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Energy Efficient Data Aggregation in Sensor Networks with Optimized Cluster Head Selection

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***Abstract*—**Wireless Sensor Network (WSN) routing is complex due to its dynamic nature, computational overhead, limited battery life, non-conventional addressing scheme, self-organization, and sensor nodes limited transmission range. An energy efficient routing protocol is a major concern in WSN. LEACH is a hierarchical WSN routing protocol to increase network life. It performs self-organizing and re-clustering functions for each round. This study proposes a better sensor networks cluster head selection for efficient data aggregation. The algorithm is based on Tabu search.

***Keywords*—**Wireless Sensor Network (WSN), LEACH, Clustering, Tabu Search.

I. Introduction

WSNs are large sensor nodes networks with nodes directly interacting with environment by sensing physical parameters like temperature and humidity [1]. They send and receive data to/from a fixed wired station called Base Station (BS) which serves as a gateway to other networks. It has wide applications range including military, environmental, and home security. WSN routing is different from conventional fixed network routing in many ways.

WSNs are infrastructure-less having unreliable wireless links with sensor nodes that can fail. Its routing protocols have rigorous energy saving requirements. Better routing, reduces messages sent by short paths and congestion avoidance [2]. Factors like localization, efficient neighbor detection, time synchronization, flooding, and query dissemination reduce messages and increase network life. The main constraint in designing a WSN routing protocol is sensor nodes limited power which mandates designing energy-efficient communication protocols.

Clustering is used for communication between nodes and BS, as it is energy efficient compared to single/multi-hop routing. In clustering, a sensor node in a cluster is elected Cluster Head (CH) and relays data from a sensor to a remote receiver [3]. Few CH nodes are heavily loaded, in clustering when energy depletion occurs. To ensure uniform energy depletion, load balancing (equal nodes to a cluster) is introduced.

CH performs aggregation function on data received and sends it to BS where it is needed. LEACH is a popular routing protocol using cluster based routing to reduce energy consumption. LEACH divides communication into rounds with a round including a set-up phase and a steady-state phase [4]. A sensor network node is equipped with a sensor, wireless communications devices like radio transceivers, small microcontroller, energy supply, and a battery. As nodes are battery operated, energy has a vital role.

WSN application involves fields like fire detection, military battleground, and extreme environments. Some are [5]:

- *Military applications* of sensor nodes consist of battlefield surveillance, monitoring, guiding intelligent missiles systems, and detecting attack by mass destruction weapons.
- *Medical Application*: Sensors are useful in patient diagnosis and monitoring. Patients wear small sensor devices that monitor physiological data like heart rate and blood pressure.
- *Environmental monitoring*: It includes traffic, habitat, and wild fires.
- *Industrial Applications*: Includes industrial sensing and diagnostics like appliances, factory, supply chains, etc.
- *Infrastructure Protection Application*: Includes power grid monitoring, water distribution monitoring, etc.
- *Miscellaneous Applications*: Sensors will soon be used in many commercial applications in home and industry.

Despite WSNs innumerable applications, these networks have restrictions, e.g., limited energy supply, limited computing power, and limited wireless links bandwidth connecting sensor nodes. WSN routing protocols design is influenced by challenging factors [6] which must be overcome before efficient communication is achieved. Some issues are listed below:

- Node deployment
- Energy consumption without losing accuracy
- Data Reporting Model
- Node/Link Heterogeneity
- Fault Tolerance
- Scalability
- Network Dynamics
- Transmission Media
- Connectivity
- Coverage
- Data Aggregation
- Quality of Service
- Unreliable communication
- Very limited resources
- Synchronization
- Security

Many protocols are proposed for energy-efficiency in

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WSNs. Clustering based schemes are the most energy efficient routing protocols. In a cluster, a node is elected as CH while others are member nodes who in their respective clusters sense ambient conditions in the environment and transmit measured data to corresponding CHs [7]. CHs collect data from member nodes, aggregate them, and finally forward it to either a neighboring CH (multi-hop) or directly (single hop) to BS. Clustering leverages advantages of small transmit distances for most nodes, requiring only a few to transmit farther distances to a BS. Thus, clustering with the reduced energy consumption improves network life. With clustering, hierarchical clustering concept plays an important role in developing energy efficient schemes for WSNs.

A clustering algorithm based on Tabu search is proposed in this study. The rest of the study is summarized as follows: Section II reviews related work. Section III explains methodology, and Section IV discusses the results. Section V concludes the work.

