

Prolonging the Lifetime of Wireless Sensor Networks using LPA-star Search Algorithm

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Abstract

Since sensors have limited power resources, energy consumption has become a critical challenge to Wireless Sensor Networks (WSNs). Most of the routing protocols proposed to transmit data packets through paths which consume low energy aim simply to reduce battery power consumption. This can lead to lead to network partition and reduce network lifetime. Therefore, to balance energy consumption and extend network lifetime while minimizing packet delivery delay; this paper proposes a new energy-routing protocol using the lifelong planning A-star (LPA-star) search algorithm. This algorithm is used to find an optimum forwarding path between the source node and the sink. The optimum path can be selected depending on highest residual sensor energy, the shortest distance to the sink and lowest traffic load. Simulation results indicate that the proposed protocol increased the lifetime of the network compared with the A-star routing (EERP) protocol.

Keywords: LPA-star algorithm, network lifetime, routing, wireless sensor networks

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1. Introduction

Growing advances in wireless communication and electronics make the Wireless Sensor Networks (WSNs) have come under intensive research over the last years. it have the enormous application potentials in defense and civilian related applications such as environmental monitoring, military field and biomedical observation [1-3]. In such applications, WSN is a distributed wireless network comprising of many number of low-cost devices called sensor nodes, which are intelligent enough to sense, calculate and communication with each other to collect and transmit the data from the environment and passes it at a centric node know as the base station (sink node) [4].

The sensor nodes in WSNs have resource constraints, including short communication range, limited processing, small memory, low bandwidth, and limited energy resource [5]. Indeed, sensor batteries powered by finite energy present difficulties in being replaced or recharged. Therefore, energy resource constrained and scarcity is an acute challenge in WSN applications. On the other hand, transmission and reception information spend most energy quickly during communication and may be considered the major sources of sensor energy consumption [6]. In one-hop transmission, the sensor nodes located farther away from the sink drain higher energy due to the long transmission data range, and may die out first. On the other hand, multi-hop transmission which expends less power at each hop is more energy-efficient than direct transmission [7]. However, multi-hop transmission is used in many-to-one communication, and in this communication pattern, the closer sensor to the sink may run out of energy sooner due to having the highest load of packets, and thus there is Uneven Energy Consumption (UEC) among sensor nodes [8]. Figure 1 shows an example of UEC problem in multi-hop transmission. The sensors nearest to the sink are overburdened because of the expulsion of other sensors data to the sink. As a consequence, nearer sensors consume much more energy and die much faster, which results in network partition problem, energy holes, and incomplete packet delivery [8]. Therefore, UEC is an innate drawback described by a many-one traffic pattern and multi-hop routing which reduces the lifetime of a wireless network significantly.

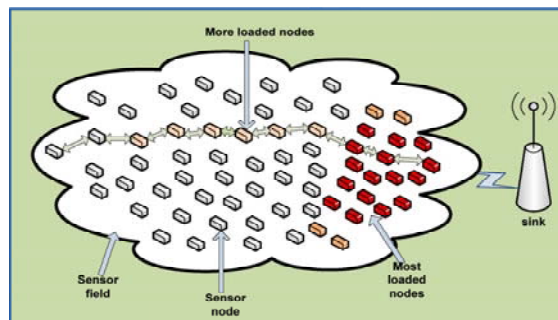


Figure 1. Uneven energy consumption in WSN multi-hop transmission

The routing algorithms in WSNs are designed to prolong network lifetime and to enhance balanced energy consumption through data forwarding [9]. As seen in Figure 2, the routing protocols select the best paths for forwarding the data packet from the source node to the sink. Furthermore, the same route path is used continuously then the existing nodes on that route path will die, which results in network partitioning. Therefore, the balancing energy consumption of sensor nodes with an optimizing routing method is a new challenge presented in many routing protocols for WSNs.

