Analyzing the Impact of Real and Non-Real Time Traffic on Joint Radio Resource Management

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Abstract—**The joint management of radio resources from different network technologies gains an increasing importance when a crescent number of heterogeneous networks are interconnected. From the user's point of view, those networks are seen as a single broad access network, while for the telecommunications operator this joint management approach improves the quality of service offered to the users and contributes to increase its revenue.**

This paper studies the performance of a new joint radio resource management strategy in face of two different traffic scenarios. One scenario considers only real-time applications, concretely voice and videostreaming, while the other scenario considers real-time and non-real-time applications running concurrently. The performance analysis is done by comparing the new strategy with two well-known strategies used in scenarios where the UMTS and the WLAN networks are interconnected. In this comparison, the new proposed strategy obtained lower call blocking probabilities for both traffic scenarios. The paper also presents results of the WLAN throughput performance analysis for several packet size scenarios.

Index Terms—**Renegotiation, Reallocation, Resource management, Heterogeneous wireless networks, Session continuity**

I. INTRODUCTION

The concept of fourth generation (4G) networks is characterized by the integration of different heterogeneous networks including celular networks, such as the Universal Mobile Telecommunication System (UMTS), Wireless Local Area Networks (WLANs), usually identified as IEEE 802.11 wireless fidelity (WiFi), and metropolitan wireless access networks, such as WiMAX. The integration of these networks forms one global access network, enabling call transference from one interface to another, seamlessly to the user.

In a context where one telecommunications operator administrates different network technologies in the same physical location, a joint and efficient management of those networks resources is desired. This will certainly improve the service offered to the users and, at the same time, will increase the operators' revenue.

This paper proposes a new joint radio resource management (JRRM) strategy for UMTS and WLAN networks, interconnected through the generic interconnection architecture defined by the 3rd Generation Partnership Project (3GPP) [1]. This new strategy, called MTend, bases its behavior in criteria related to user mobility. Additionally, in a scenario of low available resources, the strategy introduces the possibility of renegotiating requests of new calls or reallocating existing calls from one network to another. The performance of the MTend strategy is analyzed in face of two different traffic scenarios where the user is static. One scenario considers only real-time applications, concretely voice and videostreaming, while the other scenario considers real-time and non-real-time applications running concurrently. The performance analysis is done by comparing the new strategy with two well-known strategies used in scenarios where the UMTS and the WLAN networks are interconnected.

In the next section, some important related works are presented. Section III presents the call admission control mechanisms used by the UMTS and WLAN interfaces. Section IV proposes the new strategy for joint management of multi-radio resources, based on user mobility and the renegotiation or reallocation of calls; this section also describes the decision algorithm used to define the interface to which a new call should be allocated. Section V presents the simulation scenario used to analyze and compare the performance of this new joint radio resource management strategy with two other well-known strategies. Section VI analyzes in detail the simulation results. Finally, Section VII presents the main conclusions of this work.

II. RELATED WORK

The joint multi-radio resource management is an well accepted research area in telecommunications. It promotes solutions for the support of Quality of Service (QoS) classes while optimizing the usage of resources.

A strategy based on service classes is proposed in [2], where the authors use two policies: the first policy gives priority to voice calls in GSM EDGE Radio Access Network (GERAN) and interactive traffic in UMTS Terrestrial Radio Access Network (UTRAN); the second inverts the choice. According to the authors, when the mobile stations are close to the cell there is no difference between both strategies. In turn, when the distance to the cell increases, more transmission errors may occur due to Wide-Band Code-Division Multiple Access (WCDMA) characteristics, leading to a higher degradation in UTRAN users. In this case, the first policy is the most efficient one.

Two other strategies commonly used in this context are the load balancing (LBal) and the coverage area (CovAr) strategies, which will be used for comparison with the strategy proposed in this paper. The LBal strategy is characterized by directing calls to the interface with lowest load, maintaining the interfaces balanced [2], [3], [4].

The CovAr strategy directs calls preferentially to the interface associated to smaller area cell. For example, in hotspots the calls are directed firstly to the WLAN network until it saturates, and then to the UMTS network [3].

III. Single Interface Call Admission Control

The following two sections present the call admission control mechanisms used by the UMTS and WLAN network technologies for managing new calls.

