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Energy Aware Data Aggregation with Sink Relocation to Improve the Network Lifetime

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Abstract

In Wireless Sensor Network (WSN), the sensor devices are prepared with limited battery source and conserving the sensor node's power in order to increase the lifetime of a network plays a vital role. This paper proposes Energy aware Data Aggregation with Sink Relocation (EDASR) technique to improve the network lifetime. The nodes that are closer to sink will consume additional energy than others to compute and communicate data to sink. Based on the residual energy sink will relocate to another position. During Energy Aware Data Aggregation (EADA) both the Hop Count (hpc) and shortest distance to reach the sink is considered for clustering. The simulation is performed using ns-2.34 in Ubuntu for different initial battery energy and transmission range. Simulation results prove that EDASR method improves network lifetime by increasing number of rounds of message relaying until the first relocation occurs than the existing sink relocation algorithm.

Keywords: Clustering, Data Aggregation, EADA, EDASR, Residual Energy, Sink Relocation

1. Introduction

The applications of WSNs are large such as weather forecasting, military surveillance, manufacturing processes, etc. WSNs are equipped with wide number of sensor nodes having the capacity to sense the environment and communicate amongst them and also to the sink node or base station. The sensors organize themselves to form a communication network. They periodically sense the environment, process the data and then transmit it to sink node, which will inform the supervisor. As the sensing environment is harsh, recharging or replacing battery drained nodes are not viable. One of the most important issues in WSNs is to preserve the limited battery resources of sensor nodes available in it. Several researchers have been engaged to conserve the limited power resources by scheduling the sensor nodes to periodically enter into sleep state, designing efficient routing algorithm, using data aggregation techniques and mobile sensors.

The concept behind the mobile sensors is to adjust the location of sensor nodes from the region of higher power consumption to lower consumption one. Though it enhances the network lifetime, relocating all sensor nodes will also enlarge node's energy. Instead of relocating all the nodes in the network, it is enough to relocate sink node in order to conserve the battery power. Generally the nodes that are nearer to sink node will consume additional energy than the others which are farther away from sink node. If this situation persists, those nodes will drain its energy rapidly which in turn causes coverage and communication hole problem. In order to avoid overwhelming energy by a particular group of nodes, sink relocation is a promising approach to enhance the network lifetime. In sink relocation, whenever the residual energy of node nearer to sink node drops below a certain threshold, sink node will relocate itself from the energy depleted region to other region where residual energy is the maximum.

Data aggregation is a technique of collecting data from multiple nodes and provides that fused data to sink node or base station which will avoid redundant transmission. As the sensors are highly energy constrain, transmitting the sensed data directly to the base station consumes more

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energy. Moreover data generated from adjacent nodes are highly interrelated thereby resulting in the sink node losing its energy for processing those interrelated data. In order to reduce the data packets broadcasted to sink, data aggregation is a method to combine the data either at the sensors or at the intermediate nodes.

2. Literature Survey

Generally WSNs fall into two category, they can either be stationary or relocatable (mobile) WSNs. In stationary WSN, all nodes are located in a fixed position performing the task of sensing and conveying the sensed data to base station until a node drain out its energy. As soon as a node loses its battery power the whole WSN dies. In case of relocatable WSNs, the sensor nodes or sink node have the capacity to move. Whenever the energy level of sensor region falls to low level condition as a result of some nodes drain out its energy, then those nodes can relocate its position to mitigate the problem of communication or coverage hole problem. Despite the fact that this approach can extend the lifetime of WSNs, these nodes will utilize some quantity of their energy to execute repositioning task. Instead of changing the position of all nodes, relocating the sink node alone is an effective way to enhance the network lifetime. This sink relocation scheme can be categorized into pre-determined mobility path and autonomous movement of sink node.

