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DYNAMIC PRICING FOR DECENTRALISED RAT SELECTION IN HETEROGENEOUS SCENARIOS

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ABSTRACT

This paper addresses the inclusion of dynamic pricing concepts to provide CRRM solutions in heterogeneous scenarios. A RAT selection algorithm based on a dynamic pricing strategy aimed at controlling the load in the considered RATs in a decentralised way is proposed and evaluated through system level simulations. Results reveal that, by a proper variation of the RAT price, which at the end becomes transparent to the actual price paid by the users, the algorithm is able to provide better performance than when the pricing strategy is not considered.

I. INTRODUCTION

Future wireless networks in Beyond 3G (B3G) systems rely on the heterogeneous network concept, based on several radio access networks (RAN) interfacing a common core network. This enables a flexible and open architecture for applications and services with different QoS demands so that each service can be delivered through the most efficient network under the current system state conditions trying to make the heterogeneous network transparent to the user.

The heterogeneous network concept facilitates the utilization of a common manager of the radio resources in each RAN. Following the 3GPP approach, CRRM (Common Radio Resource Management) strategies are considered to co-ordinately manage the radio resources belonging to multiple radio access technologies (RATs) in an efficient way so that a trunking gain in capacity can be achieved with respect to the sum of capacities from the stand-alone RATs [1][2].

The functional model considered in 3GPP recommendations for CRRM operation assumes that the management of the total amount of radio resources is done by the RRM entity, responsible of the resources in a given RAT, and the CRRM entity, which provides the coordinated management. Several architectures are under consideration for CRRM operation depending on the implementation of RRM and CRRM entities [1][2]. In [3] a functional model is presented combining the architectural aspects with the envisaged CRRM functionalities for different degrees of interaction between local and common entities. Within the set of radio resource management functions, the initial RAT selection and the vertical or intersystem handover are devoted to decide the appropriate RAT for a given service at session initiation and during the session lifetime, respectively. Therefore, they necessarily involve different radio access technologies and it is appropriate to devise them from a common perspective. In that sense, the algorithm operation might then respond to specific policies taking into account both technical and/or economical aspects (e.g. operator or user preferences).

Different works have dealt in the literature with the CRRM problem. In [4] the benefits of CRRM in terms of inter-system handover and inter-system network controlled cell reselection are analysed in a heterogeneous UTRAN/GERAN scenario. In turn, the literature has covered the effects of load balancing in inter-RAT handover procedures. In particular, in [5], the effect of tuning the load-based handover (HO) thresholds depending on the load of inter-system/inter-layer/inter-frequency cells is studied. In [6], a force-based load balancing approach is proposed for initial RAT selection and vertical HO decision making. In turn, in [7] the authors compare the load balancing principles with respect to service-based policies. Similarly, Lincke discusses the problem from a more general perspective in e.g. [8] and references therein, comparing several substitution policies and evaluating them by means of simulations. Also in [9] different RAT selection policies are presented considering service-based and radio network-based criteria.

Even though technical issues related to the dynamic operation of the network have traditionally been targeted quite independently from economical aspects, research community has already identified the need for a major interaction, which is particularly important when heterogeneous networks are considered. In this context, this paper represents a step forward in this direction by introducing a dynamic pricing strategy in the RAT selection procedure. The purpose of the algorithm will be to achieve a decentralised load control by modifying dynamically the price in each RAT so that, whenever the load exceeds a certain threshold in one RAT, another substitutive RAT is made more attractive to the users by means of the offered price. The proposed strategy will be evaluated through simulations in a detailed scenario with UTRAN (UMTS Terrestrial Radio Access Network) and GERAN (GSM/EDGE Radio Access Network) technologies, although the proposed concept would be also applicable to other RATs.

The rest of the paper is organised as follows. Section II discusses related work on pricing applied to radio resource management. Section III presents the proposed RAT selection strategy. The simulation model details are given in Section IV and results are presented in Section V. Finally, Section VI summarises the conclusions.

