CRRM Strategies for Improving User QoS in Multimedia Heterogeneous Wireless Networks

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***Abstract*— The design of efficient Common Radio Resources Management (CRRM) techniques is a crucial aspect to enable the foreseen coexistence and cooperation of heterogeneous Radio Access Technologies in Beyond 3G wireless networks. In this context, this paper proposes a set of CRRM strategies designed to satisfy multimedia users with diverse QoS requirements while efficiently using the radio resources.**

***Keywords*— Common Radio Resources Management, Heterogeneous wireless networks.**

I. Introduction

Beyond 3G wireless networks are expected to promote the coexistence and cooperation of a wide variety of Radio Access Technologies (RATs) with diverse but complementary technical characteristics. This coexistence and seamless integration is expected to improve the overall system capacity and user perceived Quality of Service (QoS) through a more intelligent and flexible network management. To achieve these objectives, a key component of heterogeneous Beyond 3G wireless systems is the Common Radio Resource Management (CRRM). CRRM policies can be in charge of assigning an incoming call the most suitable RAT (RAT selection), and decide the number of radio resources to be assigned within the selected RAT (intra-RAT RRM) to satisfy the user/service QoS demand. Over the past years, several CRRM policies have been proposed. For example, the authors in [1] present a simple technique where incoming calls are assigned to a pre-defined RAT according to their service type. Load balancing techniques distributing traffic among various RATs were proposed in [2]. Other proposals define the RAT selection process using utility functions where certain RAT performance metrics need to be maximised (e.g. [3]). Initial proposals to jointly address the RAT selection and intra-RAT RRM have also been recently published. For example, the authors in [4] propose a CRRM algorithm based on neural networks and fuzzy logic that simultaneously determines the most appropriate RAT and its bit rate allocation. The work reported in [5] proposes a set of innovative CRRM techniques based on linear programming optimization, that select the optimum RAT and number of radio resources within such RAT to guarantee the user QoS requirements. Most of previous studies on CRRM and RAT selection have mainly focused on maximizing the overall system capacity. On the other hand, this paper presents a set of CRRM policies designed to assign incoming users to RATs capable to satisfy their QoS requirements. While all the proposed CRRM policies are aimed at guaranteeing such QoS demands, their implementation strategy varies and tries to balance performance, potential risk of RATs saturation and load distribution across the present RATs.

II. CRRM Strategies

This work proposes a set of initial RAT selection techniques designed to select the optimum RAT over which to convey an incoming call. The techniques are aimed at guaranteeing a pre-established satisfaction level that is defined based on the requested service and the user contract. The proposed techniques have been developed to operate in heterogeneous and multimedia traffic environments. In this context, this work considers a multi-RAT scenario simulating the HSDPA (High-Speed Downlink Packet Access), EDGE (Enhanced Data Rates for GSM Evolution), and GPRS (General Packet Radio Service) standards. The emulated environment considers H.263 real-time video (with different bit rates), email and web users, that are offered the possibility to choose between Gold, Silver or Bronze contracts. The Gold contract is the most expensive one but also the one guaranteeing higher user QoS levels. To define the pre-established satisfaction levels, this work follows the 3GPP specifications where web pages and emails are considered satisfactorily transmitted if their transmission ends in less than 4 seconds [6]. To differentiate among different contract types, the QoS requirement for Gold, Silver and Bronze email and web users is that a transmission is ended in less than 2, 3 and 4 seconds respectively. The satisfaction level is then defined as the percentage of web or email transmissions that satisfy the defined QoS requirement. The real-time H.263 video operation entails that a video frame is satisfactorily transmitted if its transmission ends before the next video frame needs to be transmitted. In this case, Gold, Silver and Bronze users are distinguished by their mean video bit rates (64kbps, 32kbps and 16kbps respectively). The real-time video user's satisfaction level is then defined as the percentage of video frames transmitted before the next video frame needs to be transmitted.

