A novel adaptive modulation and coding strategy based on partial feedback for enhanced MBMS network

Abstract The difference in link condition of broadcast/multicast users and the limitation of uplink resource, make it difficult to utilize adaptive modulation and coding (AMC) in the enhanced multimedia broadcast and multicast service (E-MBMS) network. To obtain the improvement of system throughput, this study proposes an adaptive modulation and coding scheme based on partial feedback, by which only partial users whose channel qualities are lower than the system threshold need to make a response to the modulation coding scheme (MCS) adaptation procedure. By this investigation, an adaptive scheme can be introduced in the E-MBMS network. Both the theoretical analysis and simulation results demonstrate the efficiency of the proposed strategy, in which the performance is close to the ideal one and has a significant throughput improvement when compared with that of the fixed MCS transmission scheme.

Keywords E-MBMS, partial feedback, AMC, system throughput

1 Introduction

Multimedia broadcast and multicast service (MBMS) is an important part of the universal mobile telecommunications system (UMTS) terrestrial radio access network (UTRAN) evolution [1]. The MBMS feature, introduced by the Third generation partnership project (3GPP) in release 6 is proposed to use network and radio resources more efficiently for transmission of multimedia services, both in the core network and more importantly in the air interface of UTRAN, where the bottleneck is placed to a large group of users. The physical layer in 3GPP long term evolution (LTE) can improve the transmission capacity significantly. To reduce the complexity of the system, the MBMS architecture in E-UTRA/E-UTRAN has been modified to the enhanced MBMS, in Refs. [2, 3]. In the enhanced MBMS (E-MBMS), the higher spectrum-efficient transmission scheme should be exploited.

Adaptive modulation and coding is a good scheme for improvement of spectrum-efficiency [4–7]. In addition, for the orthogonal frequency division multiplexing (OFDM) system, adaptive algorithms are also proposed in Ref. [8]. For the unicast system, link adaptation is possible because the channel status information (CSI) can be reported to the base-station (BS) by the terminal. However, for the broadcast/multicast system, the MCS adaptation mechanism involves a network response based on feedback from more than one terminal, and the network response cannot be precisely tailored to the feedback. Generally, this is because of the fact that the network receives a wide range of feedback from different terminals and more collision would happen between terminals if the uplink resource is limited. Consequently, the traditional AMC scheme is difficult to utilize in a broadcast/multicast system.

The counting procedure is defined by 3GPP, to estimate the number of MBMS users in target cells. In this article, the authors have proposed a novel AMC strategy based on partial feedback mechanism for E-MBMS, which is similar to a counting method and only needs partial terminals whose channel quality is lower than the system threshold’s response to the MCS procedure. Thus, the system will change the MCS level according to the partial feedback information, to utilize link adaptation. By the authors’ investigation, the uplink resource can be saved and only a slight collision would happen between terminals. Therefore, MCS adaptation can be used in the E-MBMS architecture when the uplink issue is resolved, as the total throughput can also be improved when compared with the fixed MCS mechanism.

The rest of this article is organized as follows. Section 2 describes the proposed AMC strategy based on partial feedback for the E-MBMS network. Section 3 analyzes the theoretical throughput of the stationary state in flat channel conditions. Simulation results and performance comparisons are done in Sect. 4. The article is concluded in Sect. 5.
2 AMC strategy based on partial feedback for E-MBMS

2.1 Transmission modes for E-MBMS

For E-MBMS, there are two types of transmission modes described in Ref. [2]: Single-cell transmission and multi-cell transmission. Single-cell transmission is where one cell transmits MBMS data only to local camping terminals, and the tight, synchronous character between neighbor cells is not required. Unlike single-cell transmission, multi-cell transmission requires that multicells transmit the same contents on the same frequency bandwidth simultaneously such as in the single frequency network (SFN). The signals from multicells will combine in air, and under this transmission mode, the tight, synchronous character is required.

MCS adaptation could be applied for both single-cell and multi-cell transmission. However, it should be more useful for single-cell MBMS. This is because, in the case of the multicells, co-ordination of the MCS within the SFN area is required. Moreover, because of the absence of performance benefits from multicells combining, the single-cell MBMS service is expected to have a higher packet error rate than the multi-cell MBMS service, especially at the cell edge.

2.2 Counting-like partial feedback implementation

It is difficult for broadcast/multicast users to return all their channel quality information. Therefore, the method which is similar to the counting procedure in R6 MBMS is used in this investigation.

