Optimal Load Suitability Based RAT Selection for HSDPA and IEEE 802.11e

O. Cabral, F. J. Velez
Instituto de Telecomunicações,
DEM Universidade da Beira
Interior, Covilhã, Portugal
{orlandoc, fjv}@ubi.pt

J. Rodriguez, V. Monteiro, A. Gameiro
Instituto de Telecomunicações,
Campus Universitário, Aveiro,
Portugal
{jonathan, vmonteiro}@av.it.pt,
amg@det.ua.pt,

N. R. Prasad
Center for TeleInFrastruktur
(CTIF), Aalborg University,
Aalborg, Denmark
np@es.aau.dk

Abstract— **Networks of the future envisage a network-of-wireless-networks that provide the end user the means to connect to the best available network at anytime and at any place. However, equally challenging for the operators is to provide these services at low cost in an era where spectral resources are a premium. This paper investigates cooperation between networks based Radio Access Technology (RAT) selection algorithm that uses suitability to optimize the choice between WiFi and High Speed Downlink Packet Access (HSDPA). It has been shown that this approach has the potential to provide gain by allocating a user terminal to the most preferred network based on traffic type and network load. Optimal load threshold values that maximise the total QoS throughput for the given interworking scenario are 0.6 and 0.53 for HSDPA and WiFi, respectively. This corresponds to a CRRM gain on throughput of 80% with 60 users.**

Keywords- *CRRM, load suitability, RAT selection, HSDPA, IEEE 802.11e*

I. INTRODUCTION

Networks of the future are tending towards a diverse wireless networking world, where scenarios define that the user will be able to attain any service, at any time on effectively any network that is optimized for the application at hand. Thus creating a future global infrastructure, where several systems can coexist to support transparent end-to-end communications, in an efficient, cost-effective manner. An important architectural issue is that of defining a next-generation wireless system, which acts as a “network-of-wireless-networks” accommodating a variety of radio technologies and mobile service requirements in a seamless manner.

Networks of the future will explore cooperative platforms in a bid to provide cost-effective communications to the end user. In a bid to address this challenge, interworking architectures have been proposed by ETSI/BRAN [1] and 3GPP [2] such as the loose and tight coupling approach for WiFi and UMTS/HSDPA. Moreover, several solutions have been proposed within IST projects that worked on architectures and platforms for cooperation schemes between heterogeneous Radio Access Networks [3], [4], [5], [6], mainly focusing on interworking architectures between UMTS/HSDPA and WiFi. In [7], the requirements and algorithms for cooperation of several radio access networks are presented. Cooperation can also be achieved by means of a Cooperative Radio Resource Management (CRRM) entity that is able to direct traffic through different networks according to operator specific requirements and based on cross-system information. More specifically, the CRRM is responsible for i) gathering system and user specific information, ii) processing this information according to operator specific criteria, and iii) triggering a new handover event according to the load balancing criteria and position. It is assumed that either a common operator deploys both systems or the system operators share a service level agreement (SLA). [8] and [9] investigated a CRRM type cooperation based on the load suitability for delay constrained services. The notion of suitability is based on the most preferred access system to accommodate the service, but this concept of suitability can change as load increases in order to maintain the quality of service across the networks. So the goal should be to optimize the load in each Radio Access Technology (RAT) without loss of QoS guarantee. In this paper, we extend the concept of suitability to seek the optimal load threshold in order to maximize the total system QoS throughput.

The remaining of this paper is organized as follows. Section 2 describes the RAT selection policy. Section 3 presents the simulation scenario and models used for High Speed Downlink Packet Access (HSDPA) and WiFi, and associated performance metrics. Simulation results are discussed in Section 4. Finally conclusions are presented in Section 5.

