JOINT RADIO RESOURCE MANAGEMENT IN A SDR CONTEXT

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ABSTRACT

This paper presents a spectrum efficient Joint Radio Resource Management (JRRM) scheme enabling and optimizing the triggering of Vertical Handover (VHO) between heterogeneous Radio Access Technologies (RATs). To optimize the VHO triggering, this scheme considers the overall system's load, the local radio conditions and the user profile. In order to evaluate the resulting gain, a time event-driven methodology is used. Another topic of interest of this paper is the impact of the software downloading on the overall reconfigurable system performance, which is presented through several scenarios. This implies the description of statistical modeling of software download traffic and of some methods regarding Quality Of Service (QoS) metrification. The paper concludes with simulation results highlighting the benefits in terms of capacity and QoS associated with the JRRM, also showing the benefits of using reconfigurable terminals in a heterogeneous environment. This work has been performed within the frame of European IST Projects TRUST and SCOUT.

1. INTRODUCTION

In cellular communication systems the radio conditions experienced by the users depend on their location, their speed and the environment where they evolve. In order to maintain a certain QoS through the network and permit a high mobility for users, a process called handover was developed. This is triggered by the network jointly with the mobile, and consists of searching for a better Base Station (BS) (aimed at improving pathloss, or cell loading) within the network in order to provide the user with a better QoS. However, no handover solutions can be available if the network is heavy loaded in the user's geographical zone. In this case, the user can lose his communication, i.e. he might be dropped; moreover another user trying to access this network in the same geographical zone will probably be blocked. However, connected users can maintain their links in this zone, but with a bad call quality due to the interference caused by other connected users.

In the future, with the introduction of reconfigurable terminals, the user will be able to change RAT. Given this new capability of future terminals, a user experiencing poor radio conditions can perform a VHO from a RAT to another one, this aimed at improving both user and system QoS. A VHO can be seen as a Radio Resource Management (RRM) rule, and has to be more precisely analyzed to optimize its performance.

In this paper, Section 2 describes and presents an optimizing scheme to jointly manage the radio resources of several RATs: the Joint Radio Resource Management (JRRM) Scheme. In order to evaluate the gain brought by such a scheme, a simulation methodology is detailed in Section 3. Reconfigurable terminals as suggested by their names can be softly reconfigured. This capability induces a new type of traffic: software download traffic. Future terminals could download a new air interface before performing a VHO or download new software in order to fix a bug or perform an upgrade. Section 4 deals with different scenarios of software download traffic and proposes generic traffic model. Section 5 presents first performance results for JRRM module simulations performed in a UMTS FDD-TDD environment. Another simulation has also been performed to highlight the importance of reconfigurable terminals in enabling smart VHO between RATs. The scenario for this considers that only a part of terminals are reconfigurable, and simulation results show that the gain brought about by the JRRM module decreases. Section 6 concludes the paper with an outlook for future research.

2. JOINT RADIO RESOURCE MANAGEMENT

A high level description of the proposed JRRM process is represented in Figure 1. The launch of the JRRM module will be motivated by the fact that one user experiences bad radio conditions or blocking and that no solutions are available in his current native network.

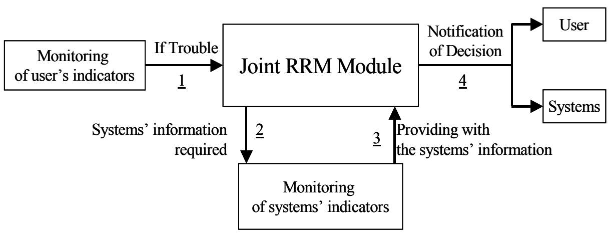

Figure 1: Macro description of VHO

To permit this launch, some users quality indicators have to be monitored and transmitted to the module in case of trouble (1). After launching the process and before ordering the VHO, the probability that the user experiences better radio conditions or can access to radio resource in the new mode without degrading the performance of this mode is evaluated. To do this, some system indicators have to be monitored which the JRRM module requires for both modes (2). These system indicators are then provided to the JRRM (3). After running its algorithm, the module notifies (4) the user and both systems of its decision to Accept/Refuse the VHO.

In order to maximize the probability of success for a VHO from RAT#i to RAT#j, several parameters are periodically monitored. Firstly, the load of each RAT is evaluated and updated. Secondly, the performances of each RAT under their present loads are evaluated taking into account the following QoS parameters: blocking probability, dropping probability, poor FER probability and BQC. The novelty of the algorithm is to consider those parameters while evaluating the probability of success of a VHO (see Figure 2).

