Performance Evaluation of CI Based Routing Protocols for WSNs

Palvinder Singh Mann[1] and Satvir Singh[2]

[1]*Department of Computer Sc. & Engineering,*
DAV Institute of Engineering & Technology, Jalandhar–144008, India
[2]*Department of Electronics & Communication Engineering,*
Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab–152004, India
E-mail: [1]psmaan@hotmail.com, [2]drsatvir.in@gmail.com

***Abstract*—Recent advances in Wireless Sensor Networks (WSNs) have led to new paradigm for protocol design especially for sensor networks where energy awareness is an essential component. Most of the research, however, has been focused on to the development of routing protocols since they might differ depending on the application area and network architecture. Computational Intelligence (CI) based optimization techniques paved the way for energy efficient routing for WSNs. In this paper, we evaluated and analyse the performance of CI based routing protocols with classical LEACH protocol. Our simulation results shows that CI based routing protocol perform better in terms of energy consumption thus increasing network life over classical protocol.**

Keywords: Wireless Sensor Networks, Computational Intelligence, Energy-efficient Routing

I. Introduction

Wireless Sensor Networks (WSNs) consist of large number of sensor nodes which sense, process and transmit data from an area of deployment. Sensor nodes should send the collected data to a Base Station (BS) or Sink for further processing and analysis. A Wireless Sensor Network design must have low power consumption with flexible scalability and robust network adaptability coupled with good fault-tolerance [3]. The key area to achieve the above mentioned features lies in efficient data routing between sensor nodes and base station. Many researchers are currently engaged in developing routing protocols that fulfill the requirements of these key features. The main aim is to find ways for energy-efficient route setup and reliable relaying of data from the sensor nodes to the base station so that the lifetime of the network is maximized [5]. There is always a trade off between computation and communication in each node when it makes the route decision and data aggregation. As the size of WSNs grows, so does the complexity of the data routing. Therefore a key area of WSNs research is in developing new routing algorithms to meet the strict low-power limitations. Computational Intelligence (CI) based routing protocols presents an optimized solutions to the energy constrained WSNs over the classical approaches. Below we discuss some classical and CI based approaches for WSNs Routing.

II. Design Challenges for WSN's Routing

Designing of routing protocols for WSNs is a challenging task due to the following parameters:

A. *Minimal Computational Requirements*

Sensor nodes are typically equipped with a low-end CPU and have limited memory. Therefore, it is customary that the routing algorithm has minimal processing overhead to make its execution feasible and effective on such a low-end processor.

B. *Energy Efficiency*

Sensor nodes are equipped with small non-rechargeable batteries therefore; the efficient battery utilization of a sensor node is a critical aspect to support the extended operational lifetime of the individual nodes and of the whole network. A WSN routing protocol is expected to:

1. Minimize the total number of transmissions involved in route discovery and data delivery.
2. Distribute the forwarding of the data packets across multiple paths, so that all nodes can deplete their batteries at a comparable rate. This will result in the overall increase of the network lifetime.

C. *Self-organization*

A WSN is expected to remain operational for an extended period of time. During this time, new nodes might be added to the network, while other nodes might incur in failures or exhaust their batteries, becoming un operational. A routing protocol must be resilient to such dynamic and generally unpredictable variations and must sustain the long-term availability of essential network services. Therefore, the network protocols, and the routing protocols in particular, must be empowered with self-organizing and self-management properties.

D. *Scalability*

In a wide range of WSN applications, thousands or even millions of nodes are expected to be deployed. A typical example is battle field surveillance, in which the criticality and the geographical extension of the scenarios require the deployment of large numbers of densely distributed sensors that have short communication ranges and high failure rates. Therefore, the routing protocol should be able to effectively cope with the challenges deriving from intensive radio interference, very long paths, and unpredictable failures. Moreover, it should be able to display scalable performance in face of these challenges.

E. Data Aggregation

Sensor networks can generate large amounts of locally redundant data. For instance, when a node detects that the temperature in its surroundings has exceeded a certain threshold value, it is likely that also its neighbouring nodes will detect the same event. If all these sensor nodes notify the event to the monitor node, which then can aggregate the received information to assess the event with high statistical confidence. The downside of this way of proceeding lies in the excessive use of network resources. However, not every single piece of information need to be communicated to the global sink. Information from a group of neighbouring nodes can be partially aggregated and processed as close as possible to its origin. In this way, it is possible to significantly reduce the number of transmissions, saving on the limited available hardware resources and reducing the negative effects due to radio interference. A good routing protocol for WSNs must be able to effectively support the setup and the use of data paths for in-network data aggregation.

