About this document

This document constitutes a white paper developed within WG6 of WWRF, concerning Cognitive Radio, Spectrum and Radio Resource Management in Reconfigurable Networks.

Cognitive Radio, Spectrum and Radio Resource Management

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Abstract:

The innovative communications services and applications imposed by ever increasing customer demands render necessary the development of efficient radio resource exploitation mechanisms and intelligent network planning methods. The whole process of planning and managing a reconfigurable network must be reconsidered, in order to live up to the expectations created by the migration towards a new era of communications. This White Paper deals with such issues, emphasizing the role of new engineering technologies in reconfigurable networks. For this purpose, it presents the respective Radio Resource Management, i.e. Spectrum Management and Joint Radio Resource Management, and Network Planning technical approaches, aiming at their application in next generation wireless access infrastructures.

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1. INTRODUCTION

The future of telecommunications is anticipated to be an evolution and convergence of mobile communication systems with IP networks, leading to the availability of a great variety of innovative services over a multitude of Radio Access Technologies (RATs). To achieve this vision, it is mandatory to embrace the requirements for support of heterogeneity in wireless access technologies, comprising different services, mobility patterns, device capabilities, and so on. Furthermore, it is equally important to promote important research in networking technology, through the provision of a guidance framework.

Present-day wireless communications, which stand at the forefront of current technological advances, comprise a multiplicity of RAT standards. Of these, the most commonly used are the Global System for Mobile communications (GSM) [1], Generalized Packet Radio Service (GPRS) [2], the Universal Mobile Telecommunications System (UMTS) [3], Broadband Radio Access Networks (BRANs), various types of Wireless Local Area Networks (WLANs) [4][5][6], and Digital Video Broadcasting (DVB) [7]. Furthermore, during the period of this work, new wireless standards like Worldwide Interoperability for Microwave Access (WiMAX) have emerged. Moreover, the complete set of wireless technologies is currently being transformed into one global infrastructure vision, called the *Beyond 3rd Generation* (B3G) wireless access infrastructure. This is aimed at offering innovative services, based on user demands, in a cost-efficient manner. Major contributing concepts towards this convergence are *cooperative networks* [8][9] and *reconfigurability* [10].

The cooperative networks concept assumes that diverse technologies, such as cellular 2.5G/3G, BRAN/WLAN and DVB systems, can be joint components of a heterogeneous wireless-access infrastructure. This allows a Network Provider (NP) to rely on more than one RAT, dependent on the encountered specific conditions (e.g., hot-spot requirements, traffic demand alterations, etc.) at different times and in different areas. The NP may also cooperate with other NPs in order to make alternative solutions available for maximization of QoS levels offered to users. Advanced management functionality is required to support the cooperative networks concept, and much associated research has been done in the recent past [11][12][13][14]. This envisaged functionality deals with the reallocation of traffic to different RATs and networks, as well as the mapping of applications to QoS levels.

The move towards the Reconfigurability concept was initiated as an evolution of Software Defined Radio [15]. It aims to provide essential mechanisms to terminals and networks, so as to enable them to adapt dynamically, transparently, and securely to the most appropriate RAT dependent on the current situation [16]. Through reconfigurability, we envisage network segments being able to change RAT in a self-organized manner, allowing them to better handle offered demand. In this context, reconfigurability also allows for the dynamic allocation of resources (such as spectrum) to RATs [17]; consequently, many new possibilities are invoked with respect to the efficient management of the whole reconfiguration process. This management involves the available resources, mostly spectrum, as well as the joint management of demand deriving from the cooperative RATs. The configuration process and the respective management needed are presented in detail in section 2.

In accordance with the above observations, this white paper has been produced within the WWRF WG6 Reconfigurability group, and is aimed at providing the basic principle that must be adhered to in order to make cooperating reconfigurable networks commercially successful. These principles lie in the effective management of the available resources, i.e. (i) more efficient utilization of available spectrum, (ii) management of radio resources belonging to different RATs with fixed spectrum allocation, and (iii) an intelligent network planning process.

This white paper is structured as follows. The next section considers the general characteristics of Radio Resource Management (RRM), providing an analysis of RRM and requirements for the effective management of resources, along with associated technical considerations. A summary of some envisaged RRM solutions is also provided. Section 3 is dedicated to Spectrum Management. As spectrum today is a scarce resource, it is necessary to use it efficiently; cooperation amongst networks will assist the efficient use of radio spectrum in future communication systems. Section 4 presents Joint Radio Resource Management (JRRM), consisting of a feasibility study for JRRM, a functional overview of the proposed JRRM scheme, and some important JRRM-related research topics, along with a novel scheme for managing resources of different RATs, namely Hierarchical Radio Resource Management (HRRM). Section 5 considers Dynamic Network Planning, which is an absolutely necessary task for network designers. Finally, section 6 discusses enabling technologies that can be utilized to facilitate the provision of Flexible Spectrum Management and JRRM, in a reconfigurability context.

2. RRM IN A RECONFIGURABILITY CONTEXT

This section presents the basic principles of Radio Resource Management in a reconfigurability context. Its requirements, technical aspects and solution methods are presented.

2.1 Analysis of RRM

End-to-end reconfigurability has a strong impact on all aspects of the system, ranging from the terminal, to the air interface, up to the network side. Future network architectures must be flexible enough to support scalability as well as reconfigurable network elements, in order to provide the best possible resource management solutions in hand with cost effective network deployment. The ultimate aim is to increase spectrum efficiency through the use of more flexible spectrum allocation and radio resource management schemes, although suitable load balancing mechanisms are also desirable to maximize system capacity, to optimize QoS provision, and to increase spectrum efficiency. 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 and suitable radio resource management approaches/algorithms are applied. In other words, the efficient management of the whole reconfiguration decision process is necessary, in order to exploit the advantages provided by reconfigurability.

For this purpose, future mobile radio networks must meet the challenge of providing higher quality of service through supporting increased mobility and throughput of multimedia services, even considering scarcity of spectrum resources. Although the size of frequency spectrum physically limits the capacity of radio networks, *effective solutions* to increase spectrum efficiency can optimise usage of available capacity.

Through inspecting the needs of relevant participants in a mobile communication system, i.e., the *Terminal*, *User*, *Service* and *Network*, *effective solutions* can be used to define the communication configuration between the *Terminal* and *Network*, dependent on the requirements of *Services* demanded by *Users*. In other words, it is necessary to identify proper communications mechanisms between communications apparatus, based on the characteristics of users and their services. This raises further questions about how to manage traffic in heterogeneous networks in an efficient way.

Mobile terminals are characterised by a wide range of capabilities, influenced by the RAT processing capability, e.g., multi-modality, processing power, display size, etc. Fast-developing SDR (*Software Defined Radio*) technologies enable mobile terminals to be adaptable to different RATs, through *software download* (SD) procedures. Reconfigurability as an extension to SDR aimed at optimising communication the mechanism between the terminal and network, comprising protocols defined across all OSI (*Open System Interaction*) layers.

From the user perspective, services are expected, which not only depend on a traditional single traffic type, but multiple traffic types from one or more radio networks. Multimedia applications are becoming popular and are already beginning to demand wireless transport. They cover information types from voice, control data to audio, video or any combination thereof. Supporting multimedia traffic with data rates of even up to several Mbps (Megabits per second) is an important aspect of future radio communication systems. A mobile user might use the mobile terminal access regular voice services in high mobility environments; however, s/he might use a laptop access to data services with higher data rates in low-mobility environments. For instance, the data rates offered by the emerging UMTS FDD system can be as high as 384 kbps (kilobits per second) for wide-area coverage, and several Mbps for local-area coverage, even using a single frequency band. With a multi-mode terminal, the user is not restricted to a single RAT. S/he is able to access a set of RATs alternately or simultaneously. The radio network is responsible for selecting the most appropriate accessible RAT, or a combination of RATs, taking into account user service and network information.

In conclusion, Radio Resource Management (RRM) is a complex process, but is necessary in the deployment of 4G networks. It consists of dynamically managing resources like spectrum, as well as allocating traffic dynamically to the RATs participating in a heterogeneous wireless access infrastructure. Consequently, RRM can be seen as a superset of Spectrum Management and Joint Radio Resource Management (JRRM). This is the starting point for the decoupling of these ideas presented herein.

2.2 Spectrum Management Overview

The configuration of resources is recently a pertinent area of research in the plethora of telecommunications technologies. Current spectrum allocation approaches, fixed by nature, do not allow for the allocation frequency bands to different RATs dynamically. However, the coexistence and cooperation of diverse technologies, which form part of a heterogeneous infrastructure, has brought about the possibility of flexibly managing the spectrum in a dynamic manner. No longer are fixed frequency bands guaranteed to apply to specific RATs, but conversely, through intelligent management mechanisms, bands can be allocated to RATs dynamically in a way such that the capacity of each RAT is maximized and interference is minimized.

In the context of this paper, the work on spectrum management involves a brief presentation of the technical requirements for flexible spectrum management, some current research activities, and the vision of spectrum for coming years, as well as related regulatory issues

2.3 Joint Radio Resource Management (JRRM) Overview

In this white paper, we specially propose and study some mechanisms controlling the communication schemes between mobile terminals and radio networks which consist in a number of RATs coexisting together and co-operating with each other, but with fixed spectrum allocation. Such mechanisms are defined as the *Joint Radio Resource Management* (JRRM) for the heterogeneous networks. The multi-mode capabilities are enabled by reconfigurability.

To design the wireless systems, we encounter typical problems, such as the signal attenuation, terminal noise, fast fading due to multipath phenomenon, shadowing, *Multiple Access Interference* (MAI) and other typical system related features, e.g., the mutual relation between interference strength and duration period given by link adaptation. All those problems prevent us from using radio resource efficiently. On the other hand, the radio resource is not only, by definition, the radio spectrum, but also realised in the real radio network as, access rights for individual mobile user, time period a mobile user being active, channelisation codes, transmission power, connection mode, etc., that require the management functions being designed in different time scales. Furthermore, radio resources from different radio networks can be managed jointly in order to solve the encountered problems more effectively. The term *Joint Resource Management* (JRRM) is therefore generalised as: a set of network's controlling mechanisms that supports intelligent admission of calls and sessions; distribution of traffic, power and the variances of them, thereby aiming at an optimized usage of radio resource and maximized system capacity. These mechanisms work simultaneously over multiple RATs with the necessary support of reconfigurable/multimode terminals.

Moreover, in the context of JRRM, we propose the novel solution of Hierarchical Radio Resource Management (HRRM). As the specifications for HRRM differ slightly dependent on the exact usage scenario, we essentially give a generalization of it. HRRM could either be implemented in entirety, or as a general concept which might be used as a facilitator for radio-efficiency, allowing sub-parts of RATs to be automatically dynamically partitioned. HRRM is a very basic idea which takes advantage of the fact that common core blocks of functionality are often present in RATs, which allows for the specification of complete RATs through a basic form of *building blocks*. These building blocks in essence constitute elements in a class-hierarchy, which are inherited sequentially to generate the complete RAT.

3. SPECTRUM MANAGEMENT

3.1 Introduction to Spectrum Management in a Reconfigurability context

Along with the advent of the 4G era in telecommunications technology, new techniques must be developed for the intelligent management of spectrum among the RATs forming a heterogeneous infrastructure. The term reconfiguration applies not only to the selection among a set of available RATs in the service area, but also to the appropriate configuration of the resources utilized, i.e. careful selection of the operating frequency band. Such issues imply that there is need for flexible managing the spectrum and are dealt with in this section.

Furthermore, there is a tight relationship between spectrum management and cognitive radio. Flexible spectrum management is needed for wireless devices that operate in either the licensed band or the unlicensed band, or both, as Illustrated in Figure 1. Cognitive radio will provide the technical means for determining, in real-time, the best band and best frequency to provide the services desired by the user at any time. In this section, even though separate sub-sections are provided for technical and regulatory aspects of spectrum management, the two are closely intertwined. For example, the European R&TTE Directive requires that the Declaration of Conformity by the manufacturer be a statement of conformity with: harmonized standard, and/or consultation with a Notified Body (the manufacturer remains responsible for the Declaration of Conformity).

Although many administrations outside Europe do not use procedures similar to the Manufacturer's Declaration of Conformity, the Regulatory Agencies in these administrations typically do rely on technical specifications/standards/ITU Recommendations as part of their certification procedures. Thus, the technical, regulatory and standardization aspects of spectrum management are closely intertwined.

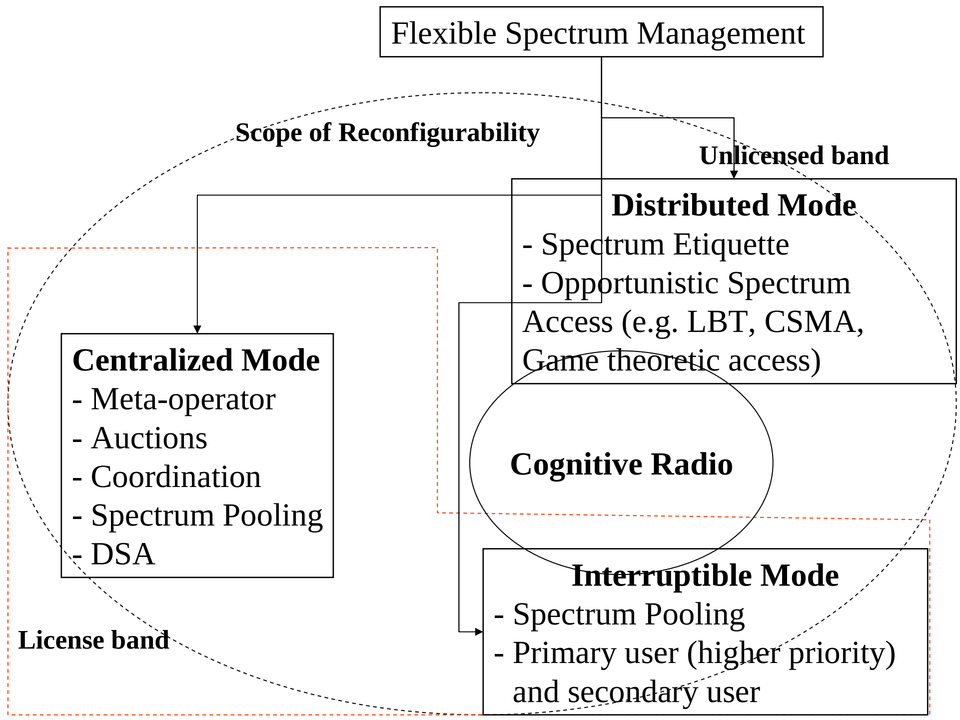

Figure 1: Technical Scope on Spectrum Management Approaches

3.2 Technical Aspects of Spectrum Management

3.2.1 Technical Spectrum Management Requirements

This part aims at identifying the required physical layer functions that radio equipments (UE and Radio Network Access Point) have to be enabled with so that multi-bands capabilities are supported. The notion underlying behind the multi-bands capabilities is discussed hereafter respectively from the frequency range, spectral resolution, spectral co-existence and switching standpoints.

3.2.2 Current Spectrum Management Research

3.2.2.1 Spectrum Management Research in the United States

There is considerable research in the United States or spectrum management technologies including cognitive radio. This section provides a brief summary of several major research programs in the United States which are focused on cognitive radio and spectrum and radio resource management. This brief summary does not purport to cover all research in the U.S. in these areas, but it does give a sample of such ongoing research.

Some of the research on cognitive radio and related topics has been fostered by the Federal Communications Commission concepts on cognitive radio and interference temperature as described in the FCC Spectrum Policy Task Force Report[1]. This report noted that:

"Preliminary data and general observations indicate that portions of the radio spectrum are not in use for significant periods of time."

The FCC report notes, however that more information is needed in order to quantify and characterize spectrum usage more accurately so that the FCC can adopt spectrum policies that take advantage of the "holes" in the spectrum usage.

Subsequent to the issuance of the Spectrum Policy Task Force Report, the FCC has issued other related documents including:

Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies, Notice of Proposed Rule Making, ET Docket 03-108.

Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands, Notice of Proposed Rule Making, ET Docket 03-237.

Unlicensed Operation in the TV Bands, Notice of Proposed Rule Making, ET Docket 04-186.

These documents and the comments and reply comments may be found at:

http://wireless.fcc.gov/spectrum/proceeding.htm?pagenum=2

The FCC is pushing for a new paradigm for spectrum management – cognitive radio, policy-based radio, reconfigurable radios and networks, and revised radio resource management will be keystones of this new paradigm.

Defense Advanced Research Projects Agency

[1] Federal Communications Commission, "Spectrum Policy Task Force Report", ET Docket 02-135, November 2002. Available at: http://www.fcc.gov/sptf/

The Defense Advanced Research Projects Agency (DARPA) is developing a new generation of spectrum access technology under the Ne**X**t **G**eneration (XG) communications program [60][61][62][63][64][65][66]. Although this program is oriented toward military communications, it is applicable to advanced spectrum management for any band and any communications services. This multi-usage is analogous to the development of data communications protocols which were originated by DARPA and used in the DARPA-net, but which have involved to what is now know as the World Wide Web. The motivation for this new spectrum access technology is the same for the commercial communications community as it is for the military communications community:

Apparent Spectrum Scarcity: The current method of allotting spectrum provides each new service with its own fixed block of spectrum. Since the amount of useable spectrum is finite, as more services are added, there will come a time at which spectrum is no longer available for allotment. We are nearing such a time, especially due to a recent dramatic increase in spectrum-based services and devices.

