A Radio Resource Management Based on Cognitive Capability Heterogeneity

Jie Chen
Chengdu Research Institute
Huawei Technologies Co., LTD.
Chengdu, China
chenjieuestc@huawei.com

Abstract—**In order to provide the best possible radio resource management solutions, a resource management framework based cognitive capability, which is capable of properly adapting to the environment conditions for optimizing multi-objective, is proposed. In such framework, three areas of cognitive capability are defined. Additionally, the cognitive capability heterogeneity, which refers to different cognitive capability for nodes, is also considered. Especially, a CRRM framework with cognitive capability heterogeneity, including cognitive resource management with cognitive capability level matching the reward and that with fairness, is developed.**

Keywords-cognitive resource management;cognitive capability heterogeneity;cognitive capability level;matching;fairness

I. INTRODUCTION

Recently the proliferation of wireless services along with spectrum scarcity has motivated researches on cognitive radio, which provides the capability to share resource in a certain manner. Generally, a CR is capable of sensing the spectrum over a wide range of frequencies and performing dynamic resource management to improve objectives such as spectrum utilization. In such network, the available spectrum will be spread over wide range including both unlicensed and licensed spectrum bands. These available spectrum bands show different characteristics varying with time and location. Therefore, dynamic and efficient radio resource management techniques are required in such network.[1]

In current wireless network, when a mobile station enters the network it is assigned a certain amount of radio resources by a centralized radio resource manager (RRM), which is optimizing the use of radio resources. All the optimization decisions in these RRM are taken by fixed algorithms. When system upgrade, these RRM algorithm are intervened by a human administrator. In such system, there is no provision of "cognitive capability". As mentioned in [1], the cognitive capability enables real time interaction with its environment to determine appropriate communication parameters and adapt to the dynamic radio environment. Recently, some researches on RRM introduce cognitive capability, such as cognitive resource management (CRM) framework proposed by RWTH [2] and enhancement of the RRM mechanism of LTE system with cognitive capabilities [3]. However, the definition of cognitive capability in RRM is still not integrally defined. Additionally, in a communication network, there are nodes with different cognitive capability. We call this characteristic as cognitive capability heterogeneity, which is not considered in these RRM frameworks.

The remainder of this paper is organized as follows. In Section II, we review related work on *Cognitive Resource Management* (CRM) and enhancement RRM in LTE. In Section III, we simply review the cognition of human and develop a *Cognitive Radio Resource Management* (CRRM) framework considering cognitive capability, and further develop a CRRM framework with cognitive capability heterogeneity in section IV.

II. RELATED WORK

A. *CRM framework*

As mentioned in [2], CRM can be run in a distributed fashion in all communicating nodes. Additionally, the CRM can be seen as a cognitive decision making unit and "operating system" that is tightly coupled with an optimization tool box that can perform local and/or global optimization based on information from the protocol stack, environmental readings or historical data stored for learning and modeling.

The CRM has access to all the layers of the protocol stack for measurements and settings via a Universal Network Interface (UNI), which abstracts the differences between different technologies and protocols, making technology-independent cross-layer optimization possible.

B. *Enhancement RRM in LTE*

By exploiting the capabilities of orthogonal frequency division multiplexing LTE access technology, network segments are capable of properly adapting to the environment conditions by applying RRM algorithms for optimized sub-carriers' assignment, power allocation and adaptive modulation [3]. The management functionality developed for enhancing RRM within LTE network segments described as follows.

Context reflects the status of the elements of the network segment and their environment.

[1] This work is supported by National High Technology Research and Development Program of China, No. 2009AA011801.

CHINACOM 2010, August 25-27, Beijing, China

DOI 10.4108/chinacom.2010.31

Profiles provide information on the capabilities of the elements and terminals of the segment, as well as the behavior, preferences, requirements and constraints of users and applications.

Policies designate rules and functionality that should be followed in context handling.

Decision consists of four main reconfiguration decisions (such as carrier bandwidth assignment, sub-carrier assignment and power allocation).

Optimization, which is based on several *Dynamic Sub-carrier Assignment* (DSA), *Adaptive Power Allocation* (APA) and *Adaptive Modulation* (AM) algorithms and machine learning techniques, consider the network environment parameters provided by context.