II. ALGORITHM DESCRIPTION AND RAT SELECTION SUITABILITY POLICY

A. RAT Selection Algorithm

An algorithm for selecting the most suitable RAT is proposed with the aim of balancing the load in critical loading situations. A preferable RAT is selected by default to handle a service, assuming in this case that the service traffic is flexible and can be handled by more than one RAT. Studies on cross-layer show that concave and convex functions are more suitable when flexibility and limited conditions are required [10], [11]. An empirical algorithm for load balancing among cells of different RATs is proposed when a new call is requested. The algorithm is targeted to flexible traffic and imposes certain flexibility on the system, meaning that the service can be held by each RAT. The algorithm for the suitability, *S*, is expressed by the following equation and depicted graphically in Suitability for the load balancing selection algorithm.

$$S(L(cell_{i,j})) = \begin{cases} 1 & \text{if} \quad L(cell_{i,j}) \le LTh_j \\ \left(\dfrac{1 - L(cell_{i,j})}{1 - LTh_j}\right)^2 & \text{if } L(cell_{i,j}) > LTh_j \end{cases} \tag{1}$$

where $cell_{i,j}$ represents the cell or Access Point (AP) *i* belonging to the RAT *j*, $L(cell_{i,j})$ is the normalized load in the $cell_{i,j}$, LTh_j is the load threshold for RAT *j*, and $S(L(cell_{i,j}))$ is the suitability value for accepting a new user in the $cell_{i,j}$.

The preferable RAT, e.g., HSDPA for near real time video (NRTV), should be selected in the case of equal suitability values obtained for cells of different RATs.

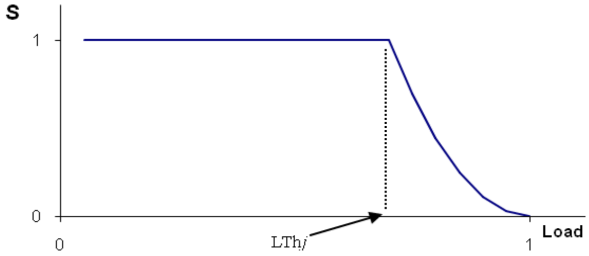

Figure 1. Suitability for the load balancing selection algorithm.

LTh_j is the parameter of the algorithm and characterizes the amount of load reserved for preferable traffic. So the operator should ‘play’ with this threshold value in order to set the amount of traffic that a RAT will use for preferable services. Simulation results will present the performance of the network when different values of LTh_i are assumed.

B. Normalized Load Estimation

The normalized load estimation in any cell is obtained as the ratio between the active load in the cell and the overall cell load capacity as described by the following equation

$$L_{normalized} = \frac{L_{active}}{L_{capacity}} . \tag{2}$$

L_{active} is the active load in the cell and can be directly obtained by the sum of average service rate associated to each user while $L_{capacity}$ is the actual capacity of cell taking into account the radio propagation conditions.

C. Load estimation in HSDPA

Due to the HSDPA characteristics, i.e., constant power transmission and link adaptation by adaptive modulation, the load is estimated based on the resources available for the cell, and actually consumed by user connections. The normalized load in HSDPA is estimated by

$$L_{normalized}(i) = \frac{\sum_{n=1}^{N} Load(n)}{R_{HSDPA}} , \tag{3}$$

where *N* is the number of HSDPA user, R_{HSDPA} is the number of High Speed Physical Downlink Shared Channel (HS-PDSCH) [12] allocated in the cell, and *Load*(*n*) is the average number of HS-PDSCH required by user *n* to support its service rate, *R*(*n*). This number is given by

$$Load(n) = \frac{R(n)}{R(CQI_n) \cdot N_{HS-PDSCH}(CQI_n)} , \tag{4}$$

where the average propagation conditions determine the channel quality indicator for user *n* (CQI_n). $R(CQI_n)$ is the achieved bit rate by user *n* allocated CQI_n. $N_{HS-PDSCH}(CQI_n)$ is the number of HS-PDSCH associated to CQI_n as defined in [12]. Table I presents the assumptions for HSDPA block sizes and bit rates associated to each CQI.

TABLE I. TRANSPORT BLOCK SIZE AND BIT RATE VERSUS CQI.

