Downlink Resource Allocation for Evolved UTRAN and WiMAX Cellular Systems

L. Jorgušeski, T. M. H. Le, E. R. Fledderus, R. Prasad

Abstract—The future broadband wireless cellular systems Evolved UTRAN (E-UTRAN) and WiMAX are receiving a lot of interest in recent years. Both systems deploy Orthogonal Frequency Division Multiplex (OFDM) physical layer consisting of large number of mutually orthogonal sub-carriers. This physical layer provides high robustness against multi-path effects, high flexibility in allocation of the physical resources, high bandwidth scalability and relatively easy combination with Multiple-Input-Multiple-Output (MIMO) transmission and reception. In this study we investigate several algorithms for allocation of the downlink resources for E-UTRAN and WiMAX cellular systems. The goal of the study is to see the differences in downlink sector and user throughput, and user throughput versus distance from the reference base station for the resource allocation algorithms: Reuse-one, Reuse-three, Soft re-use, Reuse partitioning, Proportional Fair and Maximum C/I. Additionally, we observe the difference in performance between E-UTRAN and WiMAX under the conditions selected in this study. The evaluations are done via MATLAB simulations of a cellular system with one central three-sectored site surrounded with two tiers of interfering three-sector sites.

Index Terms—OFDM, OFDMA, E-UTRAN, WiMAX, downlink resource allocation, resource allocation algorithms, sector throughput, user throughput, user throughput versus distance.

I. INTRODUCTION

The future wireless broadband systems such as Evolved UTRAN (E-UTRAN) and WiMAX aim at providing high peak rates, low latency, high efficiency and scalability of the bandwidth usage, support for wide range of services with different QoS requirements to the end users, etc. In order to meet these goals an Orthogonal Frequency Division Multiplex (OFDM) physical layer has been selected for E-UTRAN and WiMAX systems. Additionally, the OFDM physical layer enables the so-called Orthogonal Frequency Division Multiple Access (OFDMA) where the different sub-carriers are grouped in sub-channels. The sub-carriers that form a sub-channel need not be adjacent. In the downlink, a sub-channel may be intended for different users depending on their channel conditions and data requirements. The Node B can allocate more transmit power to user devices with lower Signal-to-Interference-and-Noise Ratio (SINR) per sub-channel, and less power to user devices with higher SINR.

In this study we evaluate the downlink throughput performance in an E-UTRAN system according to the recommendations in [1] [2] and a WiMAX system according to [3] [5]. Here, we extend our previous work presented in [6] with the addition of proportional fair resource allocation algorithm in the analysis and evaluation of the WiMAX system. These evaluations are important because operators world-wide are interested in the throughput performance of the E-UTRAN and WiMAX systems while few detailed results are available in the literature. The WiMAX Forum has presented performance evaluations in [3] without detailed presentation of the used allocation algorithms and in [4] a comparison is made between WiMAX and HSPA and not with E-UTRAN. In 3GPP downlink throughput evaluations were done [7]-[9] to test the downlink capabilities of the E-UTRAN without extensive analysis of different options for the allocation algorithms and with few details about the throughput versus distance performance.

The rest of the paper is organized as follows. The concept of downlink resource allocation in E-UTRAN and WiMAX is presented in Section II. The different resource allocation algorithms investigated in this study are presented in Section III. Section IV contains the simulation set-up, results and observations. The paper is finalized with the conclusions and recommendations in Section V.

II. DOWNLINK RESOURCE ALLOCATION IN E-UTRAN AND WiMAX

Orthogonal Frequency Division Multiplexing Access (OFDMA) employs multiple closely spaced sub-carriers, which are grouped in sub-channels. The sub-carriers that form a sub-channel need not be adjacent. In the downlink, a sub-channel may be intended for different users depending on their channel conditions and data requirements. The Node B can allocate more transmit power to user devices with lower Signal-to-Interference-and-Noise Ratio (SINR) per sub-channel, and less power to user devices with higher SINR.

