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A Multi -Objective Bee Swarm Optimization For Energy Efficient Clustering In Multi-Hop Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) are the same as adhoc wireless networks with the communication method being multi-hop networking. Adhoc networks support routing between node pairs, while sensor networks have specialized communication patterns. Multi-hop network sensors detect events and communicate this information to a central location which estimates the events characterizing these parameters. Transmission cost is higher than computation, and so it is advantageous to organize sensors in clusters. Data collected by sensors are communicated to data processing centers through a cluster heads hierarchy in clustered environments. This study proposes a multi objective Bee Swarm Optimization for efficient clustering.

Keywords: Wireless Sensor Network (WSN), Clustering, Low Energy Adaptive Clustering Protocol (LEACH), Bee Swarm Optimization.

Introduction

Wireless Sensor Networks (WSN) is a group of wireless mobile nodes which self-configure to form networks without any established infrastructure [1]. It is rapidly deployed and reconfigured where communication infrastructure is unavailable or destroyed. WSN is successful due to recent technological advancements that enabled low-cost, low-power and minute sensor nodes production. These tiny nodes work in a few to tens of hundreds in areas extending from sophisticated urban homes to hostile, remote areas. The design space for WSN routing algorithms is large, and classification of WSNs routing algorithms are in diverse ways. Routing protocols are classified as data-centric or location-aware (geo-centric), node centric, and Quality of Service (QoS) based routing [2]. Most adhoc network routing protocols are node-centric where destinations based on nodes numerical addresses (identifiers) are specified. In location aware routing, nodes know their location in a geographical region. Location information improves routing performance and provides new services.

Wireless and mobile systems major restrictions relate to communication bandwidth and energy underline challenges in designing a wireless adhoc network. Innovative communication techniques to increase bandwidth per user and inventive design techniques to increase energy efficiency must be developed. Most protocols use clusters to provide energy efficiency and extend network life [3].Each cluster elects a node as Cluster Head(CH), and nodes in all clusters send data to their CH. The latter sends its data to a base station. This data transfer can be done in two ways. Either directly, as where a CH is close to a base station or through intermediate CHs.

Clustering-based routing protocols are considered energy efficient as, CH produce limited useful information from huge amounts of raw sensed data by cluster node members and transmit this precise information to a network Base Station (BS) that consumes less energy [4]. Most WSN clustering protocols in literature are designed for static sensor nodes and so do not suit WSN applications needing mobile sensor nodes like habitat monitoring, wildlife monitoring, and health.

Low Energy Adaptive Clustering Protocol (LEACH) is a standard WSN clustering protocol. Clustering divides a network into interrelated substructures, called clusters, with every cluster having many sensor node headed by a CH who is this substructure’s coordinator. CH is also a temporary base station in touch with other CHs. Nodes have 4 states: normal, isolated, cluster head, and gateway. Basically, nodes are in an isolated state, and each maintains the neighbor table which stores neighbor node information. Electing the CH is a basic clustering step. Clustering is applied in WSN to manage power efficiently [5, 6]. WSN environment clustering architecture enables features like network scalability, communication overhead reduction, and fault tolerance.

Cluster formation benefits routing as cluster head/cluster gateways are responsible for inter-cluster routing, thereby restricting, creating, and spreading routing information. Local changes like nodes changing cluster are updated in corresponding clusters only. No update is required by the entire network, thus greatly reducing information stored in every mobile node.

A sensor network has three components including sensor nodes, sink, and monitored events. Supporting sink nodes mobility is important in WSN design [7]. Routing is important as routing messages from or to moving nodes is challenging as route stability is an important optimization factor, in addition to energy and bandwidth. An important challenge in WSN design is that energy resources are more limited than in wired networks [8]. Recharging or replacing sensors battery in a network may be either difficult or impossible, causing severe limitations in communication and processing time between all network sensors. Failure of regular sensors may not harm overall WSN functioning as neighboring sensors can take over, provided their density is high. So, a key parameter to optimize is network life or the time till the network is partitioned.

