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Radio Resource Management Architecture for Spectrum Sharing in B3G Systems

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***Abstract*—Flexible spectrum sharing is widely seen to be important feature for the future beyond 3G systems. Efficient implementation of spectrum sharing requires novel radio resource management (RRM) functions as well as modifications to the current RRM architectures.**

A RRM architecture for spectrum sharing in B3G systems is proposed in this paper in the context of WINNER system concept. The architecture enables B3G systems to benefit from the most important aspects of the envisioned flexible spectrum use and sharing schemes. The architecture improves the spectral scalability of the system, facilitating versatile evolution and use of the system. It also provides an option to obtain capacity enhancements through the spectrum sharing with systems using other radio access technologies. The proposed architecture provides a flexible and general framework for the further development of RRM functions needed by spectrum sharing.

***Index Terms* — Beyond 3G systems, flexible spectrum use, radio resource management, spectrum sharing**

Introduction

It has been widely recognized that use of spectrum can be significantly intensified through flexible spectrum sharing between multiple radio access systems. Benefits from spectrum sharing among compatible systems providing diverse services can be easily recognized . Significant advantages can also be obtained when spectrum is shared between radio access networks (RAN) using the same radio access technology (RAT). Most importantly, flexible spectrum use enhances spectral scalability of the system. This allows to deploy multiple RANs at the launch of the system, even when spectrum is made available gradually according to increasing traffic demands. Such flexibility may turn out to be of particular importance for beyond 3rd generation (B3G) systems requiring wide spectrum bands on frequencies suitable for efficient vehicular communications, that is, below 6 GHz [1].

To attain the envisioned gains also in practice, spectrum sharing needs to be efficient and reliable. This depends critically on radio resource management (RRM) that controls the sharing. Although flexible spectrum use has drawn wide attention in the research community, only few pragmatic solutions for the RRM functionalities required by the sharing have been presented.

The European IST FP6 project WINNER [2] aims at the development of a new radio access network concept fulfilling the requirements set for the B3G systems in [3]. In this paper, an architecture considered in WINNER project for RRM functionalities implementing flexible spectrum sharing is presented.

Spectrum sharing can be considered from several possible points of view. In the following, we distinguish the different types of sharing by the type of involved systems:

Intra-system sharing involves RANs employing the same RAT with dedicated functions for inter-RAN coordination. The sharing capabilities are part of the system requirements and thus are woven into the system design. In the context of this paper, such sharing occurs between multiple WINNER RANs.

Inter-system sharing involves systems employing different RATs belonging to possibly very diverse applications. The sharing capabilities of the systems may differ substantially and may be very limited.

RRM Architecture

A radio resource management architecture considered for the WINNER system concept is presented briefly in [4], [5]. The necessary function introduced to the RRM for controlling spectrum sharing is referred to as spectrum control and it consists of:

1) **Inter-system spectrum sharing** controlling sharing with systems using different RATs. This function is located in the logical network node Access Control Server (ACS) [4] as presented in Fig 1.

2) Intra-system **Spectrum Assignment** controlling spectrum sharing between multiple WINNER RANs. This function is also located in the ACS.

3) **Constraint Processor** implementing the time-varying transmission restrictions imposed by the spectrum sharing, located on the base stations at the MAC control plane.

The functions are run simultaneously in all WINNER networks, and the only central entity between networks is a **central data base**, maintained by regulator or some another authorized party. The basic parameters in the data base can be altered, e.g., monthly, thus allowing for higher level control on spectrum assignments through spectrum priorities and fairness/cost metrics. The architecture is depicted in Fig. 1.

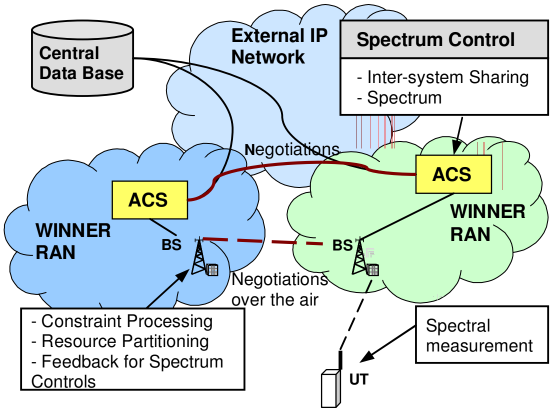

Figure 1. Illustration of spectrum sharing RRM architecture.

