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Original Article

Probabilistic Approach of Ant Colony Inspired Adaptive Routing Algorithm for Cognitive Wireless Sensor Networks

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Abstract - *Wireless sensor networks are collections of sensor nodes deployed in an unattended fashion with sensing wireless computations and communication capabilities. The wireless sensor network with the cognitive capability produced the new terminology of Cognitive Radio Sensor Networks (CRSN). In CRSN, the unlicenced sensor nodes use their temporarily available vacant, licenced spectrum band and a number of channels as required for communication. The many open challenges are still under consideration in WSN. In this paper, challenges arising for adaptive routing as fault-tolerance issues are proposed for the adaptive routing algorithm with a probabilistic approach and the metaheuristic clustering approach. The CRSN with available spectrum channels with PU (Primary User) and SU (Secondary User) activity with spectrum sensing and spectrum hands-off functionalities based on availability are considered. Inspired by the foraging approach of ANTs (Ant Colony Optimization) for making probabilistic route selection the shortest path in a multi-hop fashion. The proposed routing algorithm solves routing issues by having the capability of the cognitive approach in the AODV and DSR routing protocols as the network layer protocol is compared. Performance parameters such as packet delivery fraction, average end-to-end delay, and average throughput are analysed to find an optimised solution for the telecommunications network.*

Keywords - *Ant Colony Optimization, CRSN, Markov model, Performance analysis, Wireless Sensor Network*.

1. Introduction

Wireless sensor networks are acquiring a number of research issues and are widely used in wireless technology. From an application point of view, the development of telecommunication networks has much research scope to enhance the technological aspects of data transmission with different stochastic approaches. Currently, there is a need for next-generation [12] modified technology with utilization to fill the gaps in the knowledge inspired by biological sciences. Biologically-inspired methods have multiple aspects of research to create innovations; the analogy between bio-inspired methods and the application of technology creates the best combination for next-generation networking. The wireless sensor network deployed the sensor nodes for different applications to sense the monitoring processes of military applications, agriculture, healthcare applications, security, disaster surveillance, observing wildlife, measuring temperature, and much more. The next generation of technology required layer-wise development in the TCP/IP approach. There is MAC involvement, and the network layer produces the hybrid layer for research. The sensor network nodes are embedded with a radio transceiver and a microcontroller with a battery, which is a huge cost. Thus, the utilization of sensor nodes has the best aspects for sensing the data flow analysis with some parameters. Ant Colony Optimization has a probabilistic Markov model approach to hop-to-hop routing protocols. Developing the routing algorithm with static sensor nodes in the networking with free radio spectrum utilization is as state-of-the-art as cognitive radio sensor networks with spectrum hands-off techniques from one spectrum band to another, as shown in Figure 1. The sensing process was enhanced with the cooperation of the spectrum utilized to ensure the analysis of the quality of services. The insects in colonies utilized the available routes, which have a maximum pheromone value that may be zero or one, depending on the routes for spectrum sharing and the selection of channels for transmission of packets among nodes in the network. In conventional WSNs, all sensor nodes transmit and aggregate packets to the base station. Thus, the WSN operates in the ISM band at 2.4 GHz.

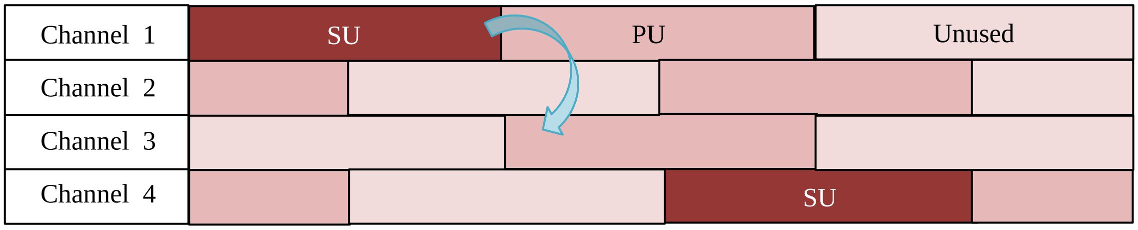


Fig. 1 Spectrum hands-off in CRSN

Thus, using multiple channels will improve the transmission in WSN, as proposed by Phung et al. (2013). Wireless sensor networks consist of sensor nodes with limited storage, limited energy, and low-cost sensor nodes. Most of the sensor nodes are deployed in an unattended fashion in the environmental conditions for various applications. In communication, the wireless sensor network uses a different channel for when the event occurred. Sensor nodes are deployed randomly in the specific region; they gather the data and forward it to the base station (sink node), fulfilling the best storage and power capability during data transfer. There is a need for sensor nodes to have better capability to route the packet with sufficient energy. If there is a possibility of heavy traffic, the node with the huge load will suddenly die.

Thus, there is a need for multiple channels to transfer the traffic load and reach the sink node. Nodes with specific conditions, either static or dynamic, still require more energy consumption in the network. Here, the objective is to use the multi-channel path with a single sink for data transfer from the source node to the destination node with neighbor discovery inspired by biologically inspired methods like ACO and develop a novel approach to routing in cognitive radio sensor networks [9] with spectrum utilization as an unlicensed band that activates the SU (secondary user) when the PU (primary user) is unused. The designed routing protocol was simulated in NS2, an open-source network simulator tool to be implemented. The architecture of each sensor node has different layers with respect to an additional module of cognitive radio with an MAC layer, considering the CSMA technique, as shown in Figure 2.

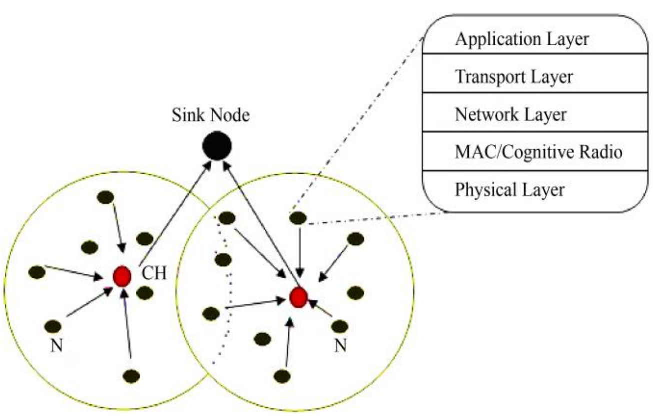


Fig. 2 Architecture of sensor network

Natural or biological organisms have the self-organization capabilities to adjust according to any changes that occur, such as BEEs, ANTs, and fish, which have self-capabilities and functionality. Inspired by those, the different novel routing algorithms were developed by different researchers, such as ANTNET, AntHocNet, BeeSensor (Saleem & Farooq, 2010), BeeAdhoc, ant colony optimization, bee colony optimization (Karaboga et al., 2009), particle swarm optimization, and techniques in swarm intelligence. The technology is used in many real-time applications. Many researchers make the same assumptions based on their experiments and findings. Here, the wireless sensor node is deployed in the region, as shown in the figure above. Here, all nodes consume energy for the transmitting and receiving processes.To improve the efficiency of all the nodes with the same configuration, try to gather in one group to save energy, just as the larvae of ants gather in one group to form a cluster in a metaheuristic pattern [31], to reduce the energy of individual larvae with the same capability. Comparing the analogous properties of ants in ant colony optimization, the sensor nodes with cognitive radio capability with the same configuration as homogeneous and different configuration as heterogeneous networks mutually selected one of the nodes as the cluster head after the formation of the cluster, and that cluster head to gather the information and transfer it to the static sink node with the involvement of the MAC of IEEE 802.11 DCF/Cognitive radio function and network layer function coordination to develop the hybrid layer with different functions, useful for the novel routing algorithm. The clustering method in CRSN is used to maintain the energy level of each node in the network and to extend the network lifetime. It also utilizes scalability in large-scale networks, which increases the network lifetime. Observing the underlying relation between complex optimization and biological evolution has developed into the new computational intelligence paradigm, the evolutionary computing technique for performing very complex searches and optimization [31].

The rest of the section is described as follows: Section II describes the literature review; Section III explains the design issues of wireless sensor networks; Section IV explains the concept of the proposed routing protocol for CRSN; and Section V presents a performance analysis of an adaptive bio-inspired routing protocol in CRSN. Finally, the paper concludes with Section VI.

2. Literature Review

Various researchers are developing a number of routing protocols and solving the number of challenges of wireless sensor networks. Associated with designing routing protocols for solving the multiple issues in wireless sensor networks, we try to contribute solutions to issues such as self-organization and network fault tolerance. We consider here the hierarchical routing protocol. With the motivation of wireless sensor networks using bio-inspired methods, there is a new scope for next-generation networks such as cognitive wireless sensor networks. We try to design an algorithm for cognitive wireless sensor networks that are useful for telecommunication networks. In the survey by I. F. Akylidiz (2002), they described the importance of WSN applications and issues. Hla Yin Min et al. [17] proposed an energy-efficient, fault-tolerant routing leach protocol for WSNs to achieve reliability and QoS. Perumalsamy Deeplakshmi et al. [18] proposed an ant colony-based multi-objective quality of service routing for mobile ad hoc networks. They proposed the protocol for a highly adaptive, efficient, and scalable network with QoS. Gianni Di Caro et al. [19] proposed the AntHocNet protocol with an ant-based hybrid routing protocol algorithm for mobile ad hoc networks. It shows that the AntHocNet protocol performs better than the AODV protocol in end-to-end delay and packet delivery ratio cases.

Vahid Esmaeelzadeh et al. [5] proposed the CogNS simulation framework to enhance, develop, and modify the existing protocol of cognitive radio sensor networks. Hang Su et al. [20] proposed cross-layer-based probabilistic multi-channel MAC access protocols for QoS provisioning over the cognitive radio. Wireless networks proposed cross-layer-based probabilistic multi-channel MAC access. Bhaskar Krishnamachari et al. [21] proposed a distributed solution for the canonical task in wireless sensor networks and proved that 95% of faults could be corrected per fault tolerance issues in wireless sensor networks.Ozgur B. Akan et al. [8] proposed the techniques of cognitive radio sensor networks and provided a novel architecture for the CRSN approach with open research issues.