Optimization is performed to maximize network life, instead of minimizing total average power consumption. The optimization problem considers energy consumption including transmission energy and circuit processing energy. Based on this, it is seen that single-hop communication is optimal in cases where circuit energy dominates energy consumption instead of transmission energy [9]. Optimizing the network lifetime of multi-hop WSNs using routing methods that utilize cooperative transmission (CT), is referred to as cooperative routing. The energy-hole problem can be described as the situation when the batteries of nodes near the sink deplete early because these nodes are heavily burdened with traffic from the rest of the network [10]. Since CT requires multiple transmitters to transmit a single packet, whereas non-CT (that does not use CT) requires only one transmitter, CT may consume more energy than non-CT, and therefore, in order to solve the energy-hole problem and extend the network lifetime through CT, one must devise a way to use CT wisely.

A WSN has to reduce energy consumption in all states (transmission, reception, idle). This study proposes a multi objective Bee Swarm Optimization. Section 2 reviews related works in literature. Section 3 explains methodology and Section 4 discusses the experimental results. Section 5 concludes the study.

Related Work

A new algorithm based on High-efficiency Electron Emission Device (HEED), named Balanced Energy-Efficiency (BEE) clustering algorithm was proposed by Xu et al., [11]. Results showed that BEE exceeded HEED and LEACH from the longevity and balanced sensor distribution perspectives. It guaranteed network coverage for a longer time, compared to HEED and LEACH. The BEE's multi-hop version was illustrated and called Balanced Energy-Efficiency Multi-hop (BEEM) clustering algorithm, which further improved BEE performance.

A new clustering problem that aims to generate overlapping multi-hop clusters was formulated by Youssef et al., [12]. A randomized, distributed multi-hop clustering algorithm -KOCA to solve overlapping clustering problem was proposed. KOCA aimed to generate connected overlapping clusters covering the entire sensor network with specific average overlapping degree. Analysis and simulation showed how to select the parameter's different values to achieve clustering objectives. The results also showed that KOCA produced approximately equal-sized clusters ensuring even load distribution over different clusters. Also, KOCA was scalable; a clustering formation terminated in constant time regardless of network size.

A self-organizing multi-hop clustering protocol based on persistent algorithm proposed by Saglamand Dalkili [13] studied its performance by equating simulation results with timer based approach regarding amount of clusters created, message complexity and configuration time. Though it had slightly higher message complexity due to extra messages needed to generate inter-cluster links, the new protocol had better clustering performance and operated well in low node densities. Configuration is faster and system scales well as network size increased.

An asynchronous node clustering protocol designed for multi-hop WSNs which consider dynamic conditions like residual node energy levels and unbalanced data traffic loads due to packet forwarding was presented by Vural et al., [14]. Simulation demonstrated the possibility of achieving similar levels of life extension by reclustering a multi-hop WSN via independently made decisions at CHs, without time synchronization needed by current synchronous protocols.

A simple clustering algorithm called Unequally Clustered Multi-hop Routing (UCMR) protocol where each cluster has a different cluster size, based on its distance to a base station was proposed by Hari et al., [15]. To minimize network energy consumption and improve overall network performance multi-hop routing with Dijkstra's shortest path algorithm was used for intra-cluster/inter-cluster transmission. Simulation proved that UCMR improved network life over Unequal Cluster-based Routing (UCR) algorithm and LEACH significantly.

A multichannel and multihop clustering communication scheme for WSNs to improve network performance and capacity with the following features: interference and contention-free, energy efficiency, multi-path routing and load balance was investigated by Phung et al., [16]. Simulation evaluated and compared the proposed algorithm's performance with similar single channel schemes regarding energy consumption, traffic load balance, number of living nodes and network throughput. The results showed that the new multi-channel scheme increased performance significantly compared to other schemes.

An intra-cluster routing algorithm – RINtraR - enabling high quality multi-hop communication between sensors was introduced by Xu et al., [17]. Simulation showed that an intra-cluster routing policy affects WSN performance significantly. Comparison between RINtraR adapted LEACH and original LEACH algorithm was provided. Results revealed better transmission reliability compared to LEACH. Also, RINtraR converged well and could be adapted to current clustering algorithms.

Qin et al., [18] defined optimal number of cluster heads based on Multi-hop-LEACH, verified by simulation. Theory and simulation showed that expression could calculate optimal number of CHs under high network density.

