Dynamic Planning and Management of Reconfigurable Networks

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Abstract—**Reconfigurability creates many challenges, but also provides opportunities, ranging, from the scale growth to harmonization and interworking among Radio Access Technologies (RATs), both in the radio network and core network. These changes consequently affect the actors of the wireless world, i.e. users, network providers, service providers and manufacturers. It is therefore indispensable to research the design and management issues of reconfigurable networks, so as to see whether and how they lead to increased efficiency, while decreasing operational (OPEX) and deployment (CAPEX) costs. This paper presents a system approach to the planning and management of reconfigurable networks. It builds on the concepts of Dynamic Network Planning and Flexible Network Management (DNPM), as well as Joint Radio Resource Management (JRRM) and Adaptive Radio Multihoming (ARMH), presenting some basic ideas along with the respective algorithms and simulation results.**

***Index Terms*—Reconfigurability, DNPM, JRRM, ARMH**

I. Introduction

Starting from Marconi's first radio transmission, the changes, developments, growths and societal impact of wireless communications has been almost unequalled. While in the beginning of mobile communications only few unconnected networks existed, the wireless world of today consists of a multitude of networks and Radio Access Technology (RAT) standards.

Among them are the conventional cellular networks like the Global System for Mobile communications (GSM) [1], General Packet Radio Service (GPRS) [2], as well as third generation (3G) systems, such as the Universal Mobile Telecommunications System (UMTS) [3] and its enhancements, like High-Speed Downlink Packet access (HSDPA) [4]. And also there are Broadband Radio Access Networks (BRAN) [5], Wireless Local Area Networks (WLAN) [6] and even Wireless Metropolitan Area Networks (WMAN) [7] that are continuously evolving, offering wireless access to an increasing number of users. Additional systems like broadcast networks such as Digital Video Broadcasting (DVB) [8] are increasingly forming part of this wireless (communication) world. Already nowadays these technologies are already operating together, however all of them use the same (radio) resources and to make this interworking more efficient is a significant research challenge.

This set of discrete and often competitive technologies will eventually transform into one global communication infrastructure, called the "*Beyond the 3rd Generation (B3G) wireless access infrastructure*", aiming at provision of innovative services, adaptable to meet user demands, in a cost efficient manner. Major technologies facilitating this convergence are the *cooperative networks* [9], and *reconfigurability* [10] concepts. The cooperative networks concept assumes that a network provider (NP) can cooperate with other NPs (and thus, rely on other RATs/networks), so as to have alternative solutions for serving customers in a cost efficient manner. Reconfigurability was conceived as an evolution and umbrella concept of Software Defined Radio. It moves one step further compared to cooperative networks, by providing mechanisms for (i) dynamically setting/altering parameter values of a single RAT, (ii) dynamically allocating resources to and among RATs and (iii) distributing RATs to network elements.

Reconfigurability offers the flexibility to adapt the settings within an end-to-end system to the actual demands, but to determine and implement the most efficient system configuration, mechanisms for advanced planning and management are required. This paper deals with these issues. For this purpose, the subsequent section presents the basic framework for research into reconfigurable networks, while section III details the proposed DNPM functionality. Section IV includes a view on JRRM issues, in support of DNPM decisions, and section V provides an overview on the ARMH concept, while concluding remarks are drawn in section VI.

II. Research in Reconfigurable Networks

End-to-end reconfigurability, supporting the aforementioned convergence impacts all aspects of the system, ranging from the terminal, via the air interface, to the network. Future system and in particular network architectures must be flexible enough to support scalability as well as reconfigurable elements, in order to provide the best possible resource management solutions and the most cost effective network deployment. Once in place, mobile users will benefit from this by being able to access required services when and where needed, at an affordable cost.

From an engineering point of view, the best possible solution can only be achieved when elements of the radio network are properly configured, i.e. the network is appropriately planned and suitable radio resource management approaches/algorithms are applied. In other words, the efficient design and management of reconfigurable networks is necessary, in order to exploit the advantages provided by reconfigurability.

The IST E^{2}R project [10] defines end-to-end reconfigurability as a concept forming a research framework which tackles a variety of areas, such as (i) the development of mechanisms to facilitate efficient, advanced & flexible end-user service provision, (ii) mechanisms and protocols for the download of reconfiguration software to reconfigurable devices/ equipment, (iii) the development of functions and facilitation of Multi-Standard platforms and (iv) the facilitation of mechanisms to customize services and applications where the developer will be able to modify the communications standard of a device without investing in a new hardware design. Particular focus is placed on investigations into the area of how to increase radio and equipment resources efficiency.