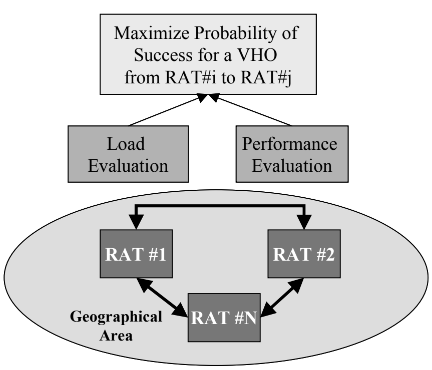

Figure 2: VHO probability of success evaluation

To compute this probability of success, several additional parameters are considered, namely, the user's profile (mobility, applications) and local radio characteristics of the hosting RAT#j. A VHO is considered as successful if and only if the user who performs it recovers a better call quality by considering the different QoS parameters (B, D, BQC), and if the impact of this VHO on the hosting RAT#j is negligible (i.e. the performance for other users of RAT#j will not be degraded). If this probability of success is high enough, the VHO is triggered.

The JRRM algorithm (described in details in [1]) is the decision policy controller, allowing access to radio resource units and ensuring overall RATs capacity through individual user QoS optimization and stability.

3. SIMULATION METHODOLOGY

The goal of the simulation tool is to characterize user QoS and the system capacity at the physical layer considering the UTRA FDD and the UTRA TDD modes. In order to characterize both these modes, a dynamic system simulator has been developed. This simulator can be considered as a whole Finite State Machine (FSM) where the system State Space (SS) is discrete and where the SS evolution depends entirely on the occurrence of asynchronous discrete events over time. Therefore, such systems can be modeled (or described) as a Discrete Event System (DES). Such a DES is defined as being a system in which the SS is a discrete set and the State Transition mechanism is the action of asynchronous discrete events over time. This mechanism is said to be Event Driven (ED) [2].

When entering the system, a user will have to respect certain rules corresponding to the defined FSM. The generic FSM describing the call status of a speech or Web user is illustrated in Figure 3.

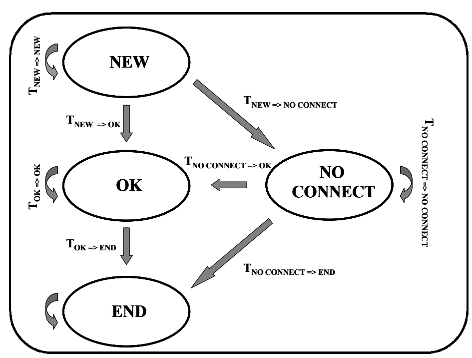

Figure 3: General FSM for a given user

When a new user arrives in the system, his call state is *NEW*. If he tries to access some resources, and if he succeeds, he goes to the *OK* state, otherwise to the *NO CONNECT* state. At the end of the call, or if the user is blocked, he proceeds to the *END* state.

The Generic FSM also manages the handover process and the different sub-states of the call state *OK*. These sub-states are mandatory if a speech ON/OFF user or Web users are considered, since in this case a user who has initiated a session, is not active during his entire session; but he is either transmitting/receiving, idle or waiting for radio resources. This is due to the burstiness of these types of traffic.

Each call state implies several actions, which can be triggered at different instants if necessary. They are described in Table 1.

State	Actions
NEW	Initialization of User profiles (Service, Mobility, Radio Environment), Call Set up
OK	Mobility Update, Handover triggering, Power Control
NO CONNECT	Mobility Update, Radio Resources negotiation
END	Radio resources released, Statistics gathered

Table 1: Actions depending on the Call state

Depending on the result of the previous actions, a user may pass from one call state to another. All transitions between the call states has to be described (see Table 2).

Transition	Description
$T_{NO \to NEW}$	User's arrival
$T_{NEW \to OK}$	Resources negotiation successful
$T_{OK \to END}$	Natural call termination, or dropping, or blocking (for ON/OFF traffic)
$T_{NEW \to NO\ CONNECT}$	Resources negotiation failure
$T_{NO\ CONNECT \to OK}$	Resources re-negotiation successful
$T_{NO\ CONNECT \to END}$	Blocking
$T_{NO\ CONNECT \to NO\ CONNECT}$	Resources re-negotiation failure
$T_{OK \to OK}$	Good communication enrolment

Table 2: Transition between the call states

This dynamic simulation methodology based on an "event driven" approach, gives the possibility of assessing temporal variations of traffic and interference conditions. Performance statistics are obtained by averaging the results from a large number of calls across the entire network.

