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QoS based congestion evasion clustering framework of wireless sensor networks

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Abstract

Congestion is a significant issue for event-based applications due to the continuous data collection and transmission by the sensors constituting the network. The congestion control technique monitors the process of adjusting the data and intends to manage the network traffic level to the threshold value. The information gathered from an intensive study is required to strengthen the knowledge base for devising a QoS based congestion evasion clustering framework of wireless sensor networks. In this scheme, the cluster heads are optimally determined and dispersed over the network. The data aggregation approach has been applied in a clustered network and set out a crucial paradigm for WSN routing. The proposal employs to mitigate congestion while messages are being forwarded via an alternate route to distribute the traffic and increase the throughput. This technique aims to balance the energy ingestion among the sensor nodes, reduce energy consumption, improve network lifetime, and achieve the quality of services. The result analysis revealed that the proposed scheme recommends 22.5% better throughput, 21% lesser end-to-end delay, 25.5% better delivery ratio, and efficiently relieves congestion while preserving the network's performance for attaining QoS in wireless sensor networks.

Keywords: Clustering; congestion control; data aggregation; quality of services; wireless sensor networks.

1. Introduction

Wireless sensor networks comprise profuse sensor nodes to create an ad hoc distributed data proliferation network that collects context information about the physical environment (Shahraki *et al.,* 2020). Routing (Zear *et al.,* 2021; Saha *et al.,* 2021) would not be an intricate calculation and can acclimate to dynamic topology changes, ensuring consistent energy indulgence across a network while also helping to accomplish the quality of services. The multipath routing strategy is extensively utilized in WSN to increase network performance by efficiently using the available network resources. Clustering (Ali *et al.,* 2020) is a network management technique for designing hierarchical structures that are both scalable and resilient. Hierarchical routing employs multi-hop communication among the network nodes in a particular region and performs data aggregation to reduce the total delivered messages to the sink node to maintain energy consumption effectively.

Congestion (Pandey *et al.,* 2020) is one of the predominant snags due to the restricted resources for data processing, communication capacity, and energy supply. Sensor nodes near the sink node are more susceptible to node-level congestion where packet loss is encountered and affects the network's lifetime. Multiple sensor nodes attempt to access the transmission medium concurrently in link-level congestion. In order to achieve QoS, end-to-end congestion control adjusts the traffic rate of source and intermediary nodes. WSN applications have their specific QoS (Kaur *et al.,* 2019) requirements and are categorized as; network-specific QoS and application-specific QoS. Due to diverse traffic flows, changing network conditions, and the resource-constricted sensor nodes, accomplishing the quality-of-service requirements of several applications remnants a hard challenge for routing protocols. Several sensors in each location will acquire numerous redundant data due to the random distribution of network nodes. Route discovery in a flat network is made by flooding, where duplicate messages expand network load and necessitate additional bandwidth.

To solve the problem, we propose a QoS based congestion evasion clustering framework for sensor networks to enrich the network performance.

The followings are the main contributions of the proposed framework:

- We have introduced cluster formation mechanism, where dynamic cluster head selection process ensures even dissemination of energy among the sensor nodes to ensure that no nodes would run out of energy. The maximum number of cluster members is restrained during cluster formation to balance the energy consumption and create routing trees where cluster heads appear as the child node of the tree.
- We have proposed cluster member level and cluster head level data aggregation strategies to assure distinct data delivery to sink node.
- We have forged the node level congestion mitigation technique for priority and regular data where sensor nodes would be aware of the congestion level of the upstream or downstream neighbour nodes before forwarding the data packets.
- In this proposal, the message forwarding has been carried out via multipath routing, which is crucial for maintaining alternate routes, distributing traffic loads, and increasing throughput.

Extensive simulation shows that our proposed framework outperforms other existing protocols and achieves better network lifetime, energy efficiency, and accomplishes the quality of services.

The rest of the paper is delineated as follows. Section 2 attempts to introduce a holistic view of the state-of-the-art congestion control technique along with the hierarchical cluster-based routing. A comprehensive study of QoS mechanisms is offered here. In section 3, we have proposed a QoS based congestion evasion clustering framework of wireless sensor networks. The simulation in section 4 reveals that the proposed technique outperforms than other existing algorithms. This paper has been concluded in section 5.

2. Related Works

This section includes a comprehensive fine-grained survey on the distinct routing protocols of WSN. Several well-known clustering algorithms have been studied to recognize the pros and cons of those proposals for designing the novel hierarchical clustering routing.

The LEACH (Heinzelman *et al.,* 2000) protocol employs a cluster-based hierarchical architecture with random cluster head rotation to disperse the energy load across the sensor nodes but is inappropriate for large networks and cannot confirm load balancing. The data aggregation in EELEACH (Arumugam *et al.,* 2015) impedes a significant amount of energy while routing is implemented based on adequate data collection and optimum clustering. In CDAS (Devi *et al.,* 2020), latency and packet loss reduction lessen the overhead and end-to-end delay while improving energy utilization and network lifetime. In (Khediri *et al.,* 2020), intra-cluster communication employs single hop; in contrast, inter-cluster communication manages multi-hop communication mode and achieves energy utilization. Although the network lifetime is the most significant concern (Han *et al.,* 2020), offline parameter optimization has a high-level complexity, creates computational overhead, and does not concern multi-hop communication. EASS (Khan *et al.,* 2020) defines different states depending on the sensor node's internal elements and aligns them based on the contents of data packets and the incidence of produced traffic. In (Salim *et al.,* 2021), cluster heads are designated based on the continuing energy and distance between the cluster heads and confirms fault tolerance level. In (Behera *et al.,* 2021) presented an adaptive, resilient cluster head selection where the threshold value of CH election is adjusted based on enduring energy and the optimum number of clusters. Brainstorm optimization with levy distribution-based clustering was proposed in (Cho *et al.,* 2021), whereas data aggregation approaches for curtailing energy intemperance are not considered. In Q-DAEER (Yoo *et al.,* 2021), a data aggregation method is utilized to compute the optimum path to extend the network's lifespan while minimizing energy utilization. Priority would be calculated using the priority function in CPMEA (Ranga *et al.,*2016), and accordingly, actors would be chosen. The major objective is choosing the smallest number of actors or the smallest overlap between their respective positions. In (Adhikary *et al.,* 2021), the clustering scheme achieves load distribution and ensures energy efficient route discovery, but this proposal does not consider data aggregation mechanism. The preceding study shows that the choice of cluster heads is a crucial issue in hierarchical cluster routing. Incredibly, the construction of clusters and the rotation of the cluster head have a substantial effect on the entire network's performance.

To identify the congestion-related parameters, we have studied a variety of congestion control mechanisms to weigh the benefits and drawbacks of those proposals. In (Bhandari *et al.,* 2018), a multi-criteria decision-making method and different routing metrics are used to identify the optimum substitute parent node that is used to alleviate the congestion. In (Singh *et al.,* 2018), the proposal uses a multi-objective optimization strategy to limit the arrival rate depending on priority by allowing priority-based communication. The authors (Farsi *et al.,* 2019), proposed congestion-aware clustering routing to reduce end-to-end delay and extend the network's lifetime by selecting the primary and secondary cluster head. Authors (Srivastava *et al.,* 2019), devised an algorithm that lowers the total end-to-end delay while increasing network endurance using the firefly optimization technique. The alternate hop selection method (Adil *et al.,* 2021) diverts sensor communication to the neighbors and regulates network traffic in a congested environment while also extending the network lifetime.

The aforesaid study identifies that the network performance has been affected due to the congestion. Congestion evasion methods should be implemented to regulate the network traffic when there is likely to be transitory congestion.

