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A Survey on Bioinspired Cluster-Based Routing and Cognitive Approaches in Wireless Sensor Networks

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Abstract

Wireless sensor network (WSN) is a type of network comprising of low-cost sensor nodes with communication and computation capabilities implemented high in the monitoring areas. Crucial challenges in WSN are optimal routing, clustering, energy, and lifetime optimization. Many bioinspired clustering and cognitive techniques are induced for optimization and solve the problems. In this paper, a complete survey is carried on bioinspired clustering algorithms like Artificial Bee Colony (ABC), Bat algorithm, Honey Bee algorithm, Genetic algorithm, firefly algorithm which play important role in solving challenges. Considering Quality of Service adding the cognitive technology provides access to a new spectrum with better propagation characteristics. Although these techniques and algorithms have conceived a lot of attention in research, the domain-specific understanding is still needed to be enhanced for its establishment. This report will concisely present the survey and study of approaches like cluster-based routing, bio-inspired clustering, and cognitive techniques in WSN.

Disciplinary: Electronics Engineering and Technology.

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1 Introduction

The implementation of wireless technology use sensor nodes makes it highly optimal. Over the last decade, there are many wireless sensor networks (WSN) research such as military surveillance, habitat study, home automation, and environmental monitoring. Due to the reduction of cost and enhancement in processing and storage aspects of Sensor nodes, these nodes in

everyday life serving as mediators of the physical environment in the digital world. However, the implementation of the sensor nodes on a large scale needs more evaluation on routing protocols to ensure the real-time transmission of data and reliable transmission when recognizing the power constraints in WSNs. The battery is used in the sensor node which seems to be unattended when it is implemented. Hence, the routing protocols must not determine issues related to the quality of services like fault tolerance, data reliability, scalability, real-time operation. There will be restricted capabilities of WSN in memory, processing, energy storage, topology, and communication changes because of the mobility of nodes. This report will present a survey of cluster-based routing, cognitive and bio-inspired approaches in WSNs.

2 Wireless Sensor Network

Wireless sensor network has emerged from the idea that small wireless sensors are used to gather information from the physical environment (Selvakennedy et al., 2006). The wireless network is a type of computer network which prefers wireless data connections to make network nodes. These networks are not connected by cables. This wireless network allows organizations to avoid the high costs of cables into the connection between various equipment locations. It consists of low-cost nodes that are organized with limitations in processing capacity, energy, and memory. Due to the advancement of wireless electronics and communications, multi-functional sensors and low power can be communicated in a nutshell distance. Smart sensors and cheap network over wireless links have been implemented in various quantities and offered opportunities for managing and administering the homes. The network sensor prefers a broad spectrum in the defense area and creates new capabilities for tactical and surveillance applications. It consists of a large number of low-power sensor nodes accessed in the unattended environment and computation capabilities (Xue et al., 2014).

3 Cluster-based Routing Protocols

Figure 1, a cluster-based routing comprises some stages such as data communication, data aggregation, cluster formation, and cluster head selection (Villalba et al., 2009). The cluster head selection initiates the setup state and starts with developing clusters. This step is followed by data transmission states that can be categorized into phases of data transmission and data aggregation (Kamesh and Priya, 2012). The steady and setup data transmission uses the cluster-based protocol that processes over the network lifetime and runs the protocol. Sensor nodes are categorized into four types.

Cluster head selection: It coordinates the group of nodes situated in the cluster boundaries and aggregate sensed data by transmission and cluster member of data to the further hop are the significant aspects of cluster head.

Base station: By having unlimited sources of energy and high processing aspects, the base station act as a network coordinator where the aggregated data will be processed as per user demand and type of application.

Relay node: a group of needs in the multi-hop approaches is used for relaying sensed or aggregated data by other nodes focused towards the destination.

General node: In this network, most of the nodes render sensed data as per the type of application (Devi et al., 2020).

