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*Original Article*

# Enhanced Energy Storage and Management Scheme in MH-CRSNs with ACO Algorithm

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***Abstract*** *- The energy-efficient scheme in cognitive radio sensor networks (CRSNs) has many advantages compared to traditional networks. In cognitive radio (CR) system, the efficiency of the routing algorithm directly affects the system performance. We propose an energy storage and management scheme for improving network throughput and energy efficiency. Energy harvesting is adopted in cognitive radio sensor networks with battery-free secondary users that perform multi-hop transmission to reduce network congestion and data loss. The proposed scheme is designed based on a partially observable Markov decision process (POMDP) framework. In the case of multi-hop energy harvesting, the optimization concept is introduced to minimize the delay and energy consumption, which is named Ant Colony Optimization (ACO). Using this method, the shortest path from the source node to the sink node is obtained, and delay and energy consumption are reduced. The simulation results show that the proposed scheme operates energy-efficiently while properly protecting packet loss.*

***Keywords*** *- CRCN, Energy harvesting, POMDP, ACO, Energy storage, and management.*

## I. INTRODUCTION

A wireless sensor network (WSN) is a self-organizing wireless network formed by a large number of low-cost, small size sensor nodes with wireless communication capabilities. These sensor nodes can monitor, perceive and extract data from the environment. Then this information data are sent to the base station through the wireless multi-hop transmission technique [11].

Today, remarkable growth in the applications that use unlicensed bands introduces the coexistence problem. Hence, WSN requires the extra potential to withstand the interference introduced by the other applications. Cognitive Radio (CR) technology provides a favorable solution to support the sensor nodes with opportunistic spectrum access (OSA) capacity. In a CRSN, a collection of wireless cognitive radio sensor nodes are arranged in a distributed manner to recognize an event signal and collectively communicate their readings over available spectrum bands in a multi-hop fashion. The power consumption problem is an evaluative issue for CRSN. The battery-controlled lifetime of sensor nodes can be improved by reducing power consumption and limiting overall energy consumption by the sensor network. The uncontrolled energy consumption will cause the network to die prematurely and reduce the network lifetime.

So, the key point for WSN is selecting the appropriate WSN routing algorithm, which can save node energy and improve the standard of network communication. One of the widely used methods for route optimization in WSNs is the Ant colony optimization (ACO) algorithm. It is a bio-inspired approach that solves the problem in a heuristic way, like natural ants. In wireless networks, there is the probability that an error may exist or may not exist. The error can be link failure, interference, and packet. So, Partially Observable Markov Decision Processes (POMDP) can be used to create errors and propose a system to mitigate the error.POMDP is a powerful decision-making tool since it contributes a general and meaningful structure for modeling practical systems.

The rest of the paper is organized as follows. In section II, related work is given. The proposed system, which includes ACO Algorithm and POMDP Framework, is introduced in section III. The simulation setup is explained in Section IV. Performance evaluation and results are included in section V. Finally, the paper is concluded in Section VI.

## II. RELATED WORKS

Cognitive techniques are used in wireless networks to solve the limitations of conventional WSNs. When CR is integrated with wireless sensors, it can overcome the many challenges in current WSNs. CR can know the unutilized spectrum in a licensed and unlicensed spectrum band and opportunistically utilize the unused spectrum.

CR gives an advantage to WSNs by increasing communication reliability and improving energy efficiency. In CR-WSNs, a wireless sensor node selects the most appropriate channel once an idle channel is identified and vacates the channel when the arrival of a licensed user on the channel is detected. It increases spectrum utilization and fulfills the end-to-end goal, increases network efficiency, and extends the lifetime of WSNs. The system can reduce packet loss and power waste and better communication quality [1].

Color-sensitive graph coloring (CSGC) is a widely used method in dynamic spectrum assignment [3]. By changing the labeling method, CSGC is effective in all situations. But the stability of CSGC is poor. To overcome these shortages, a set of intelligent algorithms has been used, genetic algorithm [4], bacterial foraging optimization algorithm [5], bee colony optimization algorithm [6], and particle swarm optimization [7].

