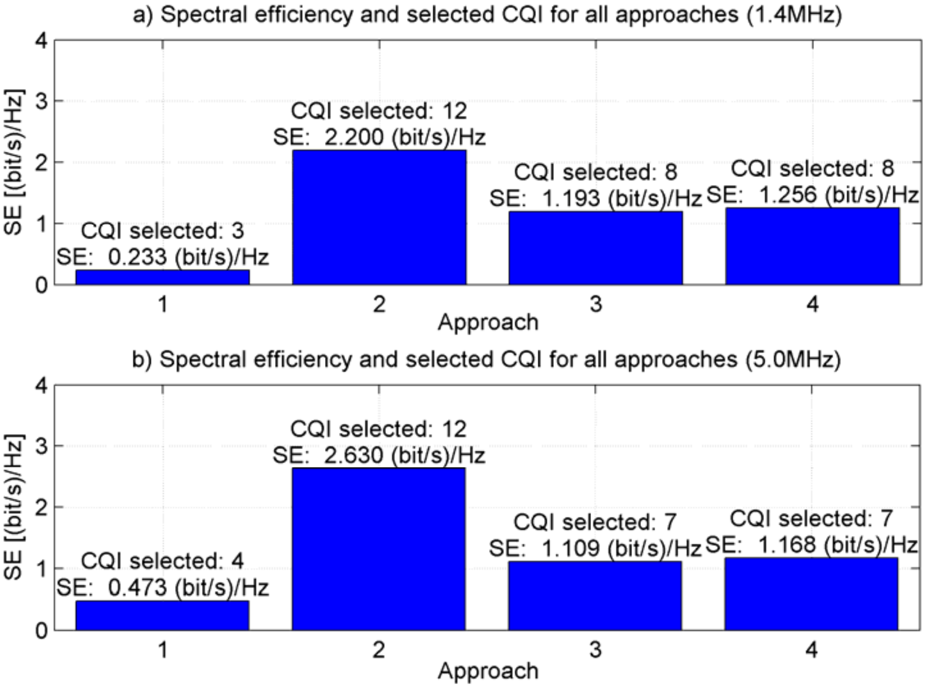

Figure 5. SE evaluation and CQI selection for predefined number of users for: a) 1.4 MHz, b) 5.0 MHz.

Scenario 2: Variable Number of Users

This paragraph presents simulation results concerning the operation of the proposed approaches for variable number of users. More specifically, Figure 6 and Figure 7 examine the performance of each approach in terms of SE and selected MCS, 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. The remaining simulation parameters are in accordance with Table 1.

As both figures present, the 1st approach achieves the lowest SE for the corresponding user population. On the other hand, the fact that this approach takes into account the lowest SINR in order to obtain the corresponding MCS 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 a potential mobility of the user with the lowest SINR could force the base station to continuously change the transmission MCS (ping-pong effect).