3.1 WSN and Cluster-based Routing

By having unique features of WSN, the cluster-based protocols exhibit the important benefits through flat strategies. There are many benefits of clustering approaches that introduce all these as effective protocols with WSN attributes. They are as follows,

- Maintaining the energy exhausting load over all nodes
- Lessening the total transmission power.
- Minimize the effective consumption of channel bandwidth and bandwidth demand.
- Avoid high correlated and redundant amount of data in the process of aggregation
- Lowering the topology and routing maintenance overhead

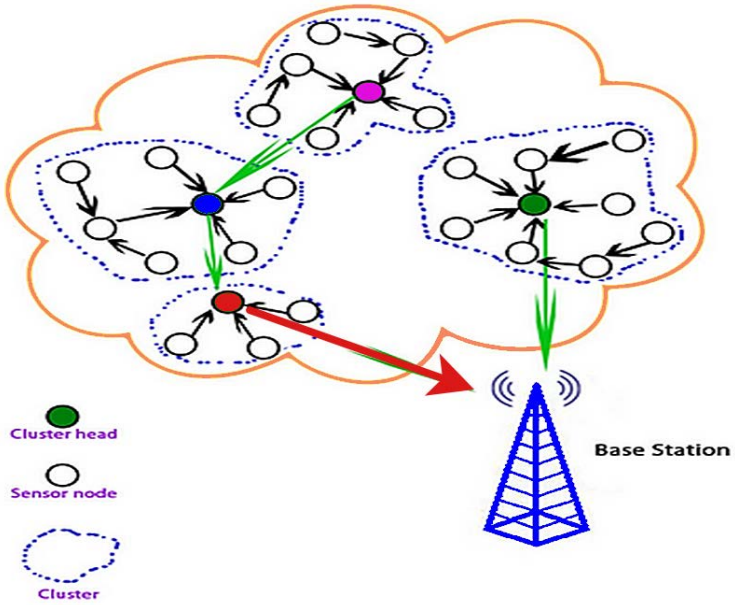

Figure 1: Cluster based WSN (Villalba et al., 2009).

- Localize the route setup and develop small size routing tables in the cluster boundaries.
- Lowering interference and data collision in the process of data transmission by using cluster scale communications and multi-power levels in the network scale.
- Enhancing the scalability and manageability of the network (Heinzelman et al., 2002)

There are some previous surveys conducted on the cluster-based routing protocols for WSNs. In this paper, the strength and weaknesses of these routing protocols for WSN will be analyzed. Younis and Fahmy (2004) have addressed several aspects and behaviors of the clustering algorithm that determines and categorizes as per the convergence rate. Akyildiz et al. (2002) have classified the algorithms into four types namely grid, weighted, hierarchical, and heuristic. The author focused on the routing protocol designed for WSN networks.

Due to the advancement in wireless communications, low-power electronics, embedded microprocessors, and WSN are increasing for several applications due to attributes like low cost and power, multifunction, and small size. In WSN, the routing seems to be challenging because of inherent features that differentiate the networks from wireless networks such as cellular or Adhoc networks. In addition to this, hierarchical cluster-based routing is applicable for sensor network applications in which many sensors are applied to sensing purposes. The cluster head belongs to the high tier whereas sensor nodes from the low tier (Wu and Hou, 2014). Sensor nodes will transmit the data to the base station. Developing WSN will make effective use of restricted energy of sensor nodes and enhancing network lifetime can be achieved by clustering.

3.2 Network Lifetime

Cluster-based routing is an effective way of lowering the consumption of energy in the cluster and manage the data fusion and aggregation to reduce the transmitted messages to the base station. Clustering is used to enhance network lifetime and significant aspect for determining the sensor network performance. There will be no unique definition of network lifetime as it is highly based on the application. The common definition has time until the node has been left out from the base station. The clustering techniques are used for the energy efficiency aspects and the network lifetime is longer (Naeimi et al., 2012).

