Application of Computational Intelligence Techniques for Optimization of Routing Protocols in Wireless Sensor Networks: A Survey

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Abstract-With the ongoing rapid advancements in technology and a vast range of inevitable applications in mission critical and real time systems in Wireless Sensor Networks (WSNs), they have been getting prominent attention in recent times. The performance of many real-world applications relating to WSNs are controlled by various factors due to limited resources and environment conditions. Routing protocols in WSNs have to deal with a number of challenges and design issues. This paper presents a review on multi-objective optimized (MOO) routing protocols based on computational intelligent (CI) techniques viz. fuzzy logic, reinforcement learning and swarm intelligence along with their strengths and limitations. This survey focuses on the effect of performance metrics to the applications considered in defining the objective function of various intelligent routing protocols. This discussion guides the researchers to integrate CI techniques with MOO for designing routing protocols in WSNs.

Keywords: Optimization, Wireless Sensor Network (WSN), Routing Protocols, Computational Intelligent (CI) Techniques, Fuzzy Logic, Reinforcement Learning (RL), Swarm Intelligence (SI).

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1. Introduction

In the present scenario of rapid technological advancement, WSNs are being widely used in Environment Monitoring, Object Tracking, Battlefield Surveillance, Health Care, Transportation, Industrial Process Control, Intruder Tracking, Disaster Relief Operations, Safety, Security and Biodiversity Mapping etc. These are comprised of large number of sensor nodes that are deployed haphazardly in a geographical region [1].The most important challenges in designing WSNs, as reported in [1], include (i) limited resources & capabilities (ii) node deployment (iii) dynamic network topology (iv) scalability (v) multi-Source multi-Sink systems (vi) various types of applications (vii) various volumes and types of traffic (viii) wireless link vulnerability and (ix) data redundancy.

The sensor nodes have the potential to sense the information from the target area with in its communication range by using its embedded microprocessors. It collects and process the sensed information and communicate it via its radio transmitter to the sink. An efficient routing technique is required to establish the reliable communication in the network efficiently. Hence the development of an efficient routing protocol has become a challenge for the researchers caused by the limitations and constraints imposed by WSN architecture and dynamic environmental conditions. WSNs have inevitable applications in mission critical and real-time systems, requiring performance guarantees posing a number of challenges for enhancing effectiveness [2].
Routing methods in WSNs have to deal with a number of challenges viz. energy efficiency, fault tolerance, data aggregation, node deployment, network dynamics,

scalability, data delivery model, node heterogeneity, coverage, transmission media and QoS. The design issues in WSNs are affected by the restrictions experienced by the sensor nodes imposed by the architecture and operating environment viz. limited power, bandwidth constraints, limited computing power and limited memory[3]. These constraints along with the environmental conditions in the target area have derived the researchers' attention towards development of the optimized routing in WSNs. The researchers have already been developed many routing protocols to improve network performance for some specific metric while other metrics remain constant but some intelligent solutions are required that allow network to reconfigure themselves efficiently at run time.

The organization of this paper is such that the review of past survey papers is given in section 2, section 3 focuses on application of multi-objective optimization techniques for routing, section 4 discusses some CI based techniques to design optimized routing in WSN and focusing on their advantages and drawbacks. Finally, conclusion in section 5 presents some findings for future research directions in developing routing protocols in WSNs.

2. Related Work

Many researchers have done various surveys to deal with routing protocols in WSN but most of the existing surveys are related to the classical routing protocols. In classical routing scheme, the emphasis is given to improve the performance of the network in terms of most critical performance metric while the remaining performance metrics remains constant. In real world WSN applications, a routing scheme is required that satisfy multiple objectives simultaneously in an optimized way. Therefore, researchers have turned their research direction to implement CI techniques to handle various issues for routing in WSN. CI techniques have been successfully applied to address many challenges in WSNs.

