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An Energy Aware Data Aggregation in Wireless Sensor Network Using Connected Dominant Set

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***Abstract*—**Wireless Sensor Networks (WSNs) have many advantages. Their deployment is easier and faster than wired sensor networks or other wireless networks, as they do not need fixed infrastructure. Nodes are partitioned into many small groups named clusters to aggregate data through network organization. WSN clustering guarantees performance achievement of sensor nodes. Sensor nodes energy consumption is reduced by eliminating redundant energy use and balancing energy sensor nodes use over a network. The aim of such clustering protocols is to prolong network life. Low Energy Adaptive Clustering Hierarchy (LEACH) is a popular protocol in WSN. LEACH is a clustering protocol in which the random rotations of local cluster heads are utilized in order to distribute energy load among all sensor nodes in the network. This paper proposes Connected Dominant Set (CDS) based cluster formation. CDS aggregates data in a promising approach for reducing routing overhead since messages are transmitted only within virtual backbone by means of CDS and also data aggregating lowers the ratio of responding hosts to the hosts existing in virtual backbones. CDS tries to increase networks lifetime considering such parameters as sensors lifetime, remaining and consumption energies in order to have an almost optimal data aggregation within networks. Experimental results proved CDS outperformed LEACH regarding number of cluster formations, average packet loss rate, average end to end delay, life computation, and remaining energy computation.

***Keywords*—**Wireless sensor network, connected dominant set, clustering, data aggregation.

I. Introduction

WSNs have hundreds/thousands of sensor nodes deployed in hostile, uninhabitable, and harsh environments, for a limited period, with a common aim of providing distributed sensing, storage, and communication services. Sensor nodes organize themselves and are the front line observation for end users placed far away. In homogeneous WSNs, sensor nodes are identical regarding battery energy and hardware complexity [1]. WSNs are systems of spatially distributed sensor nodes collecting information in a target environment. WSNs are envisioned for a range of applications like battlefield intelligence, environmental tracking, and emergency response [2]. A sensor node has limited computational capacity, battery supply, and communication capability.

Sensors are used in an ad hoc manner to monitor events and gather data about the environment. They sense, process data, and communicate with each other in the network. WSN multi-hopping causes a sensor node to communicate with a node far away allowing the network sensor nodes to expand monitored area and prove its scalability/flexibility. If the node cannot communicate with others directly i.e. they are out of coverage area, then data is sent to other nodes using nodes in between. This is called multi-hoping.

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A network is divided into clusters through clustering [3]. Clustering-based routing protocols are more energy efficient as they and Cluster Heads (CH) produce limited information from voluminous raw sensed data by cluster nodes and transmit this to a network Base Station (BS) which consumes less energy [4]. Most WSN clustering protocols in literature are meant for static sensor nodes and so are unsuitable for WSN applications needing mobile nodes for habitat, wildlife monitoring, and health. LEACH is a standard WSN clustering protocol.

Data aggregation is collecting/aggregating useful data. It is a fundamental procedure to save energy [5]. Data aggregation in WSNs is an effective way to save limited resources. The goal of data aggregation algorithms is gathering and aggregating data in an energy efficient way enhancing network life.

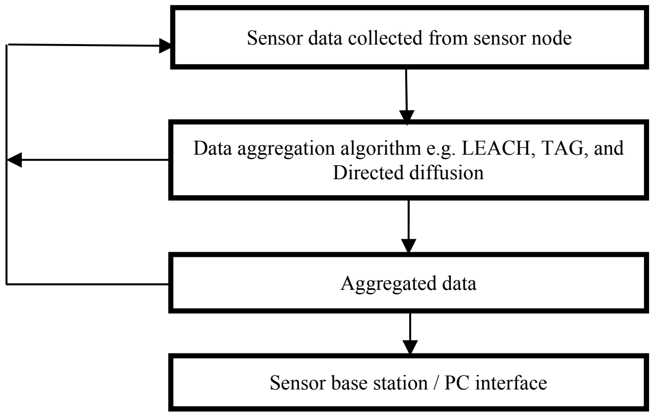

Fig. 1 Classification Accuracy

Data aggregation protocols eliminate redundant data transmission and improves the life of energy constrained WSNs [6]. Data aggregation collects critical data from sensors and makes it available to a sink in an energy efficient manner with reduced data latency. Data latency is important in applications like environment monitoring where data freshness is important [7]. Developing energy efficient data aggregation algorithms enhances network life. Many factors determine a sensor network's energy efficiency like network architecture, data aggregation mechanism, and routing protocol.

