Network lifetime maximization via energy hole alleviation in wireless sensor networks

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Abstract Energy hole creation is one of the most important issues in Wireless Sensor Networks (WSNs). This paper aims to analyze the energy hole boundary for avoiding the creation of energy hole such that network lifetime is prolonged. An analytical model is presented to analyze the network lifetime and location of energy hole from the start of network till the death of last node. Also network area is logically divided to minimize data loss.

1 Introduction

Wireless Sensor Networks (WSNs) have the capability to sense and compute the environmental changes. WSNs are used in many applications like military surveillance, medical diagnosis, pollution monitoring, industrial applications [1] and in wireless communication [2]-[4]. WSNs mainly consist of large number of sensor nodes that are deployed in a given area. These sensor nodes powered with batteries sense the monitoring area and send the collected information to the base station (sink). Direct and multi hop transmission are the two major communications modes in WSNs. Sensor nodes far away from the sink consume high energy in direct transmission mode and die at an earlier stage, while in multi hop transmission mode, sensor nodes near the sink die at an earlier stage due to heavy relaying of farther nodes data. This creates energy hole around the sink. With the presence of energy hole nodes are unable to send data to the sink. Excess amount of energy is wasted which effects the system performance. Results in [5] shows that approximately 90 percent of network energy is left unused when the network is finished in case of uniformly distributed network.

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Energy hole has become a major issue in WSNs because it directly impact the network lifetime. Olariu, *et al.*[6] highlight the scenarios of energy hole problems. However, they never mention the factors which leads to energy hole problems. In [7], the authors spotlight the conditions under which the energy hole emerges in the network. Kacimi *et al* lessen the energy hole problem by introducing Load Balancing Technique (LBT) [8]. The technique adjusts the transmission power of sensor nodes which helps in balancing the energy consumption. The scheme is able to improve network lifetime and balances the energy consumption of sensor nodes. However implementing this technique on other scenario is a challenging task. The scheme balances the energy consumption of nodes by adjusting their transmission power. Most protocols try to tackle energy hole in cluster based WSNs. The scheme proposed in [9], [10] present an efficient routing mechanism that helps to overcome the energy hole around the sink as a result increases the network lifetime. However study relates that energy hole does not always emerges close to the sink. Lian et al. [11] propose the nonuniform node distribution strategy that helps to enhance the data capacity in WSNs. However the proposed schemes unable to provide theoretical analysis for their work to locate the energy hole.

In this paper, we alleviate energy hole with the help of sleep schedule mode. The analytical model presented in this paper aim to overcome energy hole problem. Similar to [12] we consider energy consumption for data transmitting, data receiving and energy for idle listening. The assumption in this paper minimizes the energy consumption of the sensor nodes.

Mainly our contribution in this paper are:

1) Analytical model of NEHA (Network lifetime maximization with Energy Hole Alleviation in Wireless Sensor Networks) to determine the traffic load, energy consumption and nodal lifetime of nodes.

2) Energy hole location based on nodal lifetime.

3) Compare the exiting technique with [12].

2 Related Work

Many researchers did work on exploring new techniques to alleviate the problems in WSNs. The work propose by Ozgovde, *et al.* [13] highlight the FNDT (First Node Died Time) and ANDT (All Node Died Time) as X-factor to improve network lifetime. They propose a utility based framework Weighted Cumulative Operational Time (WCOT) to measure the lifetime of the network on the bases of network states history. However the proposed work focuses on network lifetime, not able to highlight energy consumption in proper way. Authors in [14], focus on connection time of sensor nodes rather than working on entire network lifetime and energy consumption. Li, *et al.* in [15] introduce analytical model in data gathering WSNs. The network is divided into different ring sectors to analyze the network lifetime. The propose scheme maximizes network lifetime on the bases of annuli. However the scheme fails to control energy consumption of the network.