However, as noted by the FCC, there are large portions of allotted spectrum that are unused. This is true both spatially and temporally. Thus, there are portions of assigned spectrum that are used only in certain geographical areas and there are some portions of assigned spectrum that are used only for brief periods of time. Studies have shown that even a straightforward reuse of such "wasted" spectrum can provide an order of magnitude improvement in available capacity. Thus the issue is not that spectrum is scarce – the issue is that we do not currently have the technology to effectively manage access to it in a manner that would satisfy the concerns of current licensed spectrum users.

The DARPA XG Program is pursuing an approach wherein static allotment of spectrum is complemented by the opportunistic use of unused spectrum on an "instant-by-instant" basis in a manner that limits interference to primary users. This approach is called "opportunistic spectrum access" spectrum management and the basic parts of this approach are:

- Sense the spectrum in which you want to transmit.
- Look for spectrum holes in time and frequency.
- Transmit so that you do not interfere with licensees.
- There are a number of research challenges to this adaptive spectrum management including:
- Wideband sensing.
- Opportunity identification.
- Network aspects of spectrum coordination when using adaptive spectrum management.
- Need for a new regulatory policy framework.
- Traceability so that sources can be identified in the event that interference does occur.
- Verification and accreditation.

More information on the DARPA XG Program for spectrum access management may be found in general briefings available at the DARPA web site[2] as well as in the following two documents which are also available at the DARPA web site:

The XG Vision – Request for Comments, v2.0, Prepared by BBN Technologies

The XG Architectural Framework – Request for Comments, v1.0, Prepared by BBN Technologies

National Science Foundation

[2] http://www.darpa.mil/ato/programs/XG/

The National Science Foundation (NSF) has a research program entitled "Programmable Wireless Networking (NeTS-ProWiN) [67] . This NSF research program is addressing issues that result from the fact that wireless systems today are characterized by wasteful static spectrum allocations, fixed radio functions, and limited network and systems coordination. This has led to a proliferation of standards that provide similar functions—wireless LAN standards (e.g., Wi-Fi/802.11, Bluetooth) and cellular standards (e.g., 3G, 4G, CDMA, and GSM)—which in turn has encouraged stovepipe architectures and services and has discouraged innovation and growth. Emerging programmable wireless systems can overcome these constraints as well as address urgent issues such as the increasing interference in unlicensed frequency bands and low overall spectrum utilization.

The research sponsored by NSF under the Programmable Wireless Networking Program is addressing these issues by supporting the creation of innovative wireless networking systems based on programmable radios. The objectives of this NSF research program are to:

- Capitalize on advances in processing capabilities and radio technology and on new developments in spectrum policy;
- Improve connectivity and make more effective use of shared spectrum resources; and
- Enhance the wireless networks community by intermixing the networking, radio, and policy communities, integrating education with research through focused activities, and diversifying participation.

Programmable radio systems offer the opportunity to use dynamic spectrum management techniques to help lower interference, adapt to time-varying local situations, provide greater quality of service, deploy networks and create services rapidly, enhance interoperability, and in general enable innovative and open network architectures through flexible and dynamic connectivity. The specific research areas under this NSF Program are:

Dynamic spectrum management architectures (including sensor-based architectures) and technologies; includes investigation of issues such as techniques to implement policies, security and robustness, quality of service, and enforcement;

Topology discovery, optimization, and network self-configuration technology;

Techniques for the interaction between routing, topology, and administrative/network management including the development of the policy and security framework;

Flexible radios for networking research.

Additional information on this NSF research program may be found at:

http://www.cise.nsf.gov/funding/pgm_display.cfm?pub_id=14744&div=cns

Software Defined Radio Forum

The Software Defined Radio Forum has an embryonic program for investigating technical, regulatory, and market aspects of cognitive radio and spectrum efficiency. The technical aspects include the development of security requirements. Some spectral occupancy measurements have been made under the auspices of the SDR Forum. The results of these measurements will be useful in determining the parameters to be used in designing policy-based cognitive radio systems and identifying which portions of the band should be considered for the initial application of such radio systems. More information on the SDR Forum may be found at:

www.sdrforum.org

3.2.2.2 Spectrum Management Research in Europe

The current scheme of allocating spectrum in a fixed manner provides the advantage that equipment always knows about the operating frequency and system parameters of each RAT. However, communication traffic load is time and space dependent, hence introducing flexibility in the spectrum allocation will allow spectrum to be allocated in a manner that better matches the operators' and users' temporal usage/provision needs within a geographical area. Thus optimising the use of spectrum.

The traditional way for allocation of spectrum was (is) to allocate a fixed amount of spectrum in a particular communication system to each operator. A more dynamic way of reallocating spectrum according to traffic needs would be required. To this purpose a comprehensive set of new Advanced Spectrum Management concepts are introduced using SDR technologies as enabler.

The goal of Flexible Spectrum Allocation needs an approache that identifies and develops new methodologies for the spectrum management in order to increase the spectrum utilization efficiency and find efficient solutions to solve the problem of "scarcity of spectrum". Spectrum as such is not really a scarce resource; yet it is not used in an optimised manner. And optimization of its usage would be much easier if a "Full Flexible Spectrum Allocation (FSA)" approach would be implemented.

Spectrum Brokerage (SB) is a part of this approach. Here spectrum is looked upon like an economic good like stocks or real estates. Automatic spectrum agents act as brokers between suppliers and spectrum purchasers. Spectrum purchasers give purchase orders with maximum prices and deadlines just like when buying stocks. Rates will develop very dynamically depending strongly on location and time of the "spectrum transaction". Even buying spectrum from users, which have already allocated spectrum is imaginable. After the identification and development of SB methods, mechanisms and algorithms to enable automatic SB processes need be developed. Then suitable user demand models and accounting and billing methods need to be investigated and included in the approach.

Within the FSA approach optimization processes for optimal spectrum management need to be defined, the goal being to propose a generic methodology for allocating/deallocating spectrum in free/unlicensed spectrum band (this includes the management of intersystem interference, the sharing rules, the operator's and regulator's role…). Steps towards full Flexible Spectrum Allocation may include to enable Dynamic Spectrum Allocation, efficient spectrum sharing between operators.

Another approach aiming to increase spectrum efficiency through higher flexibility is based on the principle of Spectrum Pooling (SP). This approach takes advantage of the cognitive radio approach, first introduced by Mitola. The ability of such a radio to detect free sub bands within a certain frequency band would enable the equipment to exploit unused frequencies without a disadvantage for the license owner of the spectrum and to enable dynamic spectrum sharing (DSS) and dynamic spectrum allocation (DSA). Classical spectrum pooling can be applied for increasing spectrum utilization without changes in existing networks. Obviously spectrum utilization efficiency may be further increased if the network provides signalling information to a spectrum pooling system.

Within the SP approach, a subset of algorithms/mechanisms follows the Highest Priority Intelligent Air Interface. The underlying idea is to look upon spectrum pooling the other way around: Instead of designing a system for the rental users, we develop an intelligent system for spectrum owners, in which the spectrum owners applications (e.g. military, search and rescue, fire fighters, police) are given access to the next available spectrum resource in any frequency region with highest priority. Formerly reserved spectra for these applications may then be released for civilian use.

The main assumption for future spectrum management schemes is that the allocation itself will be increasingly flexible and that the relevant timeframes between reallocations also can be adapted in a rather flexible and demand driven way. The present spectrum management research in the EU is being conducted in parallel by a number of research organisations and collaborative projects.

3.2.3 Spectrum Management Vision

3.2.3.1 Recommended Policy Principles to Guide Future Spectrum Regulations

Policies for licensed band and unlicensed band (See Figure 1) are different. For licensed band, spectrum management needs to agree on the following principles.

Principle 1: Allowed Radio Access Technology (RAT) is limited in an internationally agreed set of technologies (e.g., UMTS band only can be accessed by IMT 2000 technology family), i.e., not completely technology neutral

Principle 2: Using the auctioned, traded or coordinated spectrum to harmonize among those RATs in Principle 1, not to harm them

Principle 3: Secondary users should not disturb primary user under the specified 'Interference temperature' criteria

Principle 4: RAT using this band should be backward compatible or terminal can be reconfigurable or legacy terminal can be handed over

Arguments for Principle 1:

Technology neutrality is currently an intensively debated issue in CEPT/ECC and in ITU-R. The request for technology neutrality bases allegedly on corresponding treaties of the WTO but might also be initially caused by requests from the US-government to improve market chances in European market during the licensing process for UMTS in the year 2000 [18][19].

3.2.3.2 Technology Neutrality

The term Technology Neutrality is used for some time as a slogan. The term '*technology*' in this document is defined as '*Radio Access Technology* (RAT)'. Under this context, *Neutrality* is understood as the absence of regulatory rules or conditions to follow by decision makers.

It is proposed to adopt the definition of "*Technology Neutrality*" as the freedom of an operator to use in a certain spectrum whatever radio standard he wants. Technology Neutrality in the field of radio telecommunication therefore means in fact "*Standards Neutrality*".

3.2.3.3 Technology Harmonization

The term "*Harmonization*" is generally understood as a process to increase commonalities and to decrease differences with the aim to improve interoperability and compatibility (between standards). A primary goal of *Reconfigurability* is to realise technology Harmonization.

From the spectrum usage viewpoint, *harmonized spectrum* is a prerequisite for economics of scale and eases global roaming.

3.2.3.4 Harmonization versus Technology Neutrality

Harmonization and Technology Neutrality can be considered as antithetical tendencies. Whilst Harmonization aims at minimization or even avoidance of differences between standards, Technology Neutrality aims to permit different standards and their usage, and to leave it to the market preferences and other influences whether alignment will occur or not.

Harmonization aims at maximum interoperability and compatibility for mobile communication, whilst Technology Neutrality consciously risks the usage of different in-compatible standards resulting in non-interoperability and missing roaming capabilities between different systems in adjacent or even same areas and/or spectrum bands.

However, Harmonization and Technology Neutrality to a large extent do also coexist - as we can learn from the concept of IMT-2000 radio technologies. IMT-2000 radio technologies are harmonized at a certain level, but they remain partly incompatible technologies, which would require multi-mode terminals for roaming between family members. Identification of harmonized spectrum for IMT-2000 means basically that certain standards out of a limited set of standards can be used in this spectrum. Such decision will be on the other hand in favour of the reduction of the complexity of reconfigurable terminals. The comparison between Harmonization and Technology Neutrality is shown in Figure 2.

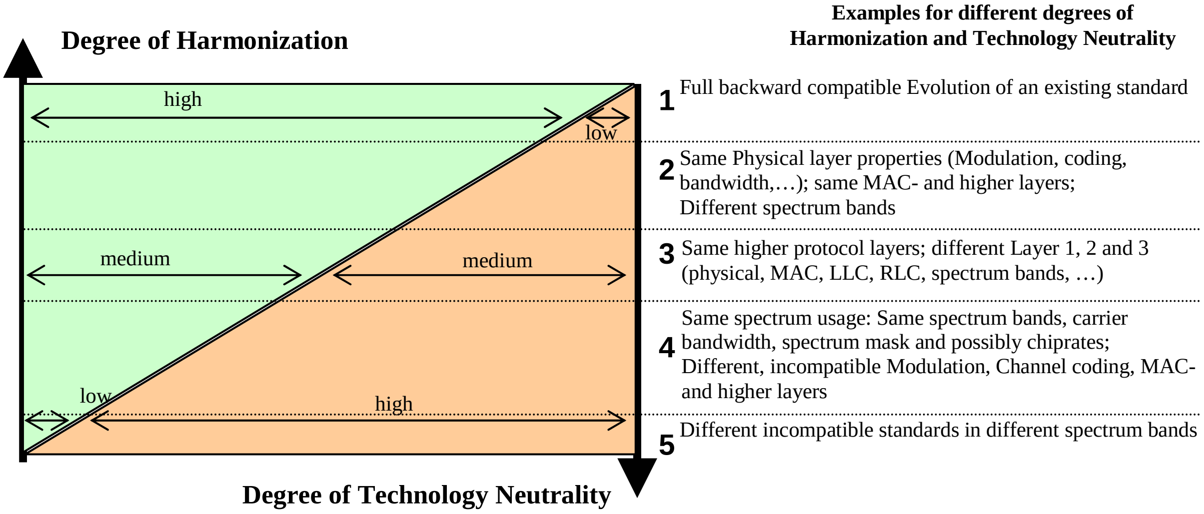

Figure 2: Harmonization versus Technology Neutrality

Short and long term history shows strong trends toward increase of harmonization. The roadmap of the technology evolution of Reconfigurability is to nowadays harmonise the existing internationally recognised and standardised RATs, as Harmonization is considered as one means to fulfil the WTO requirement to avoid Technical Barriers to Trade [21] . In the future, it needs to evolve itself as a part of new standard supporting backward compatibility.

3.3 Timeframe for implementation

The roadmap for the rollout of *Dynamic Spectrum Allocation (DSA)* relies on both the complexity of the technical implementation and the evolution of the regulation policy.

From the technical standpoint, given the achievable reconfigurable performance of the current enabling technologies with associated constraints (power consumption, compact size), the following short-term scenarios for the operation of DSA can be envisaged:

- **Radio Network Access Point (RNAP) side (**Figure 3**)**: This is the case of unconstrained equipment - like BSs, broadcast Tx/Rx or embedded devices (e.g. in a car or in a car). These equipments can support operations with a large frequency range combined with a quite good spectrum resolution.
- **Mobile handset side**: At the opposite of RNAP, the constraints associated to the handsets only enable the support of either:

Scenario 1 (Figure 4): Alternatively, handset capabilities could allow for a narrower frequency range but with a higher degree in spectrum resolution for a similar amount of complexity to the previous point.

Scenario 2 (Figure 5): For handsets, the current capabilities enable the support of a wide frequency range by using a limited number of predefined radio frequency carriers.

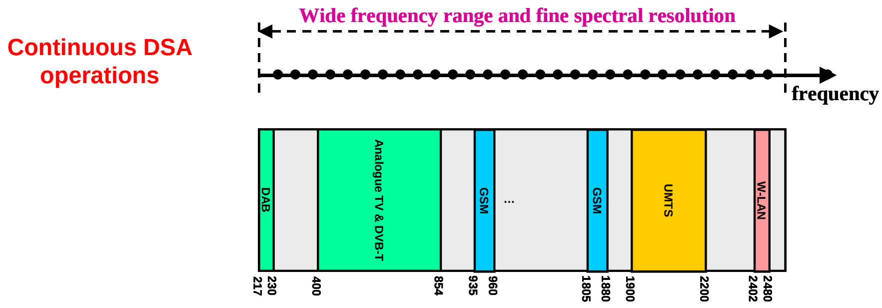

Figure 3: RNAP implementation scenario

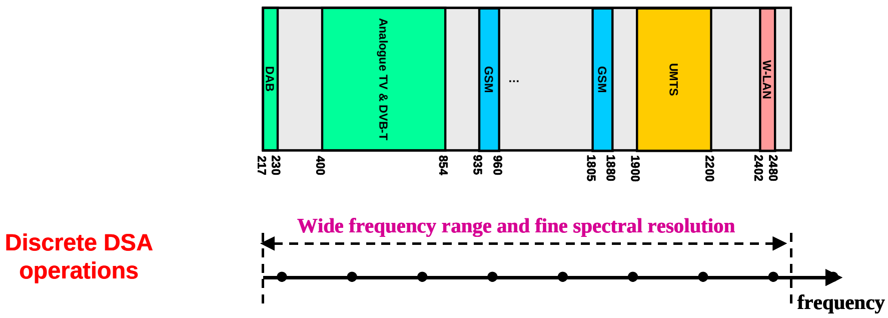

Figure 4: Scenario 1 for mobile handset implementation

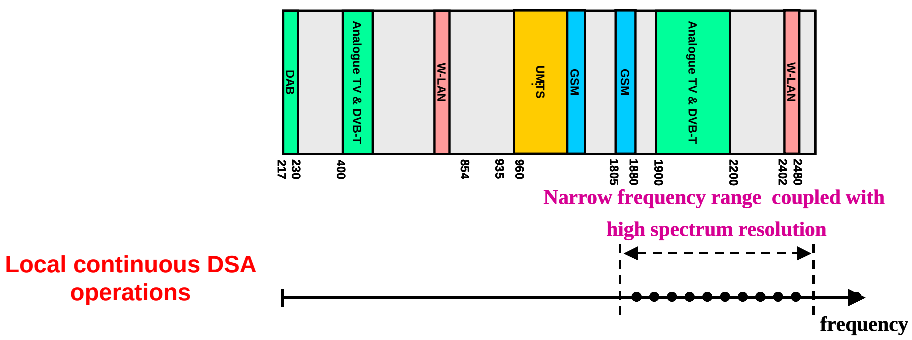

Figure 5: Scenario 2 for mobile handset implementation

From the spectrum regulation standpoint, the possible short-term scenarios for DSA implementation are captured in Table 1.

3.4 Regulatory Aspects of Spectrum Management

3.4.1 General Aspects

There is general interest in cognitive radio, reconfigurable radio, and software defined radio by a number of regulatory agencies (RAs). Regulators are primarily concerned with the security of radio software so that these types of devices can not operate outside the spectral parameters for which they are certified. They are less concerned about the other types of operational software (e.g., operating systems) unless download of these other types of software could either inadvertently or intentionally cause improper operation of the radio software.

