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Ant Colony Optimization-Based Energy Efficient Clustering and Routing in Wireless Sensor Networks

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Abstract

One of the major challenges in wireless sensor networks (WSNs) is extending the network's operational lifetime, given the limited battery power of sensor nodes. These nodes perform essential tasks such as sensing, processing, routing, and transmitting data to the base station, all of which consume significant energy. This Research reviews current energy-optimized routing protocols and evaluates their performance against a newly proposed method. We examine several well-known protocols—LEACH, DEEC, DDEEC, EDEEC, and ED-DEEC—which employ their own algorithms for energy efficiency, often using probability-based cluster head (CH) selection. However, this probabilistic approach can result in energy imbalance, where nodes with low energy may be chosen as CHs while high-energy nodes are overlooked, ultimately affecting network longevity. Furthermore, these protocols often do not account for the real-time energy levels of nodes during CH selection. To address these limitations, this study introduces an Ant Colony Optimization (ACO)-based routing protocol inspired by the natural behavior of ants. This method incorporates energy level awareness during CH selection and employs a dual-cluster-head approach within each cluster to enhance network performance. Simulation results demonstrate that the proposed algorithm significantly improves network lifetime and throughput.

Keywords: Wireless Sensor Networks, Clustering, Network Lifetime, Energy Efficiency, Nature-Inspired, Ant Colony Optimization.

1 Introduction

A Wireless Sensor Network (WSN) is a special kind of wireless network that falls under the broader category of ad-hoc networks. These networks basically consist of the nodes, commonly referred to as "sensors," as each node is generally equipped with the smart sensing capabilities. As compared to the general ad-hoc networks, the nodes in a WSN are typically less mobile, meaning WSNs exhibit limited mobility.

WSNs are fundamentally data-centric, meaning data is collected based on specific physical parameters or conditions. Each sensor node integrates several components, including an embedded processor, a transducer, limited memory, and a unique wireless transceiver. These components operate using power supplied by an internal battery.

"The sensor is basically an electromechanical device which senses or measures a physical property, stores and converts it into a signal then which can be collected or read out by a user or observer".

Modern sensors are tiny electromechanical devices they are modern "MEMS (Micro Electronics Mechanical System)" [1]. Modern advanced technologies in microelectronic mechanical systems (MEMS) [1][2] and wireless communication technologies have developed low-power, low-cost, small sized, bi-directional and multi-functional smart sensor nodes in the wireless sensor network. Sensor usually sense the physical conditions like light, motion, vibration, temperature, sound, moisture, magnetic fields, electrical fields, gravity, humidity, pressure, radiation and other physical aspects and parameters of the external environment [3].

1.1 Battery Technology in WSN

The power consumption of sensor components is typically measured in milliamps (mA), while batteries are rated by their capacity in milliamp-hours (mAh). For example, a 1000 mAh battery could theoretically power a processor drawing 10 mA for about 100 hours. However, in practice, this is not always the case. Battery performance varies due to its chemical properties, with voltage and current levels fluctuating based on how power is drawn and how the battery discharges. If a system cannot tolerate voltage drops, it may be impossible to fully utilize the battery's rated capacity. For instance, a 1.5 V alkaline battery is considered depleted only when its voltage drops to about 0.8 V.

Currently, three common battery types are suitable for wireless sensor networks: Alkaline, Lithium, and Nickel Metal Hydride [4, 5]. An AA alkaline battery typically has a nominal voltage of 1.5 V but operates between approximately 1.65 V and 0.8 V during use, as illustrated in Figure 1, with a capacity around 2850 mAh. It has an en-

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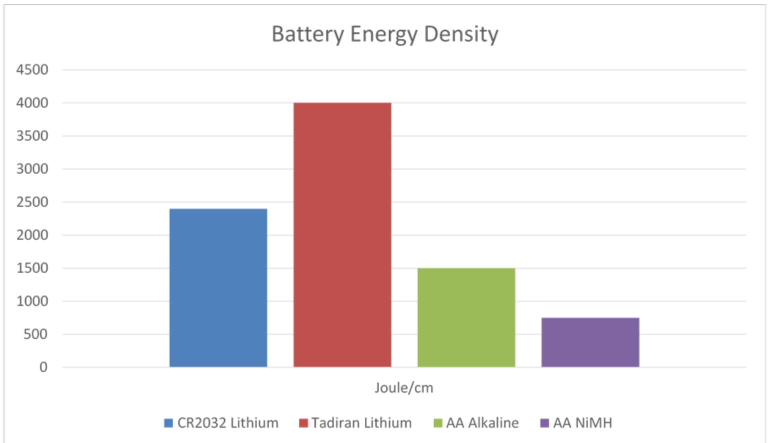

Figure 1: Battery Energy Density

ergy density of about 1500 Joules per cubic centimeter and a volume of 8.5 cm^3. While alkaline batteries offer a low-cost, high-capacity energy source, their main drawbacks include a wide voltage range that the system must tolerate and their relatively large size. Additionally, due to self-discharge, alkaline batteries generally cannot sustain long lifetimes beyond 4 to 5 years [6].

