An adaptive routing algorithm for cognitive radio-based wireless sensor networks

[1]Prachi Rajendra Salve, [2]Madhavi Patil
[1]Assistatnt Professor, [2]Assistant Professor
[1]Computer Engineering Department,
[1]DYPSOEA, Ambi, Pune, Maharashtra, India

Abstract : Cognitive radio network (CRN) introduces the idea of sharing spectrum among primary and secondary users. Dynamic spectrum access is core technology for CRN; in which it is possible for utilizing unoccupied spectrum resources which were sensed by cognitive radios without hindering primary users. Unlike commercial network, each secondary radio node in military network is allocated with unfair spectrum resources depending on its priority. This article elucidates cooperative dynamic spectrum allocation that depending on needs and priorities of user, each secondary member utilizing network may allocate resources of spectrum. The evolutionary algorithm, especially particle swarm optimization (PSO), was explored and implemented to spectrum allocation such that by considering the tactical data, a secondary member could be able to learn and adapt to spectrum access, optimizing overall reward under constraints of spectrum resource limitation, quality of services (QoS) and limitation of system. The experiment infers that priority-based evolutionary algorithm yields better outcome over fair-based evolutionary and random allocation algorithm.

***IndexTerms* - dynamic spectrum allocation, particle swarm optimization, cognitive radio network.**

I. Introduction

In modern networks, the large number of challenges has been observed with respect to different functionalities of networks in different applications must improve the data rates, packet delivery ration, decreasing overhead, energy efficient, especially the spectrum band utilization in wireless sensor networks (WSNs). The WSN sensor nodes act as CRSN networks, analogous to the insects in the colonies, the insects as CRSN and task is available channel. The spectrum sharing in the CRSN as decentralized sharing the spectrum as available licensed band used as the primary user (PU), used as an unlicensed band as a secondary user (SU) for coordination among insects in the colonies as ants trail their pheromone while searching their routes for finding their food from source to destination. The probability of selection of channel the nodes required transmission power for its QoS parameters the channel allows more transmission channel utilization.

The insects in colonies utilized the available routes and which have maximum pheromone value either may be zero or one depends on this declares the routes for spectrum sharing and selection of channels for transmission of packets among nodes in the network. The conventional WSNs shown in Figure 1 as all sensor nodes transmit aggregate packets to the base station. Thus the sensor nodes available in the market are IEEE 802.15.4 which is able to operate in non-overlapping channels in the 2.4 GHZ ISM band. Thus the using multiple channels, improve the transmission in WSN proposed by Phung et al. (2013).

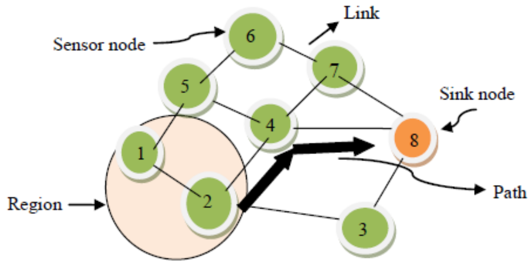

Figure 1 Conventional WSN

In ant colonies, the ant has less intelligence (Caro and Dorigo, 1998), and collective behavior has more intelligence with respect to performing any task during the searching food. They utilize the maximum channel for better searching to find the optimum requirement. They divide the number of the working ants as labor to perform the individual task and this is spectrum sharing in cognitive WSNs.

Now a day's application several heterogeneous WSN exists, but it creates long waiting time for delivering the data, there is a delay in packets receiving, therefore adaptive ability and lifetime of WSN node is important. Adaption applied in many branches with large-scale networks having number of challenges which solve the problem of complexity, heterogeneity, dynamic spectrum communication, stated by Zhang et al. (2013). Various artificial adaptive system in wireless ad hoc network and WSN have been developed with some ability to adapt in centralized and distributed approach, with adaptive routing which respond the topological changes in the network.

The natural or biological insects are also having adaptive capabilities such as Ants, Bees, Firefly, as per their adaptive capabilities, the different proposed algorithm was developed by researchers such as AntNet, AdhocNet, bee sensor (Saleem and Farooq, 2010), BeeAdhoc, ant colony optimization (ACO), bee colony optimization (BCO) (Karaboga et al., 2009), particle swarm optimization (PSO) techniques in swarm intelligence, as these technology are used in the real time experimentation for many applications.