In WSNs, network density is high. Therefore, there are much redundant data transmitted in a network and collected by spatially close nodes. Routing has an important role in data aggregation, to determine how data is routed. It helps effective data aggregation, an important WSN topic [8]. When WSN is event driven, fixed routing is not suitable due to correlation advantages between data to reduce data redundancy which results in large data load. For effective data aggregation, it is essential to build routes overlapping dynamically, according to the events. Normally, when nodes are closer, data correlation is better and data aggregation high. When events are farther then data correlation and data aggregation are not efficient.

Data aggregation is a useful paradigm for wireless routing in sensor networks to combine data from different sources enroute – eliminating redundancy, minimizing transmissions, and saving energy. Sensor data is different from data associated with conventional wireless networks as it is not the data alone that is important [9].

The type of high-level data description or data aggregation to be performed depends on monitored events and user requirements. Minimum, maximum, average, count, beam forming, and functional decomposition are examples of data aggregating functions/techniques.

Data aggregation's advantages, necessities, and opportunities in a sensor network were confirmed theoretically and experimentally. Recognizing that computation would consume less energy than communication, substantial energy savings are obtained via data aggregation. This technique achieved energy efficiency and traffic optimization in many routing protocols. All aggregation functions are assigned to powerful and specialized nodes [10] in some network architectures. Data aggregation is feasible through signal processing also.

This work presents CDS based cluster formation. The work is compared with existing LEACH protocol. The rest of this paper is organized as follows: Section II reviews clustering and data aggregation based papers from the literature. Section III explains the proposed method of CDS and Section IV discusses the experiment results. Section V concludes the work.

II. Literature Review

A lightweight management protocol that assigned tasks to sensors based on energy to ensure even energy consumption among network sensors was evaluated by Abdel Salam et al. [11]. They suggested another mechanism to aggregate data collected by sensors before reverting them to BS. The aggregation mechanism supports different functions including exact evaluation of minimum, maximum, and logical OR, and an approximation of average of collected sensory data. Finally, it compared life achieved by assigning tasks to network sensors using the new protocol against another energy-neutral protocol.

An energy efficient data aggregation protocol named Feed Forward Data Aggregation (FFDA) to construct a spanning tree proposed by Inanlou Hamed et al. [12] represented a new parameter called Energy After Transmission (EAT) which considers EAT as a parameter to select a node as root for spanning tree at the start of each data aggregation round. Using a new parameter, remaining nodes energy are more balanced thereby delaying the death of first node and improving system's life as proved by simulation.

An energy-distance aware query-based data aggregation technique named EDQD that does not need to cluster was proposed by Ahvar [13]. When neighbours witness an event, EDQD chooses the best of them as aggregator by learning automata concept. Therefore, EDQD balances network energy consumption and increases network life. Finally, EDQD was simulated/evaluated through Glomosim simulator.

An asynchronous grid-based network implemented by Zanjani and Boustani [14] was for Data Aggregation where a spread spectrum chip code was used to ensure high capability in working with asynchronous networks. This was in addition to sending data through a channel and for data aggregation. Finally, simulation proved that in environments with high noise rate the presented algorithms were more efficient with less packet damage during data transfer.

An energy-aware distributed algorithm proposed by Jen-Yeu Chen et al. [15] constructed an endurant spanning tree for WSN data aggregation. Nodes with higher residual energy are closer to trunk on the constructed aggregation tree, to maximize tree life and maintain aggregated data integrity. The algorithm by arranging nodes with higher residual energy close to aggregation tree root relieved the responsibility of nodes with less residual energy. The algorithm for tree construction was distributed; a node makes its decision by exchanging information with neighbouring nodes.

Packet attribute to data aggregation was introduced by Jiao Zhang et al. [16] who proposed an Attribute-aware Data Aggregation mechanism using Dynamic Routing (ADADR) which makes packets with same attribute converge as much as possible, and thus improved data aggregation efficiency. This goal cannot be achieved by static routing schemes used in most data aggregation mechanisms. So, it presented a potential -based dynamic routing scheme using the concept of potential in physics and pheromone in an ant colony.