Lithium batteries offer a very compact and efficient power source [7], with some of the smallest models measuring just a few millimeters in size.

1.2 Sensors and Its Voltage Requirements

Over the past ten years, there has been a rapid advancement in sensor technologies. Researchers are investigating innovative methods to extend sensor battery life, either through improved material technologies or by adopting new approaches [8]. Currently, numerous sensor options are available for integration into wireless sensing platforms. Advancements in Microelectromechanical Systems (MEMS) [9] and carbon nanotube technologies are driving the development of a wide variety of new sensors. These range from simple sensors for monitoring humidity, radiation, light, and temperature to more complex multifunctional sensors [10].

Table 1 reports commonly available microsensors along with their key characteristics. While low-power and easy-to-interface sensor nodes are advantageous, they can become problematic if their voltage requirements do not align with the system's capabilities [11]. Some sensors need voltages like +6 V or −6 V, which means special voltage converters and regulators must be integrated into systems powered by AA or lithium batteries [12]. The energy consumption and startup times of these voltage regulation and conversion circuits must be accounted for in the overall energy budget of the sensor. Current research in nanomaterials aims to enable wireless sensors to achieve maximum throughput at low operating voltages. In the future, manufacturers are expected to provide multifunctional sensors capable of detecting multiple physical conditions simultaneously, which will offer significant benefits [12].

2 Related Work

Significant research has been dedicated to the designing of the routing protocols for wireless sensor networks (WSNs). These protocols are generally tailored to the specific application requirements and the network architectures. However, various multiple factors must be considered during their development, with the energy efficiency being the most critical due to its direct impact on the network lifetime longevity. Although some previous literature and studies have addressed energy efficiency in WSNs, further exploration remains are required.

2.1 Survey on Nature Inspired Protocol for WSN

In WSNs, sensor nodes basically collect and transmit the physical and environmental data to the base station. WSNs face challenges such as energy limitations, deployment, costs, bandwidth constraints, and security. To address these issues, Farmani *et al.* [13] explored innovative, nature-inspired techniques for improving WSN performance and overcoming these challenges.

Tumula *et al.* [14] proposed an "Enhanced Bio-Inspired Energy-Efficient Localization (EBEEL)" routing algorithm for mobile WSNs. EBEEL aimed to address key challenges such as energy consumption, data redundancy, limited bandwidth, packet loss, load balancing, and Quality

Table 1: Commonly Available Wireless Sensors

Physical Condition	**Current**	**Voltage Requirement**	**Discrete Sample Time**	**Manufacturer**
Humidity	$540 - 550\ \mu A$	$2.5 - 5.5\ V$	$300\ ms$	Sensirion
Photo	$1.9\ mA$	$2.8 - 5.5\ V$	$330\ \mu s$	Taos
Pressure	$1\ mA$	$2.3 - 3.6\ V$	$35\ ms$	Intersema
Temperature	$1\ mA$	$2.5 - 5.5\ V$	$400\ ms$	Dallas Semi.
Acoustic	$0.5\ mA$	$2.5 - 10.5\ V$	$1\ ms$	Panasonic
Acceleration	$2\ mA$	$2.5 - 3.4\ V$	$10\ ms$	Analog Devices
Soil Moisture	$2\ mA$	$2.5 - 5.5\ V$	$10\ ms$	Ech2o
Photosynthetic Light	$0\ mA$	Any	$1\ ms$	Li-COr
Passive IR (Motion)	$0\ mA$	Any	$1\ ms$	Melixis
Smoke	$5\ mA$	$6 - 12\ V$	$1\ \mu s$	Motorola
Photosynthetic Light	$4\ mA$	Any	$1\ \mu s$	Honeywell

of Service (QoS), improving disaster response communication.

Vijayalakshmi *et al.* [15] presented a new "energy-efficient routing method for Wireless Sensor Networks (WSNs)" using genetic and search algorithms to extend network lifetime. By optimizing key factors like proximity and link quality, their approach outperformed traditional protocols in energy use, reliability, and data delivery, which makes it valuable for applications in smart cities, healthcare, and industrial IoT.