Two approaches for two differing scenarios were presented by Patraand Chouhan [19]. First, Energy Efficient Hybrid Clustering Scheme (EEHCS) for direct hop communication to BS when situated in the sensing region and subsequently, Energy Efficient Hybrid Multi-hop Clustering Scheme (EEHMCS) for multi-hop communication to a BS using other CHs when it is situated far from deployment region. In both, BS selected energy efficient CHs based on remaining energy and member nodes through a centralized CH election method and broadcast selected CH message to all nodes to reduce control message overhead required for distributed clustering. Simulation proved that EEHCS prolonged network life by 27:63% over LEACH-C, whereas, EEHMCS was twice better than LEACH-C for first node death in certain network settings.

An Energy Balanced Multi-hop Adaptive (EBMA) clustering protocol for WSN is presented by Bao et al., [20] using multi-hop mode to format many sub-networks. Each cluster is a sub-network. Here, each parent node's residual energy is higher than its child nodes' in the cluster, and so a node with largest residual energy becomes the CH. Experiments show that the new protocol saves energy costs, balances node energy consumption and prolongs network life effectively.

A Cluster Based Energy efficient Routing algorithm (CBER) elected CH based on nodes near optimal CH distance, and residual energy was proposed by Mammu et al.,

[21]. In WSNs, energy is most consumed for transmission and reception which is a non-linear transmission range function. Performance results revealed that CBER scheme reduced end to end energy consumption and prolonged network life of multi hop networks compared to LEACH and HEED algorithms.

An efficient clustering algorithm with position based multi-hop approach to partition network regions into levels with increasing CHs at every level was proposed by Gupta and Daniel [22]. The CH close to BS was smaller as it forwards data to BS using Round Robin Technique to make a network more efficient. The new protocol improved delay and energy consumption performance. The new approach was more scalable than the current solution.

An Energy-efficient Clustering (EC) that determined suitable cluster sizes depending on hop distance to data sink, while achieving approximate node life equalization and reducing energy consumption levels was proposed by Wei et al., [23]. An energy-efficient multi-hop data collection protocol to assess EC's effectiveness and calculate end-to-end energy consumption was proposed. EC suits any data collection protocol that focuses on energy conservation. Performance results proved that EC extended network life and achieved energy equalization better than the HEED and UCR clustering algorithms.

Kamble et al., [24] improved a clustering algorithm to minimize control packet overhead and ensure efficient use of nodes near sink and also to implement a hybrid protocol better than current hybrid protocol.

A new algorithm called fuzzy c-means induced clustering based on LEACH algorithm was proposed by Chen [25]. The Fuzzy c-means algorithm divided nodes into Q clusters and chose the CH according to a node's energy and distance between each cluster's centre position and the BS in the first round. Then clusters were fixed. In a new round, the chosen CH node was based on current energy value and distance to the BS in a cluster. During data transmission, communication took a single-hop in a cluster and multi-hop in inter-cluster. Simulation showed the algorithm to be rational and efficient.

An energy-efficient routing algorithm based on cycle-switching CH was proposed by Guo et al., [26]. It improved node energy efficiency, balanced all sensor nodes energy consumption, enhanced data transmission reliability and postponed network life compared to LEACH. Simulation showed the algorithm to be efficient. Also, the protocol increased WSN's energy dissipation balance, scalability, and reliability.

Methodology

Data gathered by sensors is communicated to data processing centers through a CH hierarchy, in a clustered environment. This study proposes a multi objective Bee Swarm optimization for efficient clustering.

Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is an energy-efficient hierarchical clustering algorithm to reduce power consumption in WSNs. Clustering task in LEACH is rotated among nodes based on duration. A CH uses direct communication to forward data to base stations. It is an application-specific data protocol which uses clusters to prolong WSN life. LEACH is based on an aggregation; a fusion technique combining or aggregating original data into a data with smaller size carrying meaningful information to individual sensors. LEACH protocol works in 2 phases as follows:

1. Setup phase: here each node decides to become a CH for the current round. It also depends on decision by node with a random number between 0 and 1. If a node's number is bigger than a threshold it then becomes the CH.
2. Steady-state phase: When data transmission starts, nodes send data during an allocated TDMA slot to CH. This uses minimum energy. The radio of all non-CH nodes are turned off till nodes are allocated with TDMA slot, minimizing energy dissipation in nodes. When all data is received, CH aggregates data and sends it to the BS. LEACH can perform local data aggregation for every cluster to reduce data transmitted to BS.

