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Enhanced Double Cluster Head Selection using Ant-colony Optimization for Energy-efficient Routing in Wireless Sensor Network

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Abstract

The energy-efficient routing strategies regulate the network lifetime for wireless sensor networks (WSNs). The researchers have continuously improved the WSN lifetime using their algorithms and strategies since the sensor world. Clustering significantly improves the network lifetime and energy efficiency in WSN. In this paper, the concept of double cluster heads (CHs) is introduced in a single cluster of the WSN and ant colony optimization as the nature-inspired algorithm is applied for a CH selection between double CHs. The ant colony optimization is based on the natural behavior of the ant. The simulation result presents that the proposed algorithm enhances the network lifetime and residual energy because a double cluster head significantly reduces the workload of a single cluster head. The other nature-inspired algorithms can be applied for the energy efficiency of WSN in the future.

Keywords:- Internet of Things, Blockchain, IoT Gateway, Security, IoT Network.

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Introduction

Wireless sensor networks (WSNs) are infrastructures-based sensing, computations, and transmission of sensed data to the observer where the administrator can control, observe, instruct, and react to the phenomena in a specific environment.[1] WSNs have become distributed technology, and their applications are speedily growing.[2] WSNs are generally a group of power-constrained sensing devices or nodes by which the environment is sensed and the data is sent to their users. Sensor devices are responsible for sensing the environmental conditions, monitoring, information collection, and sending the information from devices to the end-user. The wireless sensor is the major component of the Internet of things (IoT) devices, and it is extensively used in smart-city development. The foremost emphasis in a smart city is efficient energy control and management because of the large numbers of growing consumers. In a smart city, energy management controls the power consumption of home equipment and appliances. For customization of energy utilization for consumers, demand management is one of the applied methods. Modern sensor nodes are mostly applied in numerous commercial, industrial, and consumer applications, such as traffic control systems, home automation, industrial process control, monitoring, healthcare applications, agriculture, instrument health monitoring, etc.[3] Sensor nodes are mostly power-constrained battery operated and have space for limited storage. This restriction breaks the network into a limited lifetime. The energy consumption of customers has to be minimized to increase the network lifetime.

Several energy optimization methods are available to control and manage energy. Optimization-based residential energy management schemes have been developed to provide energy management in home appliances. Renovation is the foremost prerequisite for advanced energy efficiency. These renovation technologies primarily focus on energy dependence, renewable energy generation from efficient buildings and vehicles, security, and high penetration, which also avoids greenhouse gas emissions.[4,5] A typical wireless sensor network model is presented in Figure 1; all data from sensor devices or nodes are collected into cluster head and sent to the base station, where users get this information through the Internet. All nodes in the network are tiny electromechanical sensor devices or nodes. The "microelectronic mechanical systems

(MEMS)"[6] in today's advanced recent technology integrated wireless communications facilities, and it established low-powered, smaller sized, and minimum-cost multi-functional smart sensing devices in wireless sensor networks (WSN).[7] Traditional applications of WSNs were originated from militaries and defense systems such as battlefield surveillance; nowadays, the recent sensor networks usually support bi-directional communications and have abilities for self-controlling with plenty of applications.[8,9]

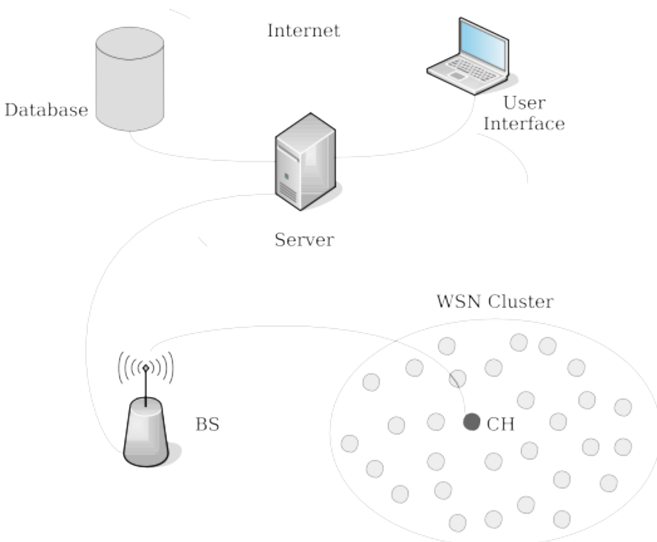

Figure 1: Basic WSN Model

Generally, a WSN contains hundreds to thousands of sensor devices, where all sensing devices are connected to all other devices. Each sensing node has several main components such as a microcontroller or microprocessor, a radio transceiver, an electronic circuitry system to interface with the small sensors and a battery or power unit, an integrated antenna or communication link with external antennas, normally a battery unit or an implanted form of power sources.[10,11]