Zungeru et al. in [4] conducted an exhaustive survey on routing protocols by dividing it into two types, classical and SI based routing protocols. The paper presents its findings on the basis of their experimental comparison using simulation. Fei in [5] analyzed various multi-objective optimization techniques to handle the issues in WSNs. In this paper, the details of MOO metrics along with the trade-off among these metrics are discussed. Different MOO algorithms and their qualitative comparison is also given in the paper. A detailed study on routing protocols based on hierarchical architecture for mobile WSN is given in [6]. This survey partitioned hierarchical routing protocols into two types, classical-based and optimization-based routing protocols and presents a comparative analysis of these protocols based on some factors like delay, energy-efficiency and network size along with its features and drawbacks. In [7], an exhaustive survey has been conducted for routing protocols in WSNs. This paper classifies routing protocols into two types, homogeneous and heterogeneous network based on types of network that are again partitioned into two types on the basis of mobility which are static and mobile homogeneous and static and mobile heterogeneous networks. This paper also focuses on classical routing protocols as well as nature inspired routing protocols. [8]-[10] presented surveys on routing protocols based on SI techniques which are inspired by the social behavior exhibit by social insects' colonies like ant and honey bees observed in natural systems. Kaur et al. in [11] have given the comparative analysis of various CI techniques routing protocols for energy- efficiency with QoS support and reviewed the protocols with their features and drawbacks.

3. Multi-Objective Optimization for Routing in WSNs

Routing optimization in WSN poses many challenges to the researchers as the performance of WSN depends on different performance metrics and constraints that changes dynamically with the environment. Many real-world applications of WSN involves optimization of multiple objectives like the highest reliability, the maximum energy efficiency, the longest network lifetime, the shortest delay. The main aim is to optimize multiple objectives simultaneously under some restrictions imposed by environment while maintaining the trade-offs amidst the aforesaid objectives that are needed to be optimized simultaneously. The factors that serves as constraints for routing optimization are interference, latency, reliability, coverage, cost, topology, quality of service, density, network connectivity, cost and delay. Hence formulation of multi-objective optimization for routing will depend on certain parameters defined as input, the objective function that needs to be optimized and the limitations imposed by the network and environmental conditions. It makes the implementation of MOO techniques for routing is a challenging task. In MOO, there may exist more than one optimal solution and the main aim is to select the best among all based on the priorities of the objectives that needs to be achieved [12].

4. Computational Intelligence based Routing Technique

Computational intelligence (CI) is an intelligent computational method that enables or facilitates intelligent behavior to adapt the dynamic nature of WSN. There are various techniques like artificial neural networks, artificial immune systems, genetic algorithm, fuzzy logic, reinforcement learning and swarm intelligence that comes under the umbrella of CI [13].

4.1 Fuzzy Logic Based Routing in WSNs

Fuzzy logic has been used to deal with many real-world problems. Fuzzy logic allows us to measure uncertainty defined by linguistic variables and presented in the form of multi-valued logic between 0 and 1. Fuzzy systems have the ability to make decisions based on conclusions drawn from fuzzy rule base which consists of fuzzifier, inference engine, fuzzy rule base and defuzzifier. A set of fuzzy rules are defined in the form of propositions in Fuzzy rule base that contains linguistic variables representing words or sentences. Fuzzy input is mapped to the fuzzy output by the inference engine on the basis of fuzzy rule base. The linguistic fuzzy rules can be defined to represent the dynamic nature of the system as given by the human experts. Fuzzy logic is suitable for formulating the multi-objective function for routing in WSNs [13].