A layered clustering structure for WSN data aggregation was proposed by Mirian and Sabaei [17] where a layer of clusters has specific delay and accuracy to aggregate information at a given time and with predetermined accuracy. The aim was construction of an application-aware structure for data aggregation. To control response's varying accuracies, a layer has specific nodes. The clusters in each layer were set to control time to aggregate and transfer data from nodes to sink within application deadlines.

A comparative study of different research proposals, suggesting different CH selection approaches for data aggregation was proposed by Nithyakalyani and Kumar [18]. The algorithms studied were Fuzzy C-means clustering algorithms, Data relay K-means clustering algorithm, and Voronoi based Genetic clustering algorithm. Significant factors evaluating/comparing the algorithms were defined, analyzed, and summarized. It was assumed that sensor nodes were randomly distributed and not mobile and BS coordinates and sensor field dimensions were known.

A WSN data aggregation and routing protocol specifically suited to large deployed sensor networks was presented by Nawaz and Bazaz [19]. The new mechanism combined a gradient based routing scheme with the LEACH protocol's hierarchical scheme. By combining both protocols and considering node energy when selecting CHs, a robust strategy for data aggregation and routing was developed.

An Energy Aware Sleep Scheduling Clustering based Routing scheme (EASSCR) for WSN proposed by Pramanick et al. [20] put nodes to sleep to prolong network life. EASSCR selects a node as CH if its residual energy was more than system's average energy. If remaining energy reached 5% of its initial energy, then it directly sends data to BS avoiding node failure during data collection or aggregation. This scheme aimed to increase network stability period and reduce sensed data loss.

A hybrid clustering based data aggregation scheme proposed by Woo-Sung Jung et al. [21] adaptively chooses suitable clustering technique based on network status increasing data aggregation efficiency, energy consumption, and successful data transmission ratio. Performance evaluation via simulation showed the proposed scheme's effectiveness.

An energy-efficient data aggregation transfer protocol based on clustering and data prediction called DACP proposed by Lingjun Meng et al. [22] ensures that sensor nodes send messages to sink node in the initialization phase. The sink node divided the network into clusters and elected CH for clusters. Sensor nodes receive predicted data and compare it with sensed data in prediction phase. In data aggregation phase CH nodes aggregate sensed data from cluster member nodes. The new protocol effectively reduced data transmission and improved data aggregation efficiency through data prediction.

Enam and Qureshi [23] developed a new, adaptive method of data aggregation exploiting the spatial correlation between sensor nodes. The main feature of the new aggregation method was that in addition to reducing the cost of redundant data transfer in networks, it optimally utilizes available packet space at each CH. Simulation results showed that payload size decreased by almost 25% of non-compressed payload in the new aggregation method.

Data aggregation and security issues were addressed together by Ranjani et al. [24] which modified Energy efficient Cluster Based Data Aggregation (ECBDA) scheme to ensure secure data transmission. As sensors nodes are low powered by nature, it is not viable to apply standard cryptography methods. CH performed data aggregation and Bayesian fusion algorithm to ensure security. Trust was a directional relationship between two sensor nodes. By checking a node's trustworthiness, it enables secure communication. Bayesian fusion algorithm calculated a sensor's trust probability based on node behaviour.

Information discovery and aggregation in large scale WSNs proposed by Shanmukhi and Ramanaiah [25] applied for mission-critical applications like military reconnaissance. To support query processing based on gathered information, an efficient/reliable information discovery mechanism was proposed for sensor networks by extending basic Comb-Needle Discovery Support Model and including Cluster-based data aggregation mechanism to reduce communication cost. Cluster based approach groups sensor nodes in sensor networks. A group node sends information to CH, which aggregates/forwards information to BS (Sink).

An Energy efficient Cluster Based Data Aggregation scheme for sensor networks (ECBDA) proposed by Ranjani et al. [26] has Cluster formation, CH election, Data aggregation, and Maintenance phases. Cluster members send data only to corresponding local CH. Data from neighbouring sensors are often redundant and highly correlated, and so a CH performs data aggregation to reduce redundant packet transmissions. Clusters were formed in a non-periodic manner to avoid unnecessary setup message transmissions in this scheme. Simulations proved that the approach reduced energy consumed effectively and increased network life.

A novel topology, frame format and protocol for cluster based data aggregation for public utility control and management was proposed by Nayaka and Biradar [27].

