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# Optimization of ant colony for next generation wireless cognitive networks

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# Optimization of Ant Colony for Next Generation Wireless Cognitive Networks

## *Highlights*

- *The algorithm of the ant colony based spectrum management is developed.*
- *The spectrum handoff process is carried out according to priority classes.*
- *The simulation model is simulated with the RIVERBED software.*
- *The number of handoffs is reduced within the most appropriate scenario.*
- *The handoff delay is decreased with the help of an ant colony algorithm.*

## *Graphical Abstract*

*In this work, we have conducted a study for minimizing the number of handoff and handoff delay parameters in cognitive radio networks with the help of the ant colony algorithm.*

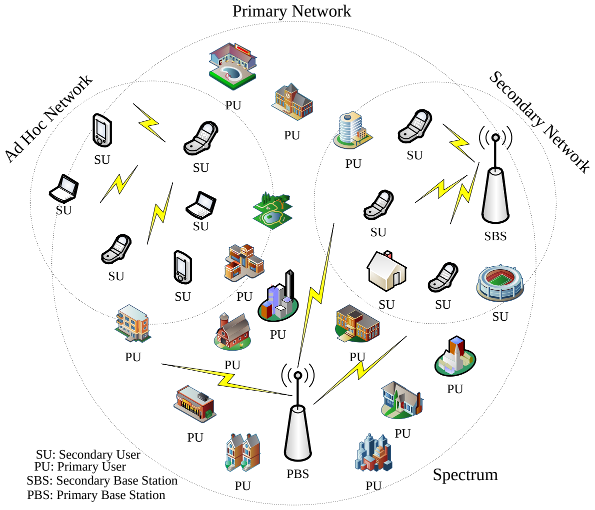


**Figure.** Cognitive radio network environment

## *Aim*

*Optimization of the spectrum handoff number with the help of an ant colony algorithm in cognitive radio networks is the aim of this work.*

## *Design & Methodology*

*The network structure design of analytical and simulation models is simulated with the RIVERBED software. The methodology is that the parameters in the RIVERBED is sent to the MATLAB via an MX interface.*

## *Originality*

*Deciding on the most suitable spectrum handoff process is determined by using multi-parameter decision-making processes with an artificial ant colony algorithm.*

## *Findings*

*The artificial ant colony algorithm has lower latency and it provides the best handoff number among fuzzy logic, artificial bee colony, and artificial neural network.*

## *Conclusion*

*The spectrum handoff delay and a number of handoffs are decreased with the help of an ant colony algorithm.*

## *Declaration of Ethical Standards*

*The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.*

# Optimization of Ant Colony for Next Generation Wireless Cognitive Networks

*Araştırma Makalesi / Research Article*

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**ABSTRACT**

In this work, the spectrum handoff process carried out by secondary users according to priority classes in cognitive radio networks is proposed. The network structure design of analytical and simulation models is simulated with the RIVERBED software. Moreover, deciding on the most suitable spectrum handoff process is determined by using artificial intelligence techniques. Using multi-parameter decision-making processes is the objective of our work. Optimization of the spectrum handoff number with the help of an ant colony algorithm is the main goal of our work. By studying similar aspects of cognitive radio networks and ant colony algorithms, the number of handoffs is reduced within the most appropriate scenario.

**Keywords: Ant colony, cognitive radio, handoff, optimization, spectrum management.**

## 1. INTRODUCTION

Cognitive radio is a new technology developed to provide efficient use of spectrum [1]. Fixed spectrum allocations in traditional network structures cause unused spectrum holes in radio and television frequency spectrum [2]. Users who use licensed channels in cognitive radio networks are called primary users, and users who use unlicensed channels are called secondary users [3]. Cognitive radio technology aims to enable secondary users to make use of the empty or unused portions of the spectrum in an opportunistic way [4]. The fact that secondary users do not interfere in any way to primary users is very important in terms of the success of cognitive radio networks [5]. In situations where spectrum holes that secondary users opportunistically use must be reused by primary users, secondary users need to continue their transmissions in a new spectrum hole [6]. This process, performed by secondary users, is known as spectrum handoff [7].