The remaining sections analyze the concepts of DNPM and JRRM as introduced above, aiming to proof the benefits of reconfigurability to the various actors in the Wireless World.

III. DNPM

Early research in the field of reconfigurable networks shows significant dependencies between network planning and network management, deriving from the time and space variant conditions that render initial planning insufficient [11]. From this starting point, we consider a NP that faces a situation requiring reconfiguration, within their administrative domain. The assumption is that the transceivers within the service area are reconfigurable. The situation arising requires reallocation of RATs to the transceivers of the “target” region, as well as reconfiguration of resources for each RAT. In the context of this paper, the whole problem is approached jointly and thus aims to determine new possible configurations (“RFDQ-A problem”, i.e. its solution aims at new assignments of RATs to transceivers, spectrum to RATs/transceivers, demand to transceiver/ RATs, and applications to QoS levels).

High Level Description

The RFDQ-A problem can generally be described with its input and expected output. The input provides information on the service area and demand, as well as on the system;

Service Area and Demand Aspects. The service area is divided into a set of area portions, called pixels. Of interest are the applications (services) offered in the service area, the quality levels (QoS levels) through which each service can be offered, the RATs through which each service can be offered and the expected demand per service and pixel. Additional requirements are utility volume and resource consumption, when a service is offered at a certain quality level, through a certain RAT.

System items to be taken into account include: (a) the set of sites that cover the region of the service area that faces the need for reconfiguration, and their locations (pixels); (b) the set of transceivers per site; (c) the set of RATs that can be used per transceiver; (d) the set of possible operating frequencies for each RAT; and finally (e) the coverage and anticipated capacity, when a RAT is used by a transceiver and operates in a certain frequency, taking into account intra- and inter-RAT interference.

The objective of the RFDQ-A problem is the determination of new configurations. Four allocations (i.e. new assignments of RATs to transceivers, frequencies to RATs/transceivers, demand to transceiver/ RATs, and applications to QoS levels) should optimise a utility-based objective function, which is associated with the resulting QoS levels.

Solution Method

Initially the method examines all possible allocations of frequencies to RATs and RATs to transceivers (configurations) within the whole service area, considering as acceptable only those allocations that satisfy the co-channel and adjacent channel interference constraints. It should be noted that the subject of interference is not considered for WLAN transceivers, as there are no adjacent channels used, while co-channel interference is also negligible, as denoted in [12]. Acceptable configurations constitute sub-problems that should be solved in parallel. In each of these sub-problems, the transceivers are initially providing the lowest acceptable QoS levels, while in subsequent reconfigurations these levels are gradually augmented in a greedy fashion. Finally, the method selects the ‘best’ combination of frequencies to RATs and RATs to transceivers, which maximizes the objective function.

Method Application and Results

A simple service area layout and structure is depicted in Figure 1.

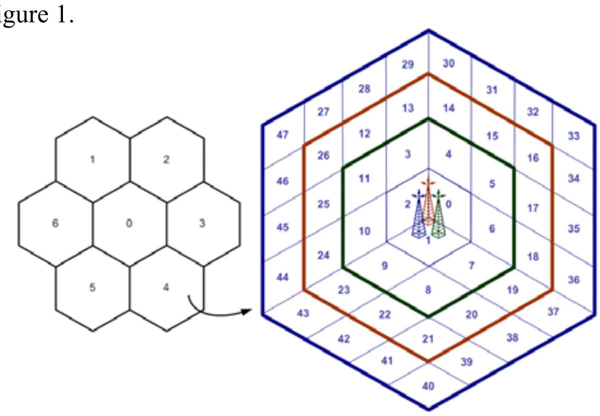

Figure 1: Typical service area layout and structure

This area consists of 7 cells/sites. Each site is equipped with *3* reconfigurable transceivers that may operate in either *UMTS* or *WLAN* radio access technologies (*2* RATs), each cell consists of *48* pixels and the transceivers are located in the cell centre. Moreover, both RATs may operate with 2 frequencies, i.e. 802.11b in 2.41 GHz and 802.11a in 5,18 GHz are assumed for WLAN, while 1980MHz and 2000Mhz carriers are utilized in UMTS. In doing so, the pixels contained in the black-lined inner cell (Figure 1) can be covered by transceivers assigned with either UMTS or WLAN-802.11a technology, the ones contained in the orange-lined middle cell can be covered by transceivers with either UMTS or WLAN-802.11b, while the remaining pixels, contained in the blue-lined outer cell, can only be covered by transceivers operating in UMTS. A maximum value of 0.6 is allowed as UMTS loading factor, while the maximum capacities of 802.11a and 802.11b are almost equal for 54Mbps and 11Mbps respectively.