WINNER radio interface super-frame is divided into time-frequency chunks providing the basic unit for subdividing the spectral resources. Spectral resources assigned to the WINNER networks are also divided into two categories, namely, resources assigned to a certain network with indisputable priority, to guarantee basic operation of network, and to common pool resources available to all networks. The division between the categories can be adjusted through the central data base.

The signalling between WINNER networks and central data base is carried over the IP-based core network. However, the WINNER mode based on time-division duplex (TDD), relying on synchronization over all networks, allows also for over-the-air signalling between networks. For this purpose, the random access channel (RAC) on the super-frame preamble is used.

Inter-System Sharing

If two or more dissimilar systems are to be operated in the same frequency band, the basic possibilities for peaceful coexistence on the same band are separation either in time or space. Other approaches, e.g., from an information theoretical perspective have to rely on very strong assumptions, which might not be feasible in practice [6]. Another limiting assumption is that no sophisticated signalling between the B3G and legacy systems is possible in general. Depending on the regulatory rules governing the shared bands, different sharing scenarios are possible. We focus on so called vertical sharing where the B3G system is in the secondary and the other system in primary position. In such scenario, the B3G system has to control its emissions to avoid interference towards the primary system. The scenario may occur when a B3G system is deployed in a band already allocated to a legacy system, and the new system may not cause interference towards the established one.

The sharing scenario considered requires introduction of a novel RRM function, called **inter-system sharing**, likely located on the ACS logical node. The function itself will depend strongly on the characteristics of the involved legacy system, yet unknown. The challenge is to make best use of the "white spaces" (unused spectrum) in frequency, space and time, and to transmit in these white spaces only, i.e., without generating interference towards the legacy system. To achieve this goal, the white spaces are identified and estimated, after which the transmission parameters are adapted accordingly, resulting in two fundamental stages:

1) Identification and estimation of white spaces and exclusion zones, presenting the core of the inter-system sharing function. The function i) coordinates measurements, ii) gathers and processes information, obtained through measurements and signalling, on radio environment, and iii) defines transmission constraints for shared spectrum.

2) Adaptation of transmissions according to the constraints and assignment of spectrum to individual cells are implemented by constraint processor and resource partitioning, located on MAC layer.

While the adaptation step is a complex but still well-defined optimisation problem, the identification step is more difficult to handle and can consist of several components:

i) spectral measurements in user terminals, measurement coordination and processing at the spectrum sharing function,

ii) regular downloads from a database maintained by a regulator or another authorized entity, requiring that the spectrum use of the primary system is quasi-static,

iii) real-time beacon signal maintained by the primary system.

The two steps can be seen to form part of a “cognitive cycle” as described in [7], [8] and illustrated in Figure 2.

In general, reliable detection of white spaces is a hard problem and is deemed to be infeasible at a reasonable complexity without knowledge of the properties of the primary system. However, solutions can be envisaged for simpler, but practical cases, e.g., when the primary system is a fixed system with low geographical density. Use of the network nature of B3G systems in measurements can also provide much more accurate information on sharing opportunities than it would be possible for single devices or short-range networks.

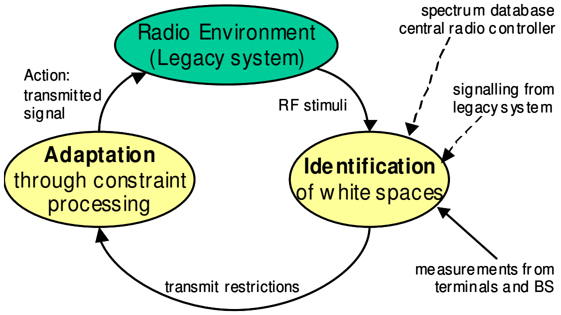

Figure 2. Cognitive radio cycle in inter-system spectrum sharing.

However, it has to be noted that operation in shared spectrum is subject to a number of constraints which cannot be influenced. In order to meet the B3G system requirements, especially QoS guarantees, operation in inter-system shared spectrum can only be considered for capacity enhancements.