CQI	Modulation	Transport Block size (bits)	Number of HS-PDSCH	*R*(CQI) [kbps]
CQI 5	QPSK	377	1	188.5
CQI 8	QPSK	792	2	396.0
CQI 15	QPSK	3319	5	1659.5
CQI 22	16-QAM	7168	5	3584.0

D. Load estimation in WiFi

For the WiFi system, the standard considered was the IEEE 802.11e one [13], [14]. The normalized load associated to the AP should be estimated also based on the available system and cell resources. Furthermore, in the intermediate phase, an amount of bandwidth is determined in the system (one AP and several nodes). This bandwidth is shared among nodes according to the service bandwidth. It should be noticed, however, that the errors in the packet transmission occur when there are collisions, since the IEEE 802.11e EDCA mode of the MAC protocol was completely implemented in the simulator [15]. The normalized load for the WiFi system in optimum conditions is given by

$$\begin{aligned} &L_{normalizedWiFi} = \\ &\sum_{n=1}^{4} \left(\frac{\begin{array}{l} frame\_duration[payload\_RTS, R_{MCS}(n)] \cdot 2 + \\ frame\_duration[payload\_RES, R_{MCS}(n)] \cdot 3 + \\ frame\_duration[payload\_BK/3, R_{MCS}(n)] \cdot 3 + \\ \qquad DIFS + 6 \cdot SIFS \end{array}}{interarrival\_time_{BK}[s]} \right) + \\ &\sum_{n=1}^{4} \left(\frac{\begin{array}{l} frame\_duration[payload\_RES, R_{MCS}(n)] \\ + frame\_duration[payload\_VO, R_{MCS}(n)] + DIFS + SIFS \end{array}}{interarrival\_time_{VO}[s]} \cdot 2 \right) \\ &+ \sum_{n=1}^{N} \left(\frac{\begin{array}{l} frame\_duration[payload\_RES, R_{MCS}(n)] \\ + frame\_duration[payload\_VI, R_{MCS}(n)] + DIFS + SIFS \end{array}}{interarrival\_time_{VI}[s]} \right) \end{aligned} \tag{5}$$

where N is the number of WiFi user, and $R_{MCS}(n)$ is the rate for the modulation and coding scheme available for user n (of the WiFi AP). SIFS is the Short interframe space, DIFS is the Distributed Coordination Function Interframe Space. *Frame_duration* returns the frame duration having as an input the payload and $R_{MCS}(n)$, adding the physical layer headers TX time. *payload_VO*, *payload_VI, payload_BK, payload_RES, payload_RTS,* are the payload of the voice, video, background, acknowledgement and RTS packets. The other terms are self explanatory. This equation accounts for the four background users, the four voice users, and the N video users. These classes of traffic have different characteristics regarding packets payload and inter-arrival time, Table II. Voice (VO) and Video (VI) packets, do not require "request to send/clear to send" (RTS/CTS) negotiation as it depends on the packet payload. Besides, no fragmentation is required; only an acknowledgement (*RES*). Background (BK) packets, in turn, require an acknowledgement, as they have a high payload, and RTS/CTS negotiation and fragmentation has to occur. Through the use of fragmentation, a packet is divided into three packets, for each fragment, an acknowledgement is required. The MAC and physical parameters used for WiFi simulation are available in Table III.

TABLE II. WIFI TRAFFIC PARAMETERS [16].

AC	Voice (VO)	Background(BK)
Packet size	1280 bit	18430 bit
Packet interarrival	20 ms	12.5 ms
Usage	50 %	20 %
Symmetry	Symmetric	asymmetric (downlink)

TABLE III. WIFI MAC AND PHY PARAMETERS.