III. Taxonomy of WSN's Routing

Depending upon the requirements of the application and area of deployment WSNs routing protocols are divided on various taxonomies.

A. Data-centric Protocols

Data-centric protocols will combine the application needed to access data with a natural framework for in-network processing. In many applications of WSNs, due to lack of global identification along with random deployment of sensor nodes, it is hard to select a specific set of sensor nodes to be queried. This consideration has led to data-centric routing, which is different from traditional address-based routing where routes are created between addressable nodes. In data-centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data.

B. Location Based Protocols

The idea of location-based protocols is using an area instead of a node identifier as the target of a packet. Any node which is positioned within the given area will be acceptable as a destination node and can receive and process a message. In the context of sensor networks, such location-based routing is evidently important to request sensor data from some region. Since there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed in a region, location information can be utilized in routing data in an energy-efficient way. For instance, if the region to be sensed is known, using the location of sensor nodes, the query can be number of transmission significantly.

C. Hierarchical Protocols

The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on the energy reserve of sensors and sensor's proximity to the cluster head. LEACH is one of the first hierarchical routing approaches for sensors networks.

IV. Approaches for WSN's Routing

Researchers around the world have developed Classical as well as CI based routing protocols for WSNs.

A. Classical Based Routing Protocols

Some of the most popular classical routing protocols are discussed below, which have addressed some of the most challenging aspects of the WSN's routing.

1. *Directed Diffusion (DD):* Taxonomy—Data Centric in Directed Diffusion (DD) events are diffused through sensor nodes by using a naming scheme for it. Attribute value pairs for the event is adopted while querying the sensors in an on demand basis. It is a popular data aggregation paradigm for WSNs. It is a data-centric and application aware paradigm in the sense that all data generated by the sensor nodes is named by attribute-value pairs. Creation of query is achieved by defining an interest using a list of attribute value pairs such as name of objects, duration of the event, and geographical location etc. DD is specific to some applications of sensor networks due to its query-driven data delivery model, since those requiring continuous data delivery to the sink will not perform efficiently.
2. *Sensor Protocol for Information via Negotiation (SPIN):* Taxonomy—Data Centric in SPIN [18], three messages are defined to aid in data dissemination: ADV message for advertisement of data, REQ message for data request, and DATA message that carry the actual information. In SPIN, data are named using meta-data. The protocol meta-data negotiation helps in elimination of overlapping, redundant information and resource blindness. The advertisement method of SPIN does not guarantee the delivery of data as nodes that are interested in the data may be far

away from the source node, and nodes in between the source and the sink may not be interested. In that case, such data will not get to the base station.