Zhongliang Liang et al. [22] proposed the CRSN and analysed its performance for supporting real-time traffic while considering burst traffic. Job Scheduling with Fault Tolerance in Grid Computing using Ant Colony Optimization is proposed to ensure that jobs are executed successfully even when a resource failure has occurred [32]. Falko Dressler et al. [34] provide a better understanding of the potential of bio-inspired methods for communication.

3. Design Approach to Following Issues

Wireless sensor networks have different challenges and issues to overcome the constraints of WSNs and solve the design application issues. The challenges and design issues in WSN are limited energy consumption, fault tolerance, scalability, productive cost, data aggregation, load balancing, congestion, security, and self-organization. In this paper, we consider the following issues to develop the algorithm: robustness in self-organizing, adaptability in fault tolerance, and scalability issues.

Self-organization: A WSN is expected to remain operational for an extended period of time. With the new node added to this network, maybe the other nodes fail because of failures or exhaust their batteries and become unoperational. A routing protocol must be resilient to such dynamic and generally unpredictable variations to sustain the long-term availability of network services.

Fault-tolerance: CR-WSNs should have self-forming, self-configuration, and self-healing properties. In other words, an alternative path that avoids the faulty node or link must be derived whenever some nodes or links fail. In CR-WSNs, faults can occur for various reasons, such as hardware or software malfunctioning or natural calamities, e.g., fire, floods, earthquakes, volcanic eruptions, tsunamis, *etc.* A CR-WSN should always be prepared to deal with such situations. The fault tolerance or reliability of a wireless sensor node using the Poisson distribution within the time interval (0,t) occurs. [9]

Scalability: Sensor node deployment in WSNs is application-dependent and affects the performance of the routing protocol. A large number of nodes are deployed in the region, which has a short communication range and high failure rates. The routing protocols are effectively acceptable for those challenges.

CRSN challenges: To provide successful event detection and tracking in CRSN, sensor nodes sense the event, and sensor nodes sense the data delivered to the sink with application-specific requirements such as packet delivery fraction, end-to-end delay, and throughput [37].

3.1. Biologically Inspired Method

Swarm optimization methods are useful in designing our next-generation routing protocol. Swarm prompted the design of very efficient optimizations and algorithms. The state-of-the-art algorithms are based on ACO (Ant Colony Optimizations) and BCO (Bee Colony Optimizations) techniques, which solve combinatorial optimization and NP-hard problems. We consider the ACO techniques to improve the adaptive routing techniques in communication.

3.1.1. Ant Colony Optimization (ACO)

It is well known that the biological ants in the real world can utilize swarm intelligence to find solutions to different problems. Ant colony optimization has been developed to mimic the behaviour of real ants to provide heuristic solutions for optimization problems.

Table 1. Capabilities of a wireless sensor with Cognitive Radio as an application[36]

Function	Action
Cognitive capabilities	
Spectrum sensing	Detect unused spaces by incumbents in spectrum bands.
Spectrum sharing	Use the unused white spaces of incumbents and share the white space information with cognitive users.
Prediction	Predict the arrival of the incumbent on the channel.
Fairness	Distribution of spectrum utilization among CR users.
Routing	Route the packet to the destination efficiently considering the network lifespan, load balancing, shortest route and delay in multi-hop CR WSNs.
Reconfiguration Capability	Reconfigure and adjust according to the environmental outcomes.
Environmental sensing	Sensing the environmental factors as in conventional wireless sensors.
Trust security	Building a trustable environment and secure network.
Power control	Control Transmission power.

It was first proposed by Macro Dorigo in 1992 in [27] his Ph.D. dissertation when searching for food. Biologically, ants exhibit complex social behaviour based on the hormones they deposit, called pheromones. Pheromones attract other ants and outline a path to the food source that other ants can follow. As other ants walk along the path, more pheromones are laid, the path will increase, and the required time is less. There is another possibility of pheromone evaporation for that purpose, which reduces the chance for other ants to consider the path [Michael Brand et al. 2010]. [29]. This characteristic of ants is adapted from ant colony optimization algorithms to solve real problems. ACO meta-heuristics approach models the real ants. In ACO, a number of artificial ants build solutions to optimization problems. Ant colonies achieve the path optimization between nest and food by exploiting the pheromone quantity dropped by ants. In WSN, the path is chosen, and data is transmitted through the labels on the heads of data packets, whereas in ACO, the path is chosen based on the pheromone left by ants in the path. At the same time, forward ants and backward ants are handling the responsibilities of forwarding information to explore paths and collect the information from source to destination. Backward ants update the information passing by nodes [28].

The first ant finds the food source anyway, then returns to the nest, leaving behind a trail pheromone. Ants follow possible routes, but strengthening the runway makes it more attractive as the shortest route. The ants take the shortest route; long portions of other ways lose their trail pheromones. These inspire the routing techniques. The optimization procedure involves adapting, positive feedback, and inherent parallelism. Each ant deposits a certain amount of pheromone during travel to search for food. The process is known as stigmatic communication [35].

3.1.2. ACO-based Algorithms

In network routing, Ant Net routing using ACO techniques provides better results [30]. Comparing all routing algorithms with ACO provides that ants are small and can be piggybacked in data packets. Frequently, the transmission of ants may be possible to update the information to solve link failure. Laura et al. (2008) proposed an ACO algorithm that aims to minimize node complexity. This proposal is optimal for a smaller number of nodes in the cluster and is also not suitable for ad hoc networks. [Mishra et al., 2010] The fault-tolerant routing protocols using greedy ACO choose a single path. Several algorithms were designed for the optimized routing process in a wireless sensor network. In the proposed routing algorithm, the sensor nodes are considered to have cognitive capabilities. The initial step is spectrum sensing on the channel, and if it is busy, rotate the cycle to select the spectrum sensing phase. After channel selection, the spectrum decision provides the carrier sensing procedure, and later on, back-off time that is backwards processed in between the spectrum decision provides the handoff for free space. During the carrier sense, it goes to the contention period or is sent to the cognitive radio users, as given in Figure 4.

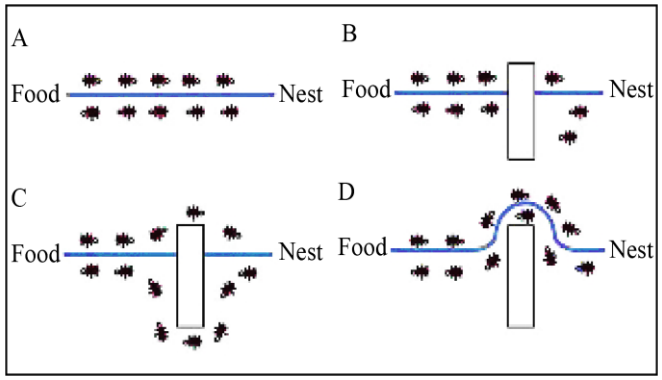


Fig. 3 Ant behavior

This paper considers the three conditions as channel selection and mobility as a static sink. Initially, we consider the static sink.The initial assumption in the proposed protocol is considered in the following form:

1. All sensor nodes and sink nodes (base stations) are stationary after deployment.
2. The sensor nodes are uniformly distributed with random deployment.
3. The sensor nodes have a heterogeneous configuration.
4. All nodes have limited energy.

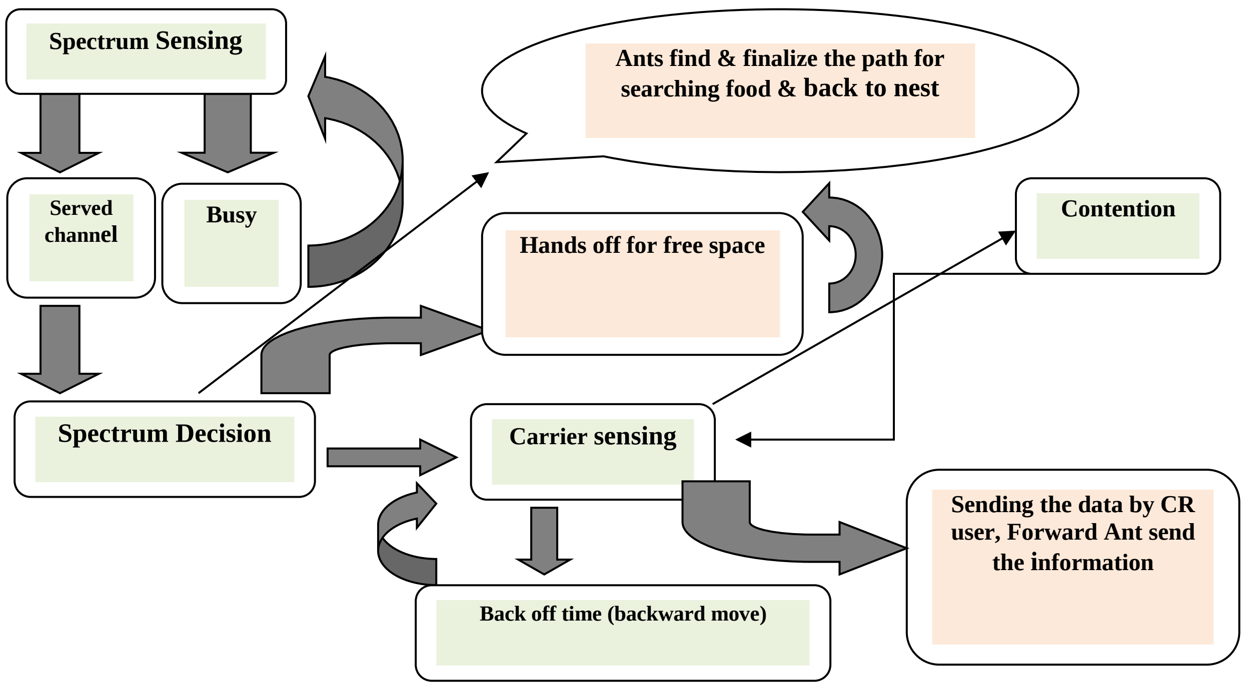


Fig. 4 Proposed structure of cognitive radio sensor network

The cross-layer MAC and network layers work jointly with the TCP transport protocol. In proposing our work, we consider two methods to demonstrate the adaptive routing protocol for solving fault tolerance issues in communication.