In an OFDMA cellular system, there is a two-dimensional space of the radio resources - Time-Frequency (T-F) resource as presented in Fig.1. There are S sub-channels in the frequency domain F. In the time domain T there are N OFDMA symbols, which are signals generated by the inverse FFT in the transmitter including a cyclic prefix and suffix. An OFDMA symbol is made up of sub-carriers, whose number is determined by the size of the FFT used.
The time-frequency resources are organized into a number of Resource Units (RUs) in both E-UTRAN system [2] and WiMAX systems [3]. The other terminology also used in E-UTRAN for RU is Physical Resource Block (PRB) [1]. A RU consists of a set of sub-carriers for a number of consecutive OFDMA symbols. Some main parameters for both systems in downlink are given as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>E-UTRAN</th>
<th>WiMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nr. OFDM sym.</td>
<td>12 per TTI</td>
<td>35 per DL frame</td>
</tr>
<tr>
<td>Total sub-carriers</td>
<td>1024</td>
<td>1024</td>
</tr>
<tr>
<td>Used sub-carriers</td>
<td>705</td>
<td>840</td>
</tr>
<tr>
<td>Number of RUs</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Nr. Sub-carriers per RU</td>
<td>47</td>
<td>28</td>
</tr>
</tbody>
</table>

In E-UTRAN systems, both transmissions on localized (consecutive) and distributed (non-consecutive) sub-carriers are supported. In this study only localized sub-carrier transmissions are considered for the E-UTRAN system.

Similarly, in WiMAX TDD systems, diversity permutation and contiguous permutation can be used for sub-channelization [3]. Note that the downlink Partially Used Sub-Channels (PUSC), one type of diversity permutations, is taken into account in our WiMAX study.

Link adaptation (AMC: Adaptation Modulation and Coding) with various modulation schemes and channel coding rates is applied to each RU and TTI (Transmission Time Interval) for E-UTRAN and downlink sub-frame for WiMAX. With AMC, the power of transmitted signal is held constant over a frame interval, and the modulation and coding format is changed to match the current received signal quality or channel conditions. When the radio link is good, a high level modulation is used, and when the radio link is bad, a low level, but robust modulation is used. QPSK, 16QAM, and 64QAM are supported downlink data modulation schemes in both E-UTRAN [2] and WiMAX [3]. The best AMC scheme per RU is selected by using Exponential Effective SIR Mapping (EESM), which is the interface between link level performance and system level simulations [2], [5]. EESM is used to derive throughput (usually determined via link level simulations) from SINR calculated on system level.

III. DOWNLINK RESOURCE ALLOCATION ALGORITHMS FOR OFDMA SYSTEMS

In this section we present in detail the considered downlink resource allocation algorithms for E-UTRAN and WiMAX.

A. Reuse-one

All available RUs can be allocated in a random fashion in each sector with reuse one. One user (E-UTRAN system) and one or more users (WiMAX system) are randomly selected for each RU.

B. Reuse-three

The number of available RUs is divided in three disjoint sets, which are consequently used in different sectors. Within one sector the users are allocated for RUs of this sector randomly.

C. Soft re-use

All available sub-carriers are used in each sector as in case of Reuse-one, but the power allocated to sub-carriers is not equal as presented in Fig. 2.

![Figure 2 Power allocations per RU for soft re-use in E-UTRAN, and WiMAX systems](image-url)

The number of sub-carriers with P_{edge} (dark color) is 1/3 of the total number of sub-carriers, hence, the rest (2/3) will have power P_{close} (light color). The algorithm works as follows. First, we classify users into “close” (close to the cell center) and “edge” (close to the cell edge) users based on comparing the user’s average geometry \( G_{avg} \) with a pre-defined threshold \( G_{th} \).

\[
\overline{G}_{avg} = \frac{1}{N_{RU}} \sum_{r=1}^{N_{RU}} G(r) \tag{1}
\]

where \( G(r) \) is the average geometry per RU and given by [5]:

\[
G(r) = \frac{p_{r,i}^{RU}/P_{th}}{\sum_{j=1}^{N_{RU}} p_{r,j}^{RU}/P_{th} + N_{RU}^{RU}} \tag{2}
\]

where \( j \neq i \) if \( i = b \).
$P_{r,k,s}^{RU}$ is the allocated transmission power to the $r^\text{th}$ RU from the $b^\text{th}$ node B and sector $s$. $L_{ij}$ is the propagation loss including path loss, shadowing, antenna gain between user and the $i^\text{th}$ node B and sector $j$. $N_{th}^{RU}$ is the thermal noise level for RU.

All users with $G_{\text{avg}} \leq G_{th}$ are "edge" users, and users with $G_{\text{avg}} > G_{th}$ are "close" users. $G_{th}$ is defined upon on the trade off between average sector throughput and average user throughput versus distance (see also Table II). All RUs with $P_{\text{close}}$ are allocated to close users while RUs with $P_{\text{edge}}$ are used by the edge users in random fashion.