3. *Geographic and Energy-Aware Routing (GEAR):* Taxonomy—Location Based in GEAR [19], each sensor node is equipped with a GPS sensor for location identification. The protocol utilizes energy aware heuristics which is based on geographic information for the selection of nodes to route data to the sink, and uses geographically recursive forwarding algorithm for data dissemination within the target area. The main idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network. By doing this, GEAR can conserve more energy than directed diffusion and proves to be a energy efficient routing protocol but GPS device add extraordinary cost to sensor [3].
4. *Low-Energy Adaptive Clustering Hierarchy (LEACH):* Taxonomy—Hierarchical Protocol LEACH [20] became the most popular and the first energy-efficient hierarchical algorithm proposed for power consumption reduction in sensor networks. LEACH rotates the clustering task among the participating nodes based on duration. Each cluster head communicates directly to the sink. The algorithm is also based on data aggregation or fusion techniques as the original data is combined and aggregated into smaller size of data that carry only required information to all individual nodes. Cluster heads change randomly over time so as to balance the energy dissipation of nodes. The protocol is completely distributed and requires no global knowledge of the network. As it uses formation of cluster heads, or dynamic clustering, it brings extra overheads, hence diminishing the gain in energy saving.
5. *Power-Efficient Gathering in Sensor Information Systems (PEGASIS):* Taxonomy—Hierarchical Protocol PEGASIS [21] is an improved version of LEACH. It avoids the formation of multiple clusters. Each node can transmit and receive data from a neighbour and only one node is selected from a chain at a time to communicate with the sink. Data is combined and moved from node to node, aggregated and sent to the sink. However, the protocol introduces excessive delay for distant nodes on the chain. In addition, the single leader exhausts its energy as it involves regular transmission.
6. *Energy-aware QoS Routing Protocol (EAQSR):* Taxonomy—QoS Based Energy aware QoS routing [23] is a table driven multi-path routing protocol with embedded QoS in its routing decision. Its aim is to find an optimal path to the gateway in terms of energy consumption and error rate while meeting the end-to-end delay requirements. Both the paths that meet the requirements for real-time traffic, as well as well as maximizing the throughput for non-real time traffic were considered.
7. *A Stateless Protocol for Real-Time Communication in Sensor Networks (SPEED):* Taxonomy—QoS Based SPEED [24] is a QoS routing protocol for sensor networks. The protocol involves three types of communication techniques: real-time unicast, real-time area-multicast and real-time area-anycast. It requires each node to maintain information about its neighbours and uses geographic forwarding in order to locate the paths. The protocol is aimed to be a stateless and localized algorithm with minimal control overhead. The protocol provides end-to-end soft real-time communication by maintaining a desired delivery speed across the sensor network through a novel combination of feedback control and nondeterministic geographic forwarding. SPEED is a highly efficient and scalable protocol for sensor networks where the resources of each node are scarce.

B. Computational Intelligence (CI) Based Routing Protocols for WSN's

Routing in WSN's remain a challenge for researchers as various classical protocols lacks on energy efficiency, fault tolerance or on scalability. Researchers around the world have developed some robust protocols based on Computational Intelligence (CI), which provide optimal solutions to the above mentioned problems. Some of the CI based routing protocols are listed below:

1. *Pheromone Based Energy Aware Directed Diffusion (PEADD):* Taxonomy—Data Centric PEADD [7] is a variant of DD, based on ant colony optimization heuristic. The protocol is aimed at maximizing the lifetime of the sensor networks by involving nodes with higher energy in the information gathering process. In this algorithm ants increase the pheromone on a path proportionally to the remaining energy levels of the nodes. Paths with larger residual energy are increased, while others are reduced i.e. the amount of pheromone decay with transmitting data because the pheromone is linked to the remaining energy. The pheromone level is updated based on the amount of transmitting data. The algorithm use the same route selection and updating as that of the general ant based routing as described above [3].
2. *Comprehensive Routing Protocol (CRP):* Taxonomy—Data Centric CRP [8] algorithm is an improved version of energy aware routing (EAR) and based on ant colony optimization, but in its

routing decision, it uses probability of selection of which it considers the network lifetime and data packet arrival rate. The protocol argues that always using the path which is considered as the best and optimal path from the point of view might not be the best as it will lead to depletion of the path nodes energy and instead proposes the use of sub-optimal paths occasionally. The protocol has three phases: routing table setup, data communication, and route maintenance.