Spectrum Assignment

Spectrum assignment adjusts the spectrum resources available to the network according to the predicted aggregate load on the cells. The update rate of the assignments is one of the crucial design parameters. Fast update rate allows for more accurate load predictions as well as for faster reactions to the sudden changes on the load. On the other hand, increased update rate induces more inter-network signalling, computational complexity and complex, unpredictable interactions with other RRM functions. To solve this problem, splitting into *long-term* and local, *short-term spectrum assignments* is proposed. Long-term assignment provides very slowly varying assignments for large geographical areas, hence, introducing fair, stable and flexible spectrum assignments between networks with acceptable inter-network signalling and computational complexity. To complement long-term assignment, short-term assignment supports faster and local spectral flexibility by introducing short-term, cell-wise variations to the large-scale solution. However, the time scale of the short-term assignment needs be clearly longer than that of other RRM functions.

Long-term Spectrum Assignment

The function coordinates and negotiates the spectrum assignments between multiple networks for large geographical areas with spatial granularity of several cells. Spectrum assignments are updated periodically and at slow rate, i.e., in time frame of tens of minutes. The signalling between networks is carried out through the IP based core network, although over the air signalling can be also employed. The function is composed of the following five sub-functions carried out sequentially.

Resource request calculation defines the requested spectral resources for the next assignment period based on the inputs from load prediction, MAC control feedback, and inter-system sharing. Also the non-negotiable spectral resource changes, i.e., voluntary resource releases and retrievals of prioritised resources, are defined and announced to the other networks.

Resource negotiations between RANs are carried out based on the resource requests and by utilizing fairness or cost metrics. After the negotiations, the spectral resources are tentatively identified and assigned, but the amount of resources available for each network is fixed.

In **Resource re-arrangement calculation,** the possibilities to optimise the tentative spectral resource assignments through the exchange of the resources with other networks are identified. Such optimisation can be attained, e.g., by seeking for more contiguous assignments that minimise the necessary inter-network guard bands.

In **Re-arrangement negotiation between RANs**, the resource exchanges are negotiated with other networks. The sub-function can be looped with the Resource re-arrangement calculation till no further requests are presented or a related time counter expires.

Resource update complies the necessary spectral resource availability and transmission constraint information for the constraint processor. The related logs are updated, and updated information is sent through the core network to the central data base. To maintain cohesive information in all network, the updated information are downloaded from the central data base. Such regular central information update facilitates the introduction of new networks as well as the changes on the network deployment. Resource update also triggers short-term spectrum assignment for further assignment optimisation, if necessary. Resource update also performs recovery from any possible signalling failures between the networks.

Short-term Spectrum Assignment

The function controls short-term and local, i.e., cell-specific variations to the large-scale spectrum assignments. The assignments may be performed in the time scale of several seconds or minutes. Hence it enables faster adaptation to the load variations and geographically more accurate spectrum assignments, thus, complementing the long-term spectrum assignment and load sharing. The function resorts to simplified signalling and computations to keep the overall complexity acceptable. The function simply requests resources from other WINNER RANs after being triggered by the long-term spectrum assignment or load sharing. In the case of a resource request from other RANs, the functionality rejects, accepts or partially accepts the request based on information from load prediction, load sharing, and MAC control feedback on the overlaying and neighbouring cells. Inter-network signalling is performed over the air or through the IP-based core network.

Short-term assignment may be extended to handle also cell-specific variations vertically, i.e., between different cells layers belonging to the same RAN in so-called Hierarchical Cell Structure (HCS). In the structure, several cells of different characteristics can be overlapped, partially or totally. The cells, being of different sizes, are intended to serve different user profiles, e.g., a large cell supporting communication in wide-area may overlap with cells of smaller size designed for hot spots.

In the HCS, optimal cell type for serving a given user is changing from time to time, e.g., due to a change in user's mobility. In general, offered load to a cell varies and other overlapping cells, more suitable for serving the possible excess load, might take over the responsibility. Although load sharing function coordinates and is the basis for this action, in some cases it does not suffice; e.g. when load sharing from wide-area cells supporting high-mobility users to short-range cells is not viable. In such situations, a proactive resource balancing among cell layers is prompted, in coordination with the normal load control functions. This balancing strives for assigning each cell the optimal resources it needs at a given time, given the constraints imposed by the HCS. These constraints affects the optimal manner the spectrum can be balanced.