II. Related Works

An energy efficient CH election protocol (LEACH-HPR) proposed by Han [8] used minimum spanning tree algorithm to construct inter-cluster routing. An improved LEACH called partition-based LEACH (pLEACH) which partitioned a network into ideal number of sectors, and chose a node with highest energy as sector head was proposed by Gou and Yoo [9] using centralized calculations. A Multi-hop Routing with LEACH (MR-LEACH) protocol was presented by [10] to prolong WSN life. MR-LEACH partitioned a network into different cluster layers. BS selected upper layer CHs to act as super CHs for lower layer CHs. Therefore, MR-LEACH followed multi-hop routing from CHs to a BS to conserve energy, unlike LEACH protocol.

The LEACH-SM protocol, which modified LEACH protocol by providing an optimal energy-saving spare management, including spare selection proposed by [11] added spare selection phase to LEACH. Identification of spares increases WSNs energy efficiency, thereby extending WSN life. LEACH-N based on LEACH was presented by [12]. In the new protocol, selecting nodes as CH depend on cluster nodes residual energy. This guarantees rationality during head nodes selection. CH selection algorithm and node power consumption inequality are disadvantages, so an energy saving LEACH-IMP based on LEACH was proposed by [13]. All nodes are divided into fixed clusters. According to the distance from the CH, cluster node members join cluster. MATLAB simulation proved that improved routing protocol was effective to overcome nodes non-uniform energy consumption due to random CH selection strategy in LEACH, thereby extending network life.

A new hierarchical routing protocol based on Artificial Fish Swarm Optimization (AFSO) proposed by [14] used AFSO algorithm in cluster formation phase, its object being to solve NP-hard problem in finding k optimal clusters according to rules. To reduce nodes energy consumption and to prolong WSN life, a clustering protocol based on Chaos-PSO was proposed by [15]. The protocol improved CH selection mechanism and considered nodes residual energy, distance to sink node, and cluster range. It optimized CH selection by Chaos-PSO. Then, other nodes decided whether to join a cluster by comparing the advertisement message's signal strength with a predefined threshold, restricting the cluster range. Simulation results showed that compared to LEACH, the new protocol efficiently saved energy and prolonged WSN life.

MS-LEACH was proposed by [16] to enhance S-LEACH security by giving data confidentiality, and a node to CH authentication using pairwise keys shared by CHs and cluster members. The new MS-LEACH's security analysis showed that it had efficient security properties achieving all WSN security goals compared to LEACH protocol's current security solutions. MS-LEACH's simulation based performance evaluation proved the effectiveness of new MS-LEACH protocol with the protocol achieving desired security goals and outperforming other protocols regarding energy consumption, network life, network throughput, and normalized routing load.

A new method of choosing CHs, which reduced unnecessary energy consumption spent on computing of a node during each round was proposed by [17]. To make energy distribution evenly in a network, consideration of sensor nodes' energy dynamic change was introduced during CHs selection. Simulation showed that the new protocol performed better than original LEACH. A revised cluster routing algorithm named E-LEACH to enhance hierarchical routing protocol LEACH was proposed by [18]. In E-LEACH algorithm, original way to choose CHs was random and round time for selection was fixed. Simulation results showed that the new protocol increased network life by 40% when compared to LEACH algorithm. A hierarchical routing protocol called Energy and Load balance LEACH (EL-LEACH) which achieved energy efficiency and load balance was proposed by [19]. Simulation showed that the new scheme EL-LEACH achieved better energy consumption, load balance, and network life than well-known LEACH protocols.

A new CH selection method for LEACH clustering routing protocol was proposed by [20]. It balanced sensor network nodes energy consumption. Simulation showed that the sensor network life was enhanced significantly compared to LEACH routing algorithm for WSNs. An energy efficient routing algorithm based on LEACH framework was presented by [21]. Much redundant data is available in WSNs due to wide deployment. This redundancy can be an advantage to increase network life. Simulation showed that MG-LEACH outperformed LEACH based on Network life.

An energy-efficiency Optimized LEACH-C was presented by [22]. A group of CHs was chosen using LEACH-C. Next, considering retransmission and acknowledgment, a CH energy consumption model was created. The quadratic sum of distances from a CH to its member nodes was calculated in an optimal solution. Finally, a single CH's largest energy consumption in the next round was estimated, and nodes with residual energy bigger than calculated consumption were taken to a new round of simulated annealing to find a better

solution. Hence, loss of CH for a round is minimized, and WSN life extended ultimately.

