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Multi-Channel Radio Resource Distribution Policies in Heterogeneous Traffic Scenarios

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Abstract—**Multi-channel operation in wireless systems has been proposed to increase user throughput and reduce transmission delays. However, multi-channel operation requires adequate resource allocation policies to guarantee user fairness and avoid channel access stagnation. The definition of such policies is particularly challenging in heterogeneous traffic scenarios where each traffic service has different quality of service requirements. In this context, this work proposes and evaluates various multi-channel radio resource distribution policies designed to operate under heterogeneous traffic environments. In particular, this paper proposes the application of bankruptcy policies to guarantee user fairness, and compares their performance to other schemes. The proposed policies can also be extended to manage radio resources in heterogeneous wireless systems.**

Keywords-component; Multi-channel, multiple access, resource allocation.

I. INTRODUCTION

The constant increase in mobile subscribers and user Quality of Service (QoS) expectations, and the launch of bandwidth demanding services with varying QoS requirements imposes new challenges for mobile operators that need to efficiently use the scarce available radio resources. Such efficient use is the aim of Radio Resource Management (RRM) techniques. One important RRM technique is multi-channel assignment, where different radio resources (time slots, codes, transmission power, etc) are simultaneously assigned to a given user.

Multi-channel assignment policies have been proposed to increase user throughput and reduce transmission delays. However, when the number of available radio resources is low or the system load is high, adequate mechanisms that consider the user QoS requirements and the operator's policies need to be defined. The work reported in [1] showed that multi-channel distributions schemes that consider all possible distribution patterns result in excessive computational costs that prevent their use in current mobile communications systems. A weighted round robin policy where weights are based on service classes was evaluated in [2]. The obtained results showed the strong performance dependence on the selected user weights, and the need to adapt such weights to the experienced system loads. The use of utility-based channel distribution policies was suggested in [3], where the authors proposed a generic assignment mechanism that distributes the available channels based on throughput-utility functions that considered the experienced channel quality conditions. Other interesting proposals using utility functions based on the price users are willing to pay for radio resources have been presented in [4] and [5]. While the proposal in [4] is defined to maximize an operator's benefit, the Vickrey auctions proposed in [5] were derived to satisfy QoS requirements for constant bit rate services. Techniques seeking to fairly distribute available resources have also been presented in the literature. Of particular interest is the proposal reported in [6]. To establish their channel distribution mechanism, the authors first define the bandwidth needed by a user to guarantee an adequate transmission. Based on such established bandwidths, the proposed scheme equally distributes resources among users. If all users are satisfied and there are yet available resources, such resources are again equally distributed among users. This proposal was used to distribute frequency bands, which represent continuous and infinitively divisible resources; this situation differs from the multi-channel assignment problem dealt within this paper where radio resources (time slots or codes) are discrete.

In this context, this paper proposes an innovative multi-channel assignment approach using bankruptcy theories that complements the previously described techniques. In bankruptcy situations, the value of a company is inferior to the sum of its debts. As a result, adequate methodologies are needed to divide its net value among its creditors [7]. Given the similarity of the problems dealt with by bankruptcy and the multi-channel assignment distribution dilemma, this work proposes the use of bankruptcy rules to define multi-channel assignment policies under heterogeneous traffic scenarios. In addition to the bankruptcy proposals, this paper also introduces a non-utility channel distribution scheme that bases its assignment policy on the required user throughput to guarantee a satisfactory transmission.

II. MULTI-CHANNEL RADIO RESOURCE DISTRIBUTION

To guarantee maximum channel efficiency and user QoS satisfaction levels, this work proposes mechanisms designed to exploit the varying radio resource needs of different service classes. To achieve such objectives, the proposed techniques are based on identifying the radio resources needed per service

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class to achieve certain user QoS satisfaction levels. In fact, achieving a given user QoS satisfaction level for different traffic classes might not require the same number of radio resources, which offers the possibility to exploit the traffic heterogeneity to define efficient multi-channel assignment policies.