Marta et al. proposed a method to enhance lifetime where multiple sink nodes[2] are available. Each sink node moves over the perimeter of a pre-determined hexagon path. The sink stops at the edges of hexagon trajectory. During this time, sink node collects data for a particular time unit and then relocates to next edge continuously. This scheme is easy as the sensor nodes predict sink node's location as it moves over the pre-determined hexagon path with constant velocity. This type of sink relocation doesn't consider the current residual energy of nodes that offers enhanced performance results during sink relocation.

In Joint sink Mobility and Routing (JMR) strategy[3], the sink node will use predetermined circular path at the border of WSN for data gathering. The sink node will use stable velocity to move around the circular path and it will gather the sensed data from nodes that are adjacent to it.

In autonomous movement, sink will gather sensor node's residual energy in close proximity. Based on this, the sink will plan where and when to relocate. In half quadrant based sink relocation[4], the residual energy of sensor nodes in the sensing environment is considered. Initially the sink node's sensing region is divided into 8 sectors. The sensor nodes with peak residual energy is consider as MoveDest and nodes with low energy is called as quasi hotspots. A sector may either be a DestSector having MoveDest or a miry sector if it has one or more quasi hotspots or a clean sector having no sensor nodes in its region. The new position is over the meeting point between a line (from the present position of sink to the MoveDest) and the boundary of sink's transmission range. In this relocation scheme, data gathering phase consists of nonstop reporting periods. Major drawback of this scheme is for every reporting period neighbor discovery phase has to be performed as the nodes are mobile in nature.

Sun et al. proposed one step and Multi-step moving strategy[5]. Based on the residual energy of nodes these methods determine a position for relocation. Once the position is identified in one step scheme, the sink node will directly move to destination regardless of the distance between them. In Multi step scheme, the sink will change its position from one intermediate destination to other iteratively. Once the sink node enters into communication range of destination node it'll select six points within its transmission range. The sink node will remain in a position where it can be able to gather huge quantity of data and the sink will remain there until another relocation event takes place. This scheme is only suitable for networks where sink node moves slowly and also for short data-gathering period.

In order to overcome buffer overflow crisis (sink node must visit nodes before their buffer overflow), hybrid sink relocation[6] method make use of both static and mobile sinks to gather data. Based on the residual energy and data production rates of sensor nodes, they are classified into two vital and non-vital nodes. The nodes having low residual energy and high data production rate are identified as vital. The non-vital nodes will have high residual energy with low data rate. With the purpose of collecting data from vital nodes, stationary sink is deployed in the centre of network. Vital nodes select one of its adjacent nodes having more residual energy as its forwarder node. These vital nodes send data to stationary sink via this forwarder node. A mobile sink is deployed to collect data from non-vital nodes.

In link aware clustering[7], initially the entire sensing environment is separated into fixed number of clusters. For each cluster, the cluster head and gateway nodes are selected depending on their respective residual energy, transmission count, forward and reverse delivery ratio. The nodes within one cluster must transmit the sensed data to their cluster heads only and performs aggregation. Both the cluster heads and gateway nodes are elected from time to time. By applying energy efficient hierarchical routing algorithm[8] lifetime of sensor nodes are enhanced. Cluster heads among neighbor nodes are elected based on the residual energy and shortest distance to sink. After every relaying of message corresponding residual energy is updated.

Generally the nodes that are closer to sink node will use extra energy than the other nodes. These nodes require more energy to compute and communicate data to sink. This problem can be conquered by direct and super cluster transmission[9] based on the distance from source node to sink node alone. In heterogeneous environment, data aggregation is used in order to minimize number of data packets transmitted to the sink. The sensor nodes are grouped into a cluster based on their characteristics and form a minimum spanning tree[10] to aggregate data.

In homogeneous type of network, in equal clustering the cluster heads nearer to base station may die early as it conveys the aggregated data to base station. To overcome this problem hierarchical unequal[12] clustering algorithm is used where the grid nearer to base station is having more cluster heads to ensure uniform energy consumption in the network. To eliminate dynamic over heading the concept of static cluster routing is proposed to enhance network lifetime. Routing phase includes setup and steady state phase[13] in which static cluster head is elected by sink. The clusters are created in hexagon shape to avoid random cluster formation.