Slot time	0.009 ms
ACK size	112 bit
SIFS	0.016 ms
DIFS	0.034 ms
RTS threshold	4000 bit
RTS size	160 bit
CTS size	112 bit
CWmin	31 slots
CWmax	1280
Collisions threshold	8
Fragmentation threshold	8192
Simulation time	10000 ms

III. SCENARIO AND EVALUATION METRICS

A. Simulation scenario and models

The scenario is based on HSDPA and WiFi indoor coverage partially overlapped zones. High-priority NRTV traffic at 64 kbps is characterised by the 3GPP model [17]. The generation of NRTV sessions are modelled by a Poisson distribution while the call duration is exponentially distributed with average 180s.

Details for the simulator features are presented in [15] [19]. The main simulation parameters are presented in Table IV. Since WiFi capacity is considerably larger than the one for the HSDPA system, a large number of NRTV users are required to be fed into the WiFi operating region of the topology leading to an excessive simulation time (until the value of the load in WiFi becomes significant). To overcome this limitation, the WiFi system was 'filled' with 4 FTP, 4 voice and 3 NRTV users from the beginning.

TABLE IV. MAIN HSDPA AND WIFI SIMULATION PARAMETERS.

Parameter	**HSDPA**	**WiFi**
Mode	FDD (Tx mode)	EDCA (MAC Tx mode)
Scheduler	MaxCI	Round-Robin
Link Adaptation	BLER 10%	Similar to [18]
Radio propagation model	3GPP indoor + FF	ITU 2GHz propagation (Path Loss)
Cell type	Omni	Omni
Number HS-PDSCH (data codes)	15	-
Bandwidth	5MHz	Variable with the user SNR
Initial number of users	20	11

Users are distributed uniformly in the area of HSDPA coverage. This area is higher than the WiFi coverage one. In the best case, WiFi covers 50% of the HSDPA area while, in the worst case scenario, it covers around 13% of it.

It is assumed that NRTV users prefer to use HSDPA. After a given load threshold the suitability for a given system is calculated. If a user is more suited to be in WiFi then it put him/her on WiFi, depending on the coverage. To analyse the benefits obtained by having CRRM procedures, several scenarios were studied:

- No handover between systems;
- The users position is fully known and only the HSDPA users that are within WiFi coverage area are the ones that are switched from HSDPA to WiFi.

B. Evaluation Metrics

The implementation of the proposed CRRM algorithm uses in each decision time instant, i.e., when a new session is requested, a measure of the load from each system. The output from the CRRM decision block is the target Node B (or AP) to which the new device should be attached. In order to evaluate the efficiency of the proposed load-balancing algorithm, performance evaluation metrics, e.g., the throughput are considered for the communication within the cell:

- Over the Air throughput (*OTA_thr*) - *OTA_thr* is proportional to the number of bits that have been transmitted by the given cell, b_{OTA}, in a given period $p=kT$, where k is the number of TTIs. To obtain $OTA\_thr_{[b\cdot s^{-1}]}$ one divides b_{OTA}, in a given period p with similar conditions regarding load, by k times the TTI duration (T):

$$OTA\_thr_{[b\cdot s^{-1}]} = \frac{b_{OTA}(p)}{k\cdot T}. \qquad (6)$$

- Service throughput/goodput (*Serv_thr*) - the ratio between number of bits that have been transmitted and correctly received in the cell without packet errors, b_{serv}, and the duration of k TTIs, and is obtained by:

$$Serv\_thr_{[b\cdot s^{-1}]} = \frac{b_{serv}(p)}{k\cdot T}\,. \tag{7}$$

- QoS throughput/goodput (*QoS_thr*) - the ratio between the number of bits correctly received without packet errors within the allowed delay, b_{QoS}, and the duration of k TTIs, and is obtained by:

$$QoS\_thr_{[b\cdot s^{-1}]} = \frac{b_{QoS}[p]}{k\cdot T}\,. \tag{8}$$

- Packet delay - the amount of time since a packet is generated up to the time it is correctly received. The maximum allowed delay is 300ms for NRTV, 10000ms for FTP, and 30ms for voice.

