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Improved LEACH algorithm for enhancing lifetime of WSN – *A Survey*

Deepa[*] & Dr. Nipin Gupta[**]

[*] *M.Tech. Student, Vaish College of Engineering, Rohtak, HR*
[**] *Head of the Deptt. (ECE), Vaish College of Engineering, Rohtak, HR*

Abstract- Wireless Sensor Networks (WSNs) consist of multiple nodes, usually tens to thousands, that are deployed to gather useful information from the environment/field. These nodes share information and carry out cooperative processing by communicating through wireless channels. These Wireless Sensor Nodes are generally grouped in clusters to increase the efficiency of the network and enhance the scalability of the network system. However, since the nodes have limited power capabilities, limited computation power and finite battery life, it becomes critical to conserve the limited resources in order to increase the up-time of the network.

This paper surveys the literature and discusses approaches to select cluster head by using swarm intelligence techniques. Ant Colony Optimization (ACO) is one such biologically inspired mechanism for routing that is based on swarm intelligence. ACO is a reliable and dynamic protocol that provides energy-aware, data gathering routing structures in a WSN. Modified versions of ACO can be employed over LEACH algorithm for efficient and effective cluster head selection. This approach is expected to considerably reduce the amount of average energy consumption.

Index Terms- ACO, LEACH, Sensors, Swarm Intelligence, WSN

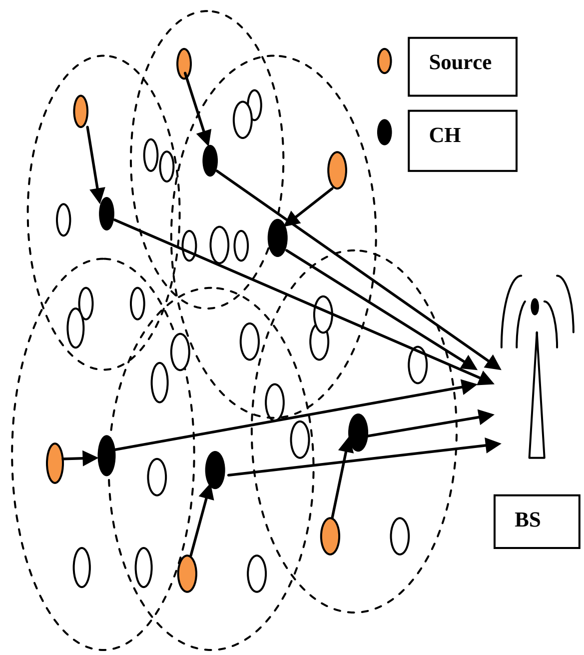

Fig. 1: Wireless Sensor Network (WSN) Architecture
Legend: **CH** – Cluster Head, **BS** – Base Station

I. Introduction

A **Wireless Sensor Network (WSN)** consists of sensor nodes which are connected wirelessly. These sensor nodes are small, low cost, low power and multi-functional. They can communicate over short distances. Each of these sensor nodes consist of components that can sense data, process data, and communicate with each other. Such sensor nodes collaborate to form wireless sensor networks.

Applications of these sensor networks include sensing environmental variables like temperature, pressure, etc. Such WSNs can also be deployed in manufacturing setups to monitor different parameters and processes. They may also be used to measure deficiencies in structures, vehicles, infrastructures, etc. A lot of research work is being carried out in this area. Nevertheless, there is a great scope of improvement and improvisation in the design and deployment of WSNs using modern meta-heuristic route optimization techniques that are inspired from natural swarm. Fig. 1 below illustrates the architecture of a WSN network.

Ant Colony Optimization (ACO) was proposed by Marco Dorigo in 1992. It is a probabilistic technique that can be used for solving computational problems that involve finding the shortest path. The first algorithm of ACO was aimed at searching for an optimal path in a graph. The basis is the behavior of ants seeking a path between their colony and a source of food. In the real world, ants initially move randomly, and after finding a food source they return to their colony while laying down chemical pheromone trails. The amount of pheromone deposited depends on the quantity and quality of the food.

Whenever other ants find such a trail, they are likely not to keep travelling at random, but to follow that trail instead, returning and reinforcing it if they eventually find the food. Thus the pheromone amount guides other ants to find the food source. As a result of this phenomenon, the optimal solution derives rapidly. By using this behavior of the ants, optimal cluster head can be selected. This original idea based on movement of real ants, after improvements, can be replicated to solve a wider class of numerical problems.