Many researchers carried out the same assumptions depend on their experimentation and findings. We have gone through the designed protocols for adaptive routing protocols based on the WSNs, wireless ad hoc networks and cognitive radio sensor networks (CRSNs) that the newly upcoming area for the research works. Here the utilization of unused licensed spectrum band as unlicensed spectrum band for the other application, used as to sense the band as spectrum sensing and then the spectrum sharing with accessing by the other channel. The shifting from one channel to another channel depends on the availability of the unused spectrum band. If the one channel is busy the other sources of other channel is utilized for the proper flow of data communication between the numbers of user's exchanging of information from one node to the other neighboring node and collectively to the base station. Though the user's points of view, there are two users were defined as PUs and SUs as licensed spectrum band users and unlicensed spectrum band users respectively. The analogies have their colonies as new observed fields for gaining some aspects regarding the research work. These analogies were considered as the cognitive radio, which sense the availability of spectrum band utilizes in both homogeneous and heterogeneous networks. Based on these fundamentals the researchers try to develop the protocols to solve the different issues in the different layers of networks.

In this paper, we proposed the new algorithm for WSN with some challenges as adaptive, robust, scalable routing protocol in case of fault-tolerance. The robustness in one layer never satisfies the conditions for the above issues. So the two-layer hybrid approach is considered for the designing purpose, the MAC and routing layer. In MAC layer, we utilize the sensing approach of spectrum with proper time scale which varies from tens of milliseconds to seconds with multi-hop fashion and routing layer to deal with topological changes for large-scale network. To handle these aspects we proposed the adaptive routing protocol with the cognitive radio utilization as an application.

The rest of the paper is organized as follows, Section 2 gives overview of the literature review, Section 3 explores the design issues and routing algorithm, Section 4 Adaptive routing protocol, Section 5 describe performance analysis of routing protocol and Section 6 concludes the paper.

II. Literature review

In the survey paper of Akylidiz et al. (2002), they described the importance of WSN in applications and issues, Kominami et al. (2013) develop the CPBR protocol consider the MAC layer and routing layer approach to find out the potential of nodes in the network. In MAC layer, considering sleep control option which directly related to the time scale factor. Though the sleep control mechanism is considered for power saving option in network as nodes has to manage the potential of individual node and their neighboring node. The node has to register the node potential periodically to maintain adaptive network (Kim et al., 2006) and in routing layer the node has the potential for transmitting to the sink node through its consider multi-sink node option in case of topological changes. Atakan et al. (2007) developed the BIOSS protocol for cognitive radio network, the author proposed that the utilization of dynamic spectrum accessibility analogous to insect colony. Atakan et al. (2012) developed the biologically inspired routing protocol for cognitive radio ad hoc network in which they consider the intermittently connected bio-inspired methods for developing the new protocol. Zhang et al. (2013) provided a survey of next generation cellular network and optimization approach depends on cognitive radio network as considering for adaptive paradigm. De Domenicoet al. (2010) provided the survey of cognitive radio related to MAC (medium access control) layer issues. Paone et al. (2010) designed the new protocol called as pheromone protocol compares with directed diffusion and done the performance analysis of novel protocol with conventional protocol. Li et al. (2010) developed the enhanced BIOSS for better improvement in the spectrum sharing in cognitive radio approach. Joshi et al. (2013) described the open challenges for newly developing cognitive WSN and their capabilities of sensor network with cognitive radio. Ding et al. (2013) explained the overview of the cognitive radio network and their advantage and disadvantages. Luo et al. (2015) described the heterogeneous CRSNs with Markov analysis and applications for smart grid application with CRSN approach consists of spectrum utilization, blocking probabilities and optimal traffic intensities for the heterogeneous SU user. Mohammady et al. (2014) developed the channel allocation scheme for networks of heterogeneous QOS classes and calculates two Markovian models for calculating average delay. Phung et al. (2013) developed the multichannel communication protocol to improve the network performance and also the collision free transmission schedule and reducing the energy waste.

III. Design approach of bio-inspired routing

3.1 Design issues and routing factors in WSN

A large number of researchers carried out the number of experiments depend on many factors of WSNs to solve the problems. We focus on design issues of algorithm based on self-organization, scalability and fault-tolerance.