A. UMTS Interface

In UMTS, the load factor estimates the amount of supported traffic per base station site; in [5], the authors describe the mechanism to obtain the available UMTS load factor for both link directions. The load factor for the uplink direction is given by:

$$\eta_{UL} = (1+i) \cdot \sum_{j=1}^{N} \frac{1}{1 + \frac{W}{(E_b/N_0)_j \cdot R_j \cdot v_j}}, \quad (1)$$

where N is the number of stations, v_j is the activity factor of station j at physical layer, E_b/N_0 is the signal-to-noise ratio, W is the chip rate, R_j is the bit rate of station j and i is the intercell interference observed by station j.

The load factor for the downlink direction is given by:

$$\eta_{DL} = \sum_{j=1}^{N} v_j \frac{(E_b/N_0)_j}{W/R_j} \cdot [(1-\alpha_j) + i_j], \quad (2)$$

where α_j is the channel orthogonality of the station j, while i_j is the signal of other cells received by station j. For v_j, α_j and i_j we used commonly accepted values proposed in [5].

The load factor is controlled to be always below a limit represented by η_{max} ($\eta_{max} < 1$). In most of the UMTS systems, the η_{max} value is not higher than 0.75, for both directions, the uplink and the downlink [5], [6]. In our work, we assumed that the operator applies this value for η_{max} in both direction.

In the UMTS interface, a new call specifies the minimum QoS requirements that should be satisfied by the network. This request includes values for different QoS parameters, such as the bit rate. A new call is accepted by the call admission control mechanism, either in the uplink or in the downlink, when the load factor is below η_{max} after integrating the new call.

B. WLAN Interface

Comparing with UMTS, the WLAN interface usually offers a higher bandwidth and a smaller cell coverage area. In turn, the radio access in WLAN is most of the times uncertain, being based on the transmission silence time [7].

The strategy used for obtaining the available bandwidth in the WLAN interface consists on monitoring the channel occupation ratio, which determines the channel capacity for transmit [8]. New calls are only admitted in WLAN when the requested bandwidth is below the available bandwidth. The WLAN available bandwidth, in bit/s, is given by:

$$Bw_{WLAN} = \frac{L \cdot (R_{th} - R_o)}{T}, \quad (3)$$

where L is the average packet size, T is the average time for having success in transmission and R_{th} is the network threshold, which is a parameter controlled by the operator [8].

The network occupation factor is given by:

$$R_{o_i} = \alpha \cdot \frac{t_{busy}}{\Delta_t} + (1-\alpha) \cdot (R_{o_{i-1}}), \quad (4)$$

where t_{busy} is the busy state time, Δ_t is the window size measurement time, and α is the importance of the current sample i.

When the RTS/CTS mechanism is not used, T is given by:

$$T = DIFS + T[EP] + SIFS + ACK. \quad (5)$$

In turn, when the RTS/CTS mechanism is used, T is given by:

$$T = DIFS + RTS + SIFS + CTS + SIFS + T[EP] + SIFS + ACK, \quad (6)$$

where $T[EP]$ is the transmission time for a packet with payload size of EP and RTS, CTS and ACK are the transmission times of RTS, CTS and ACK, respectively.

IV. JRRM Based on User Mobility, and Call Renegotiation and Reallocation

The multi-radio resource management strategy proposed in this paper, called MTend, aims to maximize the use of the radio resources, while satisfying the QoS requirements posed by the applications.

Fig. 1 represents the structure of the decision algorithm used for the joint management of interconnected UMTS and WLAN radio resources under the control of the same operator. When a new call request arrives, the algorithm decides to which interface it should be directed, based on the call characteristics and resources available. In a scenario where both networks have resources available, the strategy is based on the Mobility Tendency of the users, differentiating applications according to their tendency for mobility. For example, voice calls are inherently mobile, since the probability of a user receiving or starting a call in movement is relatively high. Thus, this strategy gives priority to mobile applications in the UMTS network, in order to avoid vertical handoffs between different network technologies. Applications usually used in static contexts (e.g., web browsing and videostreaming) are accepted preferentially in the WLAN network.

