

SDR MULTISTANDARD BASESTATION AS A KEY TO FUTURE COGNITIVE RADIO NETWORKS

Wolfgang Koenig (wolfgang.koenig@alcatel-lucent.de), Klaus Nolte, Thomas Loewel, Andreas Pascht, Alcatel-Lucent Deutschland AG

ABSTRACT

Flexibility of established RAN architectures is limited due to missing standard/frequency band adaptability of the infrastructure to the environment. There are no means to adapt the RAN dynamically to the actual mix of terminals within a cell and to changing traffic demands e.g. caused by extraordinary events e.g. such as large sport events. Furthermore deployed terminals need to support a multitude of existing radio standards. This leads to longer time to market, higher complexity and shorter battery lifetime of the terminals.

In this contribution a concept, partly developed within the E2R2 Project [1], a concept on Cognitive Radio is introduced that shall overcome these restrictions in a longer term. Exploiting the capabilities of SDR base stations a RAN is designed where the infrastructure adapts itself, i.e. autonomously, to offer the most appropriate mix of RATs according to e.g.: requested bearer services (bandwidth, QoS), capabilities of the mobiles within the cell (supported RATs, frequencies), available resources (spectrum, platform).

1 INTRODUCTION

The overall concept is based on a Cognitive Radio Network Management that inter-works with a function managing heterogeneous access to the deployed composite radio networks supporting different Radio Access Technologies and with a flexible, multi-band/multi-standard Cognitive Radio Base Station (BS). Cognitive Radio Network Management can be either fully distributed or partly centralized. The cognitive RAN shall autonomously adapt radio and infrastructure resources according to its knowledge on the environment (e.g. type of terminals, traffic demands and interference) and within the scope of policies defined by the network management. The concept will not only provide the means for self-optimization and self-configuration of RANs but also be able to support future techniques on dynamic spectrum access.

Within this contribution the following topics will be addressed:

- Requirements to a BS (BS) derived from cognitive radio network scenarios

- Management of cognitive radio networks and provision of context information towards cognitive network functions
- Overall architecture of a cognitive radio BS
- State-of-the-art analysis and perspective developments for required technologies
- Impact on existing modeling approaches (SCA, FDL, ...)

2 COGNITIVE RADIO IN INFRASTRUCTURE BASED NETWORKS

2.1 Approach and Benefits

The basic architecture of a cognitive Radio Access Network is outlined in Figure 1.

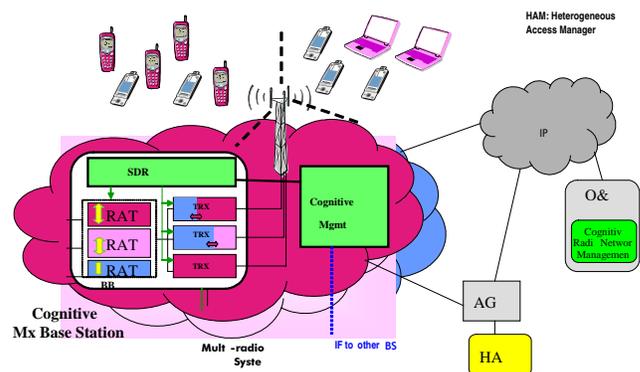


Figure 1: Cognitive Radio Access Network

A cognitive, multi-standard radio BS is assumed to provide several radio access technologies in parallel, creating a heterogeneous RAN. The BS shall be capable to flexibly reconfigure itself by dynamic allocation of resources towards different radio access technologies (RATs). Dynamic multi-standard operation is not only supported for the baseband processing but also for the transceiver capable to operate in a multi-standard, multi-carrier fashion. Flexible resource allocation respectively reconfiguration is controlled by the SDR control module, interfacing a Cognitive Multi-Radio BS Management (CMMR). This module comprises the cognitive radio properties as well as the multi-radio management functionalities. It interoperates with the Heterogeneous Access Manager (HAM) and with neighboring CMMRs supporting heterogeneous access

management for efficient coordination of available radio resources across RATs. Handover (HO) between arbitrary RANs further requires a coordinated reconfiguration of radio connectivity and involved IP mobility protocols. This is managed by the CMMR and HAM functionality that is inter-working with technology specific legacy radio resource management. The concept supports seamless IP based mobility and is featuring a coordinated and efficient management of the entire radio access resources. It comprises furthermore a sophisticated support for the detection of available UE radio properties and enables introduction of dynamic spectrum management. As a result, an optimization of the overall air interface and infrastructure resources in the RAN is obtained with respect to user application requirements, UE capabilities and network efficiency.