1. ***Self-organization:*** in WSN, the sensor node exhaust very fast, the sensor node should remain in attended fashion for a long period of time and resilient to such dynamic variations in the topology. There is an important issue to solve the problem of such network called as self-organized network for long-term sustainability.
2. ***Fault-tolerance:*** in this third issue after deployment of sensor nodes the nodes fails, the algorithm can recognize itself so that it continues for the proper functionality of network without any disruption.
3. ***Scalability:*** as another issue of a large number of nodes is deployed in the region affects in routing packets in communication in the network. To solve such issue we consider another one for scalability.

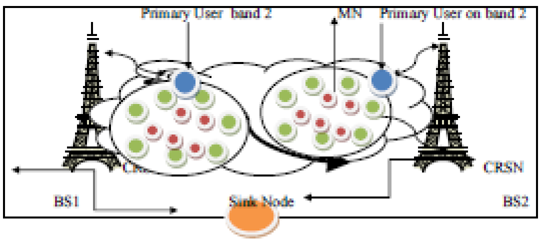

Figure 2 A typical CRSN architecture

In WSN, the large number of nodes is deployed and scattered among the area for sense the data. The number of sensor nodes in heterogeneous network the sink nodes send the hello message to the number of nodes. The sensor nodes with cognitive capability senses the data and send to its neighboring nodes for forwarding as depends on interest of nodes nearer to each other and forward collectively to the base station as given in Figure 2. The sensor nodes forming the cluster and elect the cluster head as depend on pheromone strength. Those nodes are nearer to each other, form the cluster and then selection of cluster head, which aggregate the data and send to the base station with proper channel if it fails then select another channel and send to the base station. These formed clusters-based approach to heterogeneous network formed the cluster-based cognitive radio, WSN (Akylidiz et al., 2009) and some are based on heterogeneous hierarchical has given in Figure 2. The cross-layer approach with MAC and network layer finds out the optimal solution for many issues. The above approach is inspired from biologically inspired routing protocol ACO. As the AntNet algorithm only useful for packet routing in communication network proposed by Caro and Dorigo (1998). The cognitive radio network is application which we consider for our applications to solve the problem of utilization of unused spectrum band which is the next generation approach called as CRSN (Gao and Wu, 2011) of WSNs which is need of present scenario for the development in telecommunication networks based on routing protocols always inspired from nature.

3.2 Design approach of multipath channel utilisation

The traditional WSN used single channel utilisation. In our approach multipath channel is utilised for communication. As with route discovery, RREQ and RREP play a vital role in understanding the role of path utilisation. The RREQ starts from source A to destination B as given in Figure 5. The two paths for communication between A and B, the ants start from source to destination, choose the shortest path from and source to food and back to the nest. They initially find out the optimum path from nest to food source and back to destination during these operations the pheromone trails start evaporates regularly, but the remaining ants following the optimum path for a better solution, but if channel fails because of some reason. The other channel is utilised to reach the optimum path and back to the nest in RREP format. The RREP depends on availability of the slot schedule of the network. The nodes transmit their data in multi-hop fashion with the multichannel utilisation as a novel approach in cognitive WSN depends on the probability of node selection as described in Figures 3 and 4 and formulate as given below.

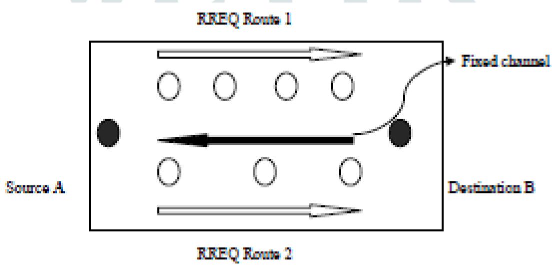

Figure 3 Single Route channel utilization

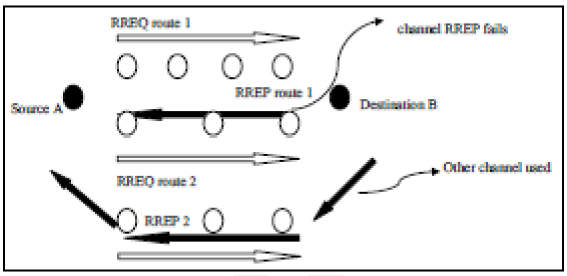

Figure 4 Multi-route channel between the source A and destination D

If the channel fails, it chooses another path (channel) for communication as the concept of PU and SU, the PU as lice and SU as cognitive as channel utilisation depends on spectrum availability. It senses the channel for the user that which channel is used for transmission of packets.