T is the transmit time interval. k is the number of steps in a period p. b_{OTA}, b_{serv}, and b_{QoS} are the number of bits that have been transmitted, correctly received, and correctly received within the allowed delay in the simulation during period p, respectively.

IV. SIMULATION RESULTS

A. Results without vertical handover

All the results obtained are presented with small bars that represent the 95% confidence interval for the mean. Throughput without CRRM entity exploring the diversity gain for the radius equal to 50 m.

Figure 2 presents results for throughput as a function of the total number of users in the absence of the proposed CRRM for *Radius*=50 m.

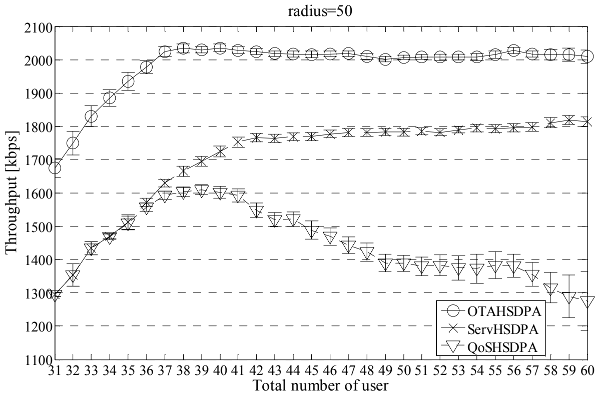

Figure 2. Throughput without CRRM entity exploring the diversity gain for the radius equal to 50 m.

After 37 users (11 within WiFi and 26 within HSDPA), the QoS throughput starts to decrease.

The number of unsatisfied users is given by

$$\frac{64kbps\cdot 49users - 1300kbps}{64kbps} \sim 28users\,. \tag{9}$$

When 60 users are active (11 in WiFi and 49 in HSDPA), ~28 users (approximately 57%) are unsatisfied, since they are being served with low quality, e.g., long queuing time.

B. Results with vertical handover

One found that the most appropriate load thresholds are LTh_0=0.6 for HSDPA (RAT 0) and LTh_1 =0.53 for WiFi (RAT 1). These values were obtained by verifying when the QoS starts to decrease in each system. Figure 3 presents results for LTh_0 =0.6. The values 0.7 and 0.8 for LTh_0 resulted in users exceeding their QoS delay threshold , i.e., 300 ms.

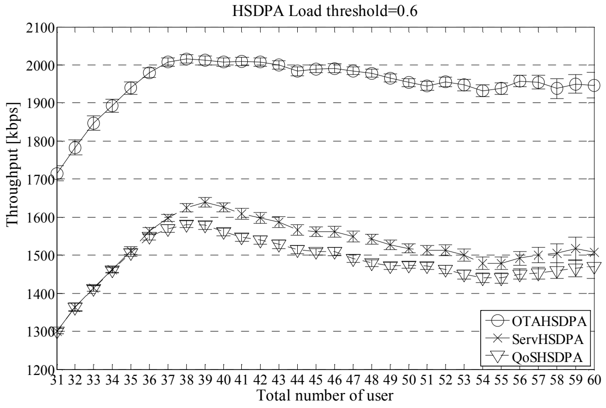

Figure 3. Throughput in HSDPA with CRRM entity exploring the diversity gain for the radius equal to 50 m.

For LTh_0=0.8, with 60 users, around 350 kbps are delivered above delay threshold, which corresponds to 10% of unsatisfied users.

In WiFi the only service that presents a problem is the background service. We used two approaches: one in which we average all the results not accounting for the different LTh_0 and another in which we analyse the results for each LTh_0. For the background application, the load against the delay threshold has been considered to be 10s. The first approach shows that a delay threshold of 10s is overcome when more than 13 users are in the WiFi system, Figure 4. This gives us a load threshold of approximately 0.53. The second approach, when averaging each LTh_0 individually, we get the results for the delay presented in [9]. The LTh_0 found previously was 0.6. For this LTh_0, the 10s delay threshold is overcome when 45 users are in the system, which corresponds to values of 0.52-0.53 for the load threshold in the WiFi system.

