Intelligent Mobile Agent Application for Spectrum and Network Management in Cognitive Radio Networks

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Abstract: Cognitive radios are radios that improve spectrum efficiency and spectrum utilization by operating on unused spectrum channels in their neighborhood. This technology offers a new mechanism for flexible usage of radio spectrum and a broad range of exciting prospects in networking research. This includes the creation of intelligent mobile agent middleware that generates an intelligent framework for deploying applications in cognitive radio networks. In this paper we propose an intelligent mobile agent model for resource and network management in a cognitive radio network, based on the injection of mobile agents into the network that can migrate or clone, following specific rules and performing specific tasks. This model discusses strategies or methods for spectrum decision, spectrum mobility, spectrum sharing, agent mobility and agent cloning.

1. Introduction

Cognitive radio technology is the key enabling technology for dynamic spectrum access (DSA), which makes it possible for unlicensed users to opportunistically share the frequency channel with the licensed user [1]. The idea of this technology was conceived due to the inefficient way the spectrum was being used, in addition to the increase in spectrum demand due to new applications. Wireless frequencies are assigned statically to specific users and for specified use leading to simplicity and better service quality. The drawback of this static allocation is that it leads to very inefficient use of the spectrum because many allocated frequency bands are significantly underutilized [1,4,6].

Cognitive radios can sense and react to its operating environment by dynamically adapting itself for good application and network performance [1]. These characteristics enable them to autonomously identify unused frequency bands and allow for usage of idle licensed frequency bands by unlicensed users. Cognitive radio networks are therefore composed of cognitive, spectrum-agile devices capable of changing their configurations on the fly based on the spectral environment.

However, as cognitive radio data and communication networks become more complex and distributed in nature, typical cognitive radio networks with control channels suffer from scalability and flexibility problems as it involves frequent signal and data transmission towards the control channel for processing. Secondly, there are multiple radios in a cognitive radio network, each vying to make use of the temporarily available spectrum hole. In this sense, a dynamic intelligent scalable resource distribution and management model based on intelligent mobile agents provides an attractive perspective to the lack of flexibility and scalability of such control channel systems [4,5,6,7].

Agents are programs that perform certain or specified tasks on behalf of the user. Mobile agents perform a user’s task by migrating and executing on several hosts connected to the network. The main difference between an intelligent agent and traditional agent is that the former perform not only actions pre-specified by a user but also those necessitated by later changes in the environment. Mobile agents introduce a new software and communication architecture, allowing a program to travel between machines for remote execution, even in heterogeneous cognitive radio networks. By transporting the agent code to the host machine in a distributed cognitive radio network, there is no need to bring intermediate signals and data across the network and thus a significant amount of network bandwidth use and communication delay can be avoided [2,3,14,16,19].

Spectrum resource distribution among secondary users is an important issue in a cognitive radio
network environment [4,5]. Control channel-based network management frameworks suffer from problems such as interoperability, reliability, flexibility and scalability, as the cognitive radio networks become more geographically distributed [6,7,8,9]. In this paper, we propose an intelligent mobile agent framework for resource distribution and network management in a cognitive radio environment. The intelligent mobile agent code will be injected into the network to detect, decide and distribute spectrum resources efficiently amongst the radios in the network.

2. Agent System Architecture

In this system, the intelligent mobile agent for cognitive radio networks (IMACRN) middleware is based on the injection of mobile agents in the network that can migrate to other nodes or clone to perform specific tasks. By doing so, each agent is given a certain degree of perception, cognition and control, forming the basis of its intelligence. A mobile code daemon (MCD) runs within a Java Virtual Machine (JVM) on each network component. Java is used because it supports code mobility. While resident in the network, mobile agents access managed resources through the Virtual Managed Component (VMC). The agents solve problems by moving over the nodes and links in the network and interacting with “chemical messages” deposited in that network. These messages are stored within virtual managed components (VMC) and are the principal medium of communication used between groups and individual agents. Chemical messages are used for communication instead of raw operational measurements from the network in order to separate measurement from reasoning. Also, chemical messages drive the migration patterns of the agents, the messages intended to lead agents to areas of the network which may require attention.

JAVA is used for IMACRN to ensure interoperability on any network device, regardless of the underlying hardware platform or operating system. IMACRN are JAVA objects capable of migrating between hosts, where they execute as separate threads and perform their specific tasks. They are supplied with an itinerary table, a data and signal folder, where they store collected information.