In the application arena, the failure of the application such as a game may result in disappointment of the customer with no additional harm done. In the radio software arena, failure of the radio software, such as frequency selection and modulation, may result in a customer having a non-functional radio device or, worse, a device that functions inappropriately and disturbs other users or other radio services. The mechanisms to download may be the same, but the specifics and scope can vary to satisfy the imposed criteria. The following regulatory requirements apply to one component of operational software, namely, radio software:

- Regulators require, in general, that the device must provide some means of indicating its current "type approval" or "conformance acceptance," often a physical label attached to the device. However, the specific need with cognitive radio, reconfigurable radio, and software defined radio is that the indications must be associated with the radio configuration that is downloaded because the radio characteristic of the device is changed after a download and reconfiguration. Consequently, the currently accepted practice of a physical label becomes untenable. Therefore, download and device management may need to include how an electronic variant (proposed in some regulatory jurisdictions) of this labeling might be accommodated and how the device could provide information as to its current version/variants.

- Regulators require that the radio must not be able to operate with an unapproved configuration. Therefore, a security mechanism must be built into the radio to prevent malicious or accidental reconfiguration.

- Regulators may require a "stronger" authentication for radio software download. Verification of a downloaded module may need different techniques than other downloads.

- To support the interest of regulators, the reconfigurable device should support a feature whereby it is possible to carry out a post-download audit to ensure that the radio software executing in the device is an approved software load for that device.

The requirements for ensuring proper operation of reconfigurable wireless devices are common to all regulatory agencies worldwide. The various regulatory agencies have somewhat differing approaches as to how these requirements should be satisfied, however. Some of the differing perspectives of different regulatory agencies is provided in the following subsections. Also, in different regulatory jurisdictions, the actors who are responsible for carrying out the solution may not be the same.

3.4.2 Existing Regulatory Environment

3.4.2.1 General Issues

The design and roll out of DSA (Dynamic Spectrum Allocation) schemes requires the support of some regulation moves in both the spectrum management policies. This section gives an overview of the main regulation effort carried out in this area through the review of different worldwide initiatives. The retained new policies will directly impact the reconfigurability requirements for DSA.

After all the spectrum auctions, the new distribution of spectrum for commercial use, and the comprehension that the limited spectrum available is not at all efficiently used, it is necessary to re-evaluate the spectrum management policies which govern all wireless industries ranging from communication, broadcast to satellite communications. Globally, most countries have applied central planning approach to spectrum management so far, but there are many alternatives with varying degrees of flexibility and market-based incentives.

Traditionally agencies of national bureaus have taken over the central planning for frequency allocations; however this approach contrasts significantly with the global trend toward market-based policies in other aspects of telecommunications. There are a number of issues that have to be addressed to achieve a timelier scheme for allocation of spectrum.

Some spectrum regulation authorities investigate new approaches to allow new spectrum allocation practices. The investigations include at least the following topics: spectrum-sharing extent, flexibility extent, and the temporary rights versus permanent rights. They also investigate to determine who gets the spectrum in term of: distribution new licenses, auctioning licences and licenses renewals, government held spectrum.

All these topics impact the spectrum sharing coordination process for DSA. The previous topics and some additional ones have been more developed in section 4 of the OverDRiVE Project deliverable D06 [20].

One the most proactive regulating agencies in the field of flexible spectrum management in Europe is the Radio Communications Agency (RA) in UK. The Radio Communications Agency [22] (UK regulating authority), have launched a consultation in 1998 to discuss the possibly introduction of spectrum trading in UK. In March 2002, Professor Martin Cave has recommended spectrum trading [23]. In October 2002, the UK government has largely assented to Martin Cave' recommendations. In the same time (July 2002), RA has published a consultation document (namely "Implementing spectrum trading"), and has received many answers from all spectrum-concerned actors, mainly assenting to spectrum trading. OFCOM[3] has suggested a proposal for the introduction of spectrum trading in UK. This proposal is currently under consultation [24] before the final decision. This aims at seeking comments on the proposal from all concerned parties. Some kind of roadmap for this introduction of spectrum trading for different systems (in term of license classes) has been proposed by OFCOM. This is illustrated in Table 1. It is shown that spectrum trading will be implemented gradually and that the earlier stage of the introduction of spectrum trading will occur this year (2004).

Table 1: Possible roadmap for the introduction of spectrum trading in UK

	Impacted systems

[3] Ofcom (Office of Communications). Since 29 December 2003, Ofcom will be the new regulator for the TV, radio, telecommunications and other communications industries. One of the regulators Ofcom will replace is the Radiocommunications Agency (RA). Ofcom will be taking over their responsibility for licensing wireless transmission equipment. Ofcom is independent of the Government. Besides Ofcom aims at looking for the most efficient way to use spectrum; and thinking about ways of allowing companies within a particular industry to regulate themselves rather than being regulated by Ofcom.

2004 (Phase 1)	• Sound broadcasting • Analogue public-access mobile radio • National paging • Fixed wireless access • Data networks • National and regional private business radio • Common base stations • On-site private business radio • 5.8 GHz band C • Fixed point-to-point radio links • 32 GHz band • Scanning telemetry
2005 (Phase 2)	• Programme making and special events • Digital public access mobile radio • Wide-area private business radio
2006 (Phase 3)	• Emergency services
2007 (Phase 4)	• TV broadcasting • Cellular (mobile phones) • Aeronautical ground-based radio communications • Maritime coastal radio communications • Radar

Similarly, some active discussions on the relaxing of some important constraints on current spectrum use are discussed by the Federal Communications Commission (FCC) [25] in the US to enable more unlicensed practices (namely “open spectrum”). In December 2002, the FCC has released a Notice of Inquiry (NOI) [26] regarding the feasibility to allow unlicensed devices to operate temporally and spatially in the TV broadcasting bands when the spectrum is not used. These sharing schemes will be supported by the introduction of new classes of radio systems: the cognitive radio [27].

Finally, from the worldwide perspective, a resolution of World Radio Conference (WRC) in 2003 has mentioned the possibility to use 5 GHz band to allow new spectrum allocation techniques by the use of smart radios. The term “cognitive” function for dynamic frequency selection (DFS) has been used.

The subsections below provide a brief summary of some of these regulatory activities.

3.4.2.2 Europe

As noted by Babb et al. [28] there are three types of rules:

- Regulatory: For a mobile phone to carry the European Community’s CE mark it must conform to the radio parameters (radio frequency, interference, etc.) and safety regulations in force throughout the European Union.
- Type approval.
- Operator approval: Assurance that the phone functions in the desired manner when connected to a particular operator’s network.

The Telecommunication Conformity Assessment and Market (TCAM) Surveillance Committee in Europe has developed a questionnaire regarding SDR and is evaluating the results of that questionnaire. It is not anticipated that security requirements for operational software download will be substantially different from those of other administrations.

Faroughi-Esfahani et al. [29] provide a summary of the European perspective of reconfigurable systems, including a view of the regulatory changes between the present and the future.

Currently there is no common view by the member states of the European Union on the regulatory requirements of SDR under the R&TTE Directive. There are some views within the European region that regulatory requirements will be dependent upon the type of marketplace for SDR and cognitive radios. Horizontal markets in which 3rd-parties can provide software for use in an SDR or cognitive radio device is of concern because regulators have interest in establishing clear responsibilities in case of non-compliance. There are some views in within the European Union member states that standardization for SDR (and presumable cognitive radio) seems to be essential for:

- Security mechanisms
- Open interfaces.

The ECC Project Team 8 is in the process of developing a report on a more flexible regulatory structure. The scope of the report, which is to be completed by the end of 2005, includes:

- Conduct a study on the overall direction of harmonisation policy, bearing in mind that harmonising measures should be technology neutral, flexible and include review stages
- Investigate ways and possibilities of establishing a more flexible regulatory structure for spectrum management to better enable the introduction of new radio technologies and adapt to the changing market demand
- The introduction of increased opportunities to share , including sharing on the basis of geographical area(s), time and service should be studied
- It is considered that the project team should also study the methods and conditions under which parts of spectrum may be designated to technology and service independent allocations, with a view to facilitating easier spectrum access.

3.4.2.3 United States

The FCC's First Report and Order [30] on software defined radio stated that industry standards organizations are still investigating security issues, and further stated, in paragraph 32:

> We continue to believe that the best approach is to rely on a general requirement that manufacturers take adequate steps to prevent unauthorized changes to the software that drives their equipment.

The FCC also asserted that it may need to specify more detailed security requirements at a later date as software defined radio technology develops. Thus, it is clear that in defining the operational software download problem, it is necessary to define the timeframe being addressed. The FCC, in December 2003, issued a Notice of Proposed Rule Making and Order for Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies [31] which, inter alia, asked for comments on the following:

> We, therefore, believe it is time to revisit the SDR rules to determine if changes are needed concerning whether the SDR rules should be permissive or mandatory, the types of

> security features that an SDR must incorporate, and the approval process for SDRs that are contained in modular transmitters.

In particular, the FCC is investigating the following statement from the preceding NPRM [30]

> Required SDRs to incorporate security features to ensure that only software that is part of an approved hardware/software combination can be loaded into an SDR. The exact methods are left to the manufacturer.

The FCC is investigating whether to require that an SDR-capable device be declared as such or whether this is left as an option to the manufacturer asking for a license for the device.

3.4.2.4 Japan

A Japanese perspective of SDR regulatory issues is provided by Suzuki [32], who identifies the following regulatory issues related to software download security which also would apply to cognitive radio:

1. Security system for granting certification and preventing illegal modification of SDR equipment
2. Test methods that permit hardware and software to be tested separately
3. Configuration control of modification history

The last two items are particularly significant, and considerable ongoing research in Japan is particularly related to the second item [33][34][35][36][37].

3.5 Standards, Technical Specifications, ITU Recommendations Needed for Spectrum Management

There is a need for a common understanding of terminology, concepts, visions, and a roadmap for cognitive radio and spectrum and radio resource management. Work on this type of high-level guidance document should be undertaken by WWRF in collaboration with other international organizations in the near future.

There is also a longer-term need for the International Telecommunication Union to develop a recommendation on the regulatory aspects of cognitive radio devices and reconfigurable networks. The ITU Radiocommunication Sector (ITU-R) is currently developing two reports on SDR; one is being developed in ITU-R Working Party 8F (IMT-2000 and Systems Beyond IMT-2000) and Working Party 8A (Mobile Telecommunications). These documents will provide useful technical information on SDR systems. However, in the long-term, a recommendation which covers issues such as the global circulation of reconfigurable terminals and reconfigurable networks need to be addressed by the ITU.

4. JOINT RADIO RESOURCE MANAGEMENT

4.1 Introduction to JRRM in a Reconfigurability Context

With reconfigurable terminals becoming available, a mobile network operator is in the position to offer a multi-system access (GERAN, UTRAN, WLAN, etc.) to ensure that users are "always best connected". In such a role as an "integrated operator" he can offer a seamless personalized access to mobile Multimedia applications charged together over one bill of the same operator.

In such a scenario the operator has full control of all single radio access technologies (RAT) involved and will be motivated to use JRRM techniques for the optimized usage of the radio resources of the different RATs.

JRRM concepts and algorithms have to meet requirements from the viewpoint of overall network performance, the individual user's point of view and the operator's point of view. JRRM solutions should integrate all these aspects.

Overall network performance:

From a technical perspective it is the general goal of JRRM to optimize the overall performance of the multi-RAT network. Users should be served based on the QoS needs of their applications and subscriptions. Radio resources should be distributed throughout the network so that all users in the network should be as satisfied as possible and are "always best connected".

User's preferences:

The developed concepts should at least consider the possibility for the user to choose the RAT. While it could be advantageous to make the usage of RATs seamless, there might be users that are aware of the technology and have a favourite RAT.

Operator's strategy:

Operators might prefer to generate traffic on a certain RAT independent of the aim to maximize user performance. Motivations for these policy based JRRM concept could be the return on a certain investment or the independence of a certain manufacturer or a certain technology. For example the operator might want to determine if UTRAN or WLAN should preferably be used independent of performance aspects.

4.2 Feasibility Study for JRRM

JRRM is not only a concept by itself, but a framework supported by network configurations in terms of interworking, spectrum assignments and terminal capabilities. Therefore, in this section, we analyse the enabling technologies in terms of network architecture and terminal capabilities, which allows deployment of JRRM.

From the network infrastructure viewpoint, the networks' integration and the intercommunication between them are emerging. The convergence towards an IP-based core network and ubiquitous, seamless access between radio access technologies in different generations, augmented by self-organizing network schemes and short-range connectivity between intelligent communicating apparatuses enforces common terminal and network entity platforms.

The future evolution of the 3rd generation mobile wireless networks is widely accepted and guided by the vision of a concept called *Mobile Wireless Internet* (MWI) and the ITU vision for the future development of IMT-2000 and systems beyond IMT-2000 [ITU-R Recommendation M-1645, Framework and Overall Objectives of the Future Development of IMT-2000 and Systems Beyond IMT-2000]. In this vision, Internet access is granted by a ubiquitous mobile network anytime and anyplace; access by mobile terminals will be the principle means of *Internet access* [38]. The MWI aims at an overall network with convergence towards an IP based network and ubiquitous, seamless access among 2G, 3G, local broadband, short range and broadcast wireless access schemes [39]. The interworking between some radio interfaces can be firstly obtained by using the existing interfaces as an intermediate step before ‘All IP based’ 3G or beyond 3G system are realised. The *Common Public Radio Interface* (CPRI) industry initiative is a typical example for this intermediate step. CPRI decomposites the radio base station into two building blocks, the *Radio Equipment Control* (REC) and the *Radio Equipment* (RE) itself. The REC provides access to RE via the Iub interface, whereas RE serves as the RAT to the mobile terminals [40]. The advantage of such proposal not only eases the RATs’ integration, but also provides deployment flexibility. As an extension to it, due to the bottleneck of processing power of a single base station required by the increasing complexity and capability of future networks, “RF on fiber” technology is considered by people to reduce the latency and cost [41]. Moreover, from the system management point of view, a system restricted by inflexible physical layer processing chain cannot match the variant multiple radio access technologies. It is a trend that people are working on a *programmable system*, with consists of flexible and scalable network elements.

Possible future radio network architecture can be equipped with radio controlling mechanisms over multiple air interfaces, which allows *tightly coupled subnetworks* [42]. Various wireless standards and air interfaces are processed in a single central office, (RNC or Hotel BTS), it targets at utilising reconfigurable processing elements for great flexibility with low cost. In Figure 6, multiple cells defined by different air interfaces can use the same optical link by using the *Wavelength Division Multiplexing* (WDM) techniques. Given the broad bandwidth of the optical link, the BTS can be implemented as multi-band/multi-mode, covering many RATs. The hotel BTS/RNC shown in Figure 6 gathers baseband signal processing and controlling tasks [42]. The locations of RNC and central hotel BTS are rather flexible in terms of co-located or displaced. Over the optical fibre, the computational power is shared. For instance, an MT associated to RNC A, its related calls can also be processed by RNC B if a temporal failure or low computational power of RNC A occurred. This step significantly simplified the implementation of the JRRM mechanisms.

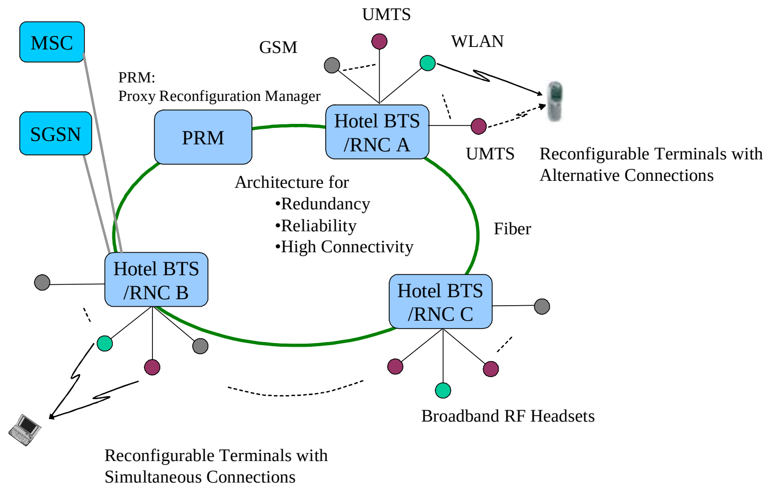

Figure 6: Programmable Network Architecture Allowing Very Tightly Coupled RATs

A number of international projects are researching on the reconfigurable terminals, which should have the functionality being able to access to different RATs. The network supports and manages terminal reconfiguration and SD [41][43].

Heterogeneous RATs locating in different regions require multi-standard terminals be able to receive seamless access. In fact, the SDR technology enables the terminal is able to be reconfigured according to a new standard [44]. At the front point of the reconfigurable terminal, the border between the digital and the analogue domain could be moved to higher frequency, using the wideband, high-speed A/D converters. Another alternative solution is to replace dedicated hardware, i.e. ASIC, by *Digital Signal Processing* (DSP) devices for baseband processing, e.g., the multimode DSP chip developed by Sandbridge Technique [45]. The *AD Converter* (ADC) in the terminal could deal directly with the RF signal from the antenna. The hardware resource managers have to check if the new baseband processing can be realized on the given hardware resources [40][46]. A solution of a multi-standard receiver which can cope with cellular systems (2.5 G and 3G) and coexist with a WLAN air interface is depicted in Figure 7, where the front receiver should be capable to receive broadband signals. From the terminal capability viewpoint, we will have access to a variety of mobile terminals with a wide range of display sizes and capabilities [47]. Furthermore, as the 3GPP documentation describes, four types of possible multi-mode 3G terminals are defined according to their capabilities in terms of concurrent reception and monitoring more than one mode. The relevant terminal type should be at least equivalent to the third type of a 3GPP terminal, i.e. one Tx and several Rx chains per terminal to allow faster scanning. This requires us to consider relevant higher layer functions targeting at full usage of the available hardware resource. In short, for high-end terminals, it is feasible to apply JRRM functions [48].