In WSNs, the energy hole problem minimizes the lifetime of the the network. In ACH2 [16], Ahmad, *et al*. improve network lifetime and energy consumption by introducing a mechanism of node association with the cluster head. In this scheme, selection of CHs are based upon optimal distance between them. However the first CH is selected on the basis of its threshold value. The proposed scheme improves the network lifetime and energy consumption, however unable to locate the energy hole problem. Similarly, [17] routing protocol is proposed to overcome shortcomings of [8]. It achieves better network lifetime due to non-uniform node distribution, still the proposed scheme are unable to recover from void regions. Data aggregation is one of the most useful paradigm in WSNs. The aim is to overcome unnecessary transmission of data. Energy Balancing Strategy (EBS) is discussed in [18], to improve the network performance. In [19], energy hole problem is alleviated through compressing and aggregating the data. Still, no one is able to provide efficient information about energy hole occurrence. Lin, *et al*. propose an Energy Efficient Ant Colony (EEAC) algorithm to gather data from nodes [20]. In this scheme, each node uses remaining energy to find the probability of remaining next hop node. The scheme improves the network lifetime however, fail to control robustness and scalability issue.

An efficient energy hole alleviating algorithm [21] is suggested to overcome the energy hole problem in the network. The algorithm uses router selection strategy to recover the energy hole to some extent. However, lengthy process increases the end-to-end delay. At 90 m distance, the lifetime reaches up to 22000 rounds. Chang, *et al*. [22] propose a scheme for maximizing network lifetime with the selection of optimal link cost. However, unable to provide a complete solution to recover the energy hole problem. Authors in [23], propose a Balance Energy Efficient Routing protocol with time reliable communication (BERR) for balanced energy consumption throughout the network lifetime. The propose scheme chose minimum depth nodes and include retransmission phenomena to lessen the energy consumption as well as to achieve better reliability. The major flaw in this routing protocol is the selection of next hop node with minimum depth, moreover, there is no such criteria to recover the energy hole.

Ghaffari, *et al*. propose a new improved energy efficient routing protocol that chooses minimum hop neighbours to forward the data [24]. The scheme consider minimum depth nodes that have shortest path to the sink, it also checks the link quality as well as minimum number of hop. It improves the network lifetime in dense regions, yet in sparse regions, it hardly finds the next forwarder node which results in more energy consumption. Energy Efficient tree based Data Collection Protocol (EEDCP-TB) [25] is proposed to maximize the network lifetime. EEDCP-TB control flooding and allocates time schedule for data aggregation to save energy of the nodes. This scheme achieves better network lifetime at the cost of high delay.

Energy consumption is the the major factor which degrades the performance of network. An efficient routing mechanism is the need in this circumstances. Bhattachargee, *et al*. [26] introduce Lifetime Maximizing Dynamic Energy Efficient routing protocol (LMDEE) for multi hop WSNs that takes into account the remaining energy of sensor nodes to forward the data to the sink [27]. LMDEE performs better in term of network lifetime still it fails to cop with the network scalability and data redundancy issues. In [28], the authors propose an Energy Efficient Clustering technique that uses run time recovery mode of sensor nodes due to failure of cluster heads. This scheme helps in prolonging the network lifetime however, at the expense of more errors in dense regions. An Innovative Balance Energy Efficient and real time reliable communication routing protocol (IBEE) is suggested to utilize energy efficiently [29]. IBEE protocol chooses minimum distance nodes as next forwarder nodes and do retransmission to decreases energy consumption. However, efficient energy consumption is achieved with high delay.

Table 1 Used Notation

Notations	Definition
R	Network Radius (m)
r	Transmission range of sensor (m)
E_o	Initial energy of sensor nodes
B	Data transmission rate
ρ	Node density
d_o	Depth threshold
S_m	The m_{th} network stage
A_x	A small region close to the sink

3 NEHA: The Proposed Scheme

In our work, we consider the following aspects:

Network and Energy Consumption Model:

