Radio resource management and network planning in a reconfigurability context

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ABSTRACT

Heterogeneous radio environments are omnipresent yet their transmission capabilities are limited by non-optimal traffic load distribution and demand insensitive network planning. This paper highlights the concept of composite radio environments and introduces an approach for Joint Radio Resource Management (JRRM) and Dynamic Network Planning and Management (DNPM).

The paper outlines the problem area and describes the technical limitations that have to be overcome and it presents the End-to-End Reconfigurability (E^2R) approach towards resource efficient flexible radio planning within composite radio environments.

I. INTRODUCTION

Wireless communication systems use many different Radio Access Technology (RAT) standards, such as GSM [1], GPRS [2], UMTS [3], (BRANs) [4] or WLANs [5] and (DVB) [6]. The current trend towards systems "Beyond 3G" and the *Composite Radio* (*CR*) concept further add to this variety. The CR concept has been developed with the aim to increase the efficiency of both service provision, and the capacity of the available RATs. The main assumption is that the different radio networks, are not competitors, but cooperate as components of one heterogeneous wireless-access infrastructure. Thereby, a network provider (NP) may own several components of the CR infrastructure and may also cooperate with affiliated NPs. In such environment, users are directed to the most appropriate radio network and technologies, available in the service area, the choice of RAT may be based on load, time, profile and actual network performance.

The deployment of CR systems will be facilitated by the *reconfigurability* concept, which furthers the concepts of "software defined radio" [7]. Reconfigurability will provide those technologies and mechanisms that enable terminals and network elements to dynamically (transparently, efficiently, reliably and securely) select and adapt to the required (and most appropriate) RATs and operating spectrum ranges. However, the mechanisms and technologies needed will have requirements towards the radio planning as well as towards the resource management functionalities that need to be applied in such composite radio environments. It also must be investigated whether reconfigurability and dynamic, demand driven, network reconfiguration actually decrease the cost (CAPEX, OPEX) for network deployment while significantly enhancing spectrum efficiency.

Introduction of reconfigurability at different levels of the network (end user terminal, radio access points, …) opens new possibilities to manage radio resources. This paper presents the approach followed in the IST project End-to-End Reconfigurability (E^2R), this approach investigates interoperability between RATs as well as inter-operators collaborations. The aim is to increase spectrum efficiency by using more flexible spectrum allocation and radio resource management schemes. Suitable traffic load balancing mechanisms are investigated to maximize the systems capacity, optimizing the QoS provision and to increase spectrum efficiency.

II. DYNAMIC NETWORK PLANNING IN COMPOSITE RADIO ENVIRONMENTS

The concept of end-to-end reconfigurability affects and influences all aspects of the system ranging from terminal, air interface to network side. Any future network architecture must support scalability as well as reconfigurable network elements to be able to provide the best possible resource management solutions as well as cost effective network deployment. Once in place, mobile users will benefit from this by being able to access the required service at times and places when and where needed, at affordable cost.

From the engineering aspect, the best possible solution can only be achieved when the elements of the radio network are properly configured and suitable radio resource management approaches/algorithms are applied. In the following subsections, scenarios and the detailed technical challenges are investigated including, network planning and management as well as radio resource management mechanisms in a reconfiguration context.

Reconfigurable technology will change the operational mechanisms of conventional wireless access. The service area of an operator will consist of subsets, where coverage is offered using the classical single air interface method, with fixed functionality and base station capability, whereas some areas will be subject to dynamic network planning and flexible network management (DNPM). Where DNPM will be deployed depends on the dynamic features of traffic demands and cost comparison between fixed and DNPM application. The classical radio network planning methods are only based on radio signal predictions but do not consider traffic distribution over cooperating networks. DNPM will offer the methods and mechanisms to control the future composite radio network.

DNPM consists of two phases; the planning and the management phase. During the planning phase, aspects to be considered are as follows:

- feasibility of configuring the appropriate radio interfaces
- location of the base stations
- antenna patterns
- coupling structure among sub-networks
- policies of Joint Radio Resource Management (JRRM)
- statistical values of required spectrum in different scenarios with the set of available RATs
- temporal and spatial varying traffic patterns.

