Radio Access Technology Selection enabled by IEEE P1900.4

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***Abstract*— This paper addresses the implementation of decentralized RAT selection strategies at the mobile terminal in a heterogeneous wireless network scenario. This can be achieved if the network provides some information or guidelines to assist the terminal in its decisions, making use of the IEEE P1900.4 protocol. In order to illustrate the procedure, a specific RAT selection strategy for heterogeneous CDMA/TDMA networks devoted to reduce interference by allocating users according to the measured path loss is analyzed. Results show that the proposed decentralized strategy is able to outperform a reference centralized load-balancing strategy.**

Key words: *RAT selection, heterogeneous networks, IEEE P1900*

I. INTRODUCTION

Heterogeneous radio access networks (RANs) concept, also known as Beyond 3G (B3G) systems, is intended to propose a flexible and open architecture for a large variety of wireless access technologies, applications and services with different QoS demands, as well as different protocol stacks. Wireless networks differ from each other by air interface technology, cell-size, coverage, services, price and ownership. The complementary characteristics offered by the different radio access technologies (RATs) make possible to exploit the trunking gain leading to a higher overall performance than the aggregated performances of the stand-alone networks. Clearly, this potential gain of B3G systems can only turn into reality by means of a proper management of the available radio resources. Joint Radio Resource Management (JRRM) refers to the set of functions that are devoted to ensure an efficient and coordinated use of the available radio resources in heterogeneous networks scenarios [1]-[3]. More specifically, JRRM strategies should ensure that the operator's goals in coverage and QoS levels are met while providing as high as possible overall capacity (i.e. the sum of the capacities achieved in every single RAN of the operator) by using the available resources. Within JRRM, the RAT selection, i.e. the allocation of connections to specific RANs either at session initiation or during the session life-time switching on-going connections from one RAT to another (i.e. inter-system or vertical handover) is the key enabler to properly manage the heterogeneous radio access network scenario [1].

Radio Resource Management (RRM) functions in a wireless cellular network are mainly centralized, i.e. the functions are implemented in a central network node such as RNC (Radio Network Controller) in UTRAN (UMTS Terrestrial Radio Access Network). This can be justified because a central network node may have a more complete picture of the radio access status than a particular node, so that RRM decisions can be made with more inputs. However, a centralized RRM implementation has some drawbacks in terms of increased signalling load or transfer delay of the RRM algorithm's inputs to the central node. This prevents an efficient implementation of short-term RRM functions such as packet scheduling and explains why wireless cellular technology evolution (e.g. HSDPA) exhibits the trend towards implementing RRM functions on the radio access network edge nodes (i.e. base stations).

Additionally, the terminal also keeps relevant information that could be of great interest for making smarter RRM/JRRM decisions. This is why some RRM functions, although typically implemented in the network side (either on central or edge nodes), are assisted by mobile terminal measurement reports. Handover algorithm is a clear example, since the knowledge of the propagation conditions from the terminal to the different surrounding cells is a key aspect for making the proper decision on what cell(s) the terminal should be connected to.

This paper goes one step beyond in this trend towards distributed RRM/JRRM functions by proposing RAT selection strategies in the mobile terminals. This approach has claimed to be inefficient in the past because of the limited information available at the terminal side (e.g. the terminal does not know what is the cell load). Nevertheless, this can be overcome if the network is able to provide some information or guidelines to the terminal assisting its decisions. In this way, while a mobile-assisted centralized decision making process requires the inputs from many terminals to a single node, the network-assisted decentralized decision making process requires the input from a single node to the terminals, which can be significantly more efficient from a signalling point of view. In this respect, the on-going IEEE P1900.4 [4] standardization effort could provide the necessary support to this network-assisted mechanism.