These algorithms have a good optimization ability and fast convergence speed. But in most cases, they only aimed at maximizing the networks' utilization. And do not care about the fairness between the users [2].

The performance analysis of four routing protocols, ACO, AODV, DSDV, and DSR, in the wireless sensor network. Simulation results show that ACO is not only energy-efficient but also has the highest packet delivery ratio and the shortest first packet arrival time [8].

Ant colony optimization is a metaheuristic in which a colony of artificial ants cooperates in finding solutions to difficult discrete optimization problems [9]. The key advantages of ACO are its low computational load, less complexity, and fast running time.

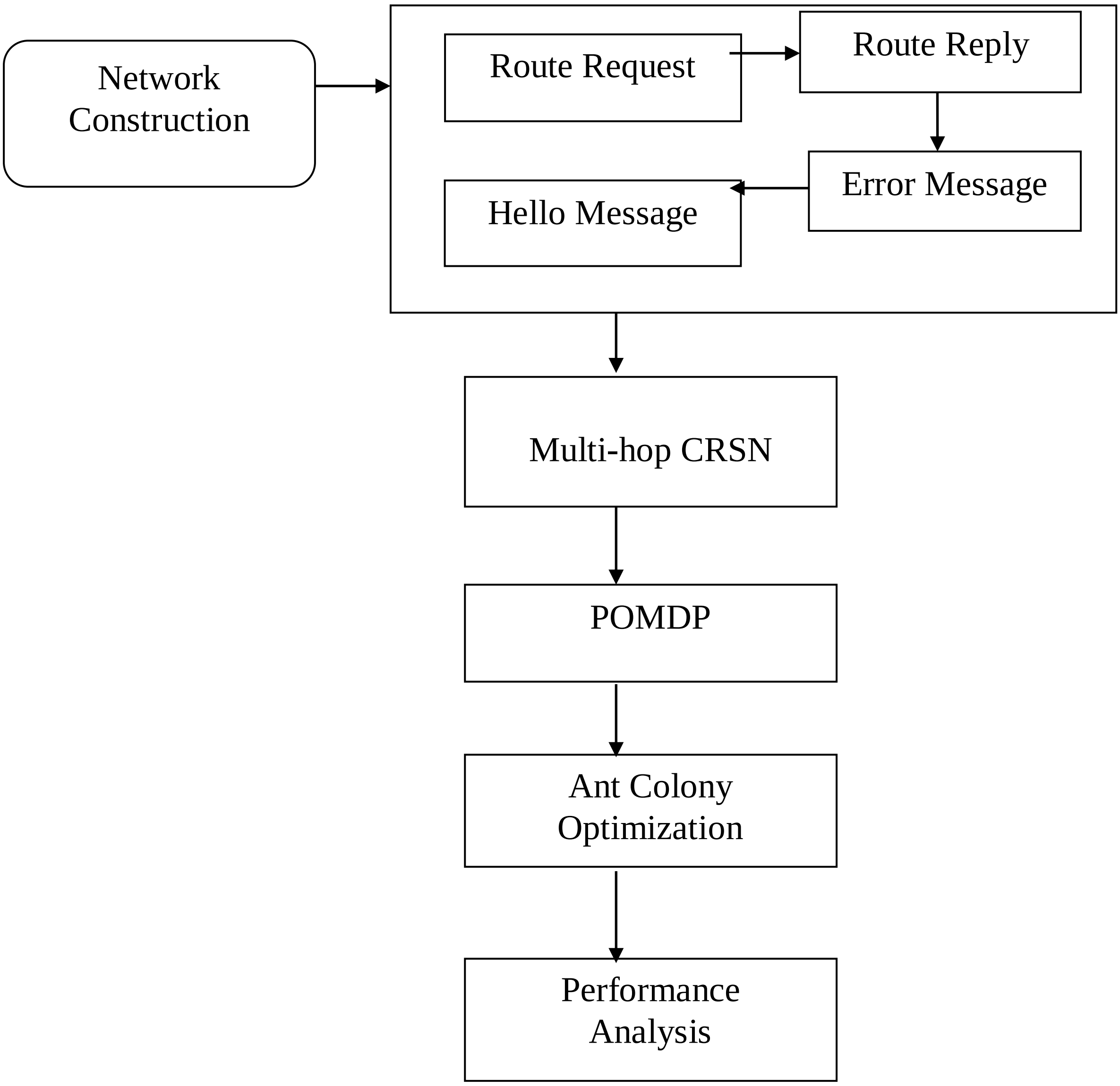


**Fig. 1. Flow diagram**

## III. PROPOSED SYSTEM

In this system model of CRSN, several primary and secondary users co-exist, sharing spectrum channels for data transmission. In this experiment, 50 mobile nodes are distributed into the system, powered by the energy harvesting technique. Information is sent to the base station through a wireless multi-hop transmission technique. But the drawback of the Multi-hop concept is that there is no method to find the shortest path from source to destination, so end-to-end delay and energy consumption will be high. ACO algorithm is used for route optimization, and it will result in reduced network delay and energy consumption, thereby improving energy efficiency and end-to-end throughput. In wireless networks, there is the probability that an error may exist or may not exist. The error can be link failure, interference, and packet loss. So, Partially Observable Markov Decision Processes (POMDP) can be used to create errors and propose a system to mitigate the error. Fig. 1 gives the flow diagram of the proposed method.

### *A. Multi-hopping Network*

- The source node sends the data into the network during data transmission, and the sink node, the destination, collects the data.
- During the data transmission process, the message reaches the destination with the help of the intermediate hop nodes.
- If the number of intermediate hop nodes is large, that process is called multi-hopping.

Due to multi-hopping, network congestion and data loss are reduced. But energy consumption and network delay will be high.