QoS mechanisms have been put through a thorough analysis that highlights the performance issues, which would help design the proposed proposal. In (Deepa *et al.,* 2020), an alternative path was dynamically selected, reducing transmission latency and communication overhead to save energy consumption and improve load balancing. The clustering technique (Faheem *et al.,* 2018) consolidates sensor nodes into a linked hierarchy for energy and traffic load distribution within the network that shrinks data route loops and network latency. Clustering, duty cycling, and collaborative communication combine in ECO-LEACH (Bahbahani *et al.,* 2018) to achieve improved energy efficiency and energy-neutral operation across several layers of the system architecture. EADCR (Panchal *et al.,* 2020) employs the residual energy, Euclidean distance, and cluster centroid as crucial factors in extending network lifespan. Efficient and secure path inference with the lowest latency and optimal bandwidth use are significant aspects of the proposed method (Alghamdi *et al.,* 2021) that improve network performance. The hybrid protocol (Sharma *et al.,* 2021) was devised for diverse networks and executed based on the multi-objective optimization approach for rate optimization and governing the data transfer rate from child to parent node. It's been revealed that uneven traffic load allocation among sensor nodes might lead to sensor node energy depletion quicker than expected. In QoS protocol, energy utilization should be distributed equally across the sensor nodes along the path to the sink node.

Table 1. Comparison of Routing Protocols

Advantage	**Disadvantage**
It is a low complexity algorithm that reduces control messages overhead	Uniform distribution of cluster heads are not offered
Performs better than LEACH	More complex, lacks integrity of data and scalability scope
Avoids unnecessary retransmissions, waiting	Starvation may occur for low priority data
Achieves uniform distribution in spatial domain of cluster head	For lifetime measurement authors measured life time of node only
Prolong the network lifetime and improve network throughput	Needs to enhance multi-hop inter-cluster communication
Successfully reduces data, extends network lifetime	Consist of many complex mechanism
Outperformed in terms of network lifetime, average residual energy, throughput	Higher complexity than LEACH
Outperformed in terms of energy efficiency, network lifetime, PDR, delay	Data aggregation technique is not offered
Involves security alongside malicious attacks as well as utilizes the bandwidth efficiently to improve QoS	The standard quality measurement parameters have not estimated

Advantage	Disadvantage	Protocol	Data Aggregation	Scalability	Power Usage	Network Lifetime	Multi-path	Delay
CoAR improves PRR, end-to-end delay, packet loss ratio, throughput, energy consumption	CoAR is described considering only a static network topology	LEACH (Heinzelman *et al.*,2000)	Yes	Low	High	Medium	No	Small
Achieves better performance in terms of packet loss, end-to-end delay, Queue Size, throughput, congestion level etc	Load balancing problem, security issues in WSNs have not addressed	EELEACH (Arumugam *et al.*,2015)	Yes	High	Low	High	No	Less than LEACH
It increases the network lifetime, does not suffer from data overflow, stability is achieved	In place of transmitting all data, transmits only changed data	CDAS (Devi *et al.*,2020)	Yes	Low	Low	High	No	Low
Achieve significant improvement in communication cost, computational cost, traffic congestion, throughput etc	It is not implemented in real IoT environment	OK-Means (Khediri *et al.*,2020)	No	Low	Low	High	Yes	Low
Achieves prominent data communication with reasonable energy conservation	This proposal is not deal with enhancing fault tolerance, security etc	CPMA (Han *et al.*, 2020)	No	High	Low	High	No	Low
Achieves better network performance	Node position and mobility would include	QDAEER (Yoo *et al.*,2021)	Yes	Low	Low	High	No	Low
Achieves the efficiency in terms of throughput and network lifetime metrics	The proposed approach assumes a static network	F-LEACH, (Behera *et al.*,2021)	Yes	High	Low	High	No	High
Provides better results in terms of a lifetime, residual energy, and coverage of the network	The standard quality measurements have not estimated	HMBCR (Cho *et al.*,2021)	No	Low	Low	High	No	Low
It is well suited to design WSN in real-world and real-time situations	The adaptive ability is not tested	EQRP (Alghamdi *et al.*,2021)	No	Low	Average	Average	No	Low

Protocol	**Data Aggregation**	**Scalability**	**Power Usage**	**Network Lifetime**	**Multi-path**	**Delay**
CoAR (Bhandari *et al.*,2018)	No	High	Low	High	Yes	Low
PSOGSA (Singh *et al.*,2018)	No	High	Low	High	Yes	Low
CCR (Farsi *et al.*,2019)	Yes	High	Medium	High	No	Low
DHSSRP (Adil *et al.*,2021)	No	Low	Low	High	Yes	Low
OQoSCMRP (Deepa *et al.*,2020)	No	Medium	Low	High	Yes	High
ECO-LEACH (Bahbahani *et al.*,2018)	No	Low	Low	High	No	Low
CMEEBZ (Adhikary *et al.*,2021)	No	Low	Low	High	Yes	Low
EADCR (Panchal *et al.*,2020)	Yes	Low	Low	High	Yes	Medium
QBEEP (Sharma *et al.*,2021)	Yes	Low	Low	High	Yes	Low

During the above study following limitations have been identified. It has been observed that most of the researchers have concentrated on the cluster head selection and cluster formation process, but very few proposals are associated to the restriction of the maximum number of cluster members has been discussed. Rather than concentrating on both cluster member and cluster head level aggregation, maximum authors concentrated on cluster head level aggregation. There has not been any precise proposal put out to alleviate the congestion for the priority data. It is unlikely that less attention is paid to reduce bottleneck conditions of the hierarchical cluster routing tree. In light of data aggregation and congestion mitigation, no specific solution has been noticed to attain the quality of services. To overcome the above concerns, we have proposed a novel QoS based congestion evasion clustering framework of WSN that optimizes energy management and achieves the quality of services.

3. Proposed framework: QoS based congestion evasion clustering framework of WSN

The previous section reveals a wide range of congestion control mechanisms and found that congestion significantly impacts the overall network performance of WSN. According to the findings of the study, cluster head selection and proper cluster formation have a considerable influence on network performance. Before sending data to the sink node, data aggregation is recommended to minimize the number of messages delivered to the node. Energy efficiency is often recognized as a significant design consideration to solve the inadequacies of the previously outlined approaches. It is a challenge to design a new framework that can fulfill all these objectives while still being as simple to implement as possible. We present a QoS based congestion evasion clustering framework of wireless sensor networks to optimize energy efficiency and improve network performance to achieve the quality of services.

The proposed framework consists of five modules. Module 3.1 introduces the cluster head selection process, whereas Module 3.2 depicts the cluster formation technique. Module 3.3 represents an aggregation technique. Module 3.4 discusses a method for congestion mitigation. Module 3.5 implements an alternate path creation technique to carry out the communication operation.

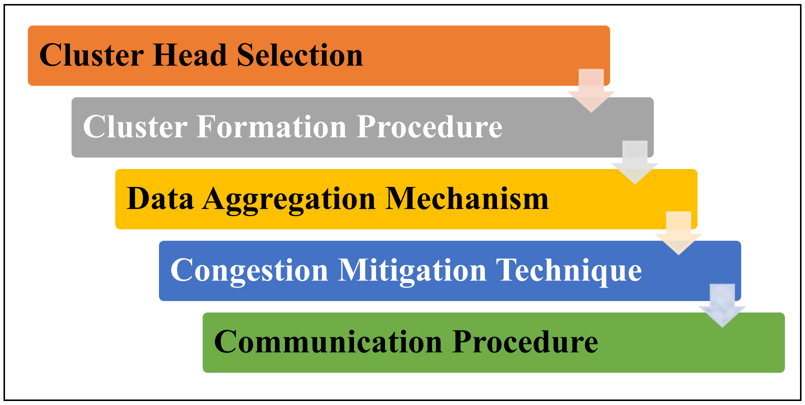


Fig. 1. System Flow of the Proposed Framework

Module 3.1: Cluster Head Selection

This module proposes a dynamic cluster head selection mechanism where node-specific information is deemed for cluster head selection. This process is initiated and monitored by sink node. The current cluster head will be substituted by the new cluster head when the energy level drops lower than the threshold value. A balanced energy distribution among the sensor nodes is confirmed by rotating the cluster head, guaranteeing that none of the nodes run out of power owing to their responsibilities. Each sensor node would find its maximum number of neighbors within a single hop distance.

