HSDPA/WiFi RAT Selection Based on Load Suitability

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Abstract: Radio access technologies (RATs) selection algorithms have been studied in the literature and nowadays equipment with several RATs incorporated into it is already common. The major goal of this work is to measure the gain obtained by using WiFi as a backup network for HSDPA, allowing for preventing from quality of service (QoS) deterioration when in a low mobility scenario. Since IEEE 802.11e already supports QoS, it was the natural choice. The proposed RAT selection algorithm is based on the load of each system, and the results show a gain of 60% on supported network load with QoS over the HSDPA-alone system. As a consequence, when there is heavy load for the IEEE 802.11e network, acceptance of high priority services will affect the delay in low priority services, like FTP.

Keywords: CRRM, load balancing algorithm, HSDPA, IEEE 802.11e.

1. Introduction

The High-Speed Downlink Packet Access (HSDPA) of UMTS had been completed in 2004, and is currently being rolled out by operators as a complement to their UMTS network, for packet-based services. Release 5 of HSDPA has the potential to deliver multimedia services with data rates up to 14 Mbps, providing wide area coverage, in contrast to UMTS R99, that was originally optimised for voice services. In parallel, the existence of IEEE 802.11e technology has been able to provide a low cost alternative to broadband access confined to local hotspot areas with quality of service support.

Although these two technologies have diverse system requirements they share a common user scenario where they could complement each other to maximise the network capacity. In an era where spectral resources are at a premium, it is essential for operators to explore new technologies that can maximise the spectral efficiency of the system in order to deliver low cost services to the end user. Hence, the systems that can complement each other by cooperation will lead to higher resource utilization.

Although there is an efficiency charge for each Radio Access Technology (RAT) to handle different services, balancing the load between multiple systems allows a better utilization of the available radio resources, and more importantly maintain the QoS provided to the end users. This multiplexing gain, due to combined systems, in contrast to disjoint ones, can be achieved if cross-system information pertaining to each radio access technology is taken into account, thus leading to the concept of cooperative networks. To achieve this multiplexing gain, there is a need for a Common Radio Resource Management (CRRM) entity that is responsible for the assignment of mobiles in each RAT, where the assignment is based on an operator specific criterion and uses cross-system information to decide on the most optimal RAT assignment for each mobile.

Related work on CRRM, where Radio Access Technologies co-exists for operators, appears as one of the definitions of the Beyond 3G system. Reference [1] presents an algorithmic for CRRM load balancing in UMTS and GSM, while [2] analyses the capacity when 3G/WLAN are available, based on the coverage. In [3] some factors that can influence the RAT and cell selection and general fittingness factor are proposed for User-centric and for Network-centric suitability.

In this paper we propose a RAT selection based on load suitability where the systems are HSDPA and WiFi, under delay constraints services. The concept of suitability is used in terms of preferred access system to accommodate the service but this concept suitability can change as load increase, in order to maintain the quality of service (QoS) of delay constraints services. So the goal should be to optimize the load in each RAT, without loss of QoS guarantee, or with a gain in QoS provisioning.

In order to support QoS in WiFi, the IEEE 802.11e standard was chosen, allowing for impairment with HSDPA classes of service. Its medium access and control (MAC) enhancements allows for supporting applications with tight QoS requirements. By dividing the traffic classes (or access categories) into four buffers, one for each service class, IEEE 802.11e prioritises the frames by using different inter-frame spacing and backoff procedures [4].

The remaining of this paper is organized as follows. Section 2 describes the HSDPA and WiFi coexistence scenario. Section 3 describes the algorithm used for RAT selection and respective instantaneous load estimation based on radio propagation conditions for both systems. Section 4 presents simulation scenario and models used for HSDPA and WiFi, performance metrics, and numerical results that measures the diversity gain obtained with CRRM. Section 5 presents the conclusions and suggestions for further work.