### *B. Partially Observable Markov Decision Process*

Partially observable Markov decision processes (POMDPs) are commonly used to model stochastic environments with hidden states. They provide general and expressive frameworks for modeling practical systems [10].

In wireless networks, there is the probability that an error may exist or may not exist. We have to create errors or interference for real-time applications, and we will propose a method to mitigate this error. The error can be link failure, interference, and packet loss. So, Partially Observable Markov Decision Processes (POMDP) can be used to create error values for all the data transmission.

### *C. ACO Algorithm*

In AdhocOn Demand Distance Vector (AODV) Protocol, routes are located on-demand, i.e., when there is a requirement for a new route, it is discovered. The source node sends Route Request packets to all the nodes. All the other nodes except the destination node transmit the Route Request packets. When a Route Request packet is received, the destination node sends a Route Reply packet in response, and it will travel in a backward direction of the corresponding Route Request packet. The Route reply packet collects the traveling cost in that path at every node. When the source node receives all the Route Reply packets, it decides which Route to take based on each Route Reply packet's accumulated cost. The AODV routing is unsuitable for large-scale wireless sensor networks since discovering the routes becomes expensive. In the worst-case scenario, all the nodes in the network may need to send the Route Request packet to discover new routes and optimize the performance of the network with changing network conditions. Thus, it would not satisfy the criteria of cost, which requires the protocol to send as less number of packets as possible.

Ant colony optimization is an algorithm whose operation is similar to real ant colony behavior. When ants search for foods, they leave a substance called pheromones on the path, and other ants will select the path according to this pheromone concentration. Pheromones have the property that they will evaporate over time, so pheromones are quickly collected in the shortest path. After some time, the shortest path is created. When an obstacle is detected on the path, the ants initially spread in two directions at an equal probability. After some time, due to the accumulation of pheromones, ants will select the shortest path.

The proposed ant-based routing algorithm has several properties, ideal for the above-specified requirements.