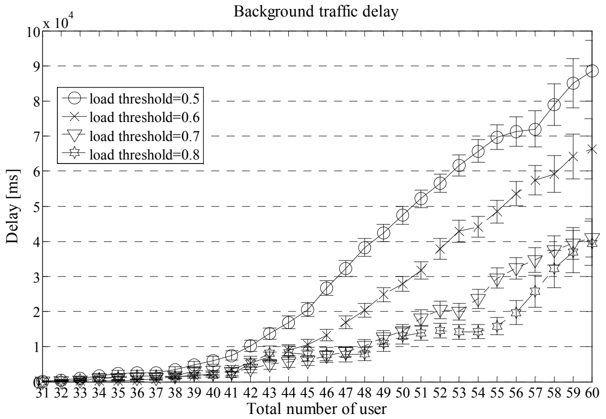

Figure 4. Delay for background traffic for the several load thresholds, depending on the total number of users.

This is congruent with the result LTh_1 = 0.53 previously found. The service class that suffers the most by adding NRTV users to WiFi is the background one as it is the one with less priority. The delays suffered either by voice or by the video service class are always lower than the thresholds specified in the literature, i.e., 30 ms for voice and 300 ms for video.

Figure 5 compares the overall QoS goodput as a function of the offered load for the cases "with" and "without" CRRM. As expected, it can be seen that the QoS goodput increases with offered load until the HSDPA system capacity is reached. By taking the available modulation and coding schemes (MCS) into account, the maximum load accommodated in HSDPA is around 1.6Mbps (see Figure 2).

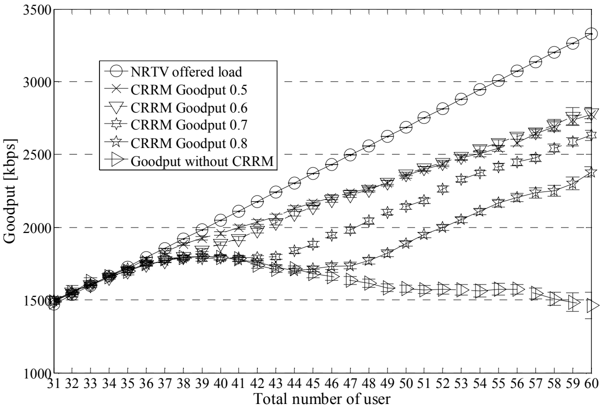

Figure 5. Comparison of the total throughput with CRRM entity exploring the diversity gain.

In Figure 5, the goodput without CRRM accounts for the HSDPA traffic plus the NRTV WiFi traffic, which includes three initial users from WiFi. As the offered load starts to go beyond this value, the QoS goodput does not exceed 1.7Mbps and starts to tail-off at around 1.5Mbps. This effect is due to the use of the max C/I scheduler. It will always provide services to users in the near vicinity of the base station. Nevertheless, the throughput gain introduced by the presence of the CRRM is significant. With the aforementioned optimal load threshold (LTh_0=0.6), by comparing the goodput with and without CRRM, the observable gain is 2700/1500=80% at 60 users. The use of lower load thresholds is not advised, since it causes the WiFi system to overload "faster" causing problems to the background traffic.

V. CONCLUSIONS

In this paper, the proposed CRRM can be used effectively to manage the available radio resources for heterogeneous wireless networks. We applied the suitability based RAT selection protocol to support cooperation between WiFi and HSDPA. This entity has full knowledge of the load in both systems and the traffic type. It is able to trigger handovers between systems and redirect traffic trough HSDPA or WiFi. This work found the optimal load threshold that maximises the total QoS throughput for the cooperation between the two networks. Simulation results have shown that optima load thresholds in this interworking scenario are 0.6 and 0.53 for HSDPA and WiFi, respectively. This corresponds to a CRRM gain on troughput of 80% with 60 users.

VI. ACKNOWLEDGMENT

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