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DYNAMIC CLUSTER HEAD SELECTION ALGORITHM FOR MAXIMIZING IOT NETWORK LIFETIME

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ABSTRACT

Internet of Things (IoT) consists of heterogeneous nodes which are randomly deployed and are intended to sense data. It suffers failure due to large amount of data to be sensed in the sensor network hence, similar data collected by nodes leads to redundancy and network lifetime is foreshorten. To enhance network lifetime, dynamic cluster head selection algorithm (DCHSA) is propounded in this work. This algorithm combines both tree and cluster based data aggregation that classifies cluster head (CH) into primary cluster head (PCH) and secondary cluster head (SCH) to improve energy efficiency and network lifetime. Proposed DCHSA consists of two phases as cluster setup phase and cluster steady phase. Cluster set-up phase corresponds to the cluster head selection, cluster formation and tree formation. Cluster steady phase corresponds to the data transmission and aggregation. The proposed work provides fault tolerance whenever primary cluster head fails and secondary cluster head takes over the task of primary cluster head. The data sent from individual node in the cluster is collected and aggregated by the cluster head. Further tree based data aggregation scheme is proposed to send the data from PCH to base station. The results obtained through simulation outperforms with respect to energy efficiency, lifetime of the network and energy dissipation in comparison with existing works.

KEYWORDS: *Clustering, Data Aggregation, Internet of Things, Network Lifetime, Power Consumption*

INTRODUCTION

The Internet of Things (IoT) is a new paradigm of heterogeneous networks which are distributed over the globe and exchanges information between them [1]. This provides the more flexibility in various applications which are used daily that includes smart home, smart farming, smart healthcare, military etc. In IoT, Wireless Sensor Networks (WSN) is responsible for collecting surrounding information [2]. WSN consists of wirelessly communicating nodes which are randomly deployed and are intended to sense data. It suffers failure due to large amount of data in sensor network hence, similar data collected by nodes leads to redundancy. Therefore, data aggregation method is an efficient method in sensor networks [3]. Due to less power of nodes redundant data become necessary to reduce energy dissipation at every sensor node to enhance the overall time period of wireless device network. Since nodes waste their power in processing redundant information thus, removing data redundancy has put forth solution for improving WSN lifetime [4]. Data aggregation is a technique that gathers the data and aggregates the data to reduce redundancy and in- creases network lifetime. Data aggregation focus on the issues like redundancy, delay, accuracy and traffic load. To overcome these issues some of the data aggregation strategies such as centralized approach aggregation, in network aggregation, tree based aggregation, cluster based aggregation as been used. Different sensors such as temperature sensor, pressure sensor, humidity sensor etc, in which data packets are correlated to each other [5, 6]. In these kind of issues, aggregation is done together and removal of redundant data to make the data aggregation more efficient [7]. Hence, data aggregation technique to enhance energy efficiency and lifetime of the network is propounded in this work.

The data is received from different nodes and aggregates these data using different algorithms such as LEACH, TREEPSI, TAG etc. The sensor readings from various nodes are considered as input and aggregated data is produced as output. To transmit collected data towards sink node an efficient shortest path is chosen by the sink node and an efficient routing method is required to select optimal route which is suitable for sending data from sensor node to base station as shown in Figure 1. In cluster based scheme, sensor nodes are grouped into clusters [8]. Every cluster has a leader, known as CH. Every non sensor nodes transmits data towards receptive CH for the process of aggregation [9]. CH aggregates and forwards data towards sink node for further processing. Cluster based WSN has following benefits. (1) Making cluster head to combine data to reduce redundancy, unrelated data and also minimizes energy dissipitation of nodes. (2) Cluster head will maintain the local route setup of other cluster head so that, the routing will be carried out more efficiently. (3) Communication with nodes is done only with the CHs, it conserves bandwidth [10]. Tree based scheme is another type used in data aggregation, which finds a efficient path and shortens the distance between sensor node and sink node by constructing a tree based aggregation. In WSN, there is an issue of limited power supply due to which the CH's will die quickly [11]. So, this failure will affect the overall lifetime of the network. Hence, to overcome from these limitations DCHSA is proposed which combines cluster and data aggregation based on tree which consists of dynamic cluster head such as PCH and SCH.

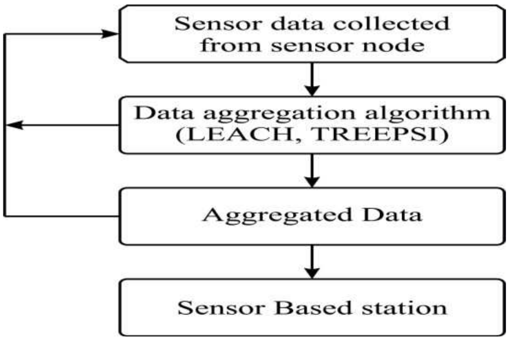

Figure 1: Aggregation of Data in WSN.

