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Spectrum Sharing and Spectrum Mobility in Cognitive Radio Networks using Intelligent Mobile Agents

NnennaChristine Eric-Nwonye and ObetenObi Ekabua
Department of Computer Science
North-West University, Mafikeng Campus,
Private Bag X2046, Mmabatho2735,South Africa

ABSTRACT
Cognitive radios (CR) are the main technology for dynamic spectrum access, which makes it possible for unlicensed users to opportunistically utilize temporarily free licensed spectrum, when the licensed users are not using them. However, they should vacate the channel on the reappearance of the primary user and continue their communication on another channel, this functionality, known as spectrum mobility, ensures that primary users communication does not get interrupted because of the secondary users and that secondary user maintain a good quality of service. A cognitive radio network is made up of primary and secondary users, coexisting together and vying to make use of the spectrum. Therefore a dynamic spectrum sharing method needs to be devised to ensure fair spectrum sharing amongst both the primary and secondary users. Presented in this paper are algorithmic approaches and implementations on using intelligent mobile agents for spectrum sharing and spectrum mobility in a cognitive radio network.

KEYWORDS
Cognitive radio networks, Primary user, secondary user, intelligent mobile agents, spectrum sharing, spectrum mobility.

1.INTRODUCTION
The rapid increase in wireless communication and applications has resulted in increase in the demand for spectrum, and this high demand has also resulted in spectrum scarcity that hinders the growth and development of new applications [1]. It has been found out, however, that the scarcity being experienced is not as a result of fewer spectrums, but rather because of the allocation policy used in allocating the spectrum. A static allocation method is used by the regulatory bodies in assigning spectrum to specific users and for a particular use. Research however shows that static allocation leads to inefficient use of the spectrum as most of the allocated bands are not used all the time by the licensed holders.
Cognitive radio technology was then introduced to combat this spectrum inefficiency by allowing unlicensed or cognitive users detect and make use of the licensed spectrum whenever it is idle, without interfering with the primary or licensed users. The four main functionalities for cognitive radio networks are spectrum detection, spectrum decision, spectrum sharing and spectrum mobility. These four functionalities, also known as spectrum management functions, ensures that cognitive radios utilizes the scarce spectrum efficiently without causing interference to the licensed holders [2,3].
Performing these management functions accurately is a challenge to radios in a cognitive radio networks due to certain constraints such as bandwidth constraints and high sensitivity requirements imposed on the radios [4,5]. Therefore a new paradigm, such as using intelligent mobile agents, seems an attractive solution to carry out these management tasks.
Agents are autonomous programs situated within an environment, which senses the environment and act upon it to achieve their goals. They are software programs which can perform specified tasks on behalf of the user. Mobile agents are agents which are not static, but can migrate to several nodes in the network to perform specified tasks. Intelligent mobile agents combine the attributes of ordinary agents and mobile agents in addition to its own unique characteristics of being able to perform tasks based on later changes in the environment, even if its not specified by the user [6, 7].
Based on these characteristics, intelligent mobile agents can be of great use in cognitive radio networks, by helping to achieve a balanced network operation and make the most out of the available radio resources. Therefore, in this paper, we present algorithmic approaches and implementations for spectrum sharing and spectrum mobility, having done same for spectrum detection and spectrum decision in another paper. The agents are injected in the network to ensure fair distribution of the resource, seamless communication for the secondary users and non-interference to the primary users.

2. COMPARATIVE STUDY OF EXISTING TECHNIQUES

Table 1. Existing Techniques

Researcher	Contribution
Ahmed A. et al. [8]	**Embedded Agent Modules** **Description:** Agents are embedded in the radio devices that coordinate their operations to benefit from network and avoid interference to the primary user. Agents carry a set of module to gather information about the terminal status and the radio environment and act accordingly to the constraints of the user application. An intelligent agent is responsible for managing a set of modules on each cognitive radio device. This agent oversees all the operations, including, methods for free band selection, modulation types, management of signal processing algorithms, management of data channels, energy control, security, quality of service etc. Interference from the acquisition of the channels in a cellular system during Handovers can be reduced according to using a CR to manage the handover. Indeed, the mobility of the device imposes a different behaviour when

