Energy-distance & degree: multi-objective based optimized clustering and route discovery in wireless sensor network

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Abstract: Network lifetime ($N_L$) and energy preserving of sensor node is the most vital problem in the deployment of wireless sensor networks ($WSN$). An approach of cluster based path establishment shows the way in which cluster heads ($CH$) collect the information with each other and transfers into the sink ($S_n$) via multi-hop routing. In this paper, we present path establishment and $CH$ selection through Energy-Distance and Degree (EDD) based clustering (EDDCH) and route discovery (EDDRD). The networks divided into multiple groups and each $CH$ support to each other for data forwarding also the smaller sized clusters closest to the $S_n$ and huge size clusters remote from the $S_n$ increases the lifetime of the network. The simulation results compared with the existing route optimization named as Particle Swarm Optimization (PSO) in terms of residual energy ($R_E$) and network lifetime ($N_L$).

Keywords: Cluster Head, CRA, PSO, EDD-CH, EDD-MR.

1. INTRODUCTION

Path establishment ($P_E$) and clustering ($C_i$) are the two most important techniques which have been considered widely for energy ($E$) balance and prolonging the network lifetime ($N_L$) in sensor networks ($SN$). The $SN$ are divided into multiple groups called as $C_i$. Every $C_i$ has an organizer named as cluster heads ($CH_s$). The responsibilities of $CH_s$ are to gather a large volume of data through sensing from their neighbour degree ($N_d$) and process it to the sink node ($S_n$) directly or through other $CH_s$.

In $C_i$ based $P_E$ method, $CH_s$ are collaborate with other $CH_s$ to transfer the information to the $S_n$ via multiple-hop routing process. Here, the $CH_s$ nearer to the $S_n$ are loaded with extended traffic lean to die precipitately and departure the network areas causes the partition of network is commonly called as hot spot issue. To rectify the above issue, we present $C_i$ and $P_E$ schemes based on EDD model. For example, the working principal of $C_i$ based real time $SN$ is presents in figure 1.

The $CH_s$ choice is a kind of the NP-hard problem (NP−hp), since the ruling of $x\ CH_s$ among $y$ nodes gives $x \subset y$ promise, for the huge size $SN$ the mathematical complexity differs exponentially.
At the same time, if an standard of \( p \) next hop distance \( N_d \), then the suitable next hop distance are \( px \).

The CRO (Chemical Reaction Optimization) is an algorithm for population based meta-heuristics (\( M_H \)) inspired method from chemical reactions. It appears different manufacturing fields to attempt various \( NP-hp \) optimal problems and proves its competitiveness, the previous \( M_H \) algorithm such as PSO, ABC, ACO, GA, etc. These algorithms imprison thought and sturdy instructions in real time network. In \( WSN \), problem solved using EDD algorithm is the new effort to concentrate capable troubles in \( S_N \) i.e., cluster head (\( CH_s \)) selection.

![Figure 1: Structure of WSN based on Clustering Mechanism](image)

Multipath routing with energy aware scheme select the next hop based on residual energy of neighbor node since nodes are limited with battery power. To reduce the node failures, energy-aware routing scheme avoids selecting the nodes which has low energy as next hop for data forwarding process. The motive of broadcasting route discovery message is to collect the information about neighboring nodes and to build the routing table for an individual node which contains information like hop distance, residual energy of all neighboring nodes. The metrics stored in the routing table helps individual node to select the suitable next hop that satisfies WSN requirements. Therefore, a new EDD algorithm is improved selection for such \( NP-hp \) due to its high QoS (quality of solution), easy execution aptitude to flight since the quick convergence and the local optima.

In this paper, we present new algorithm for \( C_i \) and \( P_E \) scheme. The first method chooses the \( CH_s \) amongst the \( S_n \) in that to pick highest number of \( CH_s \) close to \( S_n \) comparably faraway from \( S_n \). We present the Linear Programming (\( L_p \)) formulation used to solve the \( CH_s \) selection problem. We propose the \( L_p \) for the routing, the potential energy (PE) considered by various distance, residual energy (\( R_E \)) and \( N_d \) to create the optimal EDD based on the energy efficient.

