Channel-Aware Frequency Domain Packet Scheduling for MBMS in LTE

Shan Lu (1), Yi Cai (1), Li Zhang (1), Jike Li (1), Peter Skov (2), Chunye Wang (2), Zhiqiang He (1)

(1) Information Theory and Technology Center
Beijing University of Posts and Telecommunications
Beijing, China

(2) Nokia Siemens Networks R&D
Beijing, China

Abstract—Multimedia Broadcast/Multicast Service (MBMS) provides efficient solution for multimedia broadcasting services by distributing resources among a group of subscribers. Different from previous broadcasting services, MBMS subscribers will send feedback information which can be used to improve system performance by adapting resource allocation to channel state.

In this paper in LTE frameworks we propose a Frequency Domain Packet Scheduling (FDPS) algorithm for MBMS, in which resource blocks are dynamically allocated to MBMS based on knowledge of instantaneous channel condition. The objective is to optimize system throughput performance while guaranteeing system coverage. This paper examines the algorithm in details with different (Channel Quality Indicator) CQI reporting modes, alterable frequency bandwidth for MBMS and different numbers of MBMS subscribers per sector. Simulations show that comparing to a simple blind FDPS algorithm, the proposed algorithm improves system throughput without sacrificing coverage.

I. INTRODUCTION

Multimedia Broadcast/Multicast Service (MBMS) is introduced by 3GPP in Release 6 to provide high-speed multimedia broadcasting service and efficient information distribution solution by delivering data from one single source to multiple terminals [1][2]. Two single-cell transmission modes are available for MBMS: point-to-point (PtP) transmission through dedicated channel and point-to-multipoint (PtM) transmission through common channel. In PtM mode, a group of MBMS subscribers listen to a common channel. They share same time and frequency resources, as well as same modulation and coding selection (MCS). This implies that in order to fulfill Quality of Service (QoS) requirements MCS has to be adjusted to the weakest terminal of a subscription group. And in case Hybrid ARQ (HARQ) is enabled, retransmission will be triggered once Negative Acknowledgement (NACK) is reported by any of the subscribers. So the system performance of PtM mode MBMS is largely limited by the subscriber with worst channel condition.

With feedback channel state information (CSI), dynamic resource allocation is feasible strategy to make full use of frequency-selective attenuation to achieve higher performance. In this paper we focus on dynamic scheduling algorithm to enhance system throughput of PtM mode MBMS in LTE frameworks where Orthogonal Frequency Division Multiplexing (OFDM) is adopted as downlink modulation scheme. FDPS algorithms based on PtP transmission [3][4] are not directly applicable for PtM transmission because of the special characteristics of HARQ and link adaptation methods in PtM transmission mentioned in the foregoing paragraph. We propose a channel-aware FDPS algorithm, i.e. dynamical scheduling algorithm based on channel acquaintance. Different from PtP resource allocation algorithms based on single user, in PtM transmission subscribers should be considered as a group and the key point of the proposed algorithm is to improve channel condition of the weakest terminal by exploiting channel diversity of frequency-selective attenuation.

Performance of proposed algorithm is evaluated in terms of both system throughput gain and coverage gain. Here coverage is defined as the fraction of users with BLER (Block-Error Rate) less than the BLER target. We consider cases with relatively large number of MBMS subscribers (no less than 10) per sector.

This work is supported by the National Basic Research Program of China (973 Program) 2007CB310604 & 2009CB320401, and the National Natural Science Foundation of China 60772108 & 60702048.
Simulations show that the algorithm achieves more than 32% gain in system throughput with similar coverage compared to a simple blind FDPS algorithm. However, system throughput gain decreases with the increase of frequency bandwidth allocated to MBMS and the increase of MBMS subscribers per sector.

The organization of this paper is as follows. The proposed FDPS algorithm is specified in section II. Section III lays out system model and simulation assumptions we use to evaluate this algorithm, while section IV contains major simulation results and related discussions. Finally, conclusions are presented in the section V.

II. CHANNEL-AWARE FDPS FOR MBMS

The interactions between packet scheduler (PS) and other main entities, i.e., HARQ manager, link adaptation (LA), and Channel Quality Indicator (CQI) manager on Base Station (BS) side, as well as CQI formatting on User Equipment (UE) side are illustrated in Figure I.