In scenarios of insufficient resources, our strategy proposes two complementary mechanisms. The first mechanism consists of renegotiating the resources requested by the new call; the second mechanism considers the possibility of reallocating an accepted call from one network to the other, enabling resources

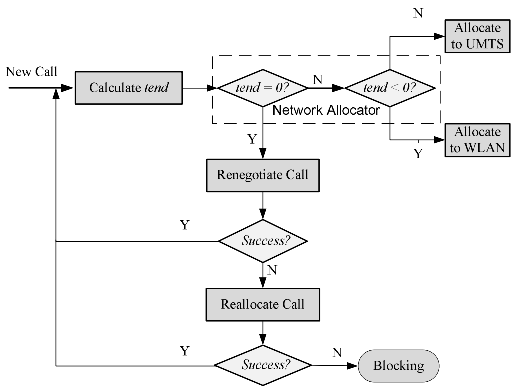


Fig. 1. Joint multi-radio resource management algorithm

to be freed in the congestioned network. The renegotiation and reallocation mechanisms require the monitoring of each access network so that their level of congestion can be evaluated.

The renegotiation mechanism consists of two renegotiation tries. In a case where the first try does not succeed, the system enables the application to reduce again the resources requested. Table I contains the renegotiation parameters for the applications used in our study.

TABLE I
APPLICATION BIT RATES AND THEIR RENEGOTIATION ALTERNATIVES

Application	**Mean bit rate (kbit/s)**		
	1st Request	1st Renegotiation	2nd Renegotiation
Voice	24	12	8
Videostreaming	128	64	32
WWW	128	64	32
FTP	128	64	32

The following paragraphs formalize the MTend strategy decision algorithm. The network interface selected to serve the new call is chosen according to Eq. (7), where *tend* represents the decision tendency. The indicator function 1_y is 1 if the event y is true, else it is zero. P_{UMTS} and P_{WLAN} are the eligibility degrees given to an arriving session, respectively to be transported over the UMTS and WLAN interfaces, as shown in Table II.

$$tend = P_{UMTS} * \mathbf{1}_{\eta a_{UMTS} \geq \Delta_{\eta r}} - P_{WLAN} * \mathbf{1}_{Bw_{WLAN} \geq r} \quad (7)$$

TABLE II
UMTS AND WLAN ELIGIBILITY DEGREES ACCORDING TO THE USER MOBILITY CRITERION

Application	**Eligibility Degree**	
	P_{UMTS}	P_{WLAN}
Voice	2	1
Videostreaming	1	2
WWW	1	2
FTP	1	2

The ηa_{UMTS} and Bw_{WLAN} variables are, respectively, the available UMTS load factor and the available bandwidth in the WLAN interface. ηa_{UMTS} is the difference between η_{max} and η_{DL}, which is given by Eq. (2), while Bw_{WLAN} is given by Eq. (3). $\Delta_{\eta r}$ is the UMTS load factor associated to a new call, given by the argument of the sum of Eq. (2), calculated with the appropriate parameters for each type of call [5]. r is the WLAN mean bit rate requested by the new call.

V. SIMULATION SCENARIO

In order to demonstrate and evaluate the joint radio resource management strategy proposed in this paper, we considered a simulation scenario corresponding to an hotspot located in a shopping center. We adopted simulation scenarios where the number of users varies from 1 to 1000 and, in the busy hour, each user is involved, in average, in 6 calls, each with an average duration of 120s. The incoming calls follow a Poisson process with mean inter-arrival interval given by

$$1/\lambda = \frac{3600}{U_q \times U_c},$$

where U_q is the average number of users and U_c is the average number of calls made by a user in the busy hour.

The simulation system was implemented in Network Simulator 3 (NS-3) [9], being the UMTS interface developed as a statistical module, based in [5], [10]. NS-3 already implements the IEEE 802.11 multi-rate standard (i.e., 6 Mbps to 54 Mbps) [11], [8]. Voice and videostreaming applications are modeled as constant bit rate (CBR) and variable bit rate (VBR) traffic, respectively, transported using UDP. WWW and FTP are modeled using the On-Off traffic source implemented in NS-3. The WWW application alternates between the On and the Off states, while FTP is modeled as constantly On, considering files sufficiently large to occupy a 120s session. WWW and FTP traffic is transported using TCP. We assumed that the UMTS network supports applications with QoS requirements, while the WLAN network does not integrate any mechanism for QoS support.