- **Contributions of this Work**

Various contributions of this work are as follows:

- To optimize the energy consumption.
- To optimize network parameters of DCHSA when compared with QADA, LEACH, TREEPSI in terms of network lifetime.
- Failure of PCH effects the overall network lifetime, so to overcome SCH will acts PCH for that round.

Paper is furnished as follows. Section 2, provides the related work. Section 3 explains problem statement. Section 4 explains system model and protocol phases, Section 5 presents the experimental evaluation and finally, section 6 concludes the paper.

RELATED WORKS

The work has been carried out in proposed LEACH protocol. In this approach election of CH and CF is done based on the received signal strength (RSS) and threshold value [12]. Aggregation of the received data from the non sensor node is done by cluster head. Each and every node get a chance to act as CH for a particular time to balance the network lifetime. This approach addresses some issues such as low energy consumption and low network lifetime. In this CH selection is based on the random number between 0 and 1, if the number is less than a threshold then that node acts as a CH for that round. A node with little energy possibly chosen as a CH, which leads in reduced network lifetime.

H. Rahman et al. [13], proposed QADA protocol. Proposed protocol is an homogeneous network protocol, which is the combination of both tree and cluster based data aggregation. Based on the distance and energy information CH is selected by the base station and the logical tree is constructed between CH's and then CH aggregates the data and forwards to upper parent node. But this protocol works well in homogeneous network and fault tolerance is not provided in case of failure of cluster head. In [14], proposed CIDT protocol, in which the DCN selection and cluster head selection is based on the residual energy of sensor nodes, RSS and connection time. This protocol shows better performance than LEACH protocol. However, it has issue in achieving required data rate.

Liu et al. [15], proposed an Efficient Energy Data Col- lection Protocol, where nodes are grouped into intra-cluster communication and the tree construction is done between the clusters to make the inter cluster communication. But, this protocol is not suitable for mobility based WSN's, because this protocol will not establish link whenever node are in mobile. Younis and Fahmy[16], proposed HEED protocol, wherein CH selection is based on the high energy of sensor nodes and the communication cost. CH distribution across the network is uniform. Data sending from CH's to base station is of multi- hop communication, which leads in more energy consumption. But, in this protocol cluster head which is near to the base station will die faster due to more routing packets, overhead caused due to delay and limited scalability. Gaurav and Mohamed [17], propounded fault-tolerance clustering approach. In this approach, detection and recovery are carried out in two phases and this makes the network in which sensors recover from the failed gateways by not re-clustering the system. However, approach fails to maintain the data rate, delay and coverage distance.

To reduce the transmission delay while sending data to the sink authors in [18], proposed FFSC protocol. This protocol is based on the additive and divisible aggregation function. But, in this method CH's directly send the aggregated data to the base station which leads in more consumption of energy, which decreases the overall network lifetime. In [19], proposed tree-based TREEPSI protocol. In this all the child nodes forwards the data to their parents and then it is rooted to the base station. The tree construction is carried out by the sink node. But, when a packet is lost at any level, then in that point the information originating from subtree is also lost. Wendi et al. [20], proposed LEACH-C protocol where the sink node initiates an centralized algorithm to select the cluster head. It consist of setup phase and steady phase, setup phase is based on the distance of the nodes and on energy information CH is selected, During steady phase data transmission is done form CH to the base station. This protocol drains more energy to receive information and it is not robust.

Stephanie Lindsey et al. [21], proposed PEGASIS protocol. It is an optimal chain base protocol and is better than LEACH protocol. Every node selects its shortest distance node as a neighbor node, ideal beginning from the fartest node from the base station. In this protocol, the chain head is selected randomly like same as leach protocol. Result shows that PEGASIS perform better when contrasted to LEACH. But, if any node dies in a chain, then network lifetime will be decreased. Kim et al. [22], propounded efficient delivery of contents in mobile nodes scenario. It is an clustering efficient routing protocol, which comprises of two phases: election phase and transmission phase. In election phase, every cluster consists of different cluster head and one CCN and ids will be assigned to every CH and CCN. In transmission phase, CH collects data from non CH and in next round this data will be forwarded to the base station through CCN nodes. But, this method has low scalability rate and requires more time during clustering.

PROBLEM STATEMENT AND OBJECTIVES

To select dynamic cluster head to maximize lifetime of heterogeneous IoT network with the following objectives:

- To optimize energy consumption. 2) To increase network lifetime. 3) To decrease overhead of network. 4) To reduce transmission of duplicate data.

SYSTEM MODEL

The proposed heterogeneous network is a combination of tree based and cluster based data aggregation schemes.

NETWORK MODEL

Consider a heterogeneous network of N sensor nodes and a base station distributed over a area. In this network model cluster head consists of PCH and SCH. By using tree construction data aggregation scheme, PCH sends their aggregated data to the upper level parent node upto data reaches to the base station. Finally aggregation and transmission of data will be done and reaches to the base station. Each node sends their distance and energy information to the base station. Based on this information, PCH is selected by the sink node.

