User Satisfaction Based CRRM Policy for Heterogeneous Wireless Networks

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***Abstract*— Beyond 3G wireless networks are characterised by the coexistence and cooperation of heterogeneous Radio Access Technologies (RAT), which requires the design of adequate Common Radio Resources Management (CRRM) techniques capable to exploit their varying characteristics and efficiently use their scarce radio resources. In this context, this paper proposes a novel CRRM initial RAT selection algorithm (USaBS – User Satisfaction Based Selection) designed to provide and guarantee users with a pre-established Quality of Service satisfaction level defined according to their contract and service type.**

I. INTRODUCTION

There is a wide consensus in the research community that Beyond 3G wireless systems will be based on a variety of Radio Access Technologies (RATs) with complementary technical characteristics that will physically coexist in a seamless integrated environment. In this context, an important challenge is how to exploit in a coordinated manner the RATs' radio resources to provide users with their required Quality of Service (QoS) levels while maximising each RAT system revenues. To achieve these objectives, important research activities have been conducted to define and optimise Common Radio Resource Management (CRRM) policies that are in charge of deciding for each incoming call, the RAT over which it will be conveyed (RAT selection) and the number of radio resources within the selected RAT (intra-RAT RRM) that will be necessary to satisfy the user/service QoS requests.

Several CRRM techniques have been proposed in the literature. For example, the authors in [1] proposed 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 contributions such as those reported in [3] and [4] address the RAT selection process using utility functions looking to maximise certain RAT performance metrics. Most of the published studies separately address the RAT selection and intra-RAT RRM policies. However, initial proposals to jointly address them have been recently published. For example, the authors in [5] propose a CRRM algorithm based on neural networks and fuzzy logic that simultaneously determines the most appropriate RAT and bit rate allocation. [6] proposes a set of innovative CRRM techniques based on linear programming optimization that simultaneously assigns to each user an adequate combination of RAT and number of radio resources within such RAT to guarantee the user/service QoS requirements. It is important to emphasize that previous studies on CRRM and RAT selection have mainly focused on maximizing the overall system capacity, while the design of strategies from the QoS-provision viewpoint has received less attention. In this context, this paper presents USaBS (User Satisfaction Based Selection), a novel CRRM RAT selection technique designed to assign incoming calls to available RATs capable to provide the user QoS requirements. The novelty of the proposed technique lies mainly in the estimation of the user's QoS demand and the RAT transmission capabilities, although the proposed technique is also capable to interact with some intra-RRM functionalities.

II. USER SATISFACTION BASED SELECTION CRRM POLICY

The proposed USaBS algorithm is an initial RAT selection technique designed to select the optimum RAT over which to convey an incoming call. The technique is aimed at guaranteeing a pre-established satisfaction level that is defined based on the requested service and the user contract.

A. Operation

To illustrate the operation and performance benefits of the USaBS proposal, this work considers a multimedia traffic environment with H.263 real-time video (with different bit rates), email and web users. The users can choose between Gold, Silver or Bronze contracts, with the Gold contract being the most expensive one but also the one guaranteeing higher user QoS (Quality of Service) levels. As it could be expected, the higher the QoS demand, the higher the number of radio resources needed to satisfy it. To define the pre-established satisfaction levels over which the USaBS proposal is based, this work follows the 3GPP specifications where web and email transmissions are considered satisfactorily transmitted if their transmission ends in less than 4 seconds [7]. To differentiate among different contract types while guaranteeing the 3GPP specifications, the QoS requirement for email and web users is that an email or web transmission is ended in less than 2, 3 and 4 seconds for Gold, Silver and Bronze users 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 the transmission of a video frame is satisfactory if it ends before the next video frame needs to be transmitted. Video user contracts are distinguished by their mean video bit rates, with Gold, Silver and Bronze users transmitting at an average bit rate of 64kbps, 32kbps and 16kbps respectively. Following the web and email satisfaction level definition, the real-time video user's satisfaction level is defined as the percentage of video frames transmitted before

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the next video frame needs to be transmitted. In this case, the differences among Gold, Silver and Bronze users lie in that the higher the video mean bit rate, the stricter the QoS requirement would be to reach the same satisfaction level.