The sensor node sends the RREQ, consists of sensor node ID with spectrum availability for available of spectrum sensing, decision, sharing among the node and find out the quality of paths depends on pheromone value as a spectrum. The RREP with the node ID and node channel with time slot scheduler for coming packets over each channel periodically.

The self-organising systems completely rely on localised decision processes which have the three aspects of successfulness of self-organisation. By concentrating radio interferences required to develop the controlled self-organisation by initialising with MAC layer. The controlled self-organisation is important for the realisation of large-scale WSNs associated with robustness to network topology changes is also important for WSNs (Dressler, 2008).

The communication protocols are not sufficiently flexible regarding environmental changes. These environmental changes and control on each layer in WSN architecture operates on widely different timescale. MAC layer supports for one hops communication where data transmission takes a few milliseconds in most sensor networks. Energy efficiency MAC protocol with sleep scheduling for prolonging lifetime are assumed in sensor networks. Whereas routing layers have to deal with topological changes to realize source to destination communications. In static sensors, nodes manage network topology by using HELLO message every ten seconds. The external timescale operation control of self-organisation is longer than routing layer. It is insufficient to discuss about the robustness within one layer. Here, we try to design the self-organised-based routing protocols for the condition of channel selection, mobility, and node failure.

In MAC layer, the sleep control is expected, so that power saving option is successful. The MAC protocol with the sleep control allows the node to sleep for every 10 ms so that each node can communicate with other nodes only when it is awake. The cycle of sleep control means minimum unit time of one-hop data transmission. In MAC layer, during the selection of a next hop node when a node 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 as cognitive radios. In nature (Saleem et al., 2009), self-organization for sensor node in WSNs which is to be analogous to biologically inspired methods, i.e., availability of different paths for ANTs and BEEs for searching the food among different paths to reach the destination, i.e., sharing resources. Consider the insect colony as a cognitive radio network and the insects as a cognitive radio for spectrum utilization. Task allocation is available channel and task associated stimuli as a permissible power to channel.

IV. Bio-inspired routing algorithm for WSN

4.1 Bio-inspired algorithm for adaptive and robust routing in CRSNs

Let consider the ants transmits the hello message after certain duration of time to its neighbouring node. The Forward ants do this task neither by the backward ants. Hello message carries the pheromone trails as *Ph* from source node *Sn* and the other node as the sink node *Ss*. As per our algorithm is cluster-based approach in WSN called as cluster Pheromone which evaluates the pheromone value in the pheromone table. The cluster is called as *Cn*(*Sn*). The ants regularly update pheromone value as mention in algorithm particular in pheromone table as

$$Ph_2(S_n, S_s) = xPh_2(S_n, S_s) + (1-x)Ph_1(S_{n1})$$

The probability of ant is $x \in \{0, 1\}$. The average pheromone value entered in the pheromone table. The ants jumps as number of hops probabilistically either in {0, 1} in form for selecting next-hop node is defined as

$$Ph_1(S_{n2}) = \frac{Ph_1(S_{n2}, S_{s1})^2}{\sum_{k_{\varepsilon N1}} Ph_1(k, S_{s1})^2}$$

The m is the neighbouring and network of N nodes. The number of ants jumps as probability of ants from one node to other nodes and update pheromone table in ant colonies.

The ants forming the number of clusters according to their larvae size, the clusters are formed by ants forming the self-organisation property (Heurtefeux et al., 2007). Here the large number of ants works and forms the cluster to save energy of a node and to become a more efficient process. The ant works for food by trailing pheromone value done lots of job for finding food, thus the solution by forming clusters by ants and forms the cluster pheromone $C_n(S_i)$ and $C_n(S_j)$ respectively given by following expression

$$C_n\left(S_j\right)=\frac{\sum_k \varepsilon_{belongs_{n1}\left(S_j\right)C_{nj}\left(S_j\right)+averagePh_n\left(S_s\right)}}{\left|belongs_n\left(S_j\right)\right|+1}$$

The sensor nodes which have a message which transfer by cluster ID whether them forming the cluster or not. In case of the failure rate of ants or sensor nodes as for cognitive approach the one channel fails other channel select in jumping of next hops in a similar way the ants suddenly change forms the cluster according to probability approach from cluster 1 to cluster 2, just as leave and join operation in failure rate.

Let consider the CRSN sensor node *i* and *j* as edge (*i*, *j*) ant starts searching food from best path.