4. TRAFFIC MODELLING AND QOS FOR RECONFIGURATION MANAGEMENT

Owing to persistent pressures on spectrum allocation due to poor wireless channel characteristics, JRRM must decide on the most efficient strategy for reconfiguration download and RAT management. To achieve this, traffic modelling has to be accurately performed, thus enabling the effect on resources of a particular download strategy for a VHO or reconfiguration to be estimated. Scenarios for reconfiguration download must be identified and the characteristics of the strain they are likely to put on resources analysed, and dynamic QoS metrification has to be continuously performed for efficiency quantification purposes.

4.1 Statistical Modelling of Software Download traffic

As stated in [3], to model packet-based download it is essential to define distributions for several important parameters: number of packet call requests within a download session, N_{pc}, number of packets within a packet call N_p, duration between two packets within a packet call D_p, duration between packet calls D_{pc}, and packet size S_p. In [3], these parameters have been modelled as follows:

N_{pc} – By definition is equal to the number of modules downloaded within a download session, as each module constitutes a packet call.

N_p – By analogy to the number of files downloaded in a single session [4], a geometric random variable is appropriate, defined by

$$f(k) = p(1-p)^{k-1}, k = 1,2.... \quad (3.1)$$

D_p – Modelled by an exponential distribution [5], defined by

$$f(x) = \lambda e^{-\lambda x} \quad (3.2)$$

D_{pc} – Dependent on specific hardware, a distribution is yet to be defined. This can, however, be equal to the installation period D_i, in the situation where a terminal devotes all of its computational power to performing an installation and does not buffer downloaded modules for mass-installation.

S_p – Conventionally [6][7] this is modelled by a Pareto random variable

$$S_p = \begin{cases} 0 & x < k, x > m \\ \dfrac{\alpha \times k^{\alpha}}{x^{\alpha+1}} & k \le x < m \\ P_m & x = m \end{cases} \quad (3.3)$$

where k and m are the lower and upper bounds of packet sizes and P_m is the value of the distribution at the upper module size bound, hence

$$P_m = \left(\frac{k}{m}\right)^{\alpha}. \quad (3.4)$$

However, packet sizes are generally discrete, as they are filled to the maximum transmission unit (MTU) or service data unit (SDU) in most cases; an exception to this rule is the UMTS streaming traffic class [8][9], which would generally send packets before they are filled due to timing requirements. For such a continuous packet size distribution, the Pareto distribution given in Eqn. (3.3) is appropriate.

Filling packets to the MTU/SDU would give the following, where n represents packet number in a module download

$$\{S_p\} \in \begin{cases} \{S_{p(n)} = MTU\}_{n \le \lfloor S_m / MTU \rfloor} \\ \left\{ S_{p(n)} = \begin{cases} 0 & x < k, x > m \\ \dfrac{\alpha \times k^{\alpha}}{x^{\alpha+1}} - (n-1) \times MTU & k \le x < m \\ P_m - (n-1) \times MTU & x = m \end{cases} \right\}_{\text{o.w.}} \end{cases}$$

(3.5)

Here, the Pareto random variable (and its bounds) apply to module size distribution, $\{A = B\}_C$ represents a set of values where $A = B$ with condition C imposed, and S_m is the size of the module to be downloaded.

4.2 Software Download Scenario Impacts

For the purpose of terminal reconfiguration download, the following download scenarios have been highlighted by the IST-SCOUT project [10] to be of interest for simulation and traffic modelling: air interface reconfiguration, the mass upgrade of terminals, and user-initiated software download.

Generally, reconfiguration download module sizes are anticipated to be either [7]: small (64-256 bytes) representing a parameter download, medium (5kB-100kB) perhaps for an upgrade or bug fix, and large (1MB-5MB) perhaps for substantial reconfiguration of the protocol stack. It is expected that for RAT reconfiguration as initiated by JRRM, terminal memory and storage capability will be sufficient to allow for concurrent storage of algorithms for many RATs. Hence downloads should be of simple parameters for these algorithms, and be in the small-medium size category. This would have little impact on 'regular traffic'. In other cases where terminal capabilities are poor or present and target RATs are substantially different, downloads are assumed to be large, and would have a considerable impact. Moreover, it is anticipated that RAT downloads will be far more frequent in long-distance transport terminals and surrounding areas, hence this situation must be heavily simulated as it is where their impact will be greatest. Consequently, it is recognised that the arrival and power-up behaviour of terminals in such a non-supporting RAT area has to be accurately statistically modelled.