- Average energy is calculated by the sink node using following equation.

$$Avg_{eng} = \frac{(Es1+Es2+\cdots Esn)}{N} \tag{1}$$

`Let Es1 is the energy of sensor node S1. Suppose energy of sensor node S1 ≥ average energy and if it is near to the base station then S1 is selected as the PCH.

- The two set of nodes distance is calculated by the sink node using below equation.

$$d = \sqrt{(a1-a2)^2 + (b1-b2)^2} \tag{2}$$

where d is the distance of nodes and (a1,b1) and (a2, b2) are the coordinates of the S1 and S2. Base station broadcasts an message called as Adv message to every sensor nodes in the network. Broadcast message contains $PCH\ ID$. If the *node ID* matches with $PCH\ ID$ then node becomes an PCH for that round. Once PCH is selected, then PCH node broadcasts a $PCH\ Adv$ message including its ID. NonCH (Non-cluster head nodes) sends JoinReq message to select PCH node within that cluster. After the cluster formation all the NonCH nodes send their energy information to PCH. Based on the highest energy of the non sensor nodes, node whose energy is greater will act as SCH (secondary CH) and it is selected by the PCH within the cluster. SCH will act as a PCH during PCH failure. After PCH, CF, SCH selection a tree is constructed by sink node considering distance information. Finally, data aggregation and transmission of data starts. NonCH send the data to the respective cluster heads during their time slots, PCH aggregates the data and forward towards upper parent node which is rooted at the base station. Figure 2 shows the architecture of the network model.

Energy Model

The usage of energy in IoT decides the lifetime of the network. A simple radio energy model divided into two stages for receiving and transmitting purpose.

In Figure 3, E_{send}(d) is the spent energy in transmitting message of Z bits over a transmission distance d. Z is the message length and E_{elec} is electronic energy. The energy consumed by the radio transmitter is defined in the following equation:

$$Efs(z,d) = \{Z.Eelec + Z.Efs\ d^2 \ldots if d < d0\ Z.Eelec + Z.Eamp\ d^4 \ldots if d \geq d0 \qquad (3)$$

In equation 3, Efs and Eamp shows the amplifier energy in the model of free space channel (energy loss d0). d is the transmitter and receiver transmission distance

If distance d < threshold d0, then free space model will be used, else two ray ground model will be considered. Threshold value d0 is defined as follows:

$$d_0 = \frac{E_{fs}}{E_{amp}} \qquad (4)$$

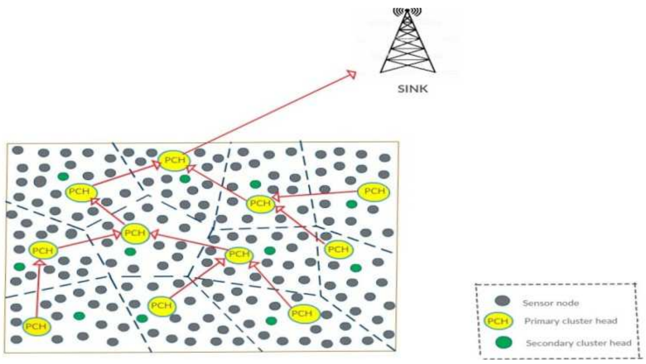

Figure 2: Network Model.

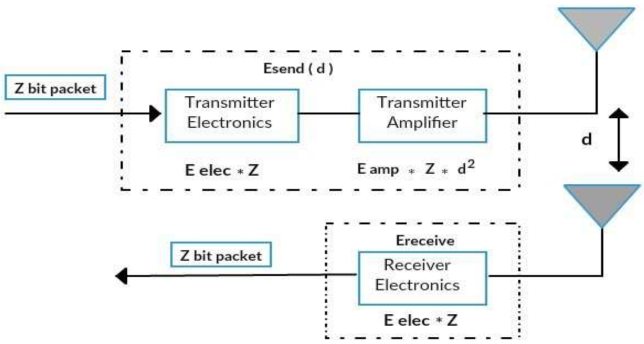

Figure 3: Energy Model.

Proposed Protocol Methodology

The inspiration for proposing the DCHSA scheme is derived from the extensive analysis of QADA and TREEPSI protocol challenges. The proposed DCHSA technique comprises of protocol phases and the fault tolerance. Algorithm 1, provides the description of proposed scheme. Initial round, corresponds to the cluster setup and cluster steady phase. At setup phase, the average energy and distance is calculated using immediate neighbor information. Based on this, PCH is selected as shown in Algorithm 2. Cluster formation and the SCH selection is shown in Algorithm 3. Tree has been constructed by using Algorithm 4. In the initial round, if average energy if average energy is greater than are equal to the PCH then data collection and data transmission will be carried out. Else there will be failure of PCH node that ends up in bootstrapping and network setup.