LEACH protocol, a popular clustering method for WSNs, improves network life significantly. It assumes that nodes can reach the base in a one hop. Network nodes elect themselves as CHs probabilistically. The election CHs is done in each round. Nodes then become CH in turn using the equation:

$$T\ n = \begin{cases} \dfrac{P}{1-P\left[r \bmod\ i/P\ \right]} & \textit{if}\ \mathrm{n} \in \mathrm{G} \\ 0 & \textit{otherwise} \end{cases}$$

In LEACH's probabilistic method, sensor nodes generate a random number distributed in [0, 1]. If random value is less than a threshold T(n), a sensor node advertises itself as a CH. T(n) is calculated using values of parameters P, r, n and G which provide a desired percentage to be a CH, current round index, sensor node index and nodes set which was not selected in the last 1/P rounds, respectively.

Bee Swarm Optimization (BSO)

Collection and processing of nectar are instances of honey bee's intelligent behavior. The difference between a bee swarm and other population-based algorithms is that different kinds of bees are employed in a bee swarm, and they use different trajectories to amend their positions [27].

The BSO algorithm has 3 types of bees: experienced forager, onlooker, and scout bees flying in a D-dimensional search space $S \subset R^D$ to locate an optimum solution. Assume a set of bees in a swarm represented as β. Bees are partitioned as $\beta = \vartheta \cup k \cup \xi$ based on their fitness, where $\xi, k\ and\ \vartheta$, represent sets of experienced forager, onlooker, and scout bees respectively. In BSO algorithm, a bee's fitness represents food source quality found by that bee so far.

BSO uses a stochastic process to find an optimal solution. Initially, the number of bees, *n(β)*, percentage of experienced forager, onlooker, and scout bees, and maximum iterations, $Iter_{max}$, are determined. Other parameters are initialized. Then, at the algorithm's start time all bees are positioned randomly in search space [28]:

$$\overline{x}_0(\beta, i) = Init(i, s) \qquad \forall i \in \beta$$

Where *Init(i,s)* is initialization function which associates a random position to bee *i* in search space *S*. After initialization, bees use the following process to fine-tune their positions throughout iterations till a termination condition is met. At the algorithm's every iteration, each bee's fitness is calculated, and bees are sorted based on fitness values. Then, a bee is classified as experienced forager, onlooker or scout.

A predefined percentage of bees with worst fitness are selected as scouts, and the remaining bees are divided similarly as experienced foragers and onlookers. First half of these bees with better fitness are chosen as experienced foragers and the other half as employers. Bee's classification into three categories ensures a swarm with highly dynamic behavior which uses different flying patterns.

Proposed Multi Objective BSO (MOBSO) Clustering

Sensor nodes in a WSN application collect data and send it to a destination which is a neighbor node or base station. CHs in a clustered approach, gather data about common phenomena from sensor nodes, aggregate raw data to form the final abstract data. The idea in data aggregation is to combine data from different sensor nodes in a neighborhood, eliminate redundancies by processing (like using max. operator) and minimize total data transmission before shifting data to base.

If WSN network is depicted as an undirected graph represented by G=(V,E), where nodes form the vertices $(n_1,\ldots,n_n)$ and edges between nodes are represented as $(e_{1,2}, e_{1,3}.., e_{i,j,\ldots,}e_{n-1,n})$. In the proposed Multi Objective BSO (MOBSO)algorithm, CHs selection process is achieved using fitness function got analytically where communication energy is considered a significant factor. Distance between communicating elements is a major energy consumption concern. And other factors like residual energy and Energy Constraint (EC) metric are also considered. Thus, the normalized values of distance, EC, and residual energy are represented as weights $w_{i,j} = w_{i,j}^1, w_{i,j}^2, .., w_{i,j}^m$ on the edges. If $x = x_{1,2}, x_{1,3}.., x_{i,j,\ldots,}x_{n-1,n}$ be defined as the connectivity between node i and j, then

$$x_{i,j} = \begin{cases} 1 & if\ e_{i,j} = 1\ and\ is\ selected \\ 0 & otherwise \end{cases}$$

The multi objective function is represented as:

$$\min f_i \quad x = \alpha \sum w_{i,j}^1 x_{i,j} + \beta \sum w_{i,j}^2 x_{i,j} + \ldots.$$

