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ARTICLE

# Outdoor Air Quality Monitoring with Enhanced Lifetime-enhancing Cooperative Data Gathering and Relaying Algorithm (E-LCDGRA) Based Sensor Network

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## ABSTRACT

The air continues to be an extremely substantial part of survival on earth. Air pollution poses a critical risk to humans and the environment. Using sensor-based structures, we can get air pollutant data in real-time. However, the sensors rely upon limited-battery sources that are immaterial to be alternated repeatedly amid extensive broadcast costs associated with real-time applications like air quality monitoring. Consequently, air quality sensor-based monitoring structures are lifetime-constrained and prone to the untimely loss of connectivity. Effective energy administration measures must therefore be implemented to handle the outlay of power dissipation. In this study, the authors propose outdoor air quality monitoring using a sensor network with an enhanced lifetime-enhancing cooperative data gathering and relaying algorithm (E-LCDGRA). LCDGRA is a cluster-based cooperative event-driven routing scheme with dedicated relay allocation mechanisms that tackle the problems of event-driven clustered WSNs with immobile gateways. The adapted variant, named E-LCDGRA, enhances the LCDGRA algorithm by incorporating a non-beacon-aided CSMA layer-2 un-slotted protocol with a back-off mechanism. The performance of the proposed E-LCDGRA is examined with other classical gathering schemes, including IEESEP and CERP, in terms of average lifetime, energy consumption, and delay.

***Keywords:*** Air quality; Cluster; Delay; Energy; Lifetime; WSN

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# 1. Introduction

In recent years, air pollution has intensified in practically all societies on the planet [1]. The amount of particles in the atmospheric air is ascending, and the repercussion on the ecosystem cannot be overlooked [2]. Air contamination is a major root of mortality worldwide [3-5]. Air pollutant status is broadly tracked by adopting traditional fixed-monitoring mechanisms [5-7]. These typical monitors are extremely expensive, massive, and bulky [6]. Besides, air contamination zones may deviate in seconds, and typical monitoring apparatuses cannot recognize such swift divergences. Using sensor-based structures, we can get air pollutant data in real-time [8-11].

WSN (wireless sensor network) is an autonomous wireless configuration, set up by mini-sized sensor node devices [12]. The sensors are supposed to observe numerous environmental parameters and transfer the observation to a gateway [13]. The sensors rely upon limited-battery sources that are unreal to be swapped always amid considerable broadcast costs. Generally, the sensors disperse their total-energy prematurely from constant tracking and broadcast tasks [14,15]. Thus, effective energy administration measures must be enforced to handle the expense of power-dissipation.In this situation, routing policies play a principal role, regulate the QoS and energy diffusion at the sensors. Clustered aggregation is an outstanding technology widely used to lessen redundancy, energy allocation and lengthen WSN longevity [16]. In a clustered structure, the sensors are split into cells while a leader is allocated to accumulate readings of their cell and convey them to the remote gateway [17]. Various clustered aggregation schemes can be found in the literature [18-24].

To enhance the lifetime of diverse clustered WSNs, the lifetime-enhancing cooperative data gathering and relaying algorithm (LCDGRA) was proposed lately [25]. LCDGRA is a cluster-based cooperative event-driven routing scheme with dedicated relay allocation mechanisms that tackle the problems of event-driven clustered WSNs with immobile gateways. It uses a centralized hybrid clustering strategy based on Huffman coding and K-means clustering to section sensors into the K-number of clusters. In LCDGRA, relay nodes are committed in the diverse cluster fields to support the CH's transporting their assembled sensory data to the central gateway. Random linear coding is realized at each hop from the event cluster to the central gateway/BS to assure minimum energy consumption. Hence, the relays exploit decode and forward techniques to cooperatively relay the observations to the central gateway. In this study, we propose outdoor air quality monitoring using WSN with an enhanced lifetime-enhancing cooperative data gathering and relaying algorithm (E-LCDGRA). The adapted E-LCDGRA improves the original LCDGRA algorithm by incorporating a non-beacon-aided CSMA layer-2 un-slotted protocol with a back-off mechanism. The performance of E-LCDGRA is examined with other typical clustered event-driven gathering schemes, including IEESEP and CERP, in terms of average lifetime, energy consumption, and delay.