2.2 Cognitive Radio Base Station Architecture and Requirements

To enable the concept of a Cognitive Radio Access Network as outlined above, significant technical enhancements of BS implementations are required.

The BS needs to support multiple frequency bands and air interfaces in parallel in a very flexible manner. Operational bands/standards shall be dynamically adjusted. For required enhancements mainly three areas can be distinguished: operation and control functions, baseband processing and transceiver. The basic architecture of a Cognitive Radio BS is shown in Figure 2.

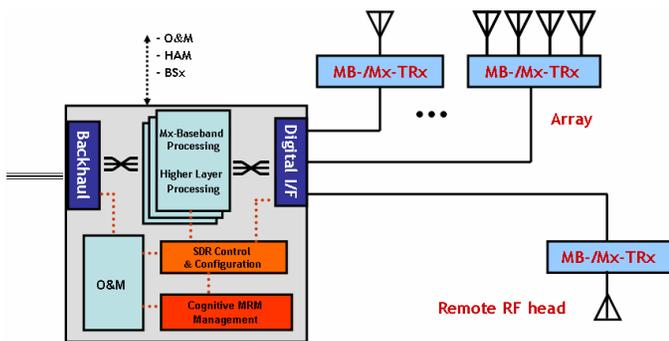


Figure 2: Cognitive Radio BS Architecture

Backhauling to the fixed network is assumed to be based on an all-IP network interface, for transport and for signaling.

Legacy Radio Resource Management functions, e.g. as for LTE, have to be extended by a Multi Radio function together with self-learning, self-organizing mechanisms for joint resource optimization. Joint optimization will be achieved by inter-working with neighboring BSs and the HAM function managing traffic distribution, radio resources and infrastructure resources for the subjacent access networks.

An SDR Control & Configuration function will enable flexible reconfiguration of the BS by means of adequate HW and SW changes. A SW framework will effectively support mapping of signal processing SW on to processing resources as required by the actual configuration.

The multi-band/multi-standard transceiver can be implemented locally or as a remote RF head, serving single or multi-antenna configurations. Targeted flexibility requires enhanced antenna networks reconfigurable to the selected frequency bands for GSM, UMTS, LTE and WiMAX as well as a combined design for FDD and TDD modes. For the receiver at least 1 GHz bandwidth with a signal bandwidth of 35 MHz is needed. New building blocks (e.g. adaptive filters, frequency agile switching, and converter linearization) need to be designed and new approaches for signal pre-conditioning are necessary to reduce filter requirements especially for the antenna filter.

2.3 Cognition in Radio Base Station

The idea of cognitive radio was presented 1999 by Joseph Mitola III and Gerald Q. Maguire, Jr. [2]. The term implies a certain level of cognition or intelligence in a radio system or device: Cognitive radio can autonomously create new waveforms, can negotiate new interfaces and can adjust the operational state to meet QoS requirements.

In general, cognitive functions are characterized by performing actions that will autonomously keep a dynamically changing system in an acceptable state near to the optimum (with respect to a given target and under given restrictions). This includes the ability to adapt the strategy by learning (taking into account successes or failures of previously applied strategies).

Equipment that supports cognitive radio technology measures e.g. the signal strength, the transmission quality, the propagation characteristics and the data throughput of different bands and radio technologies. With help of this information it configures itself to match the rules stemming from previous experiences (the rules may be set by other systems, manually or even be derived by the system itself).

The cognition cycle described by Mitola [2] applied to a BS can be seen as follows:

1. Observe the performance indicators of the BS (values and their variations) as well as of the terminals served.
2. Rules (policies) define conditions that may trigger re-configurations.
3. Events are derived from the rules. If an event occurs - the BS checks whether the rules still justify the current state and - if not - initiates a re-configuration.
4. Some re-configuration actions may be urgent and do not allow for an (almost) perfect planning. Instead, they are performed very soon (application of high priority policies).