The cost of sensor devices can vary according to their physical characteristics such as size, functionalities, types, application areas, communication ranges, and complexities. A multi-functional sensor device has a greater cost than a uni-functional normal sensor device.[12] The cost and size constraints in sensor devices result from limitations on memory, power backup, high processing, durability, computational speed, communication bandwidth, high accuracy, and efficiency.[13,14]

The topology (geographical network arrangement) of the WSNs may be different from an ordinary star network to a highly progressive multi-hop wireless hybrid and mesh network.[15] The flooding or routing method of data transmission can be applied among the multi-hop communications in the network. The clustering-based methods, techniques, and procedures have been initially projected into the wire-line networks to solve the expandability and scalability concerns.[16] Also, the recharge and replacement of batteries for sensor devices are practically impossible once the whole network is organized. Therefore, WSNs work without manipulation and user involvement, so the network's lifetime improvement is a priority and prominent. Various researchers have presented their protocols and methods for network lifetime improvement and energy efficiency.[17]

This article is organized as follows; the next section presents the previous works related to energy efficiency, section III presents the proposed system model named "enhanced double cluster head selection using Ant-colony Optimization (EDCHACO)". Section IV presents the simulation work and result in an analysis of the proposed system model, and section V finally concludes the article with recommended future suggestions.

Related Work

With the progressive evolution of sensor technology, it attempted, and crucial role in the industrial transformation with economic and social development, and its energy efficiency system is very implicated content in several areas. This section presents various techniques for the energy efficiency of WSN.

Hienzelman *et al*.[18] introduced "Low Energy Adaptive Clustering Hierarchy (LEACH)" as the original clustering-based routing protocol distributed in nature. At the start of each round, all sensor devices generate a number randomly between 0 and 1 regularly. The device, the whose generated number is less than the defined threshold value, declares itself a cluster head (CH) for that particular round. LEACH is a proactive routing method. In proactive routing methods, the sensor continuously sends up-to-date sensed data into the base station (BS) in the WSN. In a general WSN, hundreds and thousands of sensing devices or nodes are randomly deployed for even distributions of workloads among devices. These sensing devices sense data from their environment, convey them to their connected cluster head (CH) that first receive it, gather it, and lastly send their data packets into the base station (BS).

The sensing devices send joint requests to their associated nearby in the cluster-based WSN based on the strength of the received signal. Then, an acknowledgment message is sent by CH using TDMA time slot is decided as a reply for data transmission. The main drawbacks of this method are clusters of unequal size in various rounds of CH selection, level of energy is not considered for nodes in this CH election process, and single-hop data transmission between the CH and the BS.

To overcome the limitations of LEACH, Hienzelman *et al*.[19] extended their LEACH and proposed "LEACH-centralized (LEACH-C)" protocol. In this LEACH-C, the number of CHs for all rounds is kept fixed. This protocol diminishes the work overhead of CH election from the devices as it works as centralized in nature. It shows improved performance compared to LEACH but also faces the issues of single-hop data transmission and centralized-based selection of CH, which is not very efficient for the large distribution area network. There are plenty of successors of LEACH protocol proposed by various researchers for the improvement of WSN performance.