A. Utility Functions

Although the establishment of adequate utility functions is key to achieve the defined objectives, it is important to note that user satisfaction is a subjective concept that heavily depends on user perceptions and the service type under consideration; this work considers an heterogeneous traffic scenario composed of email (background), WWW (interactive) and real-time H.263 video transmissions (at 16, 32 and 64kbps mean bit rates). As established within the 3GPP [8], this work considers email and WWW transmissions satisfactory if an email or web page is transmitted in less than 4 seconds. Real-time video transmissions are considered satisfactory if video frames are completely transmitted before the next video frame is to be transmitted. To define the utility functions, this work considers the minimum, mean and maximum user QoS satisfaction levels reported in Table I. Such levels are based on user throughput for web and email transmissions, and on the percentage of correctly transmitted frames for real-time video services.

Due to the length restrictions, this paper does not present in detail the process to obtain the final utility functions per traffic service. However, Fig. 1 reports the utility values employed per traffic service and number of radio resources assigned to a user. Since the EDGE (Enhanced Data Rate for GSM Evolution) radio interface is used to evaluate the proposed techniques, the radio resources correspond to TDMA time slots, and the maximum number of resources that can be assigned to a single user is equal to eight slots. EDGE implements an adaptive radio interface that dynamically varies the used transmission mode (modulation and coding scheme) according to the experienced channel quality conditions. The utility values reported in Fig. 1 have been obtained using the EDGE MCS5 transmission mode (see Section III) that provides a mean bit rate of 22.4kbps per timeslot[1]. As it can be observed from Fig. 1, certain traffic services require more than one radio resource to achieve utility values greater than zero. This is the case because the established QoS levels reported in Table I result in certain traffic services needing more than one radio resource to reach the minimum established QoS levels. Despite not being able to detail how these utility values have been established, the analysis of the results reported in Section IV will highlight their validity.

TABLE I. USER QOS LEVELS

	Min. QoS	**Mean QoS**	**Max. QoS**
WWW	32kbps	64kbps	128kbps
Email	16kbps	32kbps	64kbps
H.263 video	75%	95%	100%
Established utility values	0.95/4	0.95/2	0.95

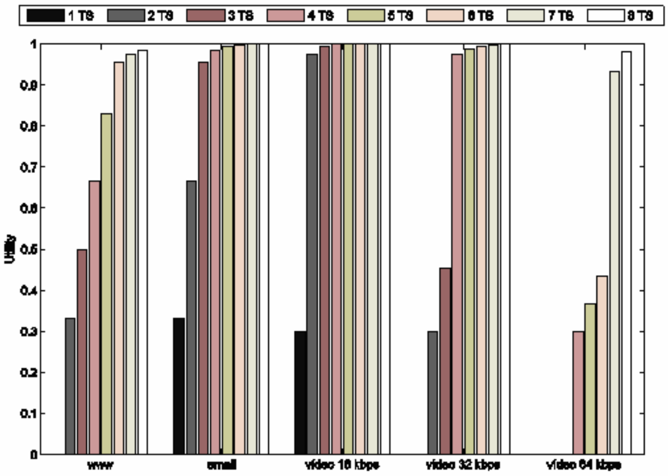

Figure 1. Utility values per traffic service and number of radio resources (TS)

B. Discrete CEA for Mobile radio resources distribution (DCEAM)

Bankruptcy theories designed to distribute a limited number of resources among a large number of creditors, can be considered good candidates to address the multi-channel assignment dilemma in mobile and wireless systems. As a result, this paper evaluates their potential through the use of the Constraint Equal Award (CEA) mechanism [7], originally designed to achieve fair distributions of scarce resources. To define the CEA scheme, let's consider a value $E \in R_+$ that has to be divided among N agents whose value is greater than E. For each $i \in N$, $c_i \in R_+$ represents the resource's request by i, and $c \equiv (c_i)_{i \in N}$ the requests vector. In this context, a resources distribution dilemma is denoted by the pair $(c,E) \in R_+ \times R_+$, such that $\Sigma c_i \geq E$. The CEA scheme assigns the same value of resources to each agent but does not assign more resources than those requested. In the CEA distribution scheme, users with the lowest demands get higher satisfaction levels than those with higher demands. The definition of the CEA distribution rule can then be established as follows: $CEA(c,E) \equiv min\{c,\lambda\}$, where λ is chosen so that $\Sigma min\{c,\lambda\} = E$.