It needs to be emphasized that WSNs can be used for many mission-critical applications such as target-tracking in battle-fields and emergency responses. In these crucial applications, reliable and timely delivery of sensor data is bound to play a crucial role in the success of the mission. However, WSN nodes that are deployed to gather useful information from the field generally consist of nodes with limited power capabilities, limited computation power and finite battery life limited power. Present research on routing in WSNs mostly focuses on protocols that are energy aware so as to maximize the lifetime of the network, thus making it scalable for large number of sensor nodes and tolerant to sensor damage and battery exhaustion.
Ant Colony Optimization (ACO), a swarm intelligence based optimization technique, is thus widely used in network routing.

This survey paper focuses on these critical applications, and discusses localized modified ACO routing protocols for them. ACO algorithms can be a good fit for WSN routing. The reasons being: ACO algorithms are decentralized just as WSNs are. WSNs can be more dynamic than a wired network – the nodes can break away, run out of energy, and their radio propagation characteristics can change. ACO algorithms have been shown to react adapt quickly to such changes in the network.

II. THEORETICAL BACKGROUND

Low Energy Adaptive Clustering Hierarchy (LEACH) has been proposed by Heinzelman *et al.*[11]. It is one of the significant clustering routing approaches that is used in Wireless Sensor Networks. The most important objective of LEACH is – to select Cluster Heads (CHs) from sensor nodes by rotation. This strategy ensures sharing of high energy dissipation that happens in the process of communication with the Base Station (BS) amongst all the sensor nodes in the network.

The working of LEACH algorithm can be divided into a number of *rounds*. Each of the round is further broken down into 2 phases: *set-up phase* and *steady-state phase*. In the set-up phase, the clusters are organized, while in the steady-state phase, data is delivered to the Base Station. Further, during the set-up phase, the decision to become a Cluster Head (CH) for the current round is taken by each node. Such a decision is based on the number of times the node has been a Cluster Head (CH) so far and the suggested percentage of Cluster Heads (CHs) for the network. The node chooses a random number between 0-1 to take such a decision. For the current round, the node becomes a Cluster Head (CH) if the number chosen above is less than the following threshold:

$$T(n) = \begin{cases} \frac{P}{1-P\,(r \bmod \frac{1}{P})}, & \text{if } n \in G \\ 0, & \text{Otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where
r : number of the rounds,
P : desired percentage of the cluster head nodes (CHs) in the current round,
G : collections of the nodes that have not yet been elected as Cluster Heads (CHs)
in the first 1/P rounds.

Threshold Equation (1) implies that all the nodes would be able to become Cluster Head (CH) nodes after 1/P rounds. When a node successfully gets elected as Cluster Head (CH), it broadcasts an advertisement message to all the other nodes. Based on the strength of the advertisement of the received signal, other nodes take a decision about the cluster they would join for this round. They, then, send a membership message to its Cluster Head (CH). For the purpose evenly distributing energy load among all the sensor nodes, Cluster Heads' rotation is performed in every round by generating new advertisement phase based on Equation (1).

The sensor nodes sense and transmit data to the Cluster Heads (CHs) during the steady state phase. The Cluster Heads, then, compress the data arriving from nodes that belong to the respective cluster, and further send an aggregated/fused packet to the Base Station (BS) directly. In addition to the above, Low Energy Adaptive Clustering Hierarchy (LEACH) protocol uses a Code Division Multiple Access (CDMA)/TDMA MAC to reduce intra-cluster and inter-cluster collisions. After elapsing of a certain pre-determined time, the network again goes back into the set-up phase and enters another round of Cluster Head (CH) election. Fig. 2 shows the basic topology of data communication in a clustered network.

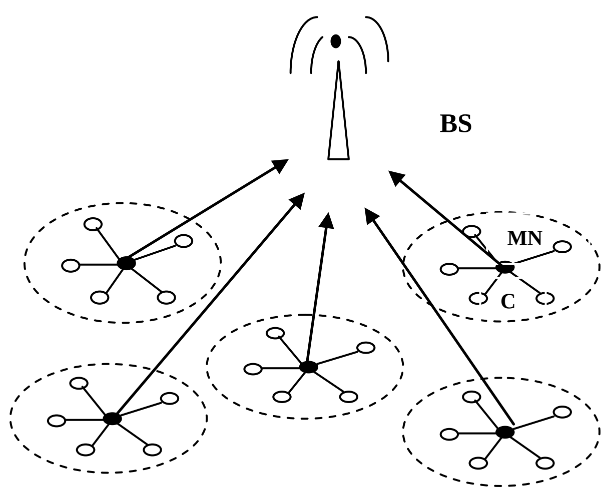

Fig. 2 : Data Communication in a Clustered Network.