5. Other re-configuration actions are the result of checking all rules and are well-prepared.
6. A measure is introduced that allows to say, how far is the current state from an ideal state (e.g. actual data throughput vs. desired data throughput, etc.).
7. By evaluating the observation data and checking them against the effect of re-configuration actions, new rules may be derived and applied.
8. The re-configuration execution logic is separated.

Cognitive functions within a base station could be classified by different criteria:

- A function may be carried out autonomously within the BS or in collaboration with other entities.
- In the collaborative case the BS may act as centralized manager, as an agent, or on equal rights as other participants

In practice, we can distinguish the following situations (this is not an exhaustive list):

1. A network management system performs a cognitive function (e.g. intelligent dynamic frequency band distribution in a geographical area due to varying demands). As a result re-configuration actions are externally triggered in the BS.
2. Two or more BSs may negotiate a re-configuration (e.g. sub-channel assignment in overlapping cell areas).
3. A BS autonomously may - based on its observations - partly re-assign its local processing resources from one RAT to another.
4. A terminal, the BS and an access management system may collaborate to improve the radio conditions for the terminal. Usually, this causes re-configuration of the terminal and not in the BS.

In general, terminal related cognitive functions and re-configuration actions require very short execution times compared to BS related functions. This is because BSs are expected to provide enough resources for a certain number of users of a standard.

3 COGNITIVE RADIO BASE STATION MANAGEMENT

3.1 Management of cognitive radio networks

Figure 3 gives an overview on the management hierarchy in cognitive radio networks. Autonomous functions in the BS shall work in the frame defined by the superior management level - the network management. The picture for autonomous cognitive terminal functions is similar.

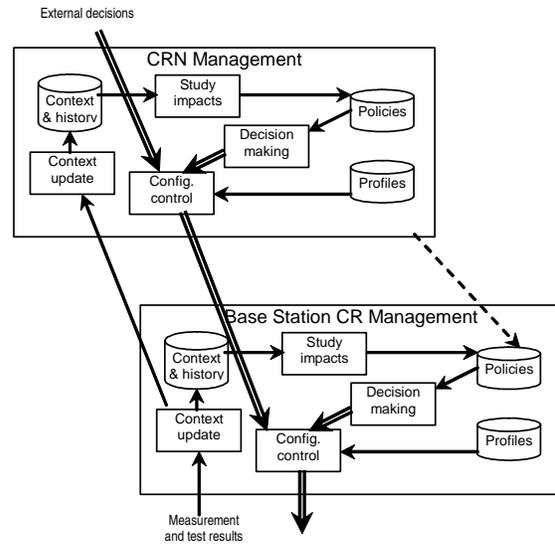


Figure 3: Management in Cognitive Radio Networks

3.2 Provision of context information towards cognitive network functions

Context information provision depends on results of measurements performed and on test results. Context data comprise e.g. SW parameter settings such as: sensing results (temperature etc.), date and time, as well as not changing parameters (number of antennas, geographical position etc.) that can be kept in a data base.

For the measurement data collection three rules are to be obeyed:

1. Perform measurements only if necessary (i.e. provide a SW mechanism to switch them on and off).
2. Summarize the measurement results as near as possible to their origin and send these summarizations to the measurement consumers (keep the number of messages small).
3. Re-use measurement results collected for radio standards (RATs) or O&M purposes.

Context information coming from different RATs shall be unified and, therefore, comparable.

3.3 Base Station Re-configuration

For the radio front-end there are usually re-configurable parameters that can be modified by software, the dependency from the RAT is rather small compared to the baseband processing parts. Therefore we put emphasis on the baseband re-configuration in this section.

The baseband processing in a composite wireless network environment shall take into account:

- Baseband operations are different per RAT (and sometimes, even within a RAT's sub-services)
- Baseband operations at RAN side are scaled per users / services per user
- A RAN side baseband processing shall serve in parallel multiple users in multiple networks with different RAT's
- Baseband operations shall down-link summarize input(s) for a cell
- Baseband operations shall up-link divide input data into data chunks dedicated to a single user /user service
- Baseband operations at RAN side shall serve the core network according to its interface(s)

A single BS may represent by its own a number of cells / hot spots on different frequencies in different wireless networks with different technologies – all depending on the BSs capabilities. Figure 4 illustrates the main functional architecture of such a flexible BS.