1. Single sink and multiple channels.
2. Multiple sinks and multiple channels.

In this paper, we considered single sink and multiple channels to demonstrate and find out performance, and in future work, we will consider multiple sinks. While finding the shortest path among routing in communication, the wireless sensor network has the capabilities of cognitive radio spectrum utilization. Here, spectrum sensing, the available spectrum band, searches for a certain duration of time for the neighboring node and jumps on the vacant band, identifying the primary band if it is free to serve the channel. If it is busy, it goes back to spectrum sensing. The served channel takes a decision and senses the carrier, which sends the data to the cognitive sensor node, the user (CR), as a forward and sends the information to next-coming ants through pheromone trails, either sending back to carrier sensing for the other vacant band as shown in Figure 4.

4. Proposed Method

The communication protocols are not sufficiently flexible regarding environmental changes. These environmental changes and controls on each wireless sensor network architecture layer operate on widely different timescales. The MAC layer supports one-hop communication, where data transmission takes a few milliseconds in most sensor networks. Energy efficiency MAC protocol with sleep scheduling for prolonging for a lifetime is assumed in sensor networks. Whereas the routing layer has to deal with topological changes to realise source-to-destination communications, static sensor nodes manage network topology using the HELLO message every several tens of seconds. The timescale of the external control of self-organization is longer than that of the routing layer. It is insufficient to discuss robustness within one layer so that we have designs for self-organized-based routing protocols. For the conditions of channel selection, mobility, and node failure.

In the MAC layer, sleep control is expected, so the power-saving option is successful. The MAC protocol with the sleep control allows the node to sleep for every ten milliseconds. So that each node can communicate with each other only when it is awake. The sleep control cycle means the minimum unit time of one-hop data transmission. In the MAC layer, the next hope node is selected. When it is in sleep mode, the data is held for a certain period of time. There is a condition for probabilistic channel selection for communication. The channel selection from spectrum sensing/sharing utilizing the available spectrum band is called cognitive radios in nature self-organization for sensor nodes in wireless sensor networks, which is analogous to biologically inspired methods, i.e., the availability of different paths for ANTs and BEEs for searching the food among different paths to reach the destination, i.e., sharing resources. Considering the insects' colony as a cognitive radio network, The insects are cognitive radios for spectrum utilization. Task allocation is an available channel, and task-associated stimuli are permissible channels.

- Select the channel with the minimum channel selection probability (appropriate channels) while avoiding interference simultaneously. (Select the paths by ants and bees as the availability of different paths.)

- Manage the number of sensor nodes nearer to each other as neighboring nodes, forming the groups called clusters (the node with fewer radiuses). Gathering the data as a response to the sink node for the Hello message as a multi-hop communication and accomplishing the task of joining regarding pheromone levels.

- If the sink node fails to send the data to the base station, the multi-sink operation is useful to improve the problem at that moment.

Ant-based clustering is a probabilistic approach where ants repeatedly realize clustering and stochastically selected eggs are picked up or dropped (join and leave the operation of sensor nodes). We introduced such a probabilistic approach to the clustering of sensor nodes. Dynamic clustering, adapting to environmental changes, can accommodate sink-node failures. The solution is using the multi-sink option. [36]

Algorithm 1: Spectrum Sensing (CRSN): Setup Phase

For each path (i, j), do
Ant performs the searching and sharing process for food.
Perform the spectrum sensing;
End for
finding the number of hops to its neighbor node (Nd, ID, List of Nd);
Compute the probability of choosing multi-hop{ 0,1}
Probability of choosing path {0,1} through channel;
either channel is busy or idle;
If [channel is busy (ON): P_{OFF}]
Primary user (active) is used;
else if [channel is Idle(OFF): P_{ON}]
Secondary user (active) is used;
Depending on channel sensing, neighbor discovery works,
For selection of channel, the next hop neighbor node with handoff for PU to SU
(Channel list, radio frequency, transmission range)
End for
End if
End

Algorithm 2: Spectrum Decision (CRSN): Steady Phase

For each channel
Find the best channel for
Spectrum decision, spectrum operation;
depends on noise or delay,
end for
For each busy channel
No Handoff;
For each Idle channel
Spectrum Handoff,
decide the P_{ON} & P_{OFF} condition;
end for
end for
Transfer the data through the primary user(PUs)
If the busy channel
Otherwise
Handoff to secondary users (SUs)
All the data is collected and sent to a single sink node with the shortest route.

The arrival rate of the Primary User (PU) as well as a Secondary User (SU) is denoted by α1, β1, and the departure rate of the primary user and secondary user is denoted by α2, β2. The primary user's detection and false alarm probabilities are either 0 or 1. Though the arrival rate of the primary user is ON and OFF when selecting the number of channels, We will vary the corresponding α and β, respectively, as the birth rate and death rate are denoted as α and β. The probability of P_{ON} and POFF is denoted as given below [4].

$$P_{ON} = \frac{\alpha}{\alpha+\beta} = \frac{\lambda}{\lambda+\mu} \quad , \quad P_{OFF} = \frac{\beta}{\beta+\alpha} = \frac{\mu}{\mu+\lambda} \qquad (1)$$

4.1. Sensing Accuracy

The channel selection activity depends on the two states: idle and active. If the state is idle, the channel is in an OFF condition, and if the state is active, it is in an ON condition. All the channels from channel 1 to channel n directly diverted from primary users to secondary users, using controlled channels with respect to time. The birth and death rates are equivalent to the arrival and departure rates of states of hope or packages, depending on each factor. The figure-5 below mentions the ON and OFF conditions of channel sensing, like {0,1}. The duration of ON/OFF periods is exponentially distributed and depends on the activity of PU directly affected by SU. Thus, it is considered a Poisson random variable.

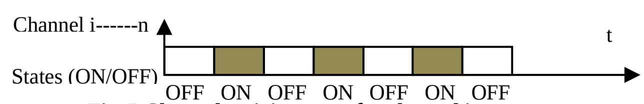


Fig. 5 Channel activity states for channel i to n

Every CR user can operate in a particular channel which is free of primary users' activity. Finding the free channels of the spectrum is done only because of sensing in CRSN. Spectrum sensing is the most important step in the cognitive radio sensor network equivalent to ACO s ants sense the path. Spectrum sensing is calculated on two parameters, first is a probability detection (Pd) and false alarm probability (Pf). The probability of detection is the channel occupied by primary users, and spectrum sensing detects that the channel is busy. Whereas the false alarm probability is when the CR user senses the channel is busy and PU does not use the spectrum. Here, the higher the probability of detection of the channel, the less the false higher probability, which uses more spectrum, and the performance of CR users will increase [5].

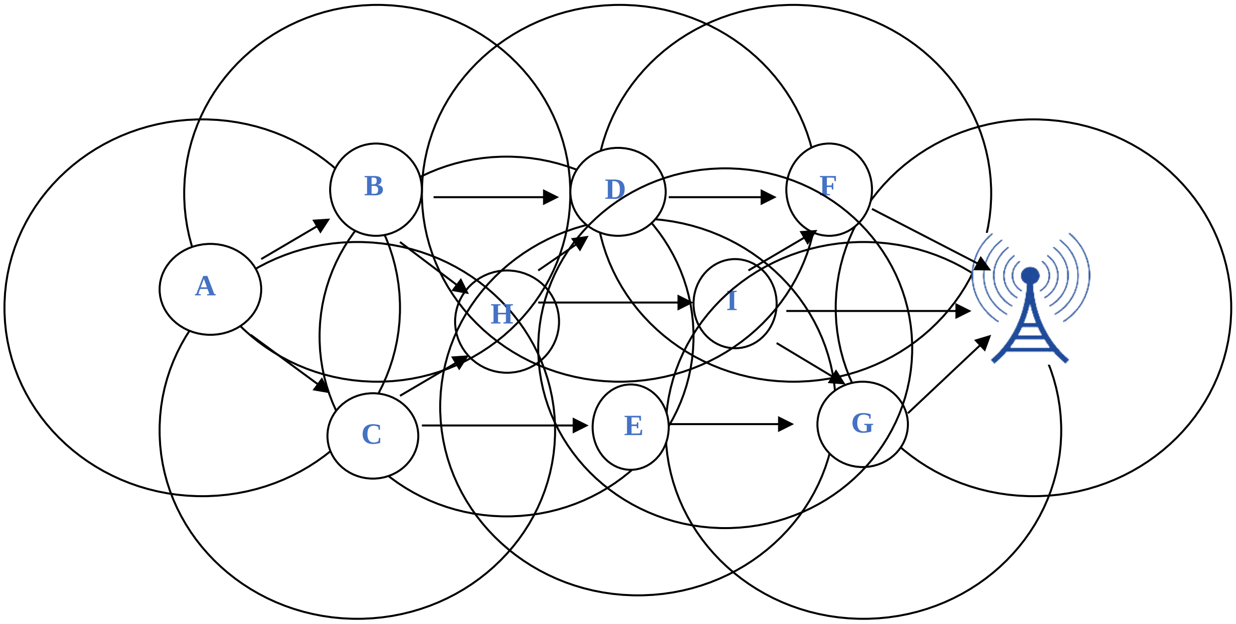


Fig. 6 Neighbor discovery in WSN

4.2. Neighbor Discovery

The sensor nodes in the wireless sensor network are the same as each PU (primary user) node in CRSN deployed in the region. In the neighbor discovery process, the base station initiates the process of a Hello message to each node to identify the neighbor of each node for communication. Each node is responsible for identifying the neighbor and sending the packets from sender to receiver. Here, each node discovers the neighbor and creates the topology to perform the operation process. After neighbor identification, each node notifies the neighbor information to the base station through its corresponding neighbor, as shown in the figure above. Consider the number of nodes N = {A, B, C, D, E, F, G, H, I} constructed the topology with information of nodes to the base station with discovering the path from source to destination. The number of nodes forming the cluster is based on an energy level with a certain threshold value. Each cluster elected the cluster head to gather the information and transfer packets to the base station or cluster head to another cluster head, considering its relay node to the base station. Here, the hops-to-hops communication and multi-channel operation are performed. Some nodes either use the single channel as they are nearer to the BS or use multi-channel operation. Knowing the information about the neighbor discovery process reduces the traffic and conserves the energy level of each node. The same process is applied by ants in ant colony optimization, which support each other in maintaining the pheromone level, identifying the forward ant and backward ant and discovering the nearest path to consume the energy level as an inspiration and designing a protocol for cognitive radio sensor network as identify the spectrum sensing process as the initial phase and take spectrum decision to identify the available spectrum band to use the channel and transfer the information and backward process does the same process to maintain the efficiency. Once the path of the primary user went to sleep mode(OFF state), the secondary user woke up to use the unlicensed band for other sources(ON state), here from above Figure 6. The base station creates the transition diagram and the matrix formation to create a Markov chain model as a probabilistic approach, as shown in Table 2 below.