The Performances of 8 widely used clustering validity indices, namely, I index, Calin´ski-Harabasz index, Davies-Bouldin index, CS index, Dunn index with two generalized versions, and silhouette statistic index, on both synthetic/real data sets in the framework of Differential-Evolution-Particle-Swarm-Optimization (DEPSO)-based clustering was compared by [23]. DEPSO is a hybrid, stochastic optimization approach evolutionary algorithm (DE) and the swarm intelligence method (PSO) that increased search capability and achieved higher flexibility in exploring problem space. According to results, silhouette statistic index stands out in most data sets. Users reached conclusions based on one index, after considering results of many indices to achieve reliable clustering structures.

Development of a hybrid routing protocol that collide with LEACH (Hierarchical routing protocol class of WSN) and Quadrant based Directional Routing (Q-DIR) (Ad-hoc Routing scheme) focused on by [24] outdoes shortcomings of LEACH and assured energy efficient operation with extended network life.

Performance of evolutionary algorithms like GA and DE, and swarm intelligence methods namely PSO and Artificial Bee Colony (ABC) to find clustering solutions by evaluating cluster quality with internal validity criteria, Sum of Square Error (SSE), based on cluster compactness was compared by [25]. Results based on three real and one synthetic dataset were compared.

A new routing approach based on ACO algorithm in WSN on which LEACH protocol was applied, to route data packets in sensor networks to maximize energy efficiency and to increase network life was proposed by [26]. The proposed algorithm's performance was compared with LEACH protocol and simulation showed that the new approach provided optimized solutions regarding efficient energy usage and enhanced network life.

In [27], a novel routing protocol based on A-Star was proposed and shown to improve the energy efficiency of the network. This work was further extended by [28] using fuzzy logic. Both the approaches for determining optimal route are based on remaining battery power. These approaches suffer from NP-Hard problem. The maximization of lifetime can be formulated as an optimization problem. Local search has been extensively used for solving NP Hard problems. In this work, Tabu Search has been used for cluster location for efficient energy management.

III. Methodology

Clusters are WSNs organizational units. Their dense nature needs them to be broken into clusters to simplify a communication [29]. Cluster formation is based on sensors energy reserve and their proximity to CHs. Clustering plays a role in WSNs energy savings. In WSNs clustering, energy consumption, network life, and scalability are improved. Clustering has applications in high-density sensor networks, as it is easier to manage cluster representatives (CH) from a cluster than to manage all sensor nodes [30].

Cluster formation leads to a 2 level hierarchy where a CH nodes form a higher level, and cluster-member nodes form a lower level. Sensor nodes periodically send data to corresponding CH nodes. CH nodes aggregate data (decreasing total relayed packets) and transmit them to a BS directly or through intermediate communication with other CH nodes [31].

Clustering ensures scalability and robustness for networks allowing spatial reuse of bandwidth and simpler routing decisions. It results in decreased energy dissipation of an entire system by reducing nodes that participate in long distance communication [32]. Clustering-based approaches reveal exciting result through reduced energy consumption via multiple ways.

Clustering algorithms are proposed in various contexts [33]. They are mostly heuristic in nature and aim to generate minimum clusters so that a node in a cluster is at most d hops away from a CH. Most algorithms have a time complexity of O(n), where n is total nodes. Many demand time synchronization among nodes, suiting them for networks with limited sensors.

Clustering enables bandwidth reuse and improves system capacity. As all normal nodes send data to the CHs in a cluster, energy saving is achieved due to absence of flooding, multiple routes, or routing loops. As clustering enables efficient resource allocation and helps in better power control designing. An advantage is that any node behavior changes in a cluster affect only that cluster and not entire network, which is robust to changes. WSN clustering aims are [34]:

Clustering topology localizes route set up in a cluster reducing routing table size stored in individual sensor nodes. Compared to a flat topology, this network topology is easier to manage, and more scalable, responding to environment events. Data aggregation/fusion aggregates data from multiple nodes to eliminate redundant transmissions and ensure fused data to BS saves WSNs energy. CHs perform data transmission in clustering routing scheme saving energy consumed.

As a clustering routing scheme copes with changes in individual clusters, the entire network is more robust and convenient to manage. Fault-tolerance is an important WSN challenge. Re-clustering is an intuitive method to recover from cluster failure though it usually disarranges on-going operations.