Lu et al. in [14] proposed FRMOO routing protocol by defining fuzzy random variables. These variables are described in terms of both fuzziness and randomness of some performance metrics such as link's reliability, delay and nodes' residual energy. The given routing model is hybrid routing algorithm introduced fuzzy random expected value and standard deviation model. Pareto optimal solution is obtained by combining fuzzy random simulation with multi-objective genetic algorithm. It outperforms for delay, longer lifetime, latency, communication interference and distributes energy evenly among the nodes. Jiang et al. proposed a fuzzy-logic-based energy optimized routing algorithm (FLEOR) in [15] which calculates energy consumption by defining some new metrics to maximize network lifetime. These metrics are defined as degree of closeness of node to the shortest path (DCSP), closeness of node to sink (DCS), and energy balance. DCSP and DCS are computed to select the forwarder close to the shortest path and close to the sink respectively to select the best route. The degree of energy balance is calculated by predicting the inequality of residual energy among the neighboring nodes through social welfare function. All these parameters are given as input to the fuzzy system and the result shows that the algorithm works effectively to optimize energy consumption, balance energy distribution among the nodes thereby prolongs network lifetime. Geetha et al. in [16] presented a Multi Criterion Fuzzy based Energy Efficient Routing Protocol (MCFEER) for MANET operates in two phases namely route discovery and route maintenance phase. Route is selected for transmission between source and destination on the basis of metrics like bandwidth, buffer occupancy, hop count and battery life by using fuzzy system in earlier phase. In route maintenance phase, link breaks are handled by providing alternate path from route cache which preserves multiple stable paths. This protocol increases the network performance while reduces the delay. These fuzzy-logic based routing protocols are summarized in Table 1.

Protocol	Year	Routing Metric	Central Idea	Strengths	Limitations
FRMOO [14]	2013	Link Reliability, Delay and Nodes' Residual Energy.	Describes Fuzzy random variables in terms of fuzziness and randomness for the selected routing metrics to optimize the routing.	Optimizes Reliability, Jitter, Energy Consumption and End-to-End Delay.	Lacking the selection of the unique path for packet transfer among the pareto optimal solution.

FLEOR [15]	2014	Degree of node proximity to the shortest path, Degree of node proximity to sink and Degree of energy balance.	Inequality of neighbor nodes' residual energy is predicted by social welfare function, degree of energy balance is calculated, the node having highest degree of energy balance is selected as forwarder.	Reveals effective enhancement in the network lifetime, Performs well in terms of energy balance and energy efficiency.	Only energy consumption is taken into consideration.
MCFEER [16]	2017	Bandwidth, Hop Count, Battery Life and Buffer Occupancy.	Operates in two phases: Route Discovery Phase selects the route for transmission between source and destination on the basis of selected metrics followed by Route Maintenance Phase to provide alternate route to handle the broken links.	Routes being more stable increase the network performance.	Reasonable Delay is noticed.

Table 1. Fuzzy Logic based routing protocols in WSN

4.2 RL Based Routing in WSNs

Reinforcement Learning (RL) is an unsupervised learning technique which is a type of machine learning. Q-learning is a kind of RL that has been successfully applied by the researchers to deal with various routing issues in WSNs. Q-learning finds an optimal solution based on the value of function Q(s, a) known as Q-value, where 'a' represents some action taken by agent at state 's' then reward 'r' is received by the agents from the environment representing the quality of action 'a' at state 's'. it is an iterative process and reward 'r' is used to update the Q-value and evaluates the next state and reward. The process continues to learn the environment till it finds optimal solution [13].

Liang et al. in [17] presented an *MRL-QRP*, a routing protocol with QoS support based on multi-agent RL for WSNs. It is a Q- Learning based algorithm that defines multiple agents to evaluate the quality of an action which leads to achieve global optimization. The Q-value of an agent is evaluated through the weighted sum of its own estimated reward and those of all its immediate neighboring nodes to learn the environment dynamically. QoS requirements are considered in the form of PDR and end-to-end delay that defines the Q-function. Network performances are studied for dynamic behavior of network and network traffic load and simulation results verifies that *MRL-QRP* is suitable for highly dynamic environments while supporting to a number of QoS metrics. Hu et al. in [18] proposed a RL based adaptive, energy-efficient, and lifetime-aware routing protocol QELAR which aims to balance the energy distribution by making nodes' residual energy more uniformly distributed to prolong the network lifetime. The reward function is calculated by taking each node's residual energy along with the energy distribution among the neighbor nodes and is used to select the best forwarder nodes for packets' transmission. The protocol considers the traffic situations and the hop count for selecting the best route by making decisions efficiently with less overhead. Renold et al. in [19] proposed a multi-agent RL based self-configuration and self-optimization (SCSO) protocol in UWSN, called MRL-SCSO. This protocol implements RL with multiple agents to find the effective active neighbor nodes through which the reliability of network is maintained. The coverage and connectivity of the network is maintained by determining the network boundary by using convex-hull algorithm. These boundary nodes are responsible for communicating data under high traffic load conditions. Reward function is defined with buffer length and residual energy. The simulation result shows that MRL-SCSO performs well with respect to PDR, throughput and average end-to-end delay. Initially, more energy is consumed as the network takes some time to learn the environment but energy consumption reduces with time due to sleep scheduling, thereby it leads to longer network lifetime. Kiani et al. in