Once the satisfaction criteria and level per service and user contract have been established, the USaBS CRRM policy computes the *Demand*, which represents the throughput necessary to guarantee the requested satisfaction level by the incoming call. To clarify the *Demand* estimation, let's consider the case of Gold email users that require an email transmission to be finished in less than 2 seconds. To achieve this objective, the necessary throughput is estimated as a function of the email size and the contract-dependent QoS requirement[1]:

$$Throughput = \frac{Email\ size}{QoS\ requirement(user\ contract)}$$

This throughput is then computed for a large number of email transmissions using the simulated traffic model, and we derive a cumulative distribution function (cdf) of the estimated throughput necessary to satisfy the established QoS requirement. Figure 1 illustrates this cdf for Gold, Silver and Bronze email users. According to Figure 1, if we now define a satisfaction level equal to 85% of the Gold email transmissions ending in less than 2 seconds, the throughput necessary to achieve such satisfaction level, or *Demand*, is then estimated to be equal to about 200kbps.

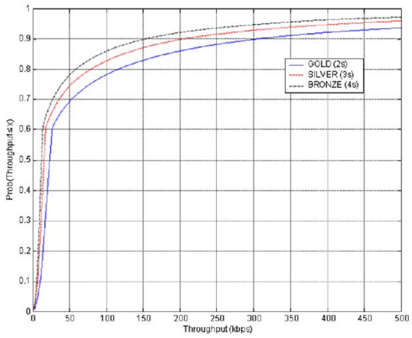

Fig. 1. Estimated throughput cdf for the email service.

To decide the optimum RAT over which to convey an incoming call characterized by a given *Demand*, USaBS then computes the estimated throughput, referred to as *Offer*, that each RAT is capable to achieve for a percentage of emails, webs or video frames. In order to account for the system and recent operating conditions, the *Offer* computation is based on the throughput and QoS levels that each RAT was capable to achieve in previous transmissions. To this aim, previous transmissions' data, such as the object size, the object's transmission time, and the queuing time waiting for radio resources to be assigned, are stored per traffic service in order to compute the throughput that was necessary to transmit each object. It is important to note that the achieved throughput heavily depends on the number of assigned radio resources per user, and it then needs to be normalized to avoid such dependence. A cdf of the estimated throughput per service and RAT is then extracted for previous object transmissions. An important parameter to define, and that is here referred to as *Time Limit*, is the time after which the throughput estimates for previous object transmissions are discarded and are not used to derive such cdf. The *Time Limit* parameter, that needs to be adequately optimized, has been defined so that only throughput estimates obtained under system and RAT conditions that are close to that currently experienced are considered to derive the throughput cdf. The RAT's *Offer* is then derived 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[2], while a too low one would overestimate them[3].

Once the *Demand* and *Offer* are estimated, the USaBS CRRM policy 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*, the current USaBS implementation assigns the incoming call the RAT providing the lower *Offer* that is higher than the call's *Demand*. Although other approaches are currently under study, assigning the RAT providing the lower *Offer* that is higher than the call's *Demand* prevents 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 low performance RAT saturation is also avoided through the definition of a multi-channel assignment penalty that prevents assigning incoming calls to overloaded RATs.

B. *Interaction with intra-RAT RRM functionalities*

The USaBS technique has been designed to efficiently operate in a multi-RAT environment, where each RAT is characterized by diverse intra-system Radio Resource Management (RRM) capabilities. In the multi-RAT environment simulated in the SPHERE (Simulation Platform for HEterogeneous wiREless systems) platform, HSDPA (High-Speed Downlink Packet Access) offers more advanced and short-time response RRM capabilities than GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution). In fact, HSDPA implements advanced scheduling techniques capable to quickly combat bad CRRM decisions or changes in the system conditions. On the other hand, the GPRS and EDGE RRM functionalities have a larger response time and a lower flexibility, thereby limiting their capacity to react. To overcome these inefficiencies, USaBS also interacts with the intra-system GPRS and EDGE RRM operation 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. Once a GPRS or EDGE user

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[1] Similar approaches tailored to each traffic service and model have been designed for web and H263 video users.

[2] Such underestimation could result in a low usage of low performance RATs.