The objective of the IEEE P1900.4 is to define standardized protocols and corresponding reconfiguration management system architecture for the optimization of resource management, in order to provide improved capacity, efficiency and utility within a heterogeneous wireless network wherein devices support multiple air interfaces, with multi-homing and dynamic spectrum access capabilities in licensed and unlicensed bands. More specifically, the scope of IEEE P1900.4 includes (1) providing protocols carrying information between network resource managers and device resource managers supporting wireless terminal and network reconfiguration management, including the context of heterogeneous networks, (2) providing corresponding reconfiguration management functionalities of the wireless system for the support of efficient optimization of resource usage, (3) providing corresponding management functions and standardized rules to allow the multimode and/or dynamic spectrum access capable devices making decisions in a distributed fashion whilst providing operators with fair and effective exploitation of network resources thanks to an exhaustive set of rules to be followed by user equipments.

Under this framework, this paper will support the proposed decentralized RRM/JRRM approach with an illustrative example focusing on RAT selection functionality. For that purpose, the paper takes as a reference the RAT selection algorithm presented in [5] for heterogeneous CDMA/TDMA scenarios and proposes its applicability in the framework of IEEE P1900.4. The rest of the paper is organized as follows. Section II discusses the RAT selection enablers defined in IEEE P1900.4. Section III presents a study case regarding how interference can be reduced through decentralized RAT selection. This strategy is evaluated with the simulation model described in Section IV and results are presented in Section V. Finally, conclusions are summarized in Section VI.

II. RAT Selection Enablers Defined by IEEE P1900.4

RAT selection strategies are devoted to decide the adequate RAT that a given user should be connected to in a heterogeneous networks scenario. This decision is taken at session initiation (i.e. initial RAT selection procedure) as well as during session lifetime, which can trigger a vertical handover procedure in case the current RAT must be changed. RAT selection strategies may respond to different principles, like e.g. service-based policies (i.e. allocating the RAT according to the service characteristics) or load balancing principles (i.e. try to keep similar load levels in the different RATs). The corresponding decision process requires enabling functionalities on the network/terminal side and a corresponding transport channel.

On the network level, IEEE P1900.4 [4] is proposing to introduce a "Network Reconfiguration Management" (NRM) entity covering the functionalities presented in Figure 1:

- The "Information on Dynamic Spectrum Allocation" module is providing management protocols giving indications on Dynamic Spectrum Allocation rules from the network to the user device. The network (meta-) operator is communicating its spectrum assignment decision to the user devices which will choose their resource selection strategies correspondingly.
- The "Radio Resource Selection Policies" module is deriving optimization constraints to be imposed onto user terminals. The goal is to constraint the resource selection optimization process in the terminals such that a global system objective is achieved (such as a maximum system capacity utilization, etc.).
- The "Recovery of Context Information" module represents the interfacing of the NRM with the network equipment for recovery of operational information from the RATs as well as the optional link to user equipment providing feed-back on observed QoS, etc.
- The "Representation Definition of Context and Policy Information" module is presenting the effort on context and policy related ontology and management protocol definitions.
- The "Control of Resource Selection Strategy Change in User Equipment" module is expected to trigger the resource selection strategies within the user devices such that the distributed optimization is performed in a controlled manner.
- The "Security Issues" module is expected to provide suitable security means in order to assure the ownership of the policies and context information provided by the network.

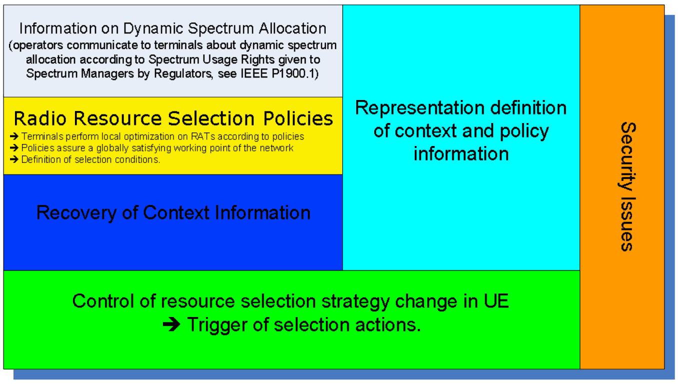

Figure 1.- Network Reconfiguration Management.