Cluster head selection algorithm

Setup phase

---

for *each path (i , j)* do
perform spectrum sensing;
end for
finding each hops from i to j as best path (shortest)
for *each ant k1 & k2* do
Compute probability of choosing multi-path;
if [*node j nearest neighbour to node i, ant k1 & k2 checks both path & take decision*]
$\leftarrow$ *chose path*, then
Calculate length;
Compute as shortest path and form a cluster (all nearer nodes);
else longest path
ant k computes best path (i , j) by dropping pheromone trail;
end
pheromone value = 1;
if *node with greater pheromone value then others* then
ant k select path(i ,j) in multi-hop fashion;
else if *node which have deeper pheromone value with < T(n) choose as CH* then
Advertise as cluster head (CH);
End
Transfer data from CH to Master CH (as sink node);
End

Steady phase: multi-hop routing algorithm

For *each edge* do
Set initial pheromone value 1;
End for
For each CH do compute the visibility
End for
While *not stop* do
For *each ant k* do
Select CH;
For i=1 to n do
Compute probability Pij and select next CH j with;
Probability pij;
End for
End for
For *each path* do
Update the pheromone value (i + 1);
End for
End while

Select shortest path ij &
Choose the CH as a leader for each CH to base station do
sends packet under leader control;
end for

Communication within clusters

---

for *each cluster* do
All nodes sends data to CH
CH check the availability of the network
if (*network is busy*) then
perform spectrum sensing;
if *a spectrum band is available* then
utilise primary network;
transfer the data through the primary networks(Pus);
wait for selection of CH and master Cluster Head (in which all CH sends data);
if *CH is elected in transferring data* then
send the data with max packet size;
Else
send the data with restricted packet size;
End
Else
Utilise secondary network (SUs);
Here to access SU over CSMA protocol;
End
Else
Utilise the secondary network;
End
End

V. Performance analysis

In this section we evaluated the CRSNs as next generation WSNs. The simulation was done in the open source software NS2 version ns-2.31. The CRSN network consists of 25 nodes, which are arranged in a grid topology of 1,000 m × 1,000 m. It is assumed that the network utilises an unlicensed channel which is shared with other legacy networks. This condition causes network interference, which is represented by the parameter (i.e., PU channel). On the other hand, here we use 11 channels for our experimentation in CRSN network. We compare the performance of the CRSN routing protocol and AODV protocol. Note that since the AODV protocol cannot utilise the cognitive radio feature of the CRSN nodes, CRSN with AODV protocol behaves as a conventional WSN with AODV protocol. In this simulation, we used the IEEE 802.11 standard as the MAC layer protocol. The following parameters are considered for the following simulation of CRSN as WSNs using bio-inspired routing protocol.

5.1 Throughput

The parameter evaluation in WSNs with the considering the above-mentioned parameters in NS2 were evaluated. In the simulation throughput of the network is decreased with respect to increasing the number of packet size. The throughput is calculated as

Throughput = Total number of bits received/Receiving time of last packet – Sending time of first packet

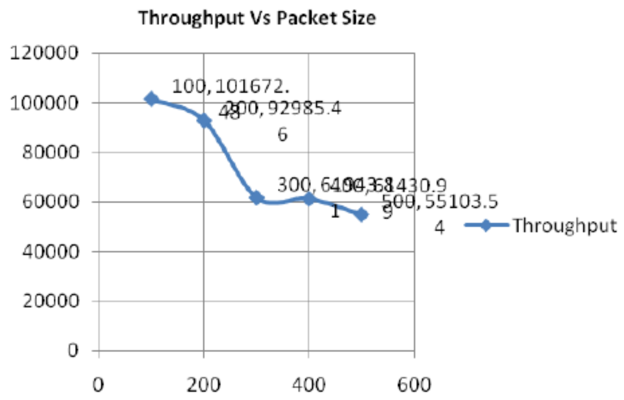

Figure 5 Throughput analysis

5.2 Average end-to-end delay

The same as throughput the average end-to-end delay for the 25 number of nodes with respect to packet size with some statistical values mention in each graphical representation. Here the average end-to-end delay is less at starting state and increasing as packet size increased.