Table 1: Basic Notations Used

Terms	Description
S	Sensor nodes
K	Expected Number of clusters
Avg Eng	Average Energy of the nodes
d	Distance of the Nodes
N	Number of nodes
E	Energy of the nodes
X_i Y_i	Coordinates for node i
PCH	Primary cluster head
SCH	Secondary cluster head
T round	Total rounds the system runs
CSMA	Carrier sense Multiple Access

Algorithm 1: Pseudocode of DCHSA scheme

```
procedure
    PCH Eng: Primary cluster head energy
    Avg Eng: Average energy of the nodes
    d: Distance of the nodes
    E: Energy of the nodes
    Setup()
    PCH selection (E, N, PCH ADV, PCH ID)
    Cluster formation (PCH ADV msg, Join Req msg)
    SCH selection(E, SCH ADV, SCH ID)
    Tree formation (PCH ID, parent, power level)
    Initial round
    while (Avg_Eng ≥ PCH Eng) do
        data_collection()
        data_aggregation()
        data_transmission()

    end while
    Failure of PCH node
    PCH Request Sink node for a CH change
    SCH acts as a PCH for that round
    Performs collection, aggregation and transmission of
    data
    Sink broadcast switch to Time driven CH rotation
    Go to step 7
end procedure
```

PROTOCOL PHASES

The proposed DCHSA technique consists of two phases- 1) Cluster setup phase 2) Cluster steady phase.

- **Cluster Setup Phase**

Cluster set-up phase corresponds to the cluster head selection, cluster formation and tree formation as shown in the Figure 4.

- Start round r=0
- All sensor nodes *S* send their energy and distance information to the base station.
- Based on that information *PCH* is selected by the sink node.
- *PCH* send ADV message to all sensor nodes.
- Initially, the NonCH nodes are supposed to keep their receiver on to receive broadcast messages.
- NonCH nodes sends JOIN-Req message to choose the *PCH* node within the cluster.
- Cluster formation is done based on step 6.
- *SCH* is selected by the *PCH*.
- Tree construction is done by sink node based on the energy and distance of cluster head nodes.

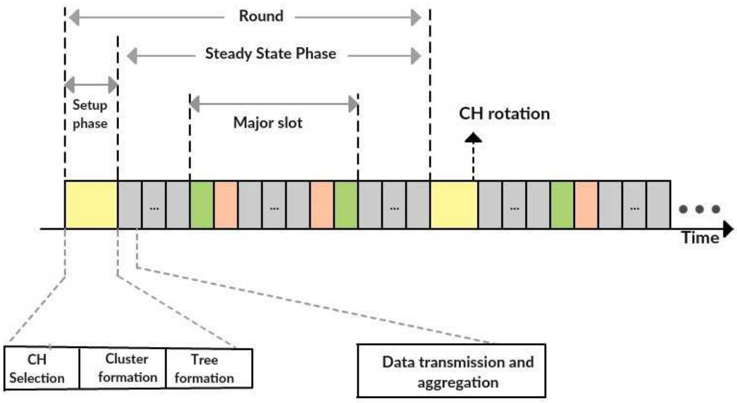

Figure 4: Phase Diagram.

Cluster Head Selection: In set-up phase, cluster head selection process is the main phase in the heterogeneous net- work. The CH is divided into *PCH* and *SCH*. Initially, every node will send their distance information and current energy information to the base station. Based on that information, sink selects the PCH. Average energy is calculated using eq 1 and distance is calculated using eq 2 as shown in the Algorithm 1. After that sink node broadcast an Adv message by utilizing *CSMA* and *MAC* protocol to distribute the *PCH* information. The sensor nodes receive the Adv message and match their ID with the received ID. If both ID matches then that sensor node will acts as a PCH node for that round as shown in below Figure 5.

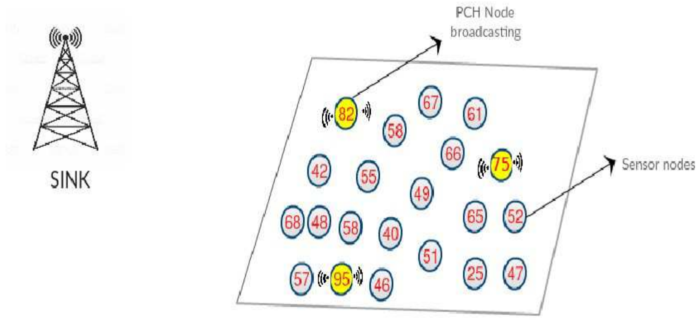

Figure 5: Cluster Head Selection.