	changing zones. The terminal must ensure service continuity of applications and the effective spectrum management. The authors propose an approach that uses negotiation, learning, reasoning and prediction to know the needs of new services in modern wireless networks. They propose an algorithm to be executed by the mobile terminal during the cognitive phase of handover.
Kloeck C. et al. [9]	**Bidding strategy** **Description:** Proposes a bidding strategy whereby radio resources can be allocated to users through prior negotiation. Users and operators are denoted by intelligent mobile agents in the auction. The strategy includes several phases and the agents embedded in the terminals include a learning module that enables to develop a bidding strategy independently.
Jiang X. et al. [10]	**Using MAS between multiple WLANs** **Description:** A technique for radio resource management using Multi-Agent Systems (MAS) between multiple Wireless Local Area Networks (WLANs) that operates in the ISM band. Intelligent agents are placed in the access points, and MAS consists of backbone that connects all the access points in the system. Agents interact with each other through the access point and exchange the state of spectrum availability in their respective coverage area. These interactions allow measuring the availability of spectrum and avoiding interference between different WLANs. This scheme seems more promising as it shows induced management of signaling loads and time delays.

3.IMACRN SYSTEM MODULE FOR SPECTRUM MANAGEMENT

Basically, our system, Intelligent Mobile Agent for Cognitive Radio Networks (IMACRN), system design is built on five different interlinked parts that forms the working of our proposed system to take care of spectrum detection, spectrum decision, spectrum sharing and spectrum mobility. However this paper deals with spectrum sharing and mobility only. Spectrum detection and decision were explained in a preceding paper. These agent modules are shown in Figure 1:

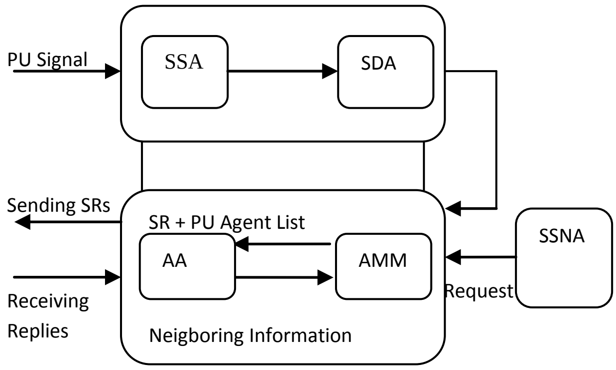

Figure 1. IMACRN system modules

i) Spectrum Sensing Agent (SSA): the function of SSA is to sense the radio spectrum holes and continuously monitor the primary user signals. SSAs cooperatively sense the channel and measure it against the threshold. Since it is not possible to know what time a spectrum band is occupied or when it is free, the sensing is done by considering a real-time dynamic environment. Factors that are taken into consideration include spectrum traffic, primary user's signal power and associated noise and sampling time intervals.
ii) Spectrum Decision Agent (SDA): SDAs characterizes the spectrum hole and its function is to arrange the idle spectrum information received through the SSAs according to channel capacity and channel information.
iii) Spectrum Sharing Negotiating Agent (SSNA): SSNAs function is to send Spectrum Request (SR) messages to the Agreement Agent, whenever a secondary user indicates that it needs to use a portion of the spectrum. The message sent is of the form: req(s,t), where s represents the size of spectrum needed by the secondary user and depends on its application, for a duration of time t.
iv) Agent Memory Module (AMM): AMMs gets the primary user's signal characterization from SDAs and stores in its database. This database list is regularly maintained and updated, thus it is not a permanent list. This module also serve as database for available spectrum and their characteristics. Based on inputs from SDA and AMM, SSNAs prepare a Spectrum Request (SR) or Call for Proposal (CFP) message

SR(SUID, s, t, d) Where,

SUID = Secondary User Agent Identification
s = Size of spectrum the secondary user needs
t = Duration of time for utilizing the spectrum
d = Deadline to receive reply from the primary user

On receiving the SRs, the primary user agents interested in spectrum sharing send their replies to the secondary user agents. The reply sent is of the following form:

REP(PUID, s,t,p) Where,

PUID = Primary User Agent Identification
s = Size of spectrum the PU is ready to share with the corresponding secondary user
t = Duration of time the secondary user should use the spectrum
p = Price the primary user wants to receive