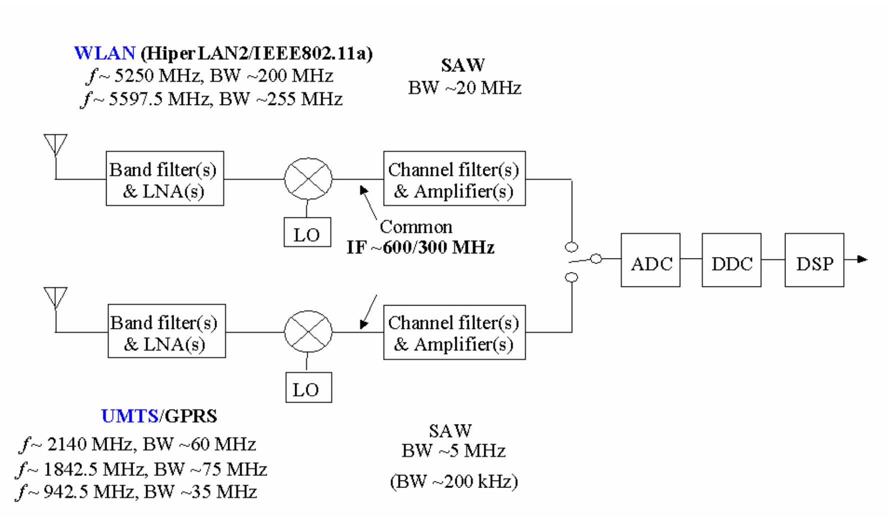

Figure 7: Block Diagram of a Multistandard Receiver

By studying the state of the art technologies concerning the network integration, terminal capabilities as well as the development of JRRM, we can expect that as time goes on, more and more advanced reconfigurable technology will penetrate into deployment of radio systems.

It is expected that in the middle of the first half-decade of the 21 century, network controlled switching over conventional radio networks is required. After 2006, multimode services with interworking of cellular networks and digital broadcasting networks will be established. Services will go towards the characters as ubiquitous, multimedia, scalable and high mean data rate with big peak to average ratio. To ease the management of the system capabilities, operability and flexibility, common RAN control based on a common transport scheme that connects all available radio networks will emerge. The common RAN control structure has been addressed by many research activities, e.g. WWRF [49] and SCOUT visions [44].

Along with the evolution of reconfigurable technologies, more interworking functioning needs to be established based on more network control via coupling points of the cooperating RATs. Reconfiguration over a common platform will enable intelligent control functions in RNC penetrating onto higher layers. The convergence of multiple standards in future radio networks enhances the feasibility and relevance of JRRM mechanisms as a consequence.

4.3 Potential Input for JRRM algorithms

The first step in the design of a JRRM solution is the identification of input parameters to be considered by the JRRM algorithms. An overview of general input parameters is presented in the following.

4.3.1 Input of JRRM algorithms obtained from network observations

JRRM algorithms should take into account information on the current and future situation of the network. Some important information is already available in today's networks and can therefore be used in short-term JRRM solutions. Other information is not yet available by measurements and might be made available for JRRM purposes by proprietary or standardized solutions (long-term JRRM solutions). If not available in the JRRM entity the information available in a certain network node has to be transferred by signaling.

The following information on the current and future network situation are of interest:

Coverage/ Availability of RAT

Current load in each RAT

Expected traffic characteristics: Based on the traffic characteristics of the past, predictions of future traffic characteristics (aggregate or for each data flow) can be made.

Position, speed, movement: Whereas in today's networks no exact information on these measures are available, estimations can be made based on the C/I (is the user indoor or outdoor) or the change of the cell id (user in a vehicle). The recurrent (e.g. daily) movement together with the service usage can be saved in a data base and used to predict the needed radio resources in the future.

Importance of application information (e.g. WWW main vs inline object)

Urgency of single IP packets: For TCP-based applications IP packets can be more urgent than others, e.g. if a TCP timeout can be avoided or if a TCP fast recovery procedure is performed. For Streaming applications the delay variance can be minimized by regarding timestamps.

4.3.2 Input of JRRM algorithms obtained from the user request or from the subscriber data base

Information on the application and subscription of the user will perform is an important input for JRRM algorithms. The information might be determined in the session setup request (specified by the user himself or the operating system on the terminal) or might be available in a subscriber data base in the network.

While some information are already available in today's networks (short-term solution), other information such as the used terminal type has to be made available by proprietary or standardized solutions.

The following information of the user and the application are of interest:

Requested QoS: throughput, delay, jitter, BLER

Security needed by application: Depending on the working environment (e.g. business user) or the application (e.g. banking, e-commerce transaction) the needed security is a needed input to the decision which RAT shall be used

Subscriber profile: The subscription (e.g. Gold user or low-cost user) of the user might be an input for JRRM.

Terminal type: Information on the terminal type can be useful to predict the future traffic characteristics and service usage and the quality of service that is necessary to be provided.

4.4 Functional Overview on JRRM

4.4.1 Introduction

The JRRM algorithms not only span over sub-systems, but also over management layers and service types. The presented management architecture and strategy are based on the assumption of co-existing different RATs with different profiles, but with fixed spectrum allocation, e.g Figure 8. The estimated traffic types and their volume are useful in dynamic usage of a fixed radio resource for a subnetwork. The load information and traffic information are shared by the cooperating subnetworks. Each subnetwork needs an efficient interworking between traffic volume, measurement (prediction) function, traffic scheduler, load control unit, and admission control function. The Traffic Estimation module (TREST) in each system informs the administrative entity Session/Call Admission Control (SAC) on the predicted traffic and planned traffic information to update the priority information for each connection and the admission decision within the subnetwork. The priority information is an input vector for the scheduling algorithm in a lower layer. The load balancing between software download traffic using broadcast/multicast channels and regular traffic over heterogeneous networks should be performed by a centric intelligent entity. The subnetworks can also be frequency layers.

4.4.2 Interworking among different subnetworks

The interworking between different subnetworks requires new protocols defined for convergence reasons. It should offer IP packet based convergence sublayers to networks to guarantee QoS. Due to the heterogeneity of coexisting different networks, many different policies are conceivable for JRRM, in particular when considering legacy and new network types. Systems in different generations are equipped with different functionalities, protocols and management requirements. For terminals having simultaneous connections to different RATs is one possible operation mode. In general, loose up to very tight coupling schemes between different types of networks must be considered for such multiple connections. For a possible tight coupling between UMTS subnetwork and a WLAN subnetwork, one must consider the restrictions in each subnetworks, e.g. the transport block size and minimum transmission time interval for each are differently defined according to the specifications. Tight coupling allows joint scheduling of traffic streams between involved networks and terminals.

The conventional admission control is designed for each access system working independently among coexisting access systems and RATs. In the cooperating environment, a joint Session/call Admission Control must be defined. As shown in Figure 8and Figure 9, the *Joint Session Admission Control* (JOSAC) takes neighbour RAT system load into account. The traffic stream can be routed alternatively through the cooperating subnetworks according to the constraints and the capacity of each. The wide coverage can be obtained by the universal cellular system, e.g. GSM, UMTS. In contrast, the high transmission rate can be obtained though WLAN. With the information of estimated load in all the subnetworks (dynamic network profile), the *Joint Load Control entity* (JOLDC) located together with JOSAC will distribute the traffic based on the characteristic of the co-existing RATs (i.e., the static and dynamic network profile), the QoS requirements for the service and the number of applicants for the software download service to determine the software download strategy, i.e., which RAT and channels with committed capacity should be selected.

The *Joint Resource Scheduler* (JOSCH) is important for terminals having simultaneous connections to different networks. JOSCH is responsible to schedule traffic streams being split over more than one RATs.

The SAC entity in each subnetwork consists of a *Software Download Traffic Control* entity (SDSAC) and a *Regular Traffic Control entity* (RESAC). Based on the time schedule and QoS requirement of the SD traffic the SDSAC assigns an optimal broadcast or multicast bearer service to distribute the download to the terminals. The load generated by this push service traffic and regular traffic should be jointly balanced by SDSAC and RESAC by taking an appropriate SD strategy to determine the needed common channel capacity defined by the JOSAC.

In case the single traffic is split into two streams carried by two tight cooperating subnetworks, the admissions should be granted to the connections in both systems, the joint scheduling can therefore be applied. In the tight cooperating scenario, queues for each subnetwork will be filled up by the amount of data coming from the corresponding sub-traffic stream.

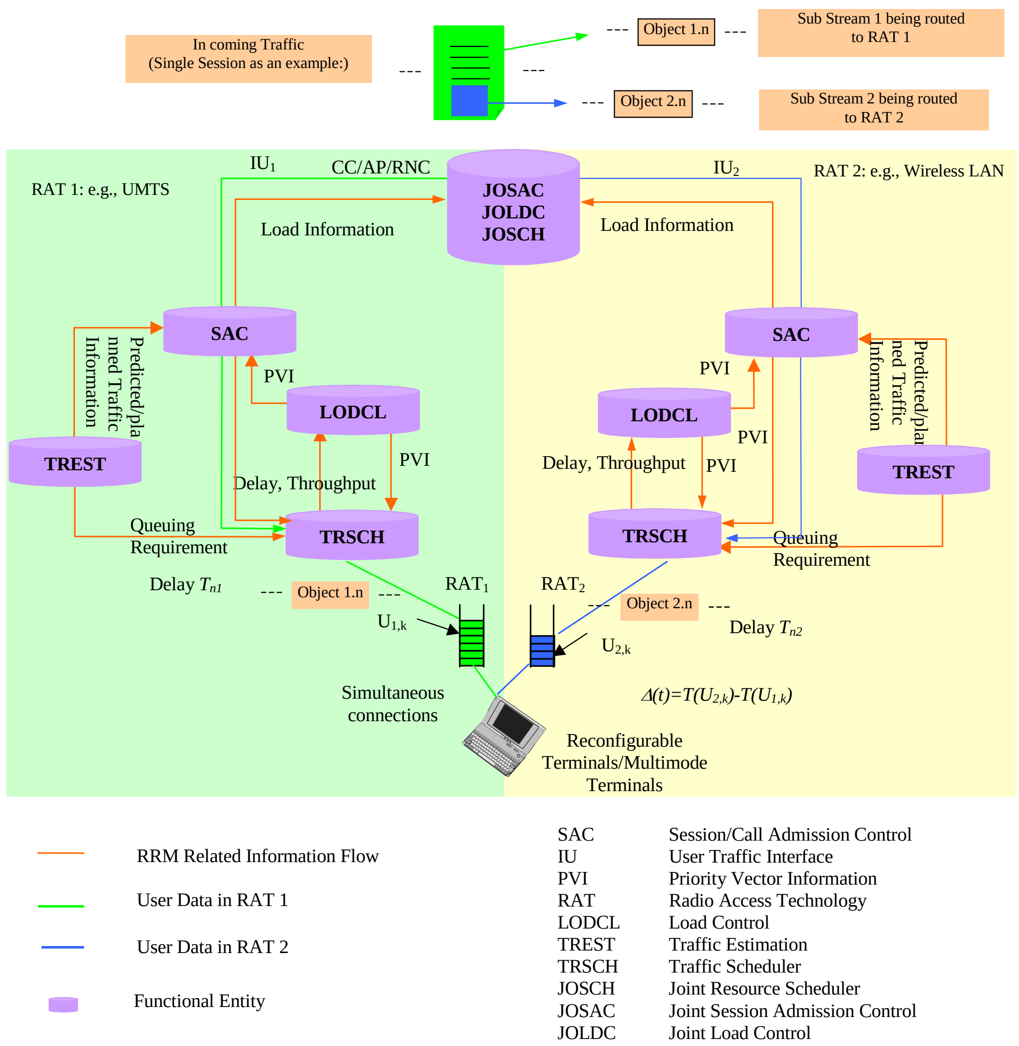

Figure 8: Joint Radio Resource Management Architecture

4.4.3 Interworking among Different Radio Resource Management Layers

The queuing of data streams and the priority arrangement should be executed by TRSCH. Some important input information required by admission control should also be offered by the TRSCH. The trade-off between maximising the utilisation of the system and reducing rate of dropping or negatively affecting the QoS demand of users should be considered to design an admission control algorithm. The interworking between admission control and *Resource Scheduling* (RS) are shown in Figure 9. The incoming traffic is divided into different traffic types after the first stage, for various QoS requirements, i.e. the real time requirement, the throughput requirement, etc. The location of users is part of the dynamic terminal profile information to decide on the bearer services to be assigned. Therefore, SAC should select the transmission physical mode of the bearer service or drop the call in case the network cannot provide the requested service. Based on the chosen static service and network profile in the first stage (JOSAC), a certain range of the weights defined for the service is offered to the second stage in the SAC. In case the incoming calls apply for service beyond the static restrictions, the JOSAC should reject them immediately. The tight-coupled traffic stream over two RATs should be scheduled by JOSCH which works between JOSAC and SAC. The split traffic after JOSCH should be forwarded to individual SAC in subnetwork with the respecting delay bounds. With the offered control information from JOSCH, SAC should map the split traffic onto the RAT specific radio channels with an additional concrete priority weight (PW) to be used by the scheduler.

As introduced in Figure 9, based on the specified PW on the QoS class dimension (Y), the traffic scheduler allocates resources for different traffic classes. In this case, the cost function parameter will be harmonized with the Y-dimension scheduling algorithm. The principle of *Generalised Processor Sharing* (GPS) algorithm can be applied to guarantee the resource for the sessions with different priorities; i.e., a minimum service rate can be obtained as the ratio between the committed weights to the sum of them all, where the weighted fair queuing algorithm is an example of this. In addition, the PW can also be applied for the calculation of the allocated resources for the committed service type according to the weights assigned for this type. The weighting vector can be handled by the *Mobile Network Operator* (MNO) to offer dedicated radio resource to particular users. The scheduler assigns radio resources for individual connections using proper transport channels such as the common/shared channels or dedicated channels. Different multiple access schemes represented by transport channels are also shown in Figure 9.

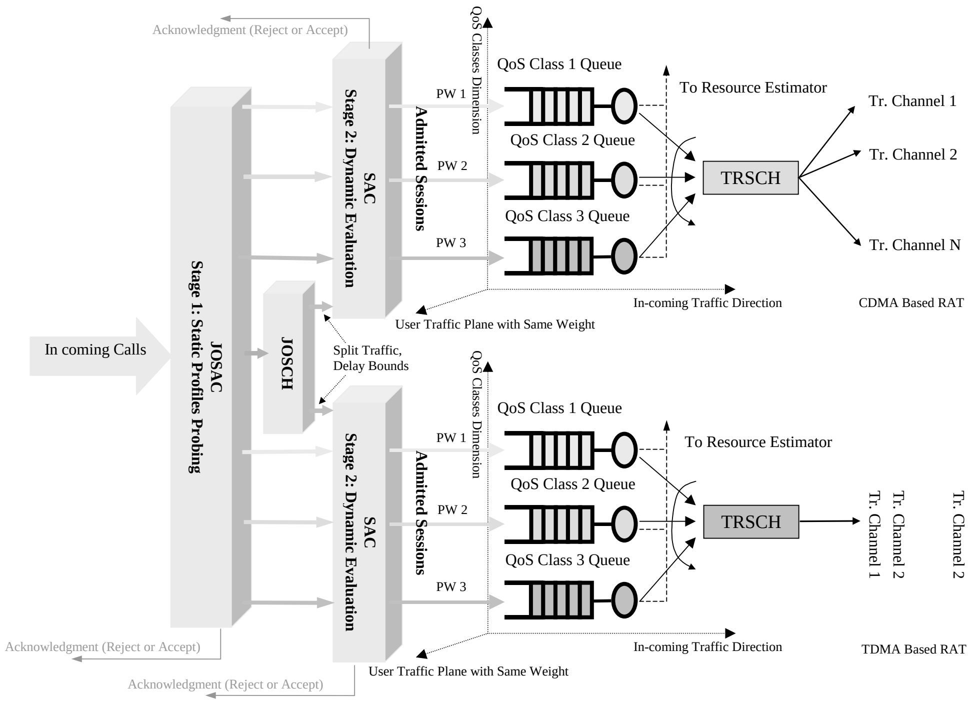

Figure 9: Interlayer Traffic Management (RS)

4.4.4 Adaptive Radio Multi-homing Concept

The *Internet Engineering Task Force* (IETF) proposed *IP Multi Homing* concept [50][51] and this concept is contributed by research projects such like IST MIND [52][53]. This framework manages IP traffic being routed through different radio access networks to the same mobile node. At the IP layer, the multi-homing algorithm allows to route the traffic for each individual stream through a specific interface according to the type of the traffic.An extension to conventional multihoming concept is to run simultaneous connections on the radio-frame level, which we call w.r.t. reconfigurable terminals as “Adaptive Radio Multi-Homing” approach.