**HARQ manager.** According to ACK/NACK feedbacks from users and hard limit on the maximum number of retransmissions, HARQ manager makes the decision of retransmission. In PtM mode MBMS individual retransmission is not admitted, so retransmission will be operated for the group of MBMS subscribers whenever any of them feeds back NACK.

**Link Adaptation.** LA contains two major function entities: adaptive modulation coding (AMC) and outer loop link adaptation (OLLA). OLLA stabilizes first BLER performance by adjusting feedback CQI value. It plays important part in guaranteeing coverage especially when users move in high speed. And it can also perform trade-off between coverage and throughput. In our simulation OLLA is disabled to simplify the analysis. Fast AMC with CQI input is adopted in our simulation. MCS is shared by MBMS subscription group, and it is adjusted to the weakest terminal to fulfill the QoS requirements.

**CQI formatting.** The accuracy and resolution of CQI feedback have important influence on the efficiency of AMC and scheduling entities. In economic point of view it is not feasible for terminals to report ideal CQI, for uplink payload will be heavy. Many algorithms aiming at reducing feedback information have been studied in [7]. In this paper we adopt both full reporting metric and “Best M and offset” CQI formatting metric the framework of which is illustrated in Figure 2. On terminal side $V_i$ ($i = 1, \ldots, N$) indicates the measured CQI value on $i$th sub-band; here sub-band size is two physical resource blocks (PRB). In full reporting mode CQI values are reported to the BS without predigestion. In Best M scheme a bitmask is used to indicate the “best” sub-bands. So in a bit mask of length $N$, $M$ sub-bands ($M \leq N$) with highest CQI values will be marked by “1” and the other worse ones are marked by “0”.

$$V_{\text{mean\_Best\_M}} = \sum_{i=1}^{M} V_i / M$$

$V_{\text{mean\_Best\_M}}$ in (1) indicates the mean value of the M best CQI values.

On the BS side, for each user the sub-bands marked by “1” will be signed the CQI value $V_{\text{mean\_Best\_M}}$ and the CQI groups marked by “0” will be evaluated by $V_{\text{mean\_Best\_M}}$ minus an offset (BS parameter).

**Packet scheduler.** Here the packet scheduler operates in both time and frequency domain. In time domain (TD) MBMS is to be scheduled every Transmission Time Interval (TTI), for either transmission or retransmission, which means that all MBMS subscribers will be scheduled every TTI. In frequency domain (FD) PS schedules MBMS on different frequency bands according to CQI. Our simulation is based on LTE frameworks where OFDM is adopted as downlink modulation scheme. The basic unit of FDPS is physical resource block (PRB) which contains 12 neighboring sub-carriers. The proposed FDPS algorithm is based on the assumption that all users in a sector are MBMS subscribers and belongs to the same group, indicating no consideration of multiplexing among different MBMS groups or different services, or the issue of fairness.

A. Channel-aware FDPS for PtM mode MBMS

The objective of proposed FDPS algorithm is to maximize system throughput with acceptable loss of coverage. As in the context of PtM mode MBMS system throughput is limited by the weakest terminal in a group, the problem turns into optimizing the channel quality of it. In the proposed algorithm, channel quality is measured by throughput, i.e. bit rate. “Max-Min” principle is applicable here, in different dimension from the fairness purpose as in [5]. However, frequency-selective fading on frequency band combined with mutual independence of fading parameters for different users, makes the problem more complicated, because the worst user on different PRBs may not be the same one. So the proposed FDPS algorithm is based on PRBs rather than users, and the scheduling problem can be formulated as the following optimization problem:

$$\max \{ \min \{ R_d \} \}.$$
In (2) \(i\) and \(j\) indicate PRB # and user # respectively, and \(R_j\) is the performance metric of \(j\)th user on \(i\)th PRB. As our aim is to maximize throughput, here we use the estimated throughput for this metric, that is, \(R_j\) is the throughput of user \(j\) on \(i\) th PRB, calculated according to the associated CQI feedback. The proposed algorithm is realized in two steps:

**Step I:** \(\text{Min}(R_j)\) - For each PRB, determine the user with least throughput on it and mark the PRB with this worst-user throughput.

**Step II:** \(\text{Max}\{\text{Min}(R_j)\}\) - Out of all available PRBs find the ones on which the worst-user throughput is the best.