Another way of soft re-use named "re-use partitioning" presented in Fig. 3 is supported in WiMAX system. The user close to a base station can operate with all available sub-channels. In case of an edge user, each sector can operate with a fraction of all available sub-channels [3], e.g., a fraction of 1/3 as in our model. The WiMAX case shows that the full load frequency reuse one is kept for "close" users to maximize spectrum efficiency, whereas fractional frequency reuse is used for "edge" users to improve their throughput as well as mitigate inter-cell interference among users.

Figure 3 Power allocations per RU for re-use partitioning in WiMAX system

D. Maximum $C/I$

The RUs are allocated based on the Channel Quality Information (CQI) feedback received from each user per RU. The user with the best CQI is allocated the particular RU. As a consequence only users in good radio conditions are allocated with resources while users in bad radio conditions will starve for resources.

E. Proportional Fair (PF)

The PF algorithm balances the throughput and fairness between users by allocating the RUs according to a scheduling priority based on the ratio between the currently feasible throughput and the average throughput over the previous scheduling periods. The PF scheduler selects per RU the user with maximum ratio of the feasible throughput to the average throughput for the current scheduling interval. In time slot $t$, the feasible rate of user $k$ for $n^\text{th}$ RU is $R_k^f(t)$ and its average throughput is denoted by $R_k(t)$. Then user $k^*$ with maximum

$$R_k^f(t)/R_k(t)$$

is served in time slot $t$ for $n^\text{th}$ RU. And the average user throughput for $n^\text{th}$ RU is updated by [10]:

$$R_k(t+1) = \begin{cases} \frac{1}{t_c} \sum_{i=1}^{t} R_k(t) + \frac{1}{t_c} R_k^f(t) & k = k^* \\ \frac{1}{t_c} \sum_{i=1}^{t} R_k(t) & k \neq k^* \end{cases}$$

where $t_c$ is the time constant for the moving average. In our models, value of $t_c$ is 100 transmission-time-intervals (TTIs).

IV. SIMULATION SET-UP AND RESULTS

The performance evaluation of the different downlink resource allocation schemes was done by MATLAB simulations. The wireless cellular system was modeled with one central three-sectored site surrounded with two tiers of interfering three-sector sites. The simulations were done for different number of users per sector randomly placed in the central site with uniform spatial distribution. The users are assumed continuously active in downlink (i.e. the full buffer approach). For the soft-reuse in E-UTRAN we have used $G_{th} = 8$ dB while for the soft-reuse and reuse partitioning in WiMAX we have used $G_{th} = 8$ dB and 14 dB, respectively. These values were chosen (by trial simulations) as a best compromise between satisfactory average sector throughput and reasonable throughput for cell edge users, as shown in Table II.

<table>
<thead>
<tr>
<th>Allocation algorithms</th>
<th>Avg sector throughput</th>
<th>Cell edge throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-UTRAN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$G_{\text{thr}} = 0$ dB</td>
<td>3.3936 Mbps</td>
<td>0.0453 Mbps</td>
</tr>
<tr>
<td>$G_{\text{thr}} = 15$ dB</td>
<td>7.2767 Mbps</td>
<td>0.0397 Mbps</td>
</tr>
<tr>
<td>$G_{\text{thr}} = 8$ dB</td>
<td>6.2177 Mbps</td>
<td>0.0603 Mbps</td>
</tr>
<tr>
<td>WiMAX (soft-reuse; reuse partitioning)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$G_{\text{thr}} = 0$, $0$ dB</td>
<td>2.9269 Mbps, 2.5448 Mbps</td>
<td>0.0411, 0.0398 Mbps</td>
</tr>
<tr>
<td>$G_{\text{thr}} = 15$, $20$ dB</td>
<td>8.6212 Mbps, 7.1100 Mbps</td>
<td>0.0451, 0.0509 Mbps</td>
</tr>
<tr>
<td>$G_{\text{thr}} = 8$, $14$ dB</td>
<td>6.1217 Mbps, 5.9526 Mbps</td>
<td>0.0534, 0.0632 Mbps</td>
</tr>
</tbody>
</table>

The important system parameters are presented in Table III.