Let sensors nodes be randomly deployed and uniformly distributed in a circular field with centrally positioned sink [31]-[32]. The transmission range of sensor nodes is r and R is the radius of the network. Sensor nodes send data to the sink in a data period (round). They are allowed to forward the received data through direct transmission or via multi hop transmission. Minimum depth neighbours are selected as data forwarder. Radio model in [33], is considered in this paper. Energy consumed in transmitting and receiving k bits data is shown in equation (1) and (2) respectively:

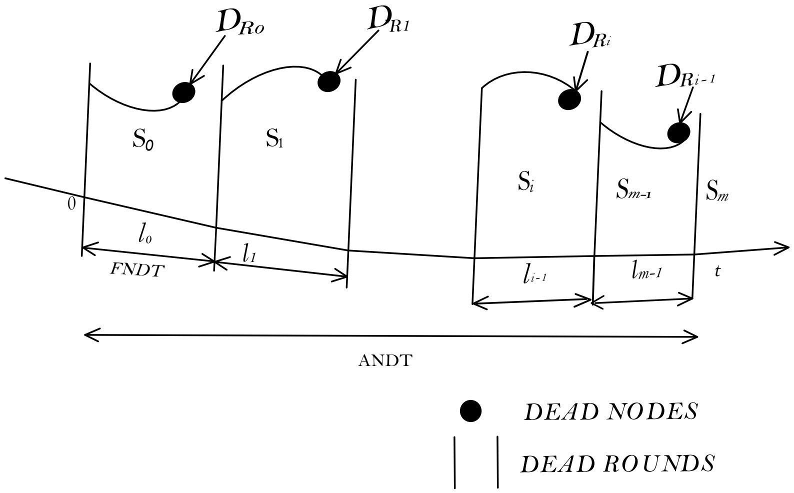

Fig. 1 Entire Process Scenario

$$E_t = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 \ if \ d \leq d_o \\ kE_{elec} + k\varepsilon_{amp}d^4 \quad otherwise \end{cases} \tag{1}$$

$$E_r = kE_{elec} \tag{2}$$

Where d_o is the threshold distance and E_{elec} denotes transmitting circuit loss. We adopt free space channel model and multipath fading channel model that are used in [34]. d denote the transmission distance. If d is less than or equal to d_o free spaced channel model is used otherwise, if distance d exceeds depth threshold, we adopt the multipath fading channel model. ε_{fs} denotes the energy for power application in free space channel model [30] while, ε_{amp} denotes the energy for multipath fading channel model.

Sensor nodes send the sense data to sink using greedy geographic routing. Sensor nodes transmit data to their neighboring nodes which are closest to the sink [12]. Nodes transmit and receive data mainly in active mode while no communication occurs between the nodes in sleep mode [12]. Energy is consumed in data transmitting and receiving while energy consumption in sleep mode is negligible. Our initial focus is to find out the location of dead nodes. Figure. 2 shows network forwarding model of the proposed protocol.

Dividing the network into small regions such that to balance the energy consumption in each region [12]. A_x denote a small region close to the sink ε denotes the width of the region and θ be the angle form by the region with the sink. $\{A_{x+r}$, $A_{x+2r}\}$ denote the upstream regions, r denotes transmission range of sensors. A_{x+r} is supposed to forward data to the region A_x because distance between A_{x+r} lies in transmission range of A_x. Also A_{x+r} relays the data of A_{x+2r} because distance be-