The degree difference (Δns_i) for every node is:

$$\Delta ns_i = \sum_{s_i \in N(S)} (d_{s_i} - d_{s_j}), \ \left[\text{where } s_i \neq s_j \text{ and } \left\{ dist\left(s_i, s_j\right) \leq \ t_r \right\}\right] \tag{1}$$

For each network node, the average distance among the neighbors is:

$\Delta ads_i = \frac{1}{n}\left[\sum_{S_j \text{€} N(S)} dist(s_i, s_j)\right]$, where $n \geq 1$ and $dist(s_i, s_j)$ is the euclidean distance between node s_i and node s_j. (2)

The distance between the sensor node and the sink node is: $\Delta snds_i = dist(SN, s_{\boldsymbol{i}})$

The minimum distance with the sink node is: $[min|\Delta snds_i|\} = \min\{dis(SN, s_{\boldsymbol{i}})\} \forall\, s_{\boldsymbol{i}} \text{ € } S = [\,\sum(SN - s_{\boldsymbol{i}})^2 |\ \forall\, s_{\boldsymbol{i}} \text{ € } S\,]$ (3)

The maximum distance with the sink node is: $[max|\Delta snds_i|\} = \max\{dis(SN, s_i)\} \forall\, s_{\boldsymbol{i}} \text{ € } S = [\,\sum(SN - s_{\boldsymbol{i}})^2 |\ \forall\, s_{\boldsymbol{i}} \text{ € } S\,]$ (4)

After a specific time interval, compute the energy ratio of each node and update the ND_ENGY_TBL $\{s_i, eins_i, ers_i\ erts_i, t_n\}$ table. Depends on the initial energy and residual energy, the energy ratio $(erts_i)$ is calculated as:

$$erts_i = \left(\frac{ers_i}{eins_i}\right) \tag{5}$$

The tier id $(tids_{\boldsymbol{i}})$ of each node is calculated based on the energy ratio and the distance between the sensor node and sink node:

$$tids_{\boldsymbol{i}} = \left\lceil \left(\frac{erts_i}{\Delta snds_i}\right) \right\rceil \tag{6}$$

Based on the initial energy, residual energy, distance between the sensor node and sink node, calculate the node priority (ps_i):

$$ps_i = \{a * \left(\frac{ers_i}{eins_i}\right) + b * \left(1 - \frac{\Delta snds_i - \min\ |\Delta snds_i|}{\max\ |\Delta snds_i| - \min\ |\Delta snds_i|}\right)\}, where\{[0 \leq (a+b) \leq 1] \tag{7}$$

Calculate node state (s_{ste}):

$s_{ste} = f\{ps_i, flg\}$, set flg=0.25, iff, s_i already executed as cluster head, otherwise set flg=0.75 (8)

Evaluate the cluster coefficient for each node by using the equation;

$cfs_i = \{\prod_{i=1}^{6} (x_i)^{cf_i}\}, \quad where \sum_{i=1}^{6} cf_i = 1, \quad [0 < cf_i < 1]$ and $[x_1 = ps_i, x_{2=}\ erts_i, x_3 = \Delta ads_i, x_4 = \Delta ns_i,\ x_5 = s_{ste},\ x_6 = tids_i]$ (9)

The node with the highest cluster coefficient value would select as cluster head.

Algorithm: Cluster Head Selection

```
Input: Node information
Output: Selection of cluster head
Begin
For each network node ($s_i$)
Repeat
Step 1:    Identify the degree of connectivity ($ds_i$)
```

```
Step 2:   Degree difference ($\Delta ns_i$) is populated using equation (1)
Step 3:   Compute the average distance ($\Delta ads_i$) using equation (2)
Step 4:   Calculate the minimum [min $|\Delta snds_i|$] and maximum distance [max $|\Delta snds_i|$] with
          the sink node using equation (3) and (4)
Step 5:   Calculate energy ratio ($erts_i$) using equation (5)
Step 6:   Calculate tier id ($tid_{s_i}$) using equation (6)
Step 7:   Compute node priority ($ps_i$) using equation (7)
Step 8:   Calculate node state ($s_{ste}$) using equation (8)
Step 9:   Evaluate cluster coefficient ($cfs_i$) using equation (9)
Step 10:  Find max$|cfs_i|$ and corresponding node select as cluster head ($ch_i$)
Step 11:  If $er_{chi} < er_{th}$
Step 12:      Then repeat Step1 to Step 10 to select a new cluster head
Step 13:  Else
Step 14:      Continue with the current cluster head
Step 15:  End if
End
```

Module 3.2: Cluster Formation Procedure

In the first phase, cluster members are connected to the cluster head through MAX_HEAP technique, wherein the second phase, cluster heads connect to neighbor cluster heads through $dARY\_HEAP$ topology. We presume that the sink node acts as the root, where cluster heads act as the child node of the constructed tree. The load balancing mechanism can distribute the network nodes among different clusters by impeding the maximum cluster members in a cluster.

The communication cost is estimated as: $comm_{cost} = \frac{intrach_{dist}}{ChSN_{dist}}$, where, $intrach_{dist} = dist(ch_i, s_i)$ and $ChSN_{dist} = dist(SN, ch_i)$ (10)

The node rank is calculated as: $rnk_{si} = \frac{erch_i}{dist(ch_i, s_i) * ers_i}$ (11)

$$chjoin_{si} = \{\alpha_1 * erts_i + \alpha_2 * (1 - \frac{\sum_{i=1}^{2} \beta_i * p_i}{rnk_{si}}) + \alpha_3 * bfravs_i\} \quad (12)$$

ch_i broadcasts the $CH\_ADV\_MSG\{ch_i, msg_{id}, cfch_i, erch_i, ttl\}$ and receives the $CM\_RPLY\_MSG\ \{ch_i, s_i, chjoin_{si}, msg_{id}, ers_i,\ ttl\}$ from neighbour nodes and store $NH\_TBL\ [s_i, chjoin_{si}, msg_{id}, ttl]$ table. Based on $chjoin_{si}, MAX\_HEAP$ is constructed where ch_i act as the root of the corresponding cluster. By sending the $CLM\_CNF\_MSG\{ch_i, cfch_i, erch_i, cm_j, pcm_j,\ ttl\}$, ch_i confirms cluster membership to cm_j. Maximum number of nodes belong to cluster $\leq (2^{h+1} - 1)$, $[where\ h = level\ of\ ch_i]$

Case 1. If s_i receives only one message $CH\_ADV\_MSG\{ch_i, msg_{id}, cfch_i, erch_i, ttl\}$ from ch_i, then it would send the $CM\_RPLY\_MSG\ \{ch_i, s_i, chjoin_{si}, msg_{id}, ers_i,\ ttl\}$ to join in the corresponding ch_i.

Case 2. If s_i receives two or more $CH\_ADV\_MSG\ \{ch_i, msg_{id}, cfch_i, erch_i, ttl\}$ from the different ch_i, then based on the equation (12) it would send the $CM\_RPLY\_MSG\{ch_i, s_i, chjoin_{si}, msg_{id}, ers_i, ttl\}$ to the particular ch_i and would want to become a cluster member of the stated cluster.

In the second phase, we assume that sink acts as root node at level 0. ch_i adds itself as the child of the sink node and sets its level to 1 when it has its place within the transmission range of the sink node. The remaining cluster heads in the network use the same technique, and a tree formation is carried out.

Algorithm: Cluster Formation Procedure

```
Input: Cluster head details
Output: Cluster formation
Begin
For each network node, do
Step 1:   $ch_i$ Broadcast $CH\_ADV\_MSG\{\ \}$
Step 2:   If ((isClusterHead) || (isExistingClusterMember)) received $CH\_ADV\_MSG\{\}$
Step 3:       Then discards $CH\_ADV\_MSG\{\ \}$
Step 4:   End If
Step 5:   If (isSingleClusterHead sends $CH\_ADV\_MSG\{\}$) then
Step 6:       $s_i$ receives $CH\_ADV\_MSG\{\}$ from one $ch_i$
Step 7:       $s_i$ calculates $chjoin_{si}$ by using Equation (12)
Step 8:       $s_i$ reply $CM\_RPLY\_MSG\{\}$ to corresponding $ch_i$
Step 9:       $ch_i$ maintains NH_TBL[$s_i, chjoin_{si}, msg_{id}$, ttl]
Step 10:      CM_HEAP ( )
Step 11:      $ch_i$ sends $CLR\_FRM\_MSG\{\}$ and confirms the membership to $cm_j$
Step 12:  Else
              If (isMultipleClusterHead send $CH\_ADV\_MSG\{\}$) then
Step 13:      Repeat Step7 and send reply $CM\_RPLY\_MSG\{\}$ to $ch_i$ having [max|$cfch_i$|]
Step 14:      End If
Step 15:  End If
Step 16:  Level of SN←0
Step 17:  $dARY\_Parent(i) = \left\lfloor \frac{i+d-2}{d} \right\rfloor$
Step 18:  For each $ch_i$ do
Step 19:  Repeat
Step 20:  Broadcast RT_MSG{}
Step 21:  For i=1 to n do
Step 22:  dARY_HEAP ( )
Step 23:  If ((|$ertch_i$| > $th_{er}$ ) && (|$ChSN_{dist}$| ≤ $th_{dist}$ )) then
Step 24:      Reply with SNC_MSG{} to Parent Node SN
Step 25:      $dARY\_Child(i,j) = [(i-1)d + j + 1]$
Step 26:  End If
Step 27:  End For
End
```