- The algorithm can dynamically reconfigure itself with changing network topology. This is done by using a certain number of data packets as ants that require the destination node to send an acknowledgment back to the source node.
- The Ant-based algorithm can support multi-path routing as each node has a certain number of neighbors with specified pheromone concentration levels. The next hop is chosen based on the pheromone concentration.
- Hence it allows the node to choose different routes each time.

The operation of the Artificial Ant protocol consists of three tasks. They are as follows:

- Periodic neighborhood discovery.
- Packet forwarding/reception.
- Retaining end-to-end reliability of finding the destination(s).

## IV. SIMULATION SETUP

Simulations are carried out in NS2. NS (version 2) is mainly used for simulating local area networks and wide area networks.

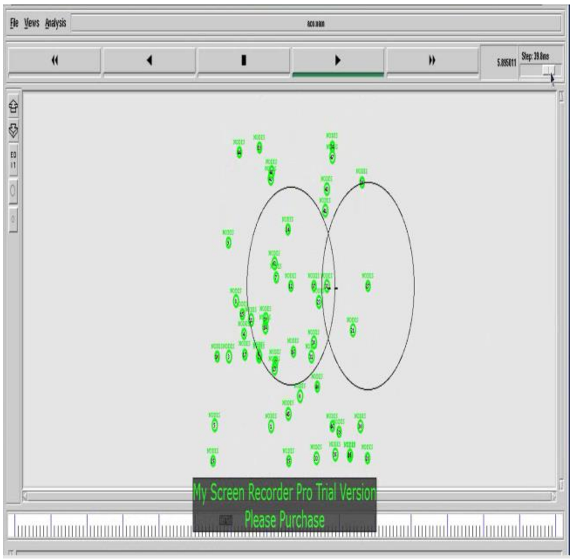


**Fig. 2 Graphical representation of simulation window**

The simulation scenario is the wireless sensor network. Nodes are responsible for data transmission, and they have distributed within a region of 500cm × 500cm topography. The total number of nodes is 50. The initial energy of nodes is set to a particular value. Table I gives the parameter settings for the simulation.

**Table I. Parameter Settings**

| Parameters | Values |
|---|---|
| Number of nodes | 50 |
| Topography | 500× 500 /m |
| Simulation time | 15ms |
| Channel type | Channel/Wireless Channel |
| Radio propagation model | Propagation/Two Ray Ground |
| Antenna type | Antenna/Omni Antenna |
| Link-layer type | LL |
| Interface queue type | Queue/DropTail/PriQueue |
| Max packet in if | 200 |
| Network interface type | Phy/WirelessPhy |
| Routing protocol | ACO |

The initial energy of the nodes is 90J. Transmit and receive powers of 50 nodes are 0.3W and 0.6W, respectively. An energy model is created based on these values. For the Markov model, there are 2 stages and 2 variable states for each stage, one is upstate and is used for sending the data, and the second state is the state for receiving the data. These states are created for all the channels and each node in the channel. For stage 1, 27% error is created for upstate and 12% for the state. Similarly, for stage 2, 0.4% error is created for both upstate and state and similarly for data reception.

## V. PERFORMANCE EVALUATION

Fig. 3, Fig. 4, and Fig. 5 demonstrate the performance evaluation of CRSNs (red color), MH-CRSNs (Green color), and ACO reinforced CRSNs (blue color). The following graphs illustrate the simulation results corresponding to 50 mobile nodes; for convenience, 2 nodes are selected as source nodes, and they will transmit the data packets to the same destination node. The mobile nodes will change their positions during data transmission to find the shortest path from the source node to the destination node.

Fig. 3 compares the received packets at the destination. 916 packets are transmitted, and 850 packets out of these 916 transmitted packets are received at the destination. ACO shows the best performance among the other 2 scenarios.