3. *Sensor Driven and Cost-Aware Ant Routing (SC):* Taxonomy—Location Based in SC [9], it is assumed that ants have sensors so that they can smell where there is food at the beginning of the routing process so as to increase in sensing the best direction that the ant will go initially. In addition to the sensing ability, each node stores the probability distribution and the estimates of the cost of destination from each of its neighbours. It suffers from misleading data when there is obstacle which might cause errors in sensing.
4. *Ant Colony Clustering Algorithm (ACALEACH):* Taxonomy—Hierarchical Protocol ACLEACH [11] is based on Ant Colony Clustering Algorithm, which is an ant colony based improved version of LEACH. The algorithm not only considers the node residual energy, but also the distance between the cluster heads was considered in selection of cluster heads. It applies the ACA into inter-cluster routing mechanism to reduce the energy consumption of cluster heads and finally prolong the lifetime of sensor networks. The protocol did not consider throughput and delay in its routing process, and hence may also be weak in energy efficiency due to overheads.
5. *Ant Colony Based Multipath Routing Algorithm (ACMRA):* Taxonomy—Hierarchical Protocol ACMRA [12] discover disjoint multipath between the source nodes and sink node. In multipath routing, multiple paths between source and destination are established. The algorithm generates two types of ants: search ant (SANT) and reinforcement ant (RANT). SANT is used to collect information about paths and the intermediate nodes local information as they travel along the path. RANT is used to update the pheromone table along the reverse path, and bring information of path to source node, such as residual energy of node, path length and energy consumption of the current path. It is an on demand multipath protocol and adopts a two-phase routing process involving the constructing routing and data transmission phases. In the constructing routing phase, cluster head in the event region generates SANTs according to the number of neighbour nodes, and chooses the next node to move to according to probability of selection. While in the data transmission phase, the network lifetime relates to hop count, energy consumption and the minimum energy at a path [3].
6. *Energy-Aware Evolutionary Routing Protocol (ERP):* Taxonomy—Hierarchical Protocol Energy-Aware Evolutionary Routing Protocol (ERP) guarantee better tradeoff between lifespan and stability period of a network with efficient energy utilization, is based on evolutionary algorithms(EAs).
7. *Multipath Routing Protocol (MRP):* Taxonomy—Hierarchical Protocol Multipath Routing Protocol (MRP), is based on dynamic clustering and CI based ant colony optimization (ACO). A CH is selected among nodes located in the event area and an improved ACO algorithm is applied in the search for multiple paths between the CH and sink node. MRP prolonged the network lifetime and reduces the average energy consumption effectively.
8. *Energy Efficient Ant Based Routing (EEABR)*: Taxonomy—QoS Based EEABR [13] is based on Ant Colony Optimization (ACO) metaheuristic. In this protocol, each node in the network launches a forward ant at a regular interval with the aim of finding a route to the destination (sink). In the protocol, each ant only carries the address of the last visited nodes which means intermediate nodes carries the records of received and forwarded ants in the tables. The table content of each node contains the previous node, forward node, ant identification, and timeout value. Each time a node receive a forward ant, it looks up its table to search for any possible loop. If no loop exists, the node saves into its table the information of the ant and restarts a timer and forwards it to the next hop. When the forward ant reaches its destination, it is converted to backward ant with the mission to update the pheromone trail of the path traversed by the forward ant.
9. *Bee-Inspired Power Aware Routing (Beesensor):* Taxonomy—QoS Based Beesensor [16] is an algorithm based on the foraging principles of honey bees with an on-demand route discovery (AODV). The algorithm works with three type of agents; packers, scouts and foragers. Packers locate appropriate foragers for the data packets at the source node. Scouts are responsible for discovering the path to a new destination using the broadcasting principle. Foragers are the main workers of BeeSensor which follow a point-to-point mode of transmission and carry the data packets to a sink node. When a source node detects an.

V. Simulation and Analysis

We simulated well known classical routing protocol LEACH, CI based hierarchal routing protocols MRP and ERP on *Nature Inspired Tool for Sensor Simulation* (NITSS), a java based open platform developed to evaluate the performance of WSNs routing protocols. We have evaluated the performance of these protocols based on following performance parameters:

A. Packet Delivery Ratio (PDR)

It is the ratio of total number of packets received at BS to the total number of packets generated at all sensor nodes.PDR gives the percentage of total packets delivered at BS. This ratio is vital as it reflects the robust performance of the protocol. Simulation results of PDR are shown in Table below:

Table 1 Packet Delivery Ratio

No. of Nodes	MRP	LEACH	ERP
30	99.95092	98.40863	99.76959
75	99.97161	99.90158	99.95242
115	99.98433	99.95214	99.93916
175	99.98753	99.98624	99.97282
220	99.97762	99.92258	99.96794

Performance of MRP is highest for delivering packets as compared to ERP and LEACH (Fig. 1.) It is evident from Fig. 1. that packet delivery ratio of MRP remains nearly 100 % even when number of nodes increased to 220. The performance of LEACH is comparable to ERP which also delivers almost 99% packets. But it is important to note that CI based routing protocols outperform over classical protocols in terms of percentage of packet delivery.

We also evaluated other performance parameters like average energy consumed and network life for WSNs. CI based routing protocols paved the way for energy efficient solutions for variety of applications and wide range of WSNs which incorporate the principals of metaheuristic to solve optimization problems like routing for WSNs which is very vital for the network performance.

