Self-management of Autonomous Agents Dedicated to Cognitive Radio Networks

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Abstract. An autonomous network is a network that is able to self-manage and deliver a service based on the resources of its nodes, it follows the concept of autonomous computing, its goal is the creation of self-management networks to support the growing complexity of internet and allow the expansion of networks beyond their current sizes. In the field of networks, cognitive radio could be considered as an intelligent agent able to adapt to its operational context, it also offers a balanced solution to the problems of spectrum congestion. The concept of cognitive radio is based on the dynamic use of any available and detectable frequency band of the radio spectrum for communications between networks of two categories, namely primaries, which have controlled and prioritized access to spectrum and the secondary ones say cognitive. In this paper, we are interested in the dynamic and intelligent management of radio resources as part of a cognitive radio network using mechanisms based on autonomous learning techniques. We have proposed a new approach for the efficient management and sharing of radio spectrum.

Keywords: Autonomous network · Cognitive radio · Learning · Modeling · Adaptation

1 Introduction

Cognitive radio (CR) has been used frequently to refer to a system that is aware of its environment and uses this information [1]. CR was formally presented in 1998 by Joseph Mitola at a seminar at the Stockholm Royal Institute of Technology, later published in an article by Mitola and Maguire Jr. [2]. The principle of cognitive radio included in the IEEE 802.22 and IEEE 802.16h standards [3], Sometimes it is considered more closely as a system with great frequency agility to explore the opportunities that may exist in the spectrum of frequencies. This allows for good spectrum management by occupying or exploiting unoccupied radio spectrum bands and, of

M. Hatti (Ed.): ICAIRES 2019, LNNS 102, pp. 372–380, 2020.
https://doi.org/10.1007/978-3-030-37207-1_39

course, improving spectrum management. That does it through the software restricted radio SDR (Software Defined Radio). The SDR is a radio system capable of adapting to any frequency band and receiving any modulation using the same hardware [4]. The CR system requires four main functions that allow it to use spectrum opportunistically [5]. These functions consist of the main steps of the CR terminal for spectrum management. These are: spectrum detection, spectrum decision, spectrum sharing and spectrum mobility [6]. Autonomy in networks has brought about a real change in IT systems and the realization of autonomous systems has revolutionized the world. Even if people could somehow find enough qualified people, the complexity exceeds the human capacity to manage it. As computing evolves, connections, dependencies, and interactions with overlapping applications require administrative decision-making and faster responses than anything man can offer. Based on the concept of autonomous computing but in the domain of networks, autonomous networks are generated by four complementary and self-managed aspects, namely self-optimization, self-configuration, self-protection and self-management. healing. These four elements form the basis of our study on cognitive systems [7]. We focused on two characteristics of cognitive systems, namely self-management and quality of service of certain types of transmission. Our objective is therefore to satisfy this type of application for autonomous networks based on the RC [8]. In this article, we propose a new approach in the cooperative and competitive multi-agent system for autonomous agents of cognitive radio based on self-management agents of different types of transmission ensuring the good functioning of cognitive systems. We will see in section two, the learning base proposed autonomous cognitive radio based on allocation of spectrum for autonomous cognitive radio networks so to see the importance of self-management in cognitive radio. Then we will see in section three the results of simulations of some types of applications for cognitive radio with the Java Agent Development Framework (JADE) platform.

2 Proposed Approach

2.1 Target

The wide deployment of digital systems and the complex management of modern technology both require the need for autonomy which has become a necessity in all application areas. Networking is benefiting more and more from functionalities that allow computer systems to get closer and closer to the human brain networks. several works in the field of dynamic spectrum allocation for autonomy-based cognitive radio [9] and QoS [10] are intended for the study of the hardware layer of the Open Systems Interconnection (OSI) model, as part of present work and continuity with our previous work [11], we are interested in a new approach to autonomy for upper layers (OSI model), which is presented as a complement to what has already been done in an earlier article [11], in order to show a new aspect of cognitive radio (CR), while remaining closely related to this CR area. In addition, this approach enables to address different points of autonomous management of a cognitive system by improving the negotiation between users and also the learning operation of the selected decisions.

In view of what has been reported in the article [11], the secondary user, also known as a cognitive radio user, SUi tries to communicate at any cost with a primary user PUj having a license on the radio spectrum (i and j are two different integer numbers), but sometimes it is difficult to ensure channel availability. The Learning Base for Autonomous Agent (LBAA) allows for a better channel allocation by introducing autonomous mechanisms that are capable of adapting to any radio environment.