2. Network Coexistence Scenario

A CRRM algorithm for RAT selection is proposed in a common coverage area based on load between HSDPA and WiFi (IEEE 802.11e). The addressed scenario is depicted in Figure 1. An IP-based core network is assumed that acts as the bridge between WiFi, and HSDPA. In fact, this is aligned with future wireless trends that envisage a B3G network, a network of wireless networks that allow the users to attain same service through heterogeneous networks. Specifically, we are addressing here legacy networks since we aim to address short-term requirements. Within this IP cloud, we envisage a cooperative networking entity that logically communicates with HSDPA, and WiFi to provide this networking bridge, more specifically referred as the CRRM entity, which is responsible for i) gathering system and user specific information, ii) processing this information according to operator specific criteria, and iii) triggering a new hand-over events according to the load balancing criteria. Moreover, it is assumed that a common operator deploys either systems, or those systems from different operators share a service level agreement.

This scenario addresses the delivery of near real time video (NRTV) services that can be streamed either over HSDPA or WiFi systems. The end user is currently subscribing to an IPTV service, which is currently also being delivered over the WiFi hotspot. This initial connection was chosen since it was deemed to be the most “fitting” network for the requested service. An example is the following. The operator, which is monitoring both networking entities, observes a sudden surge in WiFi subscribers overloading the WiFi network, whilst UMTS is under-loaded, and handling the usual voice services. The CRRM entity suddenly decides that it would be more efficient to shift some of the WiFi users to the

UMTS-HSDPA network, since this leads to better QoS provisioning, and exploits the existing network capacity in a more efficient way. As a consequence, the CRRM triggers a series of handover events that ensures an even load distribution across both networks. When a user is triggered for handover, the multi-mode terminal will initiate a new connection with UMTS-HSDPA, whilst gracefully terminating the existing connection with WiFi. Note that the handover events occur in a seamless manner.

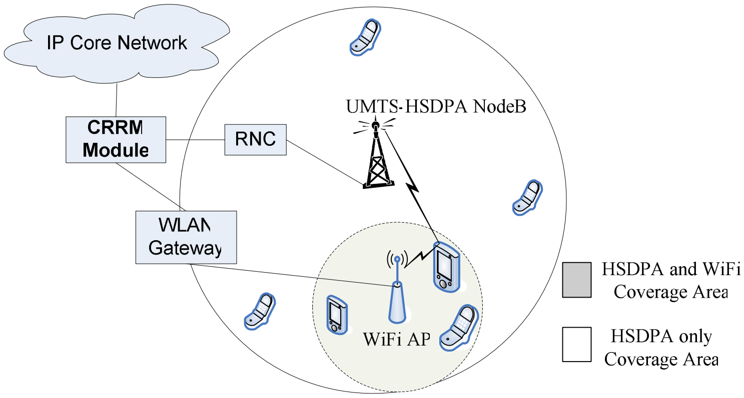

Figure 1. Coverage area for WiFi, HSDPA and for both systems

The study will mainly be focused on the criteria for handling a handover event, whilst neglecting architectural aspects of the intersystem handover, (tight/loose coupling, centralized or de-centralized), including signalling aspects. It is assumed that the values for the metrics are available and can be obtained with no errors. By using load measurement for both systems, based on the obtained suitability value, the algorithm selects the RAT which the user should be attached to.

3. Algorithm Description and RAT Selection Suitability Policy

3.1 RAT Selection Algorithm

An algorithm for selecting the most suitable RAT is proposed with the aim of balancing the load in critical loading situations. The rationale behind the algorithm is the following: 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 [5], [6]. 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 Figure 2

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

where $cell_{i,j}$ represents the cell or access point 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 NRTV, should be selected in the case of equal suitability values obtained for cells of different RATs.

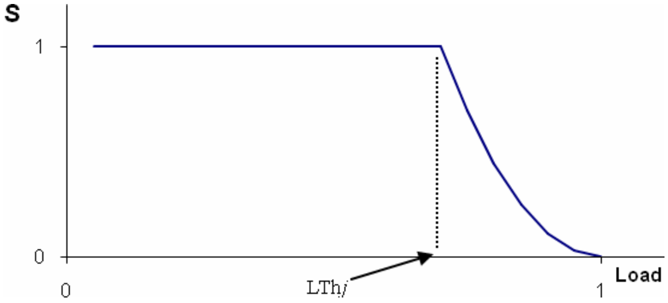

Figure 2: Suitability for the load balancing selection algorithm

LTh_j is the parameter of the algorithm and characterises 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.

3.2 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.

