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RFDDA: RIVER FORMATION DYNAMICS BASED DATA AGGREGATION IN WIRELESS SENSOR NETWORKS

Koppala.Venkateswarlu[1], T.Vijaya Rao[2]
[1]M.Tech CSE Student, S.V. College of Engineering, Tirupati, AP, India
koppalavenky@gmail.com
[2]Assistant Professor, Dept. of CSE, S.V. College of Engineering, Tirupati, AP, India,
vijayarao.t@svcolleges.edu.in

ABSTRACT:

In Wireless sensor networks (WSNs), sensor nodes are sense the data from environment according to its functionality and forwards to its base station. This process is called Data collection. The Data collection process is done in either direct or multi-hop routing. This data collection process consumes more energy in WSN. Data Aggregation is one of the energy conservation techniques. Selection of optimized aggregate node plays the vital role when collecting the data from sensor nodes. This paper introduces a new mechanism for data aggregation based on River Formation Dynamics. The proposed algorithm termed as RFDDA: River Formation Dynamics based Data Aggregation. This algorithm is implemented and tested with MATLAB. The simulation results show that the proposed algorithm performs better than DAACA.

Keywords: Data Aggregation; Data Collection; Energy efficiency; River Formation Dynamics; Wireless Sensor Networks.

1. INTRODUCTION

Wireless Sensor Networks[1,2,3] (WSNs) is widely used in various real time applications such as military, medical, disaster detection, and structural monitoring, etc. These WSNs consists of huge set of small sensor nodes, deployed in the environment for monitoring environmental conditions such as humidity, temperature, and pressure, etc. Every sensor node in WSN, working with limited constraints and sense the data from environment based on the application and forwards to the central base station or sink for further processing[4]. This process is called data collection, which is the primary task of the WSNs. In data collection process [4], the sensor nodes forward the data to the central base station either by direct communication or by multi-hop communication. The direct communication from sensor node to base station is expensive due the distance between sensor nodes and base station is more. Alternatively, Multi-hop communication [5,6,7] schemes are used for better network lifetime and performance. In multi-hop communication, every sensor node is busy in forwarding the sensed and received data to intermediate nodes or to the base station. In this process, redundant data sensed from sensor nodes forwards to the base station, which degrades the network performance. For better network performance, data aggregation or data fusion techniques [2] is used to eliminate redundant data in multi-hop communication. This technique improves the energy conservation and the lifetime of the network [2].

Selection of aggregate node in routing path for forwarding data places a vital role. Swarm intelligence is one of the areas for finding the optimized nodes in the routing path between sensor node and the base station. Various swarm intelligence mechanisms [8,9,10] are used to select the next node in the routing path. From the swarm intelligence, RFD (River Formative Dynamics) [11] is one of the mechanisms developed by the nature inspired activities. This paper used RFD for finding the aggregate node during the path selection process. The RFD mechanism uses node parameters viz., hop count distance to the base station and residual energy of that node [10]. The main contribution of the work is to save energy and enhance the lifetime of the network, the RFD based data aggregation for data collection in WSNs is proposed.

Henceforth the paper is organized as follows: Section 2 discusses the background. The related work is explained in Section 3. Section 4 describes the problem statement. The RFD based data collection protocol for WSNs is discussed in Section 5. The simulation results and analysis are presented in section 6. Finally, Section 7 concludes the paper.

2. BACKGROUND

2.1. River Formation Dynamics (RFD)

RFD [11] is one of the heuristic optimization methods and a subset topic of swarm intelligence. RFD is based on replicating the concept of how water drops combine to form rivers and rivers in turn combine to join the Sea by selecting the shortest path based on altitudes of the land through which they flow. In the process of river formation, the water drops are always flowing from higher altitude position to lower altitude positions. Since, the slope of the two positions is more, and then the water flowing from higher positions to lower positions erode and carry the eroded soil to be deposited in the lower positions. By this deposit the altitude

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of the lower position get increased. Also shortest path is formed from higher to lower position.

The basic algorithm of RFD is given in Algorithm 1. These algorithms mainly consist of two stages viz., Initialization stage and River formation stage. In initialization stage, three different positions (called water drop generating positions or Source(S), intermediate positions (I), and destination (D) or sea) are initialized. All these positions are represented with different altitude value (S and I are represented with positive altitude values and D is represented with Zero). The water drop generating positions always generates water drops. The intermediate positions receive the water drops from source and forward towards the Sea. In river formation stage, the river is created between drop generating positions and Sea using the iterative process having the functions select forward_Position(), move_Drops(), erode_Path(), and add_Sediments(). The iterative process is repeated until either all drops follow the same path or satisfying the other ending conditions such as limited number of iterations, limited execution time. In select forward_Position(), the drop generating positions select the next neighbor positions for forwarding the drops based on the probability function P(i, j) in Equation 1, where i, j are the positions such that (i ϵ S or i ϵ I) and (j ϵ I or j ϵ D). The probability function P(i,j) indicates that a position i having the probability to select the position j as a next hop position for forwarding drops.