Infrastructure Abstraction which provides technology independent information on network parameters.

Learning enables the management entities learn from the past interactions of the system with the environment and identify situations addressed in the past.

III. COGNITIVE RADIO RESOURCE MANAGEMENT FRAMEWORK

For communication system, the cognitive capability means real time interaction with its environment to determine appropriate communication parameters and adapt to the dynamic environment.

While the traditional RRM involves multiple processes which can be introduced cognitive capability for better management, this concept can be call as *Cognitive Radio Resource Management* (CRRM), as shown in Fig.1. Additionally, introducing cognitive capability in the RRM will enable the system to make intelligent choices about future actions, rather than "just" immediately adapt instantaneous changes.

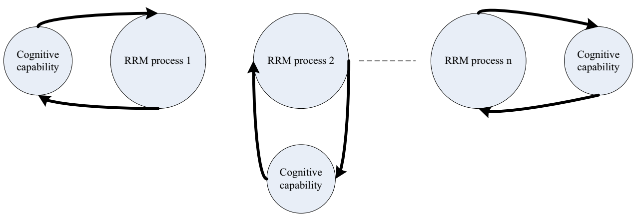

Figure 1. Cognitive RRM

Cognitive capability in CRRM framework includes three types of capabilities, which are defined as follows.

- Knowledge-gathering capability

  Knowledge-gathering capability represents the ability to take inputs from the outside world and ensure the translation of these inputs into the system to represents as accurate a transduction process as possible.

- Reasoning capability

  Reasoning capability represents the ability to examine the current state of the environment and make decisions on how the system should operate.

- Learning capability

  Learning capability represents the ability to allow the system to learn from the experience including past and present.

Three types of cognitive capability are decompounded to the RRM processes, as shown in the Fig.2. The experience, environment and rules are all the information source of knowledge gathering. The information, which is taken as the input of RRM, stimulates the adaptation of objective and the decision of reasoning. Additionally, learning learns from the decision of reasoning and experience, so as to instruct the latter reasoning.

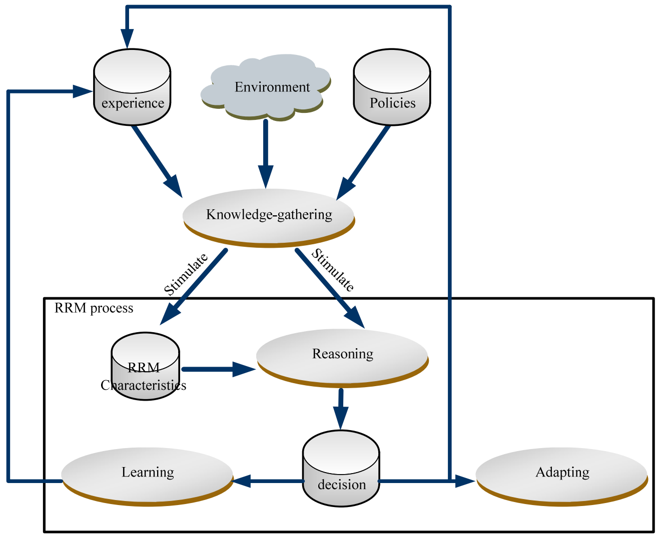

Figure 2. CRRM framework

IV. DECOMPOUNDING OF COGNITIVE CAPABILITY IN CRRM FRAMEWORK

As described in section III, cognitive capability in CRRM framework includes three types of capabilities: knowledge-gathering capability, reasoning capability and learning capability. In such framework, these three types of capability can be further divided into more detailed sub-capabilities.

1) Decompounding of Knowledge-gathering capability

Broadly speaking, knowledge-gathering is not limited to the propagation characteristics but includes all information from experience, environment and rules. The method of knowledge-gathering can be sensing or reading database built by operators or regulars. Thus, knowledge-gathering capability can be reflected by observing capability, filtering capability and storing capability.

- Observing capability

  Observing does the first step in building deep knowledge, developing a thorough understanding and a systems context awareness of the environment. Therefore, observing capability represents the ability to "observe" the surrounding environment and recognize, i.e. identify information that is relevant to communication. Observation information can be derived from internal resource (such as radio capabilities, within system activity) and external sources (such as external environmental sensors, policies, outside system activity).