Further entities introduced by IEEE P1900.4 include i) the "Terminal Reconfiguration Management" which performs distributed decision making based resource selection subject to the network constraints (policies) and controls the information flow from the terminal to the network; ii) a "Radio Enabler for Reconfiguration Management" which acts as signalling link between the network and the terminal and may be deployed as a dedicated physical or logical channel [4].

III. Case Study: Interference Reduction through Decentralized RAT Selection

In general, cellular wireless systems are interference-limited and, consequently, any engineering technique devoted to either reduce interference or to improve the robustness of the system to bear interference will readily increase network capacity and operator's revenue. In this context, the RAT selection can exploit the different sensitivity that diverse RATs may exhibit to interference so that a smart JRRM follows. In particular, in TDMA-based access systems (e.g. GSM/GPRS) there is no intra-cell interference. In turn, inter-cell interference is caused by a single user in every co-channel cell and therefore there is no inter-cell interference in neighbouring cells, as illustrated in Figure 2. In contrast, in CDMA-based systems (e.g. UMTS) the intra-cell interference is caused by every single user transmitting in the cell. Furthermore, inter-cell interference is also originated by all simultaneous users in all neighbouring cells, since a complete frequency reuse is considered, as shown in Figure 2. Consequently, CDMA systems are much more sensitive to multi-user interference than TDMA ones.

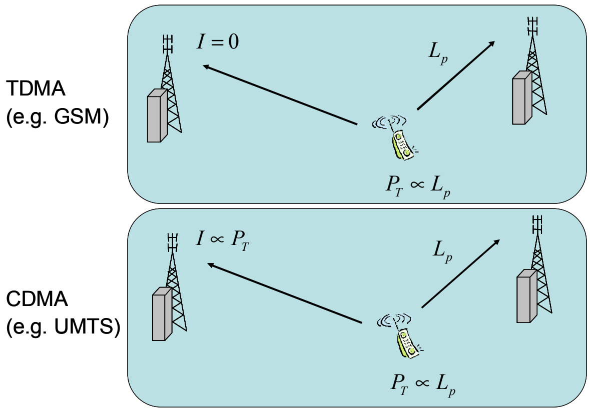

Figure 2.- Intercell interference between neighbouring cells in TDMA and CDMA systems (L_p denotes the path loss, I the inter-cell interference and P_T the transmitted power)

Taking this into account, the underlying idea of the proposed decentralized JRRM approach is to take advantage of the coverage overlap provided by the existence of several RANs using different access technologies in a certain service area in order to improve the overall interference pattern generated in the scenario for the CDMA-based systems and, consequently, to improve the capacity of the overall heterogeneous network. This can be achieved through appropriate RAT selection algorithms that avoid the connection of the more interfering users to CDMA. In that sense, notice that the users generating more interference in CDMA will be those located farther from their serving base station, because they will be transmitting a higher power level seen as interference by neighbouring base stations. As illustrated in Figure 2, the interference I seen by the neighbouring base station depends on the power transmitted by the terminal P_T, which in turn depends on the path loss L_p of this user to the serving base station due to power control. On the contrary, in TDMA the transmitted power also depends on the path loss but since the neighbouring cells operate with different frequencies no inter-cell interference is generated. Taking this into account, an interference reduction can be achieved by forcing terminals with a high path loss in CDMA to be connected to the TDMA-based RAT while CDMA keeps only the terminals with low path loss.