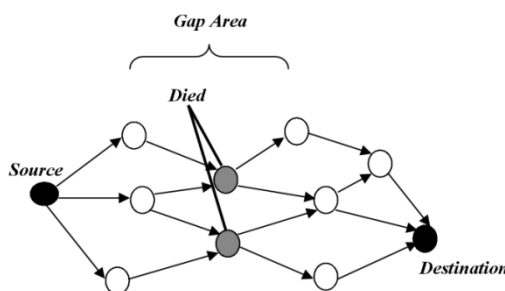


Figure 2. Death the centric nodes in WSN lead to Network partition problem

In this paper, a new energy efficient routing protocol, called the LPA-star routing protocol, is proposed. It uses an optimal aggregated cost function, and the lifelong planning A-star (LPA-star) search algorithm to find an optimum forwarding path between the source node and the destination. The LPA-star algorithm is an incremental version of A-star algorithm that reuses information from previous search paths to find a new routing path without re-running from the start node. The proposed protocol takes the following parameters into consideration to select an optimum routing path: i) highest residual sensor node energy; ii) lowest traffic load; and iii) minimum hop counts.

The remainder of the paper is organized as follows: Section 2 presents related work for the routing algorithm on improving the maximum network lifetime. The paper introduces and provides a brief background to the LPA-star algorithm in Section 3. Section 4 presents the LPA-star routing protocol. The performance evolution is discussed in Section 5. Finally, Section 6 presented the conclusion to this paper.

2. Related Work

In the traditional routing algorithms, the interest in minimizing energy consumed without consideration to balance energy consumption for the whole network lead to a network partition problem and hence will reduce network lifetime. Therefore, the elimination of UEC in order to prolong the network lifetime has become a critical issue in WSNs.

In the recent past, many energy-efficient routing algorithms have been proposed to improve and extend the network lifetime of WSNs. In [10] and [11], the authors propose two different approaches that distribute the traffic load through the nodes which have remaining

energy to ensure the stability of sensor nodes for extending wireless network lifetime. In [12], the authors propose a routing method to reduce the hop count extent of a routing path so as to reduce the power consumption of end to end transmission. All of the above routing protocols using fixed routing paths focus on obtaining energy efficiency. As a result of this, transmitting data via specific routing paths might drain nodes power quickly.

In [13], WSNHA-GAHR is a greedy and A-star heuristic routing algorithm for WSNs in home automation. The algorithm minimizes the number of hops for data transmission by using the greedy forwarding technique. Furthermore, the protocol uses the A-star search algorithm to overcome the local minimum problem. The WSNHA-GAHR protocol does not consider remaining energy in sensor nodes when selecting these nodes for routing data packets. Thus, this may deplete selected nodes energy quickly. Rena et al. [14] proposed an efficient routing algorithm which used an A-star search algorithm to pick out an optimum routing path from the source node into the sink, which was based on a node's minimum energy level value to extend the lifetime of WSNs. This routing protocol defined the threshold as the minimum energy level value sensor nodes. Consequently, a node will be excluded from the routing operation when the energy value of this node is less than the threshold value. The authors of [15] proposed OFFIS (optimized forwarding by fuzzy inference systems) for flat sensor networks to extend the lifetime of WSNs. This protocol favours criteria just as shortest path with small hops, maximum remaining battery power in order to select the best candidate node in the forwarding paths. In [16], the authors proposition is of a hybrid multi-hop routing protocol so as to optimize energy consumption and to extend the WSNs lifetime by combined hierarchical and flat multi-hop routing algorithms with a data collection scheme. In [17], the authors presented a novel sleep scheduling method to maximize network lifetime called Virtual Backbone Scheduling (VBS). This uses only backbones to forward data packets, and the other remaining nodes halt their radios so as to conserve and save energy. Al Ghaffari et al. [18] proposed an energy efficient routing (EERP) protocol to extend WSNs lifetime and balance energy consumption. In their proposed method, the routing method used an A-star search algorithm to achieve an optimum forwarding path between source node and sink by developing parameters to choose the next hop in the routing operation. This routing protocol reruns the search algorithm from the start node every round to find an optimum path without using information from the previous search operation. Moreover, this approach does not include away of checking its current path to select a new path, which will result in increased search effort. Hence, the inevitable consequence is higher consumption of energy.