The average end to end delay = [(total receiving time of i^{th} packet of destination – total sending time of packet to source) / Total number of received packets by destination nodes]

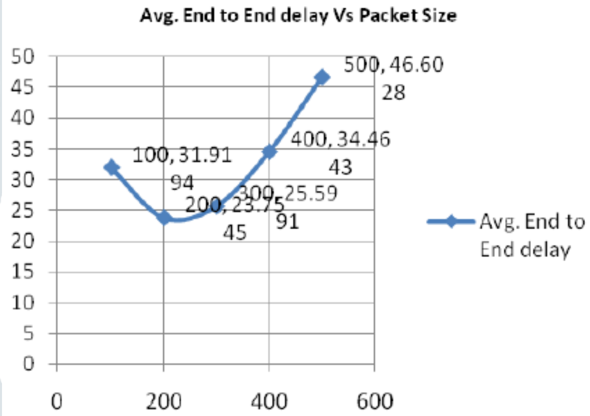

Figure 6 Average end-to-end delay

5.3 Packet delivery factorial

The PDF is another parameter in the sensor networks also depends on the total number of sending and receiving packets from any source to destination with respect to time. Here initially it is less as the packets size increases, it also increases.

Thus, from above performance analysis of WSN with the cognitive approach as application of WSN as next generation sensor networks prove the robustness as self-organization in WSNs.

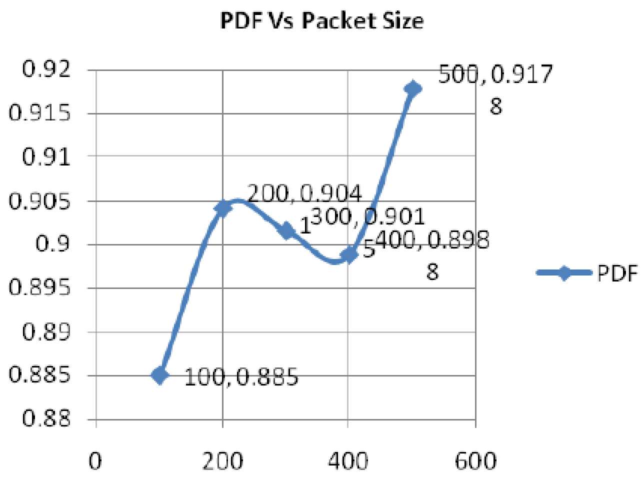

Figure 7 Packet delivery factorial analysis

5.4 Time complexity

The time complexity is the time required to achieve goals in the route discovery from source to destination or to base station. Thus the time complexity for route discovery and communication is *O*(*n*). Let n be the diameter of the network in terms of the number of hops. The time required for achieving the goal of routing protocol from source to destination. Thus time complexity to fulfill the requirement of route discovery is *O*(*n*).

VI. Conclusions

In this paper, we conclude that the design of novel algorithm has produced to find out the issues such as self-organization, fault-tolerance. Here, the Markov chain model has been describe to find out the optimum solution to the cognitive approach using bio-inspired methods with some mathematical modeling. The performance analysis of the respective parameters in WSN is analyzed. The WSN is utilized in many applications, but as per now days the requirement is in cognitive networks. So the combinations of WSNs with cognitive network producing the new research area as a cognitive WSN as next generation requirement. We try to solve the problems of the current issues based on biologically inspired methods.

References –

[1] Akan, O.B. et al. (2009) 'Cognitive radio sensor network', *IEEE Network*, July/August, Vol. 23, No. 4, pp.34–40.
[2] Akylidiz, I.F. et al. (2009) 'CRAHNs: cognitive radio ad hoc networks', *Ad Hoc Network*, Vol. 7, No. 5, pp.810–836, Elsevier.
[3] Akylidiz, I.F., Su, W., Sankarasubramaniam, Y. and Cayirci, E. (2002) 'Wireless sensor networks: a survey', *Computer Networks*, Vol. 38, No. 4, pp.393–422.
[4] Atakan, B. et al. (2007) 'Biologically-inspired spectrum sharing in cognitive radio networks', *IEEE Communication Society Proceeds of WCNS'07*.
[5] Atakan, B. et al. (2012) 'Biologically foraging inspired communication in intermittently connected mobile cognitive radio ad hoc networks', *IEEE Transaction on Vehicular Technology*, Vol. 61, No. 6, pp.2651–2658.
[6] Awwad, S.A.B. et al. (2010) 'Cluster based routing protocol for mobile nodes in wireless sensor network', 23 May, *Wireless Press Commun.*, Vol. 61, No. 2, pp.251–281.
[7] Caro, G.D. and Dorigo, M. (1998) 'Ant Colonies for adaptive routing in packet-switched communication networks', *LNCS*, Vol. 1408.
[8] de Domenico, A. et al. (2010) 'A survey on MAC strategies for cognitive radio networks', *IEEE 30th International Conference on Distributed Computing System Workshops*.
[9] Dressler, F. (2008) 'A study of self-organization mechanism in ad hoc and sensor networks', Elsevier.