In the management phase, a two-layer reconfiguration (applicable to both network and terminal side) can be envisaged, the first layer mechanisms that need to be investigated include reallocation of functions between network elements allowing adaptive interworking between RATs and autonomous parameter adjustments in terms of maximum transmission power or antenna tilting". The second layer functions are more dynamic, a typical example is the selection of the most appropriate RAT used in the most suitable frequency bands. Additional dynamic management functions are categorized in the JRRM area.

The problem of dynamic network planning can be summarised as depending on the system input encompasses the layout of the service area, the profiles of applications and users in the service area, and the system aspects in terms of network infrastructure and permitted network coupling mechanism. The network considered consists of a number of Access Points (APs) controlling the interworking of user traffic and control messages between the radio and core networks, whereby each AP is equipped with a set of transmitters, that are reconfigurable to different RATs.

Profiles specify the requirements of a service area, this includes the applications (services) offered, the QoS levels available, the RATs existent, and the service demands. The implications of service provisioning over different RATs are described in section III, but the main problems to be tackled are:

- To determine the best possible RAT configuration in the service area.
- To distribute the service demands according to the available RATs.
- To determine the system parameters (within the service area) to enable the JRRM mechanisms to deliver the demanded QoS levels.

The main concepts that are investigated and considered will complement the DNPM approach, they include:

- *Advanced Spectrum Management (**ASM**)*

enables the dynamic management (allocation, de-allocation, sharing of spectrum blocks) within a single or between different radio access systems (inter-system handover is not supported). Here, spectrum bands allocated to each of the systems are not fixed.

- *Joint Radio Resource Management (**JRRM**)* -enables the dynamic management (allocation, de-allocation) of radio resources (time slots, codes, frequency carriers, …) within a single or between different radio access systems, using the fixed spectrum bands allocated to each of these systems (spectrum sharing between systems is not supported, i.e. this approach excludes ASM). JRRM provides the procedures (monitoring, decision making) that manage inter-system handover with the aim for a more balanced load and traffic distribution.
- *Radio Resource Management (RRM)* - enables the dynamic management (allocation, de-allocation) of radio resources within a single radio access system for the fixed spectrum bands allocated to this system.

A. Joint Radio Resource Management in Composite Radio Environments

As the demands for high-speed vehicular access, high system capacity and multimedia service support are increasing, radio spectrum resources allocated in international standards become scarce. Furthermore, the signalling load, due to not-properly admitted users and overloaded traffic sessions causes additional load and interference on the managed radio interface. This makes efficient spectrum allocation, access control, session flow control, traffic management and power control very difficult to manage. Related problems are how to distribute radio resources in the access network, as well as in frequency, time and code domains. And furthermore, how to admit users based on their required service profile and terminal capabilities? Seamless connectivity and establishment of links considering all system layers from physical to application layer and to efficiently utilize the available networks are the main challenges JRRM faces.

Radio resources are limited by the available spectrum, through access rights, limited number of time slots, orthogonal codes, transmission power, connection mode, etc., all of these limiting factors need to be considered in the management functions and classically they have been designed on different time scales. The JRRM approach foresees the joint management of these radio resources in different radio networks.

B. Deployment Scenarios

The deployment scenario envisaged consists of a defined service/coverage area, with 3 available RATs: UMTS-FDD, GSM/GPRS and WLAN 802.11. GSM/GPRS covers the complete area, UMTS only covers a part of that area and WLAN provides coverage for hot spots only (both indoor and outdoor).

The main characteristics of the scenario are: Different geographical availability of RATs, different user mobility status: static/dynamic, different time varying load levels (background traffic) for services and different service types demanded by the reference users, depending on time, space and mobility levels.

The capacities of following RATs will be considered: CDMA/ UMTS-FDD, GSM/ GPRS, QoS limited as well as high speed WLAN. And the basic RRM functions investigated to be adapted for the JRRM scheme. The basic architectural concepts include loose (at GGSN level connection point) as well as tight (at SGSN connection point) coupling between the three RATs considered. The service types range from: Conversational, Streaming, Interactive and Background to a Mix of these services. The traffic distribution considers the actual user/traffic density at different geographical areas of the service area (there is a non-homogeneous traffic distribution within the service area). The traffic distribution within the service area may vary over the different times of a day along a day. Finally, standard 3GPP models are used for the mobility and propagation models.