II. PRICING IN RADIO RESOURCE MANAGEMENT

Several works in the open literature have addressed the inclusion of economical concepts in the development of different types of algorithms for wireless networks [10]. From the point of view of the network operator, pricing strategies should be devised in order to determine the price that should be paid for the access to the different services with specific

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user profiles. The objective is to maximize the obtained revenue by taking into account the user behaviour with respect to one or another price, captured with the definition of a proper acceptance function [11]. Pricing strategies are typically classified into static and dynamic pricing [12]. In static pricing the price of the different services is either fixed or is only changed at specific periods of the day or the week in the so-called time-of-day pricing, in which the price is higher during e.g. the working days than during weekends or in the night. In turn, the dynamic pricing strategies consider the price as an additional network parameter that can be changed during relatively short periods of time in order that the network operates always with the optimum price according to the available resources and the existing demand. Some static pricing models were proposed initially in [13] and in [14], where a reservation based pricing is proposed. In [15] a dynamic pricing strategy is applied to devise a network congestion control. Other applications of dynamic pricing are in the development of admission control [16], power control [17] and packet scheduling [18] algorithms. Also in [19] a comparison of static and dynamic pricing strategies is given.

III. Pricing-Based Initial RAT Selection

Let assume a heterogeneous network scenario in which a set of radio access networks are available. As stated in [9], a basic initial RAT selection policy can be defined as a function *f* that, given a set of different inputs ($\xi_1, \xi_2, ..., \xi_M$), e.g. service class, load in each RAN, UE features, mobile speed, etc. provides a suitable RAT to be allocated.

When including pricing concepts in the RAT selection problem, two basic models have to be determined, namely the utility model defined by its utility function, which defines how the user perceives the service, and the usage-based pricing model, which specifies the applicability of the pricing model in the considered problem.

A. Utility function

A utility function is defined in [20] as a fixed point equation which indicates the maximum price a user is willing to pay for a specified QoS. In this paper, a Constant Bit Rate voice service is considered and it is assumed that equivalent radio bearers exist in the considered RATs to provide the specific service, so that the same bit rate Rb (b/s) can be provided in both RATs. Consequently, the utility functions of the two considered RATs are equivalent from the point of view of QoS and the user only distinguishes between them by their prices, so that the user will always decide to transmit through the cheapest RAT in order to minimize the call expense.

B. Usage-based pricing

The purpose of the dynamic pricing strategy proposed here is to achieve a load control trying to avoid that the load in a given RAT exceeds a certain limit, thus avoiding high interference situations. This can be obtained by increasing the price of a RAT whenever its load is above a specific threshold. In this way, since users are willing to transmit through the cheapest RAT according to the utility definition in section III.A, the high loaded RAT becomes less attractive and the load is progressively moved to the other RAT. Notice that, since this load control relies on the RAT selection carried out at the terminals, it operates on a decentralised way, thus reducing the signalling to only broadcast messages indicating the price in one or another RAT and avoiding complex signalling procedures to move the user from one RAT to another like e.g. the directed retry procedure.

Considering only a single service, let P_1 and P_2 be the price for the RAT1 and RAT2, respectively, measured in monetary units (m.u.) per minute. The initial value of these prices is *p*. The price is increased or decreased in intervals of $\Delta price$, and it is kept within a maximum and a minimum price, denoted as P_{max} and P_{min}, respectively. The prices are updated periodically every Δt seconds depending on the load, which is measured and averaged periodically in each network. Without lack of generality, in this paper a WCDMA-based RAT, namely the UMTS Terrestrial Radio Access Network (UTRAN) and a TDMA-based RAT, namely the GSM/EDGE Radio Access Network (GERAN) are considered, although the proposed mechanism could be easily extended to other RATs. The load metric is the load factor for UTRAN and the ratio of occupied slots with respect to the total number of slots for GERAN. The uplink and downlink measurements of the different base stations in the scenario are also averaged to obtain a measurement of the overall RAT occupation in the scenario, assuming homogeneous user spatial distribution.

Figure 1 illustrates how the dynamic pricing strategy operates in the RAT1 in each period of Δt seconds. For the RAT2 the strategy would be equivalent. Four load thresholds are defined: η_H, $\eta_H+\Delta$, which are the thresholds indicating a high load in the access network, and η_L, $\eta_L-\Delta$, which are the low load thresholds, being Δ positive and $\eta_H>\eta_L$.