The resulting RAT selection strategy is illustrated in Figure 3. The decisions are taken autonomously by the terminal from its path loss measurements to the best CDMA cell. Notice that the path loss measurement can be obtained from the downlink received power of a common control channel whose transmit power is known and broadcast by the network (e.g. the CPICH channel in UMTS). Measurements are averaged in periods of T seconds. Then, at session initiation, in case that the resulting path loss $L_p(t)$ is above a given threshold PL_{th}, the selected RAT will be TDMA, while if the path loss is below the threshold the selected RAT will be CDMA. Notice that the threshold PL_{th} should be provided by IEEE P1900.4 radio enabler in order that the algorithm is executed autonomously at the terminal. In case that there is no capacity available for the new session in the selected RAT (i.e. admission control is not passed), the other RAT will be selected instead. Finally, if no capacity is available in any of the two RATs, the session will be blocked. In the example of Figure 3, the user at session start selects the CDMA-based RAT (e.g. UMTS), then it continuously measures the path loss to the CDMA cell and when it is above the threshold PL_{th}, a vertical handover to the TDMA-RAT is triggered (assuming that there is TDMA coverage at that point). In order to avoid undesired ping-pong effects leading to continuous RAT changes for users with path loss close to the threshold PL_{th}, a hysteresis margin Δ (dB) is introduced. Similarly, the condition that the path loss is above (alt. below) the threshold plus (alt. minus) the hysteresis margin should be continuously fulfilled during M_{up} (alt. M_{down}) consecutive samples.

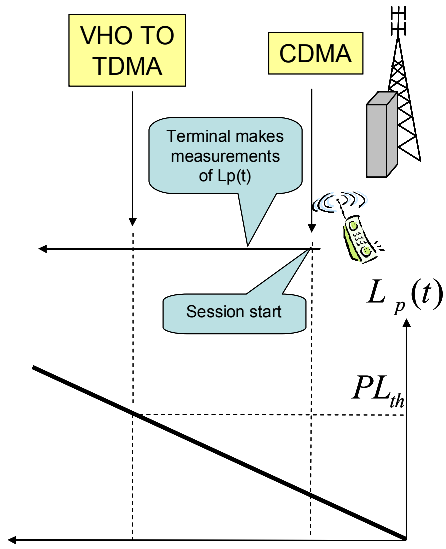

Figure 3.- Decentralized RAT selection strategy

From a practical point of view, the different thresholds PL_{th}, Δ, M_{up} and M_{down} are fixed by the network based on the collected information by the specific RRM procedures of the different RATs such as the statistical path loss distribution. The thresholds could be sent to the users via IEEE P1900.4 protocols and then the users could compare periodically the measured values with the fixed thresholds, as illustrated in Figure 4.

IV. SIMULATION MODEL

The proposed scheme has been evaluated by means of system level simulations in a scenario with a CDMA-based and a TDMA-based RAT. Specifically, UTRAN and GERAN are considered as examples of these two technologies. Seven omnidirectional cells for GERAN and seven for UTRAN are considered. The cells of both RANs are collocated. The separation between base stations is 2 km. In case of GERAN, it is assumed that the seven cells represent a cluster so that all cells operate with different carrier frequencies. The parameters of the UE, UTRAN and GERAN cells are taken from [5]. It is assumed that all terminals have multi-mode capabilities, i.e. they can be connected either to UTRAN or to GERAN. Three carriers per cell in the 1800 MHz band are assumed in GERAN and a single UTRAN FDD carrier is considered in UTRAN. The urban macro-cell propagation model in [6] is considered for both systems, with the path loss is a function of the distance d to the base station given by: Lp(dB)=128.1+37.6log [d(km)]+S(dB), where S(dB) corresponds to the log-normal shadowing with s=10 dB standard deviation. The mobility model described in [7] is considered with mobile speed 3 km/h and shadowing decorrelation distance 20 m.