MBMS counting is used to determine the optimum transmission mechanism (point to point, point to multipoint) for a given MBMS service [1]. Users who receive this service at the same time are called a “group”. Then in the broad sense, it seems to transmit the current service in a point to point mode. And the proposed strategy is applied to one given service and its receiving group. As it is desirable to avoid bringing a large number of terminals for counting purposes at the same time when the uplink resource is limited, some radio resource management (RRM) procedures may be taken, such as, setting an access probability factor (PF). Then the MBMS users decide whether to send the uplink response to the BS or not, according to the PF value.

On the basis of the counting-like method, the partial feedback function can be implemented.

At the BS side, one initial NACK probability factor $P_{\text{NACK}}$, which makes some users whose receive quality is lower than the target threshold, respond to the AMC procedure, which is set and sent to all MBMS users through MBMS control channel (MCCH), similar to Ref. [9].

$$P_{\text{NACK}} = \frac{M_{\text{UL idle}}}{N_{\text{est}}}$$

Here, $\alpha$ is the nonoverload factor, which is used to reduce the probability of vast users, to make responses at the same time, generally $0 < \alpha \leq 1$. And $M_{\text{UL idle}}$ is the number of available uplink channels in the current system. $N_{\text{est}}$ is an estimation value for the number of total users who are receiving the current MBMS service.

It is assumed that if the number of users who respond to this procedure is $n_{\text{NACK}}$, then the system can estimate the number of the users who are not satisfied with the current MCS level as $N_{\text{NACK}}$, according to the number of reported users $n_{\text{NACK}}$ and the PF value as $P_{\text{NACK}}$.

$$N_{\text{NACK}} = \frac{n_{\text{NACK}}}{P_{\text{NACK}}}$$

For the accuracy of estimation, the subprocedures should be taken into account and the $P_{\text{NACK}}^k$ for the $k$th subprocedure is set according to the last $N_{\text{NACK}}$ as follows:

$$P_{\text{NACK}}^k = \alpha \frac{M_{\text{UL idle}}}{N_{\text{NACK}}^k} = \alpha \frac{M_{\text{UL idle}}}{n_{\text{NACK}}^{k+1}}$$

The detailed counting procedure should be referenced to Ref. [1]. According to it, the uplink collision can be avoided if the system can get the information about the approximate number of users who are not satisfied with the current MCS level.

The system model is shown as Fig. 1. Comparing it with the traditional unicast system, it is different, in that, there is not only one user to receive the signal coming from the transmitter. When the MBMS service transmission starts, the user would decide whether to send the failing receiving notification NACK to BS or not, according to the $P_{\text{NACK}}$, which is sent by BS on MCCH.

2.3 MCS determination mechanism for E-MBMS

The procedure of MCS determination in this article is described in Fig. 2. Before the MBMS service transmission starts, the network side initializes the system parameters and sends them to the user equipments (UEs). The initial MCS level is also set. After the radio access network (RAN) resource is set up, the UE should decide on the signal to interference and noise ratio (SINR) and perform the probability test if its receiving SINR is lower than the threshold. Then, NACK is sent to the network by UEs who pass this test. Finally, the MCS level is adjusted according to the detection of negative acknowledgment (NACK).
Fig. 1 System model

The detailed flow is shown in Fig. 3. Thresholds of SINRs are introduced to decide if the users can get to their satisfied status or not, in the relevant MCS levels. The initial NACK probability factor $P_{\text{NACK}}$ is also set, and for avoiding fluctuation, a setting step length $\Delta$ is necessary here, to make the rate of the MCS change in moderation. $K_{\text{sub}}$ is the maximal subprocedure number.

During the MBMS transmission, the user should estimate the effective SINR and compare it with the threshold. It is clear that the user cannot receive data packets correctly and should not be satisfied with the current MCS level when the SINR is below the threshold. Therefore, they perform a probability test according to $P_{\text{NACK}}$, to decide if they should respond to the AMC procedure or not, by sending NACK information.

Here, the initial $N_{\text{est}}$ may not be precise and generally it is set over-large. Consequently, there would not be any user to make a response to the network and users should wait for the next probability iteration when the PF is set larger, just like in subcounting. It can be considered that all the users in this MBMS service group are satisfied with the current MCS level when the value of PF is set at one.

Subsequently, after the $K_{\text{sub}}$ subprocedures are complete, BS can get the number of users who have responded to the current AMC procedure. The network will set a less aggressive MCS level in the next data frame when it detects the NACK notification sent by some user. Otherwise, if the network does not receive any response when the highest probability factor (typically $PF = 1$) is used, it should switch to a more aggressive MCS level.