Algorithm: dARY_HEAP ( )

```
Step 1:   MAX_HEAP (A)
Step 2:   For i=length[A] downto 2 do
Step 3:   swap(A[1] ↔ A[i])
Step 4:   HeapSize[A] ← HeapSize[A]-1
Step 5:   dARY_MAX_HEAP(A,1)
Step 6:   End For
End
```

Algorithm: MAX_HEAP (A)

```
Step 1:   HeapSize[A] ← length[A]
Step 2:   For i=k down to 1 do, [where k=$\left\lfloor \frac{\text{length }[A]-2}{d} \right\rfloor$]
Step 3:   dARY_MAX_HEAPIFY (A, i+1)
Step 4:   End For
End
```

Algorithm: dARY_MAX_HEAPIFY (A, i)

```
Step 1:   SN←i
Step 2:   largest ← i+1
Step 3:   For j= 1 to d do
Step 4:   If (j<= HeapSize[A] && A[Child (i+1, j)] > A[i+1] then
Step 5:       largest ← child (i+1, j)]
Step 6:   End If
Step 7:   End For
Step 8:   If (largest! = i+1) then
Step 9:       swap(A[i+1] ↔ A[largest])
Step 10:      dARY_MAX_HEAPIFY (A, largest)
Step 11:  End If
End
```

Module 3.3: Data Aggregation Mechanism

Due to the high-level node density in sensor networks, many sensor nodes sensed similar data, causing redundancy. Additional bandwidth is required for redundant data transmission that makes the network more volatile. This section introduces two-level data aggregation strategies, i.e., cluster member level and cluster head level aggregation, to forward the aggregate data to the sink node and achieve energy optimization while minimizing the number of transmissions. In query driven WSN, sensor nodes forward the aggregated data in reply to the query request of the sink node.

In order to calculate the performance of the aggregation function, aggregation ratio and packet size co-efficient (Cui *et al.,* 2014) have been considered: Aggregation ratio (w) is defined as the ratio of the number of aggregated packets (n) and total packets generated (N), where $w \in [0,1]$. Let, s_i transmits the number of units of raw data $\varphi(v)$, the number of unit-size packets forwarded denoted by $\delta(v)$ that is defined as; $\delta(v) = \lceil \frac{\varphi(v)}{w} \rceil$. Packet size co-efficient (λ) shows the change in packet size due to the aggregation function $\left[\lambda = \frac{d'_i}{d_i}\right]$, where d'_i is the size of the aggregated packet, and d_i is the size of the original packet. At $t_{i+\zeta}$ time instance sensor node collects $d_{i+\zeta}$ raw data and checks for the data similarity. According to the similarity index, the concerned cluster members would make packet forwarding decisions.

$$d_{sim}(d_{i,}d_{i+\zeta}) = \left[\frac{d_i \cap d_{i+\zeta}}{d_i \cup d_{i+\zeta}}\right] \qquad (13)$$

In this proposal, the similarity threshold index (Δth_{indx}) is set to 0.5. If the data similarity is less than the threshold index, then sensor nodes send both data packets to the cluster head; otherwise, apply the aggregation technique on the collected data. In this framework, the aggregation cost is introduced during cluster head-level aggregation. i.e., $\left[aggr_{cost} = \left[\frac{w*\lambda}{rnk_{si}}\right] * d_{sim}\right]$. The aggregation level of each cluster head depends on the aggregation cost and energy ratio. i.e., $aggr_{level} = f(aggr_{cost}, ertch_i)$. A number of standard mathematical functions are taken into account in the development of this model.

Case 1. Sensor nodes collect the same data. The final aggregation value is: $\{d_{sm}(aggr) = \left(\frac{\alpha_{d1}}{2^{n-1}} + \frac{\alpha_{d2}}{2^{n-2}} + \frac{\alpha_{d3}}{2^{n-3}} \ldots\ldots + \frac{\alpha_{dk}}{2}\right)\}$ where [$\alpha_{d1} = \alpha_{d2} = \alpha_{d3} = \alpha_{dk}$ and 'n' is no of nodes.]

Case 2. Sensor nodes collect different data, i.e., The total amount of data gathered from all contributing sensors would be the final aggregate value.

$\{(d_{df}(aggr) = \left(\sum_{i=1}^{k} \beta_{di}\right)\}, where\ \beta_{d1} \neq \beta_{d2} \neq \beta_{d3} \neq \beta_{dk}]$

Case 3. Few sensor nodes collect the same data, and others collect different data, i.e., The final aggregation value is: $\{(d_{smdf}(aggr) = (\frac{¥_{d1}}{2^{q-1}} + \frac{¥_{d4}}{2^{q-2}} + \frac{¥_{d5}}{2^{q-3}} \ldots\ldots + \frac{¥_{dk-1}}{2}) + (¥_{d2} + ¥_{d3} + ¥_{dk})\}$

Case 4. The values collected by multiple sensor nodes for the same attribute; Maximum, Minimum, and Median value from the collected data is:

$\{(d_{mx}(aggr)\} = f(S_{1\ldots}S_n) = max|S_i|, \text{where } i = 1..n$

$\{(d_{mn}(aggr))\} = f(S_{1\ldots}S_n) = min|S_i|, \text{where } i = 1..n$

$\{(d_{mdn}(aggr))\} = \sum_{i=1}^{n} S_r, \text{ where } r = (i+1)/2$

Based on the query request from the sink node, sensor nodes forward the aggregated data packets to the cluster head. Depending on the aggregation level, ch_i applies aggregation mechanism on the received data from cm_j. Total data packets received by ch_i is $d(ch_i) = \sum_{j=1}^{n} d(cm_j)$. The total aggregated data received by the sink node is: $\sum_{i=1}^{m} d(ch_i) = \sum_{i=1}^{m} \sum_{j=1}^{n} d(cm_j)$

Algorithm: Data Aggregation Mechanism

```
Input: Collected data
Output: Aggregated data
Begin
For each network node do
Repeat
Each $t_{i+\zeta}$ instance sensor node collects raw data
Step 1:   $cm_{ij}$ measures the data similarity $\{d_{sim}(d_{i,}d_{i+\zeta})\}$ using equation (13)
Step 2:   If $\{d_{sim}(d_{i,}d_{i+\zeta})\} < \Delta\mathrm{th}_{\mathrm{indx}}$ then
Step 3:       $cm_{ij}$ sends $\{d_{sm}\ (aggr)\}$ data to $ch_i$
Step 4:   Else
Step 5:       $ch_i$ broadcasts SN_Query_Msg {} to each $cm_j$
Step 6:       Based on the query message, $cm_j$ applies aggregation technique on the
              collected data and sends it to $ch_i$
Step 7:   Case a:  $_{a}cm_j$ sends $\{(d_{df}\ (aggr)\}$ to $ch_i$
          Case b:  $cm_j$ sends $\{(d_{smdf}\ (aggr)\}$ to $ch_i$
          Case c:  $cm_j$ sends $\{(d_{mx}\ (aggr)\}$ to $ch_i$
          Case d:  $cm_j$ sends $\{(d_{mn}\ (aggr)\}$ to $ch_i$
          Case e:  $cm_j$ sends $\{(d_{mdn}\ (aggr)\}$ to $ch_i$
Step 8:   End If
Step 9:   $ch_i$ receives data from $cm_j, d(ch_i) = \sum_{j=1}^{n} d(cm_j)$
Step 10:  While ( $aggr_{level} \geq th_{level}$) do
Step 11:  $ch_i$ measures data similarity using Equation (14)
Step 12:      If $\{d_{sim}(d_{i,}d_{i+\zeta})\} < \Delta\mathrm{th}_{\mathrm{indx}}$ then
Step 13:          $ch_i$ sends $\{d_{sm}\ (aggr)\}$ to next-hop neighbour
Step 14:      Else
Step 15:          $ch_i$ repeats step 7 and forwards aggregated data to the next-hop neighbour
Step 16:      endif
Step 17:  If ($Next_{hop} == SN$ ) then
Step 18:      $ch_i$ sends aggregated data to SN
Step 19:      Total aggregated data received by sink node is: $\sum_{i=1}^{m} d(ch_i) =$
              $\sum_{i=1}^{m} \sum_{j=1}^{n} d(cm_j)$
Step 20:  Else
Step 21:      $ch_i$ sends aggregated data to the next upper-level neighbour cluster head
Step 22:      Repeat from step 9 onwards
Step 23:  End If
Step 24:    End While
Step 25:  If ( $aggr_{level} < th_{level}$) then
```

```
Step 26:    $ch_i$ forwards the collected data to the same level neighbour cluster head, having
            [max$|erts_i|$].
Step 27:    Repeat from step 9 onwards
Step 28: **End If**
**END**
```