A. USaBS algorithm

Following the previous definitions, the first CRRM proposal, named USaBS (User Satisfaction Based Selection), computes the incoming call's *Demand*, which corresponds to the throughput necessary to guarantee its requested satisfaction level. The *Demand* is computed per user contract and traffic service using the simulated traffic models. To this aim, the throughput necessary to satisfactorily transmit a large number of objects is computed, and a cumulative distribution function (cdf) is derived. The throughput necessary to achieve a given satisfaction level, defined as a percentage of objects satisfactorily transmitted following their QoS requirement, is then easily extracted from the derived throughput cdf. This throughput represents the incoming call's *Demand*.

To decide the optimum RAT over which to convey an incoming call characterized by a given *Demand*, USaBS computes the estimated throughput, referred to as *Offer*, that each RAT is capable to achieve for a percentage of emails, webs or video frames. The *Offer* computation is based on the throughput that each RAT was capable to achieve in previous transmissions, normalized to the number of assigned radio resources per user. The *Time Limit* parameter has been defined to filter these throughput estimates, and only use for the *Offer* computation those that were achieved under system and RAT conditions close to those experienced at the time of computing the RAT's *Offer*. A cdf of the filtered throughput estimates for previous object transmissions is then derived per service and RAT. The RAT's *Offer* is then extracted from the throughput cdf as the minimum throughput guaranteed to a given percentage of objects. Such percentage needs to be carefully selected to provide reliable estimates of the RAT's performance. In fact, a too high percentage would underestimate the RAT's capabilities, while a too low one would overestimate them[1].

Once the *Demand* and *Offer* are estimated, USaBS assigns each incoming call a RAT providing an *Offer* higher than the call's *Demand*. Since different RATs might be able to provide an *Offer* higher than the call's *Demand*, three different CRRM strategies have been implemented. The USaBS proposal assigns the incoming call the RAT providing the lower *Offer* that is higher than the call's *Demand*. This approach has been implemented to prevent low *Demand* users to unnecessarily saturate the high performance RATs. Such RATs can then be 'reserved' for high demanding users that could not be satisfied with low *Offer* RATs.

The USaBS technique has been designed to efficiently operate in a multi-RAT environment, where each RAT is characterized by diverse intra-RAT RRM capabilities. In the simulated environment, HSDPA implements more advanced and short-time response RRM techniques than GPRS and EDGE. For example, HSDPA implements advanced scheduling techniques capable to quickly combat bad CRRM decisions or changes in the system conditions. To overcome the intra-RAT operating differences in terms of their capacity to overcome potential bad CRRM decisions or changes in the system operating conditions, USaBS further interacts with GPRS and EDGE by defining in its RAT assignment decision the maximum number of channels or TimeSlots (TS) that a new incoming GPRS or EDGE user could simultaneously employ for its entire traffic session (USaBS operates at the session level). Once a GPRS or EDGE user starts an object transmission in a traffic session, it will request the maximum number of channels that it can simultaneously use as established by the USaBS protocol. If such number is not available at this time, the intra-RAT RRM protocol will assign all available channels. In this context, it is important to note that GPRS or EDGE users that were assigned a high maximum number of simultaneous channels by USaBS could suffer to achieve their *Demand*, since the probability that a large number of channels is simultaneously available is relatively low. To avoid this potential drawback if the RAT is saturated, a multi-channel assignment penalty is introduced to limit the GPRS and EDGE channel occupancy. Limiting the occupancy will in turn increase the probability that the maximum number of channels identified by the USaBS RAT assignment is simultaneously available, and that the assigned RAT can satisfy the incoming user. To define the penalty, USaBS estimates the RAT's channel occupancy that would be generated by the currently active users and the incoming one. The occupancy per user is estimated by multiplying the number of channels employed by each user and the user's channel activity. In the case of the incoming call, the number of channels is equal to the maximum number of channels a user could simultaneously employ as identified by USaBS. The channel activity is statistically computed as the time a user is on average transmitting over a channel with respect to its entire session duration. The average number of occupied channels is the result of adding the occupancy for all active users and the incoming one. If the result surpasses a defined limit, named *Occupancy Limit*, USaBS does not assign to the incoming call the initially identified maximum number of simultaneous channels of the RAT under evaluation. This RAT could still be assigned if it can satisfy the user's *Demand* with a maximum number of simultaneous channels that would not result in surpassing the *Occupancy Limit*.