4.3. Markov Chain Model for a Probabilistic Approach

The cognitive radio sensor network developments are based on partially observable Markov chain decisions [1]. In different applications, the probabilistic approach plays a vital role in solving a number of problems with an optimum solution based on the Markov chain model.The Markov Chain is a type of stochastic process characterization based on the Markov property. The meaning is that the next process depends on the current state, not the previous one.

Table 2. Probability matrix formation

	BS	***A***	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***
BS	0	0	0	0	0	0	1	1	0	1
A	0	0	1	1	0	0	0	0	0	0
B	0	1	0	0	1	0	0	0	1	0
C	0	0	0	0	0	1	0	0	1	0
D	0	0	0	0	0	0	1	1	0	1
E	0	0	0	0	0	0	0	1	0	1
F	1	0	0	0	0	0	0	0	0	1
G	1	0	0	0	0	1	0	0	0	1
H	0	0	1	1	1	1	0	0	0	1
I	1	0	0	0	1	1	1	1	0	0

To prove this for a discrete-time, as given as follows and stated by [23], Here P is the probability of selecting the behaviour of the next-hope sensor node, and X_t is the condition probability.

$$P[X_t + 1 = x|X_0 = x_0, ..., X_t] = P[X_t + 1 = x|X_t = x_t] \quad (2)$$

This process is called a Markov chain model. The Markov chain model for the sensor node is based on the (ON/OFF) condition of channel selection by the primary user and secondary user, and the probability of the next hope sensor is either {0, 1} as shown in the figure given below. In the following condition, state that it is equivalent to ants searching food stochastically with random walk probability, just as for channel selection by the secondary user after the primary user.

Fig. 7 Model for describing the behavior of next-hope sensor node analogous to channel sensing state as ON/OFF

The secondary users cooperate to sense the licensed channels in random sensing techniques. Each secondary user stochastically chooses licensed channels for sensing. SU is considered a secondary user as a CR node. We can develop the Markov chain model to calculate the probability mass function (PMF) of secondary users and denoted as the probability of secondary user denoted as Pr {Su} for the number of secondary users S = 0, 1, 2, 3 ….. n. Each one selects n channels as each sensor node selects the nodes uniformly with 1/n model defined for n + 1 states. The transition probability from states i to j is P (i, j). So, the probability transition matrix is developed as given above in Table 2.

$$\text{Pr (i , j) = Pr (Su+1 = j | Su = i)} = \begin{cases} i/n & j = i; \\ 1 - i/n & i = i + 1; \\ 0, & otherwise \end{cases} \quad (3)$$

The above equation proves that the condition of a number of states from one state to another state with probability from one user, that is, the initial state, to another node as the last state with respect to the transition from 0 to n, and the middle state is an n-1 transition with a number of probabilities to reach up to j state. Thus, the possibility of transitioning from one channel to another with a number of directions provided the sum of all possible transitions follows the equation given below.

$$\text{rij (n)} = \sum_{k=1}^{\infty} rik\ (n-1)\ Pkj$$

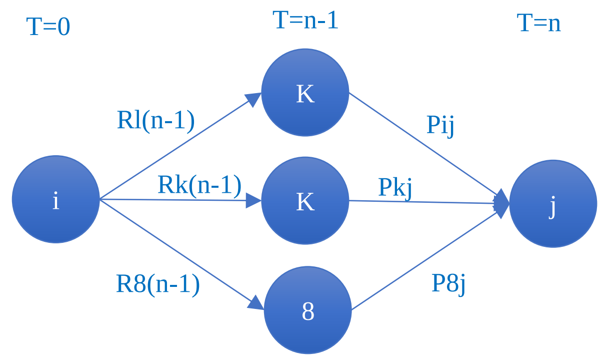


Fig. 8 The probabilistic approach for multi-hops with starting nodes and ending nodes

Here, some possibilities are fewer, and some are more; the ratio of similar probability values provides the steady state phase, but still, it keeps jumping up for a long time; the initial state does not matter. Some probability of recurrence and someone being transient depends on looping and non-looping structures. Meanwhile, in cluster formation, the probability is that there are recurrent classes and not transient classes. No matter the initial condition, it depends on the current status. From cluster to cluster, there are period classes. The transition for a particular period so that all transitions from one group lead to another group. The Markov Model Poisson Process (MMPS) [10] is a widely used tool for data flow analysis. This model brings versatile qualitative behavior. It contains an analysis of bursty traffic. In the Markov model, the current state of the Markov process controls the probability distribution of traffic. Poisson distribution with arrival rate λ It depends on the arrival time (λ) and departure time (μ). /n11

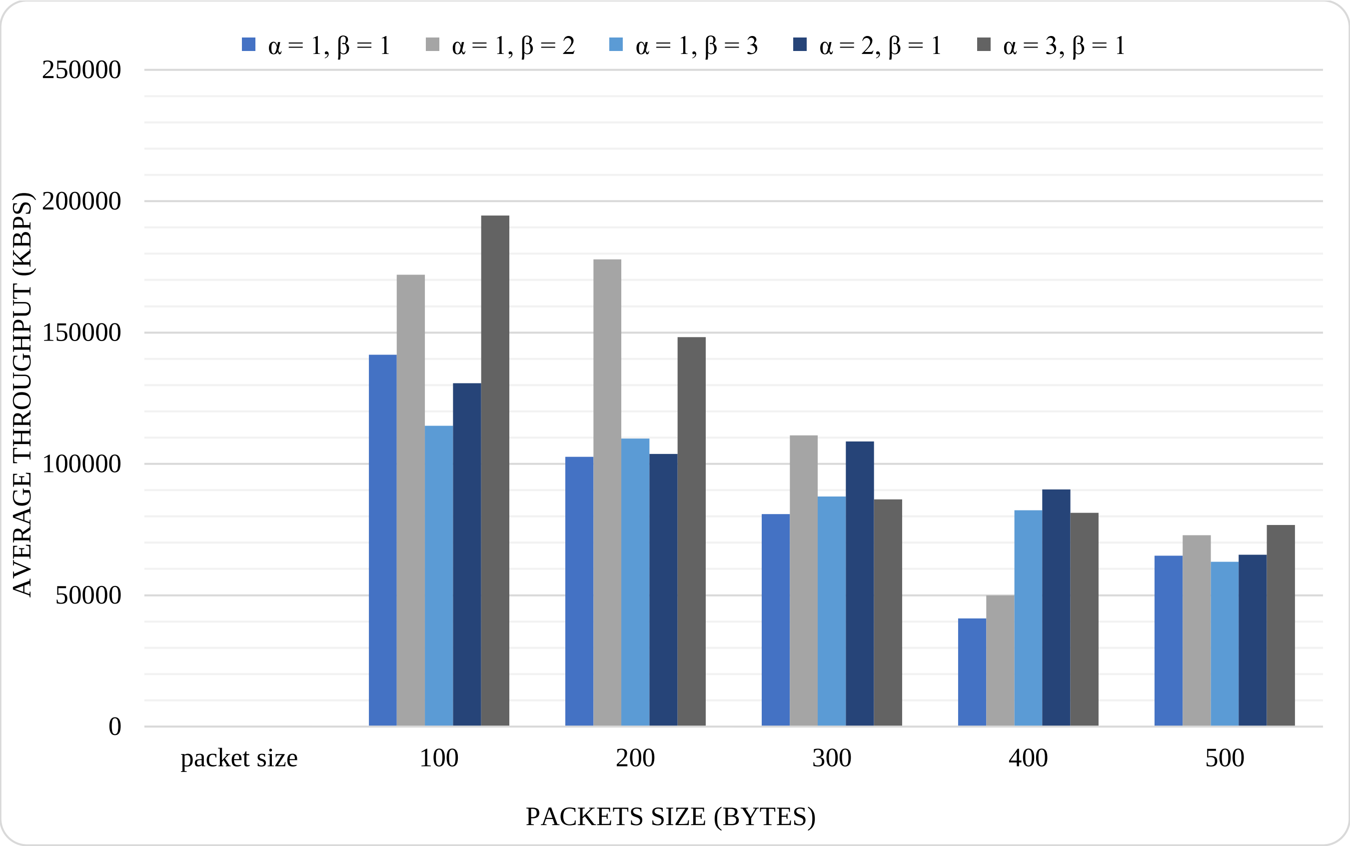
In our experiment, we consider the 25 number of users and 11 number of channels with sensing time (Tsense = 0.025 seconds and operation time Toper = 0.6 seconds). Which represents the Markov chain model for next hope node selection for the sensor node as well as channel selection from the primary user to the secondary user, analogous to ant behaviour for finding the destination node as food and source form next with probability {0, 1} follows the given probability.