To distribute equally the workload or burden among sensing devices, improve and updated network life clusters are designed in the environment. The sensing devices are planned to become CHs on their turns periodically. Devices randomly choose themselves as CHs and it is completed in such a manner that each device will become CH once in the period at $\frac{1}{P}$ round. The selections of CHS are made based on probability, where each sensor device generates an unpredictable random number *r* included of 0 and 1 if the value generated in that round is less than that predefined threshold value calculated by method given in the Eq. (1), and then this device becomes a CH.

$$T_N = \begin{cases} \dfrac{P}{1-P\left[r \bmod \dfrac{1}{P}\right]}, & \text{if } n \in G \\ & \text{Otherwise} \end{cases} \quad (1)$$

Where,

T_N = Threshold

P = Desired change (probability) for being Cluster Head (CH)

r = Current round number

G = Set of nodes or devices which have not become CH in $\frac{1}{P}$ round

Generally, each sensing device will become a CH in $\frac{1}{P}$ rounds using the threshold value.

Qing *et al.*[20] introduced "Developed Distributed Energy-Efficient Clustering (DEEC)", a distributed energy-efficient algorithm for clustering" based on the heterogeneous wireless sensor networks (WSNs). Using the basis of probability, when the CHs are chosen using the ratio of their residual energy of each device to the average energy of the network is calculated. According to the devices' initial and residual energies value, the round number of each rotating epoch for each device is dissimilar. DEEC accommodates the perception of the rotating epoch of each device to its energy.

The sensing devices have a higher probability of becoming the cluster-heads in those devices that have higher initial and residual energy than low-energy devices. Thus, the network lifetime can be prolonged in DEEC, particularly the stability period, by heterogeneous consciousness clustering. This choice always reprimands the advanced nodes, particularly when residual energies of devices are depleted and they become within the range of the normal devices. In these circumstances, the advanced devices expire more rapidly than the other devices.

For cluster head (CH) selection, DEEC uses the devices' initial and current residual energy levels to choose their associated cluster heads. To avoid it, all devices require to know the global knowledge and information of the networks; DEEC creates approximations for the perfect value of network lifetime, which is applied to calculate the reference energy for which all devices should expend during all rounds.

Elbhiri *et al.*[21] proposed "Developed Distributed Energy-Efficient Clustering DDEEC protocol that is founded on DEEC [20] method; there, all sensing devices use the levels of the initial as well as the current residual energy for defining their cluster heads. To escape and avoid that all sensing devices require to take the global knowledge and information of the networks, DEEC[20] and DDEEC[21] predict the perfect value or estimation for network lifetime, that is applied to calculate some reference energy for which all devices must expend their energies during each *m* round. Here, the WSN with *N* nodes, that are spread uniformly within the area of $M \times M$ square unit.

According to the clustering hierarchy, the sensor networks are configured, and the cluster-heads accumulate sensed data and information belongs to sensing devices from the cluster and convey that accumulated information directly into their sink or base station. It is supposed that the base station is positioned in the middle.[21] Additionally, this situation presents a heterogeneous network of two-level, where there are two groups of devices, a *mN* as advanced devices with their E_0 (1 + a) initial energy and *a*(1 − *m*)*N* as normal devices, where their initial energy is equivalent to E_0. For the heterogeneous networks, the total overall initial energy is calculated as:

$$E_{total} = N(1-m)E_0 + NmE_0(1+a) = NE_0(1+am) \quad (2)$$

DDEEC Radio Model: Primarily, the main objective of DDEEC protocol is that it applies similar energy method and study as proposed in DEEC.[20] Considering the classical model for dissipation of radio energy and to achieve an satisfactory Signal-to-Noise Ratio (SNR) in data transmission of the *L – bit* message length at a distance *d*, the energy consumed by radio is calculated as:

$$E_{TX}(L,d) = \begin{cases} LE_{elect} + LEfsd^2, & if \;\; d < d_0, \\ LE_{elect} + LEmpd^4 & if \;\; d \geq d_0, \end{cases} \quad (3)$$

where the energy consumed per bit is E_{elec} to operate the receiver circuit (E_{RX}) or the transmitter (E_{TX}). The E_{elec} depends on numerous factors, for example, the digital coding system, filtering, modulation, and scattering of the wireless signal. *Efs* and *Emp* depend upon the applied transmitters amplifier system, and the distance between the sender to the receiver is *d*. To present the experimental description there, both free space (d^2 power loss) as well as the multipath fading (d^4 power loss) based channel models are applied, which depends upon the distance between a transmitter to receiver. A free space (*fs*) classical model is applied if the distance is lower than the threshold distance; else, a multi-path (*mp*) system is applied. A value is fixed similar to DEEC at $d_0 = 70$.