VI. RESULTS ANALYSIS

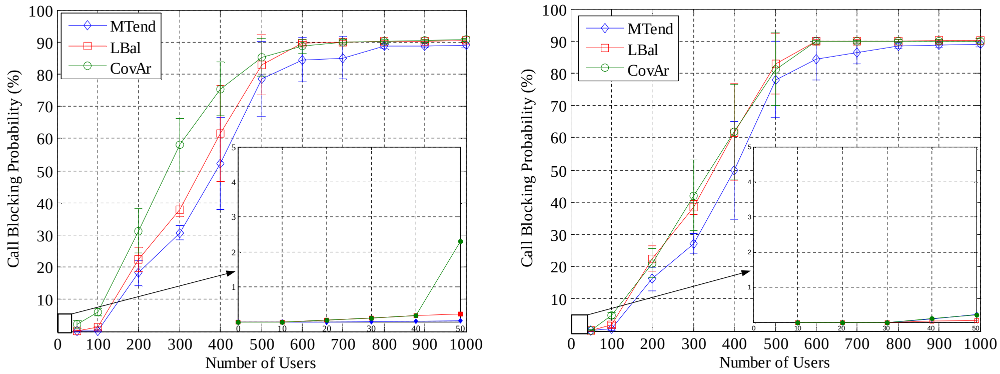
In this section we present and discuss the results obtained through the simulation of three joint multi-radio resource management strategies using the scenario described in Section V. The objective is to compare the behavior of the strategy presented in this paper, identified as Mobility Tendency (MTend), with two other strategies, namely the Load Balancing (LBal) strategy and the strategy based in the Coverage Area (CovAr).

We separate the analysis in two different scenarios. The first scenario only considers real-time applications, concretely voice and videostreaming, while the second scenario considers real-time and non-real-time applications running concurrently.

The parameter used to compare the three strategies is the call blocking probability (CBP). This probability is given by

$$CBP(\%) = \left[1 - \frac{C_{acpt}}{C_{off}}\right] \times 100,$$

where C_{acpt} is the number of application calls accepted, and C_{off} is the total number of calls offered to the system.



(a) (b)

Fig. 2. Call blocking probability for real-time traffic, without (a) and with (b) call renegotiation

A. *Real-Time Traffic Scenario*

To analyze the behavior of the three joint radio resource management strategies in the presence of real-time traffic, we considered scenarios using voice and videostreaming traffic parameterized according to Table I [12], [13]. We assumed that 50% of the calls are voice calls and the other 50% are videostreaming calls, i.e., only the two first applications from Table II were considered in these simulations.

Fig. 2 (a) shows the average values and the 95% confidence intervals of the call blocking probability for all strategies. These strategies present very high probablities for a number of users above 600, reaching a call blocking probability of almost 100% between 900 and 1000 users. The MTend strategy presents a performance better than the other two, having a call blocking probability always below the other two strategies until the number of users reaches 500.

The box inside Fig. 2 (a) shows the performance of the resource management strategies for scenarios with a reduced number of users, from 1 to 40. The MTend strategy still has a better performance than the other two strategies in those scenarios, obtaining call blocking probabilities under 2% for a number of users less than 20.

The most interesting analysis should be done for low call blocking probabilities, under 20%, which are the values considered by an operator for a real service provisioning scenario. Fixing a call blocking probability, the gain obtained with the MTend strategy comparing with the concurrent strategy S is given by Eq. (8), where $Users_S$ represents the number of users using the operator's networks with the strategy S.

$$G^{CBP}_{MTend\_S} = \frac{Users_{MTend} - Users_S}{Users_{MTend}} \quad (8)$$

Considering the call renegotiation mechanism active, for example, for a call blocking probability of 2%, the gain of $G^{2\%}_{MTend\_LBal} = 6\%$, while for the CovAr strategy, the gain is $G^{2\%}_{MTend\_CovAr} = 35\%$. It means that the operator supports 6% to 35% more users with the MTend strategy than with the other two resource management strategies, for the given call blocking probability.

Fig. 2 (b) shows the average values and the same confidence intervals for call blocking probability, now assuming that the three strategies integrate the same renegotiation mechanism described in Section IV.