# 2. System model and communication protocol

**Figure 1** reveals the WSN model examined in this work for air quality monitoring. $G= (V, S)$ denotes the network's directed graph. $V$ denotes the vertexes, which comprise arrays of nodes spread arbitrarily in the outdoor air quality monitoring zone and a central base station (BS) located at the monitoring zone-end. $S$ signifies the links or edges. According to their functions, each node fits into relay node (RN), normal node (NN), and cluster head (CH) categories. The proposed solution named E-LCDGRA is developed in cognizance of existing clustered event-driven routing design. In the examined sensor network, the sensor devices run over Zigbee/IEEE 802.15.4 protocol whilst being cognizant of the in-network aggregation methodology. Every node device possesses the same ability to run as a full-function device (FFD) and reduced function-devices (RFD). Hence, the node devices can run in either sensor monitoring or communication modes to transfer recorded air quality data to other sensor neighbours in their reach.

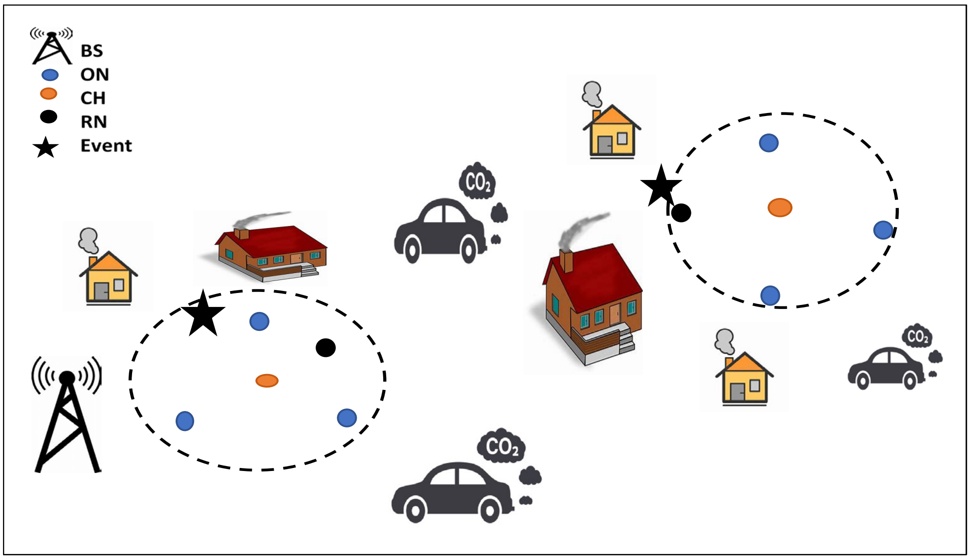


**Figure 1.** Proposed network model.

The protocol operation of the RN and CH is network coding-cognizant, and based on a non-beacon-aided CSMA layer-2 un-slotted protocol with a back-off mechanism. To boost more coding chances at the coding-layer, the CH's and RN's use CSMA-based listening and a back-off method to realize coding actions. It permits them to briefly hold their transmissions and listen to broadcasts from MAC-layers of their upper layers before disseminating their packets. This is exclusively meant to boost coding gains at the intermediate nodes, as opposed to the archetypal collision-evasion mechanisms. All coded packets ordered by NC-layer header and a notification message are routed to the MAC-layer. The receiver's hash for the MAC-address is included with the NC-header, to guarantee ease in the decoding operation. The operation of decode and forward (DF) on the packets at the relays, from the event zone is realized per-hop until they are obtained at the BS. **Figure 2** shows the proposed IEEE 802.15.4-based asynchronous communication protocol for two CH and RN.

## 3. Design methods and phases of LCDGRA algorithm

This section elaborates on the design methods of the adapted scheme named E-LCDGRA, which consists of three phases as follows:

- Initialization and clustering;
- Relay nodes allocation;
- Data aggregation and broadcasting.