$$P(i,j)=\begin{cases} \dfrac{decreasingGradient(i,j)}{\sum_{l\in V(i)} decreasingGradient(i,l)} & \text{If } (j \in V(i)) \\ 0 & \text{Otherwise} \end{cases} \qquad (1)$$

where Nb(i) is the neighbor positions of position i and

$$decreasingGradient(i,j)=\frac{subtraction(i.altitute, j.altitute)}{distance(i,j)} \qquad (2)$$

In the function erode_Path(), according to drop movements the paths are eroded. If a drop flow from position A to position B then water drops erode the soil from A and deposit that eroded soil to B using function add_Sediments(). That is, the altitude of A position is reduced and altitude value of B position is increased based on the gradient between A and B. If the down slope between A and B is more, then the erosion is more. The altitude of the destination position always constant and it is equal to 0. Finally, analyze the paths formed by drops and stores the optimized path.

There is similarity a between RFD and data collection processes in WSN. In RFD, the source (drop generating) positions generate water drops and these water drops are interested to meet the destination or Sea. Similarly, in WSN data collection process, the sensor nodes generate the data and this data is interested to reach the base station. Hence, the sensor data act like water drops, the source positions like sensor nodes, and base station as Sea. The drops are combined and flows from source to sea to form the rivers based on altitude value of position in RFD. In the same way to forward the data in WSNs, the sensor nodes can form a path to the base station based on hop-count and residual energy.

2.2. Energy Model

The first order radio energy model of sensor node is considered [12]. In this energy model, mainly sensor node consumes the energy in transmitting state $E_{TX\text{-}elec}$ (Transmitter electronics) energy and in receiving state $E_{RX\text{-}elec}$ (Receiver electronics) energy. If a sensor node wants to transfer b-bit data packet in d distance, then the energy consumption at transmitter E_{TX} (b,d) is calculates Equation 3.

$$E_{TX}(b,d)=\begin{cases} E_{TX\text{-}elec}\, b + \varepsilon_{fs}\, b\, d^2 & if\ d<=d_0 \\ E_{RX\text{-}elec}\, b + \varepsilon_{mp}\, b\, d^4 & Otherwise \end{cases} \qquad (3)$$

where ε_{fs} is energy for the transmits amplifier in the free space model. ε_{mp} is the energy needed by the transmitter amplifier in multi-path model and d_0 is the Threshold value and it is calculated using $\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. Similarly, the energy consumption for receiving b-bit of data (E_{RX} (b)) is calculated using Equation 4.

$$E_{RX}(b)= b\, E_{TX\text{-}elec} \qquad (4)$$

If a node wants to perform data aggregation or data fusion on b-bit data packet then the energy consumption of node is given in Equation 5.

$$E_F(b)= b\, E_{DA} \qquad (5)$$

where E_{DA} is the energy needed for Data Aggregation or fusion of sensor node.

3. RELATED WORK

During the last decade, researchers are extensively investigated various techniques on aggregation to enhance the energy conservation and network lifetime. The following section explained few related works [13-18].

PEDAP[13] (Power Efficient Data gathering and Aggregation Protocol), Prim based algorithm to generates Minimum Spanning Tree (MST) is proposed. It is a near optimal minimum spanning tree based routing scheme. However, it cannot guarantee the energy efficiency of the network, then an energy-aware version of PEDAP, namely PEDAP-PA is proposed to maximize the network lifetime. However, the sink node needs to periodically broadcast and calculate the MST of the network, thereby; the workload of the sink node is high.

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Local Minimum Spanning Tree algorithm [14] called LMST is proposed to launch the network topology. It can reduce the average degree of nodes. Each node needs to periodically calculate and update the MST locally which leads to a high computational overhead for each node.

L-PEDAP[15] is combination of LMST and RNG [16] to prolonging the network lifetime. The topology construction of this algorithm is same as LMST, hence, it cannot be considered as an energy-efficient algorithm.

A heuristic method called ACA [17] (Ant Colony Algorithm) is proposed to minimize the construction and maintenance cost of the energy-efficient topology. In the ant colony optimization, a colony of artificial ants is used to construct solutions. These ants are to find the shortest paths between the food source and the nest in a random manner. The author initiatively designs the rules for depositing and evaporating pheromones. There are lots of communications within the pheromones adjusting period, which leads to much energy cost overhead. Therefore, it cannot be considered as an energy-efficient algorithm either.