B. USaLoR algorithm

The second implemented CRRM policy, named USaLoR (User Satisfaction with Low Resources selection), is a variant of the USaBS proposal that tries to reduce the radio resources needed by a RAT to satisfy the incoming user's *Demand*. To this aim, USaLoR assigns the incoming call to a RAT providing an *Offer* higher than the call's *Demand*, and minimizing the product of its *Offer* and the number of radio resources it needs to assign the incoming user to achieve its *Offer*. This proposal has been implemented to avoid saturating low performance RATs that require using a large number of radio resources to achieve their *Offer* and satisfy a single incoming call. To this aim, the number of radio resources in GPRS and EDGE is equal to the number of required timeslots to achieve the RAT's *Offer*. For HSDPA, the number of radio resources has been considered equal to one, since the implemented Round-Robin scheduling policy equally distributes all available codes between the active HSDPA users. It is interesting to note, that if two RATs provide the same *Offer* to an incoming call, the proposed USaLoR technique will assign the incoming call to the RAT requiring less radio resources to achieve its *Offer*. As a result, USaLoR tends to assign high demanding users to high performing RATs that do not need to saturate their bandwidth to serve a limited number of users.

[1] The underestimation could result in a low usage of low performance RATs, while the overestimation could produce RAT assignments that are not really capable to provide the user's *Demand*.

C. USaMOS algorithm

The third proposed CRRM policy, named USaMOS (User Satisfaction with Minimum Occupancy Selection), assigns an incoming call to the RAT providing an *Offer* that is higher than the call's *Demand*, and experiencing the lowest channel occupancy with respect to its maximum capacity. The GPRS and EDGE channel occupancy and *Occupancy Limit* are computed following the methodology described in Section II. A. For HSDPA, a similar procedure is followed to estimate the channel occupancy, except that all the HSDPA codes are considered a single communications resource, and the channel occupancy is then equal to the HSDPA users channel activity, as computed for USaBS. In HSDPA, incoming users share the available codes with active users as established by the Round-Robin scheduling policy. In this case, the HSDPA *Occupancy Limit* must be set to guarantee a high performance and optimum resources usage. A high limit would increase the HSDPA availability, which will result in a higher number of users assigned to HSDPA, a lower bandwidth available to each one of them, and higher interference levels. On the other hand, a too low limit would underutilise HSDPA and over utilise the other RATs, thereby increasing their interference levels and reducing their performance. In this context, the USaMOS technique defines different *Occupancy Limits* to each user contract. In particular, higher limits are defined for the more demanding users so that they have easier access to HSDPA. In this work, the *Occupancy Limit* has been set to 2/3, ½ and 1/3 for Gold, Silver and Bronze users respectively.

USaMOS is aimed at uniformly distributing the system load among the available RATs. As reported in [2], a uniform load distribution reduces the interference and the vertical handover probability, which in turn increases the system capacity. In fact, a uniform load distribution among RATs helps guaranteeing the continuous bandwidth availability in every RAT, which can be useful to avoid vertical handovers whenever mobiles move across the heterogeneous network and not all the RATs have continuous coverage.

III. SPHERE SIMULATION PLATFORM

To analyze the performance and operation of the proposed CRRM policies, this work uses the multi-RAT SPHERE (Simulation Platform for HEterogeneous wiREless systems) simulation platform [7], a system level and event-driven tool capable to simultaneously emulate the GPRS, EDGE and HSDPA standards. The platform simulates a 27 omnidirectional cellular layout, with 500m radius cells offering GPRS, EDGE and HSDPA coverage. A reuse factor of three has been implemented for GPRS and EDGE. A 3km/h macro-cellular mobility model has been implemented, but users are bounded to a specific cell. Each simulated RAT has been assigned a single frequency carrier per cell, which results in eight channels, or timeslots, for GPRS and EDGE, and fifteen channels, or codes, for HSDPA. GPRS and EDGE channels are assigned in a First Come First Served basis, while HSDPA implements a Round-Robin scheduling policy. All three RATs implement their own Link Quality Control mechanisms to adapt their error protection and data rates to the existing channel quality conditions.