One thing to notice is that when user number per sector is relatively large, there may be a set of users with relatively small channel gain. In this case \(\text{Min}(R_j)\) can be transformed into \(f(\text{Min}(R_j))\), in which \(f()\) indicates a weighting function which may take a set of worst users into account.

B. **Blind FDPS**

This FDPS algorithm is used to set the baseline for comparison. Feedback channel information from users will not be considered in blind FDPS, i.e. static resource block allocation. PRBs for MBMS are predetermined, and the allocation will not be changed during simulation time. Remark that AMC based on CQI is still active.

### III. MODELING AND SIMULATION ASSUMPTIONS

The performance evaluation is based on multi-cell system model which follows the guidelines of multi-cell system model in [6]. We only collect throughput and BLER statistics from center cell users. Surrounding cells act as static interference sources with a frequency flat power distribution. The cell layout is a regular hexagonal grid. According to the LTE working assumptions 50 PRBs are available on a fixed bandwidth of 10 MHz, each of which contains 12 sub-carriers. Transmission power on each subcarrier is set to a constant value. The full buffer traffic model proposed for LTE benchmarking evaluation in [7] is assumed. In the beginning of a simulation run a fixed number of users are randomly dropped in geographical locations according to a uniform distribution within the simulation area. Users never change position or drop out the system during one simulation run but a fast fading channel assuming user velocity of 3 km/h is simulated.

 SINR denotes the ratio of signal to interference and noise on each subcarrier in case of OFDM. To map the instantaneous channel state, i.e. the set of sub-carrier SINR, into an instantaneous effective SINR, exponential effective SIR mapping (EESM) is adopted. The effective SINR is then used to find an estimate of the block-error probability from basic AWGN link-level-performance. The compression function that maps the sequence of varying SINR to a single is as follow:

\[
\text{SINR}_{\text{eff}} = -\beta \left( \frac{1}{P} \sum_{i=1}^{P} \exp \left( -\frac{\text{SINR}_i}{\beta} \right) \right)
\]  

Here SINR, is the SINR on the \(i\)th sub-carrier and \(P\) is the number of total sub-carriers. \(\beta\) is a scaling factor related to certain MCS. It is used to adjust the compression function in a way that the mismatch between the actual BLER and the predicted BLER is compensated. More details of simulation parameters are listed in Table I.

### IV. SIMULATION RESULTS

The performance of the proposed PRB allocation method is evaluated by sector throughput gain over Blind FDPS and system coverage. Coverage is defined as the proportion of users with BLER less than 1%. To fulfill MBMS QoS, the BLER coverage is required to be higher than 95%.

**A. Influence of PRB number and user number per sector**

In this section, we examine the performance of proposed algorithm with different settings of the two factors below:

**Frequency bandwidth for MBMS** – FDPS gain comes from channel diversity due to frequency-selective fading. Increase of bandwidth for MBMS will lead to decrease of channel diversity, and consequently decrease of gain. In our simulation, we consider the cases of 5 PRBs and 20 PRBs.

**MBMS users per sector** – As discussed above, channel quality of the worst users brings major limit to network performance of PtM mode MBMS. The larger the number of users is, the more users will be located in cell edge with low channel gain and in this case it may be impossible to find PRBs.
that are better than others. In our simulation, we consider the cases with 10, 20, 30 and 40 users per cell.

The simulation cases are illustrated in Table II:

**TABLE II MBMS BANDWIDTH AND USER NUMBER SETTING.**

<table>
<thead>
<tr>
<th>MBMS bandwidth</th>
<th>5/10/15/20 PRBs (50 PRBs in all)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of users per cell</td>
<td>10/20/30/40</td>
</tr>
</tbody>
</table>

Figure 3 shows CDF lines of users’ effective SINR of proposed FDPS (solid line) and blind FDPS (dashed line). In the case of 5 PRBs for MBMS and 10 users per sector a gap between the two lines can be observed at the bottom part — proposed FDPS has about 0.8 dB SINR gain over Blind FDPS at the point of 10% worst users. However, proposed FDPS has no advantage at the top part (about a 0.3 dB loss in 90% point comparing to Blind FDPS). This figure illustrates that the proposed algorithm works effectively in allocating PRB to improve SINR for worst users in a sector.