To apply the principles of CEA to the mobile multi-channel assignment problem, this work proposes the definition of the Discrete CEA for Mobile radio resources distribution (DCEAM) mechanism. The original CEA rule tries to equally satisfy each user considering utility values that are directly proportional to the number of assigned resources. On the other hand, the DCEAM proposal is also aimed at trying to equally satisfy all users but considering utility values that are not directly proportional to the number of assigned radio resources.

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[1] System level simulations of the adaptive EDGE radio interface were conducted considering the system scenario reported in Section III. These simulations identified MCS5 as the most widely used transmission mode. However, it is important to note that different system configurations would require a new identification of the mostly used transmission mode and a redefinition of the considered utility values.

This working assumption better represents heterogeneous wireless traffic scenarios where users from different service classes that receive the same number of radio resources might experience unequal QoS satisfaction levels. Also, while CEA considers continuous resources, the DCEAM proposal has been designed to distribute resources of discrete nature (time slots for TDMA systems or codes for CDMA). It is important to note that only recently has been addressed the extension of the CEA rule to handle discrete resources [9]. However, the work reported in [9] also considers utility values that are directly proportional to the number of assigned resources. Considering the established user QoS levels and reported utility values (see Table I and Fig. 1), an equal distribution of service QoS levels results in an unequal distribution of radio resources that is transparent to the end user. If the proposed DCEAM scheme is not able to assign the necessary resources to achieve equal user satisfaction levels due to a high system load or a limited number of available radio resources, it serves users based on the following service priorities: 64kbps video, 32kbps video, 16kbps video, www and email. To achieve its objectives, the DCEAM operation is based on the following rules:

- Radio resources are assigned one by one.
- Each radio resource is assigned to the user with the lowest utility value.
- When different users have the same utility value, a resource is assigned to the highest priority user.

C. *Required dATa ratE (RATE) policy*

Contrary to DCEAM, the proposed Required dATa rate (RATE) scheme does not establish utility functions. Instead, RATE estimates the transmission data rate needed by each user to satisfactorily end its transmission following the 3GPP and real-time QoS requirements defined in Section II.A. Subsequently, the RATE scheme assigns the number of radio resources necessary to achieve the identified data rates. In the case of real-time services, a video frame that is not transmitted before the next frame is generated will be aborted. On the other hand, if a web page is not transmitted in less than 4 seconds, its transmission is not aborted even if the established 3GPP QoS level is not reached. For transmissions that continue beyond the 4 seconds mark, the RATE scheme considers as target data rate, a fixed data rate corresponding to the minimum QoS levels defined in the previous section. Once the required data rates are established, two versions of the RATE proposal have been implemented. In the first one, user requests are served from the higher requested data rate to the lower one, but without considering any service priorities. The second variant of the RATE proposal classifies the user requests per service class, and within each class, applies the previously defined DCEAM rule. In this case, the user requests correspond to the computed data rates and not to the demands based on the previously established utility functions. As per the DCEAM proposal, users are served following the services priorities: real-time video, web browsing and email transmissions.

III. SIMULATION PLATFORM

The performance of the proposed multi-channel assignment policies has been assessed by means of an advanced heterogeneous system level simulation platform named SPHERE (Simulation Platform for HEterogeneous wiREless systems) [10]. The SPHERE platform integrates three advanced system level simulators emulating the GPRS (General Packet Radio Service), EDGE, and HSDPA (High Speed Downlink Packet Access) radio technologies. Although the authors are working on evolving the proposed policies to address the common radio resource management problem in heterogeneous wireless systems, this work concentrates on a single radio interface, in this case EDGE.

