# Dimensioning and Configuring Cross-Layer Channel Assignment Schemes in Packet Mobile Radio Networks with Mixed Traffic Services

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*Abstract*—**This work proposes a cross-layer FCA channel assignment scheme designed to efficiently handle multimedia communications in an heterogeneous traffic environment. The scheme has been designed to enable QoS priorisation of certain traffic types or user classes. To do so, the proposed technique provides mechanisms to reserve the use of given channels in interfering co-channel cells. The paper details the scheme's configuration and shows the achievable trade-offs between QoS priorisation and system performance.**

***Keywords-radio resource management, QoS provision, channel assignement schemes, mobile communications***

## I. INTRODUCTION

Channel assignment schemes are in charge of allocating, managing and distributing the available channels among users and services according to some QoS or system constraints. Although Dynamic Channel Allocation (DCA) schemes have been proposed to overcome the inefficiency of Fixed Channel Allocation (FCA) schemes under spatial traffic variations, their computational cost has not allowed their implementation in cellular systems. As a result, different FCA schemes have been proposed to optimise the system performance of the widely used random mechanism [1], and to respond to the specific needs of novel multimedia applications [2].

In [3], the authors presented a FCA cross-layer channel assignment scheme that follows the fundamental idea of Interference Adaptation (IA) DCA schemes [4] and bases its allocation decision on the instantaneous received and produced interference levels. The objective of the proposed scheme was to minimise the interference caused and received by a new channel assignment. Although this scheme significantly improved the system performance, it represented a sub-optimal 'myopic' solution given that it assigned the best channel (i.e., resulting in the lower interference produced and received) at the time of the channel allocation, but could not guarantee that the assigned channel experienced the lower interference levels during the whole transfer duration. The proposed channel assignment scheme was also designed not to differentiate among traffic services. This design approach could be questioned given that current and future mobile and wireless networks are characterised by transmitting an important variety of traffic services, each one of them with very different QoS requirements.

To overcome the 'myopic' limitation of the algorithm presented in [3] and to provide operators with methodologies to differentiate the perceived QoS by traffic services or user types, this paper presents a user priorisation interference-based cross-layer channel assignment scheme designed to guarantee lower interference levels during a call for certain users in heterogeneous traffic environments.

## II. DIMENSIONING CHANNEL ASSIGNMENT SCHEMES

The interference-based cross-layer (IB) channel assignment scheme proposed in [3] is based on an explicit coordination among co-channel interfering cells. In particular, whenever a Base Station (BS) receives a new channel request, it evaluates the number of interfering and interfered BSs that would result from assigning each one of the available channels to the new user. After all available channels have been evaluated, the BS assigns the channel resulting in the lower interference level, which is equivalent to assigning the available channel that minimizes the following utility function:

$$u(i) = \left\{ w\left[R_1^i + \xi R_2^i\right] + (1-w)\left[P_1^i + \xi P_2^j\right]\right\} \qquad (1)$$

where $i$ is the available channel under evaluation and $w$ is a weight parameter ($0 \le w \le 1$) defining the relative importance, during the evaluation process, of the interference caused and received. $R_1^i$ and $R_2^i$ correspond, respectively, to the interference received by channel $i$ from interferers of the first tiers and second tiers. $P_1^i$ and $P_2^i$ represent the interference caused by channel $i$ to BSs in the first and second tiers. The parameter $\xi$ is used to define the ratio between the interference from the first and second tiers. The interference corresponds to the number of active co-channel interfering or interfered cells. The work reported in [3] demonstrated that this simple interference estimation procedure provides very similar results

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to those obtained with more sophisticated approaches [5], therefore reducing the algorithm's implementation cost.