[3] In this case, the RAT selection decision could result in a RAT assignment that is not really capable to provide the user's *Demand*.

starts its 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-system RRM protocol will assign all available channels. This process is repeated for the transmission of all the objects in a traffic session, since the USaBS RAT assignment decision currently operates at the session level. As a result, the actual number of channels a user would be able to use for each one of its object transmissions will depend on the current channel load, and therefore on the users statistical multiplexing at the system level. 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, a multi-channel assignment penalty is introduced to limit the GPRS and EDGE channel occupancy, and increase the probability that the maximum number of channels identified by the USaBS RAT assignment is simultaneously available. This will in turn increase the probability that the RAT selected by USaBS is capable to satisfactorily guarantee the user's *Demand*. To define the USaBS' multi-channel assignment penalty, it is necessary to estimate for the RAT under evaluation the channel's occupancy generated by the incoming call and the current active users in the RAT. 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 simultaneous channels proposed by USaBS. The channel activity is statistically computed, following the user's traffic type, as the time a user is on average transmitting over a channel with respect to its entire session duration. The occupancy for all active users plus the incoming user is then added, with the result representing the number of channels or timeslots that are occupied on average. If the result surpasses a given limit, that needs to be carefully optimized and is referred to as *Occupancy Limit*, the USaBS' multi-channel assignment penalty avoids assigning the incoming call to the RAT under evaluation with the initially identified maximum number of simultaneous channels. As it could be expected, the higher the maximum number of GPRS or EDGE channels USaBS proposes to assign an incoming call, the higher the probability to overpass the RAT's *Occupancy Limit*. As a result, USaBS tends to avoid RAT assignments that require a high number of simultaneous channels to guarantee the user's *Demand*.

III. SPHERE SIMULATION PLATFORM

To analyze the performance and operation of the USaBS CRRM policy, this work uses the multi-RAT SPHERE simulation platform [8], 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 the GPRS and EDGE standards. 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. In this case, the multi-channel capabilities of each RAT results in maximum data rates of 171.2kbps, 473.6kbps and 12779kbps for GPRS, EDGE and HSDPA respectively. GPRS and EDGE channels are assigned in a First Come First Served (FCFS) basis, while HSDPA implements a Round-Robin scheduling policy. All three RAT implements their own Link Quality Control (LQC) 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 [8]. Each traffic type is simulated at the session level, with the session arrival modeled through a Poisson process [9]. The session duration is modeled by Poisson, geometric and exponential distributions for email, web and H.263 video users respectively. Erroneously received data is retransmitted using a sliding-window selective-repeat Automatic Repeat reQuest (ARQ) protocol specified by the 3GPP for GPRS and EDGE. On the other hand, HSDPA implements a 4-channel Stop-And-Wait (SAW) protocol as specified by the 3GPP standard.

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. The shadowing correlation is implemented using the Gudmundson model [10] with a de-correlation distance of 20m. 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 (LUTs), extracted from link level simulations and mapping the Packet Error Rate (PER) to the experienced channel quality conditions.

IV. USABS PERFORMANCE

To evaluate the USaBS performance, this section considers a system scenario with 42 users per cell, with each traffic type representing a third of the cell load. 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 real-time H.263 video services. In addition, the traffic models have been configured to simulate an average of four emails per session, five web pages per session, and an average duration of real-time H.263 video sessions of fifteen seconds. These traffic values have been chosen to simulate a system load high enough to be excessive for an isolated RAT, even HSDPA, and low enough to avoid saturating all RATs. Such saturation is avoided since it would not allow differentiating the performance impact of different CRRM policies. The *Occupancy Limit* parameter has been set equal to six (channels or timeslots), which allows for a maximum average channel occupancy around 75%. This value has been selected so that USaBS can choose among a variety of GPRS and

EDGE multi-channel assignments; the maximum possible value for *Occupancy Limit* is eight. The *Time Limit* parameter has been set equal to 120 seconds for web and email services, and 30 seconds for the real-time H.263 video service. The selected values are different since web and email services are characterized by a more bursty traffic than H.263 video. In any case, it is important to note that the optimization of the *Occupancy Limit* and *Time Limit* parameters is out of the scope of this paper due to space limitations.