In Energy Aware Sink Relocation (EASR)[1], initially the nodes are classified into three types according to their respective residual energy. Sink node collects information regarding residual energy of its adjacent nodes. Whenever relocation condition is reached, sink node will relocate to position where the residual energy of its neighboring nodes is maximum. The drawback of this relocation scheme is the routing algorithm considers only the residual energy of nodes in the selected path despite the distance between them. And this type uses the direct response that is whenever a sensor node detects an event it will send the data to sink node. There is more chance for redundancy. To overcome the drawback of EASR, Energy aware Data Aggregation with Sink Relocation (EDASR) is proposed in which both the residual energy of nodes and its distance to sink node is considered.

3. Proposed System

3.1 Energy Consumption Model

First order radio[11] model is used for performance simulation. Let E_T (b,x) denotes energy required by a sensor node to transmit 'b' bits of data to another node at 'x' distance away from it. And E_R (k) is the energy required to receive 'b' bits of data.

$$E_T(b, x) = E_{ec}{}^{*}b + \varepsilon_{apc}{}^{*}b^{*}x^{n}$$

$$E_R(b) = E_{ec}{}^{*}b$$

E_{ec} is the energy required to drive transmitting or receiving circuits and ε_{apc} is the energy consumed by the amplifier component.

3.2 Energy Aware Data Aggregation

Data aggregation is a technique of collecting data from multiple nodes and provides that fused data to sink node so as to avoid redundant transmission of data. The main aim of this Energy Aware Data Aggregation is to minimize the energy consumption during clustering process by exchanging fewer messages between the nodes. At the end of this algorithm, all nodes may either be a cluster head or a cluster member.

EADA algorithm consist of following phases,

a. Hop count and degree calculation.
b. Exchanging the values.
c. Cluster head selection.
d. Updating the residual energy.

3.2.1 Hop Count and Degree Calculation

The Hop Count (hpc) value for each sensor node represents the shortest path length to the sink node and degree (deg) of a node is the number of nodes within its transmission range (adjacent nodes). All nodes in the network should compute both the degree and hop count.

3.2.2 Exchanging the Values

Once a node computes its degree and hop count values, it sends the values to its neighbor nodes. Towards the end, all nodes know about their neighbor's hop count and degree value which is useful during cluster head selection phase.

3.2.3 Cluster Head Selection

Initially all nodes are declared as Cluster Member (CM). Each node checks its neighbor node's hop count and degree values. It will send a message to one of its neighbor nodes having higher degree and lower hop count. Once a node receives a message from its adjacent node it will change its Category (ct) as Cluster Head (CH). If a sensor node does not receive or generate any message it will declare itself as CH. Towards the end, a sensor node may either be a CM or a CH.

3.2.4 Updating the Residual Energy

During relaying of message, all nodes must transmit the sensed data to their respective CH only. Then the cluster head will gather data from its Cluster Member, performs data aggregation and the aggregated data will be forwarded to sink node. After performing the relaying, the respective node's residual energy will be updated based on the energy consumption model explained above.

The steps above should be repeated before performing message relaying to sink node.

```
Procedure 1: EADA
Input:
    sensor nodes in the WSN
    Tr: transmission range

    for each node n in WSN
    {
    st(n) = CM;
    /*first phase*/
    Calculate the shortest path to sink;
    hpc(n) = number of nodes in that path;
    calculate distance to all nodes;
    deg(n) = number of nodes within Tr(n);
    }
    /*second phase*/
    send hpc(n) and deg(n) to all its neighbor nodes;
    maintain neighbor node's information;
    /*third phase*/
    i = n; j = neighbor nodes of n;
    for j
    {
     if (deg (n) < deg (j) and hpc(n) > hpc (j))
     ct(j) = CH, clh(n) = j;
     else if (deg(n) = deg(j) and hpc(n) > hpc(j))
     ct(j) = CH, clh(n) = j;
     else
     ct(n) = CH, clh(n) = n;
     }
    /*fourth phase*/
    {
    send sensed data to CH(n);
    data aggregation in CH;
    send aggregated data to sink node;
    update residual energy of n;
    }
    }//end of procedure
```