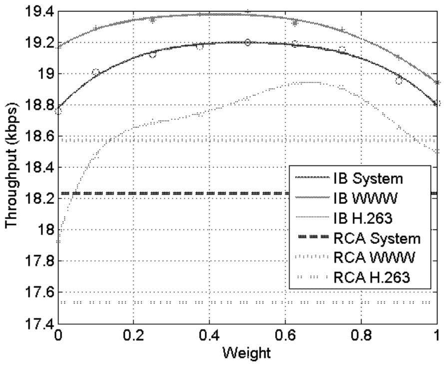


Figure 1. IB throughput performance as a function of the weight parameter

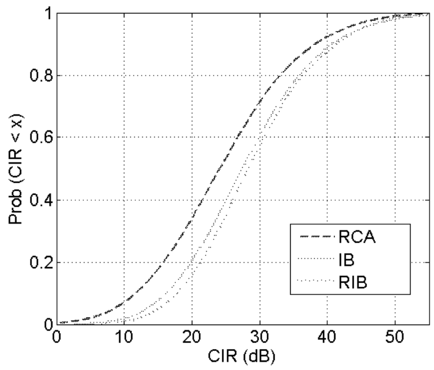


Figure 2. Carrier to Interference Ratio cumulative distribution function for H.263 traffic users

The performance of the IB and random (RCA) schemes was compared in heterogeneous traffic scenarios composed of WWW, email and real-time H.263 video traffic users. Figure 1 illustrates the IB's performance improvement over RCA and its throughput performance dependence on the weight parameter. The results illustrated in Figure 1 show that varying the weight parameter enables the possibility to optimise the performance for each traffic type. As illustrated in Figure 2, the IB's performance enhancement results from its explicit coordination among co-channel interfering cells that reduces the experienced interference levels. Despite such improvements, Figure 2 also shows that the current IB implementation does not provide the lower interference levels. The IB algorithm evaluates the optimum channel only when a new call arrives and the selected channel is maintained for the complete duration of the call. Since the assigning BS does not make any inference on the future state of each channel, an instantly optimum solution might not remain optimal during the entire call duration. To analyse the validity of this statement, we implemented a different version of the IB scheme, named RIB, in which a channel reassignment is performed after the transmission of each data block considering the utility function defined in (1). Although the RIB mechanism is not considered a valid scheme given its implementation cost (the interference levels need to be evaluated each 20ms), its use has just been considered to highlight the 'sub-optimality' of the IB algorithm. Such 'sub-optimality' is illustrated in Figure 2 where it is shown that further interference improvements can be obtained using the RIB scheme. In this context, this work proposes to modify the IB scheme in order to reduce the discussed performance sub-optimality and to provide tools to enable traffic QoS priorisation.

## III. User Priorisation Interference-Based Cross-Layer Channel Assignment Scheme

This work proposes a user priorisation interference-based cross-layer channel assignment (UPIB) scheme defined to provide operators with methodologies to priorise certain traffic types or users in heterogeneous traffic scenarios. To do so, the UPIB proposal modifies the utility function defined in (1) by including a penalty parameter. This parameter is introduced to favor the selection of channels that will produce less interference to the traffic users the algorithm aims to priorise. This work has been conducted considering a mix of web, email and H.263 real-time video users. Given that real-time H.263 video traffic exhibits the more strict QoS constraints, the implemented UPIB algorithm has been designed to priorise this traffic type. However, it is important to note that the same methodology could be followed to priorise other traffic types or even certain users irrespectively of their traffic type (for example, users paying higher subscription fees). The UPIB utility function is defined as follows:

$$u(i)=\begin{Bmatrix} w\left[R^i_{WWW}+R^i_{email}+R^i_{H263}\right]+ \\ (1-w)\left[P^i_{WWW}+P^i_{email}+(1+D)P^i_{H263}\right] \end{Bmatrix} \quad (2)$$

where $i$ is the available channel under evaluation and $w$ is the weight parameter defined in (1). While $R^i_{WWW}$, $R^i_{email}$ and $R^i_{H263}$ represent the interference produced by WWW, email and H.263 users respectively, $P^i_{WWW}$, $P^i_{email}$ and $P^i_{H263}$ represent the interference provoked to the same traffic types; only the interference from first tiers interferers is represented in (2). $D$ is defined as a penalty value for the channel assignments that would result in increasing the co-channel interference levels to the type of users we aim to priorise. Choosing a right value for the $D$ parameter will prevent co-channel BSs to assign channels allocated to H.263 users in interfered cells. An important objective is therefore to optimise the selection of the $D$ parameter to try to protect H.263 users from high interference levels without significantly degrading the system QoS, for which we propose the following methodology.

Let's consider that using the IB utility function defined in (1), the selected channel for a new channel request is channel $i$. Let's also suppose that there is a different available channel $j$ that results in a lower interference level to co-channel H.263 users than channel $i$. The proposed penalty parameter $D$ should then be defined so that the evaluation resulting from the new utility function expressed in (2) results in channel $j$ being assigned to the new channel request. This is equivalent to:

$$\begin{gathered} u(j)<u(i) \\ \left\{wR^j+(1-w)\left[P^j_{WWW}+P^j_{email}+(1+D)P^j_{H263}\right]\right\}< \\ \left\{wR^i+(1-w)\left[P^i_{WWW}+P^i_{email}+(1+D)P^i_{H263}\right]\right\} \end{gathered} \quad (3)$$

where $R$ represents the received interference levels if a given channel is assigned. If we consider a weight parameter equal to 0.5 and denote $I$ as the total received interference level (both produced and received) for the same channel, the previous equation can be simplified:

$$\begin{aligned} I^j + DP^j_{H263} &< I^i + DP^i_{H263} \\ I^j - I^i &< D\left(P^i_{H263} - P^j_{H263}\right) \end{aligned} \qquad (4)$$

If we denote $\Delta I^{ji} = I^j - I^i$ as the increased interference levels resulting from assigning channel $j$ instead of channel $i$, and $\Delta P^{ij}_{H263} = P^i_{H263} - P^j_{H263}$ as the reduction in interference produced to H.263 users when selecting channel $j$ instead of channel $i$, $D$ should be selected such that:

$$D > \frac{\Delta I^{ji}}{\Delta P^{ij}_{H263}} \qquad (5)$$

Equation (5) highlights a clear design compromise of the UPIB proposal that is analysed in this paper. In fact, increasing the $D$ parameter favors channel assignments priorising the H.263 real-time video users QoS. However, establishing high values for the $D$ parameter also results in channel assignments with higher interference levels for non-priorised users, in this case web and email. The selection of the $D$ parameter presents a clear design compromise for mobile operators and an opportunity to differentiate user or traffic type channel assignments.

TABLE I. SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| Cluster size | 4 |
| Cell radius | 1km |
| Sectorisation | 120° |
| Modelled interference | 1st and 2nd co-channel tiers |
| N° of modelled cells | 25 |
| Slots per sector | 16 |
| Medium traffic load (per sector) | video: 4 users/sector<br>WWW: 4 users/sector<br>Email: 4 users/sector |
| High traffic load (per sector) | video: 6 users/sector<br>WWW: 6 users/sector<br>Email: 6 users/sector |
| Pathloss model | Okumura-Hata |
| Shadowing | Log-normal distribution. 6dB standard deviation and a 20m decorrelation distance |
| Vehicular speed | 50km/h |
| ARQ protocol | Only for WWW and email |
| ARQ window size and report polling period | 64 RLC blocks/16 RLC blocks |
| LA updating period | 100ms |

## IV. SIMULATION ENVIRONMENT

To conduct this investigation, an event-driven simulator working at the burst level and emulating packet-data transmissions in an adaptive GPRS-like system employing Link Adaptation has been developed [6]. The simulator concentrates on the downlink performance and models a cellular network of equally sized 3-sector macrocells. Although mobility has been implemented, handover between sectors has not been considered. The boundary effects have been removed using a wrap-around technique. The emulator models a heterogeneous traffic environment with three different sources: H.263 video (target bit rate of 16kbps), email and WWW. No channel partition has been applied between the different services. Table 1 summarises the main simulation settings.

## V. PERFORMANCE EVALUATION

The performance of the UPIB proposal has been compared against that obtained using the IB technique presented in [3] and the traditional random scheme (RCA). Tables II and III report their throughput performance for various traffic loads (see Table I) and the $D$ parameter equal to 25. The obtained results show that the lower interference levels (and therefore higher CIR values) experienced by H.263 users using the UPIB proposal (see Figure 3) results in considerable throughput performance improvements, in particular to the more poorly served users. Of course, such improvements are obtained at the expense of non-priority users that see their experienced interference levels increase with the UPIB scheme (see Figure 4). As a result, the UPIB scheme offers operators the possibility to trade-off various traffic type's performance. The results reported in Tables II and III correspond, respectively, to medium and high traffic loads. Their direct comparison reveals interesting facts regarding the IB and UPIB performance trends with varying traffic loads. Table II shows that the higher IB performance improvements compared to the traditional RCA assignment mechanism are obtained at medium loads. This is the case since the IB proposal exploits the channel interference diversity characteristic of low to medium traffic scenarios. On the other hand, at high traffic loads, whenever a new call requests a channel, there are few channels available and the operation of the RCA and IB schemes does not significantly differ. Tables II and III show that the IB performance trend with traffic loads is not maintained for the UPIB proposal. In fact, the results obtained show that higher H.263 performance gains are achieved with the UPIB scheme under high traffic loads. This is the case because, although the UPIB proposal is initially based on the IB scheme, the UPIB mechanism seeks to reduce the interference levels of certain traffic users even if this requires sacrificing the system's ability to exploit channel interference diversity. Since higher interference levels are experienced at high traffic loads, the potential for H.263 improvements using the UPIB proposal increases with the traffic load. The described interference trends can be observed when analyzing the CIR experienced by H.263 real-time video users in medium and high traffic loads; see Figures 3 and 5. As it can be observed from Figure 3, the IB scheme significantly reduces the interference levels compared to RCA, whereas the interference levels reduction for UPIB compared to IB is moderate. On the other hand, at high traffic loads, the UPIB scheme results in a higher interference reduction compared to the IB mechanism than the IB proposal compared to the RCA scheme.

TABLE II . THROUGHOUT PERFORMANCE AT MEDIUM TRAFFIC LOADS

| | | RCA Perf. | IB Perf. | Impr. RCA % | UPIB Perf. D=25 | Impr. RCA % | Impr. IB % |
|---|---|---|---|---|---|---|---|
| WWW | Mean | 18.02 | 18.69 | 3.72 | 18.16 | 0.78 | -2.84 |
| | 95% | 12.83 | 14.00 | 9.12 | 12.88 | 0.39 | -8.00 |
| Email | Mean | 18.06 | 18.60 | 2.99 | 18.09 | 0.17 | -2.74 |
| | 95% | 12.84 | 13.81 | 7.55 | 12.72 | -0.93 | -7.89 |
| H.263 | Mean | 16.76 | 17.79 | 6.15 | 18.18 | 8.47 | 2.19 |
| | 95% | 11.11 | 12.93 | 16.38 | 13.81 | 24.30 | 6.81 |
| System | Mean | 17.62 | 18.36 | 4.20 | 18.14 | 2.95 | -1.20 |
| | 95% | 12.26 | 13.58 | 10.77 | 13.14 | 7.18 | -3.24 |

TABLE III . THROUGHOUT PERFORMANCE AT HIGH TRAFFIC LOADS

| | | RCA Perf. | IB Perf. | Impr. RCA % | UPIB Perf. D=25 | Impr. RCA % | Impr. IB % |
|---|---|---|---|---|---|---|---|
| WWW | Mean | 17,39 | 17,6 | 1,21 | 17,23 | -0,92 | -2,10 |
| | 95% | 11,73 | 12,04 | 2,64 | 11,32 | -3,50 | -5,98 |
| Email | Mean | 17,43 | 17,61 | 1,03 | 17,33 | -0,57 | -1,59 |
| | 95% | 11,79 | 11,99 | 1,69 | 11,46 | -2,80 | -4,42 |
| H.263 | Mean | 15,9 | 16,18 | 1,76 | 16,67 | 4,84 | 3,03 |
| | 95% | 9,77 | 10,12 | 3,58 | 11,08 | 13,41 | 9,49 |
| System | Mean | 16,91 | 17,13 | 1,30 | 17,08 | 1,01 | -0,29 |
| | 95% | 11,1 | 11,39 | 2,61 | 11,29 | 1,71 | -0,88 |

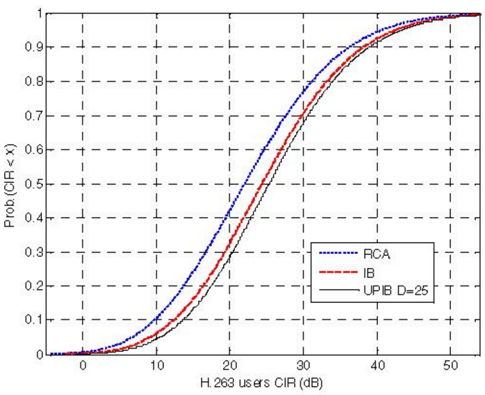


Figure 3. H.263 CIR for medium traffic loads.

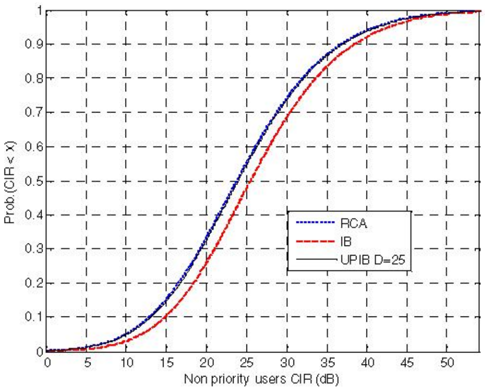


Figure 4. Non-priority users CIR for medium traffic loads.

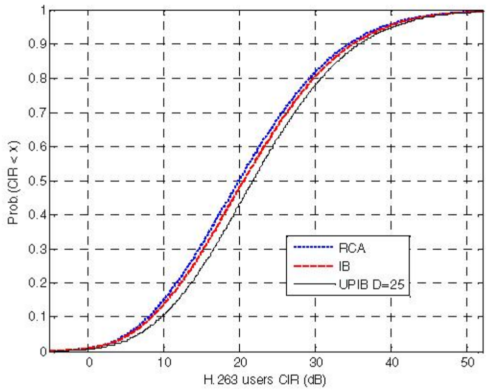


Figure 5. H.263 CIR for high traffic loads.

The results illustrated in Figures 6 and 7 prove that increasing the D parameter reduces the CIR experienced by H.263 users, but increases it to non-priority (web and email) users; as explained in section II the interference has been computed as the number of active co-channel interfering or interfered cells. The respective reduced and increased interference levels for H.263 and non-priority users result in considerable variations of the experienced Block Error Rate (see Figures 8 and 9) that are at the origin of the throughput performance differences as the *D* parameter is varied. In fact, as *D* increases, higher and lower throughputs are measured for H.263 and non-priority users respectively. The results reported in Figures 8 and 9 also show that the higher performance variations as the *D* parameter increases were obtained for the more restrictive QoS parameters, i.e. the maximum BLER guaranteed for 95% of the users. This trend highlights that the UPIB proposal is particularly capable of improving the performance of the more poorly served H.263 users. Based on the observed results, the *D* parameter offers then to mobile operators the ability to trade-off the performance improvements and reductions between priorised and non-priorised users.

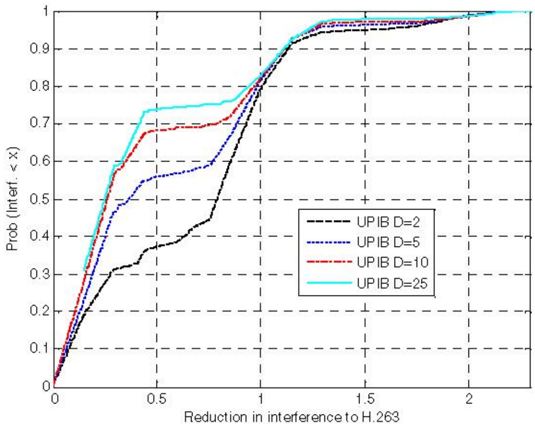


Figure 6. UPIB H.263 interference reduction for various values of the D parameter and a medium traffic load.

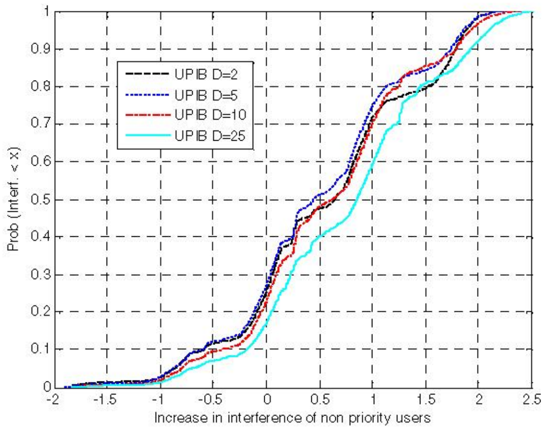


Figure 7. UPIB non-priority users interference increase for various values of the D parameter and a medium traffic load.

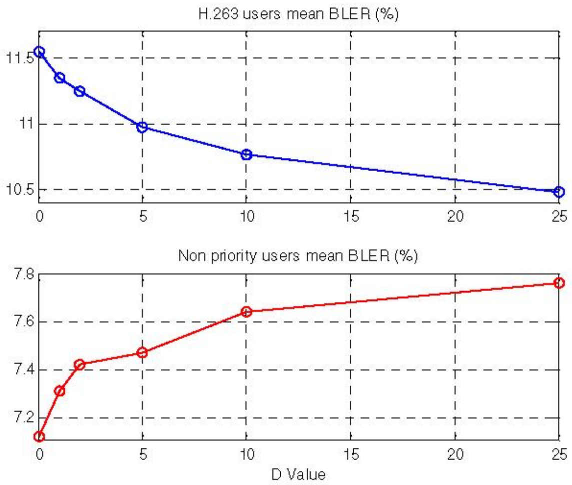


Figure 8. UPIB mean H.263 and non-priority users BLER performance for various values of the D parameter and a high traffic load.

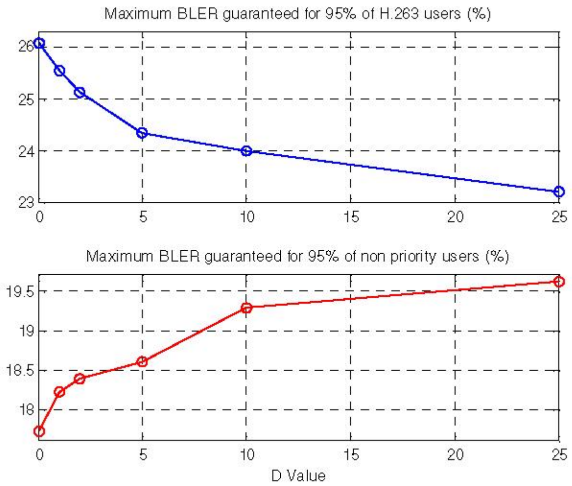


Figure 9. UPIB maximum BLER for 95% of H.263 and non-priority users for various values of the D parameter and a high traffic load.

The RCA scheme is characterised by its simplicity and a long-term uniform use of all channels. This property is interesting since it avoids surcharging particular channels and radio equipments. Figure 10 plots the average channel occupancy for all channels per cell considering the RCA, IB and UPIB schemes. The obtained results show that the UPIB algorithm also exhibits, irrespectively of the value of the *D* parameter, the same long-term uniform use of all channels, and therefore RF equipment, as the random allocation scheme.

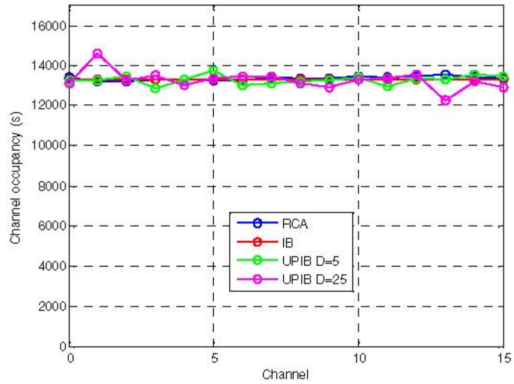


Figure 10. Average channel occupancy.

## VI. Conclusions

This paper has presented a user priorisation interference-based cross-layer channel assignment scheme designed to offer the ability of increasing the QoS perceived by certain traffic types or user categories in heterogeneous traffic environments. The proposed scheme offers mobile operators an interesting tool to configure and dynamically modify their channel assignment policy.

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