



Adaptive Data Aggregation Scheme with Optimal Hop Selection Using Optimized Distributed Voronoi-Based Cooperation with Energy-Aware Dual-Path Geographic Routing Protocol

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Abstract

In Wireless Sensor Network (WSN), the consumption of energy is high due to the data transmission in the sensing region. The Optimized Distributed Voronoi-based Collaboration (ODVOC) optimizes data delivery and it suffers from huge energy consumption. To overcome this drawback, a data aggregation scheme is introduced to expand the lifetime of the network and to minimize the energy utilization. Data aggregation is a significant approach that preserves the unwanted usage of energy during data transmission. In this paper, the Optimized Distributed Voronoi-based Cooperation scheme with Energy-aware Dual-path Geographic Routing (DAOHS-ODVOC-EDGR) is proposed which incorporates the polydisperse aggregation scheme and it aggregates the indispensable data in the intermediary nodes. The effective data aggregation is achieved by the estimation of the waiting time of the data at every intermediary node and cost function that is used for electing the next-hop node. In the proposed protocol, the buffer value of every node is divided to retain diversified kinds of flow for effective and fair delivery of data. The rate of transmission at the source and intermediary node is altered during the congestion. The proposed DAOHS-ODVOC-EDGR protocol is tested via simulation scheme. The result of the simulation exposes that DAOHS-ODVOC-EDGR outperforms the TESDA and DVOC protocol in terms of network lifetime, energy efficiency, and hop count delay.

Keywords Data aggregation · Hop-count · Logical topology · Cost function

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1 Introduction

The expansion of WSN has made the perspective of communication to the next level and it is also used in various popular applications [1, 2]. The network of WSN is composed of numerous sensor nodes with constrained resource and they are instilled with non-researchable batteries. The sensors in the WSN consume more energy during transmission rather than computation. The occurrence of overhead in the communication will influence the energy utilization and the reduced overhead decreases the energy consumption that also widens the Life time of the network [3]. The scenario of the network with a huge sensor generally creates a substantial quantity of data. Most of the cases cause complications and high redundancy in the raw data [4]. Hence, an effective design of the protocol is necessary to minimize the redundancy of data and the amount of data transmission.

Data aggregation is a significant paradigm that avoids the redundancy of data and preserves energy [5]. During the process of data aggregation, the sensor node in the sensing field is organized as a tree hierarchy that is rooted at the base station (BS). The node assigned as a non-leaf in the tree will act as an aggregator that fuses the collected data from the child and forwards the aggregated data towards the BS. By this method, aggregated data alone transmitted to the BS, rather than the generated summation of data from every node. Data aggregation can effectively minimize the communication overhead and the lifetime of WSNs are increased [6, 7]. The final decision of every application is determined on the basis of the accuracy result of aggregation and the variation of result gives varied decisions. In the applications of forest fire monitoring and surveillance on the battlefield, such variation in the decision may lead to the critical consequence [8, 9]. Therefore, the accuracy of aggregation is a significant criterion for the data aggregation technique.

The sensor network can alter the people's way of transmission with the atmosphere and others. The WSN has become an eminent platform for pervasive computing. The sensor network is deployed in most of the personal locations, likely the human body, and house. The effectiveness of data transmission is achieved by a prominent data aggregation scheme. Therefore, data aggregation should address effective data transmission. The atmosphere of application poses a set of constraints in the process of protocol design. The aggregation must be attained with transmission accuracy as high as possible and overhead as low as possible. However, the sensor network has certain limitations on network lifetime and energy constraints [10, 11].

An extensive simulation analysis has been conducted to rectify the limitation using the Trust weighted Secure Data Aggregation algorithm (TESDA) [12]. In the TESDA approach, clustering scheme is incorporated to attain the effectiveness and balances the energy utilization. The TESDA minimizes the overhead and the reduced transmission overhead leads to the collision. The node failure and energy hole issues are rectified using the Optimized Distributed Voronoi-based Collaboration (ODVOC) [13, 14]. The consumption of energy is high and the network lifetime is low in ODVOC protocol. To overcome this issue polydisperse aggregation is used for the data aggregation scheme. The polydisperse aggregation is a population balancing model and aggregation of the node is accomplished by the overlapping spheres. The simulation analysis of the proposed scheme is compared with the existing scheme. The simulation result depicts that the proposed scheme can minimize the overhead and enriches the accuracy of aggregation.