SPHERE emulates email, WWW and H.263 real-time video transmissions at the packet level, which allows an accurate evaluation of the final user perceived QoS. The simulation platform implements all EDGE transmission modes (see Table II) and models its adaptive radio interface through the use of Link Adaptation (LA). This technique periodically selects the optimum transmission mode for the experienced channel quality conditions. For non real-time services, the transmission mode that maximises the throughput is selected. For real-time services, the algorithm proposed in [11] has been used. Erroneously received data is retransmitted by means of a selective ARQ protocol, following the specifications reported in [12], for non real-time services; retransmission protocols are deactivated for delay-sensitive real-time services. Table III summarises the macrocellular downlink system configuration considered for this work.

IV. EVALUATION

To analyse the potential of the DCEAM and RATE proposals, their performance is compared against that obtained with static multi-channel assignment schemes. Based on the previously defined utility values, the static mechanisms assign the number of radio resources needed to guarantee minimum, mean and maximum QoS levels as defined in Table IV. If the number of radio resources defined in Table IV is not available, a user served by the static assignment mechanisms is queued. For all channel distribution policies, all channels are re-distributed each time a user requests access to the system or a

TABLE II. TRANSMISSION MODES

Mode	Modulation	Code Rate	Family	Bits per Radio Block	Bit Rate (kbps)
MCS-1	GMSK	0.53	C	1 × 176	8.8
MCS-2	GMSK	0.66	B	1 × 224	11.2
MCS-3	GMSK	0.85	A pad.	1 × 272	13.6
			A	1 × 296	14.8
MCS-4	GMSK	1.00	C	2 × 176	17.6
MCS-5	8-PSK	0.37	B	2 × 224	22.4
MCS-6	8-PSK	0.49	A pad.	2 × 272	27.2
			A	2 × 296	29.6
MCS-7	8-PSK	0.76	B	4 × 224	44.8
MCS-8	8-PSK	0.92	A pad.	4 × 272	54.4
MCS-9	8-PSK	1.00	A	4 × 296	59.2

TABLE III. SYSTEM LEVEL SIMULATION PARAMETERS

Parameter	Value
Simulated cells	25
Cluster size	4
Sectorisation	120º
Interfering cells	1º and 2º tiers co-channel cells
Cellular radio	1 km
Channels per sector	8 (1 carrier)
Users per sector	16: 5 web, 5 email, 2 video 16kbps, 2 video 32kbps, 2 video 64kbps
Mobility	50 km/h user speed
Pathloss	COST 231 Hata
Shadowing	Log-normal with 6dB standard deviation
Channel selection	Random
Scheduling	First Come First Served
ARQ	Window size= 384 RLC blocks ARQ report each 32 RLC blocks
Link Adaptation	Initial LA updating period=60ms LA updating period=100ms

user ends its transmission. However, users with active real-time video transmissions will maintain their assigned radio resources, unless they previously received more resources than needed to guarantee their minimum QoS levels (in this case, only the radio resources corresponding to the minimum QoS level are guaranteed and the user will have to compete with the other users to get additional radio resources). On the other hand, non-real time users are not guaranteed to maintain their previously assigned radio resources. If several users are candidates to receive the same radio resource, these are served based on the previously defined service priorities. The performance of the channel distribution policies is mainly evaluated by means of the user satisfaction parameter, which accounts for the percentage of web pages or emails transmitted in less than 4 seconds and the percentage of video frames transmitted before the next frame is to be transmitted.