The set of available services consists of *2* services. A voice service *(s1)* and a data service *(s2)*. The voice service can be offered only through UMTS and corresponds to a certain quality level (0), while for the data service a set of quality levels is provided (0, 1, 2), corresponding to the offered bit rate (32kbps, 64kbps and 128kbps respectively).

The demand in the assumed service area consists of 80 active sessions for cells 0 and 2, 45 for cell 1, 70 for 3, 4 and 6 and 50 for cell 5 (the numbers are randomly chosen). Furthermore, the sessions consist of 20% data and 80% voice sessions in each cell.

The operation results of this method, in terms of RATs and frequencies selection are shown in Figure 2.

Cell	Configuration	WLAN frequencies	UMTS carriers
0	WUU	2412MHz	1980MHZ and 2000MHz
1	WWU	2412MHz and 5180MHZ	1980MHz
2	WUU	2412MHz	1980MHZ and 2000MHz
3	WUU	2412MHz	1980MHZ and 2000MHz
4	WUU	2412MHz	1980MHZ and 2000MHz
5	WWU	2412MHz and 5180MHZ	2000MHz
6	WUU	2412MHz	1980MHZ and 2000MHz

Figure 2: Allocation of frequencies to RATs / transceivers

The allocation of demand to QoS levels for each cell is shown in Figure 3.

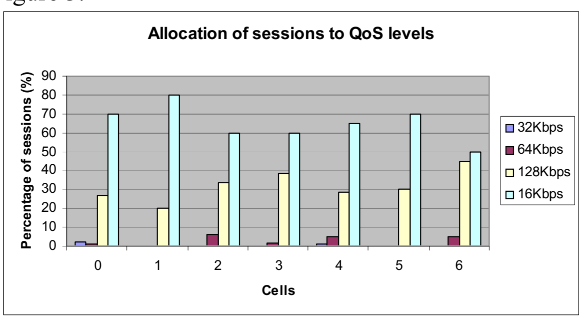

Figure 3 Allocation of applications to QoS levels for each cell

Configuration UUU, i.e. all transceivers operating in UMTS, is generally least useful, due to the existence of data sessions, which can be offered at higher bit rates from WLAN. Moreover, WWU is only appropriate when the total number of sessions is low and the voice sessions can be served from UMTS. In all other cases, WUU is the most appropriate configuration, i.e. 2 UMTS carriers co-located with one Access Point in a single cell. This is also depicted in Figure 3, where we find that in cells 1 and 5 we get the best results in terms of utility (deriving from the greater capacity of WWU). In the rest cells, WUU is the configuration selected.

Concerning the profit from reconfigurability, a reasonable question at this point might arise: “Why to use 3 reconfigurable transceivers instead of using 3 fixed elements, since the configuration could be the same (e.g 2 UMTS and 1 WLAN)?” One reason is that by using fixed elements the choice of allocations is limited by the fixed configuration and thus, the optimality of the allocations cannot be ensured. In contrast, the reconfigurability concept allows for optimality by searching among a number of possible configurations for the 3 transceivers. Another reason are the hardware requirements, the use of fixed elements would lead into 1 Node-B (supporting 2 UMTS carriers) and 1 Access Point (supporting 1 WLAN carrier). On the other hand, 3 reconfigurable transceivers could be lodged at the same site and that means a) less hardware b) less signalling information among network elements.

Future research work to be tackled within this joint approach of supporting reconfiguration decisions includes a proper distribution of sessions to the UMTS carriers or to the WLAN Access Points, in order to achieve certain criteria, such as load balancing, or power minimization.

IV. JRRM

This section introduces a new dimension into the radio resource management problem. That is, instead of performing the management of the radio resources independently for each RAT, some form of overall and global management of the pool of radio resources can be envisaged. JRRM is the process, with which a more efficient usage of the radio resources will follow.

Considering a scenario with a number of cells, where several RATs can be available along time. Aspects such as services demand in the interest area, traffic load levels and QoS requirements on one hand and spectrum availability, spectrum cost and RATs characteristics on the other hand would mainly determine the most suitable solution in terms of DNPM in that specific time and space. Those consist in the terms RATi(t) (the availability of the i-th RAT at time t), BWi(t) (the bandwidth allocated to the i-th RAT at time t) and Ri(t) (the amount of radio resources allocated to the i-th RAT at time t) for each cell. The cell relations need to be defined in case that HCS (Hierarchical Cell Structures) are used, as well as the main transmission and reception parameters for each RAT (e.g. maximum power, background noise level, etc.) need to be determined.

