Service Suitability Based RAT Selection for Beyond 3G Systems

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Abstract—**In beyond 3G systems, one of the important factors is to address Radio access technology (RAT) selection and load balancing between heterogeneous networks to ensure high spectral efficiency in an era where spectral resources are at a premium. This work aims to address the feasibility of utilizing WiFi as complementary service for HSDPA, to prevent quality of service deterioration in the event of network overload in HSDPA during the busy period. The proposed RAT selection algorithm is based on the load of each system, and the results show that the outage probability can be improved by up to 45% relative to a stand-alone HSDPA system.**

Keywords-*CRRM, load balancing algorithm, HSDPA, IEEE 802.11e*

I. 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 optimized 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 policy based on load suitability where the systems are the HSDPA and WiFi IEEE 8011e [4] under delay constrained 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 increases in order to maintain the quality of service across the network. So the goal should be to optimize the load in each RAT, without loss of QoS guarantee, or with a gain in QoS provisioning.

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.

II. 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

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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. . 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.

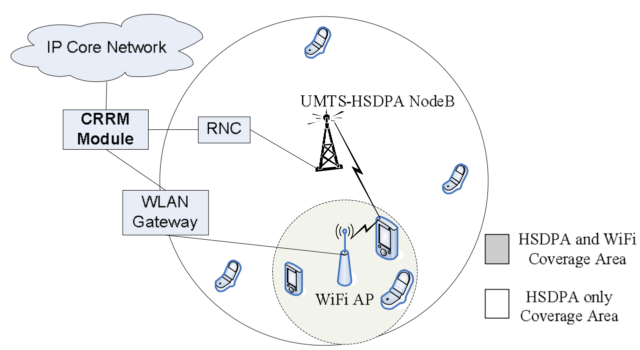

Figure 1. Coverage area for WiFi, HSDPA and for both systems

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 signaling 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.

III. 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. 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 $cell_{i,j}$. 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.

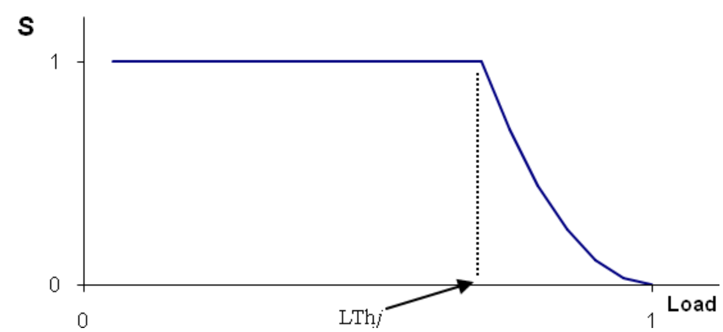

Figure 2: Suitability for the load balancing selection algorithm

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

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.

1) 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 $N_{HS-PDSCH}(CQI_n)$ 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 I. TRANSPORT BLOCK SIZE AND BIT RATE ASSOCIATED TO CQI.

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

2) 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

IV. Numerical Results

A. 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 characterized by the 3GPP model [9]. It is assumed that applications prefer to use HSDPA. The generation of NRTV calls are modeled 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 II. MAIN HSDPA AND WIFI SIMULATION PARAMETERS

Parameter	HSDPA	WiFi
Mode	TDD (Tx mode)	EDCA
Load threshold	0.6	0.6
Scheduler	MaxCI	Round-Robin
Link Adaptation	BLER 10%	-
Propagation model	3GPP indoor + FF	ITU 2GHz
Cell type	Omni	Omni
Num. HS- PDSCH	15	-

B. 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

- 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

$$R = \frac{b_{service}}{k \cdot T} \quad (6)$$

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

$$R = \frac{b_{QoS}}{k \cdot T} \quad (7)$$

- Outage probability - It is the ratio between obtained throughput (QoS and Service) and the offered load.

$$P_{outage} = \frac{R}{OfferedLoad} \quad (8)$$

Maximum allowed delay for NRTV is 300ms, and the outage threshold considered for the QoS is 85%.