This research article is emphasized as follows: The investigations of aggregation protocol are given in related work section, the methodology of DAOHS-ODVOC- EDGR is given in Sect. 3, the diagrammatical representation of TESDA, ODVOC-EDGR, and

DAOHS- ODVOC-EDGR is demonstrated via graph in Sect. 4 and the conclusions, as well as the future suggestions.

2 Related Work

Latha et al. [15] proposed a Trust Assisted- Energy Efficient Aggregation (TA- EEA) approach that enriches the precision of the aggregation process with the constraints like aggregation and reliability. The TA-EEA approach incorporated the congestion control mechanism, energy preservation using duty cycle, and trusted neighbor election scheme for seamless transmission. The utilization of energy was minimized that extended the lifetime of the node. In the context of large scale WSN, the methodology of TA-EEA was failed to attain a better result.

Kaur and Mahajan [16] proposed a hybrid protocol for data aggregation that was a combination of Ant Colony Optimization and Particle Swarm Optimization. This scheme mainly intended to enrich the lifetime of the network and it enriched the dissipation of data by effective energy utilization. ACOPSO utilizes the clustering mechanism for data segregation and the aggregation process was carried by the tree construction process. The sensor network was segmented by clustering and the process may take the time that may lead to data transmission delay.

El Fissaoui et al. [17] projected a data aggregation scheme using a minimum spanning tree (MST) and proposed Mobile Agent Protocol based Energy-aware data aggregation (MAPE). The process of data collection and gathering was attained by an optimal number of mobile agents. The sensor nodes were grouped and the cluster head was elected which in turn attained the data transmission more effective. The MAPE utilized less time to transmit the data and also energy usage is minimum when compared to other aggregation techniques. Gupta et al. [18] discussed the collaborative data processing in WSN where the mobile agent move among the node and the aggregation process has been attained. Through the proposed mechanism bloated state issue was analyzed in mobile agent-based data aggregation technique that minimizes the utilization of energy among the data transmitting active nodes. The response time, usage of energy, and lifetime was improved with the proposed approach. The inspection of the migration of the mobile agent was not considered in the collaborative data aggregation approach that may reduce the performance of the network.

Padmaja and Marutheswar [12] developed a data aggregation scheme called TESDA that optimizes the performance of the data aggregation with the assistance of the clustering process. In the TESDA approach clustering scheme was employed to accomplish the effectiveness of transmission and to balance energy utilization. The TESDA minimizes the overhead and the reduced transmission overhead leads to the situation called a collision.

2.1 Data Aggregation-Based Optimal Hop Selection with ODVOC-EDGR (DAOHS-ODVOC-EDGR) Protocol

This section elaborates the proposed framework for the effective routing of data in accordance with the optimal hops. The initial section denotes the construction procedure of logical topology. In the subsequent section election of appropriate sensor node for data transmission, the effectiveness of data aggregation and forwarding of data using polydisperse

data aggregation [18] is described. The packet loss and the hop count delay are minimized with the congestion control mechanism that is presented at the end of the section.

2.2 Construction of Logical Topology and Data Transmission

The construction of topology reduces the issues progressed in the generation of redundant and intense deployment of nodes i.e. intervention, the maximum count of feasible routes, utilization of highest energy to transmit the data to the nodes at the distance position. The control of the topology conserves the connectivity with the utilization of minimal energy. During the construction of logical topology, every sensor node in the network must aware of its position, neighboring node position, and location of the base station (BS). The construction of topology is established by the propagation of the “HELLO” message. The construction of logical topology is established by the sensor node which received the HELLO message. Every node is assigned with a random waiting time to avoid the occurrence of collision during the transmission between the peer nodes. The transmitted “HELLO” message holds the node ID, status buffer, energy level, information of location, and its hop count. Hop count of the “HELLO” message is zero ($hc=0$) at the preliminary stage of data transmission. The hop count of the message is increased by one ($hc+1$) after every transmission from the BS to its neighboring nodes. The neighbor node with minimum hop count will be elected as a receiver by the transmission node. The node poses the hc one forms the first level and hc two forms the second level of logical topology and so on. The process of construction pursues till all the sensor nodes are included and the orphan nodes are excluded from the construction of hierarchy.