4. Residual Energy based Sink Relocation

The nodes those are closer to sink will consume more energy than the other nodes those are farther away. If this situation persists, these nodes will drain its battery power more rapidly which in turn reduces the network lifetime. Sink relocation is an efficient method to solve this problem of consuming more energy for a particular group of nodes. The basic parameter for this relocation scheme is the residual energy of sensor nodes. This scheme consists following phases.

a. Adjusting the transmission range.
b. Relocation mechanism.

4.1 Adjusting the Transmission Range

Based on the residual energy, sensor nodes are classified into three major categories. Let the battery power of a sensor node be P and its residual energy is represented by 'r' having 'γ' transmission range. Table 1 denotes the types of sensor nodes and its transmission range. A node with large transmission range (high residual energy) will increase neighbor nodes and a node with low residual energy may conserve its energy by reducing its transmission range. Hence transmission range adjusting plays a vital role in enhancing the network lifetime. This phase of adjusting has to be performed after every message relaying to sink node in order to

Table 1. Types of sensor nodes

Types	Residual Energy (r)	Transmission Range (Tr)
I	$0 \le r < (P/3)$	$Tr = \gamma/4$
II	$(P/3) \le r < (P/2)$	$Tr = \gamma/2$
III	$(P/2) \le r < P$	$Tr = \gamma$

modify node's transmission range. Because based on the transmission range only degree and hop count for sensors are calculated which is useful during clustering in EADA algorithm described above. After this adjusting whenever the neighbor nodes of sink turns into Type II relocation of sink node must be performed to increase network lifetime.

4.2 Relocation Mechanism

During this phase the sink s will collect the residual energy of its neighbor nodes N. Relocation have to be carried out when: (1) one of the node's residual energy in N drops to Type II or (2) the average residual energy of N falls to Type II. Then relocation mechanism has to be performed in order to reposition sink node to new position. For relocation, the sink will determine four sub-sink positions SS_1, SS_2, SS_3, and SS_4 in the up, down, left and right direction that are γ distance from the present sink position. For each sub sink positions $SS_{i,}$ let Ni be their respective neighbor set (i = 1 to 4). A weight value wt_i is assigned to each position based on the residual energy of its neighbor set N(SSi) and this value is calculated by,

$$wt_i = \text{minimum}\ \{\text{residual energy}(n) \mid n \in N(SS_i), 1 \le i \le 4\}$$

After calculating wt_i, relocation position will be selected based on this weight value. Among these sub sink position, sink node will relocate to a position SS_i having maximum weight value. After relocation to new position, the above procedure should be performed for every message relayed by the sensor nodes.

Procedure 2: Residual Energy Based Sink Relocation
Input:
P: initial battery power.
γ : initial transmission range.
Tr: adjusted transmission range.
r(n): residual energy of sensor node.
N(s): sink node's neighbor set.
N(SSi): neighbor set of sub sink position.
{
/* **adjust transmission range** */
for each node n in WSN
{
if (r(n) is between 0 and P/3) then
Tr(n) is γ/4 and belongs to Type I;
else if (r(n) is between P/3 and P/2) then
Tr(n) is γ/2 and belongs to Type II;
else
Type III;
} // **end of range adjusting**
/* **relocation mechanism** */
if (n, where n ∈ N(s) becomes Type 2 or average residual energy of N(s) < P/2)
then {
select four sub sink position SSi (i = 1 to 4);
find their respective neighbor sets N(SSi);
calculate weight value wt_i for each position;
relocation position will be SSi with maximum wi;
relocate sink node to SSi;
} //end of relocation mechanism
} //**end of procedure**