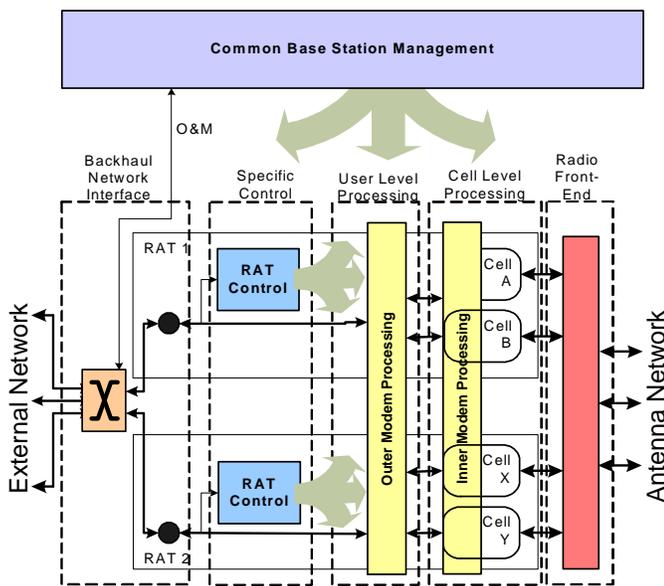


Figure 4: Base Station Functional Architecture

The figure shows that baseband re-configuration (as part of the overall management tasks in the BS) can be done at two levels:

- Station level: The BS Management part is the functional entity that is able to trigger configuration settings spanned over multiple RATs, over multiple external network interfaces, over the installed L1 software etc.
- RAT level: The RAT Control is able to trigger configuration settings that are RAT specific and do not influence the work of other parts of the BS.

At station level the following configuration /re-configuration actions may be provided (this is not an exhaustive list):

- Number and types of RATs served

- Mapping of external network lines onto the RATs (transport network configuration)
- Mapping of cell/antenna resources onto supported RATs
- Mapping of suitable HW entities onto inner or outer modem processing

At RAT level the following (re-)configuration actions may be provided (not exhaustive): control of local RAT resources, RAT specific cell management and user management.

4 SW- CONTROL ARCHITECTURE

4.1 Overall Architecture and Requirements

Most of the re-configuration actions mentioned above are bound to complete or partial replacement of SW in different processing entities of a BS. Therefore it is helpful to have generic means that help to decide what SW files shall be installed on which HW. In a BS this will be a part of the SW management. It must be possible to describe several software configurations for a BS and to store these descriptions in a database.

Policies are seen as the right means that may control in a generic way the configuration decisions in a BS. Another part of SW control is the download management. This is not further discussed in the paper. However, one should be aware of the following problems: consistency of different SW packages running in parallel in a BS, internal file distribution and fallback strategy in case of failures.

4.2 E2R Architecture: Re-configuration Management Approach

In brief, E2R defines three layers (modules) for realizing re-configuration in a reconfigurable radio equipment [3,4]:

- Configuration Management Module (CMM): It is responsible for taking configuration decisions and the reception of configuration requests from higher level management systems. Logical configurations are requested at this level only.
- Configuration Control Module (CCM): It is responsible for carrying out re-configuration requests. It determines how to best fit the required logical configuration onto the available HW resources. The supervision of re-configuration transactions is done by CCM, too.
- Configurable Equipment Module (CEM): Abstraction for processing entities like GPP, DSP, FPGA.

4.3 Objects for BS Self-Management and Cognitive Radio

Policy and profile objects are proposed as means that control the decision management. They help to realize the

Configuration Management (CMM) layer in a data driven manner. Nowadays, a BS uses static resource allocation and allows to run only one RAT on a dedicated hardware. Moving to a more flexible SDR hardware, the first question that comes up, how to reflect this flexibility in the software?

One important point is to develop new management software, which can (re-)configure the multi standard BS. Software deployment profiles are defined as abstractions to store software configurations. A deployment profile can be realized as an object that contains several attributes like predefined frequency bands, the maximum number of users that can be supported and how many boards shall be used for this configuration. Default profiles are predefined and available after start up of the control management.