3.3 Classification

Based on different conditions, the existing methods in WSN have several classifications. According to the parameters for selecting the cluster head, the algorithms are classified as adaptive and deterministic. The attributes of sensor nodes are evaluated as the number of neighbors, identifiers in the prespecified transmission of deterministic schemes. The scheme with low ID becomes a cluster head. It does not apply to the energy-constrained sensor networks as it does not evaluate the specific nodes in the network. (Kumar and Ramalakshmi, 2018) and (Chan and Perrig, 2004) have stated that select nodes with large degrees are used to select the minimal dominating set of cluster heads and develop dense clusters.

Centralized techniques need global information regarding the network topology as the efficiency will be restricted to large scale networks. Low energy adaptive clustering hierarchy (LEACH) is the clustering technique used for enhancing energy efficiency in WSN. It can run through clustering algorithms like heed and teen (Singh and Sharma, 2015). Leach makes a cluster using the distributed algorithms in which the nodes have autonomous decisions without using centralized control. The operation has two phases. The clusters are arranged and cluster heads will be selected in the setup phase. Each node should share the decision and must have a cluster head with probability (Pei et al., 2019). Each non-cluster head node chooses a cluster to make as per the signal strength from the cluster head. After making clusters, the cluster node assigns a node with a time slot about the time of transmission.

4 Challenges in Cluster-based Routing Protocol

A significant problem for routing protocol in WSN integration with the wired network. In environmental monitoring, most of the applications need data and collected from sensor nodes and transmitted to serve. The request from the user side will be given to the base station over the internet (Arora and Singh, 2017). Some issues need to be addressed. The cluster head is used for designing the communication energy model for the clustering. The availability and performance of an adjacent cluster head is the essential factor for relaying data of clusters. In large-scale deployments, there is a need for administering the area among the new nodes. Hence, careful insights are needed to monitor the scalability and adaptability of clustering techniques. Topology is required to enhance the strength of clustering methods. Fault management is associated with temporal link failures that need more attention. Reducing the use of redundant nodes for creating a relay backbone must be ensured. All of these aspects should be determined.

5 Bio-inspired

The biologically inspired solution is also called nature-inspired solutions. These solutions are highly dependent upon the collective behaviour of social communities. These will render effective algorithms and tools which can manage interesting facts applied in wireless sensor networks. Some of the algorithms are divided as shown in Figure 2. For example, the particle swarm optimization algorithm is used for optimizing the clustering whereas ant colony optimization is used for multipath cluster-based routing (Herlambang et al., 2019). The genetic algorithm is used to ensure the coverage in the deployment of the WSN and the artificial bee colony algorithm is applicable for clustering and routing in the WSN. Therefore, metaheuristic algorithms have been used in engineering and scientific problems. Bacterial foraging optimization (BFO) algorithm has been applied to the reconfiguration of the power system and estimation of the photovoltaic parameter (Sendra et al., 2015). The honey bee algorithm has been used for smart lights for feedback control and an advanced version of the artificial bee colony algorithm is used in the bioinformatics field for forecasting the secondary structure of a protein.

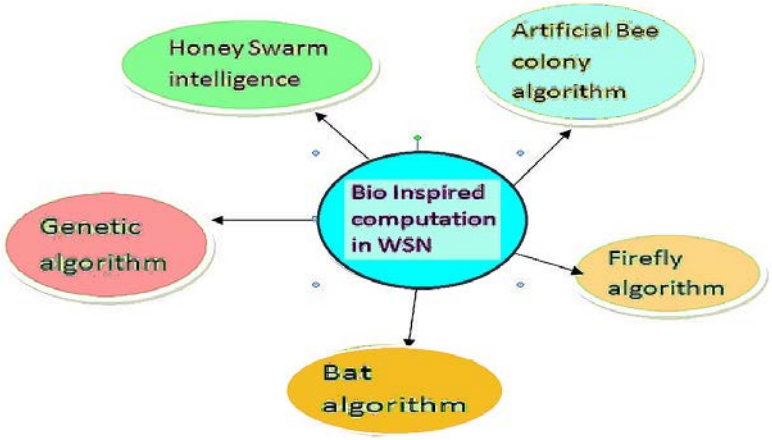

Figure 2: Bio-inspired Algorithms (Sendra et al., 2015)

5.1 Honeybees Swarm Intelligence

Honeybees are highly related to insects comprising of self-organization and capabilities of self-recognition. These honeybees will make a colony and live in a hive. It reveals the features of

auto solving problem aspects by establishing the integration of social cooperation and individual traits that are exceptional in the animal kingdom. These aspects make unique intelligent decisions in a decentralized control mechanism and a self-organized manner. In the honeybee colony, the individuals are managed to do several tasks that are significant for the survival of insects. They are also involved in various tasks like polarization, foraging, mating, and the waggle dance.