- Filtering capability

When acquiring magnanimous amount of information by observing, useful information need to be selected. Therefore, filtering capability is necessary. Filtering capability represents the ability to select observation information so as to reduce the complexity of a situation or environment by objectively filtering out the irrelevant aspects.

- Storing capability

Storing represents the ability to store the filtered information so as to minimize storage and computational expense and easy to retrieve the information relying upon algorithms.

Note that the short and long-term knowledge forms part of the input and ultimately influences the reasoning process outputs and desired actions.

2) Decompound of Reasoning capability

Reasoning identifies causal or correlative connections which may become crucial to understanding the situation, and makes rational decisions and draws logical conclusion following complex, long-term strategies and the current states of environment. Reasoning mainly includes two types of capabilities: knowledge analyzing capability and action set making capability. The detailed description can be found in the following.

- Knowledge analyzing capability

Knowledge analyzing capability represents the ability to analyze information relating to current and historical state, actions, conclusions, objectives in the reasoning process, to identify the similarities from the knowledge database and invoke a sequence of previously successful procedures in an attempt to accelerate the completion of communication tasks, and to identify that the desired communication task are not the same as previously experienced by the system, or the ensuring changes that eventually lead to success or failure.

- Action set making capability

Action set making capability represents the ability to make rational decision following the results of knowledge analyzing, and finally to try finding out a solution including the list of required components, structural configurations or possible reconfiguration instructions for existing structures, component parameter-values and deadlines by which the action set should be implemented.

3) Decompound of Learning capability

The learning is responsible for manipulating the knowledge from experience, lessons and augmenting the list available actions to the system that allow it to adapt to a changing environment. Characteristics of learning are as follows.

- Summarize learning capability

Summarize learning capability represents the ability to analyze the experience for acquiring failure or success steps, which can be used the latter reasoning reference, to interpret one's experience and, as a consequence, choose or change one's behavior in next time. This involves observing a series of events, selecting the aspects or traits that can be related to one another, and weaving those aspects together into a tapestry that blends the piece parts to form a coherent picture.

- Knowledge reanalyzing capability

Knowledge reanalyzing represents the ability to reanalyze the before solutions whether or not is the best scheme using new information, to view a situation holistically and identify the complex interrelationships among information.

V. CRRM Considering Cognitive Capability Heterogeneity

In the future network, maybe each node with cognitive capability makes decision by itself. As mentioned before, we need to considered cognitive capability heterogeneity in the CRRM framework. Assume that there are two nodes with different cognitive capability, where node 1 is with high and node 2 is with low. Node 1 with high cognitive capability may find an existing solution within the stored knowledge for solving the current problem, or find an optimal solution in a short time. While node 2 with low cognitive capability may find an optimal solution in a very long time, or find a solution which can not really solve the current problem. In this paper, a cognitive radio resource management method based on cognitive capability heterogeneity is proposed in the following.

A. Quantifying Cognitive Capability

As described in section III and IV, cognitive capability can be divided to multiple types of capabilities, such as knowledge-gathering capability, reasoning capability and learning capability. Moreover, these capabilities can be further divided into multiple types of capabilities. For example, knowledge-gathering capability can include observing capability, filtering capability and storing capability. To some extent, cognitive capability heterogeneity means difference of multiple capabilities. Therefore, cognitive capability heterogeneity can be quantified by cognitive capability level L, which is defined as:

$$L = f(K, R, S) \tag{1}$$

Where K represents knowledge-gathering capability, R represents reasoning capability, S represents the learning capability. To some extent, K is related to observing, filtering and storing capability described in section IV. R is related to knowledge analyzing and action set making capability described in section IV. S is related to summarize learning and knowledge reanalyzing capability described in section IV.

Therefore, cognitive capability heterogeneity can be represented by cognitive capability level *L*.

B. CRRM with cognitive capability level matching the reward

Cognitive radio resource management with cognitive capability level matching the reward is as follows.