The system architecture consists of distributed mobile agents working cooperatively in supporting and managing the cognitive radio network environment. The services provided by the mobile agents includes resource discovery, node monitoring, scheduling of agents and resource sharing. The mobile agents are autonomous and have the ability of migrating among hosts to maximize resource utilization.

To improve the cognitive radio networks scalability, stability and availability, multiple control channels are used instead of a single control channel. Multiple control channels will increase the throughput of the cognitive radio services and they can work together to provide services for a same part of the cognitive radio network environment. Services for different parts of the cognitive radio network environment can be distributed to multiple control channels, thereby, dynamically balancing the workload on the control channels.

The system functions are divided into independent tasks and the tasks are modeled as intelligent mobile agents which are not bound to any fixed node. Therefore, it can autonomously migrate or clone at any suitable cognitive radio node to distribute spectrum more pervasively, to ensure real-time performance and avoid collisions and starvation.

3. Agent Migration and Cloning

For the system workload to be effectively decentralized, the IMACRN software system is modeled as a group of collaborative intelligent agents. Each agent is a lightweight software component which provides a certain service for controlling the system signal and data flows. Intelligent mobile agents collaborate autonomously with each other to maintain the cognitive radio network and they can automatically migrate or clone to any qualified participating node to dynamically distribute the workload and ensure high quality cognitive radio network performance. The mobility of agents in IMACRN has two forms: agent migration and agent remote cloning (Fig. 1).

Agent Migration: is a mobile action to transfer an agent with its run-time state from one host to another, without degrading the real-time performance of the cognitive radio network application. Agents migrate from overloaded nodes to less loaded ones so that they will have sufficient computing and network bandwidth resources to provide their services. Agents can also migrate to nodes close to user nodes to enhance their service quality. Agent migration provides a method to distribute the system services to multiple hosts. In IMACRN, the state and the code are transferred together only when an agent is migrating for the first time because the JAVA class loader stores every loaded class on a local code cache.
Agent Remote Cloning: agent remote cloning is a mobile action to create a new instance of an agent with its run-time state at another host. After the remote cloning, the cloned agent provides the same service corporately with the original one. Agent remote cloning provides the mirroring service at a remote host, which can enhance the throughput of the service. In our approach, agent remote cloning provides a method to distribute the workload of a same service to multiple hosts.

![Diagram](image.png)

Fig 1: Intelligent Mobile Agents in Cognitive Radio Networks

Agent A, B and C ran at a busy control channel CC1 (fig 1a), to avoid potential bottleneck emerging at the busy CC1, B and C automatically migrate to other less loaded control channels CC2 and CC3. A automatically clones new instances A1, A2, A3 and A4 respectively at four trusted cognitive radio nodes CR and B also clones new instances B1 and B2 (fig 1b).

4. Agent Deployment

In IMACRN, tasks are performed by the agents. Because of the dynamic user interaction, the fluctuation of available resources and the ever changing nature of network traffic, the workload of each agent or node vary over time in a nondeterministic way. On the other hand, each agent is an autonomous entity which is self-aware, with their own performance and resource requirements. Three sub-processes are used to deploy mobile agents to nodes in a cognitive radio network. These sub-processes are: mobile action initiation, mobile action reasoning and node discovery [Fig 2].

(i) Mobile action initiation: this determines when it should propose an agent mobile action to avoid the degradation of the cognitive radio network performance.

(ii) Mobile action reasoning: here, when an action is initiated, the mobile action reasoning process begins and proposes which agent should perform a mobile action and what mobile action the agent should perform.
(iii) **Node discovery**: after the above steps, an agent is selected and it will migrate to the ideal node found. If the node still has agents running on it, the agent will return back to mobile action reasoning.

![Agent Deployment Process Diagram](image)

**Fig 2: Agent Deployment Process**

5. **Migration Control**

When starting an agent with a predefined itinerary, a copy is stored at the originating location. A failure at the station or node currently hosting the mobile agent does not necessarily lead to a breakdown of the agent’s task, since an up-to-date copy of the agent’s itinerary is kept at the originating location and a new agent can be created in order to visit the remaining stations or nodes of the itinerary.