In cognitive radio networks, licensed users should not be subject to any interference by unlicensed users [8]. The privilege of licensed users is a condition that must be strictly ensured by cognitive radio [9]. When an unlicensed user is transmitting on the frequency channel, the channel must be emptied if it is to be used by the licensed user [10]. Unlicensed user is required to stop the transmission or to continue transmission through another channel [11]. It is known that the unlicensed user continues to transmit in another channel with the aim of emptying the frequency channel [12]. Various methods and techniques are available for spectrum management [13]. Thanks to these methods and techniques, unlicensed users are transferred to other channels without interruption [14]. In the spectrum handoff process, one of the conditions to be considered is priority classes [15]. Priority classes specify the order of transmission between users. In other words, the user with the highest priority has the right to transmit in the first place. Another situation that needs to be known about priority classes is the use of preemptive or non-preemptive priorities. In the case of preemptive priority, high priority transmission is started by interrupting low priority transmission in the environment. In the case of non-preemptive priority, low-priority transmission in the environment is waited to be finished and high-priority the transmission is started after transmission is over.

In recent years, there have been many studies dealing with spectrum management in cognitive radio networks [16]. In a different study, the question of how to select the target channels to minimize the total service time arising from multi-spectrum handoff has been discussed [17]. Besides, a pre-defined spectrum handoff approach in cognitive radio ad-hoc networks is proposed. The problem of designing an effective topology reconstruction algorithm to provide optimal routing solutions is focused [18].

Prospective approaches have been proposed in which the initial and target channels for spectrum handoff of cognitive radio networks are identified [15]. He [10] presented a framework for restructuring general cross-layer parameters, including indispensable functional elements for autonomous restructuring decisions in relation to multiple and complex targets. In addition, the ant colony-based restructuring solution proved effective performance. Andreotti [1] has addressed the problem of dynamic resource allocation for OFDMA based cognitive radio systems. He also implemented an efficient meta-heuristic algorithm based on ant colony optimization framework.

He [11] focuses on dynamic channel assignment, which provides the most appropriate resource allocation mechanism to meet the needs of users and networks in transport. It is determined that the channel assignment is nonlinear programming because of the optimization problem. He has proposed that the ant source coding algorithm be used to manage and allocate channel

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resources dynamically in cognitive radio networks. Song [17] solves the assignment process from the perspective of ant colony optimization, taking into account the concepts of use and justice in spectrum assignment. Zhu [18] proposed an ant colony optimization algorithm that was developed to increase spectrum utilization. In the algorithm; not only the individual benefit but also the general benefit of the system is dynamically updated with the attenuation coefficient.

In our work, we have conducted a study for minimizing the number of handoff parameter in cognitive radio networks with the help of the ant colony algorithm. We have inspired by the artificial bee colony algorithm we used in our previous studies.

## 2. PRIORITY BASED QUEUING MODEL

In our work, priority queues are first modeled analytically for secondary users. Then, the simulation model was implemented on the RIVERBED software with the help of this analytical model. Finally, it has been ensured that secondary users can perform the spectrum handoff process in a well way.

In the queue model of the secondary users, non-preemptive M / G / 1 priority data traffic with different priority classes is used. Priority classes are; real-time and non-real-time, respectively. In our simulation scenario, the generation frequency of the non-real-time data is the highest while the generation rate of the real-time data is the least. Communication is carried out in the ISM (Industrial, Scientific, and Medical) band. Real-time data packets are; messaging, video conferencing, internet meeting, etc. All other data packets are considered non-real-time data communications.

In the queue algorithm, a new incoming packet is placed in the position that is prioritized in the queue by taking priority. FCFS (First Come First Served) algorithm is applied for packets with the same priority, and the corresponding packet is placed behind the packets with the same priority class. If incoming packet priority is real-time, packet transmission will start. If the time slot is requested by the primary user while the transmission is in progress, the spectrum handoff is performed and transmission continues at other times. After transmission of all real-time priority packets in the queue is completed, non-real-time data packets are transmitted in idle slots. For transmission of real-time and non-real-time data packets, it has been checked whether a higher priority packet arrives at the queue before spectrum handoff occurs.

To decide on the spectrum handoff, the parameters in the RIVERBED software is sent to the MATLAB software via an interface (MX interface) and passed through the fuzzy logic decision-making process. The result of the fuzzy logic decision process is transferred to the RIVERBED software with the same interface again. The communication of RIVERBED and MATLAB software was carried out directly on the interface without any intervention [19, 20].

Thanks to the improved queuing model, it has been possible to achieve lower handoff delays by ensuring that real-time priority traffic can perform spectrum handoff earlier than other data. When the handoff delays of each priority class are examined separately, it is seen that the real-time data packets are the least delayed. Despite the fact that end-to-end delays have been reduced, the total throughput rate of cognitive radio network has not decreased. In this way, the waiting of the real-time data packets is removed and there remains no extra delay in the overall system. For each different priority class, an ant colony optimization technique has been used to obtain the optimal number of handoffs.