The probability of watching dance and selecting the best dancer source are evaluated in this approach. Self-organization has been evolved from the foraging activity of honey bees. It is highly based on some activities. They are as follows,

- As the nectar amount increases the number of onlookers also increases.
- Bees stop the process of the exhausted food process.
- The scouts organize a random search process for identifying new food sources.
- Employed bees will share knowledge about the food source with onlookers.

The above features of honey bees are used in resolving the optimization problems.

5.2 Artificial Bee Colony Algorithm

The artificial bee colony algorithm is a metaheuristic algorithm that is a highly based swarm optimization technique designed for numerical optimization. It depends upon the low intelligent foraging behaviour of honeybees. This approach consists of three constituents' namely unemployed foragers, food sources, and employed foragers. The employed foragers are highly related to specific food sources and the second one has two types namely, scouts and onlookers. Scouts and onlookers are looking for a rich food source to use. The first half of the colony comprising of employed bees and the second half comprise onlooker bees. The onlookers' bees are foragers who focus on the waggle dance of employed foragers in the hive for selecting the food source. Based on the quality of a food source decisions will be taken. The scout bees have a job of looking for new food sources. The employed foragers will be assimilated to positive feedback and unemployed foragers have negative feedback (Xu et al., 2013).

5.3 Firefly Algorithm

WSN has more sensors in a wide geographic area that can transmit the sensed data to the base station and communicate with sensor nodes. Low energy routing is required in the process of communication. The sensor routing protocol will enhance the network lifetime using the Firefly routing algorithm. It generates a reflection of light in a short duration to acquire fireflies or prey. This high attractiveness is highly based on the light flashes intensity. These fireflies move towards another firefly with a high-intensity flight. It is highly used in sensor communication to acquired limited energy consumption (Jabeur, 2016).

5.4 Bat Algorithm

The purpose of the bat algorithm is to attain packet routing over the optimal paths are based on the cluster head selection and cluster formation. It highly depends upon the echolocation

related food-finding real bats. Generally, bats make a sound louder and adjust its frequency based on the acquired echo from obstacles or prey (Cui et al., 2019).

5.5 Genetic Algorithm

The genetic algorithm encouraged the routing approaches of biological evaluation like mutation and crossover of different chromosomes. In this algorithm, the individuals are chosen for breeding based on the fitness amount. With the integration of these solutions, it generates a new individual solution. However, the new individual indicates a new generation. This approach is repeated for attaining many fitness solutions. In sensor networks, it helps to save energy and enhance lifetime by using a reproduction approach (Kulandaivel et al., 2012).

6 WSN and Bio-inspired

Wireless sensor networks have focused on industry and academic field. Multihop wireless networks are self-healing and self-organization with maintenance and cost-effective deployment. It needs to be managed by making effective and robust solutions (Ejeian et al., 2019). The significant challenges are scalable network architecture, adaptive security mechanisms, self-healing, and self-organizing systems, artificial neural networks, swarm intelligence, and ant colonization approaches. There are several studies conducted on application, awareness, techniques, future trends, and best practices related to bio-inspired approaches in WSN.

Riva and Finochietto (2014) introduce the two nature-inspired approaches to improve the relevant data for assessing the purposes. The first scheme is focused on the simulated annealing search process and the second one is focused on the behaviour of ant colony. These schemes highlight communication costs when compared with traditional data collection approaches. (Kumar et al., 2018) have focused on lowering power consumption for WSN. The author focused on minimizing energy consumption when the nodes are self-organized dynamically. In this paper, the authors have introduced the nature-inspired routing protocol for WSN and serving as foraging ant behaviours. They acquire low routing request packets, energy consumption amounts, and high network lifetime with respect to the routing protocol.