Saini *et al.*[22] introduced "Enhanced Distributed Energy Efficient Clustering (EDEEC)" method for heterogeneous sensor networks. EDEEC enhances heterogeneity for the network using the supernodes or devices containing energy more than the normal and advanced devices with particular probabilities. EDEEC presents an improved performance in comparison with DEEC protocol concerning parameters applied. It improves the network lifetime as well as the stability of the network. EDEEC uses three forms of devices in extending the stability and lifetime of the WSN. Hereafter, it raises the device heterogeneity as well as the level of energy in the network. The simulated outcomes illustrate that EDEEC presents improved performance than earlier protocol with additional steadiness and operative communications.

Javaid *et al.*[23] introduced "Enhanced Developed Distributed Energy-Efficient Clustering (EDDEEC)" as a distributed clustering energy-efficient technique for heterogeneous devices in WSNs. Heterogeneous WSNs usually encompass two, three, or multitype of devices regarding their level of energies and are named two, three, or multi-level of heterogeneity in the network. EDDEEC contemplates three levels of heterogeneity in the network, which encompasses three dissimilar energies in the devices called: "normal, advanced, and super." Normal devices having E_0 energy, advanced devices of portion m having a times extra energy as compared to the normal devices, i.e., $E_0(1 + a)$. While supernodes or devices of fraction m_0 having b times extra energies as compared to the ordinary nodes, that is, $E_0(1 + b)$. in the network, N denotes the number of devices, then, Nmm_0, $Nm(1 - m_0)$ and $N(1 - m)$ denote the numbers of super, advanced, and normal devices correspondingly in the network. Therefore, the overall initial energy of super devices is calculated as:

$$E_{super} = Nmm_0 E_0 (1+b) \tag{4}$$

The total overall initial energy of the advanced devices is calculated as:

$$E_{adv} = Nm(1-m_0)E_0(1+a) \tag{5}$$

Correspondingly, the overall initial energy at the standard devices in the network is determined as:

$$E_{nor} = N(1-m)E_0 \tag{6}$$

The total or overall initial energy of the three-level of heterogeneity in the network is consequently determined as:

$$E_{tot} = E_{super} + E_{adv} + E_{nor} \tag{7}$$

$$E_{tot} = NE_0(1+m(a+m_0 b)) \tag{8}$$

The three-level of heterogeneity in the network has $m(a + m_0 b)$ times extra energy, compared to the homogeneous network, and this homogeneous network also chances to heterogeneity afterward few rounds because of inequality of energy consumption in devices. A cluster head usually consumes extra energy compared to the normal member devices. Afterward, after a few rounds, the energy levels in all devices become dissimilar compared to each device. Consequently, the method that controls heterogeneity is additionally more significant than a homogeneous method.

Manjeshwar and Agrawal[24] introduced a Hybrid protocol called "APTEEN" that integrates the best attributes of both reactive and proactive routing for providing a periodical collection of data as well as a near-real-time warning about crucial circumstances. They also demonstrated the practical implementation of a query that is sufficiently versatile to answer several queries. Even though the proposed query model is appropriate for the equally distributed network of sensor devices or nodes, that can be enhanced further to uneven sensor node distributions of networks.

Ma *et al.*[25] proposed an ant-colony algorithm based on the dual cluster heads selection for clustering routing in WSN named "double cluster heads adaptive periodic threshold-sensitive energy efficient network protocol (ADCAPTEEN)." Their simulation outcomes present that compared with the conventional "APTEEN" protocol, the ADCAPTEEN minimized hugely in terms of energy dissipation, consumption and accomplished improvement over the life cycle of the network that shows the effectiveness of the WSN.

Proposed System Model

In this proposed model, the concept of double cluster head is introduced, and cluster heads are selected by ant colony optimization. The proposed model "Enhanced Double Cluster Head selection using ant colony optimization (EDCHACO)" for energy-efficient routing in WSN uses two cluster heads in a single cluster of the network, and the nearest cluster head for a node is selected by the ACO method.