Definition 1: Adaptive Radio Multi Homing (ARMH) is an overall management framework extended from IP Multi Homing concept. It provides multiple radio accesses for multi-mod/multi-band terminals in order to allow terminal maintain simultaneous links with radio networks. It selects the most proper JRRM function based on the identified information from the cooperating subnetworks, terminals, user and services. In order to support the selected JRRM functions, proper traffic classification, calibration, interworking between the service application server and Radio Resource Controller (RRCR) and the configuration of transmission format as well as MAC protocols are managed by ARMH.

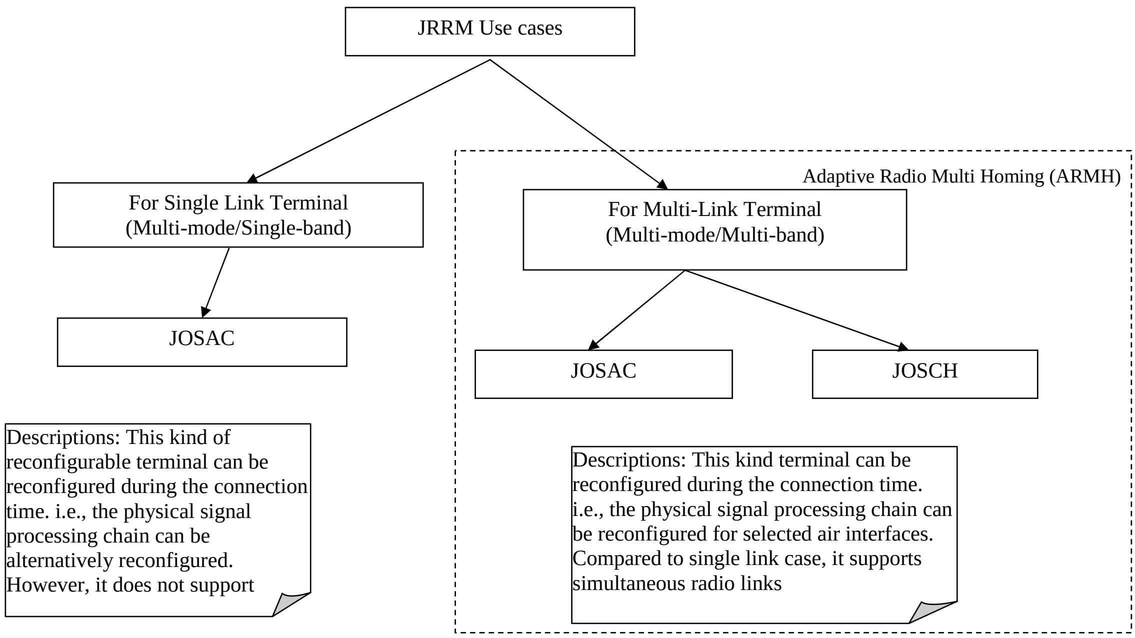

Figure 10, Illustration of use cases of JRRM and Radio Multi Homing

The system capacity gain obtained from the JRRM is in principle the enlargement of the number of operational servers from the queuing model viewpoint, which therefore results in a higher trunking gain. On the other hand, by alternatively allocating the resource to call units among the interworking radio networks or frequency layers, the load balancing effect among the radio networks are realized. In a typical soft blocking sensitive radio network, such effect is very significant.

Besides the capacity gain from network operation point of view, the advantage of having concurrently parallel streams is manifold: If one bearer service has a high availability in the network (low data rate bearer services result in high coverage, e.g. a 16 kbits/s service is available in 99% of the cases), this link would be used for transferring important information to the terminal. On the other hand, a low data rate service cannot fulfil the requirements for multimedia traffic resulting in high data rate demands. If traffic is intelligently split into rudimentary and optional information streams, a higher QoS for the user is provided. Whenever possible the user combines both streams for yielding a higher QoS and due to the higher availability of a lower data rate service in UMTS a minimal QoS can be fulfilled to the user.

4.4.5 Traffic Splitting over Heterogeneous network

Joint Session Admission Control (JOSAC) takes the neighbour RAT system load into account. The traffic stream is routed through the co-operating systems according to the restrictions and advantages of each system. From the service point of view, different level of service calibration can be identified to meet the user’s satisfaction, e.g., for video transmission, the video traffic can be split into base layer and enhancement layer, where the base layer consists of the most important lower frequency information. The user wouldn’t be satisfied if one only receives the enhancement layer information. On the other hand, from user mobility point of view, the connection of UMTS is not restricted by the location of user, but the Wireless LAN does.

Generally, three key points covered by radio multihoming:

Traffic prioritization: As Figure 11 depicts, the incoming traffic is split over two (more) sub-streams. The important information goes through reliable RAT, whereas, the rest goes through other RATs.

Traffic scheduling: Segments of users' traffic presented by packets are sent at a suitable period through optimally selected RATs associated with optimal physical mode, i.e., the Modulation and Coding Scheme (MSC).

Synchronisation: Packets belonging to sub-stream are multiplexed back to original traffic stream in the receiver based on proposed synchronisation schemes (in MT and RNC).

Buffer management: The jitters and average delay parameter are controlled by buffer size and synchronisation approaches. The static terminal and user profiles stored in network side will be retrieved by RNC to determine the calculation power and buffer size of the terminal and to evaluate the user preference and cost. The synchronisation methods are used mainly to compensate average delay whereas buffers are used to compensate jitters.

As Figure 11 shows, suppose a reconfigurable terminal is demanding a scalable video service from remote server through tight coupled sub networks. Suppose both subnetworks are controlled by one RNC. In order to establish simulteneous sub-streams belonging to the same video context, the following procedure should be fulfilled:

Step 1, Signalling and initialization step. RNC receives an application from mobile terminal with multiple radio accesses/adresses. After estimating the available radio resource in controlled Sub network; RNC will apply to the remote server for traffic splitting indicating average rate in each sub-link.

Step 2, Traffic is split according to RNC's application (Step 1) and sent to RNC. Sub-streams are labelled differently.

Step 3, RNC receives split traffic with labelled packets to further map to tightly coupled sub-networks (e.g. traffic with label 'Vi' to WLAN, label 'Ai' to UMTS, 'i' is index to inform RNC for timing relationship between sub-streams). The possible services could be applied are:

Video and Audio sub-streams

HTTP with separation of main objects and in line Objects

Scalable Video Traffic (Base Layer and Enhancement Layer)

Real time traffic and its control signalling

Step 4, Synchronisation mechanism in RNC remedies delays generated by sub-radio-networks due to:

Different TTI value for bearer services

ARQ actions due to different connection qualities

Different Processing Power of different BTS (especially in the shared processing component case, which is valid for functional partitioning scheme in section 4.2)

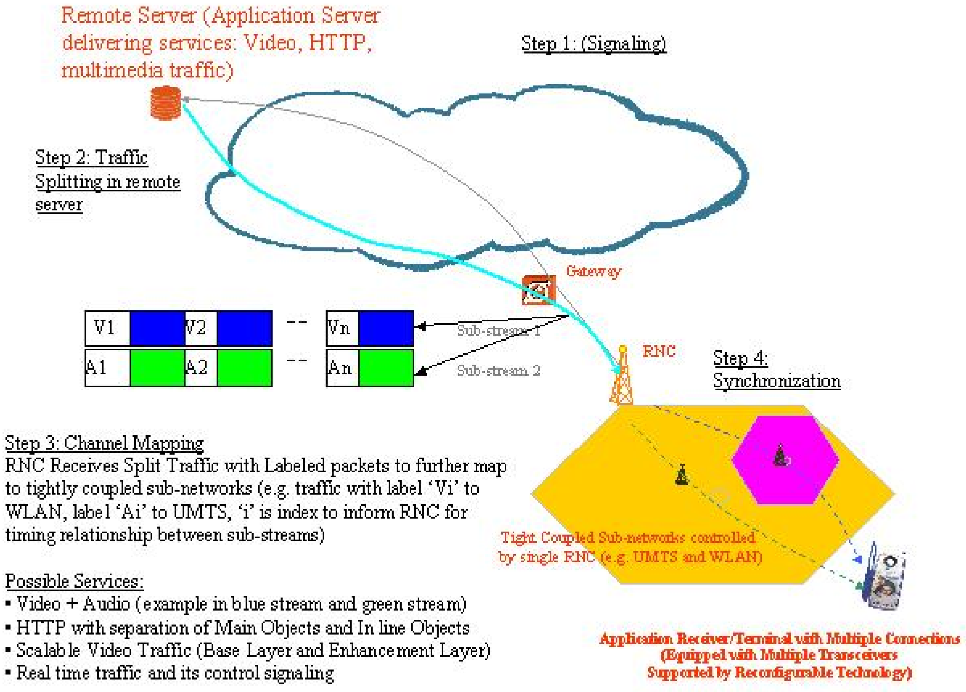

Figure 11 Overview on Procedure of Traffic Splitting over Tightly Coupled Sub-networks

4.4.6 Principles of Deploying JRRM

The ARMH approach basically requires reconfigurable terminals obtaining capability of multiple radio access, which allows incoming traffic being split over different air interface with simultaneous connections carrying prioritized sub-streams. To apply JRRM, a number of principles embedded in the radio resource controller are listed as the follows:

Principle 1: In highly loaded system, the radio controlling entity must be prepared to apply for available resources, from other spectrum pool, or from another operator.

This principle implies that the spectrum pool could be shared by the involving operator or RAT. The physical limitation given by inter-RAT spectrum sharing is rather an empirical input to the inter-operator sharing approach. Based on that the spatial orthogonality, opportunity based orthogonality and the necessity of inter-Access point synchronisation can be obtained.

Principle 2: In coupled radio networks, traffic allocation through the very tight coupled subnetwork must be jointly designed. The allocation must consider the traffic pattern including the QoS detailed to the objects level, the deployment and overlapping between subnetworks, the current load of subnetworks and the noise rise feature upon a new call arrival, etc.

Thanks to the ARMH approach, the resource allocation over the coupled radio subnetworks balances the system load. Assuming RAT_1 and RAT_2 are very tightly coupled and they have different noise rise characteristics. Without losing generality, name RAT_1 suffers more from interference, i.e., a typical soft blocking system; whereas, RAT_2 is only limited by its physically available radio units, e.g., a synchronised TDMA system. By considering the water filling principle, RAT_2 is the candidate subnetwork to receive more traffic.

Principle 3: System capacity is enhanced thanks to both the resource and traffic scalability. As can be explained by a more reliable network and resource management, in this case, the outage probability is significantly reduced.

This principle can be proven by many facts. Take the power controlled CDMA system as an example, by pouring a big trunk required traffic, e.g., Video traffic, into a single frequency layer will result in a higher average power requirement and higher interference to the existing sessions in the system compared to the case when the traffic is split over two frequency layers. The same principle is applied to hard blocking system which can be modelled by a Markov finite state machine. In fact, admission of a high throughput required traffic unit will occupy more servers compared to normal traffic, e.g., voice. Without the traffic split mechanism, the higher call blocking/dropping rate occurs.

4.5 Research Topics

Here we list a number of heated research topic in the field of JRRM for reconfigurable systems:

- Advanced Transmission Technique
- Cross layer optimisation
- Advanced Mobility Technique
- Roaming and mobility management
- Optimal service provisioning

For instance, the cross layer optimization technology aims at jointly finding the optimal end-to-end communication rates, routing, power allocation and transmission scheduling for wireless communication links taken place simultaneously in the radio network. The resulting transmission format, and time schedule for individual communication link as well as the parameter setting for higher layer protocols will significantly increase the spectrum efficiency. In general, reconfigurability needs to have optimal solution to maximize the diversity gain, antenna array gain and data scheduling gain. The multidimensional problem complicates such an optimisation paradigm.

4.6 Hierarchical Radio Resource Management

In this subsection, we outline the basics of a novel scheme for the efficient management of radio resources, which is an adapted generalisation of that first conceived by us in [54]. This scheme is intended to either work as a stand-alone solution, or for elements of it to be used to facilitate the other approaches to radio resource and spectrum management mentioned in this white paper.

We envisage a scenario where a target frequency range is unregulated or pooled, or where networks/network operators are *fully* cooperating in the resource allocation process in order to serve the common task of greatly improving spectrum efficiency and QoS in the vicinity as a whole. We envisage most if not all basestations being reconfigurable to a number of RATs; furthermore, we note that it would be useful, although not a prerequisite, for mobile terminal reconfiguration capabilities to also exist. Taken in entirety, such a scenario allows for optimal radio resource management methods to be used, in conjunction with dynamic radio resource adaptations as users move in space or their resource requirements alter.

Based on this scenario, we introduce our approach to hierarchical dynamic radio resource management. In our approach, through the division of RATs into constituent parts and the treatment of these parts in a hierarchical manner, radio resource allocations can be dealt with autonomously and efficiently by a hierarchy of *Agents* operating in networks. This is strongly in line with the functions of RATs, which can be considered as elements that can be hierarchically inherited in sequence, to constitute the complete RAT [55].

4.6.1 Use Cases

There are a number of possible use-cases for this scheme, of which we pinpoint some simple examples here. This list of use cases is not exhaustive—many further possibilities exist.

Resource Reallocation

There are two mobile networks or two parts of a single mobile network, one configured to provide FDMA/TDMA access and one configured to provide FDMA/CDMA (i.e. several frequency bands of CDMA spread-spectrum access). All FDMA/TDMA resources are already spent, but some terminals supporting *only* FDMA/TDMA still wish to join a network.

Fortuitously, spare capacity remains in the CDMA parts of the network(s). To make use of this, one of the CDMA bands is made available, possibly requiring some simple reorganization of the allocated CDMA resources to achieve this. This CDMA band is then reclassified as FDMA/TDMA (and the associated CDMA basestations are reconfigured accordingly), in order to allow the GSM-like terminals to join the network.

Demanding Resource Requirements

Everyone is very happy, and the TDMA and CDMA parts are coexisting with reasonably sufficient spare resources. However, banking group Money Inc. come along, and decide that a complex (high bandwidth) video telephony session is needed between their board members on the move, also involving high-speed file transfers. Given the revenue to be made, network operators have a pre-written agreement that their network(s) should be adapted to support such an eventuality. They reallocate some bands from TDMA to CDMA, and reconfigure basestations accordingly. These bands are then switched back to TDMA once the meeting is finished.

Automated QoS Maximisation

There are four groups of users in the vicinity: software downloaders, videophone users, and audiophone users using CDMA technology; and audiophone users only able to support a simple GSM-like radio interface. The former three groups of users would all appreciate their QoS being improved, through faster downloading, higher resolution/frame rate video calling, and an advanced high bit-rate clearer audio-calling respectively. The latter GSM users don't require any improvement, as they are already using the highest-quality codec that their system can support. There is considerable overcapacity in the FDMA/TDMA network at that time.

Given the overcapacity, FDMA/TDMA resources are freed and reconfigured to become CDMA resources. The first three sets of users are then a lot happier, and the fourth set experiences no change in perceived QoS.

Coexisting Technologies

Mobile network operators already commonly provide coexisting 2G and 3G networks. Our scheme could allow a form of load balancing between these 2G and 3G parts. It is not even a prerequisite for basestations to be reconfigurable to achieve this, as Agents at a higher level in the network could be responsible for deciding upon radio resource allocations to the 2G and 3G parts.

4.6.2 Details of the Proposed Scheme

We use a hierarchy of Agents such that an Agent at each level is responsible for allocating a particular resource type. In many cases, these Agents might exist on a single node, and their functionalities might even be combined into the same process if required. Table 2 illustrates some simple examples of resources that are allocated by Agent types.

Table 2: Examples of Agents' Resource Allocations

Agent Type	Resource Allocated
Spectrum (master agent)	Spectrum bands
FDMA	Frequency divisions within the allocated spectrum range
TDMA	Time slots
CDMA	Spreading codes

This approach is in line with the organization of RATs, which can be considered hierarchical in many respects. For example, consider a simple FDMA/TDMA RAT, somewhat akin to GSM. The allocated frequency divisions can be inherited into to module dealing with time divisions (quite likely including a prior module dealing with frequency hopping), which would allocate a time slot to the frequency division, and which in turn (omitting some steps for simplicity) would allocate the combined frequency and time slot to a terminal. Such a hierarchical treatment applies to a wide range of RATs, operating a number of resource types.