Where $\alpha + \beta + \ldots = 1$

where $f_i(x)$ is the objective to be minimized for the problem, i=1,…,n-1; j=1,…,n subject to $x \in X$ .Since distance, EC, and residual energy are used objectives, the objective function is formulated as:

$$\boldsymbol{min\ f_i(\mathrm{x}) = \alpha(min(distance)) + \beta(min(EC)) + \gamma(min(1 - residual\_energy))} \quad (4)$$

Network initialization is made in the new method when sensor nodes are deployed in an area. Then, information about distances between nodes and energy status are gathered. To obtain distance values, nodes advertise messages to the network. A node receives these advertised messages from other nodes at differing signal strengths and calculates distances using:

$$d_{ij} = s.\ \left(P^r\right)^{-1/2},\ \text{where s = c.}\ \left(P^s\right)^{1/2} / 4\pi f$$

In equation, d_{ij} is distance between node i and node j, f is communication frequency, c the speed of light, P^r the received signal strength and P^s sender signal strength. If variables of c, P^s, and f are constants then,s is a constant value to calculate distance meaning the communication range.

Residual energy is considered during CH selection. The chances of a node becoming CH are high, when it has higher residual energy, more neighbors, and strong signal strength. The CH's objective function is obtained as follows:

$$q_1 = \left(E_i\right)^{k_1} * \left(K_i\right)^{k_2} * \left(SE_i\right)^{k_3}$$

Where E_i represents residual energy, K_i set of neighboring nodes, SE_i signal strength detected and k_1, k_2, k_3 are weights controlling E_i, K_i and SE_i.

CH dynamically chooses a route for data transmission depending on path metric like energy consumption. An energy constraint metric is used while searching for multiple routes among CHs and the sink node. The EC metric computes the inter-flow interference and transmission rates variation and wireless links loss ratios. The EC metric is designed as:

$$IEC_{ij}(c) = ETT_{ij}(c) * \left|N_i(c) \cup N_j(c)\right|$$

Where $N_i(c)$ is a set of neighbors of node i

C is channel c

$\left|N_i(c) \cup N_j(c)\right|$ is total number of nodes that are interfered with by transmission activities between Node i and Node j over channel c.

$ETT_{ij}(c)$, expected transmission time, that computes transmission rates differences and links loss ratios.

Experimental Results

The evaluation setup consists of varying number of sensor nodes (75 to 450) and one sink spread over an area of 4 sq. Km. The simulations are run for 300 sec. The proposed MOBSO is compared with LEACH and BSO. Parameters like end to end delay, packet delivery ratio and lifetime of the network is evaluated during the simulations.

Table 1: End To End Delay

Number of nodes	LEACH	BSO	MOBSO
75	0.00136	0.001324	0.00139
150	0.00134	0.001674	0.001356
225	0.012855	0.015721	0.013435
300	0.022824	0.01906	0.021825
375	0.050378	0.042302	0.048868
450	0.053393	0.04678	0.05272

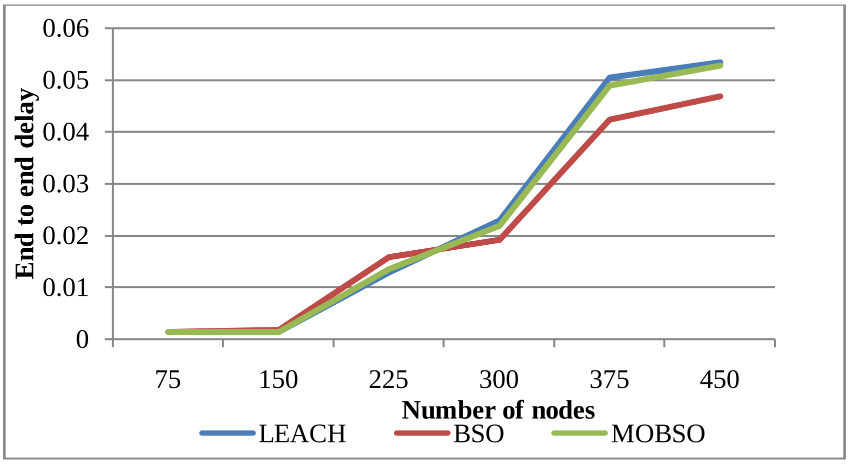

Figure 1: End To End Delay

Table 1 and figure 1 shows the results of end to end delay. The proposed method reduced end to end delay by 4.47% with 300 nodes when compared to LEACH.