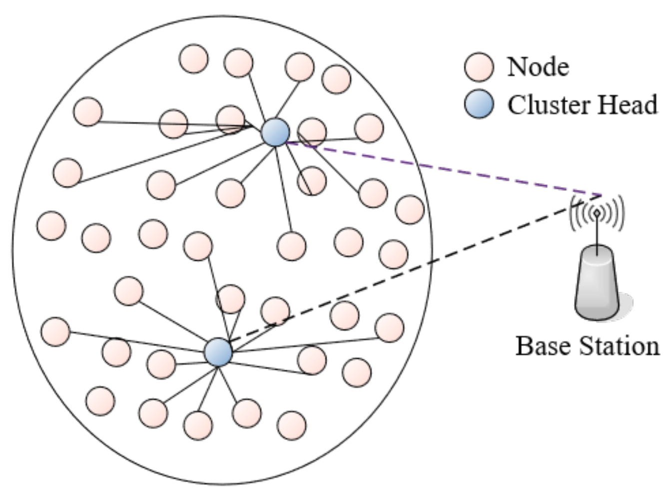

Figure 2: Double custer heads in a cluster

Double Cluster Head Selection

In WSN, all cluster heads transfer data directly into the base station, which ultimately enhances cluster nodes' energy consumption, especially in huge networks. To figure out this issue, the concept of hierarchical double cluster head routing is presented in Figure 2. In this model, based on the shortest distance, the sensor node selects any cluster head between double cluster heads in a single cluster. The node selects the nearest cluster head to send data to improve the efficiency of the network. The device or node calculates the shortest path from both cluster heads, and the nearest cluster head is selected to send data. The shortest path is calculated using the ant-colony optimization method.

Ant System

Ant System was the originally ant-colony optimization (ACO) algorithm presented by M. Dorigo *et al.*[26] Its core concept is that the amount of pheromone and values are updated at each iteration by all the nodes which have developed a solution with the iteration itself. Pheromone $\tau_{i,j}$, related with the edges connecting cluster heads *i* and *j*, is updated as follows:

$$\tau_{i,j} \leftarrow (1-\rho)\cdot\tau_{i,j} + \sum_{k=1}^{m} \Delta\tau_{i,j}^{k} \tag{9}$$

where *m* is the total number of devices or nodes, ρ is the rate of pheromone evaporation and $\Delta\tau_{i,j}^{k}$ is the amount of pheromone set on the link or edge (*i,j*) by device or node *k*:

$$\Delta\tau_{i,j}^{k} = \begin{cases} Q/L_k & \text{if node } k \text{ used edge } (i,j) \text{ in its tour,} \\ 0 & \text{otherwise,} \end{cases} \tag{10}$$

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

In developing a solution, nodes choose the following cluster head, which is to be visited by a stochastic method. When node *k* is in cluster head *i* and has constructed a partial solution s^p, the probability of visiting cluster head *j* is given by:

$$p_{i,j}^{k} = \begin{cases} \dfrac{\tau_{i,j}^{\alpha}\cdot\eta_{i,j}^{\beta}}{\sum_{ci,l\in N(s^p)} \tau_{i,j}^{\alpha}\cdot\eta_{i,j}^{\beta}} & \text{if } c_{i,j}\in N(s^p), \\ & \text{otherwise,} \end{cases} \tag{11}$$

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

$$\eta_{i,j} = \frac{1}{d_{i,j}} \tag{12}$$

where $d_{i,j}$ is the distance measurement between the cluster head *i* and another cluster head *j*.

EDCHACO

In the proposed approach "Enhanced Double Cluster Head selection using Ant Colony Optimization (EDCHACO)", the pheromone concentration is calculated as follows:

$$\tau_{mi}(t) = \frac{Q}{d_{mi}}(1-\rho) \tag{13}$$

Q is a preset parameter, and the value of *Q* is set to 10. d_{mi} is the distance from sensor device *i* to the cluster head. The rate of Pheromone vaporization ρ is defined as

$$\rho = \frac{E_{init} - E_m}{E_{init}} \tag{14}$$

E_{init} is considered as the initial energy and E_m, as current energy. Additionally, a definite quantity of pheromone in the communication link is calculated as:

$$\Delta\tau_{mi} = \alpha\frac{E_m}{E_{init}} \tag{15}$$

α is the regulatory factor.