Here, $\Delta$, which stands for the step length in the adjustment procedure, is set, to avoid altering too fast for MCS levels and the authors set $0 < \Delta < 1$.
3 Stationary state performance analysis

In this section, the authors analyze the performance of the proposed strategy according to Ref. [10], when it comes into a stationary state. Actually, there are finite MCS modes to be selected in this system, and the authors let the set \( \Omega = \{1, 2, ..., M\} \) stand for them. Here, it is assumed that the number of available MCS levels is \( M \). The MCS level of the \( i \)th subframe is denoted as \( L_{MCS}(i) \in \Omega \). In this study, a real variable \( x_i (x_i \in R) \) is defined, to adjust the MCS level with a fine step length \( \Delta \), and for simplification of analysis, a function \( F() : x \rightarrow L_{MCS}, \ (x \in R, L_{MCS} \in \Omega) \) is also needed, which can convert \( x \) into \( L_{MCS} \). Thus, the definition can be written as follows:

\[
L_{MCS}(i) = F(x_i) = \begin{cases} 
1; & x_i < 1 \\
[x_i]; & \text{other} \\
M; & x_i \geq M + 1 
\end{cases}
\]  

\[
(4)
\]

where \([\cdot]\) denotes getting the integer of the variable. According to the earlier-mentioned algorithm, the MCS level can be adjusted using a deduced method, according to the number of reported users \( n_{\text{NACK}} \).

\[
x_{i+1} = \begin{cases} 
x_i + \eta \Delta; & n_{\text{NACK}} = 0 \\
x_i - n_{\text{NACK}} \Delta; & n_{\text{NACK}} > 0, x_i - n_{\text{NACK}} \Delta \geq L_{MCS}(i) \\
\max\{1, L_{MCS}(i) - 1\}; & n_{\text{NACK}} > 0, x_i - n_{\text{NACK}} \Delta < L_{MCS}(i)
\end{cases} 
\]  

\[
(5)
\]

In Eq. (5), the effective steps are \( \eta \Delta \) and \( n_{\text{NACK}} \Delta \) in the up-forward direction and down-forward direction respectively. Therefore, in the proposed strategy, the value of \( \Delta \) should not be over-high. \( \eta \) is used to balance the speed of adjustment between the up-forward direction and the down-forward direction. The MCS level \( L_{MCS}(i+1) \) of the \( (i+1) \)th data frame should be decided based on function \( F(x_{i+1}) \), and \( x_{i+1} \) can be attained according to Eq. (5).

In this investigation, the authors focus on analyzing the throughput of the proposed strategy, comparing it with that of the ideal one. Here, the term “ideal” denotes the channel...
information of all broadcast/multicast users known by the network, whereas, it is difficult to realize in the current system. $L_{\text{MCS}}^n$ is used to express $L_{\text{MCS}} = n \ (n \in \Omega)$ and for the idealization pilot SINR assistance method with exact feedback, once the MCS level ($L_{\text{MCS}}$) is assigned to the region $[T_{n-1}, T_n]$, when one user’s pilot measurement report CSI falls into region $[T_{\text{ini}}, T_{n}]$, the user should notify BS, and transmit the data with $L_{\text{MCS}}^n$. Here, $T_{n-1}$ is the threshold of the SINR regions between $L_{\text{MCS}}^{n-1}$ and $L_{\text{MCS}}^n$, and $T_n$ is the threshold between $L_{\text{MCS}}^n$ and $L_{\text{MCS}}^{n+1}$. In this section, only the difference of throughput performance is considered between the proposed strategy and the ideal AMC mechanism.

For each $L_{\text{MCS}}^n \in \Omega$, there is a relevant throughput $\gamma_n$ (bit/symbol). It is assumed that the SINR of the current frame, which is received by the terminal, is $\chi$, and for the ideal scheme, the value of $\chi$ is known by BS. Accordingly, the optimal MCS level for the current frame can be selected as follows:

$$L_{\text{MCS}}^{\text{opt}} = L_{\text{MCS}}^n \quad T_{n-1} < \chi < T_n \quad \text{(6)}$$

Here, in the broadcast/multicast case, $\chi$ can be set to the mean SINR received by users who are receiving the same MBMS service, and then the $L_{\text{MCS}}^{\text{opt}}$ is assumed to be the optimal MCS level for this group of users. And then, the system throughput is $\gamma = \gamma_{\text{opt}}$, which is in the current MCS level $L_{\text{MCS}}^{\text{opt}}$. Here, the authors do not consider retransmission of the data packet when it could not be decoded correctly.