The construction of topology provides assistance in the effective recognition of neighborhood nodes. The protocol is dynamic and the representation of topology alters when the sensor node becomes inactive. The proposed Data Aggregation Optimal Hop Selection with ODVOC-EDGR (DAOHS-ODVOC-EDGR) protocol preserves the energy dissipated in the construction of topology by adhering to the schema-less data delivery mechanism. The overall message transmission and the construction of logical topology in the sensing field are illustrated in Fig. 1.

The sensor nodes are deployed densely in the sensing field which generates redundant and highly correlated data. The utilization of energy in WSN is reduced by selectively forwarding the sensed data to the point of aggregation. The WSN necessitates varied levels of sensing reliability in the field of sensing that is sub region (s_s). The diversified sensing field in WSN is allocated with varied reliability weights ($w_k, 1 \leq k \leq r_s$). The requirement of Quality of Service (QoS) in data transmission delay and the delivery ratio is determined by the weight factors. Based on the requirement of the reliability, the proposed DAOHS-ODVOC-EDGR divides the sensing field into a subsection to preserve energy. The sensor node in the network sense the data transmission within the sensing field (s_{dense}), and the reliability factor (R_f) is allocated to the sensed data. The rate of reliability factor of sensory information is estimated by,

$$R_f = \frac{S_{Sense} - S_{event}}{100} \quad (1)$$

where the distance among the event and node is denoted by S_{event} . The progression or the restriction of data transmission is accomplished on the basis of R_f and the transmission is determined by the condition $R_f \geq tR_f$. The threshold dependability factor of the sensing event tR_f is estimated by,

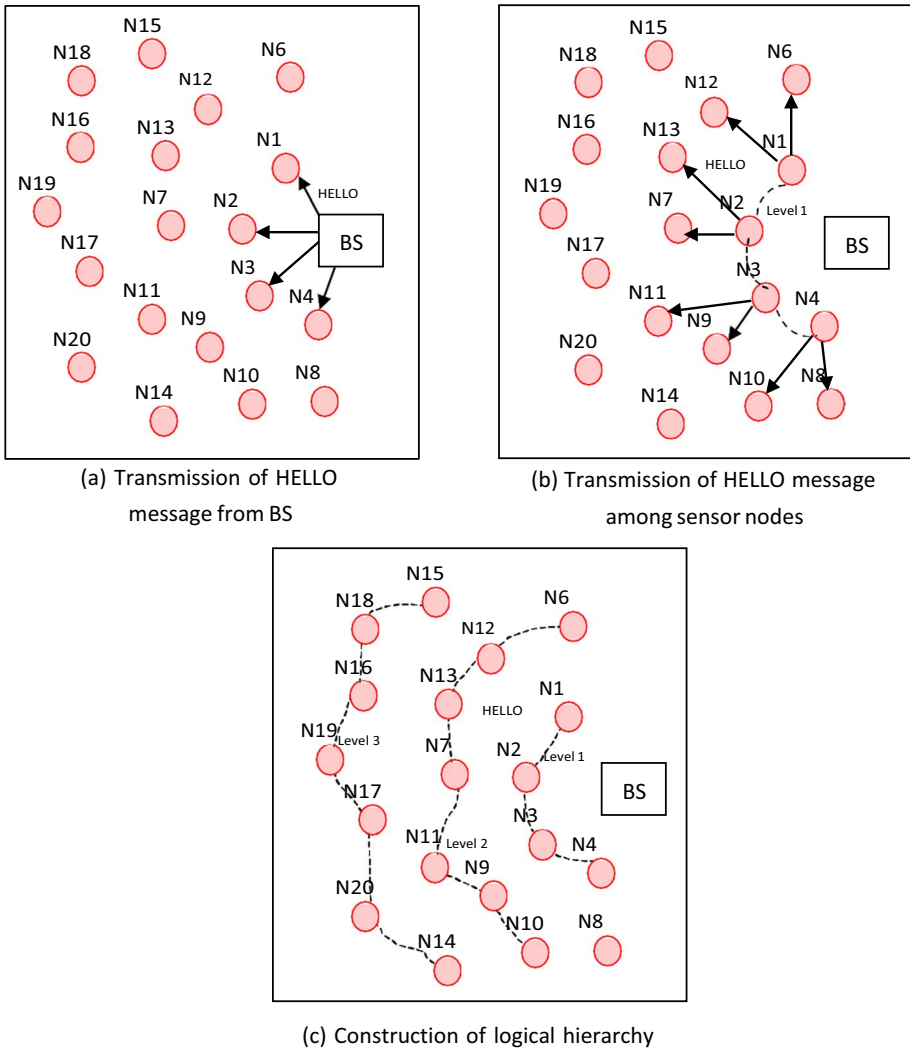


Fig. 1 Overall message transmission and the construction of logical topology in the sensing field