The following characteristics differs WSN routing with other network routing schemes (Zebbane & Chenait 2018; Ben Fradjet al. 2017; Shaet al. 2012).

- The sensor nodes are small in dimension, restricted energy supply, very hard to recharge the battery after deployment and limited memory capacity. It’s essential to maintain resource management
- A huge number of data generated from sensor nodes toward sink creates data traffic unlike other traditional routing schemes
• Traditional and internet protocol-based routing mechanisms are not appropriate for sensor networks due to large scale deployment of sensor nodes and resource constraints. [20-23].

The paper is organized into six sections, Section 2 will offer the literature review related to the challenges associated with routing algorithms, EDDCH scheme is provided in section 3, EDDRD scheme is present in section 4, the result shows the performance of routing scheme through energy efficiency and increased network lifetime in section 5 followed by conclusion and some key reference in section 6.

2. RELATED WORK

A large number of C_t method and P_E scheme developed for WSN_s by uses dissimilar types of optimization practices like PSO (Particle Swarm Optimization) and CRO (Chemical reaction optimization algorithm). Our proposed method based on EDDCH clustering and EDDRD path establishment approach. In most of the research works, C_t method and P_E scheme available in the survey based on the existing nature inspired application.

The author developed Centralized LEACH scheme using simulated annealing (SA) which works enhanced than existing LEACH. The PSO finds the closest optimal solution constant for troubles with logically complex search space scenery.

The author proposed [1-4] PSO based CH_s scheme proposed, though, they totally discount the cluster arrangement phase. The author describe [5], PSO scheme based routing and clustering, though, this scheme choose the CH_s arbitrarily and flat no assurance concerning the arrangement of C_t which may reason hotspot trouble. Now, we present some well known nature-inspired algorithms based on the unequal C_t and routing scheme.

The author [6] present an energy based balanced different shape routing and C_t scheme named as EBUC-PSO. It proficiently choose the cluster heads, though, unequal CH_s can be allocated to the closest CH_s this may causes energy incompetence of S_N. The routing scheme implementation based on EBUC which is established scenery may not possible for a large systems because the fundamental complication of ruling routes differing aggressive.

The authors [7], develops fuzzy approach with energy aware scheme to unequal clustering in WSN_s named as EAUCF. Though, unequal CH_s nodes connect the closest CH_s, which can overwork the CH_s and sources the energy exhaustion of CH_s. Unequal C_t methods has presented for S_N based on fuzzy logical named as FBUC [8]. Though, it neglect the R_E and N_p of CH_s while conveying the unequal CH_s nodes to the CH_s which can source inequality pack of C_t and energy incompetence of the WSN_s and also the presentation of the approach shames when growing the size of the S_N [9-17].

3. ENERGY MODEL

The transmitting and receiving m- bit packets over the distance of d meters are \( E_{tx}(m,d) \) and \( E_{rx}(m) \) respectively. The energy consumption depends on energy needed to run an embedded circuit to transmit or receive a signal (\( E_{sec} \)) and amplifier energy consumption (\( E_{amp} \)) for reliable transmission [18-19].
\[ E_{TX}(m,d) = E_{elec} \times m + E_{amp} \times m + d^\gamma \]  \hspace{1cm} (1)

\[ E_{RT}(m) = E_{elec} \times m \]  \hspace{1cm} (2)

The \( d_0 \) denoted as the distance threshold value, the node energy usage is relative to \( d^2 \) when the distance \( d \) less than the distance threshold \( d_0 \) otherwise it is related to \( d^4 \). Where, \( \gamma \) denoted as amplifier energy for free space model. The value of path-loss-exponent is \( \gamma \in \{2, 4\} \).