6. **Agent Spectrum Decision and Sharing**

The IMACRN is encoded to sense and detect primary user signals and send the information to the cognitive radio network. A predefined set threshold $Y$, is also input in the code for use in measuring the observed signal. This will help the radios to concentrate more on using the available spectrum without having to intermittently check for the presence of the primary user. The agents will individually or collaboratively detect active primary user transmissions over the band, and decide if the sensing results indicate that all the primary user transmitters are inactive at that band (Fig. 3).

To buttress this point, let us represent spectrum sensing by agents as follows:

\[
\begin{align*}
Y & = \text{a set threshold} \\
S & = \text{result obtained from sensing the spectrum} \\
\text{if } S > Y & \text{ then Primary User is Present} \\
\text{else} & \\
\text{if } S < Y & \text{ then Primary User is Absent.}
\end{align*}
\]

The set threshold $Y$ will be used to determine and measure the reliability of the collected results. When the collected signal $S_i$ exceeds the threshold $Y$, decision 1 will be made which assumes that the primary user is present; otherwise, decision 0 will be made. The decision $D_i$ of the agents is then given by:

\[
D_i = 0; \text{ where } 0 < S_i < Y \\
D_i = 1; \text{ where } S_i > Y
\]

![Agent Spectrum Decision and Sharing Diagram](image)

**Fig 3: Agent Spectrum Decision and Sharing**

**IMACRN-BASED SPECTRUM SHARING**

One of the important issues in cognitive radio networks is avoiding devices colliding and interfering with each other while efficiently utilizing the spectrum. Spectrum holes are not utilized by the secondary users for free, it comes at a price, and therefore they have to first negotiate with the primary user or primary user agents before using the spectrum. Also there are multiple agents, primary users and secondary users in the network, therefore, at a time, multiple primary users can have multiple free spectrums available to secondary users and multiple secondary users may also need to use spectrum at the
same time. Having access to spectrum and spectrum sharing are key issues facing opportunistic communication in multi-user cognitive radio systems. It involves user priority, whereby there is a primary and a secondary user, and so they pose unique challenges which are not encountered in ordinary wireless systems.

Spectrum availability varies over time and space in a cognitive radio network, therefore a dynamic spectrum sharing capability is required to allow for fair allocation of spectrum resources and capacity optimization while avoiding starvation problems. Mobile agents should coordinate usage and access to the free channel in a cognitive radio network in a dynamic, fair and organized manner. A cognitive radio network is made up of primary users and secondary users coexisting to utilize the available spectrum, therefore IMACRN spectrum strategies for spectrum sharing is divided into two schemes: a) primary user agent and secondary user agent spectrum sharing agreement scheme and b) secondary users local spectrum sharing scheme.

**PU AGENTS AND SU AGENTS SPECTRUM SHARING AGREEMENT SCHEME**

Improvement in spectral efficiency can be achieved through efficient primary-secondary user sharing. The quality of service guarantees for the primary user is made possible since the primary user has the license and usage rights and no harmful interference is caused by the secondary users in their activities. In cooperative sharing, there is interaction between the primary and secondary users, whereby the secondary user asks the primary user to allow it use the spectrum before using it, asking for permission before usage. This is advantageous to both the primary and secondary users because it creates opportunities for both the primary user to demand payment and for the secondary user to be guaranteed good quality of service.

IMACRN is a multi-agent system, with its agents deployed over primary and secondary devices in the network. In order to make spectrum sharing agreement, secondary user agents sends SR messages to the appropriate neighbouring primary user agents whenever it requires spectrum, and the corresponding primary user agents sends their replies to start a spectrum sharing negotiation. The process for spectrum sharing starts with a secondary user getting the user requirements and the result of spectrum characteristics. The process goes on until it sends its SRs, receives the replies and then ending in the secondary user having an agreement positively or negatively. A primary user goes through a similar process, it analyzes the SRs received, sends the replies, and ends by receiving a message from the requesting secondary user either accepting or rejecting the proposal. On receiving a message accepting the conditions, spectrum sharing begins between the secondary user and the primary user and goes on until the free spectrum is utilized completely and the agreed price paid. In a situation whereby more than one proposal received by the secondary user is satisfactory, a first in first out (FIFO) method is used to make a decision.