$$tR_f = \frac{100 - Wk}{100} \tag{2}$$

2.3 Election of subsequent Hop-Node using Adaptive Scheme

The electing of the next-hop node to send its own or aggregated data using an adaptive scheme towards the BS that is done by the sensor node and the cost function determines the election of the next-hop node. The cost function is estimated from the robustness of the association among the current and next-hop node, available buffer space, and residual energy. During the

process of forwarding the data, the neighbor information table is maintained by ever sensor node that provides assistance in estimating the cost function. The neighbor information table includes robustness of the link (L_r), buffer space (Buf_{sp}), residual energy (E_{rl}), node id (Ndi), and the coordinate position ($Nd(x,y)$). A node m (Ndm) elects a next-hop node n (Ndn) with the highest cost function values (CoF_{max}). The CoF_{max} is estimated by,

$$CoF_{max} = \max_{i \in Nd} \{ (E_{rl,i} + Buf_{al,i} + L_r \tag{3}$$

where Nd denotes a set of neighbors of Ndj and is considered as the weight factor estimated as the converse of distance among Ndj and Ndi .

$$a = \frac{1}{\sqrt{(Nd_{j,x} - Nd_{i,x})^2 + (Nd_{j,y} - Nd_{i,y})^2}} \tag{4}$$

The residual energy is estimated by

$$E_{rl,i} = E_{lvl,i} - \left\{ E_{RT}(c, dis_{tr}) + E_{SR}(c) + \sum_{i=1}^{Nd} E_{SR}(c) + E_{agr} \right\} \tag{5}$$

The $ERT(c,dis)$ represents the needed energy to propagate c number of bits to certain distance where highest propagation area of sensor node is denoted by $distr$, the level of energy is denoted by E_{lvl} , the energy used to aggregate the packet is represented by E_{agr} , the energy used for receiving a packet $ESR(c)$ and it is computed by,

$$E_S(c) = E_{ele} \times c \tag{6}$$

The accessible buffer space is estimated from the existing status of the buffer and the count of the expected packet is transmitted from the neighborhood of node Ndj . Generally, Buf_{sp} and E_{lvl} hold the acknowledgment data that is sent to the packet and it will be updated in the table of information. At the preliminary stage, the values of Buf_{sp} and E_{lvl} are assigned at the construction of the logical topology phase. The available range of buffer to a node i is estimated by,

$$Buf_{avl} = Buf_{sp,i} - \sum_{i=1}^{Nd} c \tag{7}$$

The robustness of the link for the neighbor node is estimated and renewed in the information table acknowledgment information from the neighbor node is received by the node on the sensing field and the strength of the link is estimated by,

$$L_{r,i} = \frac{Recv_{sp}}{Recv_{no\ of\ bits}} \tag{8}$$

where $Recv_{no\ of\ bit}$ denotes the count of the bit resided in the acknowledgment data from the neighbor node Ndi . The robustness of the link is the Signal Interference Noise Ratio (SINR) for the link among the node Ndj and Ndi . The signal power received during the transmission is estimated by,

$$Recv_{sp} = \frac{[Prc(d)]}{Prc(d_0)} = -10\beta \log \left(\frac{d}{d_0} \right) + Y_{rdb} \tag{9}$$

where $Prcv(d)$ is the arrived mean power with the distance d , which is estimated in relevance to a reference power $Pr(d0)$ at the specific distance $d0$. The exponent value of path loss is β and the random Gaussian variable with mean zero value Y_{rdb} and the standard deviation.