Figure 3. Comparison of SINR with Channel-aware FDPS and Blind FDPS
5 PRB and 10 users cases.

Figure 4. System throughput gain with varying number of PRBs allocated to MBMS (upper) and with varying number of users per sector (lower).

Figure 5. BLER coverage with varying number of PRBs allocated to MBMS, comparison of Blind FDPS and Channel-aware FDPS, 10 users and 40 users per sector.

Figure 6. BLER coverage with varying number of users per sector, comparison of Blind FDPS and Channel-aware FDPS, 5 PRBs and 20 PRBs for MBMS.

Figure 7. Comparison of Channel-aware FDPS gain with different CQI reporting mode: Full reporting vs. Best-M-and-Offset reporting, 5 PRBs for MBMS and 10 Users per sector case.
In Figure 4, system throughput gain of proposed FDPS over Blind FDPS varying with the two factors – number of PRBs for MBMS and number of users per sector – is plotted. In the upper figure it can be seen that with increasing the number of PRBs allocated to MBMS, throughput gain decreases. As an example we study the 10-users-per-sector case: Throughput gain decreases from around 33% with 5 PRBs to around 18% with 20 PRBs.

The decrease is mainly due to the decrease of channel diversity in frequency domain. In the 20-PRB case scheduler needs to select additional 15 PRBs with supposed better than average quality for the worst users. This explains the decrease.

The lower figure shows the trend of system throughput gain when varying the number of users per sector. This figure proves our prediction that more users in a single sector lead to poorer throughput performance. However, combined with both the adverse conditions (20 PRBs with 40 users per sector), proposed FDPS still maintain a gain over 5%.

In Figure 5 and Figure 6, results are shown in terms of BLER coverage with varying number of PRBs and users per sector. It can be seen that BLER coverage of MBMS with proposed FDPS algorithm in all the cases, no matter the PRB number for MBMS or user number, is more than 99% and the differences between the cases are tiny (less than 1%). The BLER coverage of Blind FDPS is also close to channel-aware algorithm and can even hardly be seen due to the limited resolution. BLER coverage makes the system throughput gain meaningful because coverage is a fundamental QoS requirement for communication. On the other hand, the results remind us to further explore system throughput gain by trade-off algorithms from BLER coverage.

B. Influence of CQI formatting methods

In this section, we illustrate the influence of CQI formatting methods on FDPS gain. In full reporting method every user will report CQI values on each PRB without formatting. It can be seen in Figure 7 that comparing to full reporting mode, default CQI reporting mode - Best-M-and-Offset - gain in system throughput decreases from 37 % to 34 %. BLER coverage of the two cases is almost the same. So the proposed algorithm is robust to schemes reducing the CQI feedback overhead.

V. CONCLUSIONS

In this paper we propose a frequency domain packet scheduling algorithm based on instantaneous feedback of channel quality for PtM mode MBMS. The objective of this algorithm is to maximize system throughput by adjusting PRB allocation to the worst users in a MBMS group whose channel condition will largely limit system performance. The algorithm is operating in an advanced RRM framework in LTE where UE feedback is used to enable broadcast versions of HARQ and AMC algorithms in PtM mode transmission.

A Blind FDPS algorithm is promoted to set the baseline of comparison. Simulation results show that with simplified CQI reporting by the “Best M and Offset” CQI formatting metric, the proposed algorithm works effectively to improve system performance in terms of both system throughput and BLER coverage. The effectiveness of this algorithm also heavily depends on channel diversity and the numbers of users per sector, especially number of users with relatively worse channel gain. More than 32% system throughput gain is available in the case of 5 PRBs for MBMS and 10 users per sector. Meanwhile the system BLER coverage maintains above 99% in all cases with proposed FDPS.

As QoS requirement of system BLER coverage is 95%, it is possible to promote advanced algorithms to operate trade-off between coverage and throughput, considering coverage more than 99% in our simulations should lead. One simple way is to change MCS set, i.e., to drive up the lowest MCS in the set. And also further study in FDPS may take multiple multicast groups or multiple services into account based on the idea of proposed FDPS algorithms.

ACKNOWLEDGMENT

The authors would like to thank their Nokia Siemens Networks global colleagues Tommi Koivisto and Klaus Pedersen for their support and proposal on the MBMS research project in correspondence of this paper.

REFERENCES