In the proposed strategy, BS cannot select the optimal MCS level immediately and it needs several steps to get to $L_{\text{MCS}}^{\text{opt}}$.

$L_{\text{MCS}}^{\text{ini}}$ is denoted as the initial MCS level before the MBMS service transmission starts and there are two conditions to be discussed:

If $L_{\text{MCS}}^{\text{ini}} < L_{\text{MCS}}^{\text{opt}}$

Then BS should increase the MCS level according to setting the step length and the direction is

$$L_{\text{MCS}} : \text{from } L_{\text{MCS}}^{\text{ini}} \text{ ascending} \rightarrow L_{\text{MCS}}^{\text{opt}} \quad \text{(7)}$$

It should be noted that the real variable $x$ need not to be changed when the probability factor $P_{\text{NACK}}$ is increased to the maximal value, to simplify the analysis. Therefore, only one step is considered after $P_{\text{NACK}}$ is set to one.

If $L_{\text{MCS}}^{\text{ini}} > L_{\text{MCS}}^{\text{opt}}$

With the same deduction as in condition (a), BS should decrease the MCS level and the direction is

$$L_{\text{MCS}} : \text{from } L_{\text{MCS}}^{\text{ini}} \text{ descending} \rightarrow L_{\text{MCS}}^{\text{opt}} \quad \text{(8)}$$

Then it should get to $L_{\text{MCS}}^{\text{opt}}$ in at most $S_x$ steps. And it can be denoted that

$$S_x = \frac{0.5 - L_{\text{MCS}}^{\text{ini}}}{\eta_x} + \left(L_{\text{MCS}}^{\text{opt}} - L_{\text{MCS}}^{\text{ini}} - 1\right) \quad \text{(9)}$$

According to Eq. (5), it can be seen that it is different with the ideal scheme, where the MCS level status of the proposed strategy should transit two modes periodically between $L_{\text{MCS}}^{\text{opt}}$ and $L_{\text{MCS}}^{\text{opt}} + 1$, when it comes into convergence as shown as Fig. 4.

In Fig. 4, $\rho = 1/\eta_x$ and a simple conclusion can be drawn that the period of stationary state is $1 + \rho$. Consequently, the system throughput can be expressed as follows:

$$\bar{\gamma} = \frac{\gamma_{\text{opt}}}{1 + \rho} \quad \text{(10)}$$

From Eq. (9), it can be seen that the system throughput of the proposed strategy is close to $\gamma_{\text{opt}}$, which is the throughput of the ideal one when $\Delta$ is reduced. However, the value of $\Delta$ cannot be set over-low because of the pace of convergence. Tradeoff should be considered during simulation.

4 Simulation and analysis

It is assumed that there are four different modulations available and the coding status in the simulation system is as shown in Table 1.

<table>
<thead>
<tr>
<th>MCS level</th>
<th>Modulation type</th>
<th>Turbo coding rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QPSK</td>
<td>1/2</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>3/4</td>
</tr>
<tr>
<td>3</td>
<td>16QAM</td>
<td>1/2</td>
</tr>
<tr>
<td>4</td>
<td>16QAM</td>
<td>3/4</td>
</tr>
</tbody>
</table>

Simulation is performed under the assumptions as follows: the multipath channel is a Rayleigh channel with the exponential fading gain profile. The number of subcarriers is 128 and the received SINR can be calculated according to Eq. (10).

$$\text{SINR} = \left| x \right|^2 \times \text{SINR}_{\text{avg}} \quad \text{(10)}$$
Here, $\alpha$ is the channel fading value and $\text{SINR}_{\text{avg}}$ is the predefined SINR. A summary of the simulation parameters is given in Table 2 a little later in the text. Here, because of point-to-multipoint transmission, the optimal MCS level cannot be set according to some user’s SINR. In MBMS, all users who receive the same service can be regarded as a whole “group” and it is assumed that all SINRs of this user-group are known by BS. The $\text{SINR}_{\text{avg}}$ is set according to all users’ SINRs in this group. Therefore, the optimal MCS level in this study, for the current MBMS service transmission can be decided according to $\text{SINR}_{\text{avg}}$. The system throughput (bits/symbol) of the ideal scheme and proposed strategy are compared in this investigation as shown as Fig. 5 and Fig. 6.