SPHERE emulates a multimedia traffic environment with email, web and real-time H263 video users. The scenario comprises 42 users per cell, with each traffic type representing a third of the cell load. Each traffic type is simulated at the session level, with the session arrival modeled through a Poisson process [8]. The session duration is modeled by Poisson, geometric and exponential distributions for email, web and H.263 users respectively. The session arrival rate has been set to 0.08 sessions per second for the email service, and 0.09 sessions per second for the web and H.263 services. The traffic models have been configured to simulate an average of four emails per session, five web pages per session, and an average H.263 video session duration of fifteen seconds. Erroneously received data is retransmitted using a selective-repeat ARQ protocol for GPRS and EDGE, and a 4-channel Stop-And-Wait protocol for HSDPA.

SPHERE models the pathloss by means of the Okumura-Hata COST 231 model, and the shadowing through a log-normal distribution with 6dB standard deviation. To reduce the complexity of system level simulations, the physical layer effects resulting from the probabilistic nature of the radio environment have been included by means of Look-Up Tables, extracted from link level simulations and mapping the Packet Error Rate to the experienced channel quality conditions.

IV. PERFORMANCE EVALUATION

The proposed CRRM policies have been evaluated considering a GPRS and EDGE *Occupancy Limit* equal to six channels or timeslots (the maximum being eight). The *Time Limit* parameter has been set equal to 120 seconds for web and email services, and 30 seconds for the H.263 video service. Different values have been chosen given the bursty traffic nature of web and email services. The optimization of the *Occupancy Limit* and *Time Limit* parameters is out of the scope of this paper due to space limitations. The *Demand* of an incoming user is equal to the throughput necessary to guarantee its requested satisfaction level, defined as the percentage of web, email or H.263 transmissions satisfying its contract QoS requirements. The selection of the *Demand* satisfaction levels can be tailored to different system strategies. In this study, the satisfaction levels have been set to 61%, 90% and 99% for email, web and H.263 video services respectively. The SPHERE email traffic model simulates emails with and without attachment. In this case, the selected 61% email satisfaction level guarantees that 100% of emails without attachment are satisfactorily transmitted. More strict satisfaction levels have been defined for web and video services given their interactive and real-time nature. To derive the RAT's *Offer*, this paper considers the minimum throughput guaranteed to 80% of the previous object transmissions.

Figure 1 shows the obtained satisfaction levels by the proposed CRRM strategies per service and contract type; the horizontal line indicates the defined objective satisfaction levels per traffic service. The obtained results show that

USaBS is capable to fully guarantee the objective satisfaction levels for email and web services independently of their contract type. In addition, USaBS achieves a similar performance for all contract types, which emphasizes its user and service fairness. Despite achieving high satisfaction levels for the H.263 service, USaBS does not seem to be capable to fully guarantee its objective satisfaction levels. It is worthwhile noting that the defined H.263 objective satisfaction levels are probably too ambitious and that they can be slightly reduced without compromising the H.263 video quality. However, the unexpected H.263 USaBS performance is not due to a design flaw, but to inadequate RAT assignment decisions resulting from the adaptive operation of HSDPA. As shown in Figure 2 for web services, USaBS assigns more frequently the higher performance RATs (i.e. HSDPA and GPRS-EDGE with a large number of simultaneous channels or timeslots - TS) to contract types with more strict QoS requirements (i.e. Gold users). On the other hand, users with lower QoS requirements are generally assigned to less performing RATs. Figure 2 depicts the USaBS RAT selection assignments per contract type, grouping the GPRS and EDGE multi-channel RAT assignments for clarity. The same trend was observed for email users. On the other hand, the conducted simulations have shown that certain H.263 Gold users are assigned to low performance RATs that are not capable to satisfy their *Demands*. For example, 3.39% of Gold H.263 sessions were assigned to GPRS with a maximum of four timeslots, which is clearly inadequate given the low GPRS data rates and the high H.263 QoS and bandwidth requirements. The reason for this undesired behavior lies in the aggressive operation of the HSDPA Adaptive Modulation and Coding (AMC) scheme. This scheme is in charge of continuously selecting the transmission mode based on the experienced channel quality conditions. An aggressive operation of the AMC technique would result in the continuous selection of transmission modes with high data rates but low error protection capabilities that can result in a very low HSDPA throughput performance. This behavior reduces the HSDPA *Offer*, and results in inadequate RAT assignment decisions. In fact, it is important to note that USaBS assigns an incoming user to the RAT offering the higher *Offer*, even if not sufficient, if no other RAT can provide an *Offer* higher than the incoming user's *Demand*. In this case, a low HSDPA *Offer* results in inadequate H.263 RAT assignments not capable to guarantee the objective satisfaction levels. As it will be shown later, reducing the percentage of inadequate RAT assignments derived from the aggressive operation of the HSDPA AMC mechanism improves the objective satisfaction levels. Further optimizing the AMC operation will then allow USaBS to achieve its objective satisfaction levels for the more demanding users.