A new approach to classify energy-efficient data aggregation protocols based on structure, search-based, and time-based approaches was presented by Bala Krishna and Vashishta [28]. Analysis for structure-free, structure-based, and time-based data aggregation protocols was detailed. Simulation indicated that energy and throughput rate improved in cluster-based data aggregation protocols compared to structure-free, time-based, or search-based data aggregation protocols.

III. Methods

In this section, Low-Energy Adaptive Clustering Hierarchy (LEACH) and clustering based Connected Dominating Set (CDS) are described.

A. LEACH

LEACH is a popular energy efficient hierarchical clustering algorithm for WSNs. In it, clustering is rotated among nodes, based on duration [29]. Direct communication is used by CHs to forward data to BS. LEACH divides a network into sensor clusters, constructed by using localized coordination and control to reduce data transmitted to sink and to ensure that routing and data dissemination are scalable and robust.

LEACH's key features are: (i) randomized rotation of CH and corresponding clusters, (ii) local compression to reduce global communication, (iii) and localized coordination/control for cluster set-up/operation. LEACH uses a randomized rotation of high-energy CH position instead of selecting statically to provide a chance for all sensors to act as CHs and prevent battery depletion of individual sensors which then die quickly.

LEACH uses round as unit and each round consist of cluster set-up stage, and steady-state stage, to reduce unnecessary energy costs. Steady-state stage must be longer than set-up stage [30].

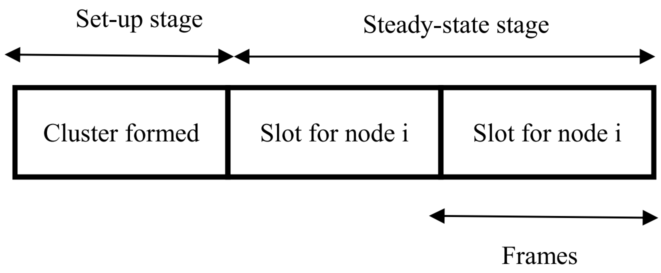

Fig. 2 LEACH Stages

In LEACH CH is chosen using threshold value t(n). A sensor node in a cluster chooses a random number either 0 or 1 and this is compared to a threshold value t(n). If the chosen number is less than t(n), then the node becomes CH otherwise it continues as an ordinary node. Fig. 2 represents transmission in LEACH.

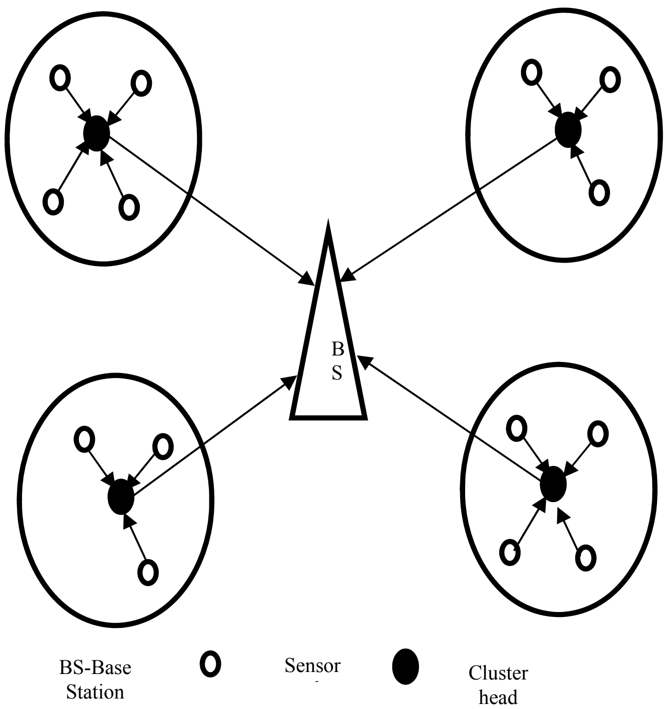

Fig. 3 LEACH

Threshold value is determined by:

$$t(n) = \begin{cases} \dfrac{p}{1 - p*(r \bmod \frac{1}{p})} & if\, n \in G \\ 0 & if\, n \notin G \end{cases} \quad (1)$$

1. Equation (1) calculates threshold value, where p is percentage of CH nodes among nodes, r is number of round, G the collections of nodes not yet chosen as head nodes in first 1/P rounds. Fig. 1 represents LEACH's 2 stages.
   - Set-Up Stage: During setup phase,
   - Each node decides whether to become CH based on threshold value.
   - After selecting CH, other nodes select own CH and join cluster based on energy.
   - A node will choose nearest CH.
2. Steady-State Stage: During steady-state phase,
   - CH fuses data from cluster members and sends it to BS through single-hop communication.
   - LEACH uses randomization to rotate CH for each round to evenly distribute energy consumption.
   - So LEACH reduces data directly transmitted to BS and balances load in WSNs.