\[ \gamma = \begin{cases} 2 & \text{if } d \leq d_0 \\ 4 & \text{if } d \geq d_0 \end{cases} \]  \hspace{1cm} (3)

Where, \( d_0 \) represented as,

\[ d_0 = \sqrt{\frac{E_{fs}}{E_{amp}}} \]  \hspace{1cm} (4)

\[ E_{TX}(m,d) = E_{elec} \times m + \epsilon_{fs} \times m + d^2 \hspace{1cm} d \leq d_0 \]  \hspace{1cm} (5)

\[ E_{TX}(m,d) = E_{elec} \times m + \epsilon_{fs} \times m + d^4 \hspace{1cm} d \geq d_0 \]  \hspace{1cm} (6)

The energy utilization by the sensor node during the sleep mode,

\[ E_s(t) = E_{in} \times t \]  \hspace{1cm} (7)

Where, \( E_{in} \) represents the energy usage of sensor node in sleep state for \( t \) seconds. The total energy consumption (\( E_{tot} \)) by a sensor node is derived by:

\[ E_{tot} = E_{TX}(m,d) + E_{RX}(m) + E_s(t) \]  \hspace{1cm} (8)

4. PROPOSED DESIGNS AND IMPLEMENTATION

We present two schemes, first scheme is \( CH_s \) selection and next scheme is \( P_E \) algorithm. These two schemes are based on EDD algorithm.

4.1 EDD based efficient \( CH_s \) selection scheme (EDDCH)

The scheme is implemented with a resourceful scheme of an encoding molecular structure and potential energy (\( PE \)) calculation which can improve to select the \( CH_s \) amongst the dynamic \( S_N \) since that to select maximum numeral of \( CH_s \) closest to the \( S_n \). The \( PE \) is calculated using different metrics like sink distance, \( R_E \) and \( N_d \).

4.1.1. \( L_p \) formulation for \( CH_s \) selection problem

We decide different distance and distance parameter that includes average sink distance, average \( N_d \) distance and \( R_E \) for select the efficient \( CH_s \). Assume that \( x1 \) can be the objective function of the normalized distance from the \( N_d \). We concentrate to reduce the \( x1 \) function for efficient \( CH_s \) selection. Let \( x2 \) can be the objective function of least normalized \( S_n \) distance and \( x3 \) can be the
intention residual energy function, which is computed from total initial energy of the $CH_s$ to the expense energy of the $CH_s$. We need to minimize this ratio for the $CH_s$ selection. We need to normalize the all three functions values between 0 to 1 series. The $L_p$ based cluster head selection process as follows:

$$PE = \text{Minimum} \{ (\beta_1 \cdot x_1) + (\beta_2 \cdot x_2) + (\beta_3 \cdot x_3) \}$$  \hspace{1cm} (9) \\
$$\beta_1 + \beta_2 + \beta_3 = 1 \hspace{1cm} \beta_1, \beta_2 \text{ and } \beta_3 \in (0,1)$$  \hspace{1cm} (10) \\
$$\beta_2 \geq (\beta_1 + \beta_3)$$  \hspace{1cm} (11)

In the equation 1, $\beta_1$, $\beta_2$, and $\beta_3$ are the weights of the objective function $x_1$, $x_2$, and $x_3$ respectively, the values range must not be 0 or 100%.