Cluster Formation

After the PCH selection, each PCH node sends a PCH Adv (Advertisement message) to non-cluster nodes. Adv message contains PCH ID. Nodes receive this message which contains a PCH ID and matches their id with PCH ID, if both the id's matches, then that Non CH will belong to that primary cluster head node for that round. Now, NonCH will send a join request message (JOIN Req) to the selected PCH using CSMA and RSS. The requesting message contains node id, PCH ID, using $CSMA$ as a MAC protocol. NonCH node chooses the nearest PCH to minimize the energy consumption. Now, each PCH an- nounces NonCH to facilitate the data using $TDMA$ schedule as shown in Algorithm 2. Each NonCH node will wakes up during TDMA time slot to transmit its data to PCH and enters sleep mode after data transfer. When clusters are formed each nodes are grouped to corresponding clusters head. The nodes in the particular cluster will send their energy details to PCH. The PCH will select the SCH based on the highest energy among the nodes and send the Adv message (Node ID) to the non sensor nodes. The nodes whose ID matches with the PCH ID becomes a SCH for the particular cluster for that round as shown in Figure 6.

Tree Construction

Based on the energy and the location information of PCH nodes, the tree construction is carried out. Tree is constructed by sink node. Tree-based data aggre- gation is done from the parent node to child node which will be a minimum spanning tree. Each node has a parent node which is PCH node, which aggregates the data and forwards the data to the sink node. The PCH will send the data to their respective parent nodes. The parent node whose parent is the root node will send the aggregated data to the base station or (sink node) as shown in the Figure 7.

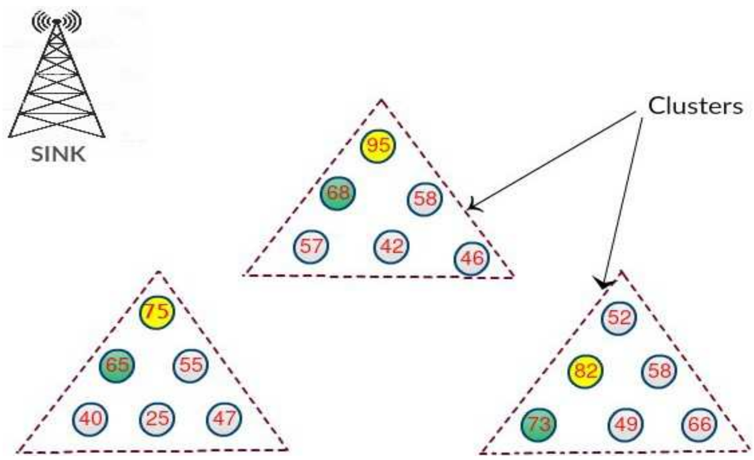

Figure 6: Cluster Formation

Algorithm 2: Primary cluster head selection

procedure
Input: Energy and distance information
Output: Selection of PCH
Every node will send E, a, b to the Sink node
Base station calculates Avg_Eng and distance
among every node

$$Avg\_eng = \frac{(Es1 + Es2 + \ldots\ldots\ldots Esn)}{N}$$

$$d = \sqrt{(a1 - a2)^2 + (b1 - b2)^2}$$

if Sensor nodes_ $energylevel$ ≥ AVG_Eng and Nearest to sink node
then
Sensor node suitable for Primary cluster head
else
Not eligible for cluster head selection process
end if
if (Node_ID==PCH_ID) **then**
N = PCH
else
N = Non-CH
end if
end procedure

Algorithm 3: Cluster Formation and SCH Section

Input: Energy and distance information
Output: Selection of SCH
PCH node broadcasts an PCH_Adv message to non-CH nodes
Message Broadcast PCH_Adv(PCH_ID)
NonCH nodes send message JOIN_Req to chosen PCH nodes
JOIN_Req contains (NodeID, PCH_ID)
TDMA schedule created by PCH within the cluster
SCH Selection (E, N)
Nodes send (Energy, ID) to the PCH of respective clusters
PCH selects the highest energy among the them
PCH sends a Adv_Msg to all non-CH node
if PCH_ID == NodeID
then
Node becomes an SCH for that round
else
N = Non-CH node
Repeat for all rounds
end if

Cluster Steady Phase

Cluster steady phase corresponds to the data transmission and aggregation.

- In this phase, all the NonCH nodes send their data to their respective primary cluster head.
- PCH nodes schedule the communication of NonCH nodes with itself based on TDMA.
- If the energy consumption of NonCH nodes are less than that of transmitter then, it will enter sleep mode.
- All the Primary CH aggregates the data which are received from the NonCH nodes.
- CHs finally transmit the data to their CH based on the tree formation.
- Finally, root node will send aggregated data to the base station.