**Table 2** Simulation parameters and assumptions

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propagation conditions</td>
<td>3-Path rayleigh</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>3 km/h</td>
</tr>
<tr>
<td>Subcarrier number</td>
<td>128</td>
</tr>
<tr>
<td>Channel estimation</td>
<td>Ideal channel estimation</td>
</tr>
<tr>
<td>Available MCS levels</td>
<td>1/2 QPSK, 3/4 QPSK; 1/2 16 QAM, 3/4 64 QAM</td>
</tr>
<tr>
<td>MCS update period</td>
<td>1 frame</td>
</tr>
<tr>
<td>MCS control delay</td>
<td>0</td>
</tr>
<tr>
<td>HARQ</td>
<td>Yes</td>
</tr>
<tr>
<td>Simulation time</td>
<td>5 000 packets per SINR value</td>
</tr>
<tr>
<td>Number of MBMS users</td>
<td>10–300</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>0.1, 0.2, 0.4</td>
</tr>
</tbody>
</table>

Figure 5 shows the comparison of system throughput for six conditions, which are, the ideal one, proposed strategy, and four fixed MCS modes. Because of multiusers receiving one MBMS service at the same time, the system throughput is replaced by “mean throughput” of all the group users. The adaptive scheme, based on partial feedback mechanism, can track the receipt quality of the group users who are receiving the current MBMS service. Consequently, the performance of the proposed one is better than that of the fixed MCS modes. However, not all the users’ SINRs are known to the BS, hence, the performance of this scheme can only be close to the ideal one, but not get better than it.

Figure 6 shows the difference of the proposed strategy performance when the step length $\Delta$ is changed. It can be seen that the performance of $\Delta=0.1$ is closest to the ideal one and when $\Delta=0.4$, the performance of the proposed method begins to fall.

The collision probability of partial feedback mechanism based on counting-like method in MBMS architecture is also presented in this investigation, as shown as Fig. 7. For the broadcast/multicast system, the MCS adaptation mechanism involves a network response, based on feedback from more than one terminal. By introduction of partial feedback, the collision can be reduced efficiently when the resource from the uplink is limited. In Fig. 7, it is assumed that the number of available uplink channels is 5, 8, and 10 respectively. The collision probability increases obviously when the uplink resource is in scarcity, such as, $M_{\text{UL}, \text{idle}} = 5$, which stands for the number of available uplink channels. When $M_{\text{UL}, \text{idle}}$ gets to 10, the probability falls to about 10% and it can also decrease it by setting a nonoverload factor $\alpha$ in Eq. (1).

Figure 8 shows the probability distribution function (PDF) of the subprocedure in one AMC response. From this figure, it is found that more than 90% of the AMC response procedures can be completed in the first two subprocedure steps. It is helpful to reduce the time delay of the partial feedback procedure in the actual system.
Conclusions

For broadcast/multicast system, it is difficult to utilize the AMC mechanism because the adaptation procedure involves vast network responses from more than one terminal and the channel status cannot be precisely tracked. In this study, a novel AMC strategy based on partial feedback is presented to the E-MBMS network, by which, only partial users whose channel qualities are lower than the system threshold need to respond to the procedure. The collision probability is reduced efficiently by counting-like partial feedback when the uplink resource is limited and according to the theoretical analysis and simulation results, the performance of the proposed strategy is close to the ideal one, as the system throughput is significantly improved compared to that of the fixed MCS E-MBMS transmission, without adaptive mechanism.

Acknowledgements This work is supported by the National Natural Science Foundation of China (60572120), the Hi-Tech Research and Development Program of China (2006AA01Z257).

References

1. Introduction of the multimedia broadcast multicast service (MBMS) in the radio access network (RAN)- Stage 2. 3GPP TS 25.346 V7.2.0, 2006
2. Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN). 3GPP TR 25.813 V7.1.0, 2006

Biographies: SHENG Yu, male, Beijing University of Posts and Telecommunications, Ph. D. Candidate, interested in the research on wireless broadcasting and resource scheduling algorithm.

PENG Mu-gen, Beijing University of Posts and Telecommunications, Ph. D., instructor, interested in the research on wireless communication 3G/B3G system and radio resource scheduling.

WANG Wen-bo, Beijing University of Posts and Telecommunications, professor and doctor supervisor, interested in the research on signal processing, mobile communications and wireless Ad-hoc network.