Different modified LEACH types are: LEACH-F, a modified version of LEACH with fixed clusters and rotating CHs. It does not allow new nodes to be added to the system and does not adjust their behaviour based on nodes dying. LEACH-Centralized is an enhancement of LEACH. LEACH-C uses a centralized clustering algorithm and same steady-state phase as LEACH. LEACH-C is more efficient than LEACH as it delivers 40% more data per unit energy than LEACH. Energy-LEACH improves CH selection procedure in LEACH [31].

V-LEACH is a new LEACH version which aims to reduce energy consumption within wireless networks. The concept behind V-LEACH is that in addition to having a CH in cluster, there is a vice-CH that takes up the role of CH when CH dies. Hierarchical LEACH minimizes communication distance between nodes to conserve energy. It uses the same clustering approach as LEACH during initial phases and later extends LEACH by clustering CHs and nominates a CH, which acts as Master Cluster Head (MCH), to forward data to BS.

LEACH protocol suits WSNs under the assumptions [32]:

- All senor nodes are identical and have same initial energy. All nodes consume energy at same rate and know their residual energy and control transmission power and distance. A node has ability to support different MAC protocols and data processing. All communication channels are identical. Energy consumed in transferring data from node A to node B is same as transferring same data from node B to node A.
- A node can directly communicate with other nodes, including sink node.
- Sink node is fixed and far from the wireless network and it is assumed that sufficient energy for operation is always available.
- Every node has data to transfer in all time frames.
- Sensor nods are static.

B. CDS

A CDS is a nodes set that any node in a network is a neighbour of some element in the set. It is connected if sub-graph formed by the set is connected. CDS property ensures that nodes receive packets. CDS forwarding rule is that a node retransmits if it has not received packet already and it is in connected dominating set. Also, selection of connected dominating set must be distributed. A node based on neighbourhood knowledge, must decide whether it is in a dominating set. CDS is a good candidate for a virtual backbone for wireless networks, as non-CDS nodes in a network is 1-hop distance from a CDS node. CDS makes routing easier and adapts quickly to network topology changes [33].

CDS formation is a promising approach to reduce broadcast routing overhead where messages are forwarded on a CDS induced virtual backbone. Forwarding on the virtual backbone alleviates broadcast storm issues as hosts responsible for broadcast routing are reduced to number of hosts in backbone. Constructing virtual backbones decreases routing overhead greatly by decreasing further dispersion and addition [34].

WSNs, with CDS as its Virtual Backbone, dominate by forwarding data only to connected dominators. Moreover, CDS with smallest size (nodes in CDS) is a Minimum sized Connected Dominating Set (MCDS). MCDS is built to reduce nodes and links involved in communication. Minimum rOuting Cost Connected Dominating Set (MOCCDS) locates a minimum CDS and assures that any routing path through this CDS is shortest in WSNs. Most existing works consider constructing MCDS and MOCCDS but do not consider WSNs load-balance factor [35]. If workload on a CDS dominator is not balanced, dominators with high load (i.e.) dominator with large number of dominates, deplete energy quickly due to which the entire network might be disconnected. So, in addition to constructing a MCDS, it is necessary to construct a Load-Balanced CDS (LBCDS).

CDS is also used for location-based routing where messages are forwarded based on hosts geographical coordinates, rather than topological connectivity. Intermediate nodes are chosen based on their proximity to message destination. It is possible for a message to reach a local maximum with this scheme where it has been sent to an intermediate node whose neighbours are farther from destination than itself. But, if messages are only forwarded to nodes in dominating set, inefficiency associated with recovery phase is reduced greatly [36].

Multicast/broadcast routing efficiency can be improved through use of CDSs. A problem in multicast/broadcast routing is that intermediate nodes forward a message unnecessarily. Nodes often hearing same message many times is a broadcast storm problem. If message is routed along a CDS, most redundant broadcasts are eliminated. Wireless network nodes often have limited energy. CDSs play a big role in power management. They were used to increase nodes that are put in a sleep mode, while still having the ability of network to forward messages.