Data Aggregation and Transmission: After tree construction, each NonCH nodes sends the data to its designated PCH node. PCH aggregates the received data and send them to the upper level parent node until it reaches to the sink node. Figure 8 shows how sensor nodes send the data to sink node

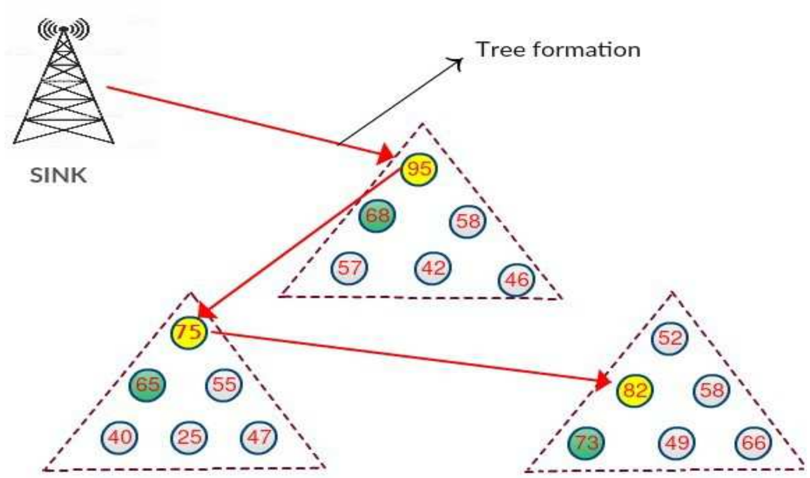

Figure 7: Tree Construction

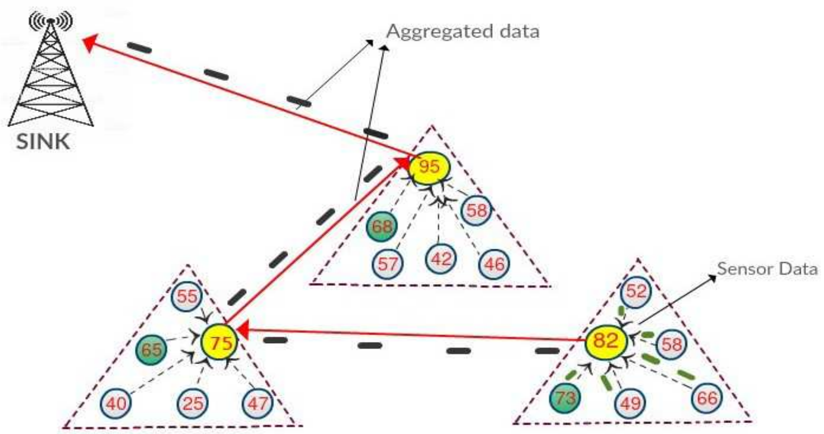

Figure 8: Aggregation and Transmission of Data

Algorithm 4: Tree construction

T msg: Message used while constructing the tree
P node: For each CH node there will be an parent node
C node: Child node j, for each CH node there will be an child node
if (Initiator node=TRUE)
  then
  $P\_node_i \leftarrow (Id_i)$
  $br\_1 < T\ msg, Id_i, P\ node_i >$
end if
Any CH_j receives T msg from any CH_i
  $C-node(j) \leftarrow C-node(j) \cup Id_i$
else
  if (Parent $\_selected_j$=FALSE)
    then
    $Br\_1 < T\ msg, Id_j, Parent\ node >$
  else
    Packet drop
  end if
end if

Fault Tolerance Scenario

Primary CH failure results in data loss and it can be recovered by fault tolerance. Failure of primary CH might occur with the error in gateway and reduction in residual energy. Primary CH failure ends up in breakage of communication with individual cluster and reconfiguration can present itself by reclustering of sensor network, which ends up in bootstrapping and network setup. So secondary cluster head will be considered in order to address this issue. In every round there will be an *SCH* nodes in every respective clusters. Suppose *PCH* is failed during transmission, it ends up in wastage to sensor data and reduces the network time period. In order to overcome this SCH will act as an *PCH* for that round as shown in the Figure 9.

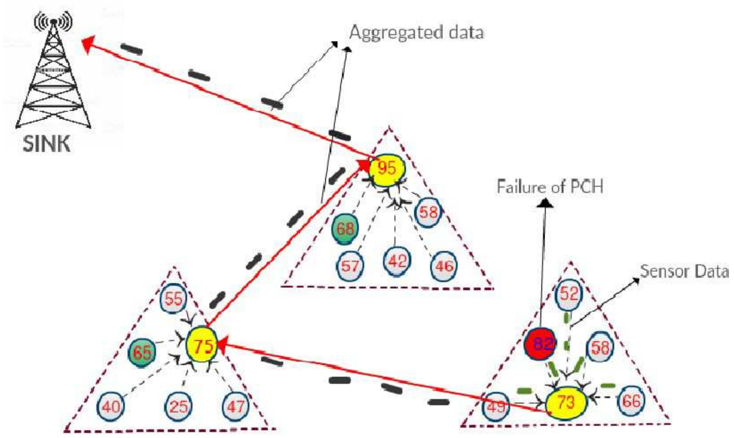

Figure 9: Fault Tolerance

SIMULATION SETTING

The proposed work has been implemented in NS-2. The simulation has been carried out in an terrain size of 100*100m, here 120 number of nodes has been considered with DSDV as routing protocol and various parameters considered for simulation has been shown in the Table 2.\

RESULTS AND DISCUSSION

Proposed DCHSA consists of cluster based and tree based data aggregations and compared with QADA [13] and TREEPSI [19] for following parameters.