Mass upgrades will present a considerable challenge for the utilised RAT, as they are likely to occur simultaneously in large volumes. Statistical distribution of download initiation requests has to be modelled in this case.

User-initiated software downloads are anticipated to fall into one of two categories: downloads advertised in advance for which users will have gained a priori information about their release, and downloads which are likely to be constantly distributed in time. In the former case, the strain on the RAT will be large, hence it must be simulated for the developed JRRM to be successful.

4.3 Metrication Methods for QoS

In UMTS a large number of QoS attributes have been specified for regular traffic users, the extent of them is dependent on traffic class [9]. For reconfiguration download, it is recognised that many functional requirements, hence attributes, would be the same as for the interactive or background traffic classes in UMTS. The background traffic class may be most appropriate as it would put less strain on the system. The most relevant attributes of these classes are maximum bitrate and residual BER, these should be monitored in conjunction with the parameters specified in section 2 which apply to a range of RATs.

In order to enable JRRM to decide on the most resource-efficient reconfiguration download and RAT switching strategies, the following must be maximised

$$\sum_n QoS_{\mathrm{Reg}(n)} + \sum_m QoS_{\mathrm{SDR}(m)} \tag{3.6}$$

for regular traffic users $\{n\}$ and reconfiguration download users $\{m\}$. Weighting of QoSs importance for different traffic class attributes and reconfiguration download can be achieved using the following (where α_i is a weighting factor for QoS metric i calculated with consideration of all metrics – regular traffic and reconfiguration traffic)

$$QoS_{(n)} = \sum_{i=1}^{n} \alpha_i f_i(x) \text{ or } QoS_{(m)} = \sum_{i=1}^{m} \alpha_i f_i(x) . \tag{3.7}$$

Substitution of expressions for QoS attributes (possibly as functions of traffic intensities) into (3.7) as $f_i(x)$, then (3.7) into (3.6), allows overall QoS to be quantified dependent on reconfiguration download strategy and possible terminal RAT switches.

In consideration of the conceptual TRUST reconfiguration architecture [3], a range of QoS parameters could be compared to target values using the concept of a 'QoS manager'. This interfaces to the mode negotiation and switching module (MNSM), proxy reconfiguration manager (PRM), applications, and the user via applications. It essentially, periodically and on request, provides information relating to the QoS implications of RAT switching and reconfiguration download.

5. SIMULATION RESULTS

5.1. Simulation Assumptions

The goal of the simulation scenarios is to highlight the gain provided by JRRM in terms of capacity and QoS. The first scenario introduces a basic JRRM scheme enabling a FDD-TDD VHO. It considers a circuit switched speech service for users evolving in a Manhattan environment, involving both RATs. Here, the main goal is to prevent users from being dropped and blockading, and to evaluate the performance of the overall system (capacity and QoS). A user experiencing dropping or blocking in his native mode is to perform a VHO as late as possible. This means the time before ordering the VHO is 5 seconds (just before dropping or blocking the user), hence it gives the user only one attempt to obtain his required radio resources in the hosting mode. An improvement to the method consists of decreasing this time; and accordingly, the call quality of the user increases (his FER decreases). But in order to avoid too many VHOs (ping pong effect), this time threshold must not be decreased too much. Two sub-scenarios have been considered: one with a time threshold of 5s (RRM policy #1) and one with a time threshold of 3s (RRM policy #2). To decide whether a VHO is possible or not, only two strategies are defined. A VHO is ordered only if the traffic in the hosting mode is lower than $L_{S,95\%}$; being the traffic value in Erlangs when 95% of users are satisfied. This limit is given by single mode studies—it is fixed and not updated with the arrival and departures of VHO users. To avoid a ping-pong effect, a user can only execute one VHO during his call.

The study is performed for a low call arrival rate for the FDD system (λ_{FDD} = 20 call/s) and for variable call arrival rates for the TDD system (λ_{TDD} = 20…70 call/s). Performance gain is calculated by comparison of the overall system (TDD+FDD) performance without VHOs to that with VHOs enabled using the described JRRM scheme.

In the first scenario, all terminals were considered in dual mode. To show the impact of the penetration of reconfigurable terminals, the second scenario considers only a percentage of terminals being in dual mode.

5.2. Simulation Results

Figure 4 shows the gain in terms of capacity for the overall system considering the first scenario. The implemented RRM policies using the JRRM scheme brought a capacity gain (at a level of 95% satisfied users) of about 7.9% for RRM policy #1 and 17.4% for RRM policy #2.