Module 3.4: Congestion Mitigation Technique

We assume that during each slot σ_i, child nodes transferred data packets to their parent node. S_{LT} (S) represents the set of slots, $\alpha_\sigma(s_i)$ is the rate of data collection, $\beta_\sigma(s_i)$ denotes the rate of data reception, $\gamma_\sigma(s_i)$ signifies the rate of data forwarding during a slot $\{\sigma \in S_{LT}(S)\}$. In this framework, we have calculated the congestion scheduling ratio $(cgsrs_i)$ of node s_i. $\{cgsrs_i = \frac{cgpksrs_i}{cgshs_i}\}$, where congestion packet scheduling $(cgshs_i)$ is defined as the number of packets schedules per unit time to forward to the next hop. Congestion packet service rate $(cgpksrs_i)$ is the average rate at which packets have been forwarded to the next neighbour.

Let, D_{s_i} and U_{s_i} are the downstream and upstream neighbors of s_i. For $\forall j \in D_{s_i}$, $\forall k \in U_{s_i}$, (*i, j*) are downstream links of node s_i, while (*k, i*) are upstream links of s_i. Let $DSR_{s_i s_j}\{\forall s_i \in N, s_j \in D_{s_i}\}$ is the average downstream data rate from s_j to s_i and $USR_{s_k s_i}\{\forall s_i \in N, s_k \in U_{s_i}\}$ be the average upstream data rate from node s_i to s_k. To mitigate the congestion, s_i adjusts the packet receiving and packet forwarding rate.

$$cglvls_i = \{(cgsrs_i + \textstyle\sum_{s_j \in D_{s_i}} DSR_{s_j s_i} - \sum_{s_k \in U_{s_i}} USR_{s_i k}), \forall s_i, \mathrm{j}, \mathrm{k}, \in N\} \tag{14}$$

Two different queues have been identified for storing the priority and regular data. Q_{Pmax} and Q_{Pmin} identifiers are used of priority data where as Q_{Rmax} and Q_{Rmin} used for regular data. When the queue length is less than the minimum threshold that ensures no congestion occurs, the congestion index is set to 0, and accordingly, the child node's transmission rate may be updated. The received data packets would be stored, i.e., $\{Q_L \leq Q_{Rmin}, Q_L \leq Q_{Pmin}, set\ Congs_{indx} = 0\}$.

When queue length is greater than a maximum threshold, significant congestion is recorded, and congestion index is assigned to 1, i.e., $\{Q_{Rmax} \leq Q_L,\ Q_{Pmax} \leq Q_L,\ set\ Congs_{indx} = 1\}$. The received data packets would be dropped, and the child node does not send the data packets to its parent node. For moderate congestion, the congestion index is set between 0 and 1 while the queue length is i.e., $\{Q_{Rmin} \leq Q_L \leq Q_{Rmax}, Q_{Pmin} \leq Q_L \leq Q_{Pmax}, set\ Congs_{indx} \in [0,1]\}$. Few packets of low priority will be discarded, while a few packets of high priority will be stored.

$$DP_i = \{\gamma_1 * ps_i + \gamma_2 * cglvls_i + \gamma_3 * hopcnt\}, \text{where } \textstyle\sum_{i=1}^{3} \gamma_i = 1, [0 < \gamma_i < 1] \tag{15}$$

When DP_i exceeds a predetermined threshold, data is designated as a priority; otherwise, it is treated as regular. Received data will be put in the appropriate buffer queue based on the category and prevent to discard the data due to a lack of capacity. $PACK\{s_i, Q_L, Q_P, Q_{Pmax}, Q_R, Q_{Rmax}, Congs_{indx}, ttl\}$ would be sent to adjacent nodes when the buffer threshold value is updated. Neighbour nodes would decide for packet forwarding to the upstream node based on the $congs_{indx}$ and available buffer space.

```
Algorithm: Congestion Mitigation Technique
Input:  Packet schedule rate, Packet service rate
Output: Minimize congestion
Begin
For each network node do
Repeat
Step 1:    Calculates $cgsrs_i$
Step 2:    $s_i$ broadcast $\{cgsrs_i, buflvls_i\}$
Step 3:    If ($cgsrs_i < cg_{th}$) then
Step 4:        No congestion occurs
Step 5:    Else If ($cgsrs_i > cg_{th}$) then
Step 6:        $cgshs_i\ greater\ than\ cgpksrs_i$, and due to buffer overflow congestion
               occurs
Step 7:        $s_i$ informs to downstream child nodes
Step 8:        Child nodes control the data transfer rate for (δ) time
Step 9:            Else If ($cgsrs_i > 1$) then
Step 10:               $cgpksrs_i$ is greater than $cgshs_i$ and $s_i$ adjusts the scheduling rate for
                       (δ) time
Step 11:           End If
Step 12:       End If
Step 13:   End If
Step 14:   Calculate $cglvls_i$ using equation (14)
Step 15:   Data categorization $DP_i$ executed using equation (15)
Step 16:   If ($DP_i > th$) then
Step 17:       Identify 'Priority' data or otherwise marked as 'Regular' data
Step 18:   End If
Step 19:   $Q_{Pmin}$ ←0 and $Q_{Rmin}$ ← [⌈$Q_L/2$⌉+1]
Step 20:   While (!($Q_{Pmax} == [\lceil Q_L/2 \rceil - 1]$) || ($Q_{Rmax} == [Q_L - 1]$)) do
Step 21:   Repeat
Step 22:       Store the categorized data in the corresponding locations.
Step 23:   End While
Step 24:   If($Q_{Pmax} == [\lceil Q_L/2 \rceil - 1]$ || $Q_{Rmax} == [Q_L - 1]$) then
Step 25:       Forward PACK {} to the neighbours
Step 26:       Neighbour nodes explore the alternative path for data forwarding
Step 27:   Else
Step 28:       The data transfer process continues
Step 29:   End If
END
```

Module 3.5: Communication Procedure

The proposed framework allows both intra-cluster and inter-cluster routing while consuming less energy. To prepare the traversing list, traversal strategies have been employed as; in-order, pre-order, post-order, level-order. The cluster head applies the TDMA technique to assign a transmission time slot to each member depending on the traversing list. According to the assigned slot, the member node forwards aggregated data packets at the beginning of the time slots. The cluster head receives aggregated data from cluster members, and the downstream cluster head transmits the aggregated data packets to the upstream cluster head for delivery to the sink node via multipath routing. When the sensor node receives a PACK message from neighbour nodes, it does not send any data packets to its neighbours to avoid data loss. A new time slot would be allotted to the sensor node for data transmission to neighbours; otherwise, find the alternative neighbour cluster head through which data would be forwarded. As the sink has numerous child nodes and by using round-robin scheduling, data is transmitted to the sink through the different child nodes that minimize the bottleneck problem and manage the energy optimization.

```
Algorithm: Communication Procedure
Input: Network information
Output: Data transfer to sink node
Begin
For each network node do
Repeat
Step 1:   Based on the traversing technique, formulate the traversing list $TL[\ ]$
Step 2:   $Ch_i$ assigns transmission slot $TS[i]$ for each $Cm_j$
Step 3:   $Cm_j$sends aggregated data to $Ch_i$
Step 4:   $Ch_i$ forwards aggregate data to $\{upstm(Ch_i)\}$
Step 5:   If $Ch_i$ receives PACK from upstream neighbour Then
Step 6:       It doesn't send data packets to the corresponding $Ch_i$ within $TS[i]$
Step 7:       Allocate new $TS[i+1]$ slot for data transfer
Step 8:       Select new $Ch_i$ based on $[f\{(\max|cfch_i|), (!\,(chld\_upstm(Ch_i)))\}]$
Step 9:       Forwards the data to the new next-hop neighbour $Ch_i$
Step 10:  End If
Step 11:  If multiple neighbour cluster heads have the same metric then
Step 12:      Data packets would forward to the upstream node using round robin
              mechanism
Step 13:      Repeat from step4 onwards unless the data is reached to sink node
Step 14:  End If
END
```