2.2 Principle

In Fig. 1, it is assumed that we are in a competitive and cooperative environment. Each secondary user (SU) detects a part of the spectrum with a set of primary users (PUs). The secondary users (SUs) proceed with the negotiation in order to share the spectrum with one of the primary users (this step is detailed in the article [9]). The secondary users (SUs) compete with each other to share a specific number of channels with the corresponding primary user (PU):

- The primary users (PUs) displayed in red cannot satisfy the requests of the corresponding secondary users (SUs) but its information will be stored in LBAA. The primary users (PUs) displayed in yellow have received no requests from the secondary users (SUs); The primary users (PUs) displayed in green share the spectrum with the requesting SU, as shown in Fig. 1.

However, each secondary user is going to cooperate with the other secondary users (SUs) through a Learning Base for Autonomous Agent (LBAA). This database allows detecting all the secondary agents or users (SUs) that are in need and to collect all information about them in order to help them choose the best primary users (PUs) that are compatible with their requests.

In its display table, the Learning Base for Autonomous Agent (LBAA) stores all the information on all secondary and primary users (SUs and PUs), in an autonomous manner (the number of channels requested by the SUs, the number of channels that can be allocated by the PUs, and the failure or acceptance of negotiation in case of risk of interference). If the secondary user (SU) shares a spectrum with a primary user (PU), it will be removed from the learning base and the information collected on the PUs will be recorded and suggested to other SUs in need. Now, if the secondary user (SU) is not satisfied in the area it has detected, the results found will be communicated to other SUs in need of PUs through the Learning Base for Autonomous Agent (LBAA); this SU will then be redirected to other PUs which can be suggested by the same autonomous base.

Figure 1 enables us to have more insight about the autonomy of this learning base. It helps us see and understand the suggestions proposed to the new SUs as well as to those which have still not found a corresponding PU (like the SU4 in the given example). It can also be noted that the primary users PU2,5,6 and PU13 suggested to the secondary user SU4,5,6,7 and SU8 are in red or yellow (without even being consulted by these secondary users). This has become possible thanks to the information provided by LBAA.

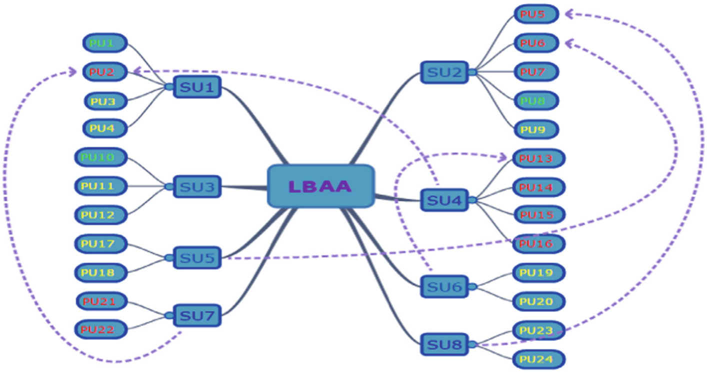

Fig. 1. LBAA approach.

2.3 Architecture of LBAA Approach

To better understand our approach, we tried to introduce an architecture based on real parameters. The first step is based on the secondary user (SU) who seeks to share the spectrum with the primary user (PU) either through direct negotiation (see article [11]), or by including the learning base of an autonomous agent (our approach). We were inspired by [12] in developing a real architecture capable of being self-managed in a radio environment. Figure 3 illustrates three high levels of standalone elements, such as a network manager, like an operator or server, which resides in the network areas or is present in the service layers. In the cognition level, different secondary users communicate with the LBAA which suggests the PUs that are compatible with their criteria. In the same context, the SUs will in turn communicate with the PUs through the primary providers that are present in the network level. These hierarchical, or rather structured, levels allow us to understand the functioning of our approach despite the autonomy of its individuals. During the autonomous management phase, the LBAA carries out the collection of information, the filtering and reporting of the data collected from the element to be managed using the sensors of the radio environment. These data are derived from the resources exchanged between the secondary user (SUi) and the Learning Base for Autonomous Agent (LBAA). The LBAA also monitors and analyzes the models, if necessary, and teaches the element the knowledge-acquisition. Also, this LBAA may include requests for suggestions to other SUs in need, in future situations. The planning step provides a mechanism structure for the actions to be taken as needed; the main objective is to facilitate communication between cognitive users. The execution of one part of the autonomous management phase gives the architecture a harmonious control of the orders in progress. The autonomous manager makes it possible to know if the commands have completed the required actions and also to update its knowledge base.

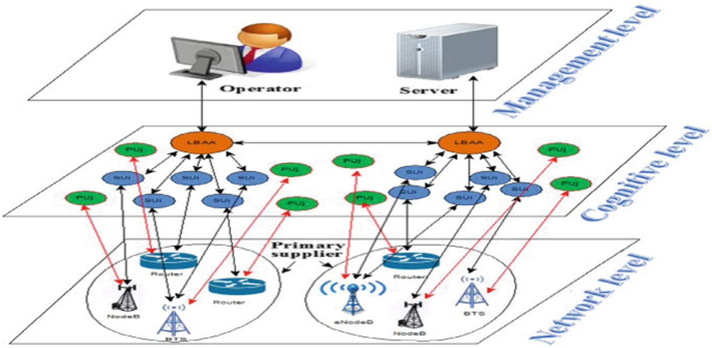

Fig. 2. Architecture of autonomous manager reacting with a cognitive environment.