**SECONDARY USERS LOCAL SPECTRUM SHARING SCHEME**

On acquiring the spectrum from the primary user agents, secondary user agents also need to coordinate the allocation and distribution of spectrum amongst the competing secondary users. A priority-based spectrum strategy is used in IMACRN for spectrum sharing amongst cognitive radios, whereby radios with high priority are considered first and those with low priority are considered last.

**Secondary Users Local Spectrum Sharing Algorithm**

//Spectrum is shared through the use of a Prioritized Queuing Model:

Class 1 requests: have the highest priority to receive a channel. These are handoff requests. This strategy tries to minimize the probability of disrupting ongoing communication.

Class 2 requests: are the channel requests by originating or starting communications.

Class 3 requests: are requests for channel reassignment that are not urgent.

```plaintext
if spectrum available then
    allocate spectrum to class 1;
class 2;
class 3;
allocate spectrum
```

This prioritized queuing scheme ensures that radios on handoff, which are radios that needs to vacate a channel they are using already due to the reappearance of the primary user or channel degradation, can continue communication seamlessly on the next available channel. Thus, ensuring good quality of service for the radios on handoff.

Channel requests by radios that want to start communication are considered next, and the channel can be allocated to them immediately if no class 1 requests are made. Channel can also be allocated to them immediately if there are other idle channels in the spectrum database.

Finally requests from radios that just want to switch channels for no urgent reasons are considered last. They can also get a channel immediately if there are
no class 1 or 2 requests or if there are idle channels in the spectrum database.

Spectrum Sharing

For spectrum sharing, the two agents involved in negotiations are the Secondary Consumer Agent (SCA) and the Primary User Agent (PUA). In Figure 4, the SCA sent a Call for Proposal (CFP) message to the PUA for spectrum sharing. The message indicates the agent identification, the size of spectrum needed, the duration the spectrum will be used and the time it expects reply from the PUA. The PUA then sent a reply indicating its identity, the size of spectrum it is willing to share, the holding time of the spectrum and the price in Dollar($). On receiving the PUAs proposal, the SCA sends a reply back to the PUA, either accepting or rejecting the proposal as shown in Figure 5. The results obtained for various experiments are as shown in Table 1.

<table>
<thead>
<tr>
<th>Number of PUs</th>
<th>Number of SUs in need of Spectrum</th>
<th>Number of Served SUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>28</td>
</tr>
</tbody>
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The correlation between the number of secondary users in need of spectrum and the number of secondary users served in the end is represented graphically in Figure 6.

Fig 4: Message exchange for spectrum sharing

Fig 5: Accept proposal message

Fig 6: Spectrum sharing data

From the results, a large percentage of secondary users wishing to acquire spectrum were served, which indicates that the secondary user agents (SUAs) were able to interact and negotiate successfully with the primary user agents (PUAs) for spectrum sharing.


To ensure efficient and effective function of large cognitive radio networks as well as provision of services, there is need for a coherent framework supporting automated and intelligent management solutions. In our system, the agents are divided into cognitive radio network maintenance agents and cognitive radio network monitoring agents to address the problems of network management.

Network Maintenance Agents: network maintenance agents perform repeatedly occurring management tasks, for example, the gathering of data from
selected network element or fault analysis. Their tasks are carried out repeatedly, only rarely requiring adjustments by the network management instance.

Network Monitoring Agents: network monitoring agents perform routine tasks such as filtering of raw data collected from network elements. Such agents are stationary, since their task is to monitor a concrete element of the network or a link.

7. Conclusion

Presented in this paper is an intelligent mobile agent approach addressing the problem of spectrum and network management in cognitive radio networks. Using intelligent mobile agents in cognitive radio networks as described in our approach is advantageous as it: (i) Reduces network traffic since only the required data is retrieved. (ii) Allows for parallelism by sending out multiple agents simultaneously. (iii) Allows for load-balancing by off-loading activities onto other hosts. (iv) Increases scalability. (v) Repetitive tasks are avoided. (vi) Increases fault tolerance through the autonomy and learning capability of the agents. Spectrum sharing between primary and secondary users and amongst secondary users is one of the most important issues, as it allows cognitive radio devices to coordinate in order to prevent multiple users’ collisions and conflicts in overlapping portions of the spectrum. Using the methodologies proposed, the primary user’s signal can be correctly detected and the resources fairly distributed.

References