Table 2. Data Dictionary

Parameter	Details	Parameter	Details
s_i	Sensor node	ch_i	Cluster ead
$eins_i$	Initial energy of s_i	cm_j	Cluster member
$eavgs_i$	Average energy of s_i	er_{chi}	Residual energy of cluster head
ps_i	Priority of Node s_i	rnk_{si}	Rank of the node s_i
SN	Sink node	t_n	Time instance
t_r	Transmission range	er_{th}	Threshold energy
s_{iloc}	Location of s_i	cf_i	Coefficient factor
msg_{id}	Message id	cfs_i	Cluster coefficient of node s_i
ttl	Time to leave	$comm_{cost}$	Communication cost
$clstr_{cmpct}$	Cluster compactness	$enrg_{cost}$	Energy cost
$intrach_{dist}$	Intra cluster distance	PACK	Positive acknowledgment

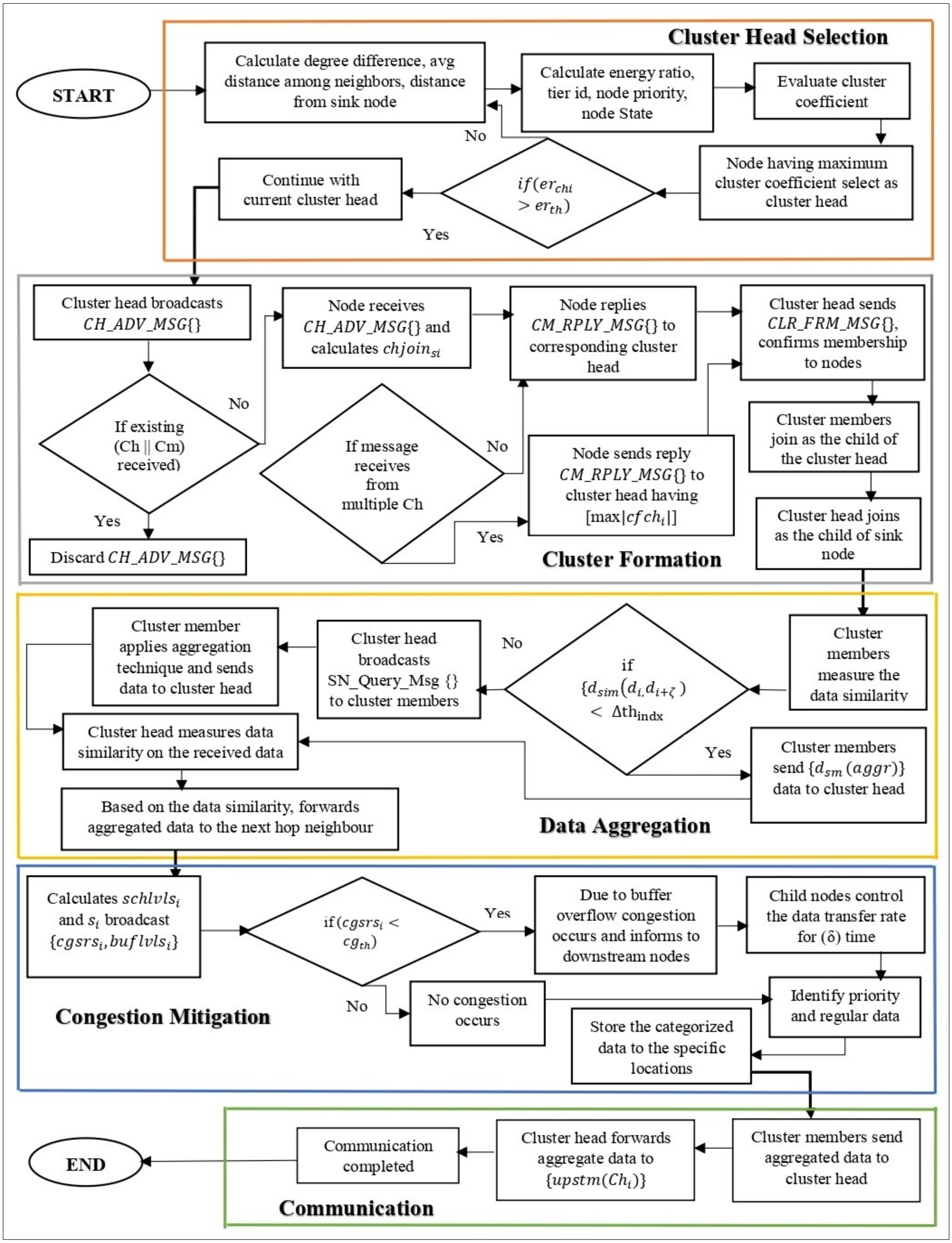


Fig. 2. Working Flow of the Proposed Framework

#Case Study: Example Network

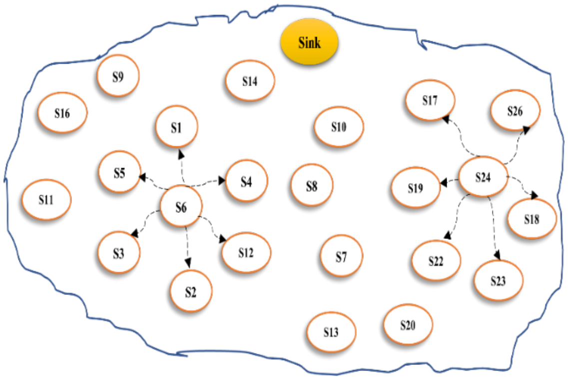


Fig. 3(a). Cluster Head Selection

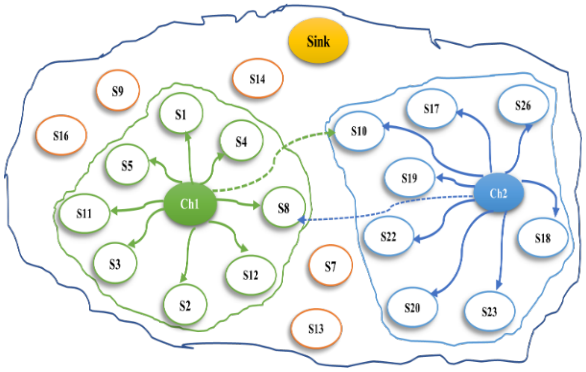


Fig. 3(b). Cluster Formation

- In Fig.3(a), Each participating node evaluates cluster coefficient. Sensor node (S6) having the maximum cluster coefficient and select as cluster head (Ch1).
- In Fig.3(b), Ch1 broadcasts $CH\_ADV\_MSG\{\}$ and neighbour nodes received the $CH\_ADV\_MSG\{\}$, calculate $chjoin_{si}$.
- In Fig.3(b), S1, S4, S8, S12, S2, S3, S11, S5 nodes reply $CM\_RPLY\_MSG\{\}$ to corresponding cluster head (Ch1)
- In Fig.3(b), Ch1 sends $CLR\_FRM\_MSG\{\}$ and confirms the membership to these nodes and they would act as the cluster member of the said cluster.
- In Fig.3(b), The same process is applicable for other cluster, where Ch2 acts as cluster head and S26, S18, S23, S20, S22, S19, S10, S17 nodes are selected as the cluster member of the said cluster.
- In Fig.3(b), S10 receives the $CH\_ADV\_MSG\{\}$ from Ch1 and truncates the message as it is already connected with Ch2. The similar process is applicable for S8 also, as this node is already the member of Ch1.