Comparing Fig. 2 (a) with 2 (b), becomes clear that the CovAr strategy increases its performance when it uses the renegotiation mechanism; this occurs because of the succeeded renegotiation of calls, mainly in scenarios where the number of users is low (between 100 and 400). Even though, the MTend strategy presents a performance better than the other two, until the number of users reaches 600. This is due mainly to the use of the reallocation mechanism implemented in the MTend strategy, which takes advantage of the resources available at both interfaces. In this case, the reallocation of calls from the congestioned network to the other network occurs. Above the 600 users, the call inter-arrive interval becomes small and the reallocation mechanism acts more frequently to maintain the networks balanced, what increases the number of blocked calls. Table III summarizes the gain obtained in real-time traffic scenarios with the MTend strategy in comparison with the other two strategies, considering call blocking probabilities varying from 2% to 10%.

TABLE III
GAIN OF MTEND STRATEGY IN RESPECT TO LBAL AND COVAR FOR REAL-TIME TRAFFIC

CBP(%)	$G^{CBP}_{MTend\_S}$ (%)			
	Without Renegotiation		**With Renegotiation**	
	S=LBal	S=CovAr	S=LBal	S=CovAr
2	8	56	6	35
5	12	33	7	26
10	14	30	9	29

Figure 3 presents the number of call renegotiation tries for the three strategies in the real-time scenario, normalized to the number of incoming calls. This number is higher for the CovAr strategy, mainly due to the higher number of blocked calls in that strategy observed when the renegotiation mechanism is switched off. Thus, the CovAr increases the number of call renegotiations to obtain a better global performance. This figure enables also to conclude that the number of first

TABLE IV

CALLS PER USER PER HOUR IN REAL-TIME AND NON-REAL-TIME TRAFFIC SIMULATIONS

Application	**Average call per user per hour**
Voice	2
Videostreaming	2
WWW	1
FTP	1

renegotiation tries is higher for the three strategies than the number of second renegotiation tries.

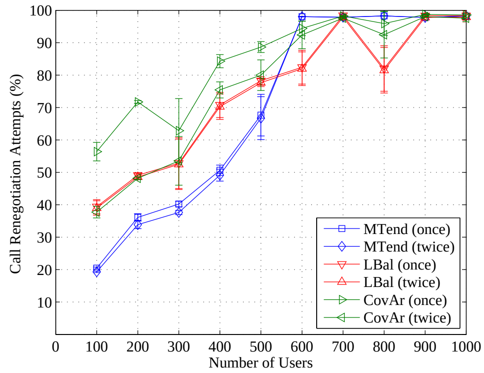


Fig. 3. Percentage of call renegotiation attempts

From this analysis, we can conclude that the renegotiation mechanism is an important contribution for the better use of both networks resources, helping to decrease the call blocking probability.

B. Real-Time with Non-Real-Time Traffic Scenario

For the scenario with real-time and non-real-time traffic the simulations considered all the four applications presented in Table I, where the average number of calls made by each user per hour is given in Table IV.

Fig. 4 shows the average values and the 95% confidence intervals of the call blocking probability for the three strategies obtained with the introduction of TCP traffic (WWW and FTP), in addiction to the real-time traffic (voice and videostreaming). In Fig. 4 (a) the strategies do not integrate the call renegotiation mechanism, while in Fig. 4 (b) this mechanism is integrated in all the three strategies.

Comparing Fig. 4 (a) with Fig. 4 (b), we conclude that the call renegotiation mechanism increases the performance of all the strategies, although not for the same number of users. However, the call renegotiation mechanism benefits are not so relevant as observed with real-time traffic, in Fig. 2, which means that with TCP traffic the call renegotiation mechanism were less used by the strategies.

Comparing Fig. 4 with Fig. 2, we should stress two aspects. The first aspect has to do with the behavior of the call blocking probability when the number of users increases. In the presence of TCP traffic, the call blocking probability increases much more gradually than when only real-time traffic is present, where this probability increases rapidly between 100 and 500 users. The reason for the gradual increase of call blocking probability in the real-time and non-real-time traffic scenarios is related with the higher diversity of applications competing for the same resources. In this scenario the number of videostreaming calls decreases, which explains the lower call blocking probabilities, even for higher number of users.