As it was previously defined, a user's *Demand* represents the throughput necessary to guarantee its requested satisfaction level. The satisfaction level was defined as the percentage of web or email transmissions that satisfy their QoS requirements, and the percentage of video frames transmitted before the next video frame needs to be transmitted. In this section, the satisfaction levels to estimate the user's *Demand* have been set to 61%, 90% and 99% for email, web and real-time H.263 video services respectively. The implemented email traffic model considers 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 are defined for web and video services, with the later being the strictest due to its real-time operation. In any case, it is important to note that the satisfaction level is a subjective parameter that can be set differently according to varied operator's interests. To derive the RAT's *Offer*, this paper considers the minimum throughput guaranteed to 80% of the previous object transmissions.

Figure 2 shows the obtained satisfaction level by USaBS per service and contract type. The red horizontal line indicates the previously defined objective satisfaction levels per traffic service. The results depicted in Figure 2 show that the USaBS proposal is capable to fully guarantee the objective satisfaction levels for email and web services independently of their contract type. It is also interesting to note that USaBS achieves similar satisfaction levels irrespectively of the users contract type and their different QoS requirements, which highlights the USaBS user and service fairness.

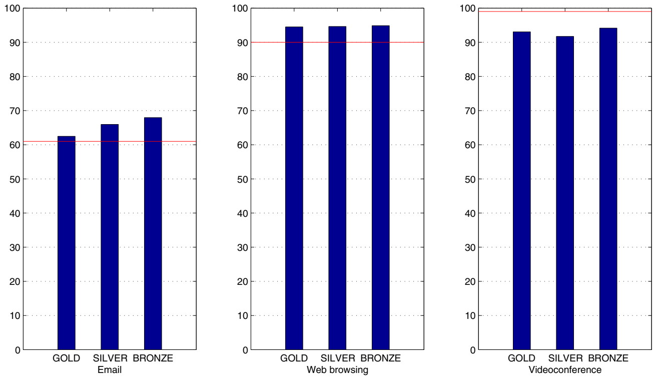

Fig. 2. USaBS mean satisfaction level (%) per service and contract type.

The satisfaction levels achieved with the USaBS proposal reveal its ability to assign each service and user type the most appropriate RAT to guarantee the user's *Demand*. Figures 3 and 4 depict the USaBS RAT selection assignments per contract type for email and web users respectively. In these figures, GPRS and EDGE multi-channel RAT assignments are grouped for clarity. As it can be observed from these figures, 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, contract types characterized by lower QoS requirements are generally assigned to less performing RATs. A comparison of Figures 3 and 4 reveals that this trend is maintained for different traffic services, although the specific RAT assignments vary due to the different defined objective satisfaction levels per traffic service.

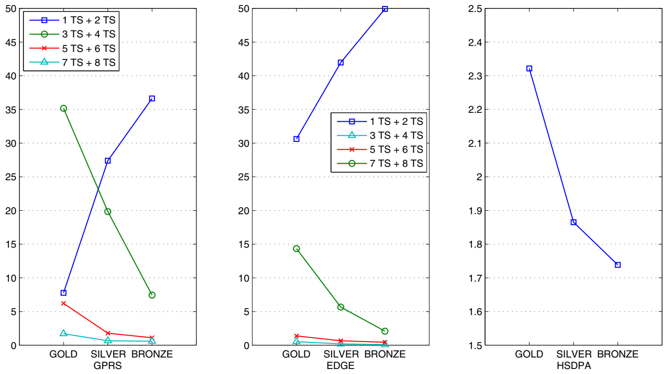

Fig. 3. USaBS RAT assignments (in %) per contract type for the email service.

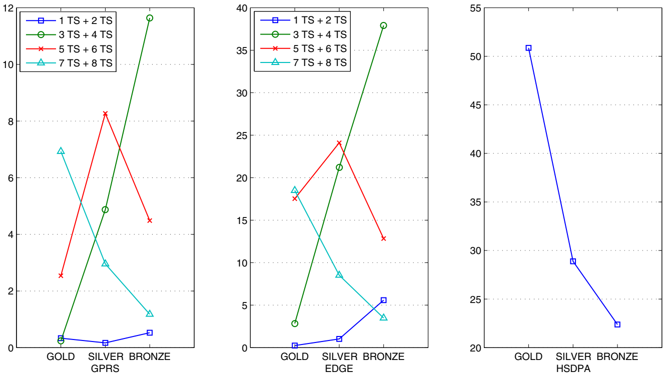

Fig. 4. USaBS RAT assignments (in %) per contract type for the web service.