## 3. SPECTRUM HANDOFF PROCESS

In Figure 1, a general wireless cognitive radio network structure is shown in which base stations, primary and secondary users are included. In the present spectrum hole, when the detection mechanism finds the primary user communication, the secondary user must evacuate the channel to avoid interfering with the primary user. Cognitive radio provides channel switching according to some quality parameters. This mechanism, which shifts the communication to the other channel band, is known as spectrum handoff.

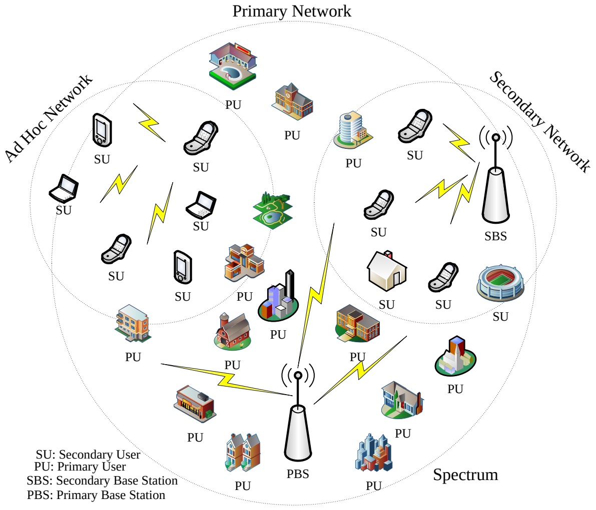


**Figure 1.** Cognitive radio network environment

Cognitive radio users are described as guests for the spectrum they use. Therefore, if a particular part of the spectrum in use is to be used by the primary user, the secondary communication must continue in another empty part of the spectrum. There are three special cases in which spectrum management occurs. The first of these is the occurrence of primary users in the environment. The second is that secondary users lose their connections due to user mobility during an ongoing communication. Finally, the existing spectrum band cannot provide the required quality of service.

Figure 2 shows how spectrum handoff is performed in cognitive radio networks. Channel 1 and Channel 2 belong to 1st and 2nd primary users, respectively. First, it appears that the secondary user is using the primary user's channel. The reason for the secondary user to prefer this channel initially is that the channel of the primary user 2 is full. At the next stage, the secondary user switched to Channel 2 because of the primary user activity in the environment. During this transition, there was a delay of spectrum handoff for a period of 'z'.

During the spectrum handoff, transient communication interruptions are inevitable due to the search for new available spectrum bands. Because the available spectrum bands are not contiguous and spread over a large area, the frequencies of cognitive radio users may need to be changed. This process also causes quite a long time delays. For this reason, spectrum handoff can be performed based on two different strategies. In the reactive handoff, cognitive radio users begin to change the spectrum after the loss of connectivity due to spectral mobility is carried out. This method requires instantaneous spectrum switching without any allocation. This leads to significant losses in ongoing communication quality.

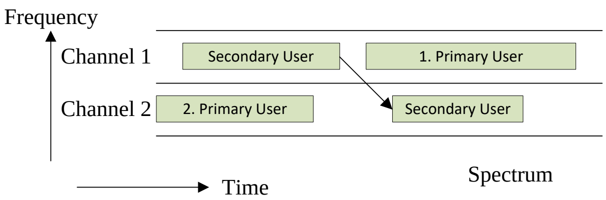


**Figure 2.** Spectrum handoff process

On the other hand, with the help of proactive spectrum management, the cognitive radio user predicts future activity on the current connection, and a new spectrum is decided as current transmission continues. The spectrum handoff is performed without any loss of connectivity. Because the proactive handoff process can continue to transmit in the new spectrum band at the same time, the spectrum handoff process is fast but requires more complex algorithms.

While the reactive spectrum handoff is generally used for the primary user occurrence, the proactive spectrum handover is used for user mobility or spectrum quality drops. These events do not require a sudden spectrum change and can be estimated easily. Proactive spectrum handoff can also be used for the primary user occurrence. Spectrum handoff delay is the most important measure in determining spectrum mobility performance. This delay is caused by the fact that certain operations are performed on cognitive radio networks. First, the different layers of the protocol must match the channel parameters of the transmission frequency. Thus, when changing the cognitive radio user frequency, it is necessary to adjust the transmission parameters of the network protocol. This also causes protocol delay. In addition, the time for spectrum sensing and the time for changing handoffs must also be accounted for.