UmaRani *et al.* aimed to extend the lifespan of WSNs by reducing energy consumption through optimized routing and clustering. They introduced a hybrid algorithm combining "Ant Colony Optimization (ACO)" and "Improved Social Spider Optimization (ISSOA)" to select the optimal Cluster Heads (CHs), which considers the factors such as "residual energy, centrality, and distance to the Base Station (BS)". Additionally, an "optics-inspired optimization (OIO) algorithm" is used to determine energy-efficient paths for data transmission. Simulation results showed that the proposed ACO-ISSOA approach significantly outperformed existing methods (e.g., LEACH-C, MW-LEACH, GA-PSO) in terms of network lifetime, throughput, packet delivery ratio (PDR), energy efficiency, and execution time.

Theja *et al.* [16] compared traditional and nature-inspired metaheuristic algorithms, specifically LEACH, PSO, and AWOA, in WSNs. They evaluated network lifetime, clustering efficiency, and energy consumption. Their results showed that PSO outperforms LEACH, while AWOA performs comparably to PSO, often yielding better results. Their study highlighted the effectiveness of swarm intelligence in optimizing routing and energy-aware clustering in WSNs.

Elashry *et al.* [17] proposed a new meta-heuristic algorithm, "HGORSA (Hybrid Gazelle Optimization and Reptile Search Algorithm)", to optimize cluster head selection in WSNs. The algorithm enhanced traditional GOA and RSA techniques to better balance exploration and exploitation, targeting improved energy management and network lifetime—key challenges in large-scale WSNs. Simulation results across various network setups showed HGORSA significantly outperformed six leading algorithms in metrics like stability period, energy consumption, network lifetime, dead node reduction, and throughput. Its robustness is further confirmed through statistical analysis across different network densities.

Rajeswari *et al.* [18] addressed the issue of network partitioning in WSNs caused by node failures, which proposed a recovery method using mobile relay nodes through the "MD-carrier Tour Planning (MDTP)" approach. It identifies failed nodes, clusters disjoint segments using k-means, and selects "Aggregator Nodes (AGNs)" via AHP and TOPSIS methods. Optimal sojourn locations are then determined using the "Donkey And Smuggler Optimization (DASO)" algorithm to coordinate data collection effectively. The MDTP method significantly reduces tour length and latency – by 30.28% and 24.56%, respectively – compared to existing solutions, enhancing network connectivity and performance.

Karpurasundharapondian and Selvi [19] surveyed optimization-based clustering and routing techniques in WSNs, which face energy efficiency challenges due to resource-constrained nodes and harsh environments. Cluster-oriented routing is highlighted as an effective method for energy optimization. Their study compared various optimization algorithms based on performance metrics and provides insights into their effectiveness. They also outlined future research directions for improving energy-efficient routing and clustering in WSNs.

Primmia DR *et al.* developed adaptive bio-inspired protocols for Underwater Wireless Sensor Networks (UWSNs) using the "Spider Monkey Optimization (SMO)" algorithm, which mimics how spider monkeys hunt collaboratively. The protocols aim to improve energy efficiency, ensure reliable data transmission, and reduce latency. Using MATLAB and Aqua-Sim for simulations, SMO selects optimal routing paths based on energy use, reliability, and transmission rates. Results show a 25% reduction in energy consumption and up to 14% reduction in end-to-end delay as compared to the AODV method or protocol, with about the packet delivery ratio of 95%. The SMO-based protocols adapt well to varying conditions and outperform traditional routing, making them promising for applications like environmental monitoring and military security. Further testing in complex underwater environments is planned.

2.2 Survey on Fundamental Energy Optimizing Protocol

In this section, energy optimizing protocols [20][21] are reviewed based on their classifications. The sensor nodes are constrained to limited one time battery power resources itself, so the main purpose is how to design an effective and energy optimizing protocol in order to enhance the networks lifetime for specific application environment [22][23]. Routing protocols are generally classified into four categories as shown in Table 2: Data Centric Protocols, Hierarchical Based Routing Protocol (Clustering), Location-Based Routing Protocol (Geographic) and Network Flow and QoS Aware Protocol depending on the network structure in WSNs [24][25].

Among so many routing protocols, only five modern energy optimizing routing protocols LEACH [26], DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30] are selected as a base for analysis and comparison.

2.3 LEACH (Low Energy Adaptive Clustering Hierarchy)

"LEACH" [26] was proposed by **Wendy B. Heinzelman** in "An application-specific protocol architecture for wireless microsensor networks" for wireless sensor network.

"LEACH" [26] is fundamentally a "proactive routing protocol", which continuously try to send the up-to-date sensed data to the base station in the WSN. This has as advantage that network connection time is fast, because when the first data packet is sent then routing information data is already available. A main disadvantage of proactive protocols is that they continuously use resources to communicate routing information, even when there is no traffic.

3 Proposed methodology

In this section, a novel proposed routing protocol in WSN is discussed which is basically based on the "Ant Colony Optimization" and energy level evaluation as well as three levels of node heterogeneity and threshold estimation. Cluster head (CH) selection is based on energy level of nodes in the proposed protocol unlike "LEACH [26], DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]" as cluster head is selected on the probability bases.