- Energy dissipation over Time.
- Network overhead over Time.
- Number of packets reached at Sink node.
- Varying Network lifetime vs total number of nodes

Energy Dissipation Over Time: Here, DCHSA, QADA and TREEPSI protocols were examined and compared in terms of the energy consumption during data transmission as shown in Figure 10 and Figure 11. In DCHSA scheme, if the communication between clusters head and the sink node decreases so that energy dissipation decreases. In QADA and TREEPSI protocols energy dissipation increases with increasing time. QADA dissipates more energy due to homogeneous network. TREEPSI consumes more energy than QADA by reducing the distance between CH and the base station.

Algorithm 5: Aggregation and Transmission of Data

```
procedure
    Collection phase
    Requires: PCH node collects data from non-sensor node
    NonCH node send data (Node_ID ,DATA, datasize) in TDMA frame

    if (No data to send)
        then
        Goes to sleep mode

    end if
    if (Node_ID = current PCH)
        then
        PCH go to sleep mode

    end if
     Aggregation phase
    Requires: Aggregation of data and reaches to destination
    Data aggregation by PCH and forwarded to upper level parent node
    Data Send (Node_ID, DATA, data size, Parent_ID)

    if (PCH fails while receiving the data)
        then
        PCH request Sink node for CH change and SCH becomes an CH for that round

    end if
    if (PCH_ID = Parent_ID) then

        Parent Cluster head goes to sleep mode

    end if

    PCH sends data to the upper level parent node until data reaches to the sink node

end procedure
```

Table 2: Simulation Parameters

Nodes used	120
AreaProtocol in routing	100*100m
MAC Type	DSDV
Transmission Range(m)	802.11
Time duration	250
Delay While Data Processing	20s
Size of the packet	25
Antenna Type	500 Bytes
Model for Mobility	Omni Antenna
Nodes initial energy	Random Wave point
	100 joules

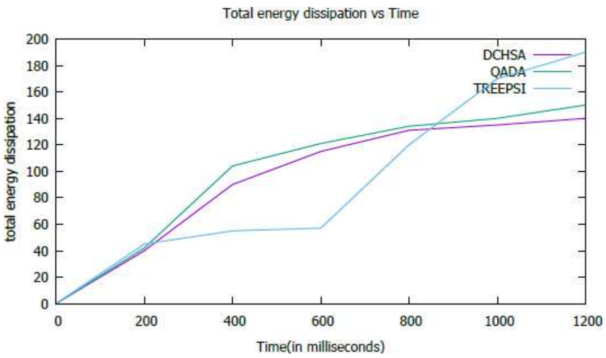

Figure 10: Total Energy Dissipation Vs Time

Network Overhead Over Time

Figure 12 and Figure 13 shows the DCHSA, QADA and TREEPSI protocols were examined and compared with one another in terms of the total overhead while sending data to the sink node over time. The overhead by proposed DCHSA scheme is less than that of QADA and TREEPSI, as it aggregates the redundant data by CH and parent node to reduce the packet transmission.

Number of Packets Reached At Sink Node

The DCHSA, QADA and TREEPSI protocols were examined and compared with the total packets received at the sink node as shown in Figure 14. The number of packets reached in the DCHSA is less than that of QADA and TREEPSI models as it reduces operation of CH and energy is minimized. In the proposed protocol, data aggregation which removes the redundant data and sends it to base station.

Varying Network Lifetime Vs Total Number of Node

The proposed DCHSA scheme compared and examined with QADA and TREEPSI protocols as shown in the below Figure 15 and Figure 16. The proposed protocol which significantly improves the network lifetime as it integrates both the tree based and cluster based data aggregation scheme. In case of failure of primary cluster head during data aggregation secondary CH will acts as an cluster head in that round. The QADA has less network lifetime when compared with DCHSA and more than TREEPSI protocol due to lack of fault tolerance during failure of cluster head and TREEPSI has less network lifetime when compared with DCHSA and QADA.