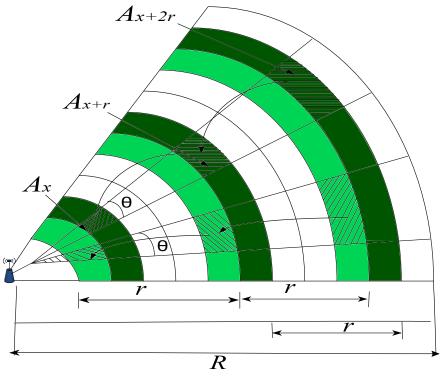

Fig. 2 Data Transmission Model at S_o

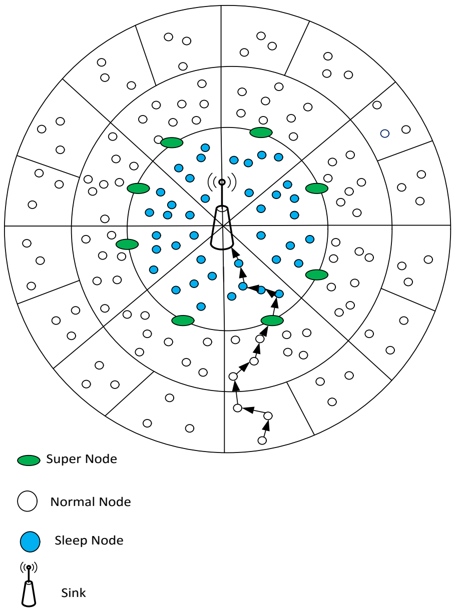

Fig. 3 Data Transmission Model

tween A_{x+r} and A_{x+2r} is equal or close to r. In other words nodes lie in upstream region will transmit data to its downstream region nodes if their distance d satisfies $d < r$ as shown in Fig. 2.

If divided region is too short, there exist few number of nodes or region contain no node. However, when divided region is large, nodes suffer data loss due to large network field which requires high energy. Nodes distance from the sink in A_x region is equal or close to x.

To cop with the network area issue, we have approximated the network area at the start of transmission. As, A_x denote the small region near the sink. $x > \varepsilon$, the volume of network field is approximated as $Z_{A_x} = (x - \varepsilon)\theta\rho$ else $Z_{A_x} = (\varepsilon - x)\theta\rho$.

Fig. 3 shows the complete network scenario of the proposed scheme NEHA. The process consist of two phase:

(i) Initialization phase and **(ii) Data sharing and collecting phase**

In **Initialization phase**, data packets are broadcasted to all the nodes that take part in the data sharing phase. During the start of the network each node transmit the received data to the neighbour nodes if they lie in the transmission range of the node. Nodes, after receiving the data look for a neighbour node to send the received data to the sink through the multihop method. Node chooses minimum depth nodes as a data forwarder. In the next phase i.e. **Data sharing and collecting phase**, the received data are collected by the neighbour node and send this data to the downstream region nodes. When first packet is received by the super node it sends an ACK message to the downstream region nodes to go into sleep mode so that to the received data do not reach to the sink nodes i.e. normal nodes are unable to receive and transmit the data. After that only the super nodes present at the boundary of the sink region are able to receive the data from the upstream nodes but unable to send this data to the normal nodes. When all the data successfully reaches to super nodes, then super nodes again send an ACK message to the normal nodes to come back to their initial position i.e. to wake up from the sleep phase. After this, all the collected data are received by the normal nodes ad send it to the sink to elevate the energy hole problem.

3.1 Data Amount at Stage S_o

S_o denotes the stage at which none of the nodes die in the the network. We find the FNDT from [12] at stage S_o as follows:

$$FNDT = E_o/max({e_x}^0) \tag{3}$$

Where E_o is the initial energy of sensor nodes and ${e_x}^0$ is the total energy of the sensor node including energy for data transmitting, receiving and idle listening at stage S_o.

We calculate the traffic load of sensor nodes on the basis of analytical model [12].

Theorem 1 *Let node i be in a small region A_x with width ε. The distance between A_x and the sink be x and θ be the angle formed by the region A_x with the sink. If i generates one data packet per round then the average data amount sent by i in a single round at stage S_o is:*

$$p_i^0 = \begin{cases} (Z_1+1)+Z_1(Z_1+1)(\varepsilon-r)/2(x-\varepsilon) \ if \ x \le \varepsilon \\ (Z_2+1)+Z_2(Z_2+1)(\varepsilon-r)/2(\varepsilon-x) \ if \ \varepsilon > x \end{cases} \tag{4}$$

where $Z_1 = (R-x)/r$ and $Z_2 = (R-\varepsilon)/r$ [12] .