3 Simulation Results of Our Contribution

The new approach was simulated in the same JADE platform [13] To validate the effectiveness of our proposed LBAA approach, JADE is a software Framework to develop agent applications in compliance with the FIPA specifications [14] for interoperable intelligent multi-agent systems. With 24 agents for the primary users (PUs), 8 agents for the secondary users (SUs) and one agent for the LBAA database. Figure 3 shows the average of the convergence times of the eight SUs for the ten attempts to communicate with the different PUs. SU1 has the highest average convergence time, exceeding 273 ms, and this may degrade and eventually harm its quality of service (QoS). The convergence time is also high for SU2, with more than 254 ms. This is also true for SU3 and SU4 whose convergence times exceed 230 ms. Also, the convergence time of the second four SUs is much smaller than that of the first four ones thanks to the suggestion from the LBAA base. Here, the convergence time is between 215 and 220 ms for SU7 and SU8. This time is considerably smaller than those mentioned above. The convergence time of SU6 is less than 185 ms; SU5 has an optimized time of 138.9 ms which represents the best average compared to those of all the other SUs.

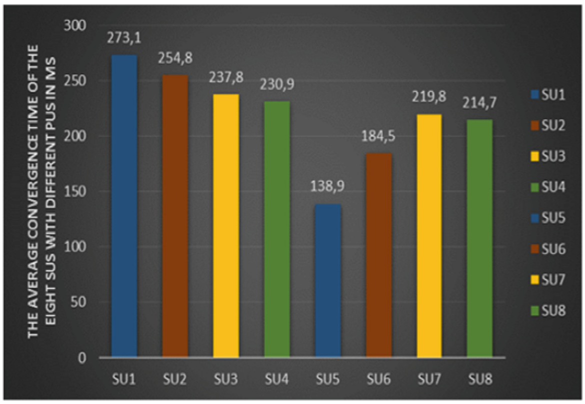

Fig. 3. The average convergence time between the eight SUs and their PUs for ten attempts communication.

On the other hand, Fig. 4 shows the average success rate of spectrum sharing for the 8 SUs with different PUs. For the first four SUs, the average success rate is 85% for SU1, which has the smallest success rate but still with a good result; it is 88% for SU2 and SU4, and 90% for SU3, which attained the best result among the 4 SUs. For the second four SUs, SU7 has a success rate of 85%, a rather mitigated result mainly because there is no suggestion from the LBAA. On the other hand, the success rate for SU8 is the same as that reached for the best of the first four SUs, namely 90%. Also, the success rate for SU6, which is 95%, is very close to the ideal spectrum sharing. Finally, SU5, which has the best success rate of 100%, makes the secondary user flexible to all suggestions and negotiations.

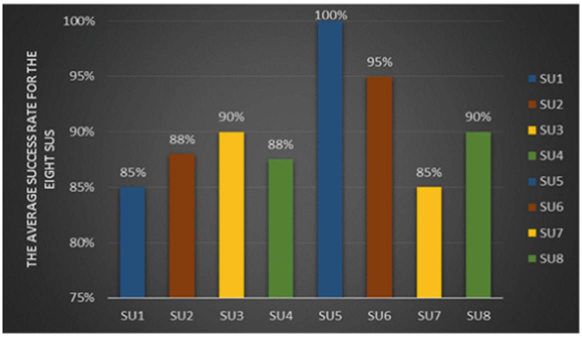

Fig. 4. The average success rate of spectrum sharing between the eight SUs and their PUs for ten attempts communication.

3.1 Interpretation of the Simulation Results of Our Contribution

The results found for the 10 communication attempts allows us to estimate the precious time that the secondary users (SUs) can gain while seeking the adequate PUs, and with a quality that meets their radio spectrum allocation requirements. Moreover, most of the SUs using the LBAA base have a success rate that is nearly complete (100%). The use of this database is not compulsory but rather suggestive. All decisions made by the agents, whether SUs, PUs or LBAA, are programmed autonomously in order to interact dynamically and in a flexible way with their environments.

3.2 Comparing the Simulation Results from Different Contributions

The QoS requirements of video conferencing are described in Cisco networks. Cisco is a network that was originally created for the city of San Francisco in the United States of America. There are two main types of video traffic, namely the interactive video (video conferencing) and video streaming (both unicast and multicast). Our study focused on interactive video, with the other three types of transmission cited before. When provisioning for interactive video (videoconferencing), the following guidelines are recommended:

The loss rate should not exceed 1%,
The one-way delay or latency (delay time for transmission) should not exceed 150 ms,
The jitter should not be more than 30 ms [15].