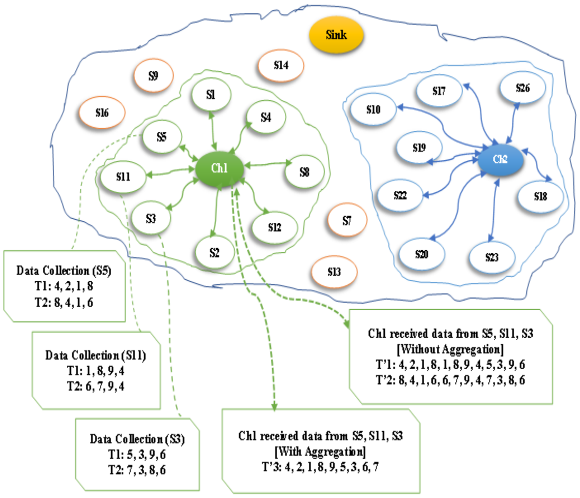


Fig. 3(c). Data Aggregation

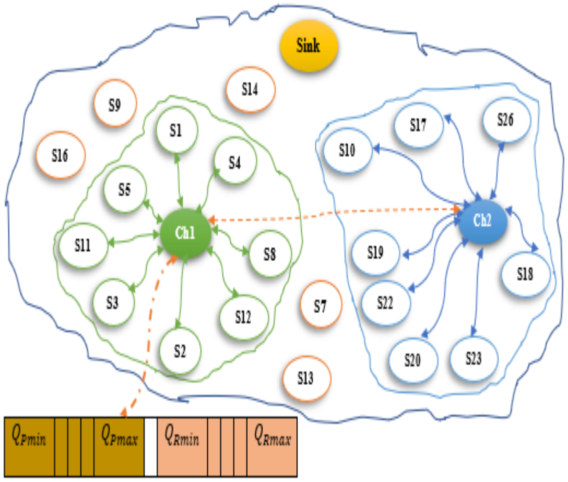
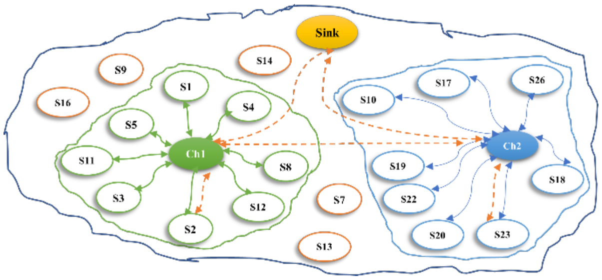


Fig. 3(d). Congestion Mitigation

- In Fig.3(c), [Without Aggregation Mechanism]: Cluster members (S3, S5, S11) collect data T1 and T2 time instance where few data are redundant, and others are distinct. The said cluster members send the collected raw data to Ch1. Cluster head received the redundant data along with distinct data from its cluster members.
- In Fig.3(c), [Considering Aggregation Mechanism]: Cluster members applied aggregation mechanism on the collected data and send the aggregated data to the cluster head. Ch1 applies aggregation mechanism on the received data from cluster members and forwards to next hop.
- In Fig.3(d), Q_{Pmax}, Q_{Pmin} are used of priority data and Q_{Rmax}, Q_{Rmin} are used for regular data. when $\{Q_L \leq Q_{Rmin}, Q_L \leq Q_{Pmin}\}$, it identifies that ensures no congestion occurs, $set\ Congs_{indx} = 0$. When $\{Q_{Rmax} \leq Q_L,\ Q_{Pmax} \leq Q_L\}$ the significant congestion is recorded, $set\ Congs_{indx} = 1$. For moderate congestion, $\{Q_{Rmin} \leq Q_L \leq Q_{Rmax}, Q_{Pmin} \leq Q_L \leq Q_{Pmax}, set\ Congs_{indx} €[0,1]\}$.
- In Fig.3(d), Neighbour nodes would decide for packet forwarding to the upstream node based on the $congs_{indx}$ and available buffer space.



In Fig.3(e), The proposed framework allows intra-cluster and inter-cluster communication. The communication paths are: [S2→Ch1→Sink], [S23→Ch2→Ch1→Sink]

Fig. 3(e). Communication

4. Comparative performance analysis

The performance of our proposed framework is analyzed using MATLAB 2018a over a 64bit Windows 10 operating system. The simulation compares the performance to prominent WSN state-of-the-art routing protocols as; LEACH (Heinzelman *et al.,* 2000), EELEACH (Arumugam *et al.,* 2015), OQoSCMRP (Deepa *et al.,* 2020), CDAS (Devi *et al.,* 2020), DHSSRP (Adil *et al.,* 2021), CMEEBZ (Adhikary *et al.,* 2021)

Table 3: Simulation Parameters

Parameters	Value	Description
WSN Area	[(0,0)~(200,200)] m	Area of Deployment
Sensor Nodes	0~50	Number of Nodes
Network Topology	Random Deployment	Distribution of Nodes
Initial Energy	3 J	Each Node's Initial Energy
Sink Location	(50, 80)	Location of the Sink

The following QoS metrics as, the energy requirement of cluster formation, throughput, packet delivery ratio, end-to-end latency, network lifetime, etc., have been identified to measure the network performance of the proposed framework that helps to attain the QoS. Fig.4. reveals the relationship between the number of nodes engaged in cluster formation and the required energy. The proposed QC2EF technique has been found to consume less energy than the existing well-known routing algorithms as; LEACH, EELEACH, OQoSCMRP, CDAS.

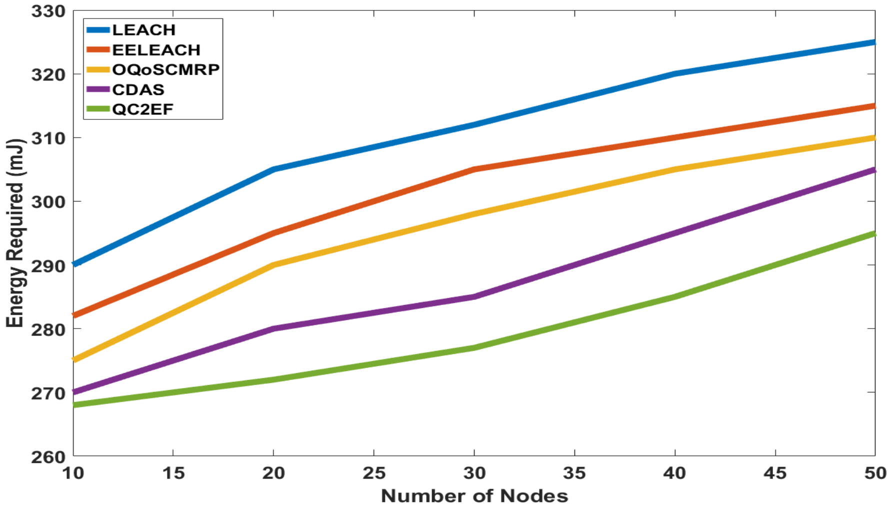


Fig. 4. Number of Nodes vs. Required Energy

Total data received in a certain period of time is used to calculate throughput. This is defined as; Throughput $= \sum_{i=0}^{n} P_s \, L_p$ where P_s is the total number of messages successfully received at the destination. A higher throughput would be achieved by multipath routing, which allows for greater P_s. Fig.5. shows that the proposed QC2EF produces 22.5% higher throughput than the existing routing protocols.