The clustering is an efficient and effective method for extending the network lifetime in WSNs. The clustering algorithms reviewed in the literature survey primarily employ two key techniques: first, the selecting cluster heads (CHs) with higher residual energy, and second, periodically rotating the CH roles based on probability to ensure balanced energy consumption among the sensor nodes within each cluster, thereby it prolongs the WSN's lifespan.

However, since cluster head (CH) selection is typically probability-based, the current approach can result in suboptimal performance. Nodes with higher residual energy may occasionally be overlooked for CH roles, while those with lower energy might be selected instead, reducing efficiency.

To overcome this limitation, a nature-inspired algorithm is proposed for WSNs that basically incorporates the residual energy estimation for the sensor nodes. This approach integrates the key strengths of the "EDDEEC protocol" [30] while introducing an efficient mechanism for periodic data collection in WSNs.

3.1 Formation of Cluster

In WSNs, sensor nodes are organized into multiple clusters, with each cluster electing a cluster head (CH) [31]. These nodes gather environmental data and transmit their readings to their respective CHs, which then forward the aggregated data packets to the base station (BS) [32].

Clustering is a widely adopted strategy for improving WSN longevity. Most clustering algorithms employ two key mechanisms:

- Selecting CHs with higher residual energy.
- Periodically rotating CH roles probabilistically to balance energy consumption across nodes within a cluster, thereby extending network lifetime.

However, a critical inefficiency arises when CHs relay data to the BS: CHs closer to the sink endure heavier traffic loads, leading to premature energy depletion. This results in network coverage gaps and potential partitioning.

During cluster formation, the BS broadcasts a signal at a fixed power level. Nodes estimate their distance from the BS using received signal strength (RSS), enabling them to adjust transmission power for efficient communication.

Table 2: Categories of Routing Protocols

CATEGORIES	REPRESENTATIVE PROTOCOLS
Data Centric Protocols	Flooding and Gossiping, SPIN, Directed Diffusion, Rumor Routing, Gradient Based Routing, Energy-Aware Routing, CADR, COUGAR & ACQUIRE.
Hierarchical Protocols	LEACH, PEGASIS, H-PEGASIS, TEEN, APTEEN, DEEC, DDEEC, EDEEC & EDDEEC.
Location Based Protocol	MECN, SMECN, GAF & GEAR.
Network Flow & QoS Aware Protocols	Maximum Lifetime Energy Routing, Maximum Lifetime Data Gathering, Minimum Cost Forwarding, SAR & SPEED.

The clustering process follows the formulation provided in Equation 1:

$$R_{ci} = \left(1 - c\frac{d_i - d_{min}}{d_{max} - d_{min}}\right) R_{max} \tag{1}$$

where,
R_{ci} = The range of radius in the network for cluster formation,
d_{max} = Maximum distance from sensor node to base station,
d_{min} = Minimum distance from sensor node to base station,
d_i = Distance from node i to base station in WSN,
c = Weighted factor (value is between 0 to 1),
R_{max} = Maximum competition radius.
The competition radius of the sensor node is estimated by d_i . If d_i is bigger, then R_{ci} will be smaller. The diameter of the cluster in the WSN dominated by node i is represented by the Equation 2.

$$R_a = 2R_{ci} \tag{2}$$

4 Proposed Algorithm

4.1 Ant System

Ant System is the original ACO algorithm presented by M. Dorigo *et al.* [33]. Its main feature is that, the pheromone amount and values are updated at each iteration by all the m ants which have developed a solution with the iteration itself. Pheromone $\tau_{i,j}$, related with the edges connecting cities i and j, are updated as follows:

$$\tau_{i,j} \leftarrow (1-\rho).\tau_{i,j} + \sum_{k=1}^{m} \Delta\tau_{i,j}^k \tag{3}$$

where m is the number of ants, ρ is the pheromone evaporation rate and $\Delta\tau_{i,j}^k$ is the amount of pheromone set on edge (i,j) by ant k:

$$\Delta\tau_{i,j}^k = \begin{cases} Q/K_k & \text{if ant } k \text{ used edge } (i,j) \text{ in its tour,} \\ 0 & \text{otherwise,} \end{cases} \tag{4}$$

where Q is a constant and L_k is the edge length of tour developed by ant k.