Thus, the input that DNPM provides to JRRM is in the form of:

$$
Cell_k = \begin{bmatrix} .... & .... & .... & .... & .... \\ RAT_i(t) & BW_i(t) & R_i(t) & TRX_i(t) & HCS_i(t) \\ .... & .... & .... & .... & .... \\ RAT_j(t) & BW_j(t) & R_j(t) & TRX_j(t) & HCS_j(t) \end{bmatrix}
$$

Besides, feedback and measurements coming from the different local RRM will act as algorithm inputs. Those can consist in uplink cell load factor, downlink Node B transmitted power and traffic classes for UTRA-FDD, or percentage of slots occupied and traffic type for GSM/GPRS. Furthermore, propagation measurements and mobile speed estimation are also taken into account.

Finally, the JRRM algorithm will also consider relevant operator-based information such as QoS parameters per traffic class and/or subscriber type, (ii) Subscriber differentiation elements and (iii) Operator policies.

With all these elements acting as algorithm inputs, JRRM may provide a range of possible outputs depending on the functional split between JRRM and local RRM entities, as shown in **Figure 4**, where different degrees of coupling between JRRM and Local RRM are reflected: JRRM may only provide RAT selection, JRRM may provide cell and RAT selection or JRRM may provide Rate selection (i.e. JRRM may take over Local RRM functions).

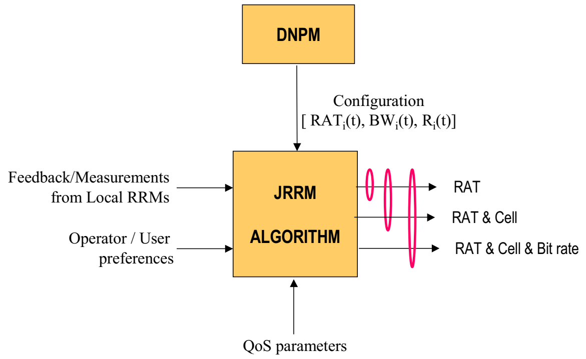

Figure 4. JRRM algorithm inputs and outputs

One possible approach for JRRM algorithms formulation is based on a Fuzzy-neural framework [13] with reinforcement learning mechanisms [14]. After the fuzzifier, inference engine and defuzzifier steps, a number ranging between 0 and 1, named Fuzzy Selected Decisions (FSD), is obtained for each RAT as the basis for the RAT selection, which could be based on the largest FSD value from the candidate RATs.

In order to illustrate the potentials of such framework for JRRM purposes, let us consider a scenario with three concentric cells, with radii R1, R2 and R3, defining WLAN, UMTS and GERAN (GSM EDGE Radio Access Network) dominant areas respectively.

Figure 5 presents the behaviour of the FSD values under a controlled situation. There are 12 users scattered in the scenario, with a generation rate of 6 calls per user and hour on the average, and average call duration of 180 s. A reference mobile is assumed to move in a straight direction from the centre to the cell edge and then in the back direction. The cell radius is 0.2 km for WLAN, 2km for UMTS and 3km for GERAN. Furthermore, 4 carriers are available in this case in the GERAN cell. In **Figure 5**(a), the distance of this reference mobile to the cell site as the user moves around is shown as a function of the simulation time measured in frames of 10ms. In turn, in **Figure 5**(b) the time evolution of the FSD for the three RATs of the reference mobile is plotted.