There are two main levels that have to be investigated for resource management in composite environments:

1. Identification of the overall ASM, JRRM and RRM functionalities and interrelations.
    a. JRRM characterization for ASM purposes. This includes the identification of the key JRRM parameters relevant for triggering and execution of ASM procedures.
    b. Identification of key local RRM parameters relevant for JRRM, identification of RRM events triggering JRRM actions.
2. Definition and evaluation of ASM/JRRM algorithms, aware of SDR capabilities and constraints.
    a. Impact of ASM on JRRM. Analysis of the impact ASM decisions may have on JRRM algorithms, identification of policy inconsistencies and definition of a ASM and JRRM framework.
    b. Analysis of the impact that JRRM decisions may have on local RRM algorithms, identification of policy inconsistencies.

III. JOINT RADIO RESOURCE MANAGEMENT AND DYNAMIC NETWORK PLANNING

The approach followed for increasing efficient usage of radio resources in a reconfigurability context is captured in Figure 1, the subsequent section will then describe the detailed techniques and approaches.

A. JRRM Architecture and Algorithm

Theoretical models and a simulation campaign are envisaged to study JRRM performance, this will be based on a set of assumptions regarding the coupling between the different radio networks considered. The performance assessment will be carried out initially on a macroscopic level (i.e. investigating the overall capacity increase in a set scenario (see previous section)). Two main JRRM mechanisms are classified: the joint session admission control (JOSAC) and joint session scheduling (JOSCH). The JOSAC approach does not offer detailed traffic splitting between subnetworks (i.e. this is neglected because of the limited gain expected due to the necessary traffic routing between the subnets). The JOSCH algorithm however offers detailed traffic splitting, this provides the possibility for optimal allocation of the traffic over subnetworks. JOSCH is also supported by the adaptive radio multihoming scheme [8].

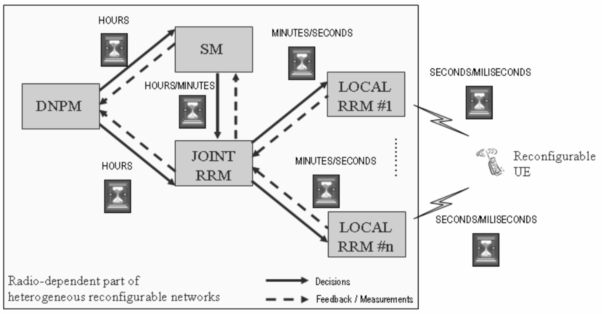

Figure 1: E^2R Approach to JRRM and DNPM

B. Modeling of JRRM Performance for DNPM

System capacity depends on load, fading and reception quality within the network. Different subnetworks load adds constraints to the traffic management algorithms. Research has shown that higher loaded networks are reluctant to accept individual heavy traffic loads [8]. This behaviour is analogous to the water filling theorem in information theory. In order to minimize the overall system load, JRRM has the capability to split incoming traffic and divert it to less loaded subnetworks. If the system does not suffer from soft blocking, extreme conditions can be reached, where the system capacities meet the upper bound. However, this does not mean that maximum capacity gain is reached. This implies that in soft blocking prone systems (cases for interference limited system) the system capacity gain can vary, based on different resource allocation schemes. Switching algorithms also impact JRRM performance, e.g. if dedicated channels are assigned to a service, it can be classified as being circuit switched.

If the radio system is modelled using a finite number of servers, it can be derived that higher system load and a higher number of available servers will result in smaller GoS improvements if JRRM is used, this implies that for an infinite number of available channels, JRRM is not needed. The combination of basic information and queuing theory theorems provides the justification for JRRM deployment in soft blocking sensitive systems, i.e. higher gains can be achieved when JRRM functions are implemented in interference limited systems.