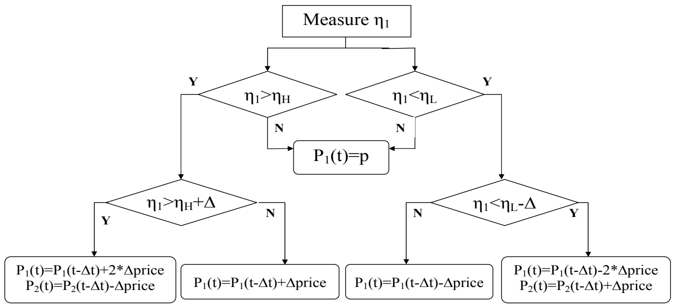

Figure 1 Pricing strategy model for RAT1

Whenever the load in a specific RAT is between η_H and η_L the price is fixed at the initial value of *p* m.u. per minute and remains constant. In turn, in those situations in which the load in a specific RAT raises above η_H the price in this RAT is increased by a factor $\Delta price$ in order that new users prefer to establish the session in the other RAT. If the load keeps rising and exceeds the highest threshold $\eta_H+\Delta$, the price is then increased by $2\Delta price$ in this RAT and at the same time the price in the other RAT is decreased by $\Delta price$, in order to allow a faster reaction. The price is never allowed neither to increase over P_{max} nor to decrease below P_{min}.

A similar price update is carried out whenever the load in a specific RAT decreases below η_L or $\eta_L-\Delta$ in order to attract users to this RAT.

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C. RAT Selection Policy

According to the above usage-based pricing scheme and utility functions, the RAT selection is done in a decentralised way by the terminals, simply by selecting the RAT with the lowest price at session initiation. It is assumed that a proper procedure exists for letting the terminal know the current price, e.g. by means of periodical broadcast messages. It is worth mentioning that a user will be charged at the price existing at session initiation in the selected RAT, so that it is not affected by further pricing changes occurring during the session lifetime.

On the other hand, in the case that both RATs have the same price, which occurs e.g. whenever the load in these RATs is between η_H and η_L, the RAT selection is performed based on path loss measurements, taking into account the larger degradation that users with high path loss experience when allocated in a CDMA-based RAT like UTRAN due to its interference-limited nature. Based on this principle, the scheme considered here for the situation when both prices are equal is called *Path Loss Threshold Policy (LP_THR)* and the terminal will select GERAN whenever its path loss to the best UTRAN base station is higher or equal than a threshold *Lp**. On the contrary, whenever this path loss is below *Lp** the terminal will select UTRAN. Notice that the path loss can be measured periodically at the terminals from the received power of the CPICH (Common Pilot Channel), whose transmit power is known, which allows keeping the decentralised nature of the proposed scheme.

IV. Simulation Environment

The previous pricing-based initial RAT selection model is evaluated within a detailed scenario with UTRAN and GERAN access technologies. The dynamic simulations consider a 2.25*2.25 km^2 scenario with 7 omnidirectional cells for GERAN and 7 for UTRAN. The cells of both RATs are collocated with 1km distance between sites. In case of GERAN, it is assumed that the 7 cells represent a cluster so that all the cells operate with different carrier frequencies. The parameters of the User Equipment (UE) and the UTRAN and GERAN base stations (BS) are summarised in Table 1. Three carriers per cell are assumed in GERAN and a single UTRAN FDD carrier is considered in UTRAN. In this way, the total bandwidth available in the cluster of seven GERAN cells is approximately the same as the bandwidth used by UTRAN. The GERAN carriers are in the 1800 MHz band. The urban macrocell propagation model in [21] with a shadowing of 10 dB is considered. Mobile speed is 3 km/h. No indoor users are considered.

A scenario with only voice service is considered. Calls are generated according to a Poisson process with an average call rate of 10 calls/h/user and exponentially distributed call duration with an average of 180 s. In UTRAN, the RAB for voice users is the 12.2 kb/s speech defined in [22], considering a dedicated channel (DCH) with spreading factor 64 in the uplink and 128 in the downlink. In turn, in GERAN, voice users are allocated to a TCH-FS (traffic channel full-rate speech), i.e. one time slot in each frame.