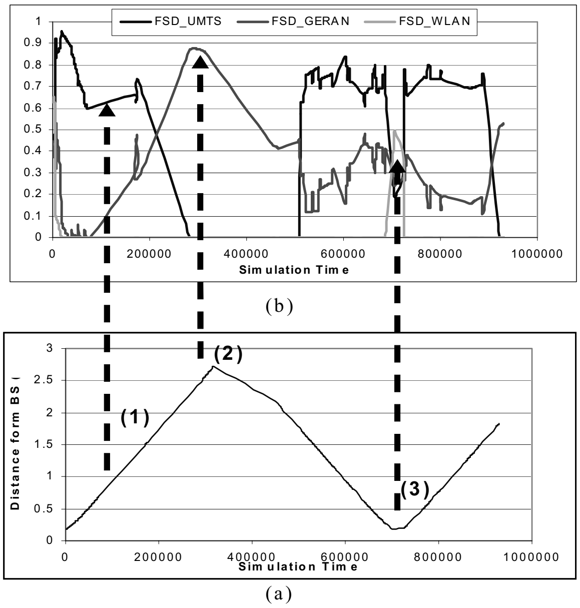

Figure 5 RAT allocated versus distance

The allocated RAT is the one with the highest FSD. It can be noticed that the allocated RAT changes, as the mobile moves around. In particular, the arrows stress three representative snapshots: 1) At about 1 Km distance UMTS is the preferred network. In this case WLAN is not available, while GERAN is not the best option 2) At about 2.5 Km, the FSD value for GERAN indicates that GERAN would be the choice (clearly, at this distance there is neither UMTS nor WLAN availability) and 3) Close to the cell site, the choice is for WLAN. The ability of the proposed framework to perform suitable Initial RAT selection and triggering ulterior Vertical Handover procedures is thus illustrated.

In turn, the capacity to control the system performance with the tools provided by the reinforcement learning mechanisms is shown in **Figure 6**, where the convergence of the percentage of non-satisfied users (in reference to a target reference bit rate) is plotted for two different target values, P_I*=3% and 1%. It can be observed that, once overcome the initial transient, the JRRM algorithm is robust enough to maintain the target QoS regardless the actual number of active users, user's position, speed and mobility features, and propagation losses variation.

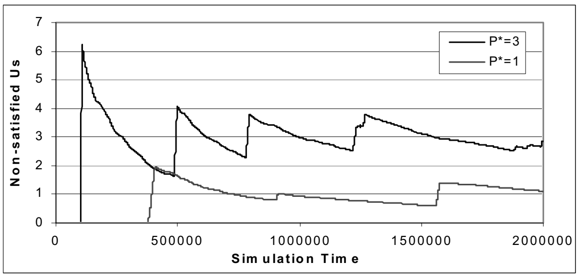

Figure 6 Percentage of non satisfied users towards convergence at starting up phase

V. THE ARMH CONCEPT

This section examines whether joint operating of multiple air interfaces gives the performance gains expected from JRRM joint with the ARMH approach [15, 16]. ARMH is an overall management framework extended from the IP Multi Homing concept [17]. It provides multiple accesses for multi-mode/multi-band terminals in order to allow terminal maintain simultaneous links with radio subnetworks. It selects the most appropriate JRRM function based on the identified information from the interworking subnetworks, terminals, user and services. From the OSI layer dimension, there are three kinds of ARMH approaches that are classified: the RLC ARMH, the MAC ARMH and the *Physical Layer* (PHY) ARMH. We adopt a processor sharing model for such packet switched services. In the packet switched domain, RLC ARMH is theoretically mapped to the *Joint Session Admission Control* (JOSAC) and MAC ARMH is mapped to Joint Session Scheduling (JOSCH), where the JOSAC does not allow traffic split for the same session, JOSCH on contrary allows concurrent traffic split. In order to apply JRRM algorithms in terms of JOSAC and JOSCH, the network has to be aware of the terminal capability and deployment pattern in order to choose an optimal JRRM approach. Theoretically, a terminal which receives relatively similar capacity from two cooperating radio networks, simply by allowing simultaneous radio access at each scheduled period, the response time for JOSCH will be reduced relative to the one given by the JOSAC algorithm.

Simulations tackled in the IST E^2R project aim to prove the effectiveness of the combination of JRRM and ARMH, in order to increase network deployment efficiency and enhance the overall system's capacity. Research into this complex framework will continue to be one of the main activities.

VI. CONCLUSIONS

This paper presents a novel management functionality proposal, for supporting reconfiguration decisions, in terms of (i) the basic DNPM modules that are necessary for the optimum network planning and the reduction of costs and (ii) JRRM modules, suitable for the short-term network fine tuning, in order to perfection DNPM decisions and (iii) interworking between JRRM and ARMH, in order to further support heterogeneity.

In conclusion, E^2R research shows the tight relationship between the network deployment pattern and the performance of radio resource management mechanisms. Consequently, advanced planning and management strategies are required to support the viability of reconfigurable networks. Such strategies will help NPs to effectively serve users, while at the same time reducing their network deployment and operation costs. Such strategies constitute basic research activities that prove the necessity of reconfigurability and reveal its virtues. Future work within E^2R will include an elaboration on the time scale of the proposed algorithms, as well as enlargement of the service area, in order to provide even more realistic solutions for prospective network designers.

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