Table 2: Packet delivery ratio

Number of nodes	LEACH	BSO	MOBSO
75	0.720416	0.81833	0.921508
150	0.68758	0.790537	0.892114
225	0.680918	0.772039	0.883478
300	0.644517	0.735124	0.831969
375	0.593199	0.684661	0.777981
450	0.513714	0.60059	0.748885

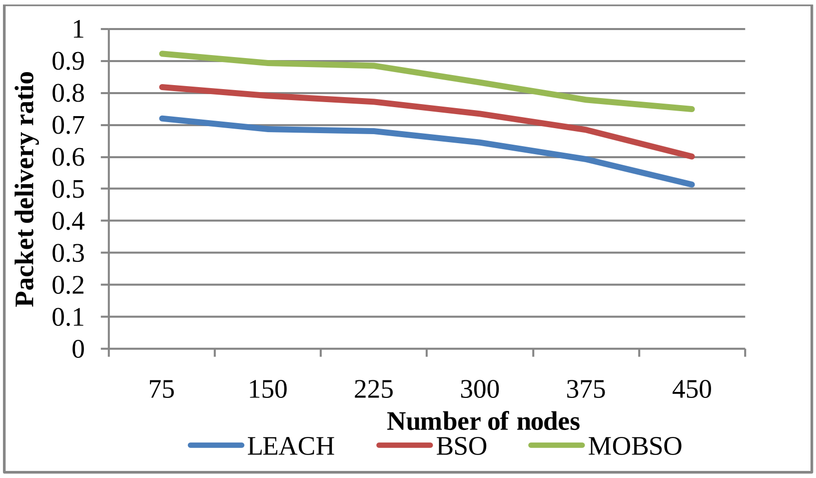

Figure 2: Packet delivery ratio

Table 2 and figure 2 shows the results of packet delivery ratio. The proposed method improved packet delivery ratio by 37.25% with 450 nodes when compared to LEACH.

Table 3: Lifetime computation

Number of rounds	LEACH	BSO	MOBSO
0	100	100	100
100	92	96	96
200	74	84	91
300	62	76	82
400	13	35	73
500	0	11	59
600	0	0	11
700	0	0	0
800	0	0	0

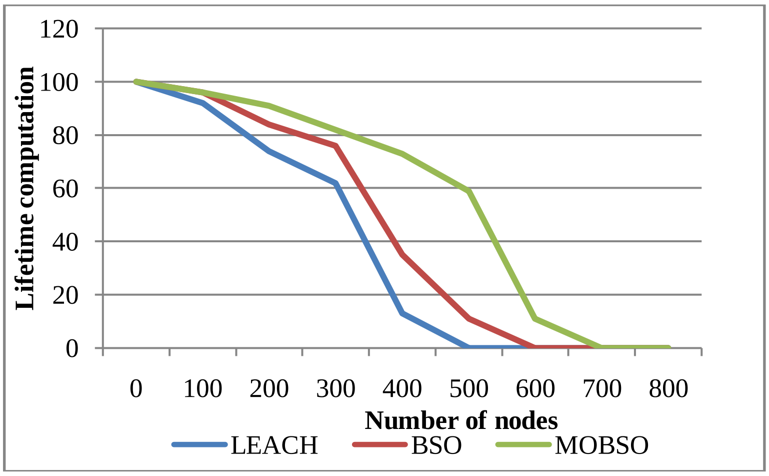

Figure 3: Lifetime computation

Table 3 and figure 3 shows the results of lifetime computation. The proposed method improved lifetime by 139.53% in 400 rounds when compared to LEACH.

Conclusion

WSNs have emerged as a new information technology infrastructure class where computing is embedded into the physical world. WSN applications include building control, traffic control, environmental monitoring, service robotics, manufacturing, and plant automation and surveillance. Data collected by sensors is communicated to data processing centers through a CH hierarchy in a clustered environment. This study proposed a multi objective Bee Swarm Optimization for efficient clustering. CHs selection process is based on communication energy and other factors like residual energy and Energy Constraint (EC) metric. Experiments reveal that the new method outperformed LEACH.

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