Clustering Using Dominating Sets: A dominating set is a graph G’s subset S so that every vertex in G is either in S or adjacent to a vertex in S. Dominating sets are used in clustering networks [37]. Dominating sets are classified into 3 classes, Independent Dominating Sets (IDS), Weakly Connected Dominating Sets (WCDS) and Connected Dominating Sets (CDS).

- Independent Dominating Sets: IDS is a dominating set S of a graph G where there are no adjacent vertices. Fig. 4 revels a sample independent dominating set where black nodes show CHs.

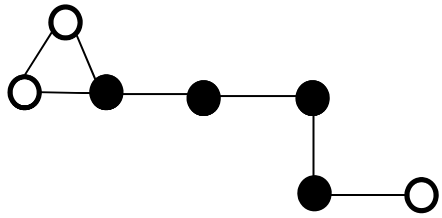

Fig. 4 IDS

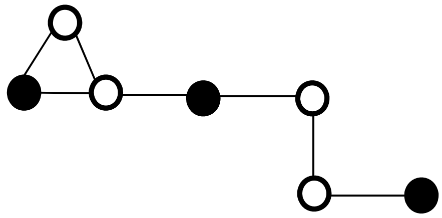

Fig. 5 MCDS

- Weakly Connected Dominating Sets (WCDS): A weakly induced sub graph (S)w is a subset S of graph G with vertices of S, their neighbours and edges of original graph G with one endpoint at least in S. A subset S is a weak-connected dominating set, if S is dominating and (S)w is connected. Black nodes in Fig. 5 reveal a WCDS example.

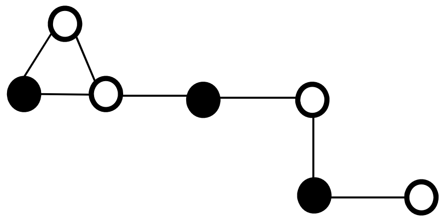

Fig. 6 CDS

- Connected Dominating Sets: A Connected Dominating Set (CDS) is a graph G’s subset S so that S forms a dominating set and is connected. Fig. 6 shows a CDS sample.

Calculating sensors and CDS lifetimes: Let n be number of sensors: B_i initial energy of sensors; $x_{i,j}$ number of bits routed from sensor i to sensor j; $x_{i,0}$ be number of bits routed from sensor i to BS; $t_{i,j}$ be sensor i communication cost to transmit one bit to sensor j; and $r_{i,j}$ be sensor i communication cost to receive one bit from sensor j. In data aggregation a sensor receives data from one/more sensors, but sends data only to a sensor [38]. Total sensor i consumed energy amount to transmit one event (ξ_i) is calculated as:

$$\xi_i = \sum_j X_{j,i} r_{j,i} + \sum_i X_{i,j} r_{i,j} \tag{2}$$

Sensor “i” remaining energy is calculated as:

$$B_i(t) = B_i(t-1) - \xi_i \tag{3}$$

B_i (t) and B_i (t-1) are current and previous remaining energies, respectively.

Sensor i life is calculated as:

$$\alpha_i = B_i / \xi_i \tag{4}$$

The average of CDS lifetime is calculated as:

$$\bar{\alpha} = \alpha_{CDS} / m \tag{5}$$

where $\bar{\alpha}_{CDS}$ equal to average lifetime of CDS and α_{CDS} equal to Total lifetime of sensors constituting CDS and is the number of sensors exist in CDS.

$$\alpha_{CDS} = \sum_{i=1}^{m} \alpha_i \tag{6}$$

IV. Results and discussion

Simulations are conducted with varying number of nodes (100 to 600). The transmission range of node is 100 m and the size of network: 2000 x 2000 m. BS is located at the center of the network. The experiments conducted for the proposed CDS-WSN and compared with LEACH and Tables I-V shows the results of the experiments conducted for number of clusters formed, average end to end delay, average packet loss rate, lifetime computation and remaining energy computation.