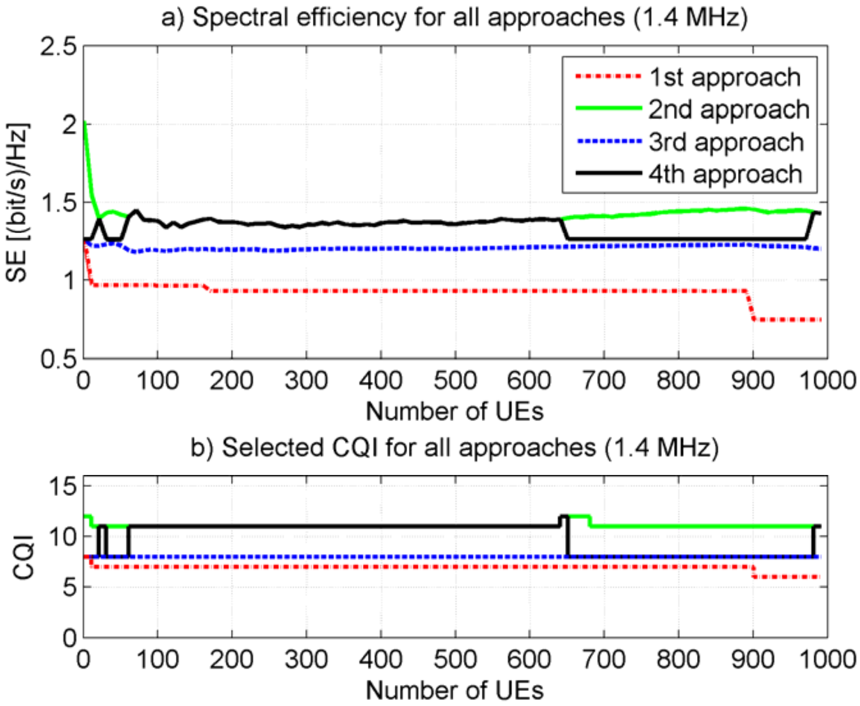

Figure 6. SE evaluation and CQI selection for variable number of users for 1.4 MHz.

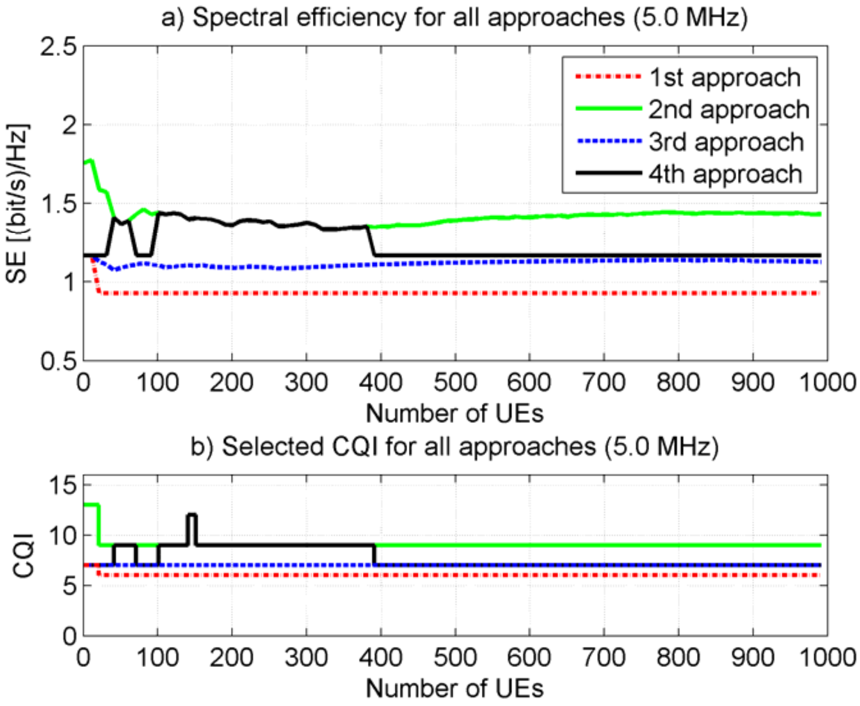

Figure 7. SE evaluation and CQI selection for variable number of users for 5.0 MHz.

As depicted in Figure 6a and Figure 7a, the 2nd approach ensures the maximum SE irrespectively of the users population. 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, we conclude that the 2nd approach tends to utilize a high MCS. As stated in (Rumney, 2009), this fact has the advantage of decreasing the users' transmit power. However, the users with bad conditions will not receive the MBMS service (see Figure 4).

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 6b (1.4 MHz) the 3rd approach utilizes CQI 8, while in Figure 7b (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 6a and Figure 7a). 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 6a and Figure 7a, 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.

To sum up, Table 2 presents a cumulative, direct comparison between the approaches analyzed in this manuscript. 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 average throughput and 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 value over the MBSFN area and minimizes the ping-pong effect in MCS selection (minimum MCS switching). Finally, the 4th approach achieves a predefined per-user SE target for at least the 95% of the users.

	Performance			
Approach	**Throughput**	**Spectral Efficiency**	**Service Provision**	**MCS Switching**
1st	Minimum	Minimum	Guaranteed	Medium
2nd	Maximum	Maximum	Not Guaranteed	Medium
3rd	Medium	Target over the area	Not Guaranteed	Minimum
4th	Medium	Target per-user	Not Guaranteed	Maximum

Table 2. Qualitative comparison of the approaches.