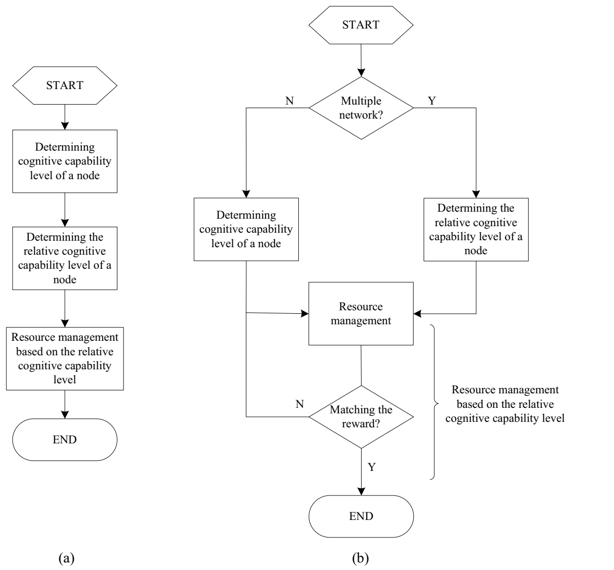

Figure 3. Cognitive radio resource management with cognitive capability level matching the reward

In such procedure, the CRRM firstly determined cognitive capability level of a node. If there are multiple networks coexist, the CRRM need to determine the relative cognitive capability level of a node. Secondly, the CRRM implemented resource management based on cognitive capability level. Finally, depending on whether matching the reward or not, the CRRM determine whether continue to resource allocation or not.

C. CRRM with fairness

In the above description, we discuss cognitive resource management procedure with cognitive capability level matching the reward. However, from the review of fairness, how to identify and help node with low cognitive capability make more precise decision is the issue which is worth being explored. The cognitive resource management with fairness can be found in Fig.5.

It can be seen from Fig. 5, shared deciding entity is introduced. The shared deciding entity is with two basic functions:

- Node cognitive capability decision. The shared deciding entity compare CRRM decision of node with itself decision considering the same condition as node. If the times which decision of node is the same as itself decision is more than a times threshold, it think this node is with high cognitive capability, else low cognitive capability.

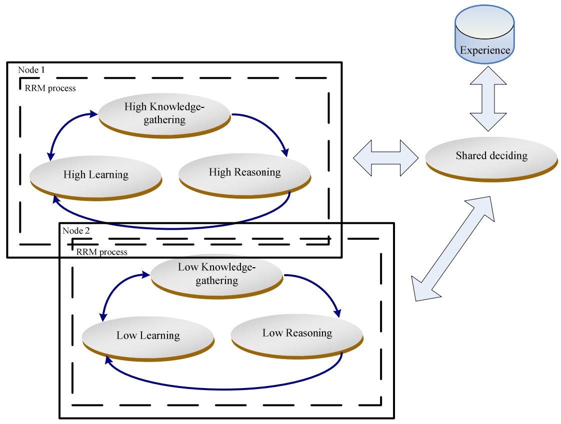

Figure 4. Cognitive Resource Management with fairness

- Node decision coordinator. The shared deciding entity help node with low cognitive capability to make correct decision. For example, when the problem which node with low cognitive capability faced with is similar with the problem stored in expert system, it can search an optimal solution and tell that node in a short time. Even the expert system can instruct node with high cognitive capability to help node with low cognitive capability, such as part of CRRM task of that node.

VI. Conclusion

In this paper, we developed a CRRM framework in which each RRM process introduces cognitive capability including knowledge-gathering, reasoning and learning. Additionally, these capabilities in the CRRM framework are further defined. Moreover, we also developed a CRRM framework with cognitive capability heterogeneity, including cognitive resource management with cognitive capability level matching the reward and that with fairness.

References

[1] S. Haykin, “Cognitive Radio: Brain-Empowered Wireless Communications,” IEEE JSAC, vol. 23, no. 2, Feb. 2005, pp. 201–220

[2] Petrova M., et al., “Evolution of Radio Resource Management: A Case for Cognitive Resource Manager with VPI”, IEEE ICC, Jun. 2007, pp. 6471-6475.

[3] Saatsakis A, et al., “Cognitive Radio Resource Management for Improving the Efficiency of LTE Network Segments in the Wireless B3G World”, DySPAN, Oct. 2008, pp. 1-5

[4] S. Haykin, “Foundations of Cognitive Dynamic Systems”, http://soma.mcmaster.ca, Sep. 2008.

[5] Ian F. Akyildiz, et. al, NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey,elsevier computer networks,pp. 2127-2159, 2006.