In the development of a solution, ants choose the following city which is to be visited by a stochastic method. When ant k is in city i and has constructed a partial solution s^p, the probability of visiting to city j is given by:

$$p_{i,j}^k = \begin{cases} \dfrac{\tau_{i,j}^{\alpha}.\eta_{i,j}^{\beta}}{\sum_{c_{i,l}\in \mathbf{N}(s^p)} \tau_{i,l}^{\alpha}.\eta_{i,l}^{\beta}} & \text{if } c_{i,j} \in \mathbf{N}(s^p), \\ 0 & \text{otherwise,} \end{cases} \tag{5}$$

where $\mathbf{N}(s^p)$ is a set of feasible components, which is, the edges (i,l) where l is a city has not visited yet by the ant k. The α and β are control parameters, the relative significance of pheromone versus heuristic information $\eta_{i,j}$, which is usually given by:

$$\eta_{i,j} = \frac{1}{d_{i,j}}, \tag{6}$$

where $d_{i,j}$ is the distance between the city i and the city j.

4.2 Double Cluster Head Selection

In WSN, each cluster head, in general, directly transmit data packets to the Sink node, which correspondingly increases the cluster nodes energy consumption especially in large networks. To solve this problem, this paper puts forward a kind of hierarchical double routing algorithm. It chose level-one cluster head from all members of the node, who is responsible for receiving data send from member nodes and sorting data fusion to level-two cluster heads. Then level-two cluster heads is selected in all non-head nodes, who is responsible for forward the packet to the Sink node. Such as cluster head responsibilities assigned to the two levels of cluster heads to complete can greatly reduce the cluster heads energy consumption and improve the network survival time.

4.3 Routing Protocol

The following equation (7) gives the average energy of r^{th} round:

$$E_a(r) = \frac{1}{N} E_{total} \left(1 - \frac{r}{R}\right) \quad (7)$$

where,
R = denotes the total rounds during the network lifetime. It is calculated by the equation 8.

$$R = \frac{E_{total}}{E_{round}} \quad (8)$$

where the energy dissipated in the network during a single round is denoted by E_{round}. Now, $d_{to\ BS}$ and $d_{to\ CH}$ can be calculated as the equation (9) and the equation (10):

$$d_{to\ BS} = 0.765 \frac{M}{2} \quad (9)$$

$$d_{to\ CH} = \frac{M}{\sqrt{2\pi K}} \quad (10)$$

By taking the derivative of E_{round} with respect to k and equating to zero, we can find the optimal number of clusters k_{opt} and is calculated by equation (11):

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\epsilon_{sf}}{\epsilon_{mp}}} \frac{M}{d^2_{to\ BS}} \quad (11)$$

At the start of each round, nodes decide on the basis of threshold whether to become CHs or not. The value of threshold is calculated by equation (12):

$$Th(S_i) = \begin{cases} \dfrac{P_i}{1 - P_i \left(mod \left(r, \frac{1}{P_i} \right) \right)}, & \text{if } S_i \in G, \\ 0, & \text{otherwise} \end{cases} \quad (12)$$

Here, G represents the group of sensor nodes qualified to serve as cluster heads (CHs) in round r, while p indicates the predetermined CH selection probability. In the practical deployments of WSN, the heterogeneity typically extends beyond two levels. Consequently, the proposed protocol implements a three-tier heterogeneous architecture, classifying nodes into three distinct categories: normal, advanced, and super. The protocol defines specific selection probabilities for each node type as follows:

$$P_i = \begin{cases} \dfrac{P_{opt} E_i(r)}{(1 + m(a + m_0 b)) E_a(r)} \times \dfrac{E_0}{E_{res}}, \\[2ex] \dfrac{P_{opt}(1 + a) E_i(r)}{(1 + m(a + m_0 b)) E_a(r)} \times \dfrac{E_0}{E_{res}}, \\[2ex] \dfrac{P_{opt}(1 + b) E_i(r)}{(1 + m(a + m_0 b)) E_a(r)} \times \dfrac{E_0}{E_{res}}, \end{cases} \quad (13)$$

Equation (13) primarily illustrates the difference between DEEC [27], DDEEC [28], EDDEEC [30] and proposed protocol by defining probabilities for CH selection as DEEC, DDEEC, EDEEC and EDDEEC use probability based cluster head (CH) selection, however, the proposed protocol uses energy levels by using the ratio of E_0 (initial energy) to E_{res} (residual energy). It is the modification of of the existing EDDEEC protocol. The objective of this expression is to balance the energy consumption between nodes such that the stability period and network lifetime are increased. However, soon after few rounds, the "super" and "advanced nodes" can have the same residual energy as that of the normals. At this point, DEEC punishes advanced nodes, proposed protocol punishes advanced as well as super nodes and proposed protocol is only effective for repeatedly selecting the CH.

The limitation of proposed protocol is that if threshold value is not reached, then the base station will not receive any information or data from sensor network and even all the sensor nodes of the network become dead, system will be ultimately unknown about these limitations. So, proposed protocol is not useful for those types of applications where a sensed data is required frequently and continuously.