The receiving secondary users locally sorts the replies and sends an 'Accept' message to the primary user with the most suitable reply. This information is also sent to SU-AMM to store for future interactions. Spectrum sharing then starts based on the terms agreed on from both sides. The primary user can still send replies to other SRs if it still has other unused channel portions and wants to share it.
Besides SR creation, secondary user-AMM (SU-AMM) maintains the neighboring primary user's information received through frequent interaction of the agents and lists of requests received previously. Having this information that includes the record of the nodes joining or leaving the network and current spectrum status helps an SSNA to create a precise Spectrum Request (SR). The primary user-AMM (PU-AMM) also saves the secondary user's departures and arrivals information and their spectrum demands in its database.
v) Secondary Consumer Agent (SCA): SCAs function is to coordinate or share the spectrum amongst secondary users in the network after it has been acquired from the primary user.

vi) Agreement Agent (AA): AAs manage the agreement and cooperation between primary and secondary users for spectrum sharing. After receiving an SR message from SCA, the Secondary user Agreement Agent (SU-AA) checks the PUAs currently available and sends the received SRs to them. If the primary users are in the corresponding secondary user's vicinity with their spectrum portions, they are considered to be available. The PU-AA chooses the most suitable and appropriate SR and sends the reply. The agreement which is deemed profitable and maximizes both the primary user and the secondary user utility values is taken as the appropriate agreement for both of them. The price paid by the SUAs for utilizing the spectrum divided by the size of spectrum shared by the primary user for a particular time t is known as the primary user utility. A secondary user agent's utility is size of spectrum used for a required time t divided by the price paid to the primary user.

4.AGENT 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.

4.1 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.

4.2Secondary 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.

4.2.1 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.

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

The flowchart depicting this scheme is given in Figure 2:

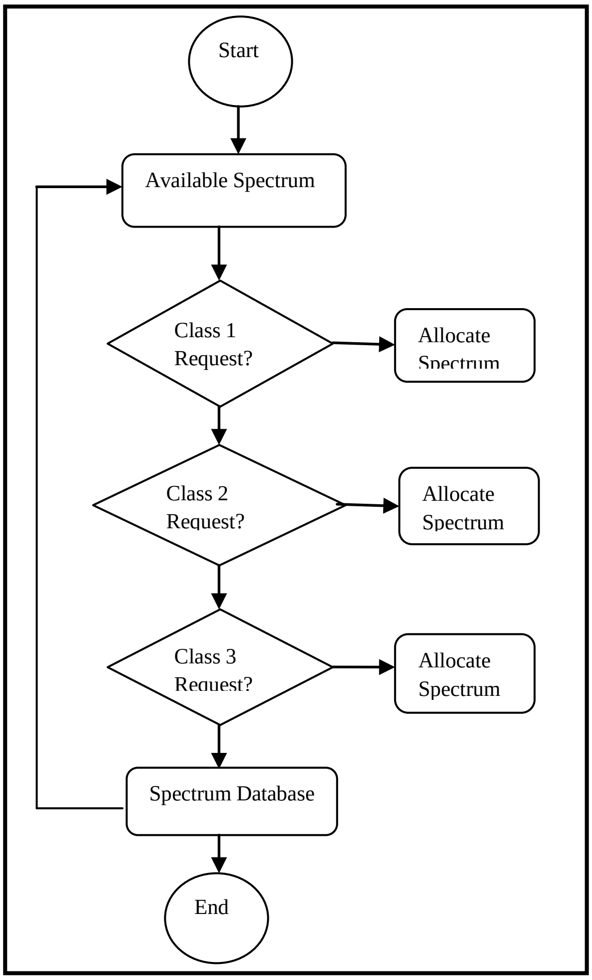

Figure 2. Prioritized queuing for spectrum sharing among secondary users

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.

5. AGENT SPECTRUM MOBILITY

Cognitive radios make it possible for users to switch channels and make dynamic use of spectral opportunities. However, channel switching takes time and may cause disruption on secondary user's transmission quality. When the channel currently used by a cognitive radio user becomes unavailable, they either switch channels or tune down their transmitter power. The activities of the primary user or license holders dictate channel opportunities of cognitive radios. The channel is available to cognitive radio users only when a primary user is inactive. Cognitive radios or secondary users have to stop usage and transmission when the primary user becomes active or else ensure the amount of interference they cause is not above a certain threshold in spectrum overlay networks.