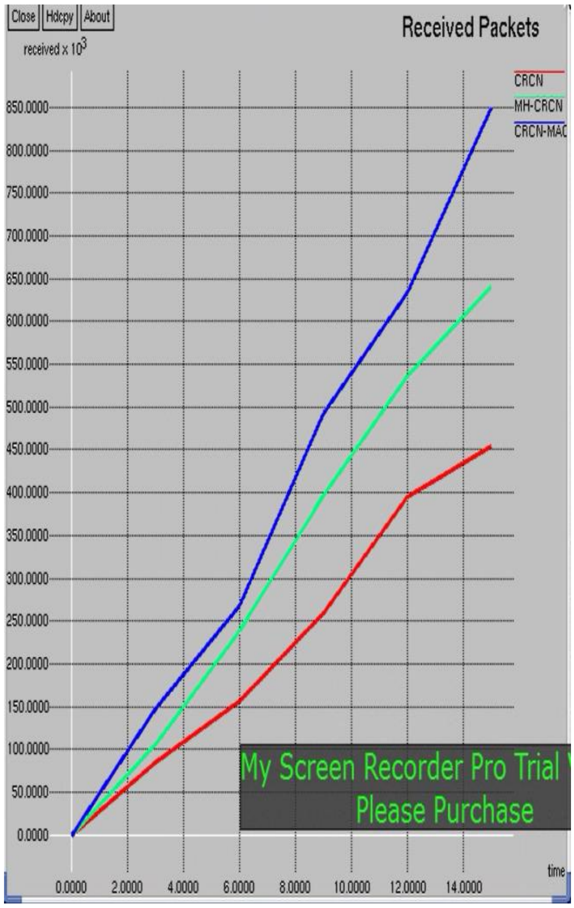


**Fig. 3 Comparison of received packets**

Fig. 4 compares the packet delivery ratios of 3 cases. ACO has the best performance among the other 2 cases, and the corresponding percentage of PDR is 93%. So from the perspective of PDR, ACO is more stable than the other two cases.

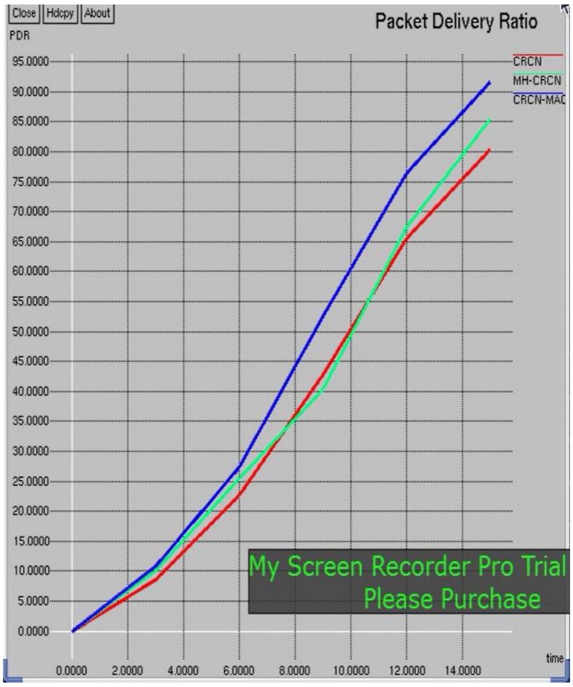


**Fig. 4 Comparison of PDR**

The total remaining energy is illustrated in Fig. 5.