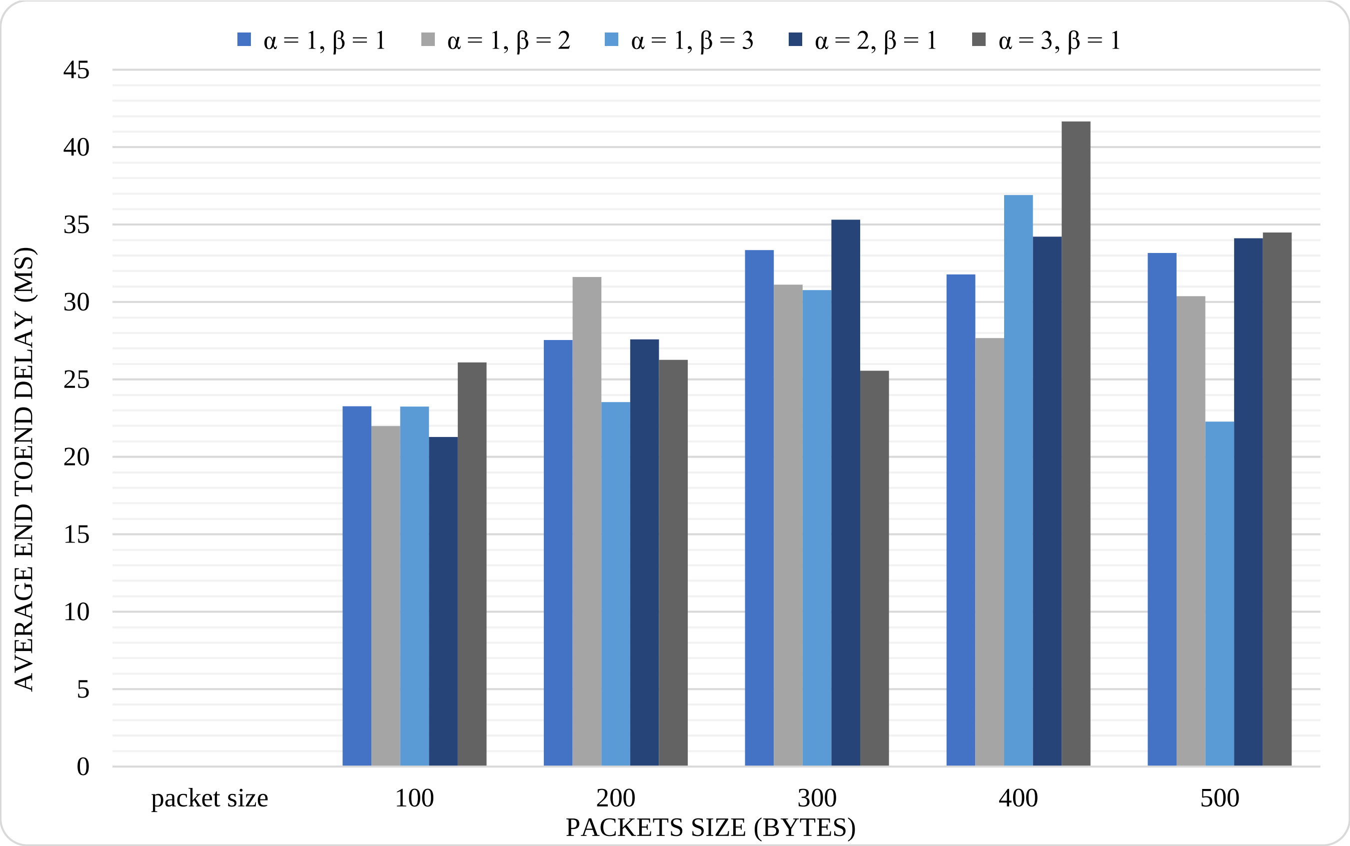
$$\text{Pr} = \begin{pmatrix} \alpha & 1-\alpha \\ 1-\beta & \beta \end{pmatrix} \quad (4)$$

$$\text{Pr} = \begin{pmatrix} 0.025 & 0.97 \\ 0.4 & 0.6 \end{pmatrix}$$

In this transition diagram, the initial state starts with α and 1 α, and the transition state is β and 1 β, which have the number of states with a probabilistic approach.The energy detectors for a spectrum sensing scheme for primary user detection, false alarm probabilistic performance, and cognitive radio sensor networks are closely related to spectrum sensing and its accuracy parameters (Pd and Pf). It's defined as follows:

$$\text{Pf}(ts, P_{OFF}, W) = P_{OFF}\ .Q\left(\frac{\lambda d - 2tsW\sigma n^2}{\sqrt{4tsW\sigma n^4}}\right) \quad (5)$$


α = 1, β = 1
α = 1, β = 2
α = 1, β = 3
α = 2, β = 1
α = 3, β = 1
250000
200000
150000
100000
50000
0
AVERAGE THROUGHPUT (KBPS)
packet size
100
200
300
400
500
PACKETS SIZE (BYTES)


α = 1, β = 1
α = 1, β = 2
α = 1, β = 3
α = 2, β = 1
α = 3, β = 1
45
40
35
30
25
20
15
10
5
0
AVERAGE END TOEND DELAY (MS)
packet size
100
200
300
400
500
PACKETS SIZE (BYTES)

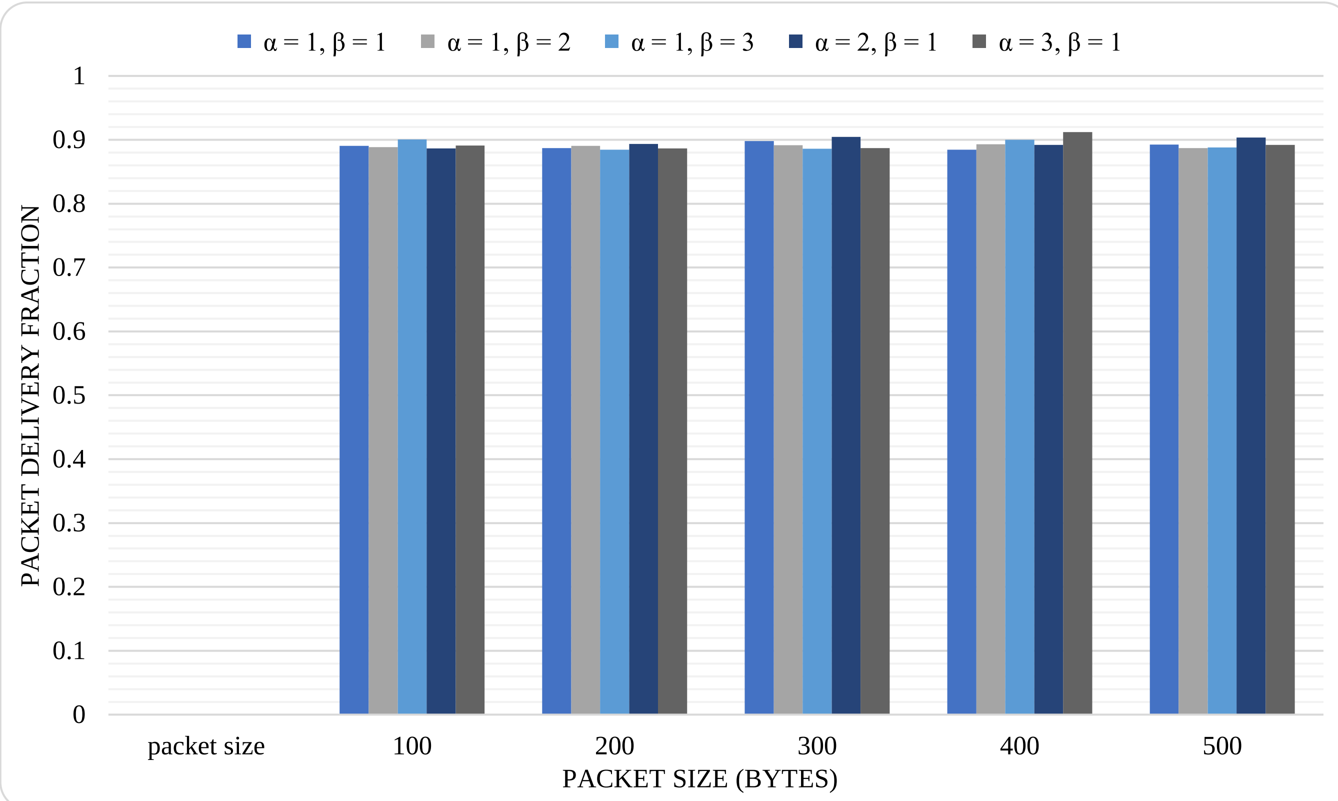


Fig. 9 Analysis of PU/SU activity with probability of ON/OFF, a) Average Throughput (kbps) Vs packet size (bytes), b) Average End-to-End delay (ms) Vs packet size (bytes), c) Packet delivery fraction Vs packet size (bytes)

POFF and PON are calculated by the arrival time and departure time, W is the bandwidth of the channel, ts is the duration of sensing, σn^2 and σn^4 is the variety of receiving signal the noise. The λd is the decision threshold of energy detection [13].

$$Pd\ (ts, P_{ON}, W) = P_{ON}, Q\left(\frac{\lambda d - 2tsW(\sigma s^2 + \sigma n^2)}{\sqrt{4tsW(\sigma s^2+\sigma n^2)^2}}\right) \quad (6)$$

Calculate the probability of ON /OFF conditions for PU and SU conditions. We get the following probability from the Equation (1). Here the value of (α, β) = (Arrival of PU/SU, Departure of PU/SU) = (1,1),(1,2),(1,3),(2,1),(3,1) and P_{ON} = (0.5), (0.33), (0.25), (0.67), (0.75) P_{OFF} = (0.5), (0.67), (0.75), (0.33), (0.25) and (Pd, Pf) = (0.5, 0), (0.33, 0), (0.25,0), (0.67, 0), (0.75, 0). We examine the five different scenarios, Scenario 1: (1,1); Scenario: (1,2); Scenario : (1,3); Scenario : (2,1); Scenario: (3,1) POFF and PON are calculated by the arrival time.

