# Advanced Radio Resource Management for IMT-Advanced in WINNER+ (II)

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**Abstract:** Two main draft standards were submitted in October 2009 as candidate technologies for IMT-Advanced, namely IEEE 802.16m and 3GPP LTE-Advanced. However, several details on their functionalities are still open and the research community is racing towards the complete definition of revolutionary next fourth generation mobile, 4G. In this framework the European Celtic project WINNER+ is bridging together experts from industry, academia and government all around Europe to devise these 4G technologies. This paper presents the second set of innovative concepts for advanced Radio Resource Management that has been identified by the Innovation Group of WINNER+ for potential inclusion in IMT-Advanced. These concepts consist of promising innovative techniques that are ready to be included in current OFDMA-based cellular systems to enhance system performance. A brief description of each technique together with the relevant state of the art is provided.

**Keywords:** IMT-Advanced, WINNER+, Radio Resource Management, 4G.

## 1. Introduction

The definition process of the fourth generation (4G) mobile communication systems, termed IMT-Advanced, started in March 2008 and encompasses to date five candidates, all of them based on the 3GPP and IEEE proposals, known as LTE-Advanced and 802.16m respectively [1]. According to [2] the main innovations included in IMT-Advanced as compared with previous OFDMA-based systems, like LTE or WiMAX are:

- Carrier aggregation to support wider transmission bandwidths up to 100MHz.
- MIMO capabilities extension up to 8x8 in downlink and 4x4 in uplink.
- Use of coordinated multi-point transmission based on either coordinated scheduling or joint processing to improve the coverage of high data rates and to increase system throughput.
- Use of intelligent relays to allow for temporary network deployment, increase cell-edge throughput and/or provide extended coverage.
- Enhanced Multi-cast and broadcast transmission.

The WINNER+ project is aligned to the ITU-R agenda established for IMT-Advanced [3]. In fact, WINNER+ aims at developing and optimising IMT-Advanced compliant technologies that are backward compatible with LTE Release 8. Therefore, the project WINNER+ intends to contribute to the future definition of the complete LTE-Advanced standard. Research activity in WINNER+ is focusing on different aspects such as Advanced Radio Resource Management (ARRM), spectrum sharing and its flexible usage, peer-to-peer communications and advanced antenna concepts.

This paper presents the second set of innovative concepts for the ARRM that has been identified within the project WINNER+. If required, refer to [4] for further information on the performance analysis of all techniques.

## 2. MAC issues in Coordinated Multipoint Systems

A major challenge in providing ubiquitous broadband wireless access in cellular networks is to mitigate the effects of inter-cellular interference. Coordinated Multipoint (CoMP) Systems tackle this problem by allowing for the cooperation between transmitters. In this section two scheduling and resource allocation schemes are described.

### *2.1 CoMP scheduling for interference avoidance*

As a result of the study on the coordinated scheduling within the WINNER+ project, a coordinated scheduling algorithm has been proposed, which uses the Utility Theory to decide on the final allocation of the resources to users. A similar approach to the one proposed in [5] has been considered extending the problem to a three dimensional one, by including the SDMA beamforming MIMO technique. The proposed optimization objective, given in (1), is to maximize the aggregate utility of users in the entire network, where each user *i* has its utility function of average throughput $U_i\left(\bar{r}_i[t]\right)$.

$$\max \sum_{i=1}^{K} U_i\left(\bar{r}_i[t]\right), \tag{1}$$

where *K* is the number of users, and $\bar{r}_i[t]$ is the average throughput of user *i* at slot *t*.

The optimal algorithm solving the optimization problem given in (1) is too complex to be realized practically. Hence, a suboptimal solution has been developed, where the coordination is performed in clusters comprising three neighbouring sectors. In each of the coordination clusters, for each physical resource block (PRB) in time slot *t* the user that maximizes the aggregate utility of already allocated users is scheduled. The scheduling process for each PRB is performed iteratively as long as the aggregate utility of scheduled users increases.