DAACA[18] (Ant Colony Algorithm using Data Aggregation) proposed to enhance the energy conservation and to prolong the network lifetime. This method considers the energy and distance when selecting the next hop node. However, ACA having some disadvantages when compared to RFD[11]. RFD method provides the following advantages with respect to ACO. One of the main advantages is in RFD local cycles are not created. This increases the energy efficiency to the model because of unwanted paths will be eliminated.

4. PROBLEM STATEMENT

Let WSN represented in Graph *G(V,E)* where V is set of Sensor nodes and E is wireless links between sensor nodes. Each node has the maximum transmission range T_R. Each node calculates its neighbor node set and routing table using T_R. Neighbor node set Nb(i) of node i indicates the set of nodes whose distance from i is less than or equal to T_R i.e. Nb(i)={j such that $d_{ij}<=T_R$}, where d_{ij} is the distance between node i and j. Each source node senses the data and forwards to next node until it reaches to BS (Base Station or Sink). The main aim is finding the energy efficient paths between each source node (V) to a BS for data collection in WSN. In this paper RFD is used for finding optimal aggregate node to achieve energy efficient paths.

5. RFDDA: RIVER FORMATION DYNAMICS BASED DATA AGGREGATION

RFDDA (River Formation Dynamics based Data Aggregation) is proposed for data collection in WSN. The example network scenario of RFD-MRP is explained in figure 1. The network is divided into different regions based on node hop count distance to BS. The nodes, having same hop count are comes under one region. BS is taken as R_0 Region.

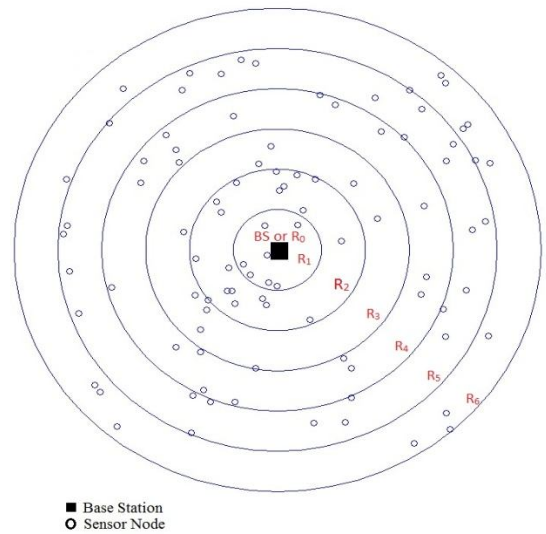

Figure 1. Example Network Scenario with various regions

The Algorithm of RFD_MRP is explained in Algorithm 2. This algorithm is divided into two stages: initialization stage and Aggregate node selection and data relay stage.

5.1. Initialization

Initialization phase consists of sensor node deployment in the environment and the hop count calculation of each node to the BS. For calculation of hop count, BS floods beacon message consists of its identity in the network. The node receives the beacon packet, and calculates the hop count to sink node based on energy levels. Every node collects neighbor node information by sending REQEST packet to its neighbors. The node which receives REQEST packet they send REPLY packet. After exchanging REQUEST and REPLY packets each node stores its neighbor node information in a neighbor node information table. The NN (Neighbor Node) table consist of NNID (Neighbor Node ID), NNHC (Neighbor Node Hop Count to sink node), NNRE (Neighbor Node Remaining Energy), and (DtoBS) Distance to Base Station. The formats of both REQUEST and REPLY are same and shown in Figure. 2.

Bytes	1	1	1	1
	NNID	NNHC	NNRE	DtoBS

Figure 2. Format of REQUEST/REPLY Packet

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5.2. Aggregation Node selection and Data relay

In this stage, path is selected between drop nodes and the BS and data is relayed through the selected path to the BS. This stage consists of three steps: i) Aggregation node selection ii) Aggregate and Forward the data iii) Update NN table by updating the energy.

5.2.1. Aggregation node selection

In the proposed approach source node sends the sensed data to the base station using aggregation node. The selection of aggregation node for onward data forwarding is an important task. Here RFD mechanism is used for aggregation node selection.

Let us assume that the node i is present in Region R_n and node j present in Region R_m, where m≤n. For forwarding or receiving data, the Residual Energy of both node i, and node j must be more than Threshold value(T_h) i.e., RE(i)≥T_h and RE(j)≥T_h. The node i having the probability to select node j as a forward node is denoted by P(i, j) and is calculated as follows:

$$P(i, j) = \begin{cases} \dfrac{H(i, j)}{\sum_{l \in NN(i) \& H(i;l)>0} H(i, l)} & \text{if (j} \in \text{NN(i) \& H(i, j) > 0)} \\ 0 & \text{Otherwise} \end{cases} \quad (6)$$

$$H(i, j) = (hopCount(I,BS) - hopCount (j,BS)) RE(j) / distance(i,j) \quad (7)$$

where distance(i,j) is the euclidean distance between node i to node. NN(i) is Neighbor Node list of node i, i.e. NN(i) = {j, such that distance(i, j) ≤ T_r}. RE(j) is residual energy of node j. T_h is threshold value = 20% of Initial Energy (E_0).