7 Challenges in Bio-inspired WSN

Over the last decade, there are several challenges exist for using bio-inspired techniques. Bio-inspired techniques have both reactive and proactive approaches that enable to enhance the network load balancing and are involved in the discovery of network topology. Bio-inspired routing has become a class of WSN routing paradigm. Bio-inspired is designed for enhancing the lifetime of WSN by communication balancing and effective adaptation to the network topology changes. This bio-inspired technique is aimed at the network with a large number of nodes and multi sinks (Khan et al., 2015). Software simulations have addressed that the proposed algorithm evaluates ant-based routing algorithms like sink aware routing protocol. The bio-inspired routing algorithm is used for WSN with multi sinks. It can be inspired by the behaviour of organisms served in a distributed manner without global information related to the network. The process of route construction is

known as signaling. Each node distributes the forwarding data and creating the routing tables. Data packets are routed to sinks make a principle of path selection.

8 Cognitive and WSN

Cognitive approaches are used for increasing the performance of WSN. The author offered an empirical design for the cognitive radio (CR) based WSN and made a performance comparison with Zigbee WSN over Opnet simulations (Cavalcanti et al., 2008). This can be resulted in transmitting power and the communication range is high in cognitive radio channels. It also minimizes increased hops count per packet and hidden node problems. It also increases Mac and multi-hop routing efficiency. The present application will be determined in cognitive radio mode. Akan et al. (2009) presented the significant application areas, advantages, design principles, and the network architecture of cognitive sensor networks. It can be used to evaluate the previous techniques for WSN and determine the challenges as well.

8.1 A Cognitive Scheme Using a Neural Network Model

Reznik and Pless (2008) presented the optimal solution for the distributed intelligence to integrate the cognition approach into the sensor network with the detection of signal change. The architecture of the Artificial neural network (ANN) has proved the advantages of using this approach with respect to the reduction of using resources like memory usage, network bandwidth, and processor power because of low communication cost and connectivity. Youssef and Younis (2008) have introduced the algorithm of gateway relocation for optimized performance and safety. As the different needs of application increases, the advancement of wireless sensor technology also increases. In WSN, the significant challenges of designing the network are resource constraints, limited energy capacity, uncontrollable environment, large deployment, and dynamic environment. It allows reliable communication while managing.

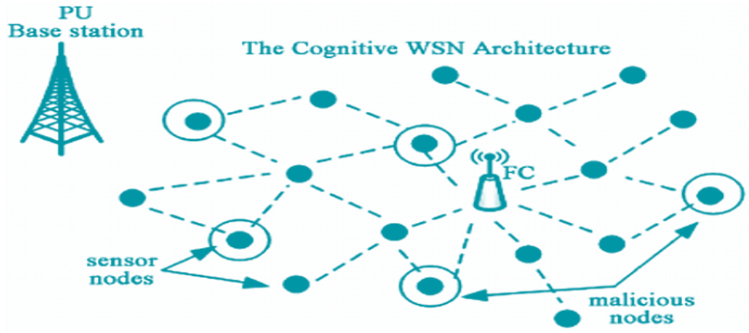

Figure 3: Cognitive WSN (Boonma and Suzuki, 2008).

Efficiency in the network is a significant problem in WSNs. However, the sensors are restricted to the capacity of saving energy. By having energy conservations, the significant requirement of WSN is throughput. To attain the challenges in routing protocol, the clustering makes sensors integrate the local interaction for the attainment of goals such as coverage, scalability, energy efficiency, and throughput. Because of the restricted transmission of sensors, the sensors are implemented in large areas. Genetic algorithms, swarm intelligence, and the

artificial immune system is used for collective intelligence, and self-organization will increase as the sensor networks focus on enhancing the management (Bhadane and Kadam, 2018).