To make use of channel opportunities efficiently, secondary users need spectrum agility, which means they need to have the ability to switch channels quickly to avoid significant interference with the license holder, make efficient use of spectrum opportunities and also reduce the amount of interference they cause for each other. However, switching channel in practice will inevitably cause disruption leading to possible broken transmission, potential packet loss and delay.

Channel switching has been extensively studied in cognitive radio networks, particularly in cases where users have stochastic channel information. In our system, agents maintain database information on the Agent Memory Module (AMM), about channel availabilities over the coming time slots, therefore users have a foreknowledge about channel availabilities over the coming T time slots. This enables them to have a spectrum mobility strategy detailing when they should perform channel switching to ensure quality of service maximization.

Spectrum mobility occurs when the primary user reappears or the current channel condition in use becomes worse. Cognitive radio networks face several challenges due to the fluctuating nature of the available spectrum, as well as the diverse service requirements of various applications. Furthermore, the primary user may appear while the channel is still being used by a cognitive radio, which will require the cognitive radio to tune down its transmitter power value or vacate the spectrum and continue its communication in another available channel.

5.1Spectrum Mobility Algorithm

//Mobile agents should ensure that cognitive radios effectively vacate the channel immediately a primary user is detected or when the channel condition becomes worse.

```
if
signal> set threshold
then
  H1 = PU present
action
reduce power value;
or vacate spectrum
if
channel condition degraded
then
H1 = channel not usable
vacate spectrum
check spectrum database
switch to the next available spectrum on the database
continue transmission
```

6. IMACRN AGENT CREATION

IMACRN agents are developed in Java Agent Development Environment (JADE), a software environment used for developing agents which comply with Foundation for Intelligent Physical Agents (FIPA) specifications. FIPA is a non-profit international association that produces specifications and standards for agent technologies. IMACRN agents creation is achieved by defining a class extending the jade.core.agent class and implementing the setup() method. This method was used to create IMACRN agents as can be seen in Figure 3