In this model, initially, the sensor node selects any one cluster head randomly to send data; after some communication, the pheromone concentration calculation by ACO method determines which cluster head is at the shortest distance to the node, then the selected cluster head is mainly responsible for receiving information from their devices or nodes.

Simulation and Result Analysis

The result and evaluation of performance for the proposed method is evaluated with the help of Python. The proposed method EDCHACO can be compared with APTEEN and ADCAPTEEN protocols on the basic network lifetime and energy consumption by the simulation outcomes.

Specific initial parameter values are taken to simulate APTEEN and ADCAPTEEN; similar parameters and their values are considered for this proposed method. Simulation results for APTEEN and ADCAPTEEN assumed with WSN contains $N = 100$ nodes or devices positioned randomly on an area of 100 m × 100 m dimension with an outside situated base station. For evaluating the methods, the used performance metrics are: network lifetime and remaining residual energy in the nodes.

In Figure 3 and 4, APTEEN method is illustrated as a green curve, ADCAPTEEN method is illustrated as the orange lined curve, and the proposed method EDCHACO is illustrated as a blue-lined curve. The proposed method EDCHACO performs better than other methods as presented in the graph concerning network lifetime and residual energy in the device. The concept of a double cluster head significantly reduces energy consumption and enhances lifetime of the network.

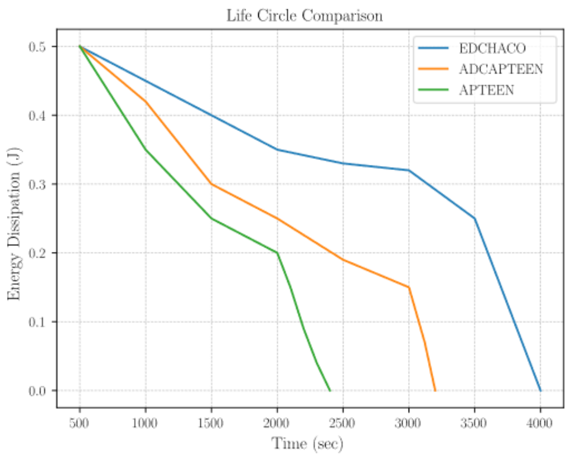

Figure 3: Network Lifetime Circle

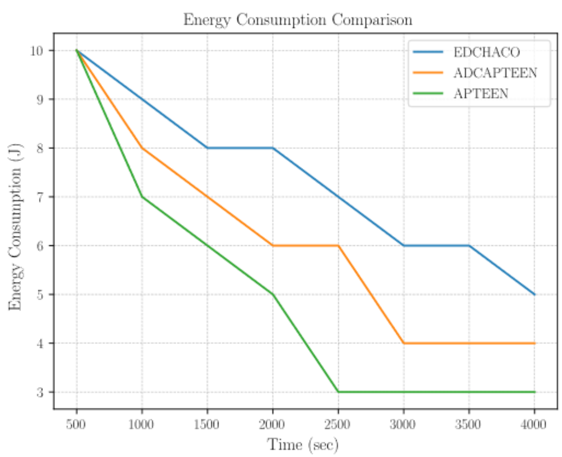

Figure 4: Energy Consumption Comparison

Conclusion and Future Work

The proposed method EDCHACO works based on a double cluster head in a single cluster for WSN. The proposed method uses the best characteristic of ant-colony optimization for shortest distance-based cluster head selection. The proposed method brings out high energy efficiency, greater network lifetime, and highest throughput as presented in the simulation result because double cluster head significantly reduces the workload of a single cluster head. It is determined from the result analysis that the proposed method can give better performance in small and also huge geographical areas. Due to performance, it can be applied for many time-critical and time constraint applications.

The movable base station (BS) model can be familiarized in the proposed method for reaching the performance of the proposed method into the next level of advanced technologies in the future. However, in this research work, only the privacy and security of sensor nodes and networks are not analyzed, so the security and integrity of sensor nodes will be considered in the future work in more detail using more inclusive analysis.

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