8.2 Cognitive Sensor Networks

The sensor data will be reported to the nodes which can be mapped to modified elements. WSN control system is used for the reliable operation of the power grid system (Joshi and Kim, 2016). These nodes are communicated with the control station and nearby notes which can be attached to the requirement layer. Automan are the agents of software cognitive who control the stations and must aware of local policies and requirements of end-to-end applications. These decisions should have sufficient information management which can be attained by intelligent data fusion and sensor coordination.

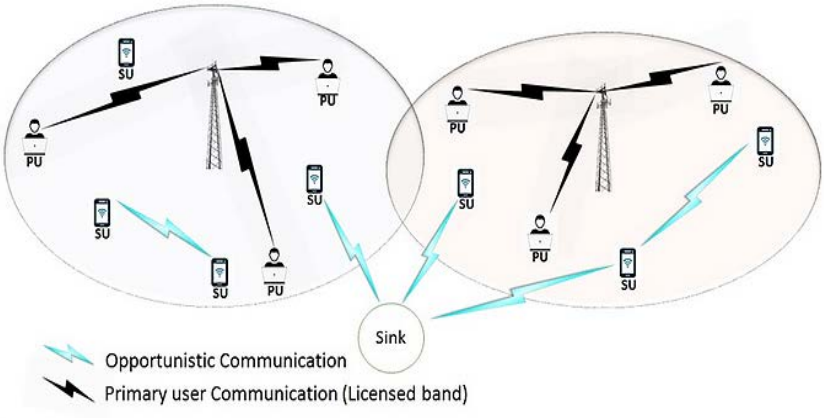

Figure 4: Cognitive radio sensor networks (Mostafaei et al., 2017)

In the changing environments, the dynamic configurations become accessible without grid downtime and ensure that the QoS requirements of customers should me. (Boonma and Suzuki, 2008) introduced a bio-inspired framework called Monsoon to create cognitive WSN applications. It can be aware of conflicting design objectives and determine optimal tradeoff with specific constraints and adheres to the network dynamic. It manages the application as the decentralized software agents which gather sensor data from the individual nodes and bring it to base stations. From the simulations, the author reveals that agents must adhere to network dynamics by managing the conflicting objectives through self-optimization, self-healing, and self-configuration properties.

8.3 Challenges in Cognitive WSN

By having a game-theoretic approach and artificial intelligence, there will have some challenges. As the number of resources is large, the agent valuation for the subset becomes infeasible (Fatima et al., 2019). Accomplishing the integrative cognition radio at the physical layer of WSN to perform a heterogeneous wireless environment is a challenging one. It needs intelligence about the spectrum decision to save energy overhead by having knowledge of sensor network protocol (Saleem et al., 2020). To make networks outperform the improvement in performance should determine the cost with respect to operation, architecture, and overhead. For implementing the cognitive approach, the network requires the informed decision for the network

implementation, and the network state information will be known to process (Zhu et al., 2020). The information given to the network is incorrect and partial which leads to security issues and management issues that should be determined. The cognitive nodes could able to acquire information from the remote locations of sensor nodes (Chang and Kuo, 2006).

9 Conclusion

In this paper, the fundamental challenges and issues in WSN are addressed. The survey is carried to provide the aspects to solve challenges using bioinspired clustering algorithms like Artificial Bee Colony (ABC), Bat algorithm, Honey Bee algorithm, Genetic algorithm, firefly algorithm, and cognitive aspects in WSN. There is an ongoing demand for Cognitive WSN (CWSN) for adapting to the various changes in the environment. This has been discussed briefly along with the techniques. The study shows that predicting the faults in the network beforehand using cognitive techniques will improve the performance of the network. Cognitive networks are a future networking technology that will allow data networks operating in complex, heterogeneous, noisy, and dynamic environments to reclaim stability by learning and adapting their behaviors to meet top-level end-to-end goals. In this regard, a vast space of many biological systems, cognitive aspects still remain unexplored which needs to be studied further.

10 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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