JOSCH is the JRRM approach providing higher gain compared to JOSAC with higher QoS satisfaction. Deploying the JOSCH requires more functionality in the access network, e.g. Node B. JRRM functions are suitable for the traffic types with higher throughput. The high capacity gain results from JRRM implemented for relatively low system resources are applicable for both circuit switched and packet switched services.

The gain JRRM provides will be most apparent in unbalanced heterogeneous environments, e.g. single cell WLAN offers much higher capacity than single cell UMTS. Considering the possible gain of optimal load balancing and the system losses in this scenario, a situation may arise where JRRM does not need to be deployed. However, considering cost/coverage, the overlapping constellation would give the highest JRRM gain, when JOSCH is deployed in non-loose coupled networks. The associated issues will be further investigated and the concepts proven during the E^2R project [viii].

Network planning then requires modelling of network performance under consideration of a given traffic distribution and network deployment cost. The network performance measures should not only be based on the carrier strength that a mobile terminal can receive, but as described, the JRRM mechanism to be applied is of significant importance for performance improvement. Stochastic performance figures for the modes of JOSAC and JOSCH must be developed and applied in the network performance optimization model of the planning tool. In the optimisation campaign, algorithms like “Greedy”, “Taboo Search”, and “Simulated Annealing” will be considered in an approach of combinations of snapshot simulations (see following section). The procedures of DNPM and the interworking between the DNPM and JRRM are illustrated in Figure 2.

C. *Approaches of Dynamic Network Planning*

The objectives of the DNPM approach are to define the required management (objective) function respecting the given constraints, these are derived from the capabilities of the RATs, the RAT related propagation conditions and transmitters operating capabilities.

After deriving the programming model, based on objective function and cost function, the optimization process searching for the optimal location of reconfigurable network elements can be executed, as depicted in Figure 2. The aforementioned algorithms like Greedy, Taboo Search, and Simulated Annealing are considered during the optimisation process.

- The greedy algorithm works in phases. In each phase, a decision is made choosing a *local optimum*. When the algorithm terminates, and this local optimum equals the *global optimum*, then the algorithm is correct; otherwise, a suboptimal solution has been produced and another phase has to be performed.
- Taboo/Tabu search is a stochastic optimisation technique which works with a population of solutions to optimise a given objective function. It is generally applied to single objective optimisation problems. Taboo search has the potential for solving multiple objective optimisation (MOO) problems, because it works with more than one solution at a time, it has the opportunity to evaluate multiple objective functions simultaneously.
- Simulated annealing presents an optimization technique that can (i) process nonlinear and stochastic cost functions, (ii) process quite arbitrarily some boundary constraints and conditions imposed on these cost functions, (iii) be implemented quite easily and (iv) statistically guarantee finding an optimal solution.

If these optimisation methods are performed as static and dynamic simulations, a valuable insight into the statistical performance of the designed system can be achieved.