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 as follows

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

where N is the number of HSDPA user, R_{HSDPA} is the number of High Speed Physical Downlink Shared Channel (HS-PDSCH) [7] 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 the following equation

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

where, the average propagation condition determines the channel quality indicator ID, CQI_n, $R(CQI_n)$ is the achieved bit rate when one CQI_n block is allocated in every frame and $N_{HS\text{-}PDSCH}(CQI_n)$ is the number of HS-PDSCH associated to CQI_n as defined in [7]. Table 1 presents the assumptions for HSDPA block sizes and bit rates associated to each CQI.

Table 1: Transport block size and bit rate associated to 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

Capacity load estimation in WiFi

For the WiFi system, the normalized load associated to the Access Point (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 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 [8]. In this intermediate phase, the normalized load for the WiFi system in optimized conditions, i.e., no packet loss, is given by the following equation

$$L_{normalizedWiFi} = \sum_{m=1}^{M} \left(\frac{payload\_VI}{interarrival\_time \cdot R_{MCS}(m)} \right), \tag{5}$$

where M is the number of WiFi user, and $R_{MCS}(m)$ is the rate for the modulation and coding scheme available for user m (of the WiFi AP). The names for other variables are self explanatory.

4. Numerical Results

4.1 Simulation Scenario and Models

The scenario is based on a co-covered HSDPA and WiFi indoor area, assuming high-priority NRTV video traffic at 64 kbps characterised by the 3GPP model [9]. It is assumed that applications prefer to use HSDPA. The generation of NRTV calls are modelled by a Poisson distribution while the call duration is exponentially distributed is used for (with average 120 s).

Details for the simulator features are presented in [10] while details for the IEEE 802.11e part of the simulator are given in [8]. The main simulation parameters are presented in Table 2. 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 6 FTP and 5 voice users from the beginning.

Table 2: Main HSDPA and WiFi simulation parameters

Parameter	**HSDPA**	**WiFi**
Mode	TDD (Tx mode)	EDCA (MAC Tx mode)
CRRM Algorithm load threshold	0.6	0.6
Scheduler	MaxCI	Round-Robin
Link Adaptation	BLER 10%	-
Radio propagation model	3GPP indoor + FF	ITU 2GHz propagation (Path Loss)
Cell type	Omni	Omni
Number HS- PDSCH (data codes)	15	-
Bandwidth	-	Variable with the user SNR

4.2 Evaluation Metrics

In this implementation of the CRRM algorithm, it 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 Access Point) to which the new mobile should be attached. In order to evaluate the efficiency of the proposed load-balancing algorithm, some performance evaluation metrics are considered for the communication within the cell, as follows

- Over the Air throughput (OTA) - It is the number of bits that have been transmitted by the given cell, during the simulation, divided by the total duration of the transmission

$$R = \frac{b_{OTA}}{k \cdot T}. \tag{6}$$

- Service throughput / goodput - It is the number of bits that have been transmitted and correctly received in the cell, during the simulation, divided by the total simulation duration

$$R = \frac{b_{service}}{k \cdot T}. \tag{7}$$

- QoS throughput - It is the number of bits correctly received within the allowed delay during the simulation, divided by the total simulation duration.

$$R = \frac{b_{QoS}}{k \cdot T} \tag{8}$$

The maximum allowed delay for NRTV is 300ms.

4.3 Simulation Results

Results for HSDPA and WiFi

Figure 3 compares the throughput values obtained in the HSDPA system with the offered load. It can be seen that QoS throughtput expectedly increases with offered load until the HSDPA system capacity is reached. Accounting for the available MCS (modulation and coding schemes), the maximum load accommodated is around 1.5Mbps, which reflects the presence of around 28 users in the system. As the offered load starts to go beyond this value, the QoS service throughput expectedly drops whilst the service throughput is maintains values around 1.8Mbps.