Polydisperse Data Aggregation Model

Data_Aggregation ()
 Determine: Ag aggregated data packet of the event
 Determine: Nd of sensor node
 executes the data aggregation Begin:

1. Generation of overlapping spheres $Agq = Agq (Ag1...Ndn (Agq), Cm)$
2. The connectivity matrix of polydisperse aggregation is framed from the overlappingspheres
3. The overlapping issue is solved using $d_{ij} = |x_i - x_j|$
4. Aggregation is formed with the binary tree and connectivitymatrix
5. $c_{i,j} = \begin{cases} 0, & \text{if } Ag_i \text{ and } Ag_j \text{ are not neighbours} \\ 1, & \text{if } Ag_i \text{ and } Ag_j \text{ are neighbours} \end{cases}$

The process of data aggregation reduces traffic, delay, and energy usage than the near sink aggregation. An aggregate Agq holds $Ndn (Agq)$ in the sensing region that is represented as overlapping spheres and it is signified as,

$$Ag_q = Ag(Ag_1 \dots \dots \dots Nd(Ag_q), C_m) \tag{10}$$

where nodes in the sensing region Agk , with k belongs $1.. Ndn (Agq)$, is denoted as

$$Ag_i = Ag(n_i, r_i, x_i) \tag{11}$$

where Cm is the connectivity matrix, Agq denotes the n_i aggregated nodes, is the formulation of the sensing field, r_i is the sensing field radius and x_i is the midpoint of the formulated region. The process of estimation of gyration reduces the complexities in computation. The degree of overlap among the neighboring node is solved by the center of separation that is equated by,

$$d_{ij} = |x_i - x_j| \tag{12}$$

The nodes in the sensing region are stored in a binary tree and it enriches the performance of the computation by permitting a very effective election. The connectivity at the initial stage determined based on the nature of the node within the sensing region. However, the computation is achieved by binary tree connectivity and it determines the neighbours. A binary tree denotes the branched structure and the representation of closed-loop that is not possible. The successive transmission of data through neighbours is constructed only once in a closed loop.

The connectivity matrix is used for representing a binary tree of dimension $Ndn (Agq) * Ndn (Agq)$ with the matrix element,

$$C_{i,j} = \begin{cases} 0, & \text{if } Ag_i \text{ and } Ag_j \text{ are not neighbours} \\ 1, & \text{if } Ag_i \text{ and } Ag_j \text{ are neighbours} \end{cases}$$

The packets involved in the aggregation rely on the path of data routing and the schema of routing. In polydisperse data aggregation, the aggregated packet data count varies from node to node may be higher than other data aggregation process. Increased packet creation may lead to the situation called traffic, congestion requirement, and requirement of the buffer. Thus, the process of aggregation is attained for the possible event. The overall methodology of the proposed protocol is demonstrated in Fig. 2.

Fig. 2 The overall function of the proposed protocol

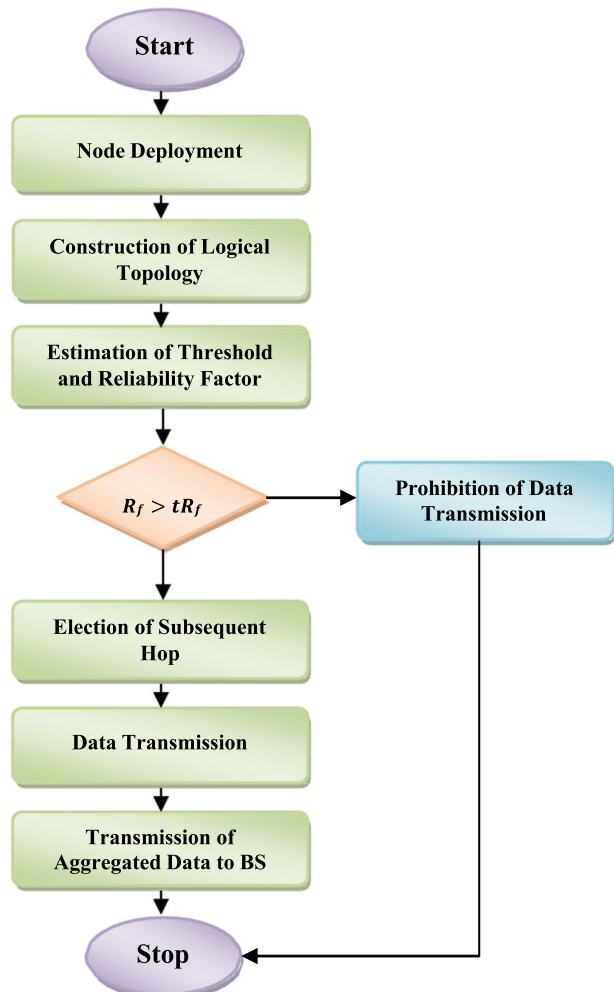


Table 1 Simulation parameters

Parameters	Values
No. of sensor nodes	550
Simulation area	1000 × 1000 m ²
Transmission range	50 m
Queue type	CMUPriQueue
Initial energy	100 J
Packet size	300 bits
Buffer length	65 packets
Initial node energy	70 J
MAC type	MAC/802.11
Simulation time	65 ms