### 4.1.2 Derivation of PE function

The $PE$ function derivation depends on the following different metrics:

#### 4.1.2.1. Average neighbor degree distance ($N_d$)

We find the $CH_s$ such that minimize the neighbor nodes distance. It takes more energy for communication in intra-cluster to transfer information to $CH_s$. We need to minimize the transfer distance between $N_d$, residual energy of the intra-cluster communication process.

$$x_1 = \text{min} \left\{ \text{dist} \sum_{\text{source}}^{BS} N_d \right\}$$  \hspace{1cm} (12)

#### 4.1.2.2 Average sink distance

We need to find the distance between a $CH_s$ and $S_n$. It plays a main task for finding the large number of the $CH_s$ closest to $S_n$. A large number of the $CH_s$ closest to the $S_n$ can reduce the unbalanced energy consumption to generate the $C_j$.

$$x_2 = \text{min} \left\{ \text{dist} \left( \text{source, BS} \right) \right\}$$  \hspace{1cm} (13)

#### 4.1.2.3 Energy Ratio

We need to minimize the energy ratio that is the greatest opportunity to choose the $CH_s$. If a cluster head consume minimum energy during the data sensing, processing and computation activities and have maximum residual energy to lower energy ratio.

$$x_3 = \text{max} \left\{ \text{Node} \left( \text{Residual Energy} \right) \right\}$$  \hspace{1cm} (14)

### 5. EDD BASED ENERGY EFFICIENT MULTI-HOP ROUTING SCHEME (EDDRD)

Multi-path routing mechanisms deals with load balancing, security and reliability issues existing in single path routing mechanism through allocating redundant paths to transfer the data from source to destination. In recent days, multipath routing with load balancing technique attracts the research community to enhance the energy efficiency and delaying the network partition due to node failures.
by distributing the data through multiple paths with a reduced load instead of transmitting whole data through a single path. The sensed information from the $CH_s$ of the clusters to be transfer to the $S_n$ sink via multi hop routing. The finest collection of multi hop route from all the $CH_s$ to $S_n$ is based on the $PE$ function.

5.1 $L_p$ formulation for multi-hop routing

We need to exploit the $N_L$, balance the network load and residual energy. For example, $y_1$ be the function, to choose the next $CH_s$ with more energy for routing process to prolong the network lifetime. Next $y_2$ be the function, to select the least distance between $CH_s$ to the neighbor hop $CH_s$ and neighbor hop $CH_s$ to $S_n$. We need to minimize the network energy usage such that to reduce the $y_2$. The third function is $y_3$; we need to select the neighbor hop cluster head with minimum $N_d$ for cluster load balancing.

$$PE = \text{Minimum} \left\{ (\delta_1 \ast y_1) + (\delta_2 \ast y_2) + (\delta_3 \ast y_3) \right\}$$

(15)

$$\delta_1 + \delta_2 + \delta_3 = 1$$

(16)

$$\delta_2 \geq (\delta_1 + \delta_3)$$

(17)

In the equation 15, $\delta_1$, $\delta_2$, and $\delta_3$ are the weights of the objective function $y_1$, $y_2$, and $y_3$ respectively, the values range must not be 0 or 100%.

![Figure 2: Sample Environment](image)

For example, from figure 2 CH1 have three data transferring nodes towards sink such as CH2, CH3, and CH4, means a arbitrary number is created either 2, 3 and 4. CH2 have two data transferring nodes toward sink such as CH5 or CH7 means an arbitrary number is created either 5 or 7 and so on. The first source node CH1 can forward the information to CH3 and in the way CH2 transfer the data to CH7 and so on. If BS is the minimum distance of any cluster that transfer data to the BS directly shown in table 1.
Table 1. Representation of cluster head

| Cluster Head | Possible Next hop | Next Hop |
|--------------|-------------------|----------|
| CH1          | {CH2, CH3, CH4}   | CH3      |
| CH2          | {CH5, CH7}        | CH7      |
| CH3          | {CH5}             | CH5      |
| CH4          | {CH6}             | CH6      |
| CH5          | {CH6, CH7, BS}    | BS       |
| CH6          | {BS}              | BS       |
| CH7          | {BS}              | BS       |

6. RESULTS AND PERFORMANCE EVALUATION

The proposed protocol is analyzed with existing PSO algorithm and results are plotted using NS2 simulator. The results are worked with different \( S_n \) starting from 75 to 175 nodes and the number of CHs differs from 20 to 60. Based on the packet interval as a data generation gap considered from 0.1 to 0.5 seconds, total simulation varied from 100 seconds to 200 seconds. Sensor nodes initial energy considered from 0.5 j. In simulation environment, we ran our proposed algorithm with exiting PSO algorithm for comparing the node 75 with 20 cluster head. The EDD network fundamental used parameter descriptions enclosed in table 2.