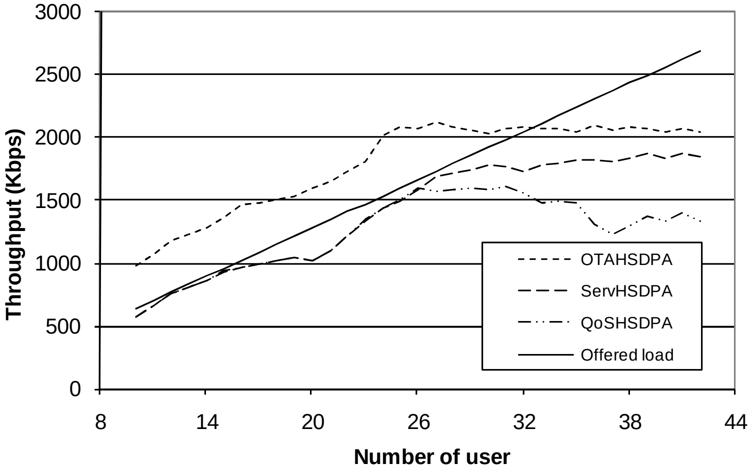

Figure 3. Throughput results for stand alone HSDPA system

IEEE 802.11e is quite different of HSDPA. While the former is centralized, IEEE 802.11e is decentralized and the medium access and control protocol is based on collision detection avoidance. In Figure 4 one can notice that, in WiFi, by increasing the number of NRTV users we do not notice degradation on the goodput. However, we noticed that the 'stability' in the NRTV service is obtained at the cost of degradation of the performance of the FTP traffic as its delay increases substantially.

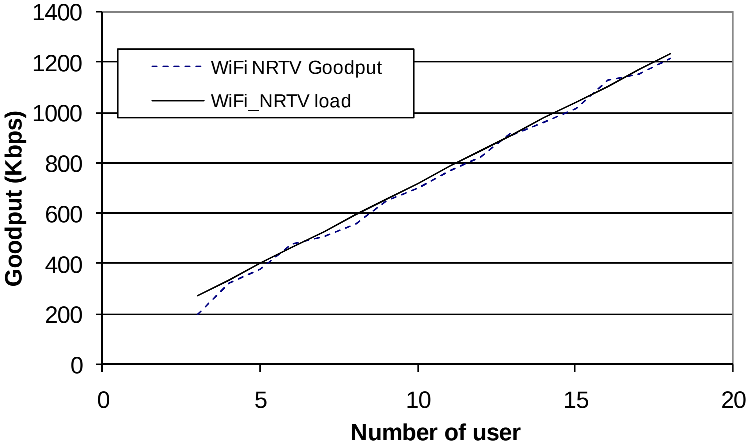

Figure 4. IEEE 802.11e results for the Goodput

Results for CRRM versus HSDPA alone

Figure 5 presents results for QoS throughput when CRRM is used with HSDPA/WiFi coexistence. With the purpose to avoid deterioration of the QoS in a co-covered system, a comparison between the cases of absence and application of the Common Radio Resource Management (CRRM) for network load optimization is performed. Hence, the comparison is between the case where HSDPA alone is used to support NRTV users without CRRM, and the case of the application of CRRM in a system composed by cooperative HSDPA and WiFi by selecting the most suitable RAT for the NRTV service. Results show that up to 42 users were supported. A gain of 60% on the supported QoS load was achieved with the CRRM (intelligently adapted algorithm) over HSDPA alone.

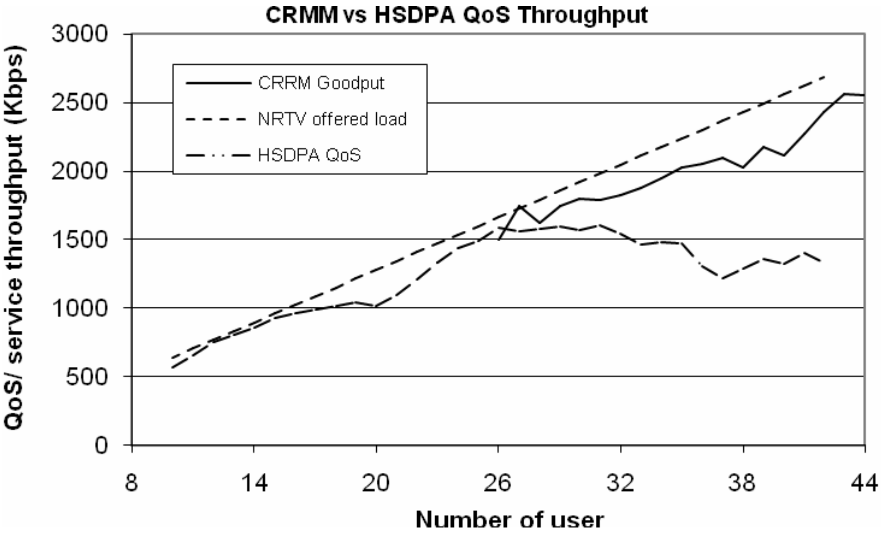

Figure 5. HSDPA normalized load as a function of the number of user (CRRM versus HSDPA alone)

5. Conclusions

In this work, CRRM is employed, exploring the common management of the whole radio resources and the specific advantages of each system with respect to coverage, system capacity and service support in a context of HSDPA/WiFi coexistence.