Proof: Since A_x is the small region close to the sink and node i is in the region A_x so we are able to calculate traffic load in the region. As ε denotes the width of *the region and θ is the angle formed by the region A_x with the sink and x is the distance of the region A_x from the sink. As nodes in region A_x relay the data of nodes in the upstream region and forward the collected data to the sink so, traffic load is calculated. As A_{x+ir} denotes the upstream region and sensor nodes located in this region are upstream nodes then according to the equation (4) area of upstream region is be approximated as:*

$$N_{A_x} = \begin{cases} ((x-\varepsilon)+ir)\varepsilon\theta\rho \ if \ x \leq \varepsilon \\ ((\varepsilon-x)+ir)\varepsilon\theta\rho \ if \ \varepsilon > x \end{cases} \tag{5}$$

Since, data is generated by sensor nodes and in each round sensor nodes sends one data packet so the total number of data packets must be equal to the number of nodes involve in the process. We write the equation (6) as the sum of data packets from the upstream region is the total data packets on A_x [12].

$$D_{A_x} = N_{A_x} + N_{A_{x+r}} + ... + N_{A_{x+zr}} \tag{6}$$

So, the average traffic load on node i in a region A_x must be equal the ratio of number of data packets sent to the total number of nodes involved i.e. $p_i{}^0 = D_{A_x}/N_{A_x}$ [12]. We find the traffic load at stage S_o of node i, by some doing some arithmetic operation we have $p_i{}^0$ as (4).

3.2 Energy Consumption at Stage S_o

If each node generates λ bits packets then the total amount of data transmitted is $p_x{}^0\lambda$. Energy consumption at stage S_o is calculated according to theorem given below:

Theorem 2 *Let node i lies in the region A_x, x denotes the distance between the region A_x and the sink. If a sensor node transmit data at rate B bits/sec then the average energy consumed by the i in a data round is $e_i^0 = e_{i,r}{}^0 + e_{i,t}{}^0 + e_{i,j}{}^0$ [12].*

$$\begin{cases} e_{i,r^0} = (p_x{}^0 - 1)\lambda E_{elec} \\ e_{i,t^0} = p_x{}^0\lambda(\varepsilon_k d^\beta + E_{elec} \\ e_{i,j^0} = E_{idle}(A_t + \lambda/B(1-2p_x{}^0) \end{cases} \tag{7}$$

Where $d = r$ if $x > r$ else $d = x$. For $\varepsilon_k = \varepsilon_{fs}$ distance must be greater than or equal to depth threshold i.e. $d \geq d_o$ and $\beta = 2$ in this case [12], else $\varepsilon_k = \varepsilon_{amp}$ and $\beta = 4$.

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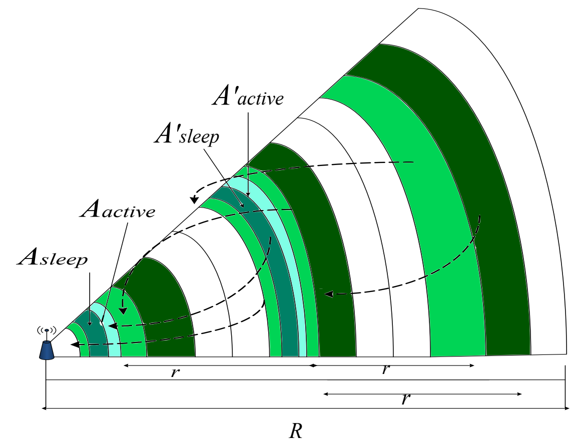
3.3 Avoiding Energy Hole Problem