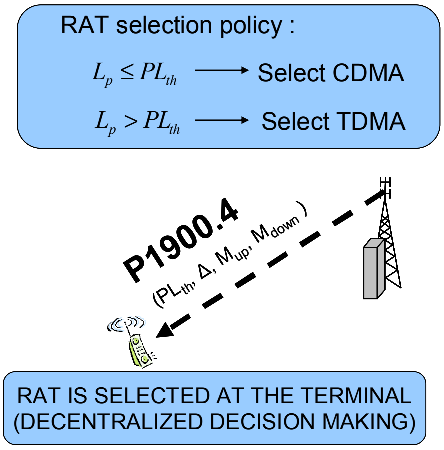

Figure 4.- Information to be transmitted through P1900.4

In UTRAN, an iterative power control procedure is considered to simulate the inner loop power control aiming at achieving the target (E_b/N_0) that ensures the required Block Error Rate (BLER). With respect to GERAN, a slow power control is simulated in the uplink, so that the transmitted power is changed in steps of 2 dB every measurement period of 0.48s in order to reach a specific sensitivity level. No power control is simulated in the downlink, and all the channels are transmitted with maximum power.

The scenario considers only the voice service. Calls are generated according to a Poisson process with call rate of 10 calls/h/user and exponentially distributed call duration with an average of 180 s. In UTRAN, the Radio Access Bearer (RAB) for voice users is the 12.2 kb/s speech bearer defined in [8], considering a dedicated channel (DCH) with spreading factor 64 in the uplink and 128 in the downlink. In GERAN, each voice user is allocated to one TCH-FS (traffic channel full-rate speech), i.e. one time slot in each frame of a given frequency.

A summary of the main RRM parameters is given in Table I, together with the parameters of the RAT selection algorithm. With respect to the admission control procedure in UTRAN, three conditions are checked [1], namely the uplink load factor should be below the threshold η_{max}, the downlink transmitted power below P_{max} and there must be available OVSF codes in the base station. In GERAN, voice users are accepted if there are available time slots. With respect to the admission control for horizontal handovers, the availability of OVSF codes for UTRAN or time slots for GERAN is checked in the new cell. If admission is not passed, a vertical handover will be tried. If the vertical handover is not possible, then the call will be dropped. Vertical handovers will also be tried before dropping a call.

For comparison purposes, the proposed strategy is compared to a classical centralized Load Balancing (LB) strategy, in which the network allocates the user to the RAT having the lowest load level. In the latter, load measurements are averaged within periods of 10s to smooth load fluctuations and are obtained from the base stations having the lowest path loss among those of each RAT. Whenever a horizontal handover is required in the current RAT, the suitability of executing a vertical handover instead is evaluated, so that the mobile is again served by the lowest loaded RAT.

Table I.- RRM parameters

UTRAN RRM PARAMETERS	
UL admission threshold (η_{max})	1.0
DL admission threshold (P_{max})	42 dBm
Measurement time	1s
Active Set size	1
Replacement hystheresis	3 dB
Time to trigger handover	0.64 s
Minimum Ec/Io	-16 dB
GERAN RRM PARAMETERS	
Measurement period	0.48s
Minimum access power	-105 dBm
Minimum received power to trigger handover (UL or DL)	-100 dBm
Samples below minimum power to trigger handover	3
RAT SELECTION ALGORITHM PARAMETERS	
Measurement interval (T)	1s
Hysteresis margin (Δ)	1 dB
Mup / Mdown	3 / 3
PLth	120 dB

V. RESULTS

This section analyses the system performance obtained by means of the proposed strategy. One of the critical parameters to be set is the path loss threshold, PL_{th}, which has high impact on the performance of the proposed algorithm, as detailed in the following. On the one hand, the value of PL_{th} affects the QoS levels of users in the RATs in the sense that low PL_{th} values will tend to reduce the UTRAN interference thus improving the performance of users connected to this RAT. On the other hand, it also controls the traffic distribution between the considered RATs, in the sense that low PL_{th} values will tend to increase the number of users allocated to GERAN while high values will tend to reduce these number of users and to allocate more users in UTRAN. Consequently, the setting of the path loss threshold PL_{th} results from the trade-off between how much the UTRAN interference can be reduced while avoiding an excessive load unbalance. To illustrate these effects, three different representatives values of PL_{th} have been selected, namely PL_{th}={115dB, 120dB, 125dB}, corresponding, approximately to the 40-th, 60-th and 80-th percentiles of the path loss distribution, respectively.