Network life is an inevitable WSN consideration as sensor nodes are constrained in power supply, processing capability, and transmission bandwidth, especially for applications in harsh environments. Energy-aware idea is to select routes that prolong network life in inter-cluster communications, and node routes with higher energy resources are preferred.

Tabu Search (TS)

Tabu Search (TS) is an iterative procedure designed to solve optimization problems. TS starts with a random solution and evaluates fitness function for a solution. Then, the solution's neighbors are generated and evaluated [35]. A neighbor is a

solution reached from current solution through a simple, basic transformation. If the best of neighbors is not in a Tabu list, then pick one from a new current solution. The Tabu list tracks previously explored solutions and prohibit it from revisiting them. Thus, if a best neighbor solution is worse than the current one it goes uphill. This way, local minima is overcome.

TS adaptive memory feature allows implementation of procedures capable of searching solution space economically and effectively [36]. As local choices are guided by information collected during a search, TS contrasts memory-less designs that rely on semi-random processes implementing a form of sampling. Fig. 1 shows a simple Tabu search algorithm [37].

1. *Select an initial* $x \in X$ *and let* $x^* := x$.
   Set the iteration counter $k = 0$ *and*
   begin with T empty
2. *If* $S(x) - T$ *is empty, go to Step* 4.
   Otherwise, set $k := k + 1$ *and*
   select $s_k \in S(x) - T$
   such that $s_k(x) = OPTIMUM(s(x):$
   $s \in S(x) - T$
3. *Let* $x := s_k(x)$. *If* $C(X) < c(x^*)$*w,*
   here x^* *denotes the best solution*
   currently found, let $x^* := x$
4. *If a chosen number of iterations has*
   elapsed either in total or since x^* *was*
   last improved, or
   if $S(x) - T = 0$ *upon reaching this*
   step directly from Step 2, *stop.*
   Otherwise, update T (as subsequently
   identified) and return to Step 2

Fig. 1 Simple Tabu Search

IV. Results and Discussion

200 numbers of nodes are used for experiments. The Transmission range of node is 100 m and the location of sink is 100 meter from (0,0) location of network. The results for number of clusters formed, average end to end delay, packet loss rate, and lifetime computation are shown in tables.

TABLE I
Number of Clusters Formed

Size of network	LEACH	Cluster formation using local search
200 sqm	12	13
300 sqm	16	18
400 sqm	25	29
500 sqm	30	28

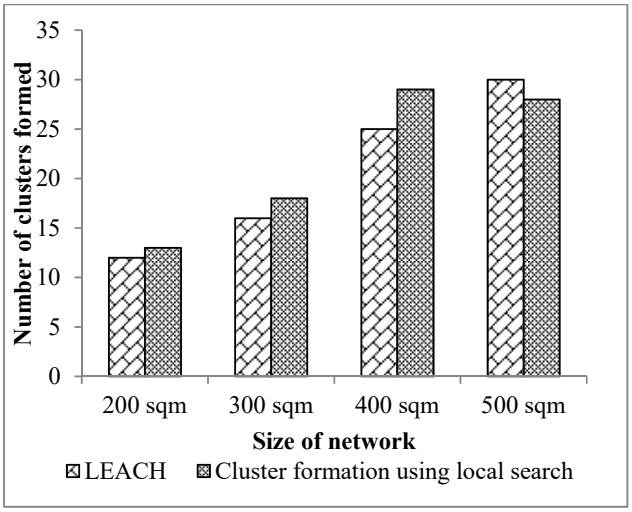

Fig. 2 Number of clusters formed

Fig. 2 shows that the proposed method increased the number of clusters formed by 14.82% when compared with LEACH with network size 400 sqm.