Data aggregation algorithm, in general, uses sensor data from the sensor nodes of the Wireless Sensor Network (WSN). The sensor data is then aggregated by using aggregation algorithms such as LEACH (Low Energy Adaptive Clustering Hierarchy), etc. The next step, as illustrated in the Fig. 3, is then transferred to the sink node by way of selecting the most efficient path.

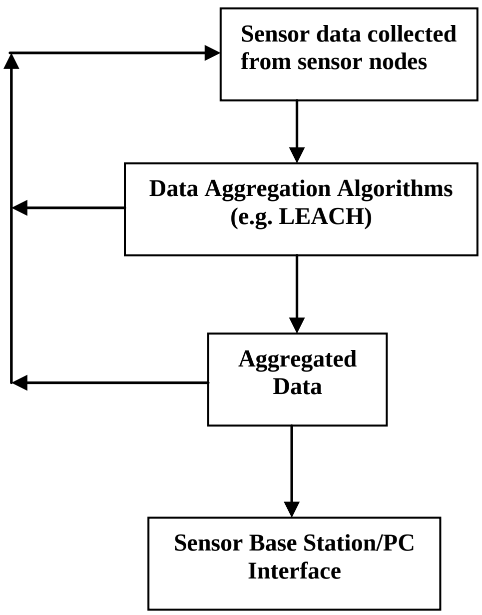

Fig. 3: General Data Aggregation Algorithm Architecture

LEACH and it's various flavors

LEACH protocol follows a distributed approach and does not require global information of the network. In literature, various modifications to the LEACH protocol have been suggested, such as LEACH-C, TL-LEACH, V-LEACH, EECH-LEACH *etc*.

LEACH algorithm has a few shortcomings. The most important being: 1. Random election of CHs causes an imbalance in the energy consumption of the sensor network, and 2. Threshold *T(n)* is function of only the CH probability, *P* and the number of the current round, *r (Eqn.1)*.

To overcome these limitations of LEACH, various improvised versions of LEACH have been suggested, including:

- **LEACH-C:** LEACH-C protocol uses a centralized clustering algorithm. The steady-state phase of LEACH-C is same as the same steady-state phase of LEACH. LEACH-C protocol delivers better performance by dispersing the cluster heads throughout the network.
- **TL-LEACH:** In TL-LEACH, the CH collects data from other cluster members in the same manner as original LEACH. However, rather than transferring the data directly to the Base Station, TL-LEACH uses one of the CHs that lies between the CH and the BS as a relay station.
- **V-LEACH:** V-LEACH protocol makes use of a vice-CH in addition to the CH in the cluster. The vice-CH takes the role of the CH when the CH dies.
- **EECHS-LEACH:** In EECHS-LEACH protocol, a number of parameters are used at the time of CH selection – residual energy of the nodes, distance between the nodes and the BS, number of consecutive rounds in which a node has not been a CH etc.

III. RELATED RESEARCH BACKGROUND

A numbers of important issues related to development of low power wireless sensor application have consistently been an area of research. Most important of these issues is to use available energy in the most efficient way, without compromising the performance of the sensor nodes. Sensor nodes use batteries as a power source that have quite limited lifetime. Thus efficiency of energy management becomes a key requirement in the wireless sensor network design. The routing protocols used in sensor networks are classified into three categories: flat-based, hierarchical-based, and location-based routing.

LEACH protocol is one such routing protocol that is grouped in hierarchical routing approaches of WSNs. LEACH is the earliest proposed single-hop cluster routing protocol in Wireless Sensor Networks. It is a self-organizing robust clustering protocol that can significantly conserve network energy. However, the effectiveness of LEACH protocol in cluster head selection is not optimized because of the probability model. This survey paper reviews the LEACH protocol and its other variants so that an improvement in the clustering algorithm can be proposed. The proposed LEACH would take into account node's residual energy and location information in order to optimize the selection method for electing the cluster head. If, by adopting an improvised approach, the number of cluster heads can be optimized, then the energy consumption of the sensor nodes may be distributed in the WSNs more evenly. It would thus avoid extra energy consumption of a single node and prevent its untimely death, thus directly affecting the network life cycle and up-time.