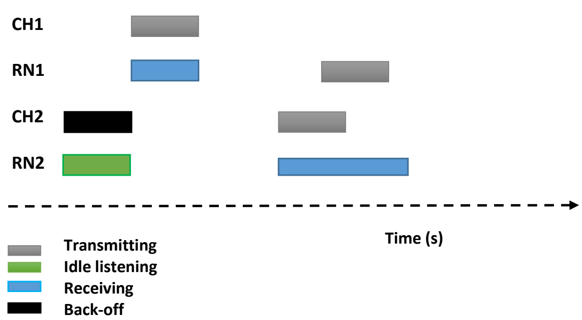


**Figure 2.** Proposed IEEE 802.15.4 based asynchronous communication protocol of 2-CH's and 2- RN's.

### 3.1 Initialization and clustering

In this phase, the sensor network is initialized, then the sensors are clustered into equal K cells. The central gateway starts this phase with messages of initialization (*I-REQ*) forwarded to every node in the network space; whilst each node replies to the request by sending responses for initialization (*I-REP*). The responses (*I-REP's*) from sensors have information about their locations and energy.

By the procedures defined above, the network is initialized. A centralized hybrid clustering strategy based on Huffman coding and K-means clustering is employed to section sensors into K-number of clusters. It is intended to augment the node's coverage distances with their energy usage at the K formation stage. The allocation of the CHs is based on gauged competing value for each node regarding the distance from a competing node to its K-unit members, the contending node's residual energy with reference to the energy desired for the transceiving of the member's K-bit packets, and the energy for RLNC-based aggregation. The clustering and CH allocation scheme are defined in the following subsections.

### *Cluster development stage*

At this epoch, the nodes are shared into K-divisions of clusters. Firstly, the optimal overall K-points are computed using Equation (1).

$$k_O = \frac{A}{D(N,BS)^2} \times \sqrt{{d_o}^2} \times \sqrt{\frac{N}{2\pi}} \quad (1)$$

Here, $D$ ($N$, $BS$) denotes the node's Euclidean distances to BS, $d_o$ signifies the threshold for communication and $A$ represents the monitoring area. Once the overall quantity of K-points is worked out, the sensors are allocated to their nearby cluster centroids. The distance between the cluster center-point (centroid) and the nodes is defined by Equation (2).

$$d(j) = \sum_{i=1}^{N} \sqrt{\left(X_{Ni} - X_j\right)^2 + \left(X_{Yi} - Y_j\right)^2} \quad (2)$$

where, $i=1,2,....,N$, $X_{Ni}$ and $X_j$ signify the node and cluster-centroid's $X$ coordinates, while $Y_{Ni}$ and $Y_j$ represent their respective $Y$ coordinates, meanwhile; $N$ stands for total nodes. Lastly, fresh center-points are calculated for all clusters till the points become unchaining.

### *Nomination of CH's*

In this phase, CH's are nominated. Firstly, a competing-value $N_{compi}$ is premeditated for every node in entire clusters employing Equation (3).

$$N_{compi} = \frac{E_{resi}}{\sum_{i=1}^{N} d_{Node}^2 + k\,(E_{rx} + E_{tx}) + E_{DAN}} \quad (3)$$

where, $i=1,2...$ , $N$, and $N$ signifies the cluster overall members, $d_{node}$ connotes distance from the members to the competing node,$E_{resi}$signifies the competing node's residual energy, $E_{rx}$ signifies the energy desirable for the receipt of the member's $k$-bit packets, $E_{tx}$ signifies the energy required to transfer the packets to the adjoining relays, while $E_{DAN}$ represents the requisite energy for realizing RLNC and In-network aggregation.

Next, succeeding evaluation of contending value $N_{compi}$ for every node, each sensor node's cost is multiplied by a random value in the line of 0 and 1, in order to ascertain their various probabilities. The obtained probabilities for all node is subsequently summed to one and set up in a descending set. Later, a code is found for all the nodes with Huffman coding method to figure out their weights. Eventually, the sensor node that possesses the lightest weight in the distinct clusters is adopted as the head node and introduced to the K members. In each round-cycle, other CH's are appointed in all K-clusters to promote load balancing until every node drains its battery power within the sensing area.