[20] presented QL-CLUSTER, a cluster-based protocol for routing in wireless body sensor network (WBSN) based on Q- learning approach. In the proposed work, first cluster is formed and the node having maximum residual power in the cluster is selected as cluster head. Then Q-learning algorithm is employed to select the optimal route for forwarding the packets from the source to the sink via intermediate nodes. Thus, less energy is required to transmit the packets thereby network lifetime is increased. Guo et al. in [21] proposed a RL-based routing protocol (RLBR) for the optimization of the energy consumption to maximize the lifetime of network. To learn the best path, it selects the forwarder node based on its learning experience and its current estimated information by defining the reward function in terms of residual energy, link distance and number of hop count which leads to reduction in total consumed energy and improvement in packet delivery and energy efficiency. Table 2 emphasizes the characteristics of aforesaid protocols in summarized form.

4.3 Swarm Intelligence Based Routing in WSNs

Swarm Intelligence (SI) is a kind of meta-heuristic method used by the researchers to find the optimal solutions for various real-world optimization problems successfully. SI techniques are inspired by the adaptation of collective behavior exhibit by the societies in nature such as birds, fish, honeybees and ants. SI systems are composed of population of agents and decentralized and self-configuration in nature. These agents interact with each other and with the environment to solve the complex problem efficiently. The popular SI techniques that have been applied for routing optimization in WSN include Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bacterial Foraging Optimization (BFO), Artificial Bee Colony (ABC) [13]

Kuila et al. in [22] adopted PSO for clustering and routing algorithm to prolong network lifetime. The algorithm assumes that the network is composed of ordinary nodes and gateways. Gateways collects the information from the nodes that lies within their communication range and responsible to communicate this local data to BS. Then PSO-based routing algorithm is executed by BS to select a route between all the gateways and the BS by maintaining the trade-off between hop count and transmission distance to reduce the delay. The PSO-based clustering algorithm is also executed by BS to form the clusters by considering the energy consumption of both types of nodes, normal sensor nodes and gateways which leads to balance the load that results in increased network lifetime. Elhabyan et al. presented a PSO-inspired routing scheme known as TPSO-CR in [23] that operates in two phases. The first phase forms the cluster and selects the best CHs based on the metrics like network coverage, energy efficiency and transmission reliability. The second phase implements the routing algorithm that defines the objective function by considering the trade-off between data delivery reliability and energy-efficiency which constructs the optimal routing tree for transmission between CHs and BS. The protocol is tested for homogeneous nodes as well as heterogeneous nodes through simulation and verifies that the proposed scheme improves the PDR at both the places, CHs and the BS as well as increases coverage while maintaining acceptable energy consumption.

Protocol	Year	Routing Metric	Central Idea	Strengths	Limitation
MRL-QRP [17]	2008	End-to-End Delay, PDR.	Nodes adjust their level of exploration according to their mobility. Global optimization can be achieved through local information about the network.	Performs well under heavy traffic load, Reduces network overhead.	Power Consumption is ignored while computing routes.