Table 1 UE and BS parameters

BS parameters	**UTRAN**	**GERAN**
Maximum transmitted power	43 dBm	43 dBm
Thermal noise	-104 dBm	-117 dBm
Common Control Channels Power	33 dBm	43 dBm
Maximum DL power per user	41 dBm	43 dBm
Number of carriers	1	3
UE parameters	**UTRAN**	**GERAN**
Maximum transmitted power	21 dBm	33 dBm
Minimum transmitted power	-44 dBm	0 dBm
Thermal noise	-100 dBm	-113 dBm
DL Orthogonality factor	0.4	N/A

Table 2 RRM PARAMETERS

UTRAN	
UL admission threshold (η_{max})	1.0
DL admission threshold (P_{max})	42 dBm
Active Set size	1
Replacement hystheresis	3 dB
Time to trigger handover	0.64 s
BLER target voice	1%
BLER target interactive	10%
Dropping condition	1 dB below target during 20 s
GERAN	
Minimum power to trigger handover	-100 dBm
Samples to trigger handover	3
Dropping condition	5 dB below sensitivity during 20 s
PRICING ALGORITHM PARAMETERS	
p	1 m.u./min
$\Delta price$	0.1 m.u./min
P_{max}	6 m.u./min
P_{min}	0.02 m.u./min
η_H	0.8
η_L	0.2
Δ	0.1
Lp^*	104 dB

A summary of the main RRM parameters for UTRAN and GERAN is given in Table 2, together with the parameters of the pricing-based RAT selection strategy. The price updating interval Δt will be varied in different simulations. As a reference for comparison, the simulations also consider a RAT selection strategy according to the LP_THR algorithm without varying the pricing. In this case, the price is constant and equal to 1 m.u. per minute.

V. Results

This section evaluates the considered pricing-based initial RAT selection policy in the previously described scenario. Since the focus of the paper is on the initial RAT selection, no vertical handover is considered.

The first results presented in this section deal with the operation of the whole model, concentrating on the price behaviour. Figure 2 shows the results gathered from a scenario with a population of 1000 voice users and a price updating period Δt of 60 seconds. The instantaneous prices for both RATs are shown together with the actual price paid by the user, which corresponds to the minimum among the prices of each RAT. It can be observed that the price paid by the user is almost a constant function with a value of 1 m.u. per minute, thus being the dynamic strategy almost transparent to the user. Notice that this has an important and positive effect over the user, who is actually paying the same in spite of the dynamic pricing strategy.

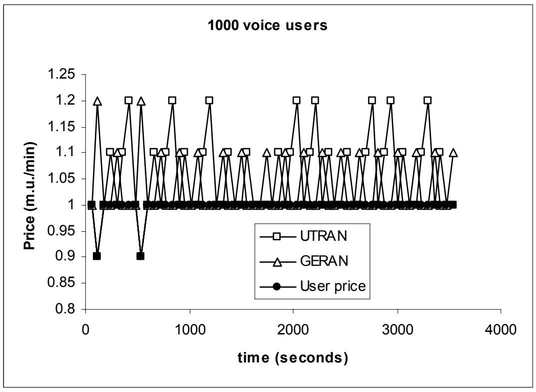

Figure 2 Price updating behaviour

In order to see the effects of the proposed algorithm in terms of QoS perception, Figure 3 plots the uplink block error rate (BLER) for the proposed pricing algorithm as a function of the number of users in the scenario and for different values of the interval Δt. The total BLER is computed by weighting the BLER in UTRAN and GERAN with the percentage of traffic transmitted through each RAT. The results for the path loss threshold strategy are also presented. Up to medium voice loads (i.e. up to 600 users) no relevant differences are observed for the pricing strategy with different Δt and the LP_THR. The reason is that, for these numbers of users, the averaged load in both radio access networks does not normally exceed the threshold η_H in any of the RATs, and therefore the selection is mainly done according to LP_THR, as explained in section III, because the price of both RATs is the same. Nevertheless, when the number of users increases (i.e. more than 800 users), the average load exceeds more frequently the threshold η_H and consequently, the pricing-based strategy reacts by distributing the users towards the less loaded RAT. In this way, the overall interference in UTRAN and consequently the BLER are reduced. Consequently, by a proper setting of the interval Δt, the performance achieved by the pricing strategy can outperform the LP_THR strategy. The role played by the interval between price updates Δt is related with the reaction capability of the algorithm, in the sense that very large values (e.g. 300 s in Figure 3) do not allow the algorithm to react fast enough to overload situations. As a result of that, the average BLER with the pricing strategy decreases when the value of Δt is reduced.