The other relevant aspect is associated with the call blocking probability for a low number of users. Comparing the boxes inside Figs. 2 and 4, it can be observed that for the real-time and non-real-time traffic scenario the call blocking probability starts to grow right at the beginning of the graphic, while in real-time traffic scenario this probability remains constantly low until 50 users. However, the MTend strategy outperforms the other two strategies, even for this number of users.

Table V summarizes the gain obtained in real-time and non-real-time traffic scenarios with the MTend strategy in comparison with the other two strategies, considering call blocking probabilities varying from 2% to 10%. By comparing Table V with Table III, we can observe that the gains presented by MTend strategy over the other strategies increase for the real-time and non-real-time traffic scenario; that is, the gains in the this scenario, which supports also WWW and FTP applications, are higher than in the real-time traffic scenario, where only voice and videostreaming applications were used.

TABLE V

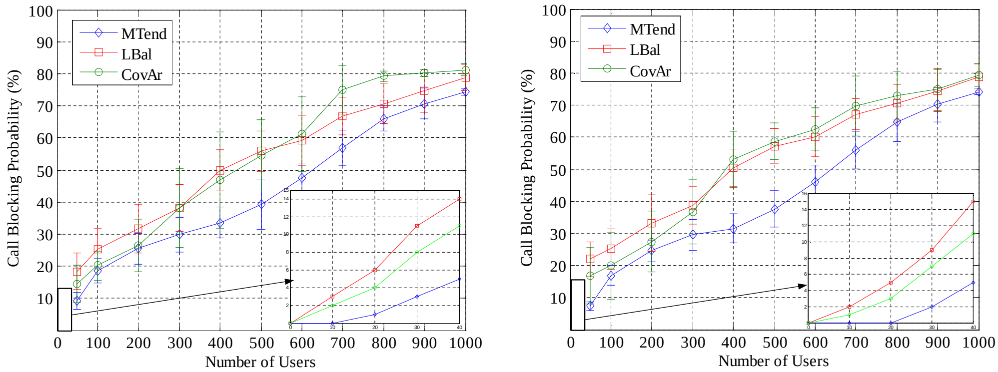
GAIN OF MTEND STRATEGY IN RESPECT TO LBAL AND COVAR FOR REAL-TIME AND NON-REAL-TIME TRAFFIC

CBP(%)	$G^{CBP}_{MTend\_S}$ (%)			
	Without Renegotiation		**With Renegotiation**	
	S=LBal	S=CovAr	S=LBal	S=CovAr
2	10	60	67	50
5	22	45	50	38
10	36	33	52	42

C. Packet Size Analysis

An important aspect that contributed to the better performance of MTend strategy, compared with the other two strategies, is the different packet size of the simulated applications. Videostreaming, WWW and FTP applications have their packets larger than the voice application packets, what makes the WLAN medium access more efficient in terms of throughput. In [11], [14] the WLAN throughput performance is analyzed for several packet size scenarios. These studies show that the increase of throughput is proportional to the increase of packet size, what was also confirmed with our results. The MTend strategy takes also advantage of this fact.

Fig. 5 presents the average occupation ratio of the WLAN network when different packet sizes are used, namely 500, 1000 and 1500 bytes, for transporting the data generated by videostreaming, WWW and FTP applications. Packets of 50 bytes were used for the voice application. For each experience, we considered the same load and the same simulation scenario presented in Section V. The average occupation ratio is measured using the Eq. (4), presented in Section III-B. From Fig. 5 two important aspects can be observed: 1) the occupation ratio



(a)

(b)

Fig. 4. Call blocking probability for real-time and non-real-time traffic, without (a) and with (b) call renegotiation

increases with the number of users, what seems natural since the amount of traffic generated increases with the number of users; 2) the occupation ratio decreases with the packet length - in fact by using large packets, less overhead is introduced in the system for transporting the same amount of data and, in turn, the number of transmission attempts is also smaller than for scenarios where small packets are used. Our strategy takes advantage of using large packets in WLAN, since it tends to place there applications which generate large packets.

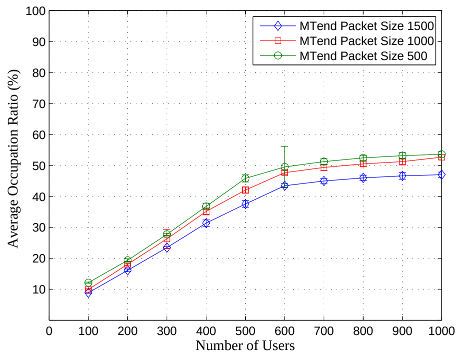


Fig. 5. WLAN average occupation ratio in respect to different packet sizes

VII. Conclusion

This paper analyzes the impact of real and non-real time traffic on joint radio resource management, presenting a performance analysis of three JRRM strategies for locations simultaneously covered by UMTS and WLAN networks. This analysis compares the behavior of two well-known strategies in this context, one based on the coverage area and the other based on load balancing, with a new strategy proposed by the authors, the MTend strategy. This new strategy distributes efficiently the new calls by both network interfaces, using criteria related with the mobility of users. Besides, it also introduces mechanisms for call renegotiation and call reallocation, which showed to significantly increase the global system performance.

The simulation results presented in the paper show that the MTend strategy has a performance which is globally better than the two other strategies used for comparison, either in the presence of real-time traffic or in the presence of real-time and non-real-time traffic. Besides accepting more calls, the MTend strategy guaranties a better QoS support for the applications. This strategy tends also to decrease the number of handoffs between the UMTS and the WLAN interfaces, giving priority to voice calls in the UMTS interface.

References

[1] 3GPP, "Mobility Between 3GPP-Wireless Local Area Network (WLAN) Interworking and 3GPP Systems (Release 8)," Services and System Aspects Group, TS-23.327 v.8.2.0, December 2008.

[2] R. Agustí, "Radio Resource Management in Beyond 3G Systems," in *IEEE Mediterranean Electrotechnical Conference (MELECON 2006)*, 2006, pp. 569–574.

[3] S. Ramirez, M. Genoves, M. Navarro, R. Skehill, and S. McGrath, "Evaluation of Policy-Based Admission Control Algorithms for a Joint Radio Resource Management Environment," in *IEEE Mediterranean Electrotechnical Conference (MELECON 2006)*, 2006, pp. 599–603.

[4] A. Tolli, P. Hakalin, and H. Holma, "Performance Evaluation of Common Radio Resource Management (CRRM)," in *IEEE International Conference on Communications (ICC 2002)*, 2002, pp. 3429–3433.

[5] H. Holma and A. Toskala, *WCDMA For UMTS - HSPA Evolution and LTE*. John Wiley & Sons, Ltd, 2007.

[6] ETSI, "Selection procedures for the choice of radio transmission technologies of the UMTS," TR-101.112 v.3.2.0, April 1998.

[7] A. Bazzi, M. Diolaiti, C. Gambetti, and G. Pasolini, "WLAN Call Admission Control Strategies for Voice Traffic over Integrated 3G/WLAN Networks," in *3rd IEEE Consumer Communications and Networking Conference, (CCNC 2006)*, vol. 2, 2006, pp. 1234–1238.

[8] H. Zhai, X. Chen, and Y. Fang, "How Well can the IEEE 802.11 Wireless LAN Support Quality of Service?" *IEEE Transactions on Wireless Communications*, vol. 4, no. 6, pp. 3084–3094, 2005.

[9] NS-3, "Network Simulator 3." [Online]. Available: http://www.nsnam.org

[10] J. Pérez-Romero, O. Sallent, and R. Agustí, *Radio Resource Management Strategies in UMTS*. John Wiley & Sons, Ltd, 2005.

[11] G. Bianchi, "Performance Analysis of the IEEE 802.11 Distributed Coordination Function," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 3, pp. 535–547, March 2000.

[12] 3GPP, "Improvement of RRM across RNS and RNS/BSS (Release 5)," Radio Access Network Group, TR-25.881 v.5.0.0, December 2001.

[13] P. T.-G. D. Staehle, K. Leibnitz, "Source Traffic Modeling of Wireles Applications," University of Wurzburg, Research Report 261, June 2000.

[14] H. Chen and Y. Li, "Performance Model of IEEE 802.11 DCF with Variable Packet Length," *IEEE Communications Letters*, vol. 8, no. 3, pp. 186–188, March 2004.