Energy hole problem is the fundamental aspect in WSNs due to this problem network lifetime tend to decrease with the passage of time. To avoid this, the aim is to cover the loss of dead nodes in order to maximize network lifetime. Nodes in the region close to sink exhaust their energy quickly and die so nodes in upstream region are unable to share data to nodes in downstream region. In LAEHA, this problem is covered by assuming the nodes death region as dead region in which all nodes are dead. The data that are supposed to forward by the dead region are now forwarded by the upstream region that is A_{hot}. We are not allowed to use nodes that are dead during certain rounds as a result we are unable to receive data from that nodes. To cop with this, we set sleep schedule mode by placing nodes at the boundary of the region closed to the sink. We called these nodes as super nodes. They have enough energy to bear the traffic of upstream region nodes. Nodes in the region close to sink are in sleep mode they are unable to send or receive any data from upstream node. Super nodes function is to gather the data from upstream node. The data is transmitted through direct hop or multi hop depends on the scenario whether nodes are in range of super nodes or not. During the start of network nodes send data to their respective nodes. The nodes chooses minimum depth nodes as their neighbor to forward their data. Nodes lie in A_{sleep} send their data to nodes lie in A_{sleep} region, as the nodes in A_{sleep} region are in sleep mode they are unable to receive any data from the upstream nodes so this data is now further gather by the super nodes which further sends this gathered data to the nodes in A_{sleep} region. After all the data is successfully received by these nodes. Super nodes send the message to A_{sleep} nodes to become active. This process decreases the node death probability as a result network lifetime is increased.

4 Operation

Let A_{sleep} denotes the region in which all nodes are in sleep mode, no data is transferred through this region while A_{active} denotes the region in which all nodes are active sending data to its neighbour node through direct transmission or multi-hop transmission. Nodes located in A'_{active} region send the collected data to its downward region A_{active} nodes. While, A'_{sleep} nodes which are in sleep position when nodes in the region become active, they send the data to their downward region nodes i.e. A_{sleep} nodes. As nodes in A'_{sleep} region are supposed to forward the collected data to its downward region A_{sleep} nodes, however, the nodes in A_{sleep} region are in sleep mode they are unable to send or receive the data. Thus, A_{active} nodes collects the data of A'_{sleep} and send the data to the super nodes on the boundary of A_{died}. They transfer this collected data to the sink when nodes in A'_{sleep} region become active. Transmission model is shown in Fig. 5.

Fig. 4 Data Transmission Model of NEHA after S_o



Algorithm 1 Calculating the Traffic Load, Energy Consumption and Network lifetime after stage S_o

Input: Network range R, transmission range r between sensor, N number of nodes, node density ρ etc.
Output: for a node $i \in N$ determine the traffic load ${p_i}^m$ and energy consumption ${e_i}^m$ at stage S_m
1: for each node $j \in N$ and $j = \{1,2,3,.....N\}$ at stage S_o calculate the traffic load $[{p_1}^0, {p_2}^0, {p_3}^0, ..., {p_N}^0]$ and energy consumption $[{e_1}^0, {e_2}^0, {e_3}^0, ..., {e_N}^0]$
2: $m = 0$;
3: for stage $m+1$
4: Calculate distance d of node i with super nodes
5: if d is less than or equal to transmission range of super node, send packet to the super node.
6: while sink nodes are in sleep mode.
7: super node continuously gathering the data of nodes in a data period.
8: if time expires:
9: Send the collected data to the sink node if lies in transmission range r.
10: while sink receive data **do**
11: Calculate lifetime of senor nodes at stage S_{m-1} i.e l^{m-1}
12: Calculate the overall traffic load, energy consumption and lifetime of nodes at stage S_m i.e. $[{p_1}^m, {p_2}^m, {p_3}^m, ..., {p_N}^n]$, $[{e_1}^m, {e_2}^m, {e_3}^m, ..., {e_N}^m]$ as in theorem (1) and (2) for m number of stages.

5 Conclusion and Future Work

In this paper, we have proposed NEHA routing protocol for WSNs. An analytical model is used in our technique to calculate the traffic load at each stage of the network field. The shortcomings of LAEHA are addressed in more efficient manner. Moreover, the proposed protocol alleviate the death probability of nodes due to super nodes located at the boundary of the sink region. An energy hole problem is minimized with scheduled sleeping mechanism in the network. The small division of area decreased the number of nodes while reliability of data packet is increased. In future, we have planned to improve network performance with cluster based routing. In order to recover void nodes zone based routing will be considered.

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