Table 2 Comparison of packet delivery ratio

Network density	TESDA	ODVOC- EDGR	DAOHS-ODVOC-EDGR
1	0.95	0.958	0.96
1.15	0.96	0.969	0.97
1.3	0.974	0.982	0.984
1.45	0.971	0.982	0.991
1.6	0.982	0.986	0.992

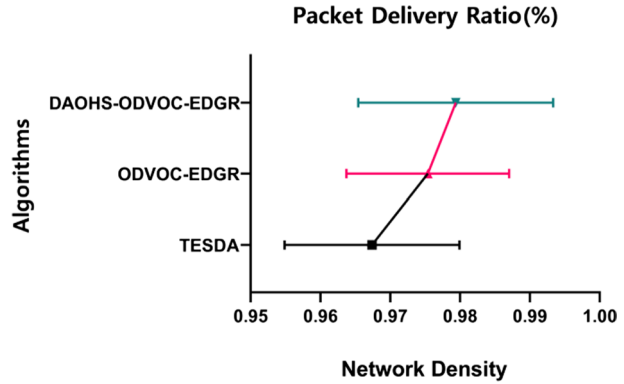
3 Analysis of Simulation

In this section, the simulation effects of the proposed DAOHS-ODVOC-EDGR protocol are depicted and it is evaluated with the existing TESDA and ODVOC-EDGR using Network Simulator (NS-2.34). The simulation is executed under two contexts such as sensing reliability with variations and network density. The parameters incorporated in the simulation are listed in Table 1.

3.1 Packet Delivery Ratio

Packet Delivery Ratio (PDR) is estimated as the count of packets delivered in the total count of packets transmitted from the source to the destination node [19]. The algorithm with higher packet delivery is considered as the best algorithm. The process of aggregation is accomplished by considering the delivery time of a sensitive packet in the network. In the DAOHS-ODVOC-EDGR, the transmission schedule is made on the basis of priority that provides assistance to accomplish the limitations of the delay in transmission. Thus, a node with maximal density DAOHS-ODVOC-EDGR performs better PDR value than the TESDA and ODVOC-EDGR. The performance of the algorithm is illustrated in Table 2 and Fig. 3.

Fig. 3 Comparison of packet delivery ratio



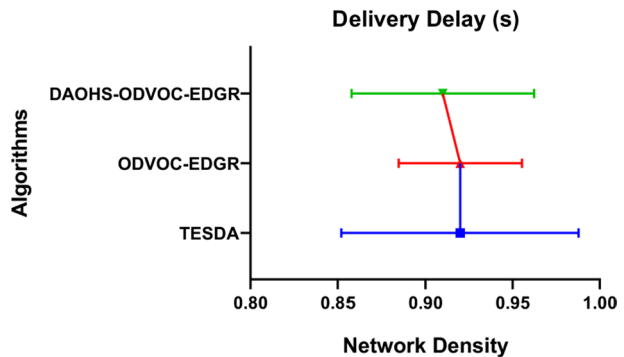
3.2 Delivery Delay

In TESDA, the process of aggregation duration relies on the nodes in the aggregation tree with a downstream process. The size of the tree rises with the compactness of the node and the delay in data transmission is also increases [20]. In the DAOHS-ODVOC-EDGR, the aggregation process and the binary tree construction is attained on the overlapping spheres. The binary tree is effective and the aggregation process is enriched and the process of data transmission is also improved with minimum delivery time. Table 3 and Fig. 4 depict the delivery delay of the proposed and existing algorithm. The data delivery time is minimized in the DAOHS-ODVOC-EDGR protocol effectively.