5. Numerical Analysis

This section describes simulation environment and comparisons with the existing system. Network lifetime is considered as a comparison factor and it is defined as the number of rounds of message relaying until the first relocation occurs. In the simulation environment except sink node all nodes are stationary. The parameters used for simulations are mentioned in Table 2. Figure 1 explains the performance results for different initial energy of sensor

Table 2. Simulation Parameters

Simulation Parameters	Values
Network size	300m x 300m
Initial battery energy	500,750,1000,1250,1500
Transmission range	100,120,130
Number of nodes	50
E_{ec}	50nJ/bit
ε_{apc}	100pJ/bit/bit/m^2

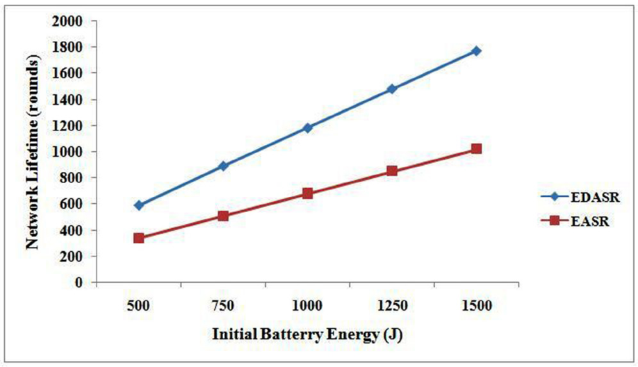

Figure 1. Network lifetime comparison with various initial battery energies.

nodes. As the initial energy increases, there is an increase in the number of rounds of message relaying for both scheme of sink relocation. In the graph, proposed EDASR scheme has increased network lifetime as the nodes send only the aggregated data to sink node. Figure 2 explains the result for various transmission ranges. If the node's transmission range increases, then its neighbor nodes will increase which in turn reduces the number of clusters in the sensing environment.

The results prove that the proposed EDASR method outperforms the existing EASR method.

6. Conclusion and Future Work

One of the most important issues in WSNs is to preserve the limited battery resources of sensor nodes available in it. Data generated from adjacent nodes are highly interrelated thereby formulating the sink node to lose its energy for processing those interrelated data. In order to minimize the data packets broadcasted to sink, data aggregation is a method to combine the data either at the sensors or at the intermediate nodes. Sink relocation is a promising approach to enhance the network lifetime, to avoid overwhelming energy by a particular group of nodes. The proposed EDASR method improves lifetime by aggregating data at the cluster heads and forwarding the aggregated data to sink node. Simulation results prove that EDASR method improves network lifetime than the EASR method under various transmission range and by changing initial battery energy of nodes in the sensing environment.

In future, network lifetime will further be enhanced either by implementing another data aggregation algorithm or by re-allocating the task of sink to another node when the residual energy of sink node drops to Type II in Table 1.

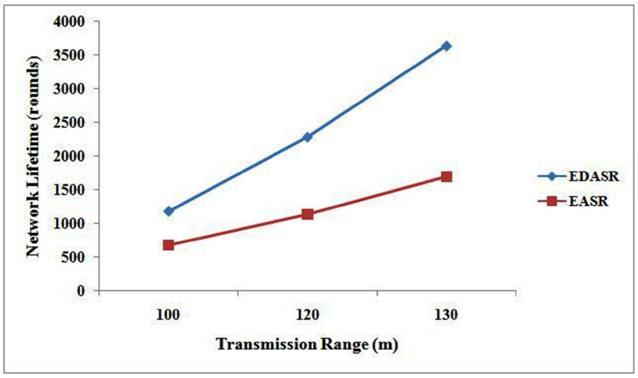

Figure 2. Network lifetime comparison with various transmission ranges.

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