## 3.2 Relay node allocation

Here, the relay node appointment takes place. Relay nodes are committed in the diverse cluster fields to support the CH's transporting their assembled sensory data to the central gateway. Analogous to the CH appointment, the relay allocation scheme is computed by the central gateway employing a gradient-descent (GD) based relay allocation algorithm. Algorithm 1 gives the GD relay assignment scheme.

## 3.3 Data aggregation and broadcasting

After the CH's and relays are determined, the nodes switch into idle states forecasting events. An event means a mutation in the perceived sensory value of air quality (AQ) above defined-thresholds. Accompanied by incidents of an event within the outdoor air quality monitoring region are phases of aggregation and broadcasting. It is well acquainted that in WSN, the number of data transmissions substantially affects the network's energy usage. Accordingly, it becomes vital to mitigate the estimate of communications to maintain remarkably less energy usage. In the designed scheme, random linear coding is realized at each hop from the event cluster

**Algorithm 1. Relay Node Election Algorithm**

Step1: Input: Initial Guess ($x_0$), Step length ($a$),
Step 2**: Initialization**
**Repeat**
Step 3: **For** i=0, i< Max i;
i++ **do**
Step 4: **For** ***N*** **do**
Step 2: Calculate model parameters
Step 3: Set the parameters and assess $f_{(GD)}$ gradient with reference to the weights
Step 4: Modify the weights taking steps proportionate to the $f_{(GD)}$ –Gradient, to find the optimal values that minimizes $f_{(GD)}$
Step 5: Update relays
Step 6: **End for**
Step 7: **End for**
Step 8: Until the iteration Maximum
Step 9: Assign the best node as "RN"

to the central gateway/BS to assure minimum energy consumption. Hence, the relays exploit decode and forward techniques to cooperatively relay the observations to the central gateway.

Upon event incidence in the monitoring space, the event region K-members convey their recorded data to the head node. Then, the cluster head, gathers received outdoor air quality (AQ) variation beyond a set event threshold and arranges into $n$-blocks of packets $P_i$=[$P_1$, $P_2$..., $P_N$] in accordance with the node's IDs. The CH allocate $2^8$ coding vectors $a_i$= [1, 2..., $a_N$] and codes them mutually by linear mixture as represented in Equation (4).

$$P_{RLNC} = \sum_{i=0}^{N} P_i * a_i \quad (4)$$

Here, $i$=1, 2…$N$, $P_{RLNC}$ represents the coded-packet, $P_i$ signifies the source-packet, $a_i$ is the coding-vectors. Following the coding operation at the CH, the coded-packet is transferred to the nearby relay hop. Recovery of the source-packet from the coded-packet at the relay destination depends on the acquired amount of packet. Firstly, this involves Gaussian extinction. The header-message is then set-up to $n*n$ matrix and eventually to (reff) reduced-row-echelon. Eventually, the source-packets are reconstructed upon evaluating a few series of underlying linear equations. The operation of decode and forward (DF) on the packets at the relays, from the event zone is realized per-hop until they are obtained at the BS. **Figure 3** illustrates the full-flowchart of the suggested E-LCDGRA.