Tables V and VI report the user satisfaction levels that can be achieved with the proposed channel distribution policies under the high system load scenario defined in Table III. The obtained results clearly highlight the inefficiency of static multi-channel assignment policies, in particular for real-time services with higher QoS and radio resources demands. On the other hand, the DCEAM proposal achieves high user satisfaction levels for the real-time users. In fact, the established service priorities resulted in more than, on average, 90% of video users receiving radio resources during each channel distribution round (see Table VII). It is also interesting to note that these users received, on average, the number of radio resources required to guarantee their minimum QoS levels. The achieved real-time performance is obtained at the expense of web or email services that are more poorly served[2]. To understand these observations, it is important to note that at the beginning of a channel distribution process, most users will have a utility value equal to zero (except for previously active video users that maintain their assigned radio resources). Consequently, priorised real-time users will first be served until being assigned the radio resources needed to achieve the minimum QoS levels, which explains why experiencing a low percentage of unsent video frames. As a result, only when priorised users receive such radio resources, will interactive and background services be served. Considering the emulated high system load and the low number of radio resources per sector, only a limited number of radio resources are then available for interactive and background services. The emulated conditions also explain why users tend to be served with the resources equivalent to their minimum QoS requests. Such minimum resources result in low user throughputs and increased transmission durations. The extended user transmission durations result in a high number of competing users at each channel distribution round, which explains the observed channel access stagnation for low priority users. Low user throughputs are also at the origin of the measured percentage of video frames that need to be aborted. The DCEAM performance for interactive and background services could be improved if the established 3GPP QoS requirements were relaxed. For example, 63% and 70% web user QoS satisfaction levels could be achieved if the transmission of a web page was considered satisfactory for transmission lengths below 5 and 6 seconds respectively. Alternatively, user waiting times could be considered in the channel distribution process to improve the interactive and background QoS performance. The modified DCEAM proposal reported in Table VI is based on the DCEAM principles, but assigns the radio resources to the users experiencing the highest waiting times when competing users are characterized with equal utility values. The results depicted in Tables VI and VIII highlight that considering users waiting times helps increasing service fairness at the expense of reducing the QoS levels for the most demanding services, although they still maintain homogeneous QoS levels.

Table VI also depicts the performance achieved with the two versions of the RATE proposal. The results obtained show that not considering service priorities considerably degrades the performance of real-time services in favor of interactive and background services. However, the observed non-real-time performance improvement is not proportional to the real-time performance degradation. The achieved user satisfaction levels per service class actually reflect the requested data rates and corresponding service order. On the other hand, DCEAM and the second version of the RATE proposal achieve similar results. This observation is very significant since it indicates that the established DCEAM utility functions adequately reflect the user needs, which validates the procedure employed to define them. Although achieving very similar results, the RATE proposal needs to compute in real-time, and for each distribution round, the user required data rates. On the other hand, the DCEAM proposal is based on an offline process that requires an adequate tuning but reduces the real-time computational costs.

V. CONCLUSION

This work has proposed different techniques to address the multi-channel distribution problem in heterogeneous traffic scenarios. The proposed techniques are based on previously established utility functions or on the real-time throughput

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[2] The web and email services QoS degradation is due to the fact that no limit on the mean waiting time was established.

needs of active users. The obtained results have highlighted the importance of adequately defining the utility functions, and of establishing service priorities that are in accordance with the operator's policies. The research conducted has also demonstrated the potential of the bankruptcy techniques to address radio resource management problems. The authors are now working on extending these promising policies to address the radio resource management problem in heterogeneous 4G wireless systems.

TABLE IV. RADIO RESOURCES FOR STATIC ASSIGNMENT POLICIES

	Web	**Email**	**16kbps video**	**32kbps video**	**64kbps video**
Min QoS	2	1	1	2	4
Mean QoS	3	2	2	4	7
Max QoS	6	3	4	8	8

TABLE V. USER SATISFACTION (%) WITH STATIC SCHEMES

	Min QoS	**Mean QoS**	**Max QoS**
Web	79.38	79.99	76.32
Email	66.05	77.22	70.59
16kbps video	74.88	81.11	43.42
32kbps video	57.17	38.22	23.20
64kbps video	25.93	9.93	22.11

TABLE VI. DCEAM AND RATE USER SATISFACTION (%)

	DCEAM	**Modified DCEAM**	**RATEv1**	**RATEv2**
Web	53.02	60.31	60.08	46.38
Email	13.42	44.27	25.02	10.09
16kbps video	86.42	70.91	34.93	89.91
32kbps video	87.43	71.08	62.37	88.54
64kbps video	86.81	70.45	78.25	85.15

TABLE VII. DCEAM PERFORMANCE [a]