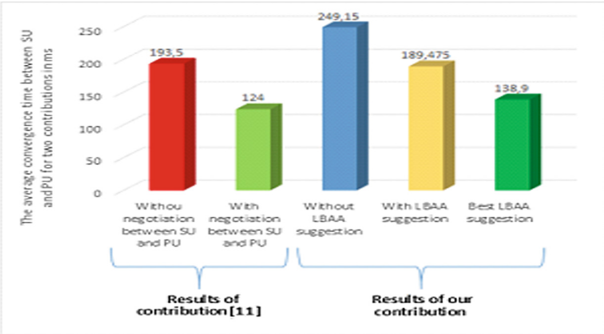

Fig. 5. Comparison between two contributions of the convergence time of SU and PU communication.

Figure 5 illustrates the comparison between different results of simulations of the two contributions (the reference contribution [11] and the new contribution) for the transmission of the video conference, based on the criteria required for the video conferencing quality of service. It was decided to continue on the same track and compare the two contributions on this same type of transmission. The average convergence time for the first contribution is 124 ms in the presence of negotiation between the secondary user SU and the corresponding primary user PU. This value is much smaller than that obtained in the case where there is no negotiation; here the average convergence time is equal to 193.5 ms. Compared to the second contribution, it was found that the average convergence time for the first four SUs without LBAA suggestion is 249.15 ms. This time is too high compared to that of the contribution proposed by [11]. On the other hand, the average convergence time for the second four SUs with the suggestion from the LBAA is much smaller than that of the first four ones, but this time remains a little worse than that of the contribution suggested by [11], with 124 ms. The secondary user SU5 presents the best result in the presence of a suggestion from the LBAA, with an average convergence time equal to 138.9 ms, which is less than the time of 150 ms required for the QoS in the literature [15] and quite close to the value found by [11], which remains the best result obtained for the convergence time.

Figure 6 compares the average success rates found in the two contributions regarding the QoS of the video conference. The results reached with our approach are much better than those reported in reference [11]. The average success rate exceeds 91% when there is negotiation between the secondary user (SU) and the primary user (PU), whereas in the case without negotiation, this rate is only 68.75%. The results of the approach developed in this article are much better, with a success rate of 93% for the second four SUs in the presence of the LBAA suggestion. This rate is higher than that of the first four SUs (without LBAA suggestion) and that of the contribution proposed in reference [11]. Finally, the secondary user SU5 has the best average success rate of spectrum sharing with 100% success rate, a value that ensures the QoS required in the literature [15], where the loss rate must be less than 1%.

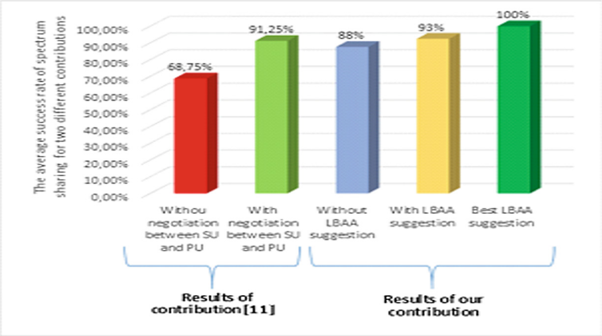

Fig. 6. Comparison between two contributions of the success rate of spectrum sharing between SU and PU

3.3 Interpretation of Results from the Comparison of the Two Contributions

The results of this contribution are satisfactory. They have addressed issues related to spectrum management. The results obtained have a direct positive impact on the quality of service (QoS). The response time, error rate and jitter in our contribution are in accordance with the QoS requirements of video conferencing. Our results are better than those proposed in the article [11]. Autonomy in decision making allows cognitive systems to be less dependent on administrators, with good management of the radio spectrum.

4 Conclusion

This article addressed the aspect of autonomy in cognitive radio systems. Multi-agent systems were used to study the behavior of these agents and to analyze the interactions between them, using a self-management system allowing cognitive users to better share the radio spectrum with minimal interference between the various primary and secondary users. Several architectures and descriptions have been put forward in this article to better understand the aspect of this new approach of the LBAA and to better appreciate the usefulness of this autonomous learning base.

This new contribution allowed us to develop an algorithm that illustrates the communication of secondary users with the autonomous learning base and with the primary users. Subsequently, the results of the learning base simulation were found to be conclusive, with a significant gain for the cognitive radio. The system relies on autonomous management and learning; it is capable of manipulating the spectrum in an opportunistic and reliable manner. Finally, the results of our new approach were compared with those of the contribution provided in [11] in order to better apprehend the quality of service of video conferencing.

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