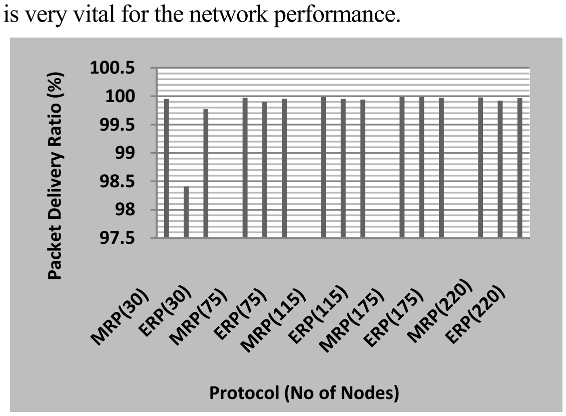

Fig. 1 Packet Delivery Ratio

B. Average Energy Consumed

It is the average energy consumed by all the sensor nodes in delivering all data packets generated at all its nodes to BS. This is another most significant parameter to determine the energy efficiency of the protocol. The below Table shows the results of average energy consumed at various nodes.

Table 2 Average Energy Consumed

No. of Nodes	MRP	LEACH	ERP
30	0.00102	0.00105	0.00109
75	0.00116	0.00124	0.00122
115	0.00136	0.0015	0.00131
175	0.00127	0.0014	0.00105
220	0.0011	0.00138	0.00089

MRP consumes less energy initially as compared to LEACH and MRP (Fig. 2.) when number to nodes are less but gradually when number of nodes increased, ERP perform better in terms of less amount of energy consumption.

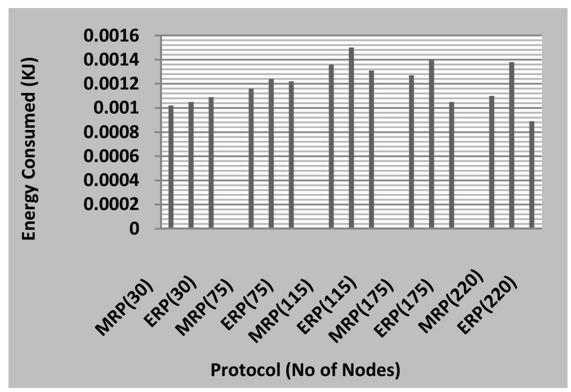

Fig. 2 Average Energy Consumed

C. Network Life

Network Life is one of the most significant parameter which describes the extended life of the network. If a protocol supports more number of rounds, it ultimately increases the life of the network; hence more packets can be delivered at BS for longer duration. The below Table, shows the comparative results for number of rounds of LEACH, ERP and MRP.

Table 3 Number of Rounds (Network Life)

No. of Nodes	MRP	LEACH	ERP
30	293	257	175
75	290	247	195
115	278	229	207
175	235	195	215
220	218	168	209

In terms of Network Life, which is most vital parameter of network performance, it is evident form

Fig 3. that MRP took largest number of rounds as compared to ERP and LEACH.

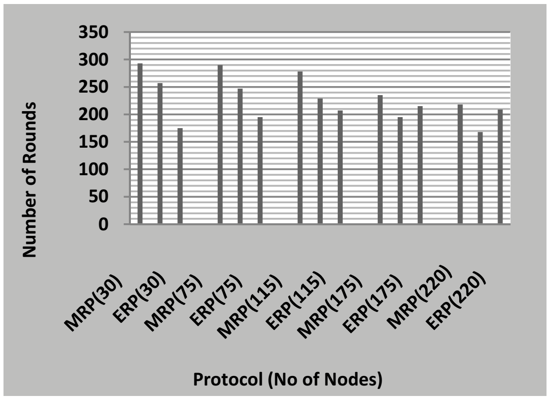

Fig. 3 Network Life

Another important factor is that CI based routing protocols provide increased network life to WSNs.

VI. CONCLUSION

WSNs consist of hundreds of thousands of nodes which collect vital data for wide range of applications. Due to constraints like less battery power, routing remains a challenge for researchers around the world. CI based routing protocols paved the way for efficient data routing for WSNs and our evaluation proved that CI based routing protocols outperformed over classical approaches. It encourages us to incorporate other nature inspired CI based methods to build efficient protocols for WSNs.

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