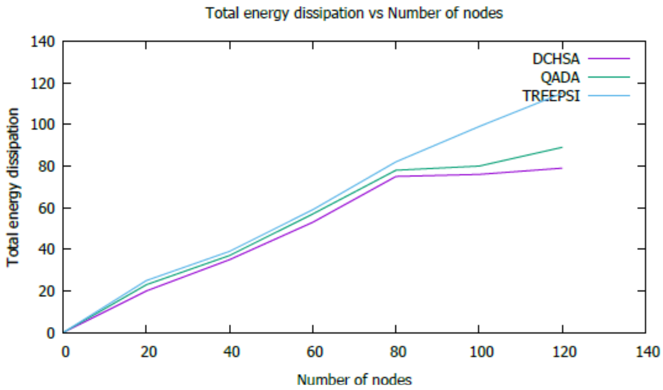

Figure 11: Total Energy Dissipation Vs Nodes Number

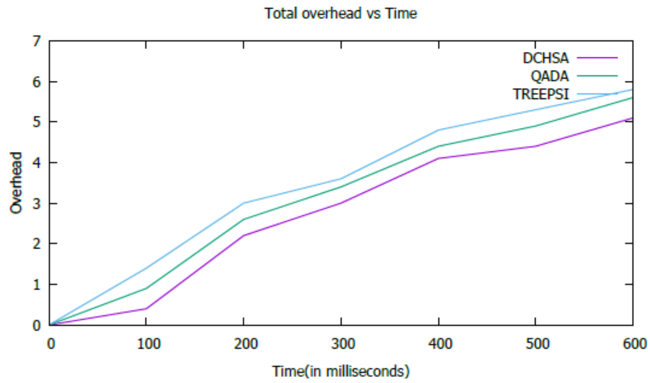

Figure 12: Overhead Vs Time

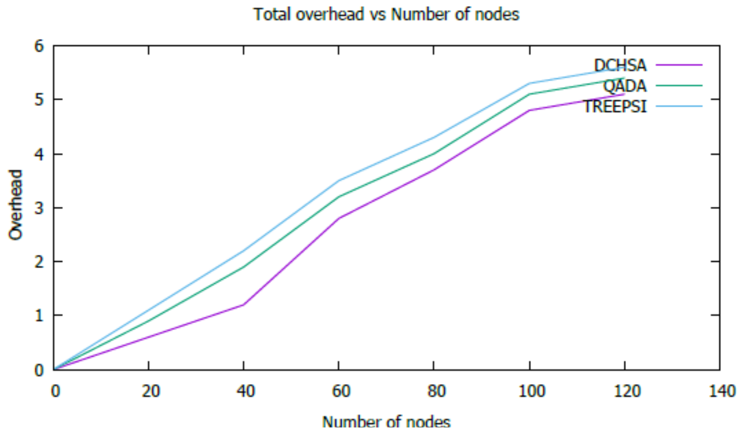

Figure 13: Total Overhead Vs Nodes Number

CONCLUSIONS

DCHSA scheme is proposed in this work in context to improve IoT network lifetime by classifying cluster into PCH and SCH. The cluster-based scheme maximizes the network lifetime by selecting the highest energy nodes as a primary CH node and also by selecting secondary cluster head in the failure of primary CH. Reduction in power consumption results due to tree based scheme, which reduces distance between CH and Base station. Results obtained through simulations concludes that DCHSA provides improved performances than the QADA & TREEPSI protocol on network lifetime, power consumption and packet delivery. Future work in terms of enhancing proposed work is by providing security and fault tolerance in routing.

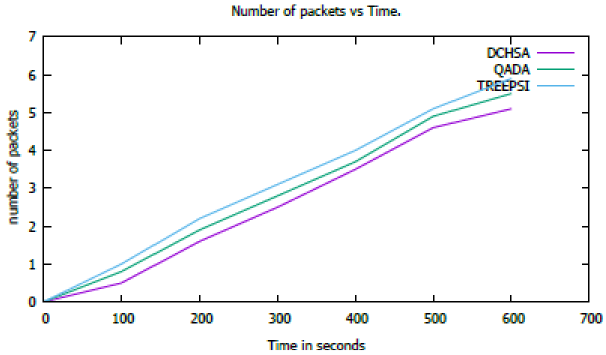

Figure 14: Number of Packets Vs Time.

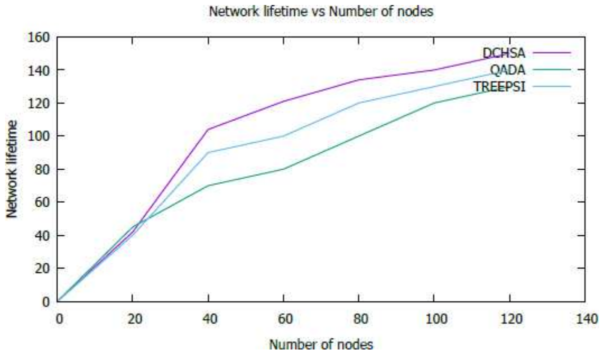

Figure 15: Network Lifetime Vs Nodes Number

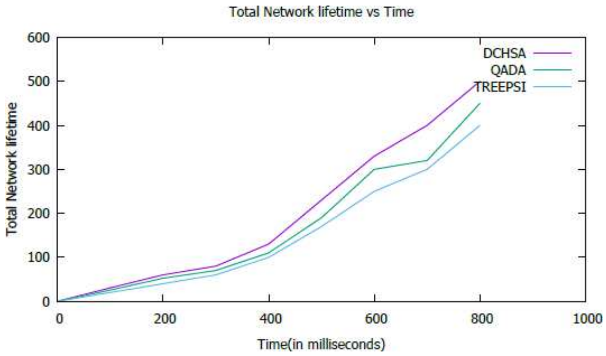

Figure 16: Network Lifetime Vs Time.

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