CONCLUSION

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 manuscript 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 scenarios that could be realized in real world such as ensuring service continuity for the user with lowest SINR value and therefore for all users in the MBSFN area, selecting the MCS that maximizes the SE, selecting the MCS based on the covered area or the percentage of the users that receive the service in an acceptable quality.

In brief, we could say that the selection of the appropriate MCS is an operator dependent issue. Different operator requirements may lead to different MCS approach selection. To that end, service continuity can be secured by employing the 1st (Bottom Up) approach, while for high demanding MBMS applications, which are targeted to users that experience optimal network and link conditions, the 2nd (Top Down) approach is the most efficient one. Additionally, ping-pong effect can be regulated by employing the 3rd (Area-Oriented) approach and simultaneously, all MBMS users are treated by the approach as equal irrespectively of the network and link conditions that they experience. Finally, the 4th (User-Oriented) approach gives the ability to the network operator to predefine both the per-user target SE and the percentage of users that will be taken into account for the calculation of the achieved SE.

To conclude, it could be mentioned that the analysis presented in this manuscript underlines that the introduction of an adaptive MCS selection algorithm for MBFSN enabled LTE networks is a prerequisite for network operators in order deploy high quality broadcast networks capable of delivering high demanding real time multimedia applications to mobile users.

FUTURE RESEARCH DIRECTIONS

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 operator needs each time. Our analysis indicates that approaches switching is possible to happen in real time. Furthermore, the combined usage of different approaches is also possible and could solve the particular inefficiencies that each approach has.

Another direction that we intent to investigate is the application of Forward Error Correction (FEC) for MBSFN transmissions in LTE networks. FEC is an error control method that can be used to augment or replace other methods for reliable data transmission. The main attribute of FEC schemes is that the sender adds redundant information in the messages transmitted to the receiver. This information allows the receiver to reconstruct the source data. Such schemes inevitably add a constant overhead in the transmitted data and are computationally expensive. This additional communication cost will be calculated and based on this; the efficiency of FEC use in different scenarios will be evaluated.

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APPENDIX A - ACRONYMS

Acronym	Explanation
3GPP	3rd Generation Partnership Project
AMC	Adaptive Modulation and Coding
AWGN	Additive White Gaussian Noise
BLER	Block Error Rate
CCI	Co-Channel Interference
CP	Cyclic Prefix
CQI	Channel Quality Indicators
CSI	Channel Status Information
e-BM-SC	evolved Broadcast Multicast Service Center
ECR	Effective Code Rate
EESM	Exponential Effective SIR Mapping
e-MBMS	evolved MBMS
e-MBMS GW	e-MBMS Gateway
e-NBs	evolved Node Bs
EPC	Evolved Packet Core
e-UTRAN	evolved UMTS Terrestrial Radio Access Network
FEC	Forward Error Correction
HARQ	Hybrid Automatic Repeat Request
ISD	Inter Site Distance
LTE	Long Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast/Multicast Service
MBSFN	MBMS over Single Frequency Network
MCCH	Multicast Control Channel
MCE	Multi-cell/multicast Coordination Entity
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MME	Mobility Management Entity
M-QAM	M-ary Quadrature Amplitude Modulation
MTCH	Multicast Traffic Channel
OFDMA	Orthogonal Frequency Division Multiple Access
PTM	Point-to-Multipoint
PTP	Point-to-Point
SE	Spectral Efficiency
SINR	Signal to Interference plus Noise Ratio
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

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KEY TERMS & DEFINITIONS

AMC: A link adaptation method that raises the overall system capacity and provides the flexibility to match the MCS to the average channel conditions.

LTE: The evolution of the 3G mobile telecommunications technologies.

MBMS: A service introduced by 3GPP to broadcast and multicast information to mobile users, with mobile TV being the main feature offered.

MBSFN: A transmission scheme where data are transmitted simultaneously over the air from multiple tightly time-synchronized cells.

MBSFN area: A group of time-synchronized cells which are targeted to receive the MBSFN data.

MCS selection: The procedure of selecting the appropriate MCS in order to make an efficient use of the air interface.

SE: 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.