[10] Ding, G. et al. (2013) 'Spectrum sensing in opportunity-heterogeneous cognitive sensor networks: how to cooperate?', *IEEE Sensors Journal*, November, Vol. 13, No. 11.

[11] Gao, M. and Wu, J. (2011) 'An improved ant colony optimization for routing in cognitive radio network', *International Journal of Advancements in Computing Technology*, Vol. 3, No. 7.

[12] Heinzelman, W. et al. (2000) 'Energy-efficient communication protocols for wireless microsensor networks', *Proceedings of Hawaiian International Conference on Systems Science*.

[13] Heurtefeux, K. et al. (2007) 'Self-organization protocols: behavior during the sensor networks life', *Proceeding of PIMRC'07*, IEEE.

[14] Joshi, G.P. et al. (2013) 'Cognitive radio wireless sensor networks: applications, challenges and research trends', *Sensors*, Vol. 13, 11196.

[15] Karaboga, D. et al. (2009) 'A survey: algorithm simulating bee swarm intelligence', 28 October, Springer.

[16] Kim, D-S. et al. (2006) 'Self-organized routing protocol supporting mobile nodes for wireless sensor network', *Proceeding of the First International Multi-Symposiums on Computer and Computational Sciences (IMSCCS'06)*, IEEE.

[17] Kiri, T. et al. (2007) 'Self-organized data-gathering scheme for multi-sink sensor networks inspired by swarm intelligence', *IEEE 7th International Conference on Self-Adaptive and Self-Organizing Systems*, pp.161–172.

[18] Kominami, D. et al. (2013) 'A design approach for controlled self-organization based sensor networks focused on control timescale', *IJDSN*, Hindawi.

[19] Li, G. et al. (2010) 'Enhanced biologically inspired spectrum sharing for cognitive radio networks', *ICCS*, IEEE.

[20] Luo, L. et al. (2015) 'Heteogeneous cognitive radio sensor networks for smart grid: Markov analysis and applications', *International Journal of Distributed Sensor Networks*, Vol. 2015, pp.1–15.

[21] Mahmood, D. et al. (2013) 'MODLEACH: a variant of leach in WSN', *Eighth International Conference on Broadband, Wireless Computing & Communication Applications*.

[22] Mohammady, R.D. et al. (2014) 'Spectrum allocation and QoS provisioning framework for cognitive radio with heterogeneous service classes', *IEEE Transaction on Wireless Communications*, Vol. 13, No. 7, pp.3938–3950.

[23] Paone, M. et al. (2010) 'A bio-inspired distributed routing protocol for wireless sensor networks: performance evaluation', in *Distributed Computing Systems Workshops (ICDCSW), 2010 IEEE 30th Int. Conf. on*, pp.247–255, IEEE Computer Society.

[24] Phung, K-H. et al. (2013) 'Adaptive learning based scheduling in multichannel protocol for energy efficient data-gathering wireless sensor networks', *International Journal of Distributed Sensor Networks*, Vol. 2013, pp.1–11.

[25] Saleem, K. et al. (2009) 'Ant based self-organized routing protocol for wireless sensor networks', *International Journal of Communication Networks and Information Security (IJCNIS)*, Vol. 1, No. 2, pp.42–46.

[26] Saleem, M. and Farooq, M. (2010) 'Bee sensor: a bee-inspired power aware routing protocol for wireless sensor networks: survey and future directions information sciences', *Proceeding of the 4th EVOCOMNET*.

[27] Yang, W. (2013) *Markov Chains and Ant Colony Optimization*, in *Proceedings Yang 2013*, Markov, CA.

[28] Zhang, Z. and Dressler, F. (2014) 'On swarm intelligence inspired self-organized networking: its bionic mechanisms, designing principles and optimization approaches', *IEEE Communications Surveys & AMP Tutorials*, Vol. 16, No. 1, 1st qtr., pp.513–37.

[29] Zhang, Z. et al. (2013) 'Self-organization paradigm and optimization approaches for cognitive radio technologies: a survey', *IEEE Wireless Communication*, May, Vol. 12, No. 5, pp.2524–2532.