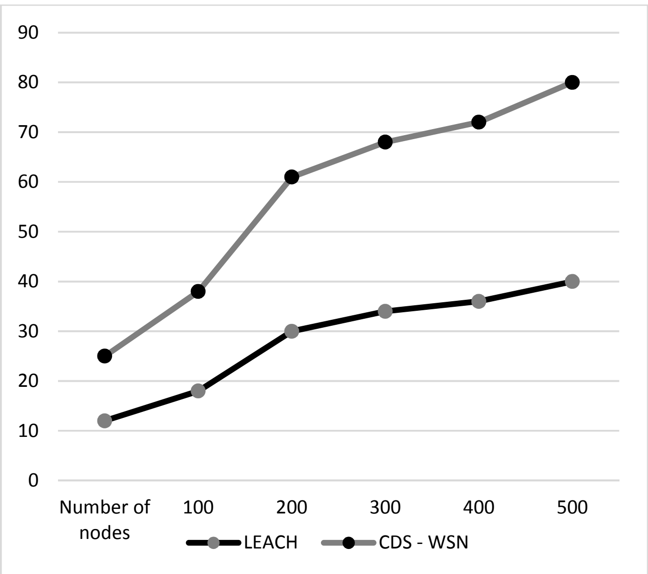

Fig. 7 Number of clusters formed

From Fig. 7, it can be observed that the proposed method improved the number of clusters formed by 8% when compared with LEACH method with 100 number of nodes and it can be observed that the proposed method improved the number of clusters by 3.28% when compared with LEACH method with 300 number of nodes.

TABLE I
NUMBER OF CLUSTERS FORMED

Number Of Nodes	LEACH	CDS - WSN
100	12	13
200	18	20
300	30	31
400	34	34
500	36	36
600	40	40

TABLE II
AVERAGE END TO END DELAY

Number Of Nodes	LEACH	CDS - WSN
100	0.001624	0.001616
200	0.001716	0.001989
300	0.01693	0.018007
400	0.026305	0.022011
500	0.054397	0.052581
600	0.061074	0.056286

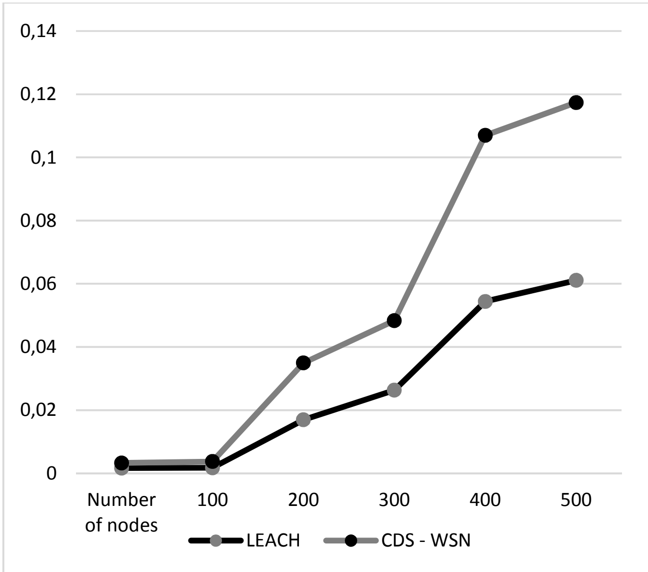

Fig. 8 Average end to end delay

From Fig. 8, it can be observed that the proposed method decreased the average end to end delay by 6.11% when compared with LEACH method with various numbers of nodes.

TABLE III
AVERAGE PACKET LOSS RATE

Number Of Nodes	LEACH	CDS - WSN
100	10.09536	9.150242
200	15.542937	13.765609
300	16.066463	15.443441
400	22.324248	20.771756
500	30.138109	28.094322
600	41.979386	39.944671

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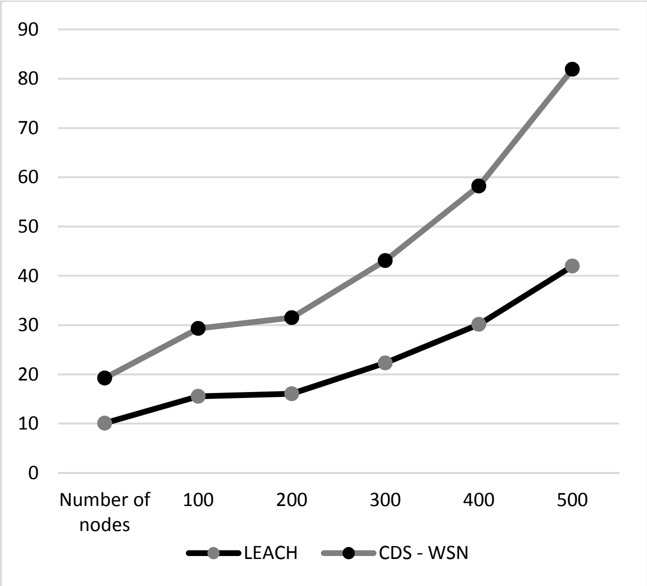

Fig. 9 Average packet loss rate

From Fig. 9, it can be observed that the proposed method decreased the average Packet loss rate by 6.82% when compared with LEACH method with various numbers of nodes.