The expression, *Swarm intelligence (SI)* was introduced by Gerardo Beni and Jing Wang in 1989, in the context of cellular robotic systems. It is the collective behavior of decentralized, self-organized systems, that may be natural or artificial. SI systems are typically made up of a population of simple agents or boids ("bird-oid object") that interact locally with one another and with their environment. The inspiration of such a model often comes from nature, esp. biological systems. These agents follow very simple rules. Even though there is no centralized control mechanism dictating how individual agents should behave, but local, and to a certain degree random, interactions between such agents lead to the emergence of "intelligent" global behavior, which is unknown to the individual agents.

Natural examples of Swarm Intelligence include bird flocking, ant colonies, animal herding, bacterial growth, fish schooling etc. In principle, it should be a multi-agent system that has self-organized behavior that eventually displays some intelligent behavior.

Ant colony optimization (ACOs) algorithms are speculative procedures and probabilistic techniques that can be useful in the process of searching. The essential component of ACO, as discussed earlier, is the pheromone model, which is used to sample the search space equally. Ant colony algorithm can be applied on a routing mechanism for finding the best path from the cluster heads to the base station. ACO, thus, can be used for solving computational problems which can be further reduced to finding paths.

This concept can be adapted and applied in WSNs, for finding the optimal paths from the source nodes to the base station, wherein each node maintains its probabilistic routing table, also called as pheromone tables. On the basis of the death of the first node, ant colony algorithm can be applied on the LEACH protocol in the Wireless Sensor Network. The proposed algorithm is focused on enhancing the network lifetime, which in-turn affects the performance of LEACH protocol in terms of energy consumption.

A number of researchers have already implemented various routing algorithms on Wireless Sensor Network for better performance and longer up-time. Mohammad El-Basioni et al. [10] implemented hierarchical protocols such as EAP protocol – which is essentially LEAP protocol which works around LEACH. Later on, the EAP routing protocol was further improved and named as LLEAP. The author experimented with this protocol and has observed better results as compared to previous routing protocols mentioned earlier in the paper. This routing protocol only improves the other parameters except network lifetime over EAP.

Heinzelman[11] have proposed LEACH which is adaptive clustering protocol for distributing the energy load among the sensor nodes in the network. LEACH protocol uses randomized rotation of the cluster base stations or cluster heads and the corresponding clusters. It is thus able to distribute energy dissipation evenly throughout the sensors in the Wireless Sensor Network, thus increasing the up-time to almost double. The clusters are used for transmitting data to the base station and provide the advantages of smaller transmitting distances for most of the nodes, thus necessitating the need of only a few nodes for transmission of the data from far-off distances to the base station. It further increases the performance of classical clustering algorithms by using adaptive clusters and rotating cluster heads. In addition to the above, the specified protocol is able to perform local computation in each cluster which reduces the amount of data that must be transmitted to the base station. This also helps in achieving a large reduction in the energy dissipation in the WSN.

Zhao et. al.[8] have highlighted that the classical hierarchical protocols such as LEACH and LEACH-C have better performance in saving the energy consumption. However, the selection formula neglects the change of nodes' energy, thus making the nodes act as cluster heads too many times. Such nodes, then, die early owing to the consumption of too much energy. They also remark that the high frequency of re-clustering wastes certain amount of energy. The traditional equation used for selecting cluster heads has thus been improved by considering the dynamic change of nodes' energy in order to distribute the energy more evenly among different nodes. It has also been proposed to establish a vice cluster head for each cluster during the communication process, with the intent to diminish the energy consumption spent on re-clustering and to prolong the time of being in a steady-state phase.

Elrahim[6] in his paper has proposed an energy efficient data forwarding protocol called Energy Aware Geographic Routing Protocol (EAGRP) for wireless sensor networks to extend the life time of the network. In EAGRP, both position information and energy are available at nodes used to route packets from sources to destination. The routing design of EAGRP is based on two parameters: location and energy levels of nodes. Each node knows the location and energy level of its neighbors. The performance measures have been analyzed with variable number of nodes. The results of the research show that EGARP does efficiently and effectively extend the network lifetime by increasing the successful data delivery rate.