The impact of interval Δt over the price paid by the users is shown in Figure 4, which plots the average price observed by the users as a function of Δt for different numbers of users in the system. Whenever the value of Δt decreases below 1 second, the price updating is done in a very fast way and price may increase several times before the call generation and ending balances the load through the RAT selection. This leads to high values of the price in both access networks which easily reach the maximum price P_{max}. Thereby, the average price users are paying for the voice service reaches high values, being this price not constant and, therefore, being the pricing model not transparent to the user. On the contrary, for values of Δt above 1s, the actual price paid by the user remains constant.

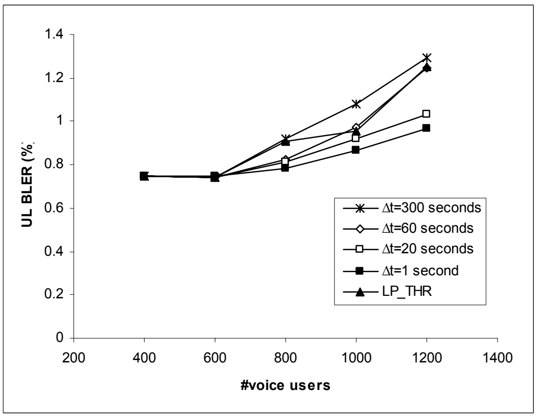

Figure 3 Averaged UL BLER for different values of Δt

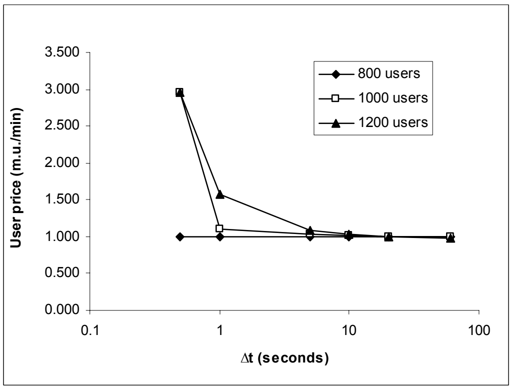

Figure 4 Averaged user price for different values of Δt

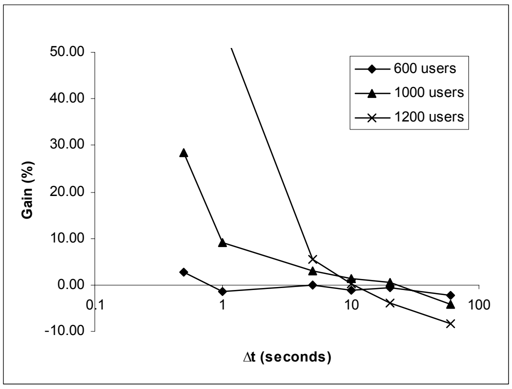

Figure 5 Revenue gain in % obtained with the dynamic pricing strategy with respect to applying only the LP_THR strategy

Finally, Figure 5 plots the percentage of gain in revenue obtained by the pricing strategy with respect to the LP_THR mechanism as a function of the time interval Δt and for different numbers of users. The total revenue is calculated by means of adding the revenue for each call, which is the value of its time duration multiplied by the current call price in m.u. per minute at the call start. It is worth mentioning that once a call has begun, price is not changed for that call. Down to medium values of Δt (i.e. 10 seconds), LP_THR achieves better results in terms of total revenue because, due to the slower reactivity of the pricing strategy, the price may remain longer at low values to attract more users to a given RAT.

However, as the value of Δt decreases, the pricing model presents better results. In turn, for Δt<1 there is a significant increase in revenue but this is due to the large prices paid by the users, as explained in Figure 4, which may not be desirable from the user point of view. On the other hand, for low and medium numbers of users (i.e. 600 in Figure 5) there are not significant differences between the two strategies.

VI. CONCLUSIONS

This paper has presented a dynamic pricing-based strategy for decentralised RAT selection in a heterogeneous networks scenario. The price in the different RATs is varied so that the users are attracted towards the less loaded RAT whenever the load in one RAT exceeds a certain threshold, assuming that the two RATs can provide the service with the same bit rate requirements. This allows avoiding overload situations and keeping similar load levels in the two considered RATs. It has been observed that, by a proper setting of the pricing update period between 1 and 10s it is possible to obtain better performance and higher revenues than in the case of not applying pricing concepts. Furthermore, it has been shown that, since users always select the cheapest RAT, the pricing strategy reveals to be transparent to the user, who does not perceive significant price variations.

ACKNOWLEDGEMENTS

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