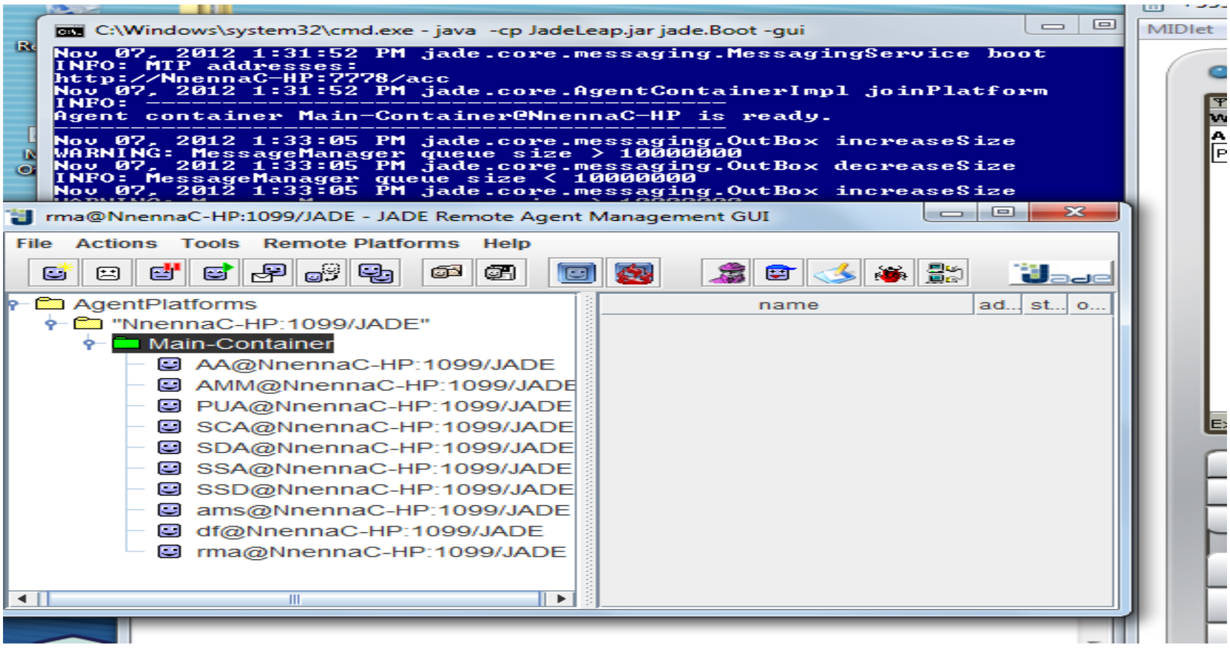

Figure 3. IMACRN agents in JADE

6.1 IMACRN Agent Identifiers

An Agent Identifier (AID) is used to identify IMACRN agents and this identifier is an instance of the jade.core.AIDclass. Retrieving the agent identifier is made possible through the getAID() method of the agent class. IMACRN AIDs include a name and an address for each agent, and has the form < name > @ < platform name >, the platform name being the address. As can be seen in figure 3, the created IMACRN agents are all living in the platform named NnennaC-HP, so as an example, the spectrum sensing agent (SSA) called SSA living in the platform have SSA@NnennaC-HP as its distinguished name.

6.2 Agent Communication

The communication method used by IMACRN agents is the asynchronous message passing. Using this method, each agent has a mail box where messages sent by other agents are posted by the JADE runtime. For message exchanges, IMACRN agents use Agent Communication Language (ACL) format defined and approved by FIPA for agent interactions [12,13]. The specified ACLs used by IMACRN agents include:

i) identity or name of the sender

ii) identity or name of the receiver(s)

iii) the purpose of the communication (known as performative), showing what the sender wants to achieve. For instance, in IMACRN:

a) if the sender requires the receiver to perform an action, the REQUEST performative is sent

b) if the sender wants to notify the receiver of a fact, the INFORM performative is sent

c) if the sender wants to know the truth of a given condition or statement, QUERY-IF performative is used

d) if the sender wants to initiate negotiation, the CFP (Call for Proposal) perfomative is sent

e) if the sender and receiver are negotiating, the PROPOSE, REJECT_PROPOSAL, ACCEPT_PROPOSAL

7. EXPERIMENTAL RESULTS

In this section, various numerical results to evaluate the multi-agent approach are presented. The simulation time is set at 120minutes. All the simulations are conducted in Java Application Development Environment (JADE), with two PCs having processor values of 3.40GHz and 2.30GHz and 4GB memory. The parameters used are as shown in Table 2.

Table 2. Parameters for experiment

Parameters	**Value**
Size of spectrum portion	4MHz
Simulation time	120 minutes
Max. number of PUs	30
Max. number of SUs	30
Max. number of each type of agent	5

7.1Spectrum 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 Rand (R).

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 3.