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>SIMULATION PARAMETERS FOR E-UTRAN AND WiMAX</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>E-UTRAN</th>
<th>WiMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{\text{carrier}}$ [GHz]</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>$f_{\text{carrier}}$ [MHz]</td>
<td>6.528</td>
<td>11.2</td>
</tr>
<tr>
<td>Bandwidth [MHz]</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Frame length [ms]</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Cell radius [km]</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>$f_{\text{carrier}}$ [MHz]</td>
<td>6.528</td>
<td>10.9375</td>
</tr>
<tr>
<td>Guard time [μs]</td>
<td>9.803e-06</td>
<td>11.43e-06</td>
</tr>
</tbody>
</table>
The link level results [2] (Table 22, 23) and [11] (Table 3.1 to 3.4) are used for the E-UTRAN and WiMAX system, respectively, for the mapping between the effective SINR and the block error rate (BLER) for each AMC combination.

The normalized average sector and user throughput for WiMAX and E-UTRAN systems is presented in Fig. 4 to Fig. 7. The normalization is done with the system bandwidth. Note that the vertical bars in these figures are the 95% confidence intervals. For both systems the maximum C/I resource allocation algorithm has the best average sector/user throughput performance. This is because the RUs are allocated always to the user that has the best channel conditions at the moment of allocation.

The Proportional Fair (PF), Soft Re-use and Reuse-Partitioning have similar performance with regard to the average sector/user throughput. In practice it is expected that the PF algorithm will perform better as it uses the channel quality feedback from the UEs and tries to achieve fairness by weighting the achieved throughput in the previous allocations. The soft reuse schemes in this study were already ‘optimized’ for the uniform spatial distribution of the end users by selecting an appropriate geometry threshold for deciding if the UE is ‘close’ or at the ‘cell edge’. In practice this could be difficult to achieve. The reuse three has the worst performance as it uses only one third of the available bandwidth.
The reuse one has better performance than the reuse three and its performance can be improved by either differentiation between close and edge users (e.g. soft reuse or reuse partitioning) or implementing channel aware resource allocation (e.g. proportional fair).

Another important performance measure is the dependence of the average user throughput versus the distance from the reference cell. This evaluation is presented in Fig. 8 and Fig. 9 for the WiMAX and E-UTRAN system, respectively. From the enlargement of Fig. 9 and Fig. 10 we can see that the drawback of the maximum C/I algorithm is that it discriminates users near the cell edge. Especially, the users at the cell edge (e.g. distances larger than 0.45 km) are starved for resources and have a rather low downlink throughput.

![Normalized User Throughput vs Distance; 30 users; Pedestrian B; WiMAX](image)

![Normalized User Throughput vs Distance; 30 users; Pedestrian B; E-UTRAN](image)

Figure 8 WiMAX user throughput versus distance for 30 users per sector
Normalised User Throughput vs Distance; 30 users; Pedestrian B; E-UTRAN

Figure 9 E-UTRAN user throughput versus distance for 30 users per sector

The proportional fair algorithm has the best performance with regard to the user throughput versus distance as it makes the trade-off between the current channel conditions and previously experienced throughputs.

V. CONCLUSIONS AND RECOMMENDATIONS

From the overall results presented in this study it can be concluded that the throughput performance trends with regard to the different downlink resource allocation algorithms are same for E-UTRAN and WiMAX. The proportional fair algorithm can be seen as the best option for the E-UTRAN and WiMAX systems as it has significantly high sector/user throughput and reasonable fair user throughput distribution with regard to the distance from the reference site.

The downlink throughput performance of the E-UTRAN system outperforms the throughput performance of WiMAX. For example, if we select the proportional fair downlink resource allocation as a reference we see that E-UTRAN outperforms the WiMAX system roughly by 50% regarding the average sector throughput and 100% regarding the average user throughput or user throughput at the cell edge. However, this should be taken with a reserve as it highly depends on the system conditions taken in this study and the assumptions made for the link level performance in E-UTRAN [2] and WiMAX [11].

As a recommendation for further study we plan to further estimate the downlink throughput performance of E-UTRAN and WiMAX via an analytical approach and compare these analytical estimations with the simulation results presented here. Furthermore, this comparison should be repeated when minimum link-level requirements are available for the E-UTRAN system in 3GPP (expected in second half of 2008) and link-level results for WiMAX in IEEE and/or WiMAX forum.

REFERENCES

[2] 3GPP TR 25.892, “Feasibility study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancements”, V 6.0.0, June 2004