Two utility functions have been considered, corresponding to the Maximum Rate and Proportional Fairness criterion. The performance of the proposed coordinated algorithm has been compared against two selected algorithms, such as Proportional Fair (PF) and Semiorthogonal User Selection (SUS) [6], with the results given in Table 1. One may notice a significant gain in average cell throughput, and cell-edge throughput when comparing the algorithms with and without coordination. However, the coordination process introduces an additional cost caused by the introduction of central entities, backhaul link and higher complexity of the scheduling process. Thus, more extensive studies on the proposed approach are necessary, preferably extending the proposed algorithm to perform also power adaptation and beamforming coordination, to prove the advantages of this technique.

*Table 1: Simulation results obtained with 300 users distributed in the considered observation area*

| **Scheduler** | PF | SUS | Coordinated Max Rate | Coordinated PF |
|---|---|---|---|---|
| **Average cell throughput [Mbit/s]** | 41.74 | 45.79 | 70.41 | 59.14 |
| **Cell-edge user throughput [Mbit/s]** | 2.09 | 2.64 | 5.50 | 6.71 |

### 2.2 *CoMP and self organized infrastructureless resource assignment*

Multiple antenna techniques at the base station (BS), such as a switched beam approach [7] or adaptive beamforming with opportunistic scheduling, provide a powerful mechanism to enhance the reusability of radio resources, but these techniques generally suffer from the hidden node problem. On the other hand, The busy burst (BB) concept for time division duplex (TDD) systems mitigates excessive interference by means of receiver feedback [8] and therefore solves the hidden node problem; potential transmitters that sense a BB above a certain threshold must refrain from transmitting. In this section it is demonstrated that BB enabled interference avoidance and beamforming techniques perfectly complement each other enabling a high frequency reuse in the system while mitigating inter-cell interference. This basic principle is a potential enabler for generic coordinated multi-point transmission (CoMP) approaches with decentralized control.

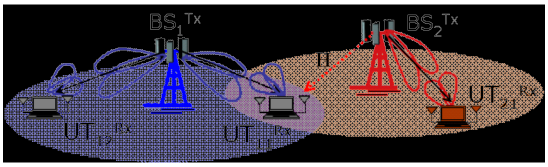


*Figure 1*: *Interference aware beam selection enabled by the BB protocol*

Figure 1 illustrates the combination of beamforming with the BB protocol. In Figure 1 $UT_{11}^{Rx}$ is exposed to interference from $BS_2^{Tx}$ located in an adjacent cell. Provided that the data transmitted by $BS_1^{Tx}$ is successfully received by $UT_{11}^{Rx}$, and $BS_1^{Tx}$ intends to transmit more data; in response $UT_{11}^{Rx}$ broadcasts a busy burst (BB) in an associated time-multiplexed minislot [8]. Provided that channel reciprocity holds, the region where the busy signal can be detected establishes an exclusion zone around vulnerable receivers for protection against inter-cell interference. In abstract, for the BB protocol to support a MIMO system the effective channel (the channel including spatial processing at transmitter and receiver) needs to be reciprocal. This is accomplished by:

- use precoder $\mathbf{v}^{(i)}$ on the feedback link as receive filter for scanning the busy slot,
- emit the busy burst using the spatial precoder **u** used spatial receive filter for data.

Hence, receiver feedback weighted by the receive filter **u** enables the interferer to select his spatial precoder $\mathbf{v}^{(i)}$ such that the interference to already existing links is kept below a predefined interference threshold $I_{\text{th}}$. Then, transmission with spatial precoder $\mathbf{v}^{(i)}$ is allowed, if the following condition holds [9]

$$I_b^{(i)} = \mathbf{v}^{(i)T}\mathbf{H}\,\mathbf{u}\;T_b \le I_{\text{th}} \qquad (2)$$

where $T_{\text{b}}$ is the fixed, known busy signal transmit power, $\mathbf{v}^{(i)T}\mathbf{H}\,\mathbf{u}$ represents the effective channel, and **H** is the unweighted MIMO channel matrix.