Figure 9 shows the performance analysis of the routing protocol with variations in packet size of 100, 200, 300, 400, and 500. Here, we consider the various scenarios with respect to arrival time and departure time, considered as α and β, respectively. In this variation of arrival time and departure time of PU and SU handoffs, we analysed with respect to the three parameters: average throughput, average end-to-end delay, and packet delivery fraction. From the obtained results, conceptually, when the arrival rate is 3, and the departure rate is 1, in a packet size of 100, the average throughput will be very high as compared to other scenarios, which means the arrival rate is higher than the departure rate with the minimum packet size, which provides a better output of throughput in cognitive radio sensor networks. On the other hand, in average end-to-end delay, when the packet size is 400, the end-to-end delay gives the highest delay compared to the other packet sizes in CRSN. The packet delivery fraction is about the same but still varies between 100 and 500. The delivery ratio is highest in packet sizes of 400. From the above results, the observation is that the routing protocol provides robustness in the CRSN network.

This paper considers the wireless multi-hop for the cognitive wireless sensor network. The secondary user, SU, uses the frequency band only when the primary user, PU, is not using the band. The node is distributed in the network of 1000*1000 m^2, and the node distribution according to Poisson distribution is called the homogeneous Poisson point, defined in [11]. The Poisson distribution is either the number of arrivals for the number of PUs or the number of SUs in CRSN. If an arrival occurs at random, the information of interest is the probability of n arrivals in a given time period departure time, W is the bandwidth of the channel, ts is the duration of sense, and ^{4} is the variety of the receiving signal and the noise. The λd is the decision threshold for energy detection [13].

Suppose n is the number of users as n = 0, 1, 2, 3, 4 ….n-1. N = 25. Let λ be the arrival rate, the constant representing the average rate of arrival in an interval of time t. The probability of exactly n nodes arriving provides the Poisson distribution. λ is the arrival rate and the Poisson distribution P(x).

$$P(x) = \frac{\lambda^x \, e^{-\lambda}}{x!} \quad (7)$$

If λ = 10 intervals, x = 25, e = 2.1718, Cumulative Distribution Function (CMF) = 0.99998, Probability Distribution Function (PMF) = 0.00003, Variances = 12, Poisson Distribution = 0.00027, The Poisson distribution given below shows that it varies from 0.12 to 0.13. Thus, the number of packet samples varies from hope to another.

5. Performance Evaluation

In this paper, we have considered the QoS (quality of services) analysed with the three parameters: the average end-to-end delay, average throughput, and packet delivery fraction. The performance parameter average throughput is obtained as the ratio of the total number of bits received by a layer of destination nodes to the total number of simulated time slots (the sending time of the first packet minus the receiving time of the last packet by the destination node).

5.1. Average Throughput $= \frac{N}{Rt - St}$, where the N = Total number of packets received by the destination node, Rt and St are the receiving time of the last packet and sending time of the first packet.

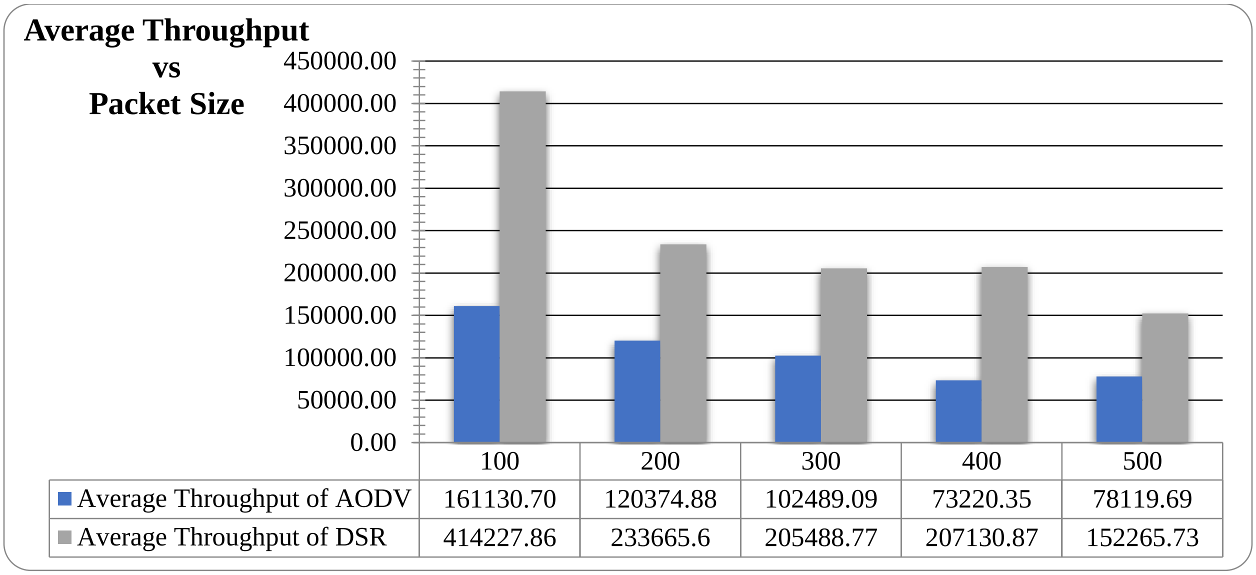
5.2. Average End-to-End Delay = The ratio of the total number of receiving packets by destination node and the receiving time of its packet by destination minus the sending time of its packet from the source.

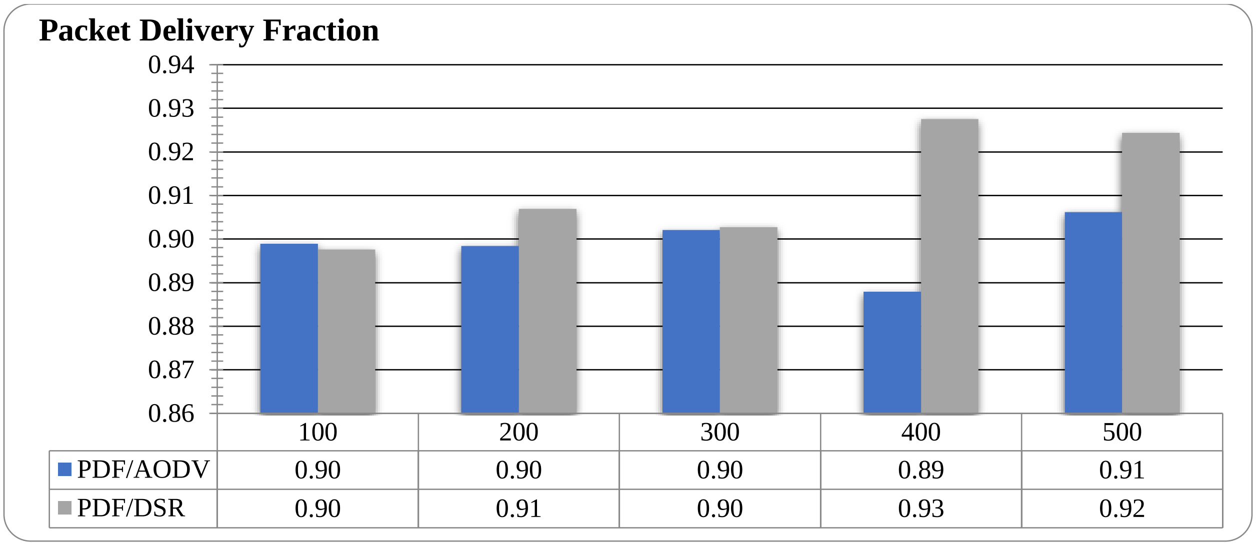
5.3. Packet Delivery Factorial = The ratio of receiving the number of packets by the destination node to sending the number of packets by the source node.

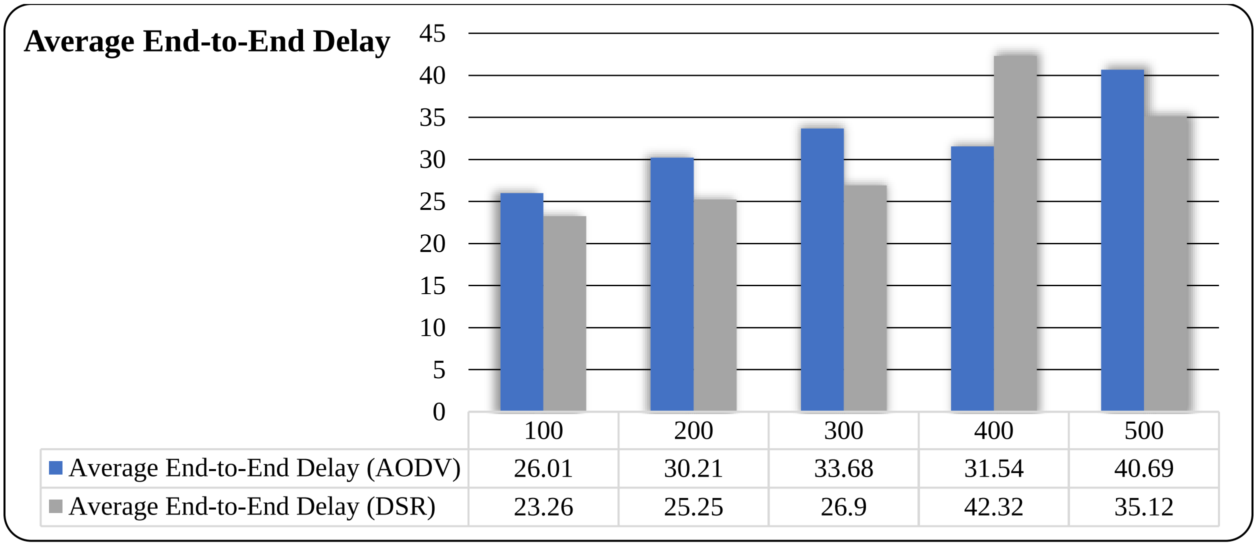
The proposed routing protocol is simulated in the open-source software tool NS2 [24]. There are some assumptions while analysing; initially, the number of nodes is in a static mode with a heterogeneous network. The consideration of a cognitive wireless sensor network with PU and SU activity as primary and secondary users with licenced and unlicenced spectrum band sensing techniques to fill the gap between the available space for the utilisation of unused spectrum bands to occupy the specific channels in operation mode to solve the self-organising, fault tolerance, and scalability issues.