4.4 Functioning of Network

In proposed protocol, at the beginning of each round, node by node cluster head (CH) changes take place usually. At the time of the cluster change, the cluster head (CH) transmits the following parameters:

- **Report Time:** It is the time period required during in which each sensor node transfers the data and reports successfully.
- **Attributes:** It is basically the physical parameter sets on which the data and information is being sent over.
- **Hard Threshold:** It represents the maximum threshold for the sensed attribute; exceeding this value triggers the nodes to activate their transmitters and send data to their cluster head.
- **Soft Threshold:** It is the minimum threshold value below which nodes activate their transmitters and send data to their cluster head (CH).

All sensor nodes continuously sense their environment continuously. As the parameters value from attributes equals or exceeds hard threshold limit, then the transmitter is turned on and its data packets are transmitted to their cluster heads (CHs), however this is for the first time when hard threshold condition is taken place. The sensed parameter value is stored by the sensor node is called the "Sensed

Value". So, the next time, sensor nodes transmit data if the sensed value equals or exceeds the upper limit of the hard threshold or if currently sensed value and the previously sensed value equals or exceeds the limit of soft threshold value. So, by estimating hard threshold and soft threshold, the frequent data packet transmissions can be minimized, as the data transmission usually takes place only when the sensed value equals or exceeds the value of hard threshold. Subsequent data transmissions are controlled by the soft threshold, which reduces unnecessary transmissions when only minor value changes occur.

5 Simulation Result

MATLAB as a simulator is used for this implementation and performance evaluation of the proposed protocol. The purpose of estimating simulations is to compare the performance of proposed protocol with DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30] protocols based on the consumption of energy, the sensor network lifetime and the throughput of the network.
Some performance properties and attributes can be used in the MATLAB simulations that are as follows:

1. The number of sensor nodes that are alive during each round is also known as the "Network Lifetime".

2. The number of data packets that are sent from cluster heads (CHs) to the base station (BS) is also known as the "Throughput".

To create simulation of "DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]", some of the initial parameters and values are considered and the similar parameters and values are also considered for the proposed protocol. The simulation results for" DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]" are presented in this section as three-levels and multi-levels heterogeneous WSN simulation system with the help of MATLAB. WSN frame work contains $N = 100$ sensor nodes that are deployed randomly in a region of 100×100 m^2 dimension where base statio is located at the center. All the sensor nodes are considered either fixed in there position or micro-movable for simplicity and interference between signals of the different sensor nodes and the energy loss due to collision are completely ignore in calculations. The performance metrics used for the evaluation of the protocols are: the stability period, the lifetime of network, and the number of data packets delivered to the BS.

- **Stability Period:** It means the round number on which the first sensor node dies or number of rounds from the initialization of network till death of the first node.

- **Network Lifetime:** It means the round number at which all nodes die or the number of rounds from network initialization till the death of all nodes.

- **Number of packets sent to BS:** It means the total number of data packets that are delivered directly to the BS either from CHs or non-CH sensor nodes.

The Table 3 reports the parameters applied in simulations. The results along with discussions are provided in the following subsections. These are considering that initially

Table 3: Initial Parameter Settings

Parameters	Values
E_0	0.60 $Joule$
E_{elect}	60 $nJoule/bits$
L	400 $bits$
ϵ_{fs}	15 $nJoule/bits/m^2$
ϵ_{mp}	0.0015 $pJoule/bits/m^4$
E_{DA}	6 $nJoule/bits/signal$

the WSN consists of 200 sensor nodes, all sensor nodes are randomly planted in a region and the base station (BS) is located at the outside of that region. For MATLAB simulation, some parameters are initialized like E_0 as 0.60 $Joule$, E_{elect} as 60 $Joule$, L as 400 $bits$, ϵ_{fs} as 15 $nJoule/bits/m^2$ and ϵ_{mp} as 0.0015 $pJoule/bits/m^4$. On the next MATLAB simulation, the parameters setting are changed to different values.

5.1 Simulation and Performance Matrices

Table 4 shows the "Network Lifetime" as sensor nodes remain alive during rounds as a chart of nodes alive percentage versus number of rounds. As this can be observed form Table 4 that 90 % of sensor nodes remain alive during 850 rounds in DEEC [27] protocol, 1100 rounds in DDEEC [28] protocol, 1000 rounds in EDEEC [29] protocol, 1400 rounds in EDDEEC [30] protocol and 1500 rounds in proposed protocol. Again, 50 % of sensor nodes remain alive during 2000 rounds in DEEC protocol, 2500 rounds in DDEEC protocol, 2700 rounds in EDEEC protocol, 2800 rounds in EDDEEC protocol and 3000 rounds in proposed protocol. Finally, 10 % of sensor nodes remain alive during 2700 rounds in DEEC protocol, 2800 rounds in DDEEC protocol, 3500 rounds in EDEEC protocol, 3550 rounds in EDDEEC protocol and more than 5000 rounds in proposed protocol. Chart shows that in the proposed protocol, sensor nodes remain alive for longer time duration as compared to DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30] protocols.