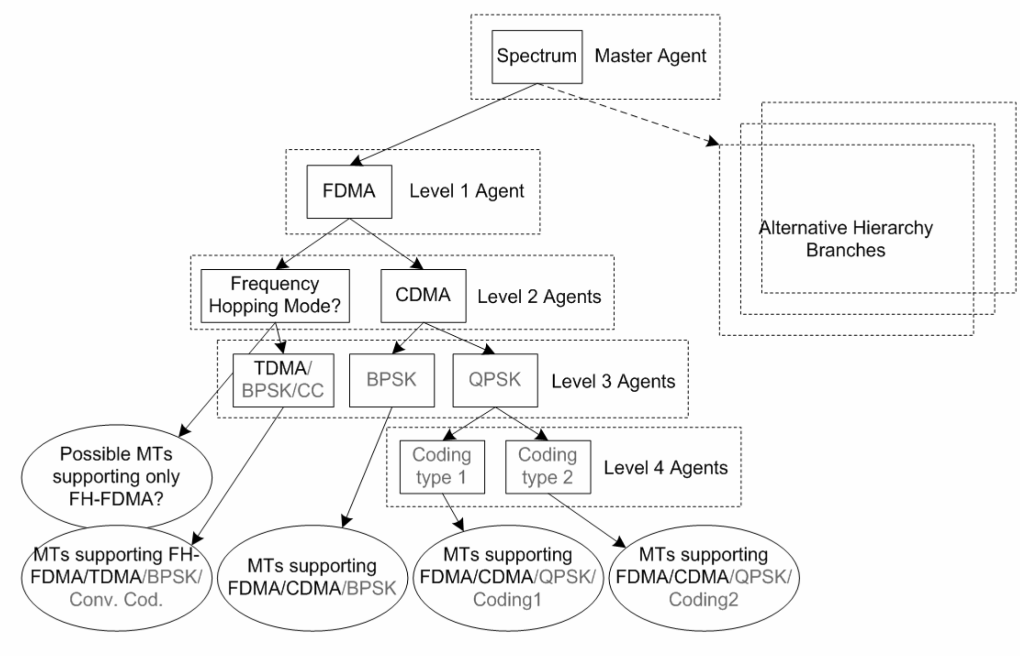

Figure 12: Example radio resource management hierarchy, including attribution of other RAT functions (denoted in grey)

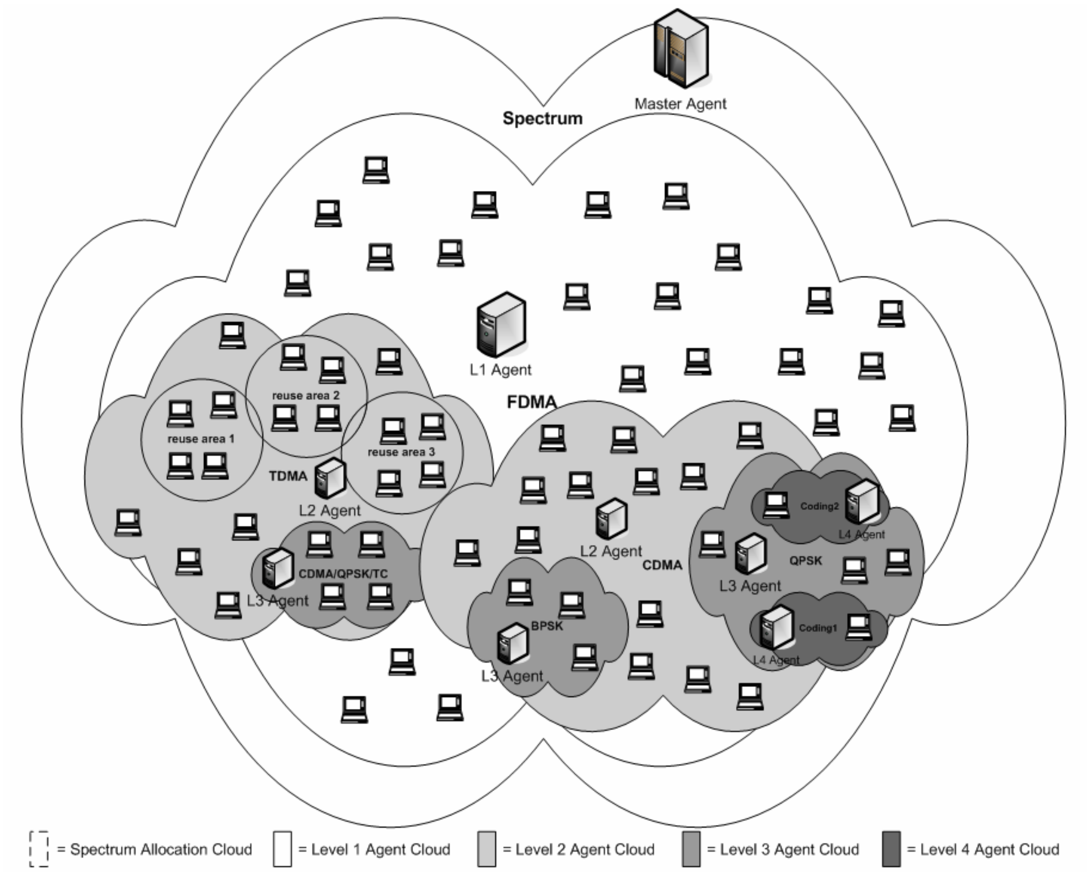

Figure 13: Spatial representation of hierarchical radio resource management

An example of the hierarchy's allocation tree is illustrated in Figure 12, for which a spatial allocation equivalent is depicted in Figure 13. Referring to Figure 12, at the highest level of the hierarchy is always spectrum allocation, and an Agent in an entity separate from the networks should ideally be responsible for this. Most likely, frequency division allocations (FDMA) would be best dealt with at the second level. Note that it is useful to have a level for FDMA allocations in addition to spectrum allocations, because allocated spectrum is often sub-divided for frequency allocation purposes by particular operators. Additional options can exist at lower levels, such as time division allocations, code division allocations, etc. Furthermore, in addition to dealing with the allocation of resources, the scheme might also deal other functions such as the specified keying/coding type. Since all such functionalities must inherit the rest of the specified RAT, further levels can be easily added.

4.6.3 Resource Acquisition Process

A terminal joining a network must follow the given resource acquisition process.

Step 1: Using the common channel (see section 4.6.5), the terminal sends a resource_request to the network, which is forwarded to the lowest-level Agent. Should a common channel not be defined, the terminal logs onto its home network using the default mode, then sends the resource_request using that mode. A resource_request contains the information as in Table 3.

Step 2: The Agent compares information in the resource_request with the radio access and service it has to offer, and if it is able to support the required QoS/RAT it replies with a resource_confirmation which allocates the resource to the terminal—this is termed *direct resource allocation*.

Step 3: If the Agent does not support the resources requested by the incoming mobile node, it forwards the resource_request up the hierarchy, and further Agents might forward the request in turn. When an Agent at an appropriate hierarchy level is found, the request is sent downstream to the child Agent of correct functionality/QoS capability. An *appropriate* Agent is one that supports (or one of whose children supports) both the required RAT and the required level of QoS.

Step 4: The Agent that finally receives the request allocates a channel to the terminal. This is termed *indirect resource allocation*.

Table 3: Information in Resource Requests

Supported frequency bands (possibly, number of channels?)
Supported transmission power range
Required QoS: Max delay, max packet-level jitter, min bandwidth
QoS optimization preferred?
Supported multiple access schemes: FDMA, CDMA, TDMA, etc
Supported keying modes, supported coding, other supported functions?
Supported RAT specifications: GSM, UMTS/IMT 2000, IS95 etc
Reconfiguration supported? If yes, specifications of the reconfiguration support

4.6.4 A Change in Circumstances

Upon any change in circumstances which could affect allocated resources, it is necessary for this to be signalled to all the affected Agents. Such possible changes are wide-ranging, although two examples are the requesting of greater or lesser QoS by a user or the terminal. We highlight the procedures for these two simple cases.

Increase in QoS Requirements

The series of steps that must be undergone to allow an increase in QoS for a terminal are as follows.

Step 1: The terminal sends a resource_increase request, indicating its new resource requirements, to its allocating Agent.

Step 2: The Agent compares the resource requirements of this request with its available resources, and makes a decision as to whether it is able to directly support the requested service. If the Agent decides to support the service, it replies with a resource_increase_confirmation allocating new/additional resources to the terminal.

Step 3: If the Agent is not able to support the requested QoS, it sends the resource_increase request up to the next level in the hierarchy.

Step 4: The Agent at this new level checks if there are sufficient resources/functionalities in its other child Agents to support the terminal, and if there are it forwards the resource_increase downstream to the most appropriate child, which in turn sends a resource_increase_confirmation to the terminal and allocates the resource.

Step 5: Otherwise, the request is forwarded to the next level up in the hierarchy. The process then repeats from Step 4.

Decrease in QoS Requirements

Step 1: The terminal sends a resource_decrease, indicating its new resource requirements, to its allocating Agent.

Step 2: The allocating Agent sends a resource_decrease_confirmation, thereby also deallocating the now-unnecessary resources from the terminal.

Synchronisation

Synchronisation serves a number of purposes in the scheme, some of which we highlight here. Synchronisation is like a form of housekeeping, invoking simple information exchanges and procedures which optimise the scheme as a whole, and keep it afloat. The synchronisation process is as follows.

Step 1: Synchronisation is autonomously initiated by leaf-Agents, which each sends a synchronise message to its parent Agent every synchronisation time period T_s. synchronise messages indicate information about the resources allocated by the Agent (for example, bandwidth allocation, resource requirements of allocated terminals, resource type etc).

Step 2: The parent Agents then store information about the hierarchy below them, and aggregate the synchronise messages for a time period T_s. This gives scope to make it unnecessary for leaf-Agents to have to coordinate their synchronisation initiations. The parent Agents then append (in a new field) their allocated resources to the synchronise message, and send the synchronise message upstream to the next level in the hierarchy.

Step 3: Step 2 then repeats until the whole hierarchy is covered.

Using the information received about the hierarchy below them, Agents proceed to revise the allocations of their particular resource types as needed amongst their child Agents. Depending on the exact usage details for the scheme, this could allow for a form of QoS optimisation to apply (i.e., ensuring that the maximum capacity is extracted from the spectrum band by terminals), or simply could allow resource partitioning/load balancing dependent on changing resource requirements. Such resource rebalancing would usually be achieved by basestations being reconfigured, or by the resources offered to fixed-specification basestations (such as frequency band sizes) being adjusted.

4.6.5 Common Channel

Given no prior assumptions about the networks and terminals that are to partake in the hierarchical radio resource management scheme, it is necessary for a globally understood common channel to exist for a range of uses, such as for terminals to apply for resources, and for some types of signaling to apply. Past research to this end includes the definition of a Network Access and Connectivity Channel (NACCH) [56][57], through a possible "bootstrap" to a Global Pilot Mechanism (ETSI) or Global Radio Control Channel (ITU) [58][59].

We require the common channel to not involve complicated prerequisite channel establishment processes, and it has to be simple enough to be understood by terminals of very low functionality. It is therefore necessary to identify a very small frequency range which is universally available, over which a very simple radio access will be used, which all terminals can listen to at all times and default to if necessary. A universally available frequency range for such a purpose is open to question and has been a matter for much discussion in specifications bodies and consortia [58][59], perhaps with limited avail due to global differences in band allocations. However, considering the other aspects of the scheme, we suggest that keying should be BPSK with a guard period bit sequence sent before each message, for the purposes of collision avoidance and synchronization. Given a terminal detecting a potential collision upon attempting to transmit, a Binary Exponential Backoff (BEB) algorithm should be used to time further transmission attempts.

Figure 14 illustrates a simple example of message transmission contention amongst three competing terminals on the common channel.

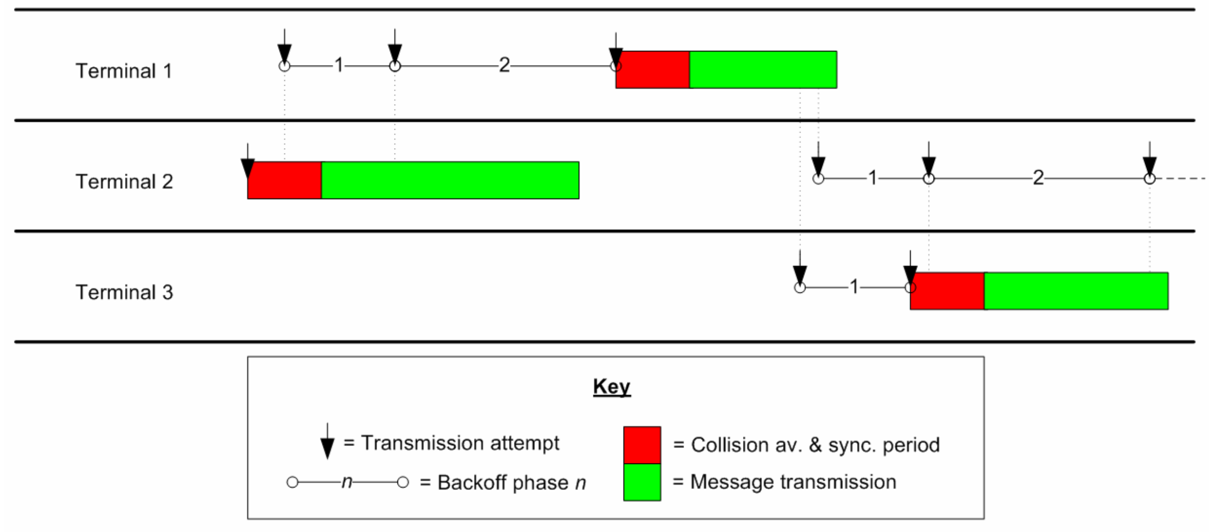

Figure 14: Sharing of the common channel by three terminals

4.6.6 Further Research

The hierarchical radio resource management scheme is a matter for ongoing research at this moment. Clearly, the scheme is operable in a number of radio-communication scenarios—a fact which is emphasised by its original form being devised for Mobile Ad-hoc Networks [54]. Many of the finer details of the scheme require honing dependent on the exact usage scenario, and its adjustment to different scenarios is a continuing area of work.

Reconfigurability

Reconfigurability goes hand-in-hand with our scheme. Reconfigurability offers a number of advantages, some of which are already very clear from the above work—one of these being the reconfiguration of basestations to dynamically change balances of allocations to different radio access types in an area. However, much further work is being performed on determining specifications for the use of mobile terminal reconfigurability to support such a scheme. Mobile terminal reconfigurability would both greatly improve the scope and hence performance of the dynamic hierarchical resource management process, and would allow terminals to support much more demanding services through reconfiguration as and when required.

Other Topics

A number further topics are anticipated to undergo advanced research. Again, note that many of these require slightly different solutions depending on the exact scenarios of usage for the scheme, where such different usages might be determined by: (i) whether terminal reconfiguration is allowed, (ii) whether, and to what extent, basestations are allowed to be reconfigured, and (iii) the overall objectives of the scheme (QoS maximisation, resource allocation fairness, or user satisfaction maximisation etc). Some of these research topics are:-

- Detailed specification of *exactly* what must be sent in resource_request and resource_increase messages
- Detailed specification of *exactly* what must be appended by Agents to synchronise messages
- A method for describing the scope of reconfigurability capabilities of basestations and terminals to Agents
- Further work on improvements to the scheme where spatial distributions of resource loads vary due to mobility of users (handover etc). Greater spatially-aware resource allocation efficiency
- Detailing of *exact* specifications for the use of a common channel
    - Possible specification of a bootstrapping method to allow slightly different location-wise specifications (frequency bands etc)

It is hoped that further progress will be made in these areas in the near future.

5. Network Planning for Reconfigurable Networks

5.1 Requirements for Dynamic Network Planning for Reconfigurable Networks

The ever growing demand for high-speed access to all kinds of telecommunication systems has rendered necessary the reconsideration of traditional network planning methods. Taking into account that the advent of composite reconfigurable networks has become an inseparable part of almost every communications conference and journal, dynamic network planning is essential in order to handle the alternations that take place in frequent time periods, with respect to the demand pattern in a specific geographical area.

With the support of reconfigurability and flexible network reconfiguration, the cost for network deployment evaluated by the Capital of Expenditure (CAPEX) and Operational Expenditure (OPEX) can be reduced, while significantly enhancing the efficiency of user traffic handling. During the network planning phase, the following mechanisms are included:

- Setting feasible radio interfaces
- Determining allowed location of base stations
- Setting antenna patterns
- Creating coupling structure among sub-networks
- Configuring policy of Joint Radio Resource Management (JRRM)
- Planning statistic values of required spectrum in different scenarios with available Radio Access Technologies (RATs)

Furthermore, taking into consideration that reconfigurability does include utilization of the current sites and/or deploying the necessary reconfigurable sites, the goal of dynamic network planning is to reduce the cost for network deployment, through the selection of the appropriate RATs for operation at different time and space regions.

Consequently, the network planning topic is considered as a subset of a more general framework, namely *Dynamic Network Planning and Management* (DNPM). It consists of planning phase and management phase. During the initial planning phase, feasibility of setting radio interfaces; location of base stations; antenna patterns; coupling structure among sub-networks, as *Base Station* (BS), *Access points* (AP) and *Radio Network Controller* (RNC), etc.; policy of Joint Radio Resource Management (JRRM); statistic values of required spectrum in different scenarios with available Radio Access Technologies (RATs) are developed. In the management phase, radio network elements are subject to be reconfigured which is triggered by the management entities, e.g., the network element manager, so that self-tuning of a radio network targeting at optimal parameter settings can be carried out. From our immediate intuition, the capacity gain will result in a reduction of the number base stations to be deployed in the radio network.

5.2 Current Research Activities concerning Dynamic Network Planning

This subsection contains a high level description of the problem of dynamic network planning which can serve as a guideline for utilizing strategic methods aiming at a successful network deployment.

The network planning problem has a certain input and a certain objective (output), which can be depicted on Figure 15.