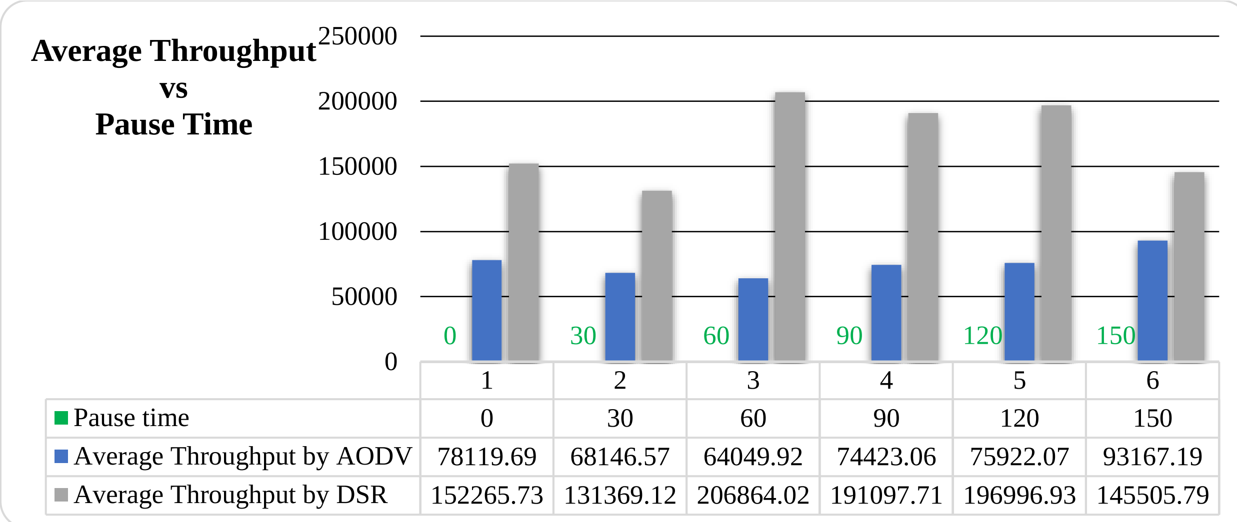
Table 3. Proposed routing protocol

Simulation Parameters	Values
Channel Type	Channel/WirelessChannel
Radio-Propagation Model	Propagation/TwoRayGround
Network Interface Type	Phy/WirelessPhy
MAC Type	MAC/cogmac/802_11
Interface Queue Type	Queue/DropTail/PriQueue
Antenna Model	Antenna/OmniAntenna
Max packet in ifq	50
Number of Mobile nodes	25
Routing Protocol	/AODV (cogns)/DSR (cogns)/AntHocNet
Topography	1000mx1000m
Energy Model(Initial)	100 Joule
Data transmission rate	2 sec
Radio transmission range	200
Pause time	0,30,60,90,120,150 sec.
Packet Size	100,200,300,400,500 bytes
Constant Bit Rate (CBR)	256 kb
Channel Number Type/Radio	11
Time of Simulation	150
Frequency band	2.4 GHz

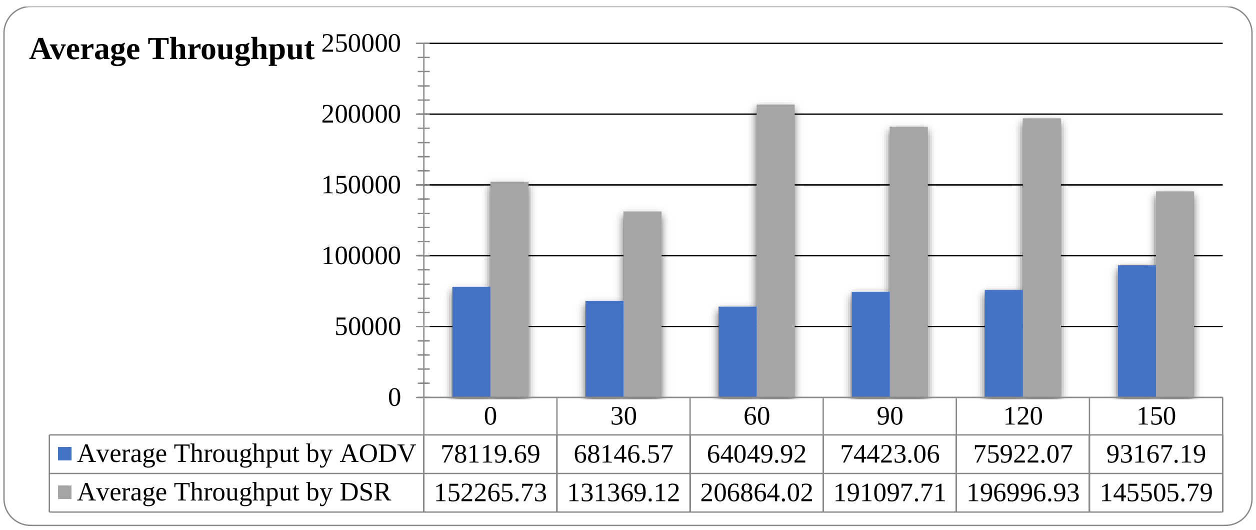

Average Throughput
vs
Packet Size
450000.00
400000.00
350000.00
300000.00
250000.00
200000.00
150000.00
100000.00
50000.00
0.00
100
200
300
400
500
Average Throughput of AODV
161130.70
120374.88
102489.09
73220.35
78119.69
Average Throughput of DSR
414227.86
233665.6
205488.77
207130.87
152265.73


Packet Delivery Fraction
0.94
0.93
0.92
0.91
0.90
0.89
0.88
0.87
0.86
100
200
300
400
500
PDF/AODV
0.90
0.90
0.90
0.89
0.91
PDF/DSR
0.90
0.91
0.90
0.93
0.92

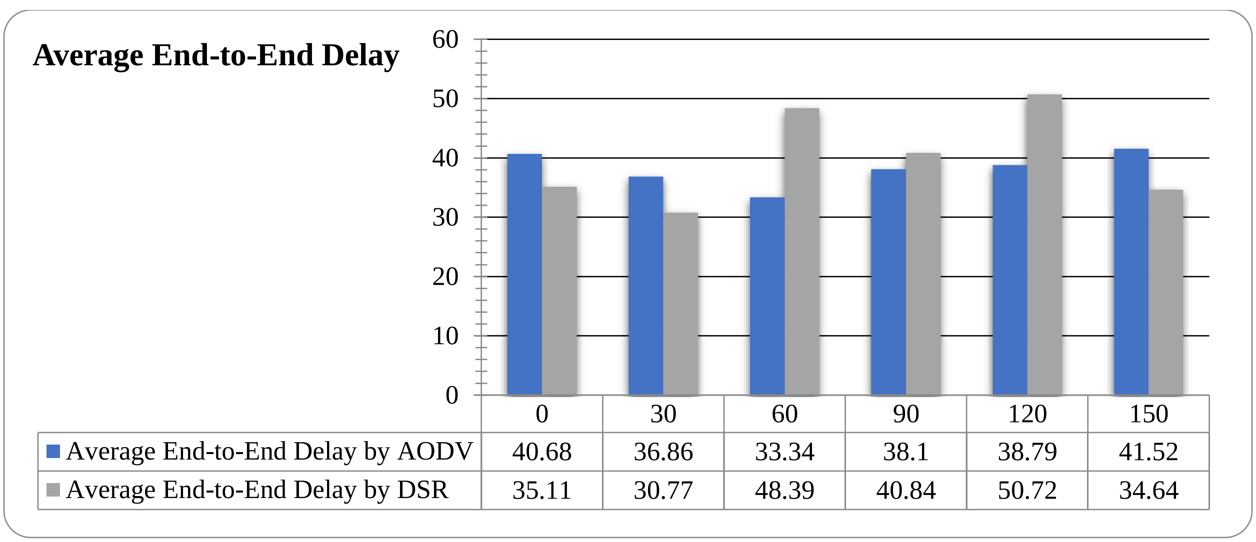

Average End-to-End Delay
45
40
35
30
25
20
15
10
5
0
100
200
300
400
500
Average End-to-End Delay (AODV)
26.01
30.21
33.68
31.54
40.69
Average End-to-End Delay (DSR)
23.26
25.25
26.9
42.32
35.12



	1	2	3	4	5	6
Pause time	0	30	60	90	120	150
Average Throughput by AODV	78119.69	68146.57	64049.92	74423.06	75922.07	93167.19
Average Throughput by DSR	152265.73	131369.12	206864.02	191097.71	196996.93	145505.79



	0	30	60	90	120	150
Average Throughput by AODV	78119.69	68146.57	64049.92	74423.06	75922.07	93167.19
Average Throughput by DSR	152265.73	131369.12	206864.02	191097.71	196996.93	145505.79



	0	30	60	90	120	150
Average End-to-End Delay by AODV	40.68	36.86	33.34	38.1	38.79	41.52
Average End-to-End Delay by DSR	35.11	30.77	48.39	40.84	50.72	34.64

Fig. 10 Performance Analysis of Cognitive wireless sensor networks, routing protocol with variation in packet size and pause time to analyze the above parameters as average Throughput, Average End-to-End Delay, Packet Delivery fraction based on cognitive wireless sensor network protocol AODV and DSR

a) Output of cluster-based simulation of 25 nodes; b) packet transmission between the nodes using hops-to-hops. C) Packet delivery fraction shows the AODV is much better than DSR; d) Average throughput with AODV is better than DSR; e) Average delay in DSR initially is greater than AODV with variation in packet size; f) Results using pause time variations of PDF show the AODV with CogNS has better output than DSR; g) Average end-to-end delay of AODV is lower than rise compared to DSR; h) Average throughput of cognitive AODV is better than cognitive DSR. From the above results, as we increase the packet size in cognitive wireless sensor networks, there is variation in the results of cognitive AODV and cognitive DSR routing protocols. If the packet size increases, the results of a PDF are increasing. The AODV protocol increases compared to the DSR protocol, which varies from 90% to 93%. Average throughput decreases as packet size increases. The average end-to-end delay increases as packet size increases. As the variation in pause time (seconds) results from various parameter changes, as we increase the pause time, the cognitive wireless sensor networks-based AODV routing protocol increases compared to the DSR routing protocol. It is observed that the DSR routing protocol with the cognitive MAC approach provides better results as compared to the AODV routing protocol. The observation shows that a designed routing protocol for cognitive wireless sensor networks with bio-inspired methods such as Ant Colony Optimization creates a novel technique for next-generation telecommunication networks.