Table 3 Comparison of delivery delay

Network density	TESDA	ODVOC-EDGR	DAOHS-ODVOC-EDGR
1	104	99	98
1.5	103	96	94
1.3	99	93	91
1.45	97	90	87
1.6	94	87	85

Fig. 4 Comparison of delivery delay



3.2.1 Energy Consumption

In the WSN, every node in the transmission network is instilled with the minimum amount of energy and the process of recharging is also difficult [20]. The binary tree construction and aggregation considerably reduce congestion and traffic load. The process of transmission is carried without any hindrance and data transmission is attained in the shortest path. This situation reduces the exhaust of energy in the transmission nodes. The DAOHS-ODVOC- EDGR protocol has reduced the consumption of energy across various network densities and sensing reliability. The energy consumption value of the existing and proposed algorithm is displayed in Tables 4 and 5.

In Figs. 5 and 6, the utilization of energy across various network densities is illustrated and from the observation, it is identified that the proposed algorithm utilizes minimum energy.

Table4 Comparison of energy consumption

No of nodes	TESDA	ODVOC-EDGR	DAOHS-ODVOC-EDGR
20	0.0781	0.0651	0.0355
40	0.0761	0.0668	0.0378
60	0.0828	0.0797	0.0517
80	0.0852	0.0812	0.0582
100	0.0892	0.082	0.0652

Table 5 Comparison of energy consumption versus network densities

Network density	TESDA	ODVOC-EDGR	DAOHS-ODVOC-EDGR
1	2.8	2.7	2.51
1.15	2.72	2.62	2.56
1.3	2.64	2.54	2.54
1.45	2.6	2.5	2.48
1.6	2.57	2.47	2.37

Fig. 5 Comparison of energy consumption

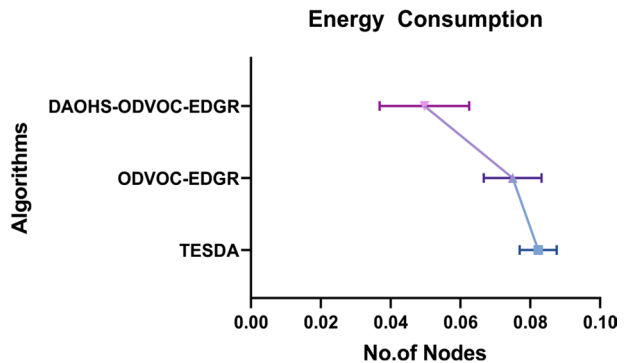
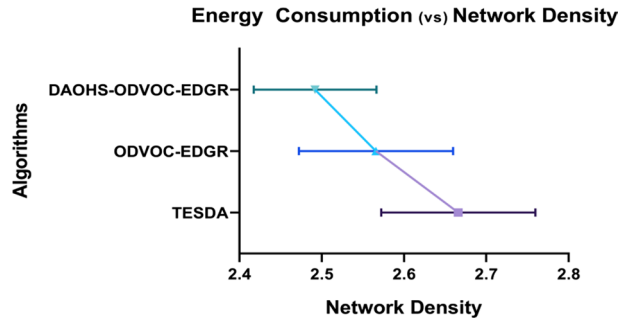


Fig. 6 Comparison of energy consumption versus network density



3.2.2 Network Lifetime

The effective hop election in the transmission made the proposed algorithm to attain a longer lifetime [21]. The increased lifetime of the algorithm results in better performance and the values are shown in Table 6. The network lifetime comparison and the efficiency of the proposed algorithm are reflected in Fig. 7.

3.2.3 Hop Count Delay

The average count of hop in the solution replicates the quality of the transmission path. Figure 8 reflects the hop count delay of TESDA, ODVOC-EDGR, and DAOHS-ODVOC-EDGR protocol. The proposed algorithm DAOHS-ODVOC-EDGR identifies the shortest

Table 6 Comparison of network lifetime

Network density	TESDA	ODVOC-EDGR	DAOHS-ODVOC-EDGR
1	321	332	345
1.15	329	340	348
1.3	334	345	351
1.45	339	350	359
1.6	346	358	363