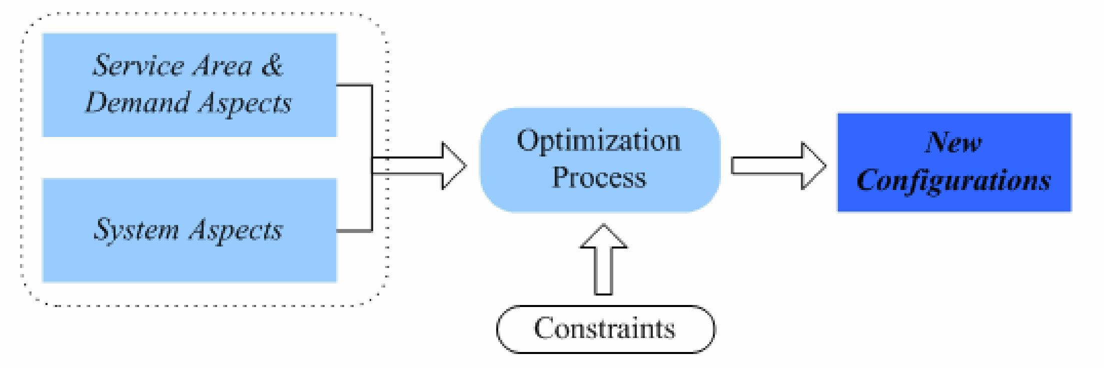

Figure 15: Problem description

The input can be categorized as follows:

- *Service Area and Demand Aspects*. The service area is divided into a set of portions (minimum pieces), called pixels. More specifically, 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 demand per service and service area portion. Moreover, additional requirements are the utility volume and the resource consumption, when a service is offered at a certain quality level, through a certain RAT.
- *System Aspects*. The items need to be taken into account are: (a) the set of sites that cover the service area region 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 coverage, and the anticipated capacity, when a certain RAT is used by a certain transceiver.

The objective (output) of the problem is to determine new configurations, i.e., new assignments of RATs to transceivers, demand to transceiver/RATs, and applications to QoS levels. The three allocations should optimise an objective function, which can be associated with the resulting QoS levels. Applications should be assigned to the best possible QoS levels.

Moreover, the allocations should respect constraints. The demand in the service area should be satisfied. Applications should be assigned to acceptable QoS levels. Permissible RATs should be assigned to transceivers. The allocations of RATs to transceivers should provide adequate capacity and coverage levels.

The network planning problem can be solved with the utilization of the appropriate optimization functionality. This refers mainly to the respective mid-term algorithms, necessary for dynamic network planning issues. Simulations for dynamic networks taking into account multi-standard radio network elements must be performed and the requisite recommendations for network planning must be deduced. Automatic network planning is another use-case for reconfigurable, multi-standard network elements, i.e. autonomous selection of carrier frequencies.

6. Enabling Technologies – Cognitive Radio

6.1 System functional requirements

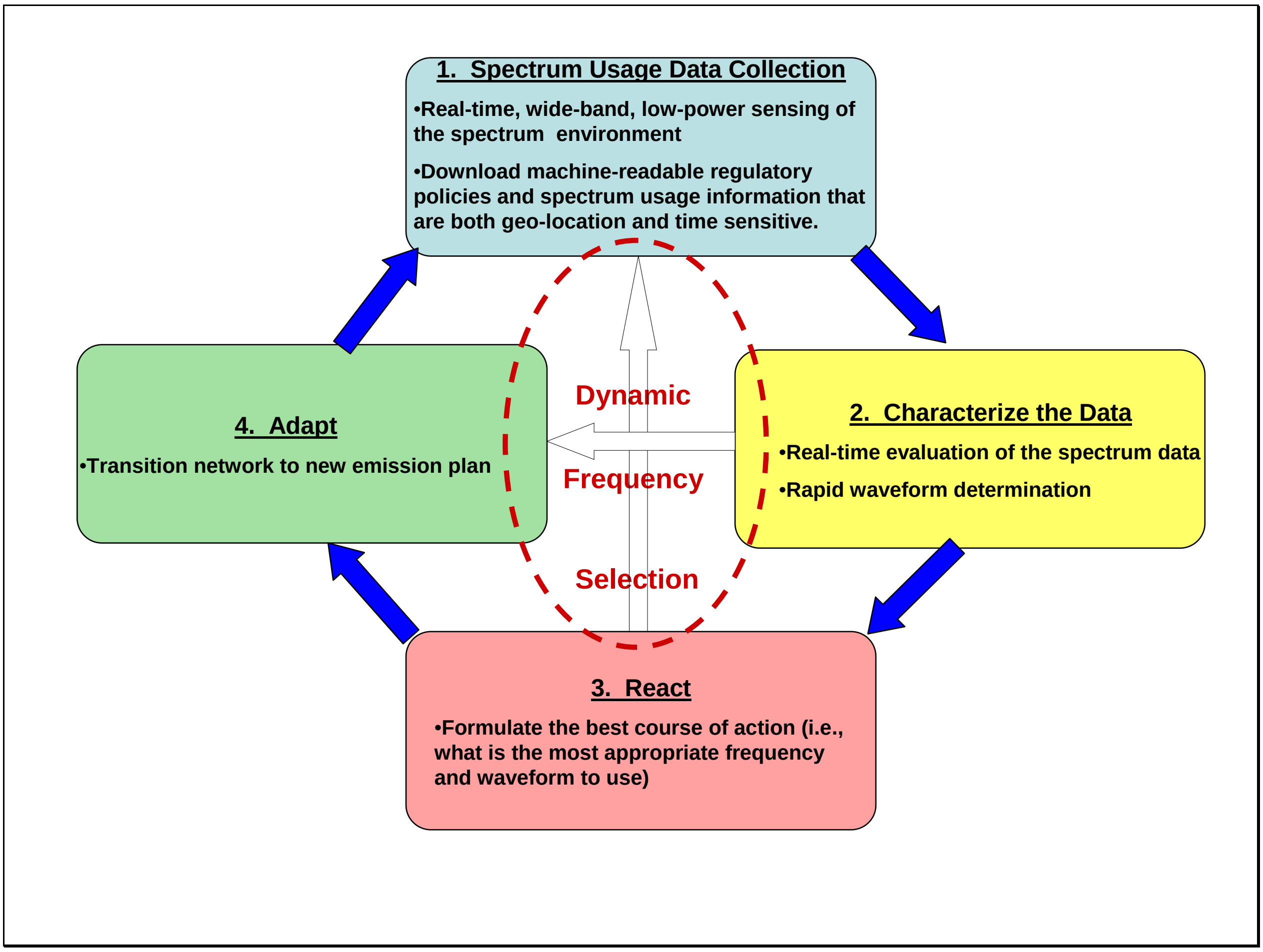

Figure 16: Key Technology Components of Policy-Based Cognitive Radio Needed for Dynamic Frequency Selection

Figure 16 is an adaptation of a figure that was part of a presentation at the Plenary Session of WWRF 10 in NYC. The figure depicts the technological functionalities that are needed to accomplish dynamic frequency selection using cognitive radio which can be referred to as policy-based radio. Clearly a system approach is needed to accomplish the goals of dynamic frequency selection.

The functionality requirements in Block 1 of Figure 16 are critical technology drivers. Dynamic frequency selection requires the ability for a real-time, wide-band sensing of the spectral environment. This is the process of sampling the channel in order to determine occupancy. It should be noted that there is no agreed definition of when a channel is occupied; several factors are involved including receiver sensitivity, the sampling time and sampling interval, thresholds for discriminating wide-band noise from signals, etc. It is noted in Block 1 that along with this sensing capability is the need for policy agility which is the ability to change the policies controlling the behavior of the radio to be changed dynamically. Policy agility allows adaptation to policies changing over time and geography. Such policy changes could be downloaded from the internet in a machine-readable format. The timescale for such changes of course is much different from the frequency agility timescale needed for dynamic frequency selection.

The functionality requirements in Block 2 of Figure 16 include an analysis of the data to determine if the the particular channel is an opportunity for usage. This identification process includes the characterization of the data and uses this information to determine if the channel can be used by another communications service or system. The identification process also includes communication with some subset of its neighbors because what may appear to be a clear channel at one end of the link may not be a clear channel at the other end of the link. For some mobile wireless subsystems this communication may require a narrow-band pilot channel.

Block 3 of Figure 16 is the synthesis of the specific dynamic waveform and frequency that are appropriate for use at this time and this location. This leads to the need for the network to adapt (Block 4). Note that dynamic network planning requirements and methods were described in Section 5.

6.2 Physical layer functions

So far we have discussed the different functions (physical layer and network) required to support DSA multi-bands operations. This part reviews how these functions can actually be designed and implemented with the current technologies. In particular, the state of the art of the current SDR technologies enabling the support of the physical layer functions is reviewed. In the meanwhile, it is reviewed the possible emerging and promising enabling technologies that could overcome the limitations of the current enabling technologies.

A summary of current and emerging (breakthrough) technologies for the support of RF reconfigurable modules at ADC, the antenna, RF front end and digital processing can be found respectively from Table 4 to Table 7.

Table 4: Current and emerging enabling technologies for ADC

	Current Enabling Technologies	Enabling Technologies Breakthrough
ADC	• Silicon based - best achievable Nyquist sampling rate performance is around 10 Gsamples/s	• Superconductivity based - • Optically based -

Table 5: Current and emerging enabling technologies for Antennas

	Current Enabling Technologies	Enabling Technologies Breakthrough
Miniaturisation	Planar Inverted F Antenna (PIFA)	• Lengthening of current paths based antennas (e.g. fractal antennas) • Capacitive or selfic charging based antennas (e.g. PIFA antenna)
Multi-band	Associations of several resonators with the introduction of slits	• Association of several resonators with the use of particular antenna geometry (e.g. fractal antennas) • Radio wavelength adaptation with commuting or variable components (e.g. MEMS or diode PIN based)

Wideband	Planar antenna based	• Dielectric resonator • Association of several resonators frequency shifted • Independent frequency based antennas (e.g. b-conical or spiral antennas) • MEMS – Micro Electro Mechanical Systems

Table 6: Current and emerging enabling technologies for some RF front-end modules

	Current Enabling Technologies	**Enabling Technologies Breakthrough**
Filter	• Filter rank to cover a wide range of frequencies •Tunable filters electronically controlled based on varactor	• Superconductivity based tenable band pass filters - analogue based • MEMS switches based tuneable band pass filters - analogue based
Amplifier	• Specific to each band - Analogue silicon RF technology based (below 2GHz) •Software switching between amplifiers dedicated to different bands	• Silicon - Germanium transistors based (would enable operations up to 40 GHz) • Ultra linear amplifier
Oscillator	• Fixed frequency oscillator • Phase locked oscillator (VCO) - analog based: ▪ Narrow band VCO (High Q), ▪ Wideband VCO (free running), • Phase locked oscillator (VCO) - digital based: ▪ Numerically control oscillator (NCO).	• MEMS based Wideband VCO • Precise balanced quadrature oscillator to enable direct down conversion architectures • MMIC based multiport junctions
Mixer	• Analog mixer – MMIC based. Several mixers are usually needed to cover large bands (by switching) • Digital mixer – ASIC, FPGA, DSP, DDS based	• MMIC based multiport junctions

Table 7: Current and emerging enabling technologies for digital processing

	Current Enabling Technologies	Enabling Technologies Breakthrough
Configurable	• ASIC	
Reconfigurable	• DSP • FPGA	• Reconfigurable Computing Machine (Algorithm and operational levels) • General purpose processors (GPP) using portable software code • ASIP based approach
Dynamically Reconfigurable		• Technologies convergence (hybrid DSP/ASIC/FPGA architectures) • Enhanced FPGA • FPAA • Reconfigurable Computing Machine (Algorithm and operational levels) – Only ACM provides dynamically reconfigurability. • General purpose processors (GPP) using portable software code • ASIP based approach

7. SUMMARY

Recapitulating the research approach, it must be noted that reconfigurable networks will become commercially successful, only if

(i) New applications are introduced and massively adopted (if offered at acceptable costs).

(ii) The required quality of service (QoS) and capacity levels are achieved in a cost-effective manner.

(iii) appropriate spectrum management techniques for dynamic frequency sharing are developed including the ability to perform the following functions in real-time:

  a. real-time, wide-band, low-power sensing of the spectrum environment,

  b. real-time characterization of the spectrum data,

  c. real-time formulation of the best course of action (i.e., dynamic frequency and waveform selection), and

  d. real-time adaptation in the network layers.

(iv) Needed regulatory changes are adopted on a global basis.

This white paper outlined the working framework for the design, development and implementation of the functionalities needed for (i) the efficient management of spectrum in an end-to-end reconfigurability context, (ii) the joint management of the RATs participating in a wireless access heterogeneous infrastructure and (iii) the network planning strategies necessary for the design phase of next generation wireless networks.

For this purpose, chapter 1 gave an overview of the main aspects that were dealt with.

Chapter 2 introduced Radio Resource Management (RRM) as an overall strategies superset, divided in the following subsets:

(i) Spectrum Management, i.e. efficient spectrum allocation among RATs that were originally selected in order to increase the overall spectrum efficiency.

(ii) Joint Radio Resource Management, i.e. load balancing and traffic splitting among RATs with fixed amount of spectrum granted to each RAT and in certain cases only, redistribution of demand to RATs.

Chapter 3 dealt with Spectrum Management. More specifically, it presented the basic requirements that arise from the increased user demands in terms of spectrum and the necessity for dynamic spectrum allocation among in an end to end reconfigurability context. Then it outlined the basic technical approaches in flexible spectrum management and finally it gave an overview of the respective regulatory issues that should be taken into account.

Chapter 4 presented the key characteristics of Joint Radio Resource Management in reconfigurable networks, with respect to the challenges that must be met by such a joint optimization approach and the functionality to be developed, in order to handle specific traffic conditions in heterogeneous networks with a given spectrum. This chapter also introduced the novel scheme of Hierarchical Radio Resource Management. The scheme was presented in a generic fashion so as not to limit its scope. The logic behind the use of a hierarchy in the radio resource allocation process was particularly discussed, and a basic description of the implementation architecture for the scheme was given.

In addition, chapter 5 dealt with network planning issues, which are now mandatory to be reconsidered and further evaluated compared to the classical network planning methods. More specifically, this section presented the way for utilizing existing network infrastructures in terms of reconfigurable networks with many RATs, among which a selection of the most appropriate is essential.

Furthermore, chapter 6 presented the technologies that are up today considered for successfully encompassing all the previously mentioned features in next generation terminals and network segments.

8. REFERENCES

[1] M. Mouly, M.-B. Pautet, "*The GSM system for mobile communications*", published by the authors, Palaiseau, France, 1992
[2] R. Kalden, I. Meirick, M. Meyer, "Wireless Internet access based on GPRS", *IEEE Personal Commun.*, Vol. 7 No. 2, April 2000
[3] 3rd Generation Partnership Project (3GPP) Web Site, www.3gpp.org
[4] Institute of Electrical and Electronics Engineers (IEEE) 802 standards, Web site, www.ieee802.org, 2004
[5] J.Khun-Jush, P.Schramm, G.Malmgren, J.Torsner, "HiperLAN2: Broadband wireless communications at 5 GHz", IEEE Commun. Mag., Vol. 40, No. 6, June 2002
[6] U.Varshney, "The status and future of 802.11-based WLANs", *IEEE Computer*, Vol. 36, No. 6, June 2003
[7] Digital Video Broadcasting (DVB) Web site, www.dvb.org, Jan. 2002
[8] P.Demestichas, L.Papadopoulou, V.Stavroulaki, M.Theologou, G.Vivier, G.Martinez, F.Galliano, "Wireless beyond 3G: Managing Services and Network Resources", *IEEE Computer*, Vol. 35, No. 8, Aug. 2002
[9] D.Kouis, P.Demestichas, V.Stavroulaki, G.Koundourakis, N.Koutsouris, L.Papadopoulou, N.Mitrou, "A system for enhanced network management towards jointly exploiting WLANs and other wireless network infrastructures", accepted for publication in the *IEE Proceedings in Communications* Journal
[10] End to End Reconfigurability (E2R), IST-2003-507995 E2R, http://www.e2r.motlabs.com
[11] P. Demestichas, N. Koutsouris, G. Koundourakis, K. Tsagkaris, A. Oikonomou, V. Stavroulaki, L. Papadopoulou, M. Theologou, G. Vivier, K.El-Khazen, "Management of networks and services in a composite radio context", *IEEE Wireless Commun. Mag.*, Vol. 10, No. 4, Aug. 2003, pp. 44-51
[12] P. Demestichas, V. Stavroulaki, "Issues in introducing resource brokerage functionality in B3G, composite radio, environments", *IEEE Wireless Communications Magazine*, Vol. 11, No. 10, October 2004
[13] P. Demestichas, G. Vivier, K.El-Khazen, M. Theologou, "Evolution in wireless systems management concepts: from composite radio to reconfigurability", *IEEE Communications Magazine*, Vol. 42, No. 5, pp. 90-98, May 2004
[14] P.Demestichas, V.Stavroulaki, L.Papadopoulou, A.Vasilakos, M.Theologou, "Service configuration and distribution in composite radio environments", *IEEE Transactions on Systems, Man and Cybernetics* Journal, vol. 33, No. 4, pp. 69-81, Nov. 2003
[15] Software Defined Radio forum: www.sdrforum.org
[16] IST project SCOUT (Smart user-centric communications environment), www.ist-scout.org
[17] Paul Leaves, David Grandblaise, Ralf Tönjes, Klaus Moessner, Michele Breveglieri, Didier Bourse, Rahim Tafazolli, "Dynamic Spectrum Allocation in Composite Reconfigurable Wireless Networks", *IEEE Communications Magazine*, Vol. 42, No. 5, May 2004
[18] Testimony Before the Subcommittee on Trade of the House Committee on Ways and Means Hearing on Trade Relations with Europe and the New Transatlantic Economic Partnership, Kevin Kelly, July 28, 1998 http://waysandmeans.house.gov/legacy/trade/105cong/7-28-98/7-28kell.htm
[19] UNITED STATES WELCOMES EC STATEMENT OF SUPPORT FOR ITU PROCESS ON SETTING NEW MOBILE TELECOMMUNICATIONS STANDARDS http://www.fcc.gov/Speeches/Kennard/Statements/stwek905.html
[20] P. Leaves and al, "Dynamic Spectrum Allocation and Coexistence – Functional Specification and Algorithm", March 2003, IST-2001-35125/OverDRiVE/WP1/D06
[21] Agreement on Technical Barriers to Trade", WTO, http://www.wto.org/english/docs_e/legal_e/17-tbt.doc
[22] United Kingdom Radiocommunications Agency, http://www.radio.gov.uk/
[23] M. Cave, "Review of Radio Spectrum Management," UK Department of Trade and Industry, 2002, Available at: http://www.spectrumreview.radio.gov.uk/
[24] "Spectrum trading consultation", November 2003, OFCOM
[25] U.S. Federal Communications Commission, "Spectrum Policy Task Force Report," ET Docket No. 02-135, 2002
[26] U.S. Federal Communications Commission, "Notice of Inquiry: Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band", ET Docket No. 02-380, December 11, 2002
[27] Babb, D. Bishop, C. and Dodgson, T. (2002). Security Issues for Downloaded Code in Mobile Phones, *Elect. & Commun. Engineering J.*, Vol. 14, pp 219 – 227