5.2.2. Aggregate and forward the data

Aggregate nodes perform data fusion or aggregation on receiving and/or sensed data and then forward to the next selected aggregate node towards the BS. The energy consumption for data aggregation is calculated using the Equation 5.

5.2.3. Update energy of node and NNtable:

Using the energy model explained in the Section 2 calculate the remaining energies of a node when it transmits or receives the data packet. Later all nodes are update its neighbor node information table by exchanging the REQUEST/REPLY packets.

Algorithm 2 RFD-MRP algorithm

```
procedure RFDDA_ Algorithm()
    begin
    //Stage I: Initialization Stage
    nodeDeployment()
    NNTableCreation()
    //Stage II: Aggregate node selection and Data Relay
    while (not all nodes are dead) do
    begin
        repeat
            aggregation_Node_Selection()
            forward_Data()
            update_Energy()
            update NNtable()
        until it reach to base station
    end
endprocedure
```

6. SIMULATION RESULTS AND ANALYSIS

The proposed RFDDA routing algorithm is developed and tested using the MATLAB (2012b). The algorithm is simulated using the simulated parameters listed in Table 1.

Table. 1 Simulation Parameters

Parameter	Value
Number of nodes	100
Source nodes	10
Network size	100m × 100m
BS location	(50, 50)
Initial node energy(E_o)	0.5 J
E_{elec}	50nJ/bit
ε_{mp}	10pJ/bit/m^2
E_{fs}	0.0013pJ/bit/m^4
E_{DA}	5nJ/bit
Data packet size	4000 bytes
Transmission Range	20m

6.1. Result Analysis:

In this Section the performance of proposed algorithm RFDDA is analyzed and compared with LMST, PEDAP-PA & LEDAP-PA, L-PEDAP, ACA, DAACA protocols.

Figure 3 presents the final result of our proposed RFD algorithm. The aggregation trees topology formation is showed in Figure 3.

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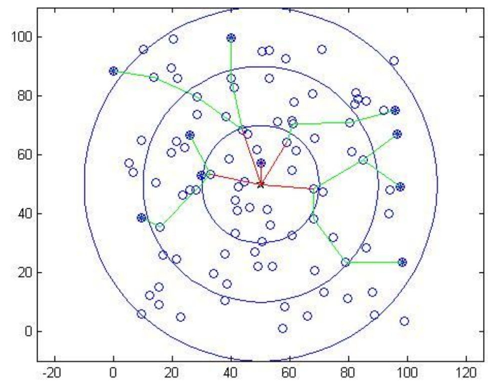

Figure 3 Aggregation trees formation

Table 2 shows the topology constriction complexity. The RFDDA has the complexity same as DAACA of $O(n^2)$. Where 'e' is the number of links between nodes.

Table. 2 Complexity of topology construction

Algorithm	Time complexity
LMST	*O(nelog(n))*
PEDAP-PA & LEDAP-PA	*O(elog(n))*
L-PEDAP	*O(nelog(n))*
ACA	$O(n^2)$
DAACA	$O(n^2)$
RFDDA	$O(n^2)$

Table 3 shows the topology maintenance complexity. The RFDDA has the complexity same as DAACA of *O(n)*. Where 'e' is the number of links between nodes. 'r' is roundToUpdate.

Table. 2 Complexity of topology maintenance

Algorithm	Time complexity
LMST DAACA	*O(nelog(n))*
PEDAP-PA & LEDAP-PA	*O(elog(n))*
L-PEDAP	*O(nelog(n))*
ACA	*O(rn)*
DAACA	$O(n^2)$
RFDDA	*O(n)*

7. CONCLUSION

In WSN data collection process, selection of aggregation node is effectively uses resources of sensor node and forwards the data hop by hop from sensor nodes to base station. The aggregation node selection for data collection process play vital role in WSNs. In this paper, one of the swarm intelligence mechanisms called RFD is used for aggregate node selection for forwarding the data and proposed RFDDA. This approach is an RFD based data aggregation protocol for data collection in WSN to save energy and enhance the lifetime of the network. In RFD-MRP, RFD is considers the hop count value and residual energy as parameters for aggregare node selection. Finally, proposed work simulation results are compared with existing algorithms namely LMST, PEDAP-PA & LEDAP-PA, L-PEDAP, ACA, DAACA.

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