Fig. 7 Comparison of network lifetime

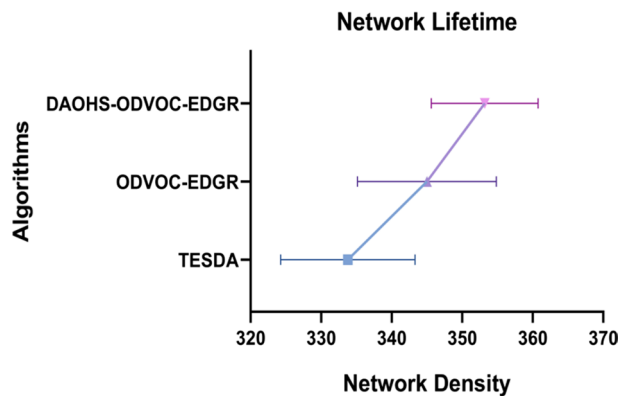
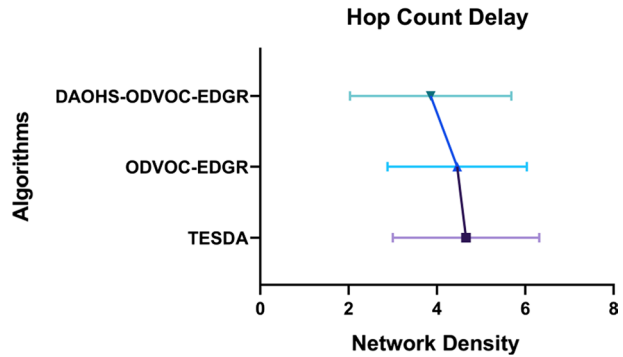


Fig. 8 Comparison of hop count delay

path from the BS to the sink node. Therefore, the transmission path is considered as an optimal, and hop count delay is also minimum [22]. The proposed algorithm has a shorter delay than other algorithm and it is desirable. The algorithm with a longer lifetime also yields very minimum delay. The increase in network density will result in a drop in the lifetime of the network that may increase the hop count delay. Though, a trade-off occurs among both the performance metrics, efficient utilization of resources results in the effectiveness of the algorithm. The proposed algorithm utilizes more sensor nodes to transmit the data than the traditional algorithm and also DAOHS-ODVOC-EDGR performs effectively. The hop count delay is given in Table 7.

In Fig. 8, hop count delay of the proposed and the existing algorithm is depicted with various network densities. From the observation, it is identified that the proposed algorithm has a better result.

The simulation results prove that the strategy presented by DAOHS- ODVOC-EDGR approach is applicable in both small and large networks and the results demonstrated that the network lifetime using DAOHS-ODVOC-EDGR approach is high when compared to other existing protocols with respect to various network densities respectively. Further, cluster based scheduling enabled the DAOHS- ODVOC-EDGR algorithm to decrease node energy consumption and achieved better load balancing among the nodes. From the results analysis, it has been also evidenced that the computational cost in terms of end to end delay is not improved as expected on increasing the network density. Stress testing in WSN can be considered as the process of determining that the network can continue to operate effectively under challenging circumstances or under high network densities. In this research work, the performance of the network is analyzed using various network densities which has been considered as a stress testing factor. Then, the PDR, End to End Delay, Energy Consumption, Network Lifetime, Communication Overhead and Throughput has

Table 7 Comparison of hop count delay

Network density	TESDA	ODVOC-EDGR	DAOHS-ODVOC-EDGR
1	6.3	6.1	5.9
1.15	5.9	5.6	5.1
1.3	5.2	4.9	4.4
1.45	3.5	3.4	2.1
1.6	2.4	2.3	1.8

been analyzed and the proposed approach is found better than the existing algorithms under various network densities (stress factor).

4 Conclusion

In this article, a proficient and polydisperse data aggregation scheme with effective usage of energy in WSN is discussed. In the DAOHS-ODVOC-EDGR, the sensing section is segregated into varied overlapping spheres that are dived on the basis of reliability requirements. The proposed protocol permits only a limited number of nodes and the construction of the binary tree is also initiated depends on the necessity. This context minimizes the utilization of energy among the sensor nodes and also the traffic load is reduced. The effective subsequent hop node election enriches the temporal and spatial convergence of the polydisperse data aggregation. The data in the network is aggregated selectively based on the overlapping spheres that improve the network lifetime and PDR value. The delay and the hop count delay are reduced considerably in the proposed algorithm. In the future, the algorithm is altered and tested for a real-time dynamic environment. The effective scheduling procedures incorporated in the aggregation process that can improve the overall performance of the algorithm.

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Code availability Codes can be shared on request.

Declarations

Conflict of interest Author does not have any conflict of interest.

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