TABLE II
Average End to End Delay

Size of network	LEACH	Cluster formation using local search
200 sqm	0.001444	0.001401
300 sqm	0.001424	0.001764
400 sqm	0.01327	0.015966
500 sqm	0.022663	0.020976

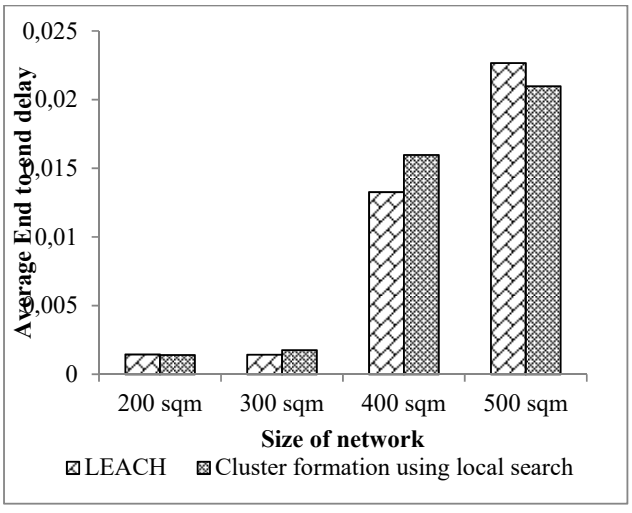

Fig. 3 Average End to end delay

From Fig. 3 it is observed that the proposed method reduced average end to end delay from 3.02% to 21.33% when compared with LEACH.

TABLE III
AVERAGE PACKET LOSS RATE

Size of network	LEACH	Cluster formation using local search
200 sqm	0.1112	0.1023
300 sqm	0.1628	0.1416
400 sqm	0.1633	0.1608
500 sqm	0.2334	0.2092

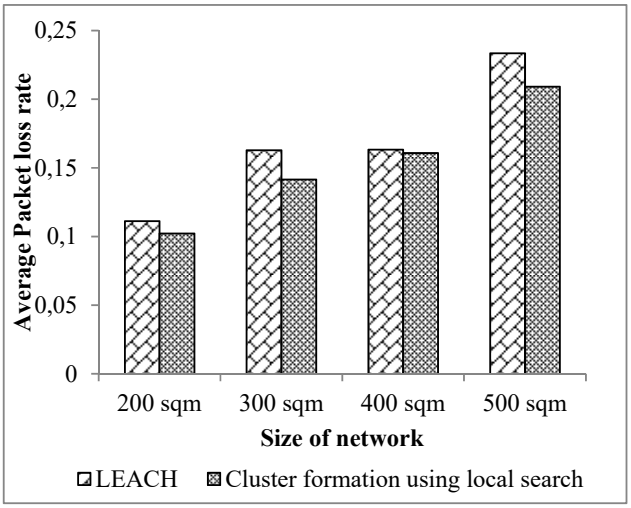

Fig. 4 Average Packet loss rate

Fig. 4 shows that the proposed method decreased packet loss rate averagely by 8.84% when compared to LEACH for various network size.

TABLE IV
LIFETIME COMPUTATION

Lifetime computation	LEACH	Cluster formation using local search
0	100	100
100	100	100
200	89	91
300	84	95
400	45	47
500	22	50
600	11	23
700	0	2
800	0	0

The proposed method improved network lifetime averagely from 2.22% to 77.78% when compared to LEACH for various network sizes.

V. CONCLUSION

Clustering extends a sensor network's life by reducing energy consumed. A sensor network is scalable through cluster formation. A CH is elected by a cluster's sensors or pre-assigned by a network designer. Many clustering algorithms are designed for WSNs for scalability and communication. A cluster based routing concept performs energy-efficient routing in WSNs. Improved CH selection for efficient data aggregation is proposed in WSNs. The new algorithm is Tabu search based.

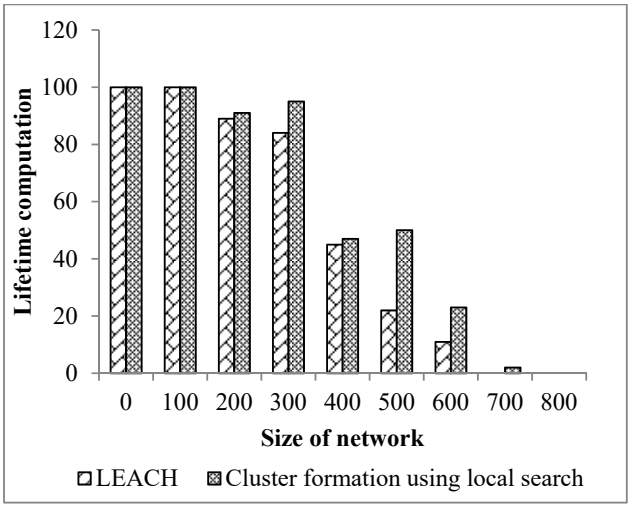

Fig. 5 Lifetime Computation

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