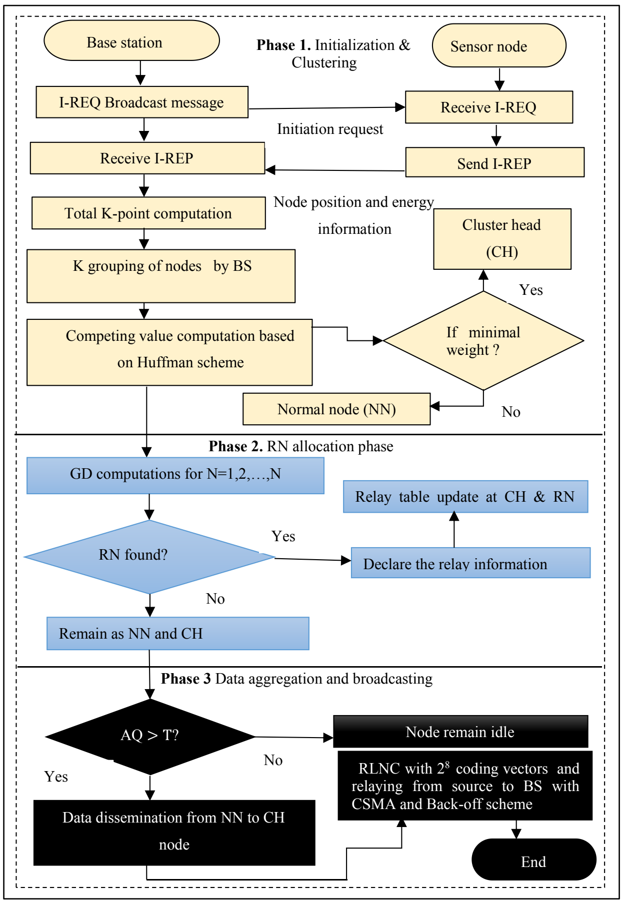


**Figure 3.** E-LCDGRA full-flowchart.

## 4. Comparative experimental simulation results

We assess E-LCDGRA performance employing MATLAB 2018b simulations. The experimental study was performed using 100 sensors spread arbitrarily across (X = 100 m, Y = 100 m) 2D interest zone with one a gateway positioned at (X = 100 m, Y = 50 m) remotely from the 2D sensing zone. Further basic parameters employed in the experimental study are offered in **Table 1**. We chose IEESEP and CERP data-gathering schemes to authenticate the soundness of our adapted algorithm, named E-LCDGRA.

**Table 1.** Simulation parameters.

| Parameter | Value |
|---|---|
| Sensed-traffic | Event driven |
| Round-time | 4000 |
| No of nodes | 100 |
| Dimension of field | X=100 m, Y=100 m |
| No. of BS | 1 |
| BS placement | X=100 m, Y = 50 m |
| Initial-Energy | 5J |
| Data packet size | 100(bytes) |
| $E_{elec}$ | 50 nJ/bit |
| Aggregation-energy | 5 nJ/bit/signal |
| $e_{mp}$ | 0.0013pJ/bit/m |
| $e_{fs}$ | 100 pJ/bit/m$^2$ |
| Size of broadcast packet | 25 (bit) |

**Figure 4** measures the average network latency with each of the schemes. The latency signifies the interval between data dissemination from the source to the receivers' reception time. It comprises delays in propagation, data queuing, and data processing. It is noticeable from the experimental results obtainable in **Figure 4** that the network's average latency when using E-LCDGRA is rationally less compared to IEESEP. Again, when paying attention to the system's latency in **Figure 4**, it is indisputable that the average latency of IEESEP is relatively lesser than that of CERP.

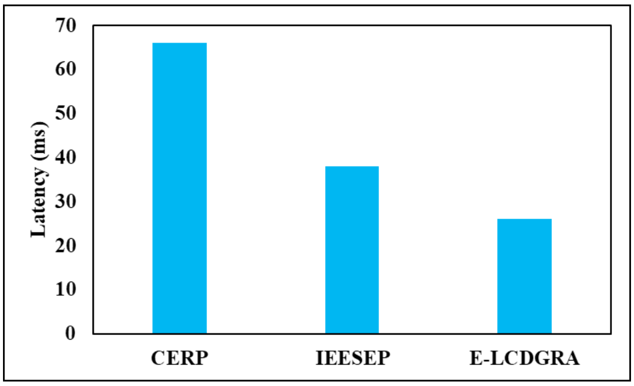


**Figure 4.** Network latency.

**Figure 5** examines the network's average network energy consumption in data gathering. The energy consumption per round is defined by Equation (5).

$$E = \sum_{i=1}^{N} \frac{E_{ri}}{R} \tag{5}$$

where, $i$=1,2,…$N$, $N$ denotes the over-all sensors, $E$ represents the round energy consumption, and $R$ signifies the total rounds, $E_{ri}$ signifies the node's residual energy upon a round conclusion. As can be inferred from **Figure 5**, it is clear that network energy consumption for E-LCDGRA is considerably lower than IEESEP and CERP, respectively.