From the reviewed literature, it can be conclude that a number of different metrics are used to avert network partition and prolong WSNs lifetime, such as balancing energy consumption, shortest path to the sink and balancing load traffic. In this paper, we propose a new energy-efficient routing protocol using LPA-star search algorithm. The LPA-star algorithm repeatedly utilizes a similar optimum forwarding path from source node to sink. It recalculates the new optimum path using data from its previous search results. The proposed protocol selects the optimum routing path depending on the above criteria (residual energy sensor node, distance to the sink of a node and traffic load in the node queue). Furthermore, the routing protocol balances between these parameters to protract the network lifetime with lowest effort and time as far as possible.

3. Lifelong Planning A-star Search Algorithm

Lifelong Planning A-star (LPA-star) is an incremental version of the A-star algorithm introduced in 2001 by Sven and Maxim as a combination of the heuristic A-star search algorithm, which speeds up shortest static path planning and Dynamic SWSF-FP incremental search algorithm, which speeds up replanning [19, 20]

LPA-star employs heuristic knowledge to focus the search and select the optimum path from the start node to the goal node while the environment dynamically changing over time [20]. Furthermore, LPA-star utilize incremental technique to reuse information from previous searches operation to find a new optimum path without rerunning the algorithm from scratch. In fact, LPA-star is repeatedly selects similar optimum path every time the nodes state remains without changes and always efficiently recalculates an optimum path from only those nodes that have changed to the goal node rather than recomputing the path from the start node [19]. As a result, LPA-star decreases the number of start nodes which need to be recomputed and

decreases the search effort for determining the new path to the goal. The LPA-star search algorithm uses the key value ($k(n)$) with two components to select the next node which will be expanded based on the following equations:

$$k(n) = (k1(n), k2(n)) \quad (1)$$

$$k1(n) = \min(g(n), RHS(n)) + h(n) \quad (2)$$

$$k2(n) = \min(g(n), RHS(n)) \quad (3)$$

Where $g(n)$ and $h(n)$ values are the actual cost path from the start node to node n and the estimated cost of the optimum path from node n to the target node(destination node) respectively. Also, the Right-Hand-Side ($RHS(n)$) value is the minimum value of the path costs computed from the node's neighboring node n . The RHS -value is a way for node that changed its key value to notify neighboring nodes. the components of the keys ($k1$ and $k2$) can be thought of as identical to the f -values and g -values utilized by the A-star algorithm respectively, because both the g -values and RHS -values for the component of keys ($k1$ and $k2$) in the LPA-star algorithm correspond to the g -values used in the A-star algorithm and the h -values of the LPA-star algorithm correspond directly to the h -values in the A-star algorithm [21-25]. As consequently, the key($k(n)$) evaluation functions can be represented as:

$$k(n) = (k1(n), k2(n)) \quad (4)$$

$$k1(n) = g(n) + h(n) \quad (5)$$

$$k2(n) = g(n) \quad (6)$$

Generally, LPA-star algorithm maintains a priority queue to keep track of the nodes to detect the next node with pick the smallest key value. More specifically, the node expands in the priority queue when it has smallest $k1$ -value and if there are many nodes with same smallest $k1$ value, finally, the node selected when it has the smallest $k2$ -value.

4. LPA-star Routing Protocol

In this paper, the WSN topology is abstracts as a directed graph $G(N, D)$, where N is the set of n nodes and D is the set of direct radio communication links between the nodes. A direct link $d = (v, u)$, $d \in D$ exists if the Euclidean distance between node v and u inside the domain of r , where r is the radius of the transmission range of nodes. The Base station (BS) is responsible for sensory data gathered from all other nodes in the network within its transmission range [13], [26-27]. The procedure of finding an optimum path from the source node to the BS is regard to some parameters in each sensor node like the residual energy, traffic load and the distance to the sink. The BS must know the current level for the criteria of each sensor node so as to find the optimum path. Therefore, the BS send queries to all sensor nodes in the network at the first round and each sensor node sends above parameter to the BS. At the remaining round, only the sensor has data to send appends its parameters with the data packet toward the BS. The BS should calculate and broadcast an optimum routing schedule to each sensor node [17].

The model of the proposed method assumes that WSN has the following properties:

1. All sensor nodes that randomly distributed inside the area.
2. All sensor nodes have the same initial energy and the same maximum transmission range.
3. Each sensor node knows the location of BS as well as its own and its neighbors.
4. Each sensor node has the different quantities of traffic load inