Improving QoS in Packet Mobile Radio Networks through Coordinated Cross-Layer Channel Assignment Schemes

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Abstract - **Channel assignment schemes are responsible for deciding which available channel is assigned to an incoming call. This work proposes a cross-layer channel assignment mechanism for FCA mobile radio networks that bases its allocation decision on the instantaneous received and produced interference levels. The obtained results demonstrate the potential performance improvements that can be obtained with the proposed scheme with a low implementation cost. The conducted research also analyzes the optimum configuration of the proposed allocation scheme under different operating conditions in a heterogeneous traffic environment.**

1. Introduction

The recent evolution of mobile communication systems is being characterized by high user expectations and demands in terms of Quality of Service (QoS) provision. Such demands require the design and implementation of the necessary means to accomplish an efficient use of the scarce available resources. One way to achieve such objective is through the design of appropriate Radio Resource Management (RRM) techniques.

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. Two main channel assignment categories can be defined: Fixed Channel Allocation (FCA) and Dynamic Channel Allocation (DCA) [1]. Current cellular systems employ FCA where the available channels are divided into as many disjoint sets as there are cells in a particular cluster and each set of channels is permanently assigned to a cell. To overcome the inefficiency of FCA schemes under high spatial traffic variations, DCA schemes do not permanently allocate channels to a cell but assign them dynamically, as new calls arrive in the system, based on a predefined cost function. In particular, Interference Adaptation (IA) DCA algorithms use real-time interference measurements to assign an incoming call the most suitable available channel [2]. Despite the acclaimed superior performance of DCA over FCA [1], the implementation of DCA in cellular systems has not been considered yet due to its computational cost and implementation difficulties. As a result, this work is concerned with the optimisation of FCA schemes through the design of novel channel allocation algorithms.

Current FCA cellular systems traditionally assign an incoming call a randomly selected available channel. This random assignment simplifies the allocation problem and ensures that all channels, and therefore RF equipment, are uniformly used over time. However, the random allocation mechanism results in a non-optimal system performance and is not able to cope with the specific needs of multimedia applications [3]. This last drawback is becoming particularly important as wireless data services gain popularity and novel applications are introduced. To improve the system performance and adapt the allocation scheme to the particular needs of specific services, other channel allocation mechanisms have been reported in the literature (e.g. [4]). The work reported in [3] proposed and evaluated a set of allocation mechanisms that assign incoming calls the available channel that experienced the best channel quality conditions during previous transmissions. The proposed schemes outperformed the random mechanism by establishing an implicit coordination among co-channel interfering cells during the allocation process. Such coordination resulted in lower interference levels since interfering cells avoided transmitting using the same channels. Based on these observations, this paper proposes and evaluates a novel cross-layer channel assignment scheme designed to explicitly increase the coordination among co-channel interfering cells. In fact, the proposed scheme bases its allocation decision on the interference that is experienced on each one of the available channels at the time of the allocation.

2. Coordinated cross-layer channel assignment scheme

2.1. Utility function

This paper proposes a cross-layer channel assignment scheme based on perfect information regarding the occupied channels in co-channel interfering cells. At this point, it is important to consider the differences between an omnidirectional cellular scenario and a sectorized one. In the first case, two co-channel interfering cells produce and receive from each other the same interference level. As a result, there is no difference in between considering in the channel assignment process just the interference received or the interference produced and received by a new channel allocation[1]. In the case of a sectorized cellular network, a cell (in this case representing a sector) receives interference from a set of co-channel cells but produces interference to a different set of co-channel cells[2]. As a result, an important parameter during the channel allocation process is how much weight is given in the decision to the interference received in a channel being allocated and to the interference produced to other cells by this channel allocation. In the rest of this section, both the interference caused and received are considered.

The objective of the proposed scheme is to minimise the interference caused and received by a new channel assignment. For that purpose, a BS that receives a new channel request evaluates, for each one of its available channels, the number of interfering and interfered BSs that would result from assigning each channel to the new user. After all available channels have been evaluated, the BS assigns the channel resulting in the lower interference level (both received and created). This process is equivalent to assigning the available channel that minimizes the following utility function[3]:

$$U(i) = w\left(\left|I_1(i)\right| + \xi\left|I_2(i)\right|\right) + (1-w)\left(\left|I'_1(i)\right| + \xi\left|I'_2(i)\right|\right)$$

where i is the available channel under evaluation and w is a weight parameter ($0 \leq w \leq 1$) defining the relative importance, during the evaluation process, of the interference caused and received. If w is equal to 0, the proposed scheme only considers in the utility function the interference caused to the rest of BSs by a potential new channel assignment (*generous behaviour*). On the other hand, if w is equal to 1, the scheme behaves selfishly and only considers the interference received by other BSs if the evaluated channel is being assigned. If w is set to 0.5, the BS equally considers in the evaluation process the interference received and caused if each one of the available channels was allocated to the incoming call.

The proposed channel assignment scheme can consider in its interference evaluation process co-channel interferers from the first and second tiers. $I_1(i)$ and $I_2(i)$ correspond, respectively, to the interference received from interferers of the first tiers and second tiers. On the other hand, $I'_1(i)$ and $I'_2(i)$ represent the interference caused to BSs in the first and second tiers. The interference caused and received can either be exactly computed (assuming the distance and transmitting power are known) or estimated. For the latest option, the interference I corresponds to the number of active co-channel interfering or interfered cells. When estimating the interference, the parameter ξ has been used to define the ratio between the interference from the first and second tiers. For this work, ξ has been set to 0.15[4].

Some interference-based allocation algorithms, such as the IA-DCA scheme proposed in [5], claim that to maximize the performance, the allocation scheme should solely consider the interference received. On the other hand, this research will show that the system performance is improved by not only considering the interference received if a given channel is allocated to an incoming call but also the interference produced to other users by this channel assignment.

The described algorithm is a particular implementation of a general one developed in a game-theoretic framework. Such framework is not detailed in this paper due to the lack of space.

2.2. Implementation cost

The proposed scheme follows the philosophy of IA-DCA schemes (e.g. [5] and [6]), but with important differences, apart from the fact that this work focuses on FCA schemes. For example, the algorithm proposed in [5] predicts the experienced interference level on each channel based on signal level measurements of the serving cell and the neighbouring cells. Although this procedure seeks to ease the implementation cost, the algorithm's performance can be adversely affected by inaccurate and limited interference estimates. On the other hand, the allocation mechanism proposed in this work directly estimates the interference by exchanging channel occupation information among co-channel interfering Base Stations. Assuming BSs can exchange channel occupancy information is realistic and can be justified as follows. First of all, bandwidth availability on the core network to transfer all the signalling information necessary to implement the proposed scheme is not such a problem compared to the radio access network. The needed bandwidth could be considerable if the operation of the proposed scheme required an important number of co-channel interfering BSs to exchange channel occupancy information. However, this work will demonstrate that this is not actually the case and that in fact, only a reduced set of co-channel BSs need to exchange channel occupancy information to achieve the algorithm's highest system performance. It is also important to note that in current cellular systems the channel assignment decisions are controlled by the BSC (Base Station Controller) and that a single BSC can handle the communications of a considerable number of BSs. In this case, the BSC that controls a set of neighbouring cells directly knows their channel occupancy situation and our proposed scheme can be implemented at the BSC without incurring in an additional relevant implementation cost.

3. Simulation environment

In order to ensure high accuracy and to account for sudden channel quality variations, an event-driven simulator working at the burst level and emulating

[1] This statement will be demonstrated later on using simulations.

[2] This property results from the use of directive antennas.

[3] Different utility functions have been considered and evaluated, e.g. a lexicographic function. However, the additive utility function reported in this paper showed the highest system performance.

[4] This parameter has been set considering the ratio between the received power at second tiers and first tiers co-channel cells (a fixed transmitting power was assumed).

packet-data transmissions in a GPRS-like system has been used [7]. The simulator concentrates on the downlink performance and models a cellular network of omnidirectional macrocells or 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, email and WWW browsing. No channel partition has been applied between the different services. The H.263 video traffic model considered employs three different frame types, namely I, P and PB, and targets a bit rate of 16 kbit/s. In order to reduce the complexity of system level simulations, the simulator includes the effects at the physical layer by means of an advanced link-to-system level interface working at the burst level. This interface, composed of two different types of Look-Up Tables, is able to include the effect of fast fading at the system level. The system considers the use of Link Adaptation (LA), an adaptive radio link technique that selects the coding scheme (CS) based on the experienced channel quality conditions. In this work, the LA algorithm selects the coding scheme that maximizes the throughput. Table 1 summarises the main simulation settings.

Parameter	*Value*
Cluster size	4
Cell radius	1km
Sectorisation	120º
Modelled interference	1st and 2nd co-channel tiers
Nº of modelled cells	25
Slots per sector	16
Users per sector	8
Traffic type	video: 2 users/sector. WWW: 3 users/sector. Email: 3 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

Table 1: Simulation parameters

4. System level performance

This section compares the performance of the proposed channel assignment scheme against that obtained used the random mechanism and the minBLER proposal [3]. The minBLER algorithm assigns an incoming call the available channel that experienced the lower Block Error Rate (BLER) during previous transmissions. The performance of the three channel assignment schemes is compared within omnidirectional and sectorised cellular scenarios in order to define the optimum configuration of the proposed algorithm under different operating conditions.

4.1. Sectorised cellular network

Figure 1 shows the system throughout performance of the proposed channel assignment scheme against that achieved with the random and minBLER mechanisms. While the A2T (Approximated 2 Tiers) scheme estimates the interference produced by the first and second tiers of co-channel interfering cells, the A1T (Approximated 1 Tiers) mechanism only considers the first tiers. The E2T (Exact 2 Tiers) algorithm also considers the first and second tiers of co-channel interfering cells but instead of just estimating the interference it exactly calculates it, which assumes that the position of mobile stations is perfectly known at each BS. The A2T, A1T and E2T schemes consider a weight w equal to 0.5, while the A2T selfish proposal considers a weight w equal to 1.

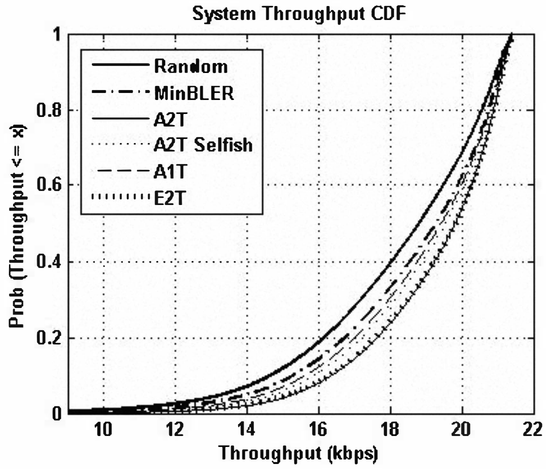

Figure 1: System throughput cumulative distribution function (cdf) in the sectorised cellular scenario

Figure 1 shows that all the evaluated configurations of the proposed scheme outperform the random and minBLER algorithms. The A2T configuration provides the highest system throughput which proves, that for sectorised cellular networks, the proposed scheme needs to consider the channel occupancy in co-channel cells of the first and second tiers. The A2T and E2T performance is nearly identical which suggests that an interference estimation not only reduces the implementation cost but is also enough to guarantee the highest performance levels. Contrary to the indications provided in [5] for DCA schemes, Figure 1 proves that considering the interference received and produced in a new channel assignment improves the system performance compared to only considering the interference received. Finally, Table 2 shows that the observed trends in Figure 1 are maintained when considering other system parameters. The improved throughput performance is due to the lower experienced BLER as a result of inducing co-channel cells to avoid using simultaneously the same channels. The resulting better channel conditions promoted the use of the less robust GPRS coding scheme (CS4) and reduced the signalling load associated with the use of LA.

Parameter	Random	A2T, w=0.5	A1T, w=0.5	E2T, w =0.5	A2T, w=0
Mean BLER (%)	6.45	4.52	5.02	4.54	5.29
Mean Normalized Delay (ms/kbit)	61.65	58.66	59.47	58.66	59.84
Mean number of CS changes per sec	2.25	1.83	1.96	1.82	2.03
Proportion of RLC blocks transmitted with the optimal CS (%)	72.20	79.19	76.96	78.75	76.19

Table 2. System performance in sectorised cellular scenarios

Throughput		Random	MinBLER		A2T, w=0.5		
		Perf. (kbps)	Perf. (kbps)	Impr. Rand (%)	Perf. (kbps)	Impr. Rand (%)	Impr. MinBLER (%)
System	Mean	18.23	18.64	2.19	19.2	5.05	2.91
	%95	13.33	14.02	4.92	15.3	12.87	8.36
WWW	Mean	18.57	18.89	1.69	19.39	4.22	2.57
	%95	13.78	14.34	3.9	15.43	10.69	7.06
Email	Mean	18.60	18.82	1.18	19.37	4.14	2.92
	95%	13.85	14.15	2.17	15.39	11.12	8.76
H263	Mean	17.53	18.2	3.68	18.84	6.95	3.39
	%95	12.37	13.59	8.97	15.08	17.97	9.88

Table 3. Throughput performance per services

Table 3 compares, for each traffic type, the A2T throughput performance against that obtained using the random or minBLER mechanisms. First of all, it is interesting to note that the proposed channel assignment scheme particularly improves the most restrictive QoS parameter, i.e. the minimum throughput guaranteed for 95% of the samples. This observation is highly relevant since it indicates that the developed algorithm increases the system fairness, by improving the performance of the more poorly served users, without degrading the mean performance.

A very important observation resulting from Table 3 is that the traffic type that mostly beneficiates from the proposed channel assignment scheme is real-time H.263 video transmissions. This is highly relevant if we consider that this service, which does not employ ARQ protocols to guarantee the correct radio transmission, is the one imposing the most restrictive QoS constraints. In the implemented real-time video transmission model, a video frame is discarded if it is not completely transmitted by the time the next video frame is generated; in this case, the user maintains the same channel to transmit the new video frame. To increase the system capacity, a channel is released whenever a video frame is transmitted before the next one is generated. Since the implemented simulator only considered single slot transmissions, a considerable number of video frames had to be discarded and the user maintained the same channel for a long period of time compared to more bursty services such as web or email. In this case, a non-optimal channel assignment results in a prolonged poorer performance, which explains why the real-time H.263 video performance is notably improved with the proposed channel assignment scheme.

Figure 2 shows that the highest A2T system performance is obtained when the interference received and produced is equally considered during the channel allocation process (w=0.5). While the same conclusion has been observed for best-effort services (web and email), real-time H.263 video transmissions benefit from a slightly selfish behaviour during the channel assignment process. This is the case because in the implemented emulator, real-time H.263 transmissions resulted in longer periods of time using the same channel. The obtained results seem then to suggest the possibility of varying the setting of the weight parameter according to the transmitting service in a heterogeneous traffic scenario.

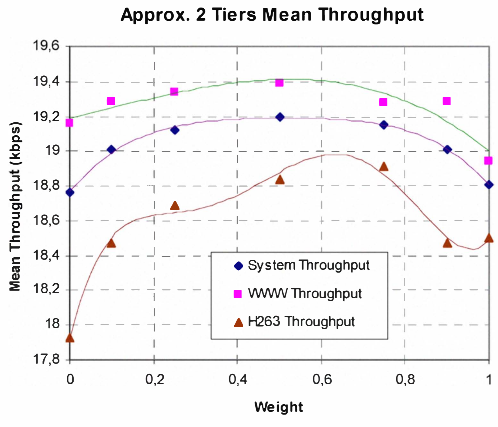

Figure 2. Effect of the weight parameter on the mean throughput performance

4.2. Omnidirectional cellular network

Figure 3 shows that for omnidirectional cellular networks, the proposed channel assignment scheme also improves the system performance compared to the random and minBLER algorithms. In the case of omnidirectional networks, the weight parameter has not an influence on the utility function and therefore on the system performance. The most important difference observed with the sectorised scenario is that, in omnidirectional environments, the highest system performance is achieved when only considering the first tiers of co-channel interferers, which highlights their dominant effect on the interference levels. Considering also the second-tiers co-channel cells not only does not improve the system performance but also increases the implementation cost of the proposed channel assignment scheme.

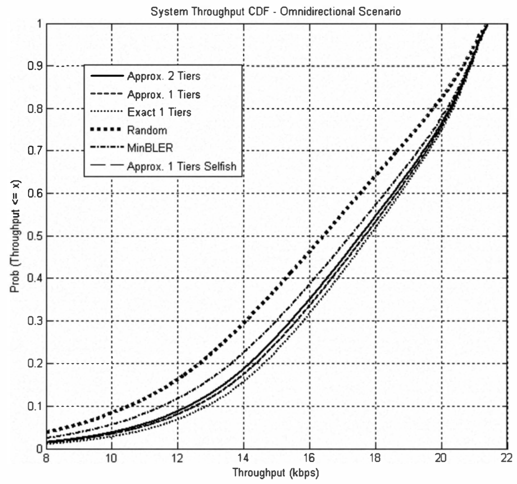

Figure 3. System throughput cdf for an omnidirectional cellular network

4.3. Channel occupancy

Random channel assignment schemes are characterised by a long-term uniform use of all physical channels. This property is interesting since it avoids surcharging particular channels and radio equipments. Figure 4 plots the average channel occupancy for all channels per cell considering the random and the proposed channel assignment scheme that achieved the highest performance in the case of omnidirectional and sectorized cellular networks. The obtained results show that the proposed algorithm exhibits the same long-term uniform use of all channels, and therefore RF equipment, as the random allocation scheme. Their improved performance is then not due to the long-term channel use pattern but to the short-term one. In fact, the operation of the proposed scheme guarantees lower instantaneous interference levels, compared to the random allocation mechanism, that result in higher system performance.

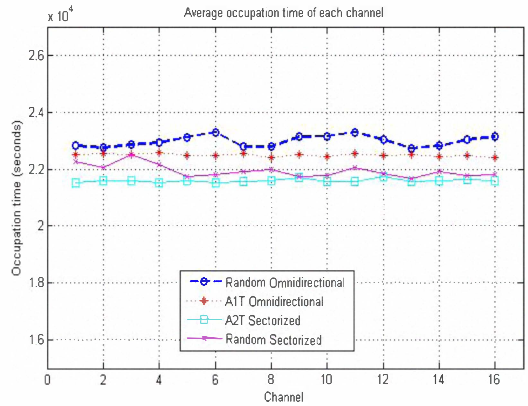

Figure 4. Average channel occupancy

5. Conclusions

This paper has proposed and evaluated a cross-layer channel assignment scheme that bases its allocation decision on the instantaneous received and produced interference levels. The obtained results have demonstrated that the proposed scheme not only improves the system performance, compared to the commonly used random allocation algorithm and other mechanisms previously reported in the literature, but also exhibits a long-term uniform use of all channels and therefore RF equipment.

The implementation cost of the proposed channel assignment scheme is reasonable considering that only a reduced set of base stations should need to exchange channel occupancy information, and that the proposed scheme could be implemented at the Base Station Controllers. It is also important to note that the conducted study has shown that it is not necessary to compute the interference levels but that just estimating them is enough to ensure the highest performance results, which further reduces the implementation cost of the algorithm.

The conducted study has also highlighted the need to modify the proposal's configuration based on the cellular deployment scenario and the type of service that has requested the channel allocation.

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REFERENCES

[1] I. Katzela and M. Naghshineh, "*Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: A Comprehensive Survey*", IEEE Personal Communications Magazine, pp. 10-31, June 1996.

[2] R. Verdone, A. Zanella, L. Zuliani, "*Dynamic channel allocation schemes in mobile radio systems with frequency hopping*", Proc. of the IEEE PIMRC, pp. 157-162, Oct. 2001.

[3] J. Gozalvez and J.J González-Delicado, "*Channel allocation mechanisms for improving QoS in packet mobile radio network*", Electronics Letters, Vol. 41, pp 21-22, Jan. 2005.

[4] Y.F. Leung, "*Adaptive channel allocation methods for distributed MPEG player system over a cellular radio network*", Proc. of the 6th International Conference on RTCSA, pp 220-223, December 1999.

[5] M. Salmenkaita, J. Gimenez, P. Tapia, M. Fernandez-Navarro, "*Optimizing the GSM/EDGE Air Interface for Multiple Services with Dynamic Frequency and Channel Assignment*", Proc. of the IEEE VTC 2002-Fall, pp 2215-2219, Sept. 2002.

[6] M. Cheng and J. Chuang, "*Performance Evaluation of Distributed Measurement-Based Dynamic Channel Assignment in Local Wireless Communications*", IEEE Journal on Selected Areas in Communications, Vol. 14, pp 698-710, May 1996.

[7] J. Gozalvez and J. Dunlop, "*System Performance and Adaptive Configuration of Link Adaptation Techniques in Packet-Switched Cellular Radio Networks*", Computer Networks Journal, Vol. 49, pp 404-426, Oct. 2005.