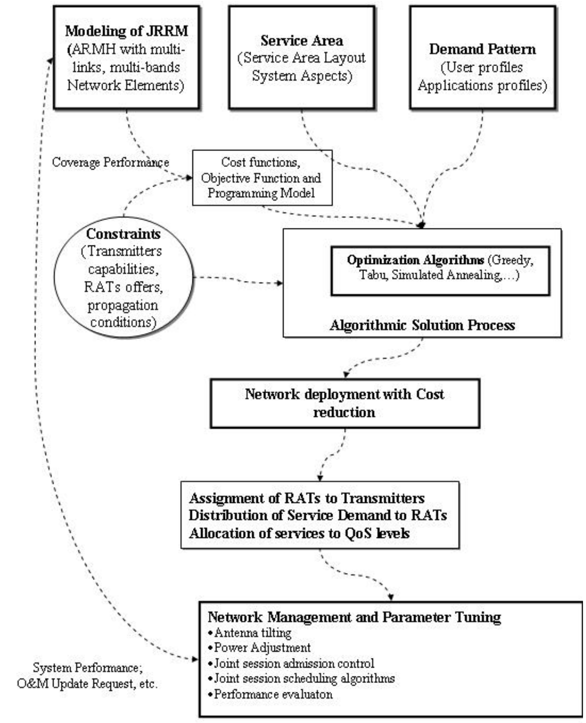

Figure 2: DNPM Procedure and Interworking with JRRM

IV. INITIAL RESULTS

D. *JRRM Deployment Gain*

The upper bound of deployment gain can be analyzed by the operational gain given by JRRM mechanism. For instance, the classical RRM mechanism in an operational area $\mathbf{A}$ offers capacity of C_C bps in each operating site. For simplicity reason, each site modelled consists of the same number of RATs as the system applying JRRM. The conventional solution needs N_C sites in order to fulfil traffic demands in $\mathbf{A}$. If all reconfigurable terminals support multiple air interfaces, and penetration of JRRM is 100%, offering capacity gain G_C, it can be derived that the capacity offered by a site is $C_{JRRM} = C_C(1+G_C)$.

This implies a bigger coverage, however, the coverage gain is not identical to the capacity gain. This is due to the user traffic at the border of a radio cell which normally requires considerable radio resources. I.e. the capacity gain for the site where JRRM is to be implemented can be described by:

$$C_{SJ} = C_C(1+G_C) - o(C_C) \qquad \textbf{(1)}$$

The deployment gain given by JRRM is upper bounded by G_C.

E. Deployment gain due to varying traffic pattern and reconfigurability

Spatial-temporal varying traffic patterns are a requirement for application of DNPM, this provides the chance of reducing the number of reconfigurable base stations compared to the conventional planning task. One can envisage that the average of a spatial-temporal varying traffic over time and space is lower than busy hour traffic patterns integrated over time and space. This implies that, the deployment gain from reconfigurable network planning is limited by temporal and spatial distribution. The accurate calculation of deployment gain requires therefore proper partitioning of the operating area and clear understanding of varying traffic distribution.

F. JRRM Mechanisms in Coupled Radio Networks

The operation principle envisaged is that coupled networks with different radio access technologies will support JRRM functions with the aim to enhance the operational spectrum efficiency and end user QoS. The feasibility of this however relies on availability of network reconfiguration, a functional architecture and traffic synchronization techniques under the concept of multi-homing. The performance of different JRRM schemes with regards to network deployment and constellation needs to be investigated. Delivery of seamless mobile multimedia services, enabled by the inter-operability of wireless heterogeneous radio access networks, poses additional requirements and addresses new challenges concerning radio network planning. For the operation of the JRRM and DNPM approaches, cooperation between operators is required. This may be achieved through an agreement of delivering traffic for other networks using a defined coupling structure, which is required provide services in changing new service area conditions (e.g., hot-spot situations, traffic demand alterations, etc.), or to react to changing service management requests. Different coupling structures influence the system performance, the level of interworking and the relative constellations of subnetworks are implemented through the agreement to absorb traffic from other networks using the JRRM mechanisms in the applied coupling structure.

The system performance has initially been tested according to the JRRM deployment in different overlapping scenarios between WLAN and UMTS radio system, the following conclusions can be obtained:

- Remote overlapping of WLAN as complimentary radio networks to UMTS enhances coverage under the constraints of the same computational power and number of access points/base stations.
- Less overlapping and more remote overlapping between sub-networks result in benefit for deploying JOSCH, e.g. pure throughput will increase by more than 50% in 10% overlapping case; in case the main object/sub-stream has 10 times significance against the rest of traffic, the effective throughput will be increased by more than 100%.
- In a centre-overlapping-low user density scenario, JRRM function needs not to be configured to JOSCH level, i.e., JOSAC level based JRRM offers even better throughput performance than JOSCH.

JOSCH requires service scalability, which requires on one hand more functionality defined for coupling point need to be considered by network reconfiguration, and significant trunking gain compared to JOSAC.

V. CONCLUSIONS

Two emerging concepts in wireless communications, namely composite radio and reconfigurability are discussed in this paper. These concepts will be the enablers of the widespread use of the reconfigurable radio technology. The concepts for Joint Radio Resource Management and Dynamic Network Planning and Management will provide increased efficiency in composite radio environments and will require high flexibility and reconfigurability from the access and core network. The approaches presented are viable solutions to increase access network efficiency and to exploit the possibilities of reconfigurable wireless technologies.

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