Table 5 shows the "Throughput" chart as "packet sent to the base station (BS) versus number of rounds". Only the proposed protocol delivers over 2.5×10^5 data packets.

Table 4: Network Lifetime (Nodes Alive Percentage vs Number of Rounds)

	Number of Rounds				
Nodes Alive Percentage %	**DEEC** [27]	**DDEEC** [28]	**EDEEC** [29]	**EDDEEC** [30]	**Ant Colony (Proposed Protocol)**
90% Nodes	850	1100	1000	1400	1500
80% Nodes	1000	1100	1200	1700	1700
50% Nodes	2000	2500	2700	2800	3000
20% Nodes	2300	2500	2900	3000	5000
10% Nodes	2700	2800	3500	3550	5000

Table 5: Throughput (Packets Sent to Base Station vs Number of Rounds)

	Number of Rounds				
Throughput (Packets Sent to BS)	**DEEC** [27]	**DDEEC** [28]	**EDEEC** [29]	**EDDEEC** [30]	**Ant Colony (Proposed Protocol)**
0.5×10^5 Packets	1500	1600	500	550	700
1.0×10^5 Packets	–	–	1000	1100	1700
1.5×10^5 Packets	–	–	1800	1500	2000
2.0×10^5 Packets	–	–	–	2500	3000
2.5×10^5 Packets	–	–	–	–	4500

By observing the result graph, the throughput of the proposed protocol is visualized better than the other routing protocols.

As reported in the Table 5, the maximum throughput ("packet sent to the base station") of "DEEC and DDEEC" are 0.5×10^5, and the maximum throughput of "EDEEC and EDDEEC" are 2×10^5. Whereas the maximum throughput ("packet sent to the base station") achieved by the proposed protocol gets over 2.5×10^5 data packets during its maximum round as reported in Table 5, which represents that proposed protocol has better throughput as compared to the strategies of DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30] protocols. Only EDEEC and proposed protocol protocols can send more than 2.0×10^5 packets and only proposed protocol sends more than 2.5×10^5 packet during its maximum rounds.

5.2 Result Metrics

Result metrics used in the simulations are based on the following:

1. Number of the alive nodes during each round ("network lifetime").
2. Number of data packets sent from the cluster heads (CHs) to the base station ("throughput").

5.3 Result Analysis of Network Lifetime (Nodes Alive Per Round)

In Figure 2, "DEEC" protocol is illustrated as the black curve, "DDEEC" protocol is illustrated as the red curve, "EDEEC" protocol is illustrated as dashed blue curve, "EDDEEC" is illustrated as magenta curve and the proposed protocol is illustrated in Figure 3 as dashed dark blue curve. The graph of Figure 2 for "DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]" represents the graph of nodes alive during each round (network lifetime). Again the proposed protocol performs better as compared to the other protocols as presented in the graph.

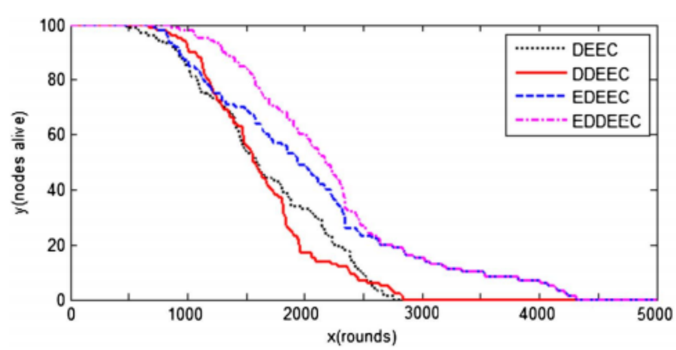

Figure 2: Network Lifetime

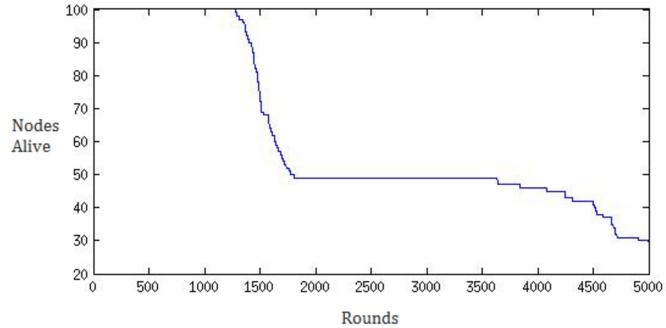

Figure 3: Network Lifetime of Proposed Protocol

5.4 Result Analysis of Throughput

The result in the graph of Figure 4 plots the data packets that send to the base station (BS) or throughput. Again the same colored curve are used for DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30] protocols. For per-