*Table 2: Simulation results for switched beam approach with and without BB interference avoidance*

| Interference threshold $I_{\text{th}}$ | System throughput | 10%-ile user throughput |
|---|---|---|
| -75 | 155.7 Mbps/cell | 5.68 Mbps |
| -70 | 168.6 Mbps/cell | 4.39 Mbps |
| Full reuse | 137.5 Mbps/cell | 0.76 Mbps |

Results for system level simulation in hexagonal cell deployment are shown in Table 2 using the switched beam approach of [7] with and without BB interference avoidance. It it is seen that the switched beam approach combined with the BB protocol achieves substantial gains in both system throughput and user throughput.

### *2.3 Closed Loop Control MAC Layer*

The many MAC layer tasks required for IMT-Advanced systems are coupled in a way that it is not comprehensive to the system architect. Usual approaches try to handle all optimization algorithms in a monolithic block, e.g. an integer linear programming job. They are unaware that *resource scheduling* (RS) is orthogonal to *packet scheduling* (PS). And packet scheduling with variable departure rates was solved already centuries ago. Even the tasks for RS have limited coupling interfaces if they are viewed in a different way.

Here, we propose a control theoretic block diagram process, because an Adaptive Power Control (APC) block compares the target and real Signal to Interference plus Noise Ratio (SINR) value of each OFDMA subchannel and controls the transmit power (within the possible bounds) to achieve the target. The dynamic subcarrier assignment (DSA) has been performed before this, which is why the subchannels for any UE are known and can be assigned a PhyMode in the adaptive modulation and coding (APC) step. At this point the service offer (in bits) is known for any user and the packets can be assigned into the resource blocks by the order controlled by the packet scheduler and its sub-strategies (one per QoS/priority class).

From transmission to reception the signal is subject to path loss and fading plus interference which results in a received SINR value. The components are measured and reported by CQI which, after signalling, offers the input values to the DSA block again. In [10] the controller has been investigated using the OpenWNS simulator tool. A MAC like this works hop-by-hop in a relay environment, where relay nodes have both eNB and user parts.

## 3. Cross-Layer Aspects of QoS Management

### *3.1 Cross-Layer Optimization for Rate-Adaptive Applications and Advanced Scheduling*

In [11, 12] we have investigated how cross-layer optimization (CLO) improves the system efficiency so that more users can be served by controlling and matching the resource allocation at the link layer and the resource consumption of the applications. Applications adapt their data rate depending on the decision of a cross-layer optimizer, e.g., by transcoding of a video streaming at the eNodeB. The utility metric mean opinion score (MOS) [11] is used by the cross-layer optimizer to mathematically model the applications.

In previous publications on CLO a packet-based general processor sharing (PGPS) scheduler is used, which assigns physical resource blocks (PRB's) independently of a user's channel. Here, CLO is combined with proportional fair (PF) scheduling, which assign PRB's to the user with the relatively best channel. For the PF scheduler the signal-to-noise (SNR) ratio of each PRB is provided. In contrast, the cross-layer optimizer is making use of long-term CSI (e.g., average link capacity as presented in [11]).

An LTE system implementation in the 5-MHz bandwidth downlink (DL) mode is simulated. Video streaming servers send packets with full data rate (corresponding to MOS=4.5) to an eNodeB. There, the packets are transcoded to the data rate (and MOS) decided by CLO according to an optimization criterion, which aims to guarantee a service quality of at least $MOS_{guar}$=3.0 and serves the users fairly, i.e., with the same service quality.

In Figure 2 (left) the probability distribution of the MOS is shown. With PF scheduling more users are served with the desired quality of MOS=3.0. This is further investigated in Figure 2 (right), which shows the probability that the guaranteed MOS of 3.0 is achieved. With PF scheduling more users can be served at a certain outage ratio than with PGPS scheduling. For example, at 5% outage ratio (i.e., 95% of the users achieve MOS>=3.0) instead of four users with PGPS nine users can be served with PF scheduling.