	Mean through put (kbps)	**Mean waiting time (seconds)**	**nº of assigned slots**	**% of aborted frames**	**% of unsent frames**	**% of served users**
Web	54.15	5.3321	1.86	-	-	38.12
Email	34.88	91.8317	1.16	-	-	6.79
16kbps video	25.18	0.0171	1.08	10.51	3.07	86.53
32kbps video	46.53	0.0137	2.02	11.51	1.44	90.90
64kbps video	82.24	0.0085	3.71	13.08	0.12	97.36

a. The mean transmission time corresponds to the time elapsed between the resources request and the end of transmission. The mean waiting time accounts for the time the user waits for resources to be assigned. The implemented real-time video model aborts a video frame if its transmission is not ended before the next video frame is to be transmitted. For long waiting times, it can also occur than that a video user never gests resources for a video frame to be transmitted. The percentage of served users reflects the ratio of users that are assigned radio resources with respect to the total number of users requesting channels.

TABLE VIII. MODIFIED DCEAM PERFORMANCE

	Mean through put (kbps)	**Mean waiting time (seconds)**	**Nº of assigned slots**	**% of aborted frames**	**% of unsent frames**	**% of served users**
Web	55.95	3.4728	1.97	-	-	47.48
Email	32.82	7.9923	1.13	-	-	44.11
16kbps video	26.21	0.0426	1.22	15.12	13.97	64.48
32kbps video	46.00	0.0389	2.11	16.86	12.06	69.16
64kbps video	80.24	0.0309	3.65	19.73	9.82	74.47

REFERENCES

[1] E. Vivier, M. Terré, B. Fino, "Determination of all possible resource allocations in a packet communication network", in Proc. of the IEEE Vehicular Technology Conference, September 2002, pp. 2346-2350.

[2] A. Kuurne, D. Fernández, R. Sánchez, "Service based prioritization in (E)GPRS radio interface", in Proc. of the IEEE Vehicular Technology Conference, September 2004, pp. 2625-2629.

[3] P. Y. Kong, D. He, "An efficient resource allocation scheme for time-sensitive traffic in wireless networks", in Proc. of the IEEE PIMRC conference, 7-10 September 2003, pp. 2312-2316.

[4] C. Zhou, D. Qian, N.Pissinou, K. Makki, "Resource allocation based on pricing for wireless multimedia networks", in Proc. of the IEEE WCNC conference, 21-25 March 2004, pp. 477-482.

[5] M. Dramatinos, G. D. Stamoulis, C. Courcoubetis, "Auction-based resource allocation in UMTS high speed downlink Packet Access (HSDPA)", in Proc. of the Next Generation Internet Networks conference, 18-20 April 2005, pp. 434-441.

[6] A. Malla, M. El-Kadi, S. Olariu, P. Todorova, "A fair resource allocation protocol for multimedia wireless networks", *IEEE Transactions on Parallel and Distributed Systems*, vol.14, pp. 63-71, January 2003.

[7] W. Thomson, "Axiomatic and game-theoretic analysis of bankruptcy and taxation problems: a survey", *Mathematical Social Sciences*, vol. 45, pp 249-297, 2003.

[8] 3GPP, Services and service capabilities, 3GPP TS 22.105, version 6.3.0, 2005.

[9] C. Herrero and R. Martinez, "Balanced allocation methods for claims problems with indivisibilities", CORE Discussion Paper 2006/66, July 2006. Available at SSRN: http://ssrn.com/abstract=944416

[10] M. López-Benítez, M. Lucas-Estañ and J. Gozalvez, "A dynamic radio simulation platform for the study of radio resource management techniques in heterogeneous wireless systems", in Proc. of the 9th ACM/IEEE MSWIM conference (Demos Session), October 2006.

[11] J. Gozálvez, M. López-Benítez and O. Lázaro, "Link adaptation algorithm for improved wireless transmission of delay-sensitive packet data services", *Electronic Letters*, pp 813-815, July 2005.

[12] 3GPP, General Packet Radio Service (GPRS); Mobile Station (MS) - Base Station System (BSS) interface; Radio Link Control/Medium Access Control (RLC/MAC) protocol, 3GPP TS 44.060, version 3.10.0, 2005.