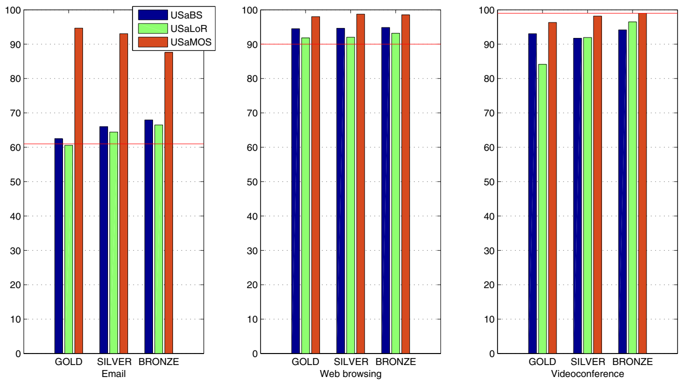

Fig. 1. Average satisfaction level (%) per service and contract type.

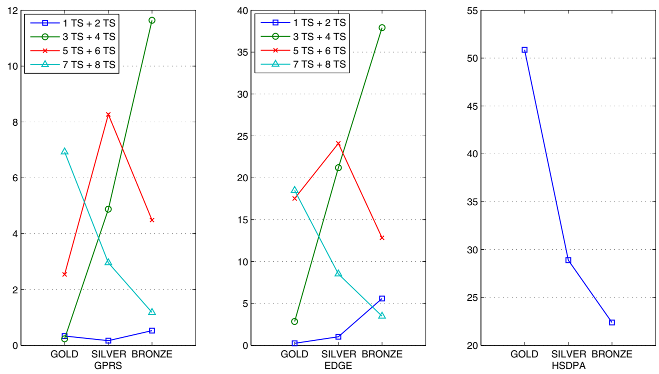

Fig. 2. USaBS RAT assignments (in %) per contract type for the web service.

The USaLoR technique was designed to avoid saturating low performance RATs that require assigning a large number of radio resources to a single user to provide an *Offer* that satisfies the user's *Demand*. The obtained results confirm that USaLoR reduces the probability to saturate low performance RATs, since the number of users assigned to GPRS or EDGE with five to eight simultaneous channels has been reduced by 3.6% and 7.7% respectively compared to USaBS. On the other hand, the number of users assigned to GPRS or EDGE with a maximum of four simultaneous channels remains stable for GPRS and increased by 5.3% for EDGE. The USaLoR HSDPA session assignments have also increased by 6.1% with respect to USaBS. The observed USaLoR behavior has been achieved at the expense of slightly reducing the mean satisfaction level, although it is still remains above the objective satisfaction levels for data transmissions (Figure 1).

The USaMOS CRRM technique was designed to assign an incoming call to the RAT providing an *Offer* that is higher than the call's *Demand*, and experiencing the lowest channel occupancy with respect to its *Occupancy Limit*. The technique was aimed at distributing the system load among the available RATs. Figure 3 compares the average RAT channel occupancy for the three proposed CRRM policies. As it was intended, USaMOS achieves a more uniform average load distribution among the simulated RATs.