From the point of view of load distribution in the two RATs, Figure 5 plots the average uplink load in UTRAN and GERAN with the different PL_{th} values and for the LB strategy. The case PL_{th} =120 dB achieves the better load balancing between both RATs, while for PL_{th} =115 dB there is a higher load in GERAN and for PL_{th}=125 dB the load is higher in UTRAN. Then, the proposed algorithm with PL_{th} =120 dB achieves a load distribution similar to the LB case, so that with this setting of the parameter load balancing considerations are also included in the proposed algorithm.

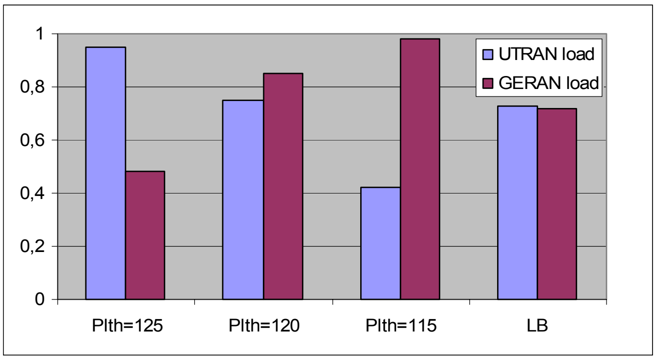

Figure 5.- Uplink load in UTRAN and GERAN for the different values of PL_{th}

From a performance point of view the total aggregated throughput (i.e. including UTRAN and GERAN) is depicted in Figure 6 for the downlink (although similar performance improvements not shown here for the sake of brevity are also observed for the uplink). The highest throughput is provided by PL_{th} =120dB, revealing to be the most suitable solution from both QoS and load balancing points of view. Compared to a pure LB, the achieved gain can be up to about 24% for heavy load conditions. The origin of the gain comes from the fact that the decentralized RAT selection algorithm with PL_{th} =120dB also achieves load balancing between RATs through a more intelligent and efficient user distribution, reducing the overall interference in the system. Compared to the other settings, i.e. PL_{th} =115dB or 125 dB, the gain comes from the benefits of the better load balancing obtained with PL_{th}=120dB.

VI. Conclusions

This paper has addressed the decentralized implementation of RAT selection strategies for heterogeneous wireless networks based on the functionalities enabled by IEEE P1900.4. A case study corresponding to a RAT selection which intends to reduce the interference in a CDMA network by a smart allocation of users to RATs according to the path loss measured in CDMA has been analyzed. In this case, only a minimum set of configuration parameters should be transmitted with the help of IEEE P1900.4 so that the RAT selection decision is taken autonomously by the mobile terminal. In this way, signalling can be reduced with respect to the centralized scheme. Results have shown that with this approach load balancing considerations can be retained while at the same time achieving a higher throughput than if a pure load balancing strategy was used.

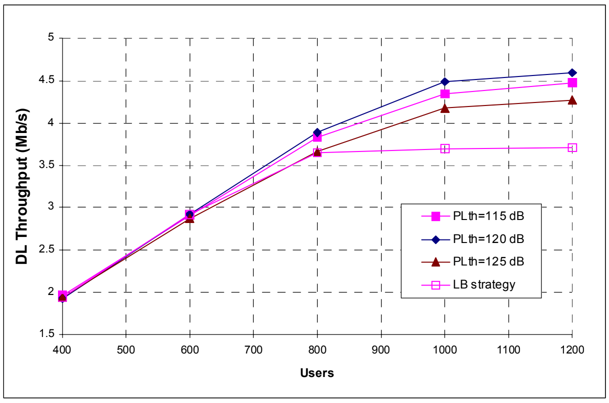

Figure 6.- Downlink throughput for different values of PL_{th}

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