[28] Babb, D. Bishop, C. and Dodgson, T. (2002). Security Issues for Downloaded Code in Mobile Phones, *Elect. & Commun. Engineering J*., Vol. 14, pp 219 – 227
[29] Faroughi-Esfahani, J., Falk, R., Drew, N., and Bender, P., (2002). A Regulatory View on Security Requirements for Reconfigurable Radio," SDR Forum Technical Conference, San Diego, Paper no. SW3-03
[30] FCC (2001), First Report and Order, Authorization and Use of Software Defined Radios, ET Docket No. 00-47, September
[31] FCC (2003), Notice of Proposed Rule Making and Order, Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies (ET Docket No. 03-108); Authorization and Use of Software Defined Radios (ET Docket No. 00-47), December
[32] Suzuki, Y. (2002). Interoperability and Regulatory Issues around Software Defined Radio (SDR) Implementation, *IEICE Trans. Commun*., Vol. E85-B, No. 12, pp. 2564-2572, December
[33] Harada, H., (2003), *Research and Development on Regulatory Issue of SDR*, Yokosuka Radio Communications Research Center, Communications Research Laboratory (CRL), Independent Administrative Institute, Japan, September 17 presentation to SDR Forum
[34] Harada, H., Kuroda, M., Morikawa, H., Wakana, H., and Adachi, F., (2003). The Overview of the New Generation Mobile Communication System and the Role of Software Defined Radio Technology, *IEICE Trans. Commun.*, Vol. E86-B, No. 12, December, pp. 3374 – 3384
[35] Suzuki, Y., Oda, K., Hidaka, R., Harada, H., Hamai, T., and Yokoi, T. (2003a). Technical Regulation Conformity Evaluation System for Software Defined Radio, *IEICE Trans. Commun.*, Vol. E86-B, No. 12, December 2003, pp. 3392-3400
[36] Suzuki, Y., Harada, H., Uehara, K., Fujii, T., Yokoyama, Y., Oda, K., and Hidaka, R. (2003b). Adaptability Check during Software Installation in Software Defined Radio, *IEICE Trans. Commun.*, Vol. E86-B, No. 12, December 2003, pp. 3401-3407
[37] Suzuki, Y., Yokoi, T., Iki, Y., Kawaguchi, E., Nakajima, N., Oda, K., and Hidaka, R. (2003c). Development of Experimental Prototype System for SDR Certification Simulation, *IEICE Trans. Commun*., Vol. E86-B, No. 12, December 2003, pp. 3408-3416
[38] B. Walke, Mobile Radio Networks, Networking, Protocols and Traffic Performance, Second Editon, John Wiley & Sons, ISBN: 0471 499021, 2002
[39] B. Walke, Mobilfunknetze und ihre Protokolle, Band 1 und Band 2, B. G. Teubner Sturttgart, Leipzig, Wiesbaden, ISBN: 3-519-16431-0/2, 2000
[40] 3GPP TR 21.910 3.0.0, Multi-mode UE issues; categories, principles and procedures
[41] A. Fasbender, F. Reichert, E. Geulen, J. Hjelm, T. Wierlemann, Any Network, Any Terminal, Anywhere, IEEE Personal Communications, Vol.6, No2, pp.22-30, April 1999
[42] Markus Dillinger, etc, Software Defined Radio Architecture, Systems and Functions, ISBN: 0-470-85164-3, John Wiley, May, 2003
[43] J. Mitola, The Software Radio Architecture, IEEE Communications Magazine, pp. 26-38, May, 1995
[44] IST-1999-12070 TRUST, D4.1, Report on State of the Art and Requirements on SDR system features, 1999
[45] Tom's Hard Newsletter, SandBridge Core Eyes Software-Defined Radio, 15, Oct., 2002
[46] R. Schuh, P. Eneroth and P. Karlsson, Multi-standard Mobile Terminals, IST Mobile Communications Summit 2002, Thessaloniki, Greece, pp. 174-178, June, 2002
[47] T. Farnham, G. Clemo, R. Haines, E. Seidel, A. Benamar, S. Billington, N. Greco, N. Drew, T. H. Le, B. Arram, P. Mangold, Reconfiguration of Future Mobile Terminals using Software Download, IST Mobile Communications Summit, Galway, Eire, 2002
[48] N. Drew and M. Dillinger, Evolution Toward Re-configurable User Equipment, IEEE Communications Magazine, pp. 158-164, Feb. 2001
[49] Göran Malmgren, Radio Resource Management in a Multiaccess all IP network, WWRF, 2002
[50] J. Abley, B. Black, and V. Gill. RFC 3582: Goals for IPv6 Site-Multihoming Architectures. IETF, August 2000
[51] T. Bates and Y. Rekhter, RFC 2260: Scalable Support for Multi-homed Multi-provider Connectivity. IETF, January, 1998
[52] Andrej Mihailovic, Tapio Suihko, Mark West, Aspects of Multi-Homing in IP Access Networks, IST Mobile Communications Summit, pp. 115-119, Thessaloniki, Greece, June, 2002
[53] IST-2000-28584 MIND Deliverable D2.2, "MIND protocols and mechanisms specification, simulation and validation", Nov. 2002
[54] Oliver Holland, Qi Fan, A. Hamid Aghvami, "A Dynamic Hierarchical Radio Resource Allocation Scheme for Mobile Ad-Hoc Networks," IEEE PIMRC 2004, Barcelona, Spain, September 2004

[55] J. Mitola, Software Radio Architecture–Object Oriented Approaches to Wireless Systems Engineering, Wiley, 2000
[56] C. Noblet, H. Aghvami, "Assessing the Over-The-Air Software Download For Reconfigurable Terminals," IEE Colloq. on Pers. Comms. in the 21st Century, London, UK, February 1998
[57] D. Hunold, A. Barreto, G. Fettweis, M. Mecking, "Concept for Universal Access and Connectivity in Mobile Radio Networks," PIMRC 2000, London, UK, September 2000
[58] Global Pilot Mechanism, Tdoc 52/97, Luela, Sweden, 1997
[59] N. Jamadagni, "A minimal signaling channel for SDR download support," 22nd General Meeting of the Software Defined Radio Forum, Atlanta, Georgia, USA, February 2001
[60] The XG Vision Request for Comments, V 2.0"; Defense Advanced Research Agency, available at:http://www.darpa.mil/ato/programs/xg/rfc_vision.pdf
[61] "The XG Architectural Framework Request for Comments V1.0"; Defense Advance Research Agency, available at: http://www.darpa.mil/ato/programs/xg/rfc_af.pdf
[62] "XG – Next Generation Communications" Preston Marshall, WWRF 10 Opening Plenary, New York City, 27 October 2004.
[63] "XG Communications Program Briefing", Preston Marshall, ITU Study Group 8; September 2004; available at:http://www.itu.int/ITU-R/study-groups/rsg8/sem-tech-innov/docs/
[64] "What's Beyond Software Defined Radios? Policy Defined Radios", Preston Marshall; Panel Session at SDR Forum Technical Conference.
[65] "Towards Policy Defined Cognitive Radios," Rajesh Krishnan, NSF Workshop on Programmable Wireless Networking Information Meeting, 5 February 2004; available at:www.cra.org/Activities/workshops/ nsf.wireless/BBN_Krishnan2.pdf
[66] "XG Communications Program Overview", Preston Marshall, XG Industry Workshop; 30 June 2004.
[67] Programmable Wireless Networking Details and Logistics, Joseph Evans, National Science Foundation Programmable Wireless Networking Informational Meeting, 5 February 2004; available at:http://www.cra.org/Activities/workshops/nsf.wireless/Evans_ProWiN_Openin2.pdf

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10. APPENDIX 2: GLOSSARY

A

Advanced spectrum Management (ASM):

Process that 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, i.e. excludes ARRM). Here, spectrum bands allocated to each of the systems are not fixed.

Advanced Radio Resource Management (ARRM):

Process that enables the management (allocation, de-allocation) of radio resources (like time slots, codes, or frequency carriers …) within a single or between different radio access systems for the fixed spectrum bands allocated to each of these systems (spectrum sharing between systems is not supported, i.e. excludes ASM). This process takes place after the relevant element sites have been determined during the network planning phase.

Adaptive radio multihoming (ARMH):

Adaptive radio multi-homing concept is a term extended from 'multi-homing' concept. It provides multiple radio access for single terminal in order to allow terminal maintaining simultaneous links with radio network. From the radio resource point of view, traffic splitting supported by joint scheduling under the concept of adaptive radio multi-homing, will increase the system capacity and provide better user QoS.

B

Busy Hour (BH)

Busy hour traffic requirement for network planning. The Busy Hour is the peak 60 minute period during a business day when the largest volume of traffic is handled by a network

C

Core Network (CN):
The core network is the system that links the different RANs together, to form the multi-radio environment. The core networks enable the cooperation between the different RANs in the system. The use of the core network allows sharing of the traffic between the access networks, according to some traffic engineering rules, optimally routing traffic through the most appropriate access system.

D

Dynamic Network Planning and Management (DNPM):

This refers to the radio network planning processes in support of JRRM processes.

Dynamic Spectrum Allocation (DSA):

DSA refers to the partitioning of the spectrum, that dynamically changes to adapt to the current or future demand on the radio resources resulting in certain gain in spectrum allocation. The gain in DSA could lead to an increase in the system capacity or could translate to the reduction on the system cost.

Dynamic Spectrum Sharing:

This is the result of Advanced Spectrum Management (ASM). The whole spectrum is available for different radio access systems that can "share" it. See also "Spectrum Sharing".

Dynamic Channel Allocation (DCA)

Radio resource for a particular service is not managed in a dedicated manner. The optimal channel allocation is realized by measuring service profile in terms of the temporal communication quality.

Diagonal Handover (DH):

Communication would be channeled temporally and spatially through different radio access technologies flexible in their spectrum allocation.

F

Flexible Spectrum Management:

This is another acronym referring to ASM. FSM and ASM terminologies are equivalent.

Fixed channel allocation (FCA)

After the bearer service establishment for a service, the resource is always fixed in terms of time slot based on RLC protocol, the orthogonal codes and spectrum range is fixed.

I

Intersystem Handover (ISH):

An ISH is the process in which the radio access network changes the radio transmitters or radio access mode or radio system used to provide the bearer services.

Interfrequency Handover (IFH):

For a given radio access technology, this refers to the process that supports the hand over of one or several radio links from one frequency carrier to another one.

Infrastructure-less multihop networks:

This term refers to ad-hoc networks.

J

Joint Radio Resource Management (JRRM):

This term appears to be exactly the same with ARRM.

Joint Session Admission Control (JOSAC):

JOSAC is one JRRM approach. It does not offer detailed traffic splitting to subnetworks, but only alternatively diverts traffic into different sub-radio-networks

Joint session scheduling (JOSCH)

JOSCH is one JRRM approach. It offers detailed traffic splitting, which provides the possibility for optimal allocation of the traffic over subnetworks. This approach is supported by the adaptive radio multihoming (ARMH) protocols.

Joint load control (JOLDC)

The JOLDC allocate the load caused by incoming traffic to different RATs. The optimal load allocation is one input value for optimal intersystem handover.

L

Loose coupling structure (LSC)

Interworking between two RATs is loose, only switching related control message is included in the interface in between.

M

Mobility management (MM)

MM covers protocol and resource reservation schemes for mobile terminals with certain mobility. In a composite radio environment, the MM needs to consider: registration/paging in the switching subsystem, resource reservation and management in the radio subsystem. The handover under the reconfiguration context covers time, space, spectrum and RAT dimensions.

N

Network planning:

This process aims at determining the optimal element sites and the element configuration, within a number of radio access technologies, in order to satisfy the requirements of coverage and capacity.

Q

Quality of Service (QoS):

The collective effect of service performances which determine the degree of satisfaction of a user of a service. It is characterised by the combined aspects of performance factors applicable to all services, such as;

- service operability performance;
- service accessibility performance;
- service retainability performance;
- service integrity performance; and
- other factors specific to each service.

R

Radio Access Network (RAN):

A RAN is a network for wireless access comprising of transceivers and base station controllers connected in a radio network infrastructure excluding the core network, e.g. UTRAN (UMTS RAN) in a UMTS network.

Radio Access Technology (RAT):

The radio access technology is the air interface used to ensure the link between the end user equipment and the access point of the RAN. The RAT is usually specific to each RAN.

Radio resource unit (RRU)

Basic granularity of a certain radio resource managed by JRRM/ARRM and local RRM controlling entities.

Resource scheduling (RS)

Scheduling algorithm in the MAC/DLC layer.

S

Spectrum:
Spectrum is the physical medium used to support wireless communications.

Spectrum sharing:

Ability for different radio technologies to use the same portion of spectrum without creating harmful interferences to each other. The operation of the RATs may be co-channel or adjacent channel and may be constrained by technical provisions deduced from the results of compatibility studies between the two systems involved in the sharing scenario (see also "Dynamic Spectrum Sharing").

Spectrum Brokerage:

Process according to which spectrum is looked upon like an economic good like stocks or real estates. Automatic spectrum agents act as brokers between suppliers and spectrum purchasers. Spectrum purchasers give purchase orders with maximum prices and deadlines just like when buying stocks. Rates will develop very dynamically depending strongly on location and time of the "spectrum transaction". Even buying spectrum from users, which have already allocated spectrum is imaginable

Spectrum Pooling:

The ability of reconfigurable equipment to detect free sub bands within a certain frequency band

Spectrum Coordinator (SC):
The spectrum coordinator is the entity that owns, or has been licensed, the use of the radio spectrum flexibly. The spectrum coordinator then controls the allocations and de-allocation of radio spectrum to the radio access networks.

Spectrum Holder (SH):

Spectrum license holder is the party that owns a certain amount of spectrum that can be contiguous or fragmented. This spectrum license can operate totally or partially this band, or can envisage some other uses with some other parties.

Service (S):
The service is a component of the portfolio of choices offered by service providers to a user, a functionality offered to a user.

Service class:

A service offered to the users described by a set of performance parameters and their specified values, limits or ranges. The set of parameters provides a comprehensive description of the service capability.

Service Provider (SP):

A service provider is an organization that delivers services in the form of applications or content to the users of the system. The services would be delivered to the users via the radio access networks. Typical services include voice telephony, Internet access, and video services. Content could include navigational & traffic information, news, sports, and entertainment.

Session admission control (SAC)

A service consists of a number of sessions. The admission control in a subnetwork can control the admission detail to the session level.

Soft Handover (SHO)

Generic Handover schemes over multiple geographical cells, multiple air interfaces and multiple bands. The aim is to reduce burden of radio system and reduction of call dropping rate. Soft handover is a category of handover procedures where the radio links are added and abandoned in such manner that the mobile always keeps at least one radio link established.

Software Download (SD)

It envisages downloading software through the air interface. Due to the population of SD in favour of reconfiguration, radio resource management should be defined for such special service type. Typical traffic types are:

- Software for higher layer communications and computing applications
- Software patches, software upgrades, software licenses & keys, install scripts, test cases, device configuration files,
- Lower-level code, such as protocol entities for modification or changing of the air interface or the bearer service
- DSP algorithms for modification of the physical layer
- FPGA reconfiguration

T

Tight coupling structure (TCS)

Two RATs are very tightly coupled with each other, the interface in between is IuR like.

U

User (U):

The users are the people using the terminal equipment to receive services via the radio access networks. The users may not be aware of what RAN was being used to access the services. However, the user may be lead to choose manually on his terminal between two service providers delivering the same application with two different billings. In that case, even if not aware, the user can be an actor in the “choice” of the RAN.

User Equipment (UE):

Often found as “end user equipment”. The end user equipment is the entity supporting the needed functionalities enabling the delivery of the requested service.

V

Vertical Handover (VH):

In a multi-radio environment, a vertical handover is the process of moving a traffic flow from one link to another (e.g. from GRPS to DVB). The decision to trigger a vertical handover may depend on several link parameters, such as coverage, performance, price and authorization.