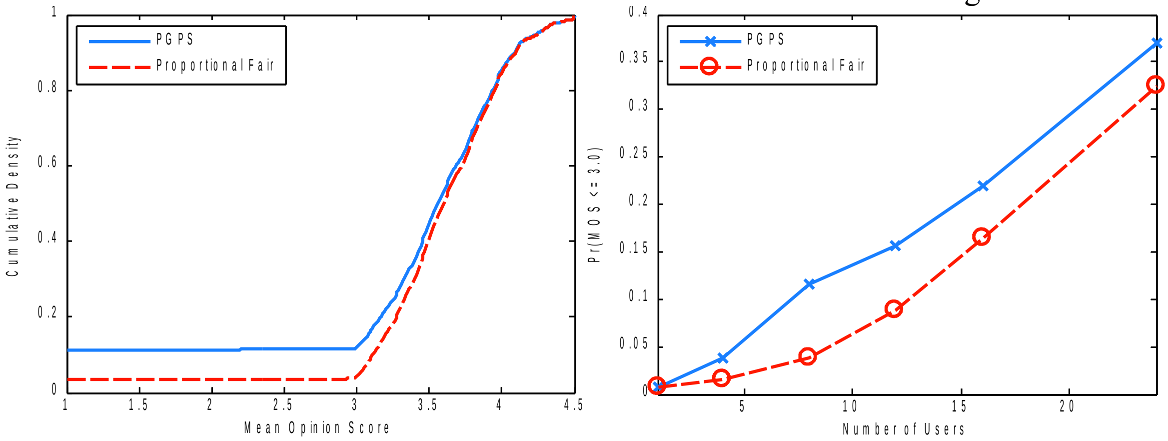


*Figure 2: CLO with PGPS and PF scheduling. Left: CDF of 8 users. Right: Number of served users*

### *3.2 Joint Resource Allocation-Admission Control*

A cross-layer approach is proposed here that unifies the operation of a two-dimensional OFDMA scheduler with that of an admission control (AC) algorithm in order to maintain the QoS satisfaction level of the admitted users, while reducing the blocking probabilities of new users. The scheduler allocates resources on the Downlink (DL) OFDMA frame according to a prediction of the QoS based on channel Quality information (CQI). The allocated services are characterized by satisfaction indexes (SI) that express the level of QoS fulfilment in terms of rate and delay. These are calculated at the Base Station (BS) for each frame. Based on the SI, the resource allocation (RA) adapts the priority for scheduling, thus adapting to the channel variations. On the other hand, the AC at the BS uses the SI to derive the general QoS satisfaction for already admitted users. The SI are used both by the RA and AC procedures to define a priority function, based on which a decision is taken. Fairness is provided to the pool of admitted users. Such and approach reduces the blocking probabilities of incoming users without degrading the QoS of the already admitted ones. Further improvements can be achieved by improved decision accuracy based on a Markov model.

The QoS level is derived from the SI and is estimated in terms of delay and rate each time a DL frame is composed by the RA and transmitted. The cross-layer design is based on a model initially proposed in [13], to express the satisfaction of the users in terms of rate and delay. New users requesting service might be blocked, if the system resources are not available. Already admitted users do not experience degradation of the QoS. The mechanism proposed always tries to provide the QoS that the user initially has requested while maximizing the number of users that would be granted services.

Investigations were performed for video streaming, and VoIP traffic. Figure 3 shows the blocking rate for two selected service classes with (dashed) and without prediction.

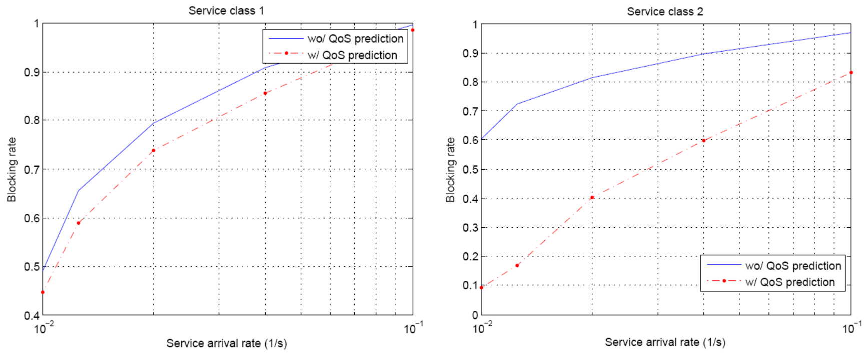


*Figure 3: Blocking Probability for different service classes with and without prediction.*

By binding the decision process to a condition based on predicted QoS information, significant improvements can be achieved for all service classes in terms of reduced blocking rates without QoS degradation for admitted users. The mechanism can be extended to negotiate the QoS parameters in terms of priority, mean data rate, delay, and jitter in order to improve resource utilization.