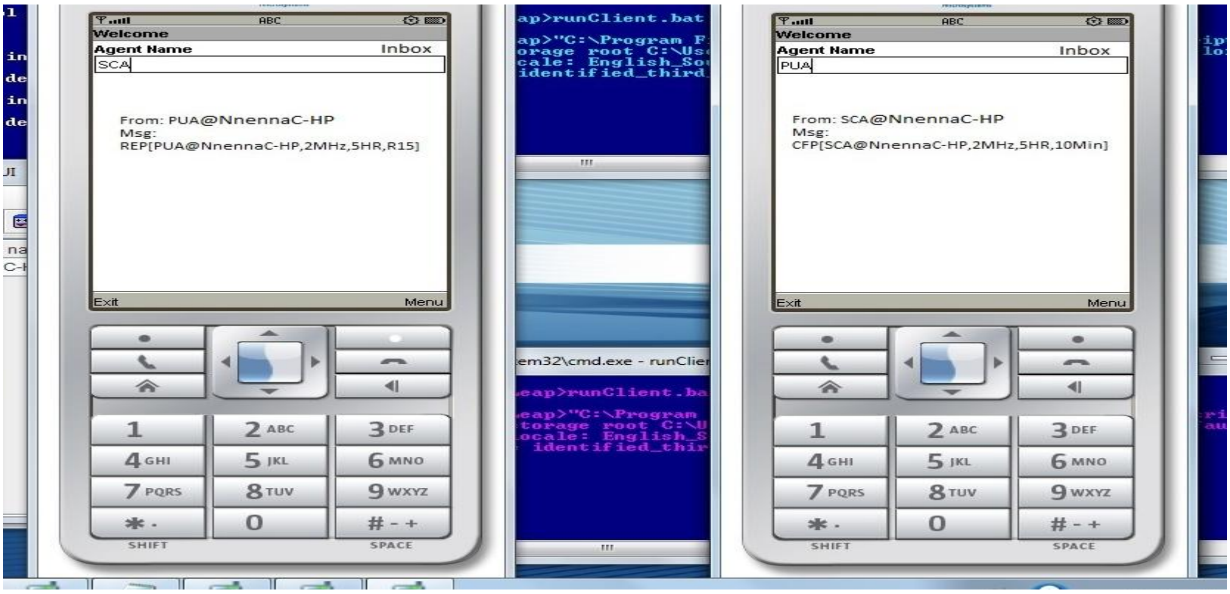

Figure 4.Message exchange for spectrum sharing

Figure5. Accept proposal message

Table 3. Spectrum sharing data

Number of PUs	**Number of SUs in need of Spectrum**	**Number of Served SUs**
10	20	17
20	25	22
30	30	28

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.

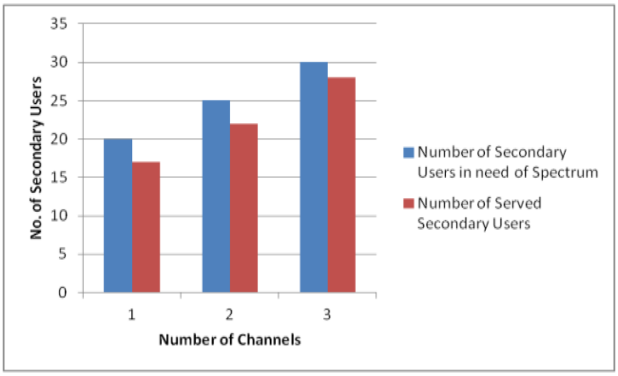

Figure 6. Spectrum sharing data

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.

7.2 Spectrum Mobility

For spectrum mobility, once the spectrum sensing agent (SSA) detects the reappearance of primary user, it sent out a message into the network and to the SCA using the channel to vacate as can be seen in Figure 8 and Figure 9.

Figure 8. Spectrum mobility message (1)

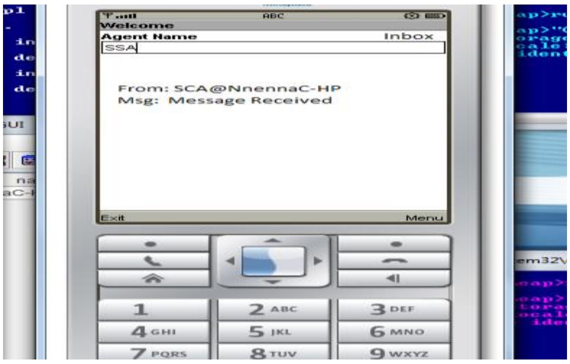

Figure 9. Spectrum mobility message (2)

The experiment for spectrum mobility was conducted a number of times to determine the switching time, which is the difference between the time of primary user reappearance and the vacating time of the secondary user currently utilizing the channel. Table 4 shows the result obtained at different times of the reappearance of the primary user.

Table 4. Spectrum mobility times

Time of PU Reappearance	**Time of SU Vacating**	**Switching Time (seconds)**
12:25:04:08	12:25:04:13	0.5
12:45:32:20	12:45:32:28	0.8
1:16:02:00	1:16:02:02	0.2
1:30:15:24	1:30:15:30	0.6
2:05:14:56	2:05:15:00	0.4

The results show that the switching times were quite small, therefore causing no or minimal interference to other users. This is made possible because the radios had a foreknowledge of the reappearance of the primary user, based on messages sent by the agents.

8.CONCLUSION

Spectrum sharing and spectrum mobility are management functions that ensures fair resource distribution and usage in a cognitive radio network. 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. Spectrum mobility requires that secondary users vacate the spectrum on reappearance of the primary user and continue their communication on another vacant channel. However, due to the dynamic and fluctuating spectrum environments, it is more complicated to maintain a seamless and reliable communication in cognitive radio networks. Reported in this paper is an intelligent mobile agent-oriented implementation that enhances collaborative spectrum sharing and mobility in a cognitive radio network. The use of intelligent mobile agent has the advantage of allowing the network users to have an optimal usage of the network resource opportunistically.

9. REFERENCES

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