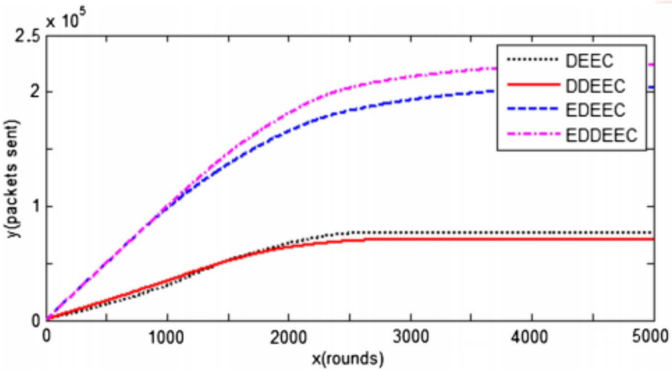

Figure 4: Throughput

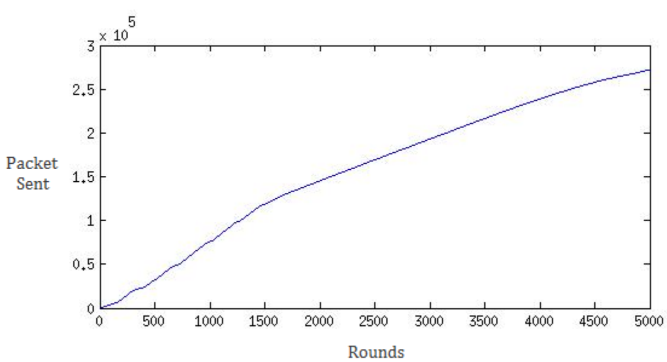

Figure 5: Throughput of Proposed Protocol

formance evaluation of proposed protocol in MATLAB, the same initial parameter values are considered and the next parameter values as used in DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]. As illustrated in Figure 4 and Figure 5, the proposed protocol presents maximum throughput as compared to these protocols.

5.5 Overall Result Analysis

To evaluate the overall performance analysis of proposed protocol in the MATLAB simulation, the same previous parameter setting is considered to compare "DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]". The throughput of proposed protocol as the graph of data packet sent to the base station is around four times as compared to DEEC and DDEEC, as illustrated in Figure 4 and Figure 5 which is better than "DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]". The curve of proposed protocol throughput shows the proposed protocol sends more data packets to the base station (around 50 to 70 % more) as compared to other protocols discussed above. After comparison of proposed protocol with strategies of "DEEC [27], DDEEC [28], EDEEC [29] and EDDEEC [30]", it is evaluated that by using the proposed protocol, better energy efficiency, enhanced network lifetime and greater throughput are achieved.

6 Conclusion

There are many protocols which focus on the energy efficiency of the routing method in WSN because commonly these networks are generally deployed in the particular polluted region or the high radiation zone where the human manipulation is not feasible and possible for recharging or replacing the energy sources or battery units. Once the WSN is successfully deployed in any working region then it continuously works up to the death of battery power and the complete sensor node, so the energy efficiency in this sensor network became a high challenging task to increase its lifetime. Currently, there are so numerous algorithms and protocols proposed for the energy efficient routing to significantly increase the lifetime of the entire WSN. The modern routing protocols DEEC, DDEEC, EDEEC and EDDEEC use their own algorithm for energy efficiency.

In this research, the "Ant Colony Optimization-based" algorithm in WSN as a "reactive network routing protocol" are proposed with considering three different heterogeneity levels of the sensor node. The proposed protocol in this research combines the best features of "EDDEEC protocol" and energy level evaluation technique. The applied concept of energy level based cluster for the head selection, hard and soft threshold value, three levels of node heterogeneity and being reactive routing network proposed protocol produces increase in energy efficiency, enhanced lifetime of network and also maximum throughput as shown in the simulation result. In comparison with "DEEC, DDEEC, EDEEC and EDDEEC" with the proposed strategy of proposed protocol, it can be observed and concluded that the proposed protocol performed well in the small as well as the large geographical networks and best suited for time critical applications.

However, the proposed protocol is not suitable where frequent information is received from WSN. The future work will be to overcome and improvement of this disadvantage in this proposed protocol. Ultimately, in the future, concepts and implementations of the movable base stations can be implemented in the proposed technique to perform toward the next level of modern advanced technologies of WSN. More than three levels of the heterogeneity can be applied and other reactive routing network protocol can be used to design enhanced level of the energy efficiency and network lifetime in WSN.

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