## 4. Resource Allocation with Carrier Aggregation

### *4.1 PHY and MAC implications of Spectrum aggregation*

Carrier aggregation is one of the main factors of the success of the next 4G technologies. This concept implies transmitting data on multiple contiguous or non-contiguous sub-bands, called component carriers. Each component carrier occupies up to 20 MHz of bandwidth in which it can be transmitted information towards LTE or LTE-Advanced mobiles.

The non-contiguous carrier aggregations have the advantage of having spectral diversity gain, due to the different bandwidths that imply different types of channels or different power delay profiles (PDP). However, this comes at the expense of few physical layer processing chains – one per each of the aggregated bands. On the other hand, contiguous carrier aggregation can save much spectrum, because a lot of sub-carriers used to guard bands can be employed for data and control information. Without carrier aggregation some frequency bands were unused to distinguish different services. With carrier aggregation frequency bands are only reserved in the frequency edges and, therefore, it can be possible to receive data and control information between two component carriers. Moreover, contiguous carrier aggregation could use only one baseband (BB) processing chain (large FFT block), if the transmitter and receiver are suited to it. Hence, it is important to determine which aggregation strategy is preferable from the system performance point of view. Moreover, different scheduling strategies can be considered when aggregating multiple sub-bands dividing the process into separate scheduling of sub-bands or performing a single allocation process spanning all of the aggregated carriers.

The investigation on the different aggregation and scheduling strategies has been performed by analyzing the system performance in terms of overall throughput in simulations. Slight advantage of the non-contiguous aggregation over contiguous strategy has been observed due to the higher spectral diversity. Moreover, minimally better system performance has been achieved when performing separate scheduling for each of the aggregated sub-bands. However, one should notice that additional gains from employment of single HARQ process for contiguous aggregation has not been considered. Thus, the general outcome of the comparison may be in favour of the contiguous aggregation thanks to the benefits of single HARQ processing.

When a user receives data from several frequency bands the best choice is not clear, whether to encode data in separate transport blocks or to combine all information and distribute the bits into the physical layer. If the last option is selected, the usage of Low Density Parity Check (LDPC) codes instead of Turbo Codes (TC) would be interesting due to the fact that a better performance can be obtained with longer blocks and hence, it could be reasonable to change the channel coding mechanism. During the study phase of LTE, the operators and manufacturers discussed this alternative. The main advantages and disadvantages of using LDPC or TC are: 1) LDPC and Turbo codes are two codes close to the Shannon limit, which can achieve low bit error rates for low SNR applications; 2) The original patent of LDPC codes has already expired unlike TC, the patent of which still exists; 3) Concerning its technological usage, LDPC is a hot research topic at many universities but there is no common implementation available. However, TC is a well established and implemented technology. Moreover, Turbo decoders are already available for ASIC and in FPGAs. This was the main reason to choose TC as coding technology. Now, in LTE-Advanced, which has bandwidths up to 100 MHz, this above topic is discussed again. Different studies have been carried out for the sake of comparing the performance of LDPC codes and TC. The difference of performance does not reach 0.5 dB for different modulations and code rates. Therefore, TC continues to be an appropriate solution for the next technologies of radio access networks.

### *4.2 CQI signalling in Carrier Aggregation*

OFDMA system such as LTE and LTE-Advanced can perform link adaptation and user multiplexing in the frequency domain if the packet scheduler in the eNodeB has the knowledge of the instantaneous channel quality. Frequency selective scheduling (FSS) significantly improves system performance. Depending on the CQI bandwidth used, explicit CQI feedback for every Resource Block (RB) can result in significant overhead and therefore reduced capacity. In case of reducing excessively the CQI bandwidth the FSS performance benefit could result degraded. An efficient and flexible technique for the CQI reporting would optimize the trade-off between the system performance of a frequency selective scheduling algorithm and the uplink bandwidth occupancy. Therefore, it could be useful to define a flexible CQI reporting method to select a certain level of granularity in the time domain and in the frequency domain depending on the radio channel condition the UE experiences.