Table 2. Network Environmental Values

| Simulation parameter     | Value                        |
|--------------------------|-----------------------------|
| Simulator                | NS-2.34                     |
| Topology size            | 300 sqm X 300 sqm           |
| Number of Nodes          | 75-175 nodes                |
| Mobility                 | Random way point            |
| Transmission range       | 250 m                       |
| Initial energy of nodes  | 100 joules                  |
| Bandwidth                | 2 Mbps                      |
| Packet Interval          | 0.1 to 0.5 seconds          |
| Transmitting Power       | 0.02 mW                     |
| Receiving Power          | 0.01 mW                     |
| Traffic type             | Sense application           |
| Packet Size              | 60 bytes                    |
| Simulation Time          | 100-200 seconds             |

Figure 3 shows that \( R_E \) of proposed algorithm comparing residual energy with varies sensor node. The Energy consumption shown in figure 3 that means each sensor on path and network has high residual energy. PSO consumes 0.413 joules and 0.42 joules, EDDCH consumes 0.38 and 0.39 joules and EDDRD consumes 0.07 and 0.08 joules when the numbers of nodes are 75 and 175. From graph, it can be analyzed that proposed scheme outperform well in sensor environment in terms of energy.
Figure 3. Number of Nodes vs. Average Energy Consumption

Figure 4 show that Packet delivery ratio (PDR) of proposed algorithm comparing the number of rounds with varies sensor node. In simulation environment, we ran our proposed algorithm with exiting PSO algorithm for comparing the node 75 with 20 cluster head. The proposed scheme shows the maximum lifetime because the protocol balanced all the above issues by route cost metrics. In PSO, CHs selection is randomly but our proposed algorithm selects the CHs with different parameters and uses efficient multi-hop routing. The proposed EDDRD scheme achieves 92% of PDR. The PDR output graph shows the performance of receiving packets in percentage based on the sending packets.

Figure 4. Number of Nodes vs. Packet Delivery Ratio

In proposed protocol, the output figure 5 shows the high residual energy than the previous inventions.
because of stability based routing selection and energy-aware path selection built with a strong path that minimizes the packet drops. PSO consumes 3.53 and 2.17 joules, EDDCH with 3.33 and 1.29 joules and EDDRD consumes 2.25 and 1.16 joules when the packet arriving intervals are 0.1 and 0.5 second.

Packet arriving interval which is from 0.1 to 0.5 second as shown in figure 6, it can be observed that the proposed algorithm outperforms than PSO algorithms since EDDRD selects the next hop with higher residual energy and minimum distance from the base station also with neighbor nodes, increases the EDDRD performance in terms of effective decision making in path establishment process.

7. CONCLUSION

To save the energy consumption, reactive routing strategy used in the energy-aware routing protocols which creates routing path when it’s required to forward the data. The path maintenance also another concern in multipath routing, the path performance can be arrived based on packet inter-arrival delay. The destination node decides that the path is broken or the node got failure when the inter-arrival packet delay exceeds the threshold value. In this proposed method, we presents the \( L_p \) for different optimization problems such as multi-hop routing and \( CH_s \) selection. Here, \( CH_s \) selection scheme to select a large number of \( CH_s \) closest to the BS by deciding distance and energy parameters and then multi-hop routing scheme is implemented which choose the neighbor hop \( CH_s \) based on \( N_s \cdot R_E \) and distance. The simulation output shows that the EDDRD performs enhanced than EDDCH and PSO in terms of \( R_E \) and \( N_s \).

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