The results depicted in Figure 2 also showed that despite a high performance for the real-time video service, USaBS does not seem to be capable to fully guarantee the objective satisfaction levels under the simulated system load and conditions. However, it is worthwhile noting that the defined objective H.263 satisfaction levels are quite ambitious, and that they could be relaxed following the indication in [11] stating that a block error rate below 5% would not produce a noticeable video degradation for H.263 video transmissions. In this case, it is expected that USaBS will be capable to guarantee the real-time H.263 satisfaction levels. However, to understand why USaBS has not been capable to closely guarantee the H.263 objective satisfaction levels in the current simulation environment, it is worthwhile analyzing the RAT selection assignments per contract type for H.263 users depicted in Figure 5. Contrary to the behavior observed for web and email users, certain H.263 Gold users are assigned to low performance RATs that are not capable to satisfy their *Demands* and reduce the overall performance. For example, 3.39% and 0.72% of Gold user sessions are assigned to GPRS with a maximum of four timeslots, and to EDGE with a maximum of two timeslots, respectively. 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 (modulation and coding scheme) 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 for the experienced channel quality conditions. In this case, HSDPA would achieve a very low throughput performance, close to zero, which will reduce its *Offer* giving that it is estimated using the throughput achieved in previous transmissions. The current USaBS implementation considers that if no RAT provides an *Offer* higher than the incoming user's *Demand*, the RAT with the highest *Offer* is still assigned to the incoming user. In this case, a low HSDPA *Offer* results in inadequate H.263 video assignments to RATs that are not capable to guarantee the objective satisfaction levels, even under ideal operating conditions without transmissions errors. The undesired HSDPA AMC operation can be highlighted by analysing the *Offer*'s calculation, defined as the minimum throughput guaranteed to a given percentage of previous object transmissions. Increasing this percentage to 90% compared to the 80% value used in this work, decreases the guaranteed minimum throughput and increases the probability of incorrectly estimating the HSDPA *Offer* due to an aggressive operation of its AMC protocol. In fact, the results obtained showed that reducing such percentage from 90% to 80% reduces the percentage of inadequate USaBS RAT assignments (i.e. RAT assignments not capable to satisfy the user's *Demand* even under ideal conditions) by 56.9%, and improves by 4.5% the achieved H.263 Gold user's satisfaction level. These results highlight that the unexpected H.263 video performance was not due to an inadequate USaBS design but to the adaptive HSDPA operation that needs to be further optimised.

V. CONCLUSIONS

This paper has proposed and evaluated a new initial RAT selection CRRM policy designed for heterogeneous and multimedia wireless networks. The USaBS proposal decides on the optimum RAT for an incoming call based on the requested QoS and satisfaction levels, and the performance that each available RAT can provide using estimates from previous transmissions. The proposal has been tested in a multimedia environment with different contract types. The obtained results demonstrate that USaBS is capable to achieve the objective satisfaction levels, while fairly treating different users and service types. The USaBS proposal has been initially configured so that an incoming call is assigned the RAT providing the lower *Offer* that is higher than its *Demand*. The authors are currently working on new USaBS variants implementing different CRRM strategies.

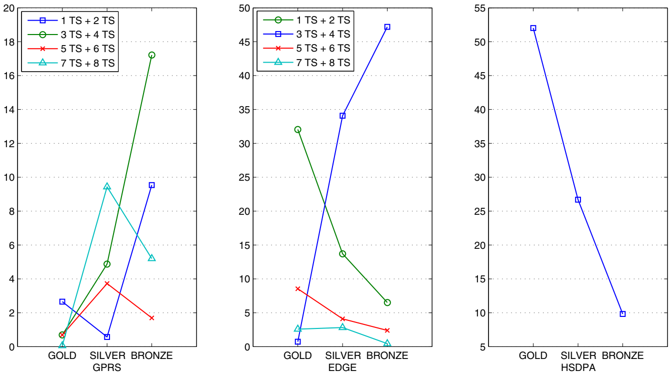

Fig. 5. USaBS RAT assignments (in %) per contract type for H.263 service.

ACKNOWLEDGMENTS

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