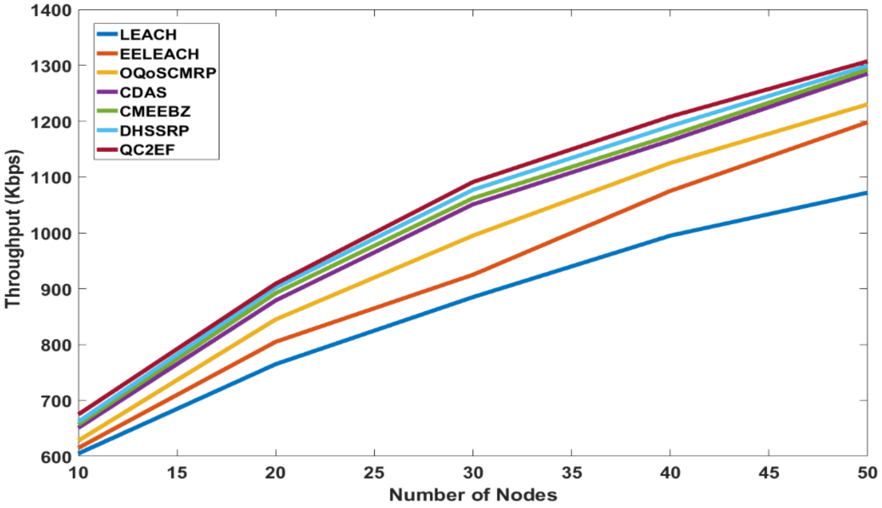


Fig. 5. Number of Nodes vs. Throughput

The packet delivery ratio is calculated as; $\left[PDR = \frac{\sum Number\_of\_Packet\_Received}{\sum Number\_of\_Packet\_Send}\right]$. In this proposal, congestion control and data aggregation mechanism are included to minimize unwanted data transfer in the network and help to enhance network performance. Fig.6. depicts that the PDR of the proposed QC2EF system offers 25.5% higher performance than the existing well-known selected routing protocols.

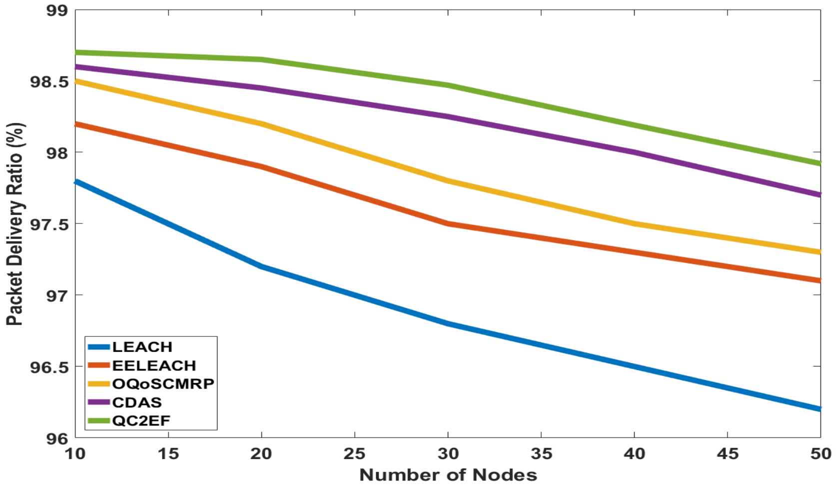


Fig. 6. Number of Nodes vs. Packet Delivery Ratio

The overall time takes for a data packet to deliver from the source node to sink node is known as the end-to-end delay and calculated as; $\left\{\text{End to end Delay} = \left[\frac{\sum arriveal\ time - sendingtime}{\sum Number\ of\ connected\ Neighbours}\right]\right\}$. The proposed approach aggregates and forwards data more rapidly to the next neighbors with less routing load, resulting in a smaller delay and better QoS. Fig 7 compares the end-to-end delay of the proposed QC2EF protocol with other well-known protocols and finds that in all cases, the delay of the proposed mechanism is 21% lesser than of the other selected approaches.

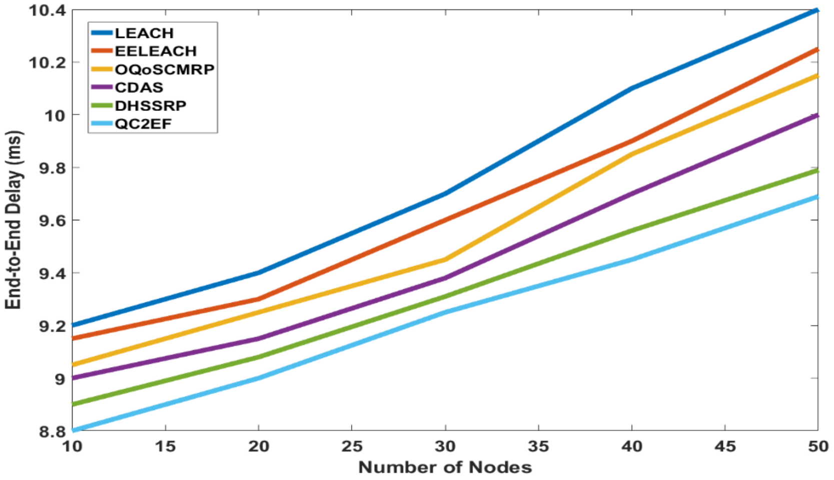


Fig. 7. Number of Nodes vs. End-to-End Delay

The network lifetime is the time it takes for all of its nodes to run out of energy. A number of important issues are considered while designing the proposal, such as dynamic cluster head selection and cluster formation, two-level data aggregation technique, congestion mitigation, and communication between network nodes using multipath routing. The proposed data aggregation methods reduce redundant data transfer while also consuming less energy. Congestion minimization strategy restricts the unsolicited data flowing over the network, all of which help to increase the network lifetime.

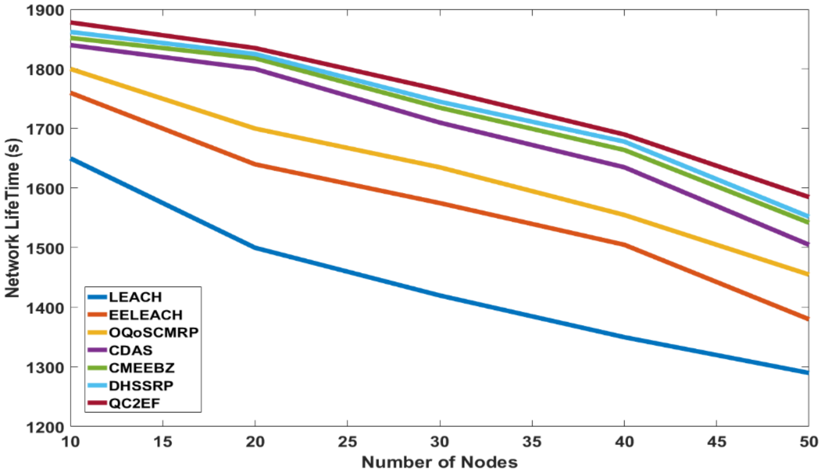


Fig. 8. Number of Nodes vs. Network Lifetime

The Fig.8. compares the network lifetime of the proposed QC2EF scheme with the others existing protocols and indicates that the proposed technique augments the network lifetime compared to others. As a result of packet drops and delays being reduced during communication, throughput has increased, helping to improve the lifetime of a network significantly. The above results identify that the proposed system outstrips better than the existing protocols and offers better throughput, less end-to-end delay, improved delivery ratio, energy efficiency, better network lifetime, and achieves the quality of services.

5. Conclusions

This comprehensive study of diverse clustering approaches and congestion control mechanisms reveals the pros and cons of the prevailing approaches. The empirical study to recognize several QoS metrics facilitates authors in assessing network performance and attaining the quality of services. The dynamic cluster head selection ensures an equitable energy load distribution among the sensor nodes and ensures that no sensor node would run out of energy earlier due to the additional responsibilities. Cluster members are connected to the cluster head through max heap topology. Cluster heads serve as child nodes of the sink node and are connected to neighbours through the dARY_HEAP topology. Two-level data aggregation techniques have been applied to curtail the redundant data flow that helps to minimize energy consumption. Prior to data transmission, the buffer occupancy level would sync with all relevant neighbours, ensuring that no data is lost due to congestion and optimal network performance is attained. The load balancing mechanism provides the load distribution among the sensor nodes through multipath approaches. There is less possibility of a bottleneck forming since the sink node has an assorted number of children. Depending on the routing strategy, data can be routed to sink through any of the children. Alternative path construction is another crucial aspect for enabling real-time communication without introducing an additional delay.

The proposed framework has a greater throughput and better delivery ratio than the well-known existing techniques, as packet drops, and end-to-end delays are minimized during communication. Due to less energy consumption, the network has a more extended network lifetime and achieves the quality of services. The objective of the proposed QC2EF is attained. In future, this framework can be enhanced with a machine learning algorithm and would apply in the covid waste management systems in aspects of smart city.

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