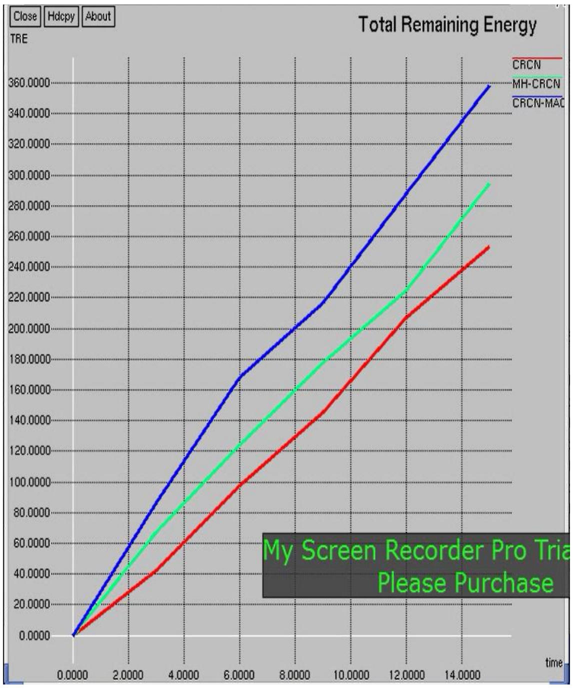


**Fig. 5 Comparison of total remaining energy**

Network delay and throughput are shown in Fig. 6 and Fig. 7, respectively.

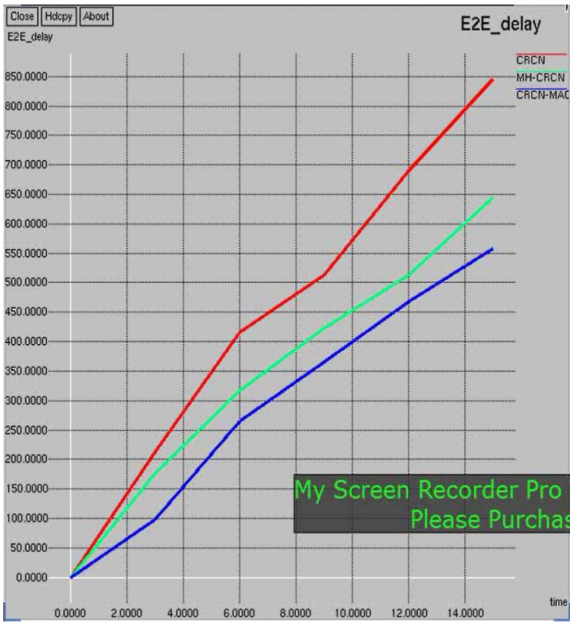


**Fig. 6 Comparison of end to end delay**


**Fig. 7 Comparison of throughput**

Simulation results are summarized in Table II

**Table 2. Simulation Results**

| Parameter | value |
|---|---|
| Average end to end delay | 427.29 ms |
| Throughput | 22.20 Kbps |
| Energy spent | 17.1146 J |
| Residual energy | 82.8854 J |
| Transmitted packets | 914 |
| Received packets | 850 |
| Packet delivery ratio | 93% |

The main reasons for the superiority of the proposed algorithm over the other algorithms are summarized as follows:

- First of all, the source node sends the data during data transmission, and the destination node collects the data in the network. The message reaches the destination with the help of the intermediate hop nodes. If the number of intermediate hop nodes is large, that process is called multi-hopping. Due to multi-hopping, network congestion and data loss are reduced. But energy consumption and network delay will be high. So ACO will find the shortest path from the source to the destination node and overcome the difficulties.
- Other algorithms examine the transmission distance to the next node i and don't consider the distance from node i to the Sink, but this distance will reflect the network energy consumption. Within the range of communications closer to the destination node, the energy consumption of the network node will be smaller.

## VI. CONCLUSION

Compared with the traditional ad hoc network, the sensor network, such as the cognitive radio sensor network with a multi-hopping concept, proposes a higher requirement for network energy consumption. In this paper, aiming at some cognitive radio sensor network features, the ant colony optimization routing algorithm based on a partially observable Markov decision process is proposed. The simulation results indicate that by comparing with MH-CRSNs, the method proposed in the paper minimizes the average energy consumption and extends the functioning period of the sensor node. From the performance analysis of various parameters, it can be concluded that this scheme is efficient in reducing energy consumption and increasing the network's throughput. It also gives a better Packet delivery ratio, increased throughput, and reduced overall network delay. The parameters like average remaining energy, packet delivery ratio, received packets, end-to-end delay, and throughput are calculated during the performance analysis.

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