Basile et. al.[7] did a formal analysis of a key management protocol, called LEAP (Localized Encryption and Authentication Protocol), intended for wireless sensor networks through the high level formal language HLSPL and checked using the AVISPA tool for attacks on the security and authenticity of the exchanges. They focused on the protocol's establishment of pairwise keys for nearest neighbors and for multi-hop neighbors. They then used this foundation to test the protocol's method of cluster key redistribution.

Chaturvedi et. al.[4] illustrated that the main issues in wireless Sensor Networks (WSNs) are efficient uses of limited resources and appropriate routing of network path. They suggested multiple sinks to be the most efficient and effective in overcoming these issues when used with proper routing protocols. The authors further compared residual energy status of entire network nodes of single stationary and multiple sinks, compared and evaluated the performances. They further suggested that properly framed heuristic algorithms are the most suitable for query based routing protocol. The performance of multiple stationary sink is better than the single stationary sink because almost all the nodes generally get the opportunity to do the job of Cluster Head (CH). Thus, the authors conclude that the WSN life time can be prolonged by using multiple sinks.

Prajapati et. al.[1] proposed modified Geographical energy aware routing in WSN. In this approach, separation of the sensor nodes is based on their location using GPS, wherein certain regions are classified. Base Station (i.e. Sink Node) is established away from the sensing region and a gateway node is present at the middle of sensing region. When the distance of sensor nodes from sink node and gateway node is relatively less than the pre-defined distance threshold, then the node uses direct communication for data transmission. It separates the rest of nodes into the equal regions whose distance is more than the threshold distance. Cluster Heads (CHs) are selected in each region independently of the other regions. Such selection is based on the probability and residual energy of nodes. The author has found out that the proposed routing protocol performance with LEACH and their results showed better in terms of network energy consumption, lifetime and packet transmission to base station.

Bishnoi et. al.[3] discussed the developments of wireless sensor networks technology with respect to how to prolong the lifetime of Wireless Sensor Network and reduce energy consumption by the sensor nodes. The authors analyzed the cluster head selection phase of LEACH protocol and proposed the improved approach of LEACH i.e. CSLQ (Cluster-head based on link quality) that improves the lifetime of the network. In CSLQ the cluster – head is selected on the basis of link quality so that number of packets lost decrease as compared to the LEACH-C protocol. In the proposed model, sensor nodes are deployed to sense information and send it to the CH and then CH sends that information to the BS. The authors also evaluated both LEACH-C and CSLQ showing that CBLQ protocol performs better than the LEACH-C protocol.

Rajasekaran et. al.[2] emphasized that Wireless Sensor Networks (WSN) is an emerging technology which is challenging due to its scope, limited processing power, and associated low energy. Thus WSN routing differs from conventional routing in fixed networks. The reasons being – it lacks infrastructure, has unreliable wireless links, sensor nodes are susceptible to fail and routing protocols are expected to meet tough energy saving requirements. Data aggregation is essential in WSN because it effectively saves limited resources. The objective of data aggregation algorithms is gathering and aggregation of data in an energy efficient manner so as to improve the network life. Clustering is used to extend the network life by reducing energy consumption. The authors propose a better cluster head selection in sensor networks for efficient data aggregation. Their proposed algorithm is based on Local search and incorporated in Low Energy Adaptive Cluster Hierarchy protocol (LEACH).

Siddiqui F.A. et al.[5] suggest that the lifetime of WSNs is affected by the cluster head (CH) selection. CH consumes more power than a regular (non-CH) node. Consequently, an energy efficient cluster head selection in Mobile Wireless Sensor Networks has been proposed, analysed and validated on the basis of residual energy and randomized selection of the node. The proposed approach has shown significant improvements when compared with LEACH in terms of energy consumption of sensor nodes, enhanced network lifetime and efficient data gathering.

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VI. AUTHORS

First Author – Deepa, *M.Tech. Student, Vaish College of Engineering, Rohtak, HR*
E-mail: deepa.rohilla12@gmail.com

Second Author – Dr. Nipin Gupta, *Head of the Deptt. (ECE), Vaish College of Engineering, Rohtak, HR*
E-mail: callnipin@gmail.com