In our work, it is ensured that the secondary users are able to continuously detect spectrum holes with spectrum sensing before performing spectrum handoff. It is assumed that in the simulation environment, wireless communication is performed in AWGN (Additive White Gaussian Noise) channel and therefore has no disruptive effects on the environment. The spectrum handoff is performed with RIVERBED software on the network where all users and base stations are located. In addition, the network structure simulated on RIVERBED software has been tested with different scenarios.

## 4. ANT COLONY OPTIMIZATION

In our multi-parameter decision making process, artificial intelligence techniques are used to ensure that secondary users can send their packets faultlessly through the base station. The base station has made decisions with the help of fuzzy logic, one of the artificial intelligence techniques. Input parameters in the fuzzy logic process; priority, data rate, channel usage, etc. are selected as parameters. As a result, the decision for spectrum handoff is made. To perform this operation, interfaces of RIVERBED and MATLAB software are communicated. A special variable is defined in the RIVERBED software after defining the environment variables to provide this communication. The input and output parameters for the base station are then defined as variables and sent to the MATLAB software. Variables coming into the MATLAB software are processed with fuzzy logic and the output parameter is transmitted to the RIVERBED software through the interface. The last output parameter is used by the base station to perform spectrum handoff. In summary, in the RIVERBED software decision making process that we implemented the simulation model is carried out. Output parameters are obtained by communicating with the MATLAB software that has artificial intelligence functions.

The inspiration for the ant colony algorithm is the behavior that real ants exhibit when collecting food. When searching for food, ants randomly search the area surrounding their home. An ant evaluates the quantity and quality of a food source it finds. Some of the food it finds goes back to the sink. During the return journey, the ant drops chemical pheromone traces on the ground. Depending on the quantity and quality of the food, the amount of pheromone that accumulated in the ground leads other ants to the food source. Thanks to the accumulated amount of pheromone, indirect communication is provided between the ants on the roads. This communication allows the ants to find the shortest path between the nest and food sources. These characteristics of real ant colony are also used in artificial ant colony to solve problems.

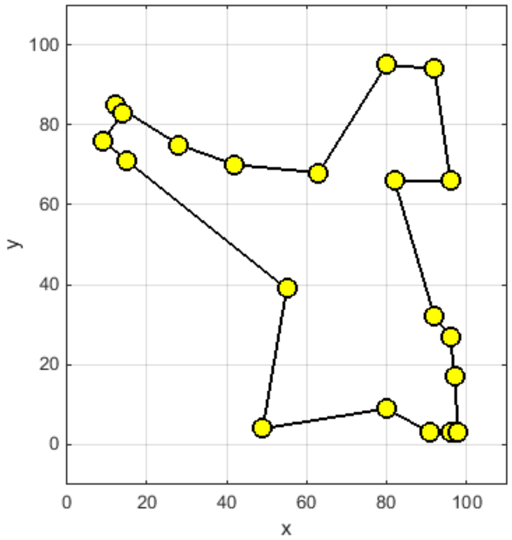


**Figure 3.** Artificial ant colony

In this study, a new algorithm is developed for artificial ant colony based spectrum management. As an example in Figure 3, pheromone traces and food sources appear in the operation of an artificial ant colony algorithm. In our work, first of all, the general work structure is defined by giving basic information about an artificial ant colony algorithm. For each ant in the artificial ant colony; cognitive radio networks are structured similarly to different secondary users. According to this; secondary users have a task where they collect information about transmission bandwidth and empty bandwidth for spectrum handoff. The nest in the ant colony is equivalent to the coverage area of the access point on the cognitive radio and is the unit of coordination according to the collected information.

In the optimization process of cognitive radio, the adaptation function is first defined to determine the search direction. In our work, there are two single objective adaptive functions. These are minimization of a number of handoffs and minimization of delay. The minimization adaptation function of the number of handoffs is calculated where E means handoff number and $E_{max}$ is maximum handoff count:

$$f_{\text{mine}} = 1 - \frac{E}{E_{max}} \tag{1}$$

G is the average delay; the minimization adaptation function of the delay is as follows:

$$f_{\text{ming}} = 1 - \frac{log_{10}(0,5)}{log_{10}(G)} \tag{2}$$

In the algorithm we have developed, channel usability properties are examined based on the position of the ants in the artificial ant colony algorithm in order to minimize the number of spectrum handoff. Because the artificial ant colony algorithm gives better results under low network load, the simulation parameters are chosen according to this case. With the help of the algorithm we have developed using the artificial ant colony algorithm; the spectrum handoff delay of the secondary users is reduced to an acceptable level. Furthermore, under low network load, the total spectrum handoff delay is also reduced.