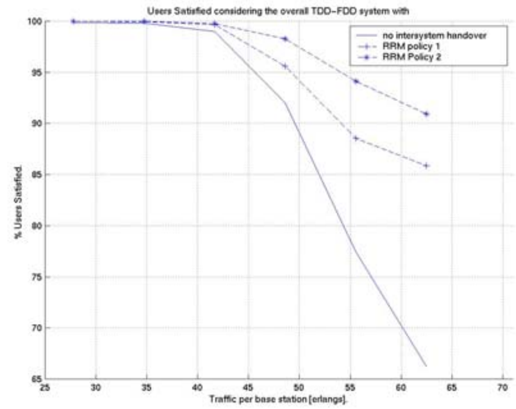

Figure 4: Capacity gain for the first scenario

In other words, for the same initial set of radio resources, more users are admitted and satisfied in the TDD/FDD system. With the introduction of these policies, no more users are dropped or blocked. Accordingly, user QoS is also increased. The decrease in the dropping time threshold from 5s to 3s reduces the number of bad FER users significantly. The levels of QoS improvement for blocking, dropping and bad FER are respectively 12%, 8% and 5%. For the same offered traffic, each user's QoS is also improved in consideration of those three meters.

Another simulation was performed to highlight the importance of reconfigurable terminals enabling VHO between RATs. This simulation is similar as the first scenario (speech only) using RRM policy #1, but here only some of the terminals are considered as dual mode.

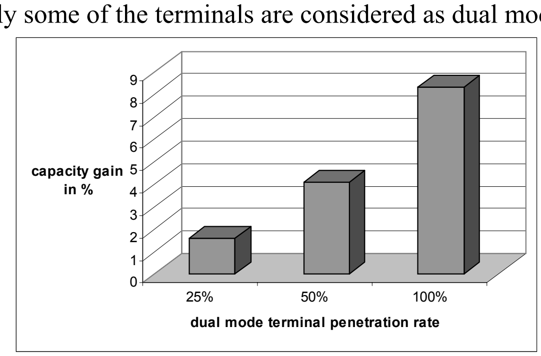

Figure 5: Influence of dual mode terminal penetration rate on the JRRM performance

Figure 5 illustrates the gain brought about by the JRRM for different penetration rates of dual mode terminals (in terms of capacity). If 25% of terminals are dual mode, the gain brought by JRRM (in terms of capacity) is only about 1.6%; where for 50%, the gain is about 4.1% and if all terminals are dual mode, the gain is about 8.3%.

Figure 6 shows the evolution of blocking and dropping probabilities in the (TDD+FDD) system. The main result shows that there is neither blocking, nor dropping if all are dual mode terminals.

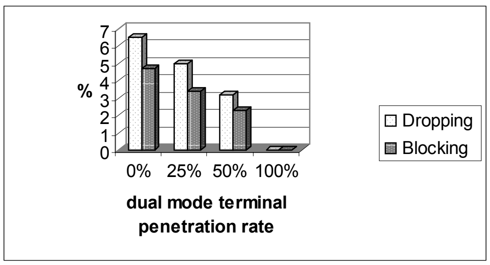

Figure 6: Blocking and Dropping probabilities for different dual mode terminal penetration rate

The introduction of the JRRM scheme has brought gains for the first scenario and for the second scenario has highlighted the importance of the penetration rate of reconfigurable terminals.

6. CONCLUSIONS

Using the multi-technology and multi-band capabilities of reconfigurable terminals, the JRRM proposes an optimized VHO triggering process by considering the potential impact of such a VHO on the user and on the hosting mode before ordering it. This results in an increase in overall system capacity and user QoS. After we have described the simulation methodology used to quantify JRRM gain, section 4 presents a simple methodology for reconfiguration traffic modelling and basic QoS metrification, enabling JRRM to decide on the best strategy for reconfiguration download and RAT switching. Several necessary areas of work have been highlighted in this section, many of which will be realized in future papers. Simulation results obtained for a speech service show important gains for capacity (17.4%) and QoS (12% for blocking, 8% for dropping and 5% for Bad FER call). The second scenario highlights the importance of the reconfigurable terminal penetration rate, the main result being that there is neither blocking, nor dropping if all terminals are dual mode ones.

However, the scheme for JRRM considered here is relatively basic. Higher gains are expected through enhanced strategies, and scenarios considering software download traffic have also to be simulated.

7. ACKNOWLEDGEMENTS

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