This section performs a preliminary analysis using a dynamic system level simulator that follows the indications of [14]. The aim is to identify, for a set of different scenarios, the optimum CQI reporting period and the number of RBs included per report.

From the obtained results it can be concluded that in all scenarios augmenting the reporting period provokes a significant degradation on spectral efficiency. This degradation is more or less significant depending on the specific scenario. However, the reporting bandwidth does not affect the same way in all cases. For the urban case (macrocellular, UMa, and microcellular UMi), a lower reporting period increase the spectral efficiency, since errors on channel estimation are minimised. On the contrary, for the rural case (RMa) the differences among reporting bandwidths are not significant.

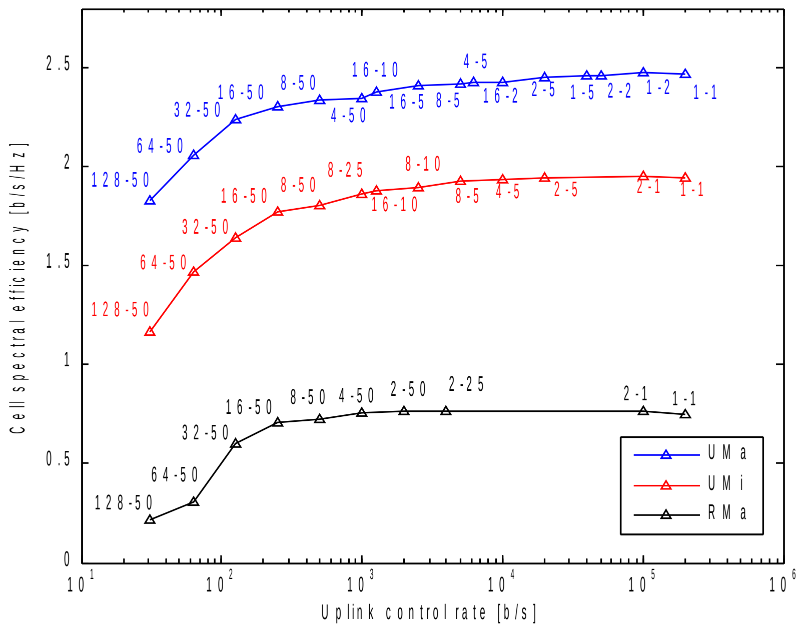


*Figure 4: Cell spectral efficiency vs uplink overhead*

These preliminary results have been summarized in Figure 4 taking into account only the best results in terms of cell performance in order to find the optimal trade-off between the maximization of the cell efficiency and the minimization of the uplink overhead. Based on these results, and assuming the definition of an acceptable degradation in terms of system performance, it could be identified the optimal pair (number of TTI - number of RBs) that could be the optimal trade-off considering each scenario. In the figure each pair of numbers represent the reporting period and reporting bandwidth respectively.

## 5. Conclusions

This paper has described some promising techniques for RRM to be implemented in the future IMT-Advanced systems. Three innovative concepts have been identified, namely CoMP, Cross-Layering aspects and Carrier Aggregation. A careful description of those concepts has been provided together with their repercussion in the system. It is worth highlighting that neither technique has an effect on the current LTE-A architecture as defined in the candidate description. Therefore, the system in mind must be able to use and coordinate multiple transmitters. Besides, the system must be able to aggregate joint and disjoint frequency bands so as to extend capacity up to 1Gbps. System architecture encompasses just a set of base stations and a gateway that connects the system with other IP-based networks. Only slight modifications on this flat architecture are envisaged to cope with the needed data interchange among base stations. Finally, it could be interesting to add some kind of cluster controller to collect common information and make joint decisions, as for call admission control or joint scheduling for interference reduction.


## Acknowledgements

This article has been written in the framework of the CELTIC project CP5-026 WINNER+. The authors would like to acknowledge the contributions of their colleagues.


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