The major point is that a profile can include a deployment of multiple RATs. That means for example, to deploy a UMTS RAT and a WiMAX RAT at the same time on one BS and to have the possibility to scale up these RATs when necessary. With the assistance of a profile handler it is possible to manage all the profiles and their settings. Especially, the profile handler supports the creation and the removal of profiles.

There are two options to activate such a profile. The first is to do it manually via an external trigger, e.g. on behalf of an operator. But to get it more flexible and independent, it is also possible/necessary to trigger the activation dynamically by a decision-making module (policy handler). With this module the BS is able to reconfigure itself. The policy handler contains a dynamic number of policies.

A policy consists of a condition that evaluates a Boolean value and of one or more actions. The policy handler checks the condition of a policy and runs the corresponding actions. Attention should be paid to the relation between the RATs and the condition, because values used in the condition can have different interpretations depending on the selected RAT. The corresponding actions are function calls with predefined parameters, generally to reconfigure the active deployment profile or to exchange it with another profile. For customization the policy handler offers the possibility to modify and to remove a policy or to create a new one.

For both, the profiles and the policies, it is important that only one authority has the exclusive management access them. It must be ensured that the policies active at a time do not contradict each other.

With regard to the impact on existing modeling approaches, currently two main areas have to be addressed:

- Within OMG a SW Radio Specification [5] is defined as a Framework for re-configurable Hardware. This well-known specification (derived from SCA) helps to implement a framework that knows and tracks the available hardware resources of a distributed system and is able to install and configure distributed SW

applications on them. Based on this framework, a BS can implement an efficient SW management that is flexible enough for adaptable multi-standard operation. Improvement of the SW radio spec supporting scalable applications (add/remove component instances or instance groups to an application during operation) would better reflect the need of BSs.

- Definition of a functional description language for describing the logical configurations and their corresponding functions is highly desirable.

5 TRANSCEIVER FOR COGNITIVE RADIO BS

A Cognitive Radio Transceiver is a radio front-end that can be operated in a number of frequency bands and standards. The frequency bands and standards can easily be changed without modifying the hardware, giving network operators considerable flexibility not only when introducing new frequency bands and standards, but also for subsequent network reconfiguration and optimization.

5.1 Architecture of a Cognitive Radio Transceiver

Figure 5 depicts the modules deployed in the Cognitive TRX, each of them must meet much more stringent requirements than those for a single-band approach [6].

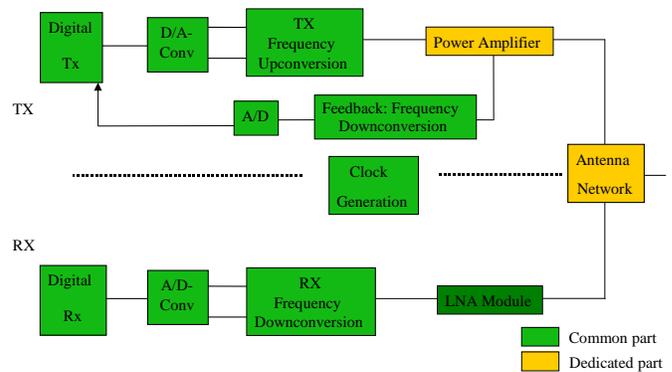


Figure 5: Overall architecture of the Cognitive TRX

The approach splits the transceiver front-end in a dedicated and in a common part. The dedicated part consists of the power amplifier and the antenna network. This is required due to the large frequency range, the different power classes and the different operating modes like FDD and TDD.

The common part consists of the signal conditioning units, the converters, the frequency conversion units, the low noise amplifier and the clock generation and distribution unit. For the linearization of the power amplifier an additional feedback path in the transmit unit is required.

The digital module consists of a crest factor reduction module, a pre-distortion module for the linearization of the power amplifier and a module for the image- and carrier suppression required due to analogue imperfections of the transmit chain of the transmit chain.

5.2 Cognitive TRX Building Blocks

Compared to an SDR TRX the following building blocks need to be enhanced:

- **Enhanced Antenna Network:** it has to be reconfigurable to select different frequency bands like GSM, UMTS, LTE or WiMAX bands. To cover not only FDD operation but also TDD operation a combined antenna network is required. This antenna network is based on a combination of a duplex filter and a circulator.
- **Enhanced Receiver Design:** the next building block is a broadband receiver design bandwidth is limited due to the Low Noise Amplifier bottleneck advanced LNAs a bandwidth of more than noise figure and the gain of frequency.