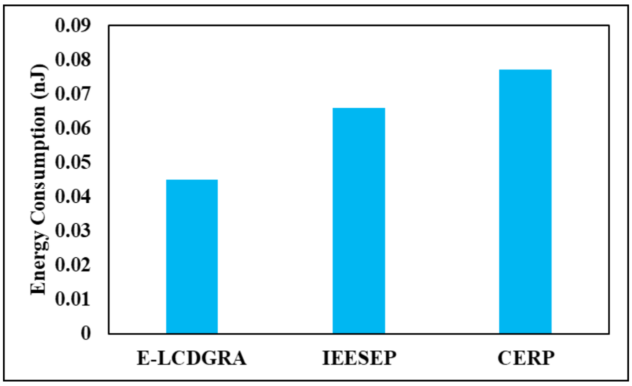


**Figure 5.** Energy consumption.

**Figure 6** evaluates the sensor network's lifetime for each protocol. The lifetime is viewed as the epoch from initialization to the time halves of sensors drain their energy over the sensor network. It is explicit from **Figure 6** that in E-LCDGRA, halves of the sensor deplete their energy at around 3500. On the other hand, it can be seen that in IEESEP and TEEN, halves of the sensors drained their energy around 3000 and 2600.

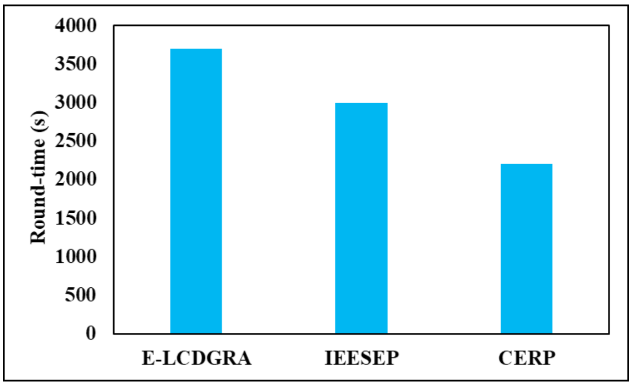


**Figure 6.** Network lifetime.

The above experimental results affirm that the adapted solution named E-LCDGRA incorporates the aids of a non-beacon-aided CSMA layer-2 un-slotted protocol with a back-off mechanism, cooperative multi-hop communication, and random linear coding technology with the most suitable relays in a clustered topology. These results verify that the designed strategy does not solely lessen system latency and energy expenditure, but again augments the longevity and energy efficiency above comparable schemes. Thus, our solution, named E-LCDGRA, proves its supremacy in sufficing the need for further energy-efficient, reliable, and well-timed event dissemination in energy-constrained WSN set-ups for air quality monitoring.

## 5. Conclusions

Air pollution is a severe problem that has raised the concerns of communities, the public, and scientists globally. By employing sensor-based structures, we can get pollutant data in real time and implement preventive measures. However, associated with sensor structures deployed for air pollution monitoring are the problems of the constrained lifetime of sensors and poor broadcast reliability. Thus, to tackle these issues, this work proposed outdoor air quality monitoring using a sensor network with an enhanced lifetime-enhancing cooperative data gathering and relaying algorithm (E-LCDGRA). LCDGRA is a cluster-based cooperative event-driven routing scheme with dedicated relay allocation mechanisms that tackle the problems of event-driven clustered WSNs with immobile gateways. The adapted variant, named E-LCDGRA, enhances the LCDGRA algorithm by incorporating a non-beacon-aided CSMA layer-2 un-slotted protocol with a back-off mechanism. The performance of E-LCDGRA was examined with other typical clustered event-driven gathering schemes, including IEESEP and CERP, in terms of average lifetime, energy consumption, and delay.

## Conflict of Interest

There is no conflict of interest.

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