Constraint Processor

A constraint processor is introduced to take the varying space-time-frequency constraints as well as available resources into account on the radio transmissions, as well as to provide necessary measurement information to the spectrum sharing and spectrum assignment functions.

The resource partitioning function prepares the structure of the next super-frame by using the time-frequency chunk as the basic unit for subdividing the radio resources. The partitioning of the super-frame will be performed with chunk granularity. The resource partitioning may be changed on a super-frame basis, but most parameters will typically stay unchanged over longer time horizons. The time-frequency resources within the next super-frame are subdivided in the following sequence.

First, all constraints on the use of chunks are updated by the constraint combining function of the constraint processor at the base station. It receives information on restrictions due to spectrum sharing as well as due to interference avoidance with neighbouring base stations. The restrictions may have also a spatial component. The restrictions are combined into two chunk masks: 1) Chunks that must be avoided. 2) Chunks that may be used, but that are shared with neighbouring cells/other operators, and thus may contain significant interference.

As said, the constraint processor combines constraints on the use of chunks and chunk layers. These arise from interference between user terminals, interference avoidance scheduling with neighbouring cells and spectrum sharing between operators. The output is in the form of chunk masks that define restricted use of the chunks of a super-frame. The constraint processor also processes measurements that support the inter-RAN negotiations in the spectrum assignment function.

Discussion on Architecture

In the proposed RRM architecture, the complex problem of spectrum sharing is tackled by dividing it into smaller, tractable functions: inter-system sharing, long-term spectrum assignment between WINNER RANs, short-term assignment, and constraint processing. Functions operate also on clearly separated time scales, thus, partially preventing unpredictable interactions between the functions. The purpose of the modular approach taken is to have a clear architecture with predictable behaviour as well as to have minimal deteriorating impact on the design of conventional RRM functions.

The proposed inter-system sharing function provides an option to use shared spectrum as capacity enhancement for the system, and defines a coordination point for the spectral measurements on the terminals, which allows for harvesting on the hidden sensor network character of the system.

Long-term spectrum assignment introduces spectral scalability to the system that allows multiple RANs to be deployed despite of possible variations on the amount of spectrum made available for them. Such variations may be caused by gradual introduction of the system, or by geographical differences on the spectrum allocations. Spectral scalability facilitates also versatile operation of networks, e.g., with some operators providing more focused services and coverage than others. The function allows also that spectrum assignments are adapted to reflect the changes on the number of subscribers as well as on daily load patterns.

Short-term spectrum assignment provides possibility to improve long-term assignments further with smaller, cell-wise, geographical granularity as well as a novel, augmenting method for load control in the network. However, careful selection of proper time scale is especially important to this function to prevent undesirable oscillations with load control. Hence, further work is needed to define efficient interaction with load control and resource partitioning, and to evaluate the true benefits of the function.

The division of the resources into common pool and prioritised categories aims for combining the benefits of the both approaches. Balance between the categories can be changed, even dynamically, which provides another degree of freedom to the configurability of the system. It may be needed, e.g., to support differences in the used spectrum trading policies.

Conclusions

Capabilities for flexible spectrum sharing are widely seen to be a novel and important feature in the beyond 3G systems. Efficient implementation of the capabilities calls for introduction of new RRM functions and modifications to the current architectures.

A RRM architecture for spectrum sharing in B3G systems is proposed in this paper in the context of WINNER system concept. Proposed RRM architecture enables B3G systems to benefit from the most important aspects of the envisioned flexible spectrum assignment and sharing schemes. The architecture improves the spectral scalability of the system, facilitating versatile evolution and use of the system. It also provides an option to obtain capacity enhancements through the inter-system spectrum sharing.

More studies are needed in the development and evaluation of introduced RRM functions. Proposed RRM architecture provides an important, and flexible, framework for the further research.

ACKNOWLEDGEMENT

This work has been performed in the framework of the IST project IST-2003-507581 WINNER, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues, although the views expressed are those of the authors and do not necessarily represent the project.

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