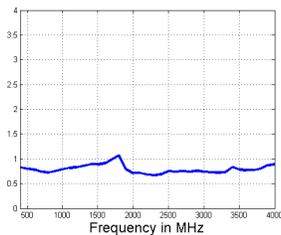


Figure 6: LNA noise figure and gain

- **Increase of Signal Bandwidth:** Nowadays SDR transceivers are limited by the signal bandwidth. We see Cognitive Radio from the transceiver point of view in four dimensions: Frequency, Standard, Power Class and Signal Bandwidth. The last dimension has also to be increased for Cognitive Radio Transceivers. This could be done by optimized linearization algorithms. The overall linearity of the transmitter chain is also a limitation in signal band improvement. Therefore approaches for the linearization of the converters are also taken into account.

Cognitive Radio Transceivers could not only be realized by improving the SDR transceivers. New innovations respectively building blocks are required to enable these transceivers:

- **Frequency Agile Switching:** New switching devices are under evaluation based on frequency selective strip lines to improve the power amplifier matching

- **Smart Filters:** A second importing approach is the realization of so-called “Smart Filters”. The idea is to reduce the overall filter requirements by digital pre-processing of the signal in the digital domain.

These building blocks and innovations are needed and used to set up a Cognitive Transceiver Unit. By using the direct-conversion principle – due to analog imperfections – it is necessary to implement adequate compensation mechanisms, which are very effective. It has been shown that an architecture based on direct-conversion is really multi-band capable. The selected concept has been proven in TX direction for zero-IF and low-IF operation.

6 CONCLUSION

Exploiting the capabilities of an SDR BS introducing cognition functions in the RAN opens the way for significant enhancements of mobile network operation. New techniques and technologies are required to implement a cognitive radio BS as outlined in this contribution. Design has already been started in number of initiatives; E2R2 is providing a major contribution to that. The way to an ultimate Cognitive Radio BS is still a long one and further efforts on technological innovations as well as on the standardization and regulation framework is required. The planned E3 project [7], in the context of the EU research program FP7, intends to further develop these enablers to make cognitive radio networks a reality in the near future.

7 ACKNOWLEDGMENT

This work was performed in project E2R II which has received research funding from the Community's Sixth Framework program. This paper reflects only the authors' views and the Community is not liable for any use that may be made of the information contained therein. The contributions of colleagues from E2R II consortium are hereby acknowledged.

8 REFERENCES

- [1] End-to-End Reconfigurability Phase II (E2R2), IST-2005-027714, <http://www.e2r2.motlabs.com>
- [2] [Mitola, 1999] J. Mitola, III and G.Q. Maguire, Jr., "Cognitive Radio: Making Software Radios More Personal," IEEE Personal Communications, vol. 6, no. 4, 1999.
- [3] Eric Nicolle, Wolfgang König, Klaus Nolte, Teck Kiong Lee, Raymond J. Jayabal, Frédéric Lafaye: "Reconfigurable Base Station Processing and Resource Allocation", 16th IST Mobile & Wireless Communications Summit, Budapest, 2007.
- [4] A. Mihailovic, N. Olaziregi, N. Berthet, D. Pirez, Z. Boufidis et.al.: « End-to-End Reconfigurability System Architecture Fundamentals », IST Summit 06, Mykonos, Greece, 05-07.06.06

- [5] OMG: UML Profile for Software Radio (also referred to as PIM & PSM for Software Radio Components), V1.0,
http://www.omg.org/technology/documents/profile_catalog.htm
- [6] EUMC Amsterdam, "Advanced High Efficiency Multi-Carrier Transmitter for UMTS Base Stations", T. Bitzer, T. Bohn, G. Jacob, P. Jaenecke, A. Pascht, J. Schaepperle, G. Schwoerer, J. Strauss
- [7] Didier Bourse, Markus Muck, Wolfgang Koenig, et.al.: FP7 E3 PROJECT KEY CHALLENGES, SDRF Technical Conference Proceedings, November 5-9, Denver, 2007