C. Simulation Results

1) Results for HSDPA and WiFi stand alone systems

Figure 3 compares the outage probability on the throughput obtained in the HSDPA system. It can be seen that outage probability on QoS throughput expectedly decreases with offered load until the HSDPA system capacity is reached, with about 30 users. As the offered load (number of users) starts to go beyond this value, the outage probability of the QoS (and service) throughput expectedly drops.

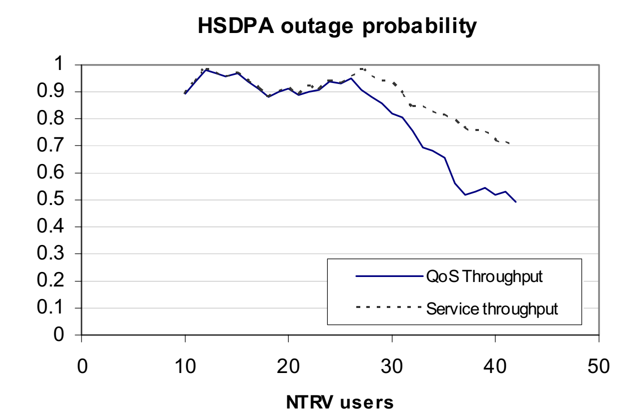

Figure 3. Throughput results for stand alone HSDPA system

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 outage probability. 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.

2) Results for CRRM versus HSDPA alone

Figure 5 presents results for the QoS throughput outage probability, when Common Radio Resource Management (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 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. Results show that up to 42 users were supported against 29 users for the HSDPA case only, resulting in a gain of 45% on outage probability with the CRRM (intelligently adapted algorithm) over HSDPA alone.

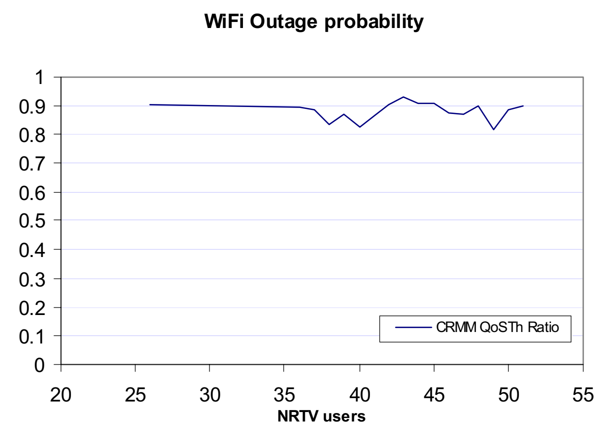

Figure 4. IEEE 802.11e Outage probability results.

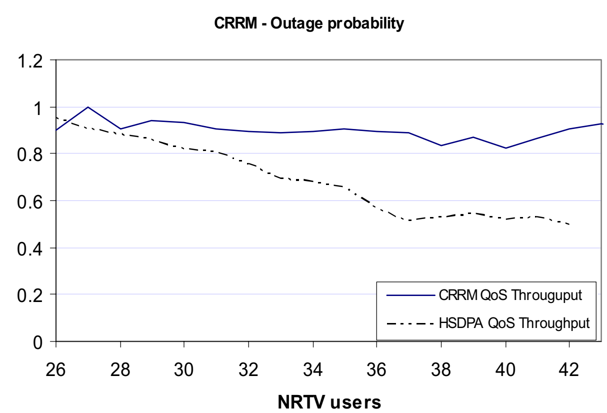

Figure 5. HSDPA normalized load as a function of the number of user (CRRM versus HSDPA alone)

V. 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. The proposed CRRM/RAT selection algorithm could provide a gain of up to 45% in outage probability relative to HSDPA alone in the presence of NRTV services...

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