. The goal of CRRM is to optimize the network load in co-located systems without deteriorating the quality of service, e.g., blocking or dropping probabilities for voice services, delay and throughput figures for data services. It allows for the reduction of the overall radio transmission resources in the case of multilayer systems operating at different frequencies.

By using the CRRM algorithm for selecting the RAT to attach new NRTV call based on actual load in each system, a gain of 60% on the supported network QoS throughput is obtained over HSDPA alone. Despite the high capacity of IEEE 802.11e networks, the acceptance of high priority services will affect the delay in low priority services, like FTP, which is a background type of service. However, in HSDPA, although the QoS degradation is directly affected by the high-priority services, a balance occurs between real time and non-real time services and the packet delay also slightly increases for NRTV .

Acknowledgment

This work was partially funded by CROSSNET (Portuguese Foundation for Science and Technology, FCT, POSC project with FEDER funding), by IST-UNITE, by the FCT PhD grant SFRH/BD/28517/2006, and by “Projecto de Re-equipamento Científico” REEQ/1201/EEI/ 2005 (a Portuguese Foundation for Science and Technology project).

References

[1] Apillekeit, F. Derakhshan, E. Jugl, AMitschele-Thiel, “Force-based load balancing in co-located UMTS/GSM networks”, in *Proc. of VTC 2004 Fall - 60th IEEE Vehicular Technology Conference 2004-Fall "Wireless Technologies for Global Security"*, Los Angeles, CA, USA, Vol. 6, Sep. 2004.

[2] H. Liu, H. Bhaskaran, D. Raychaudhuri, S. Verna, “Capacity analysis of cellular data system with 3G/WLAN interworking”, in *Proc. of VTC 2003 Fall - 58th IEEE Vehicular Technology Conference 2003 –Fall*, Orlando, Florida, USA, Oct. 2003.

[3] O. Sallent, J. Pérez-Romero, R. M. Ljung, P. Karlsson, A. Barbaresi “Operator’s RAT selection policies based on the fittingness factor concept”, in *Proc. of IST Summit 2007 -16th IST Mobile and Wireless Communication Summit 2007*, Budapest, Hungary, July 2007.

[4] IEEE Std. 802.11e; Wireless LAN Media Access Control (MAC) and Physical Layer (PHY) Specifications, 2005.

[5] S. Ryu, B.-H. Ryu, H. Seo, M. Shin, S. Park “Wireless packet scheduling algorithm for OFDMA system based on time-utility and channel state”, *ETRI Journal*, Vol. 27, No. 6, Dec. 2006.

[6] Patrick Hosein “On the optimal scheduling of uplink resources in OFDMA-based wireless networks”, *Proc. of EW 2006 - 12th European Wireless Conference*, Athens, Greece, Apr. 2006.

[7] 3GPP 25.214, “Physical layer procedures (FDD)” 3GPP TS 25.214 V5.9.0 2004 -6.

[8] O. Cabral, A. Segarra, F. J. Velez, “Simulation of IEEE 802.11e in the context of interoperability”, in *Proc. of WCWN’ 2007 – The 2007 International Conference of Wireless Networks (held in the context of WCE’ 2007 - World Congress on Engineering*, Vol. 2, London, UK, July 2007.

[9] 3GPP TR 25.892 v6.0.0 “Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement” 3rd Generation Partnership Project, Technical Specification Group Radio Access Network, 2004-06.

[10] CEA-LETI, and al., "D1.1.1 Definition of Cross-Layer and Cross-System Framework Scenarios", *www.ist-unite.org*, IST-4-026906 UNITE, Deliverable D1.1.1, IST Central Office, Brussels, Belgium, Sep. 2006.