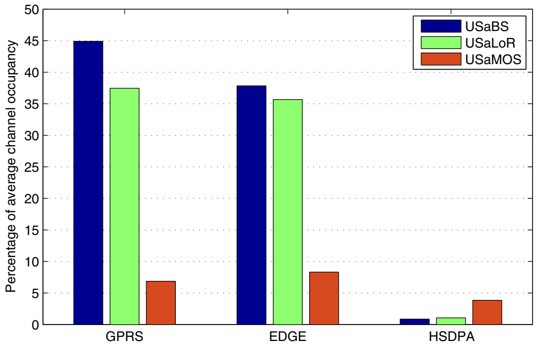

Fig. 3. RAT average channel occupancy (in %).

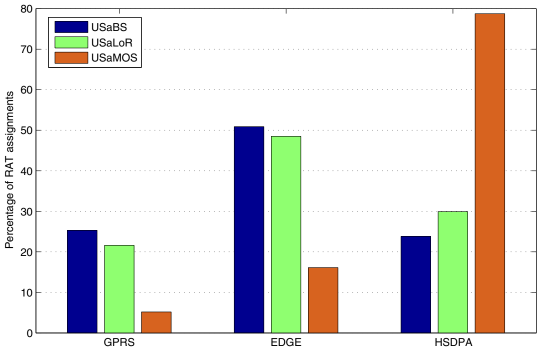

Fig. 4. Percentage of RAT assignments.

The results depicted in Figure 4 show that USaMOS is capable to guarantee a uniform load distribution among the simulated RATs by significantly increasing the number of sessions assigned to HSDPA. This is due to the significant differences in terms of bandwidth and transmission capacities offered by HSDPA, EDGE and GPRS. The load distribution achieved with USaMOS reduces the load and interference in the low performing RATs, which increases their performance. The improved GPRS and EDGE performance results in higher satisfaction levels (Figure 1). The satisfaction level improvements obtained with USaMOS with respect to USaBS vary with the traffic service and contract type. The major improvements are observed for the email users, which significantly increase their HSDPA assignments with respect to USaBS. For example, while only 2.3% of Gold email sessions were assigned to HSDPA with USaBS, this percentage increases to 95% with USaMOS. Despite offering a throughput performance much higher than needed, USaMOS assigns the majority of email sessions to HSDPA to balance the traffic load among RATs. The USaMOS improvements for the remaining traffic services are not so significant, although it is worthwhile highlighting that USaMOS achieves a performance closer to the objective satisfaction levels for the most demanding users, i.e. real-time H.263 video users. This improvement is mainly due to the reduction in the percentage of inadequate RAT assignments resulting from the HSDPA AMC aggressive operation (Table I). In fact, the results depicted in Table I show that increasing the HSDPA assignments does not always result in improving the satisfaction level, while a higher percentage of inadequate RAT assignments always reduces the obtained satisfaction. These results clearly indicate that the performance of the proposed CRRM policies would be further improved if the HSDPA AMC operation is optimised.

TABLE I. H.263 GOLD PERFORMANCE (IN %)

Technique	USaBS	USaLoR	USaMOS
Satisfaction level	93.05	84.12	96.31
Inadequate RAT assignments	3.39	7.57	0.96
HSDPA assignments	52.05	70.28	71.23

V. CONCLUSIONS

This paper has proposed and evaluated a set of CRRM policies designed to assign incoming calls to RATs capable to satisfy their QoS demands. The policies differ in their implementation strategy, and try to balance performance, load distribution and the saturation of low performance RATs. The developed CRRM techniques have been tested in a multimedia environment, and the obtained results have shown that their RAT assignment decisions generally tend to satisfy the user QoS demands. In addition, the conducted study has highlighted that the performance of the developed techniques could be further improved by optimizing the adaptive operation of intra-RAT RRM mechanisms.

ACKNOWLEDGMENTS

This work has been supported by the Spanish Ministry of Science and Innovation, the Spanish Ministry of Industry, Tourism and Commerce and FEDER funds under the projects TEC2005-08211-C02-02, TEC2008-06728 and TSI-02400-2008-113.

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