TABLE IV
LIFETIME COMPUTATION

Number Of Rounds	LEACH	CDS - WSN
0	100	100
100	100	100
200	89	91
300	68	84
400	73	76
500	22	54
600	3	18
700	0	0

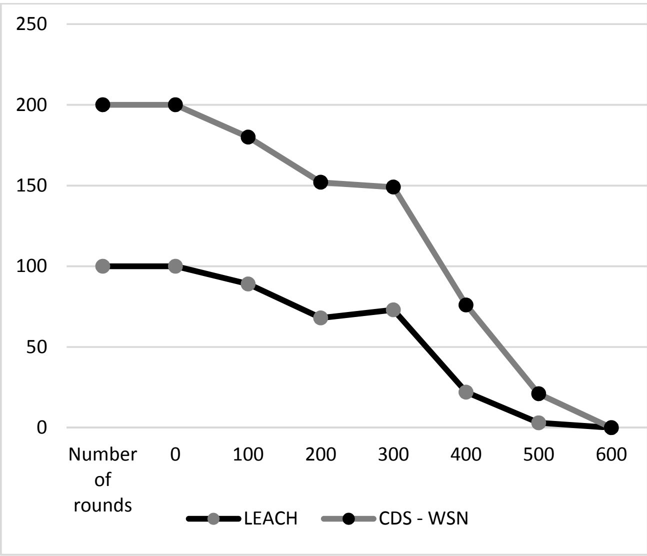

Fig. 10 Lifetime computation

From Fig. 10, it can be observed that the proposed method improved the Lifetime computation by 21.05% and 142.86% when compared with LEACH method with 300 and 600 number of rounds.

TABLE V
REMAINING ENERGY COMPUTATION

Number Of Rounds	LEACH	CDS - WSN
0	0.5	0.5
100	0.43	0.46
200	0.23	0.34
300	0.18	0.29
400	0.19	0.27
500	0.11	0.18
600	0	0.1
700	0	0

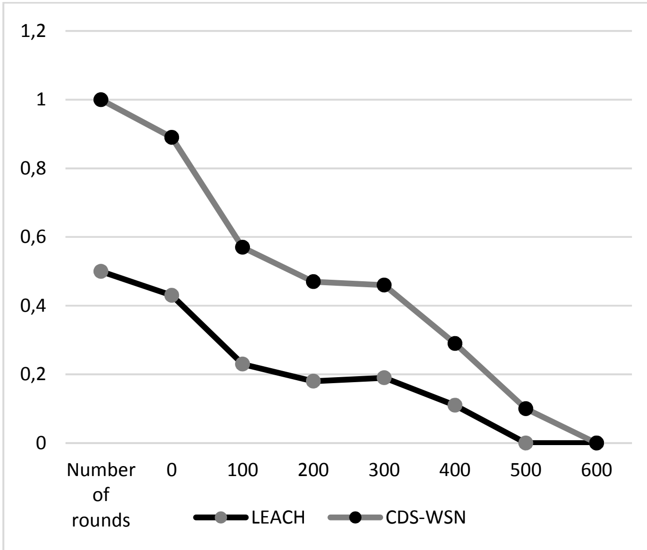

Fig. 11 Remaining energy computation

From Fig. 11, it can be observed that the proposed method improved the remaining energy computation by 6.74%, 46.8085% and 48.28% when compared with LEACH method with 100, 300 and 500 number of rounds.

V. CONCLUSION

This paper investigates energy aware data aggregation in WSN using CDS. LEACH uses randomized rotation of high-energy CH position instead of choosing statically, to provide all sensors a chance to act as CHs and avoid battery depletion of individual sensors. A CDS is a set of nodes where a network node is always a neighbour to some element. It is connected if sub-graph formed by the set is connected. CDS property ensures all nodes receive packets. LEACH and the proposed cluster formation based on CDS are evaluated. Experimental results proved CDS outperformed LEACH regarding number of cluster formations, average packet loss rate, average end to end delay, life computation, and remaining energy computation.

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