QELAR [18]	2010	Residual Energy of Nodes, Energy Distribution among a group of nodes.	It implements Q-learning for packet delivery based on maximum reward. It also employs the mechanism to detect and handle transmission failure.	Energy Efficiency is achieved at reduced Computation and Transmission Costs.	Routing selection is not suitable for dynamic network topology as it demands more time to learn from the environment.
MRL-SCSO [19]	2016	Residual Energy of the node, Buffer Length.	Multi-Agent RL algorithm is used to select the active neighbour nodes to maintain the reliable topology. The connectivity and coverage for the boundary nodes is sustained through a convex hull algorithm.	Reveals better QoS in terms of PDR, Average end-to-end Delay and Throughput. Optimizes the network performance under heavy load condition. Increases network lifetime.	Average energy consumption is increased due to exchange of messages for network set up for the determination of convex nodes and the initial learning of nodes about neighbours.
QL-CLUSTER [20]	2017	Distance between the Next Feasible Node and the Destination Node.	A lock variable is used for deviation in Q-values of the current node, next node and destination node. It reduces the delay by reduced path and minimizes memory requirements.	It requires less time and power to transmit data from source to sink node.	Lacking in finding a routing path that satisfies multiple QoS constraints.
RLBR [21]	2019	Link Distance, Nodes' Residual Energy and Hop Count.	Selects the next forwarder based on current estimation information and historically learnt information.	Maintains better connectivity, Balances energy consumption, and Improves packet delivery.	Not suitable for large-scale WSNs as RLBR implements flat architecture.

Table 2. RL based routing protocols in WSN

A cluster-based routing protocol that integrates the chain based PEGASIS protocol with Ant Colony Optimization (ACO) is proposed in [24]. First network is partitioned into static clusters and ACO is implemented to build the chain in each cluster either horizontally or vertically. Cluster heads are selected by evaluating weighted sum of nodes' residual energy and distance between the node and the destination to maintain the proper load balancing. Multi-hop communication is used by CHs to transfer the information to BS thereby delay is reduced and consumption of transmission energy is minimized. The proposed protocol shows superiority with respect to alive nodes left, load balancing, throughput and latency. Table 3 presents the summary of given RL-based optimized routing protocols along with their strengths and limitations.

5. Conclusion

In this paper some routing protocols in WSN have been investigated that exhibits some intelligent behavior to achieve the multi-objective optimization. The performance of reviewed protocols is analyzed on the basis of routing metrics that are considered as the main factors for defining the objective function to optimize the conflicting goals in WSNs. This survey can be helpful to the designers to formulate the multiple desirable objectives that may compete with each other which results in more than one solution. The main aim is to select the best among them by maintaining the trade-off among all objectives. In future, various routing metrics can be analyzed to solve the different routing issues such as security, QoS, reliability and energy consumption that may encourage the researchers to design the adaptive routing in complex dynamic environment in WSNs.

Protocol	Year	Routing Metric	Central Idea	Strengths	Limitation
EECR [22]	2014	Number of Hop Count and Transmission Distance.	Implements PSO-based clustering. Routing algorithms operate on ordinary nodes and gateways to balance the energy consumption.	Performs better with respect to network life, energy consumption, and total data packet transmission to the BS.	Energy dissipation is more due to long haul communication.
TPSO-CR [23]	2015	Number of Relay Nodes, Link Quality between Relay Nodes.	Operates in two phases: Clustering Algorithm forms the clusters to efficiently use energy, improve reliability and coverage followed by a Routing Algorithm to construct the optimal routing tree to establish connection between the CHs and BS.	Performs better in terms of PDR at CHs, scalability, and total delivery of packets to BS.	Transmission delay becomes high due to buffering of packets by each node before sending it to the next hop node.
PEG-ACO [24]	2018	Distance between Nodes and Destination, Residual Energy of Nodes.	Multi-hop communication is adopted for intra-cluster or inter-cluster communication to reduce delay and energy consumption.	Reveals superiority in terms of latency, alive nodes, load balancing, throughput and latency.	Transmission fails and packets are lost when node failure occurs.

Table 3. SI based routing protocols in WSNs

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