In our study, optimization of the spectrum handoff process, which is one of the most basic functions of cognitive radio networks, has been made with an artificial ant colony algorithm. The main task of the ants is to find plenty of good quality food, while the secondary users on the cognitive radio are tasked with finding empty frequency channels with high bandwidth. In this context, our objective function is to minimize the total number of spectrum handoff of secondary users.

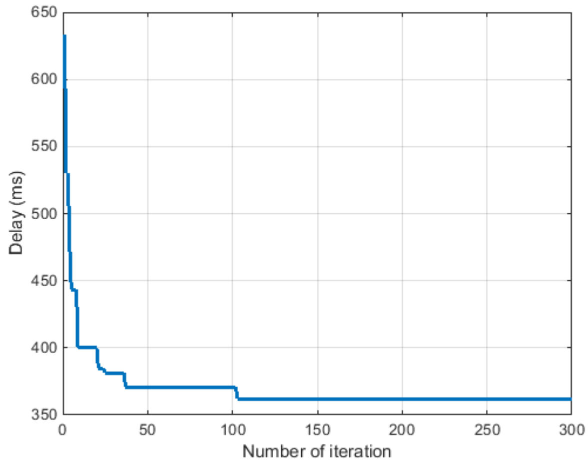


**Figure 4.** Delay

In Figure 4, the results of the appropriate channel selection delay are shown. It is seen that the optimal channel selection in the designed artificial ant colony based spectrum handoff algorithm reaches its optimal value after approximately 200 repetitions. The optimal channel selection delay reaches its optimum value means that the spectrum handoff process is carried out with minimum delay, which is the main purpose of our work.

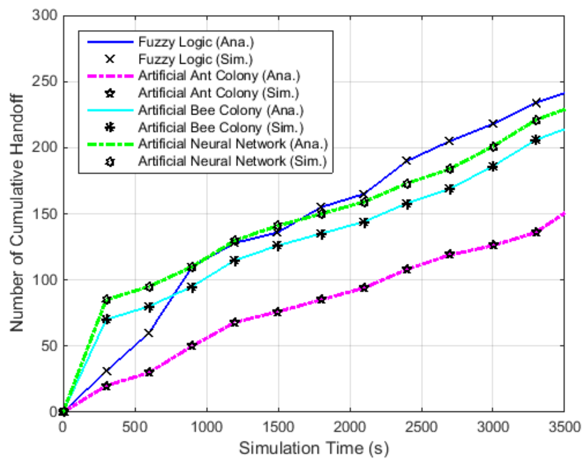


**Figure 5.** Comparison of number of handoff

As can be seen from Figure 5, the cumulative number of handoffs in the fuzzy logic approach is greater than the number of handoffs in the artificial neural network approach. For this reason, the fuzzy logic approach is to be influenced by parameters such as false alarm probability and false detection probability. The artificial neural network approach uses predefined time periods. The artificial bee colony approach has fewer handoff changes since it re-checks the predefined time slots through the sensing process. Although fuzzy logic and artificial neural network results are close, the total number of handoffs for artificial neural networks is slightly lower. The artificial ant colony algorithm has lower latency and it provides the best handoff number as expected.

## 5. CONCLUSION

In this study, the algorithm of the ant colony based spectrum management has been developed. First, the general work structure is defined by giving basic information about the ant colony algorithm. Next, the fit functions for the parameters that we optimize are mathematically expressed. In the developed algorithm, the channel usability characteristic of the ant colony algorithm is investigated in order to minimize the spectrum handoff delay and a number of handoffs. Since the ant colony algorithm yields better results for low network load, the simulation parameters are set based on this. When compared to other techniques, the ant colony gives the least number of handoffs.

In future studies, other parameters of the spectrum handoff process such as the probability of blocking and the probability of forced termination can be optimized with the ant colony algorithm.

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## DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

## AUTHORS’ CONTRIBUTIONS

**Muhammed Enes BAYRAKDAR:** Performed the experiments and analyse the results. Wrote the manuscript.

**Ali ÇALHAN:** Performed the experiments and analyse the results. Wrote the manuscript.

## CONFLICT OF INTEREST

There is no conflict of interest in this study.

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