6. Conclusion

In this paper, we conclude that the design of the routing algorithm with respect to adaptive networking has produced the best results in all the parameters while comparing the AODV and DSR protocols with cognitive capabilities. Using a single sink and multi-channel approach, the CRSN routing algorithm solves routing issues in wireless sensor networks with cognitive capabilities. Here, the Markov chain model with Poisson distribution is computed with respect to a statistical approach applied to telecommunication using the CRSN approach to try to solve the issues of wireless sensor networks. Combining WSN and CRSN using the analogy of bio-inspired routing protocols satisfies the different parameters of sensor networks inspired by Ant Colony Optimization. The design of a probabilistic approach for hop-to-hop communication with a Markov chain model satisfies the condition that there is a certain number of hops in networks with different hypotheses of ON and OFF. Here, the packet delivery fraction with regression analysis shows that CogNS with AODV and CogNS with DSR are compared and observed to have a better output of regression than CogNS with AODV, which provides a better adaptive routing algorithm useful for applications like telecommunication networks to route the packet with better utilisation of available vacant spectrum bands regular PU/SU activity as shown in results similar habitat having in ant colony optimization to use the route for finding food search as an inspiration for our research work with better time complexity of O(n).

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References

[1] Hang Su, and Xi Zhang, "Cross–Layer Based Opportunistic MAC Protocols for QoS Provisioning Over Cognitive Radio Wireless Networks," *IEEE Journal on Selecting Areas in Communications*, vol. 26, no. 1, pp. 118-129, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[2] D.P. Mackinuon, *Introduction to Statistical Mediation Analysis*, 1st ed., Routledge, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[3] D.G. Reina, "The Role of Congestion in Probabilistic Broadcasting for Ubiquitous Wireless Multi-Hop Networks through Mediation Analysis," *Pervasive and Mobile Computing*, vol. 24, pp. 16-29, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[4] Gunter Bolch et al., *Queueing Networks and Markov Chains: Modeling and Performance Evaluation with Computer Science Applications*, John Wiley & Sons, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[5] Vahid Esmaeelzadeh et al., "CogNS: A Simulation Framework for Cognitive Radio Networks," *Wireless Personal Communications*, vol. 72, no. 4, pp. 2849-2865, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[6] M.D. Felice, and K.R. Chowdhury, "Search: A Routing Protocol for Mobile Cognitive Radio Ad-Hoc Networks," *Computer Communications*, vol. 32, no. 18, pp. 1983-1997, 1997. [CrossRef] [Google Scholar] [Publisher Link]

[7] Zhongliang Liang et al., "Delay Performance Analysis for Supporting Real-Time Traffic in a Cognitive Radio Sensor Network," *IEEE Transactions on Wireless Communications*, vol. 10, no. 1, pp. 325-335, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[8] Ozgur B. Akan, Osman B. Karli, and Ozgur Ergul, "Cognitive Radio Sensor Network," *IEEE Network*, vol. 23, no. 4, pp. 34-40, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[9] Gyanendra Prasad Joshi, Seung Yeob Nam, and Sung Won Kim, "Cognitive Radio Wireless Sensor Networks: Applications, Challenges and Research Trends," *Sensors*, vol. 13, no. 9, pp. 11196–11228, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[10] Balakrishnan Chandrashekaran, "*Survey of Network Traffic Models*," Thesis, Washington University in St. Louis CSE, 2009. [Google Scholar] [Publisher Link]

[11] Le The Dung, Tran Dinh Hieu, and Seong-Gon Choi, "Simulation Modeling and Analysis of One Hop Count Distribution in Cognitive Radio Ad-Hoc Networks with Shadow Fading," *Simulation, Modeling Practice and Theory*, vol. 69, pp. 43-54, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[12] Ian F. Akyildiz et al., "NeXt Generation/Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey," *Computer Networks*, vol. 50, no. 13, pp. 2127-2159, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[13] Won-yeol Lee, and Ian. F. Akyildiz, "Optimal Spectrum Sensing Framework for Cognitive Radio Networks," *IEEE Transactions on Wireless Communications*, vol. 7, no. 10, pp. 3845-3857, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[14] W.B. Heinzelman, A.P. Chandrakasan, and H. Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks," *IEEE Transactions on Wireless Communications*, vol. 1, no. 4, pp. 660-670, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[15] Siva D. Muruganthan et al., "A Centralized Energy-Efficient Routing Protocol for Wireless Sensor Networks," *IEEE Communications Magazine*, vol. 43, no. 3, pp. 8-13, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[16] D. Mahmood et al., "MODLEACH: A Variant of LEACH for WSNs," *2013 Eighth International Conference on Broadband and Wireless Computing, Communication and Applications*, Compiegne, France, pp. 158-163, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[17] Min Hla Yin, and Z. Win, "Fault Management Using Cluster-Based Protocol in Wireless Sensor Networks," *International Journal of Future Computer and Communication*, vol. 3, no. 1, pp. 36-39, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[18] Perumalsamy Deepalakshmi, and Shanmugasundaram Radhakrishnan, "An Ant Colony-Based Multi-Objective Quality of Service Routing For Mobile Ad-Hoc Networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, no. 153, pp. 1-12, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[19] Gianni Di Caro, Frederick Ducatelle, and Luca Maria Gambardella, "Anthocnet: An Adaptive Nature-Inspired Algorithm for Routing in Mobile Ad Hoc Networks," *European Transactions on Telecommunications*, vol. 16, no. 5, pp. 443-455, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[20] Hang Su, and Xi Zhang, "Cross-Layer-Based Opportunistic MAC Protocols for QoS Provisioning Over Cognitive Radio Wireless Networks," *IEEE Journal on Selected Areas in Communications*, vol. 26, no. 1, pp. 118-129, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[21] B. Krishnamachari, and S. Iyengar, "Distributed Bayesian Algorithms for Fault-Tolerant Event Region Detection in Wireless Sensor Networks," *IEEE Transactions on Computers*, vol. 53, no. 3, pp. 241- 250, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[22] Z. Liang, and D. Zhao, "Quality of Service Performance of a Cognitive Radio Sensor Network," *International Conference on Communications (ICC)*, Cape Town, South Africa, pp. 1-5, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[23] Wayne Yang, "*Markov Chains and Ant Colony Optimization*," The University of Chicago Mathematics, pp. 1-27, 2013. [Publisher Link]

[24] The Network Simulator - ns-2. [Online]. Available: http://www.isi.edu/nsnam/ns/

[25] Introduction to Probability, Statistics, and Random Processes. [Online]. Available: https://www.probabilitycourse.com

[26] J.F.C. Kingman, *Poisson Process*, Clarendon Press, 1993. [Google Scholar] [Publisher Link]

[27] M. Darigo, "*Optimization, Learning and Natural Algorithms*," Ph.D. Thesis, Politecnico di Milano, Italian, 1992. [Google Scholar] [Publisher Link]

[28] Kashif Saleem et al., "Ant-Based Self-Organized Routing Protocol for Wireless Sensor Networks," *International Journal of Communication Networks and Information Security (IJCNIS)*, vol. 1, no. 2, 2009. [Google Scholar] [Publisher Link]

[29] Michael Brand et al., "Ant Colony Optimization Algorithm for Robot Path Planning," *2010 International Conference on Computer Design and Applications*, Qinhuangdao, China, pp. 436-440, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[30] Kwang Mong Sim, and Weng Hong Sun, "Ant Colony Optimization for Routing and Load Balancing: Survey and New Directions," *IEEE Transactions on Systems and Humans*, vol. 33, no. 5, pp. 560-572, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[31] Swagatam Das, Ajith Abraham, and Amit Konar, *Metaheuristic Clustering. In: Studies in Computational Intelligence*, Springer Berlin Heidelberg, pp. 1-252, 2009. [Google Scholar] [Publisher Link]

[32] Hajara Idris et al., "An Improved Ant Colony Optimization Algorithm with Fault Tolerance for Job Scheduling in Grid Computing Systems," *PLoS ONE*, vol. 12, no. 5, pp. 1-24, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[33] Lary pass, *Beginning R: An Introduction to Statistical Programming*, Apress, pp. 1-336, 2012. [Google Scholar] [Publisher Link]

[34] Falko Dessler, and Ozgur Akan, "A Survey of Bio-Inspired Networking," *Computer Networks*, vol. 54, no. 6, pp. 881-900, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[35] R. Latha, P. Vetrivelan, and M. Jagannath, "Balancing Emergency Message Dissemination and Network Lifetime in Wireless Body Area Network Using Ant Colony Optimization and Bayesian Game Formulation," *Information in Medicine Unlocked*, vol. 8, pp. 60-65, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[36] Amit. N.Thakare, Latesh G. Bhagat(Malik), Achamma Thomas, "*Analysis od adaptive bio-inspired routing protocol with multi-hops communication in WSN*", Mc-Graw Hill education publication, 2017.
[37] A. Ozan Bicen, and Ozgur B. Akan, "Reliability and Congestion Control in Cognitive Radio Sensor Networks," *Ad Hoc Networks*, vol. 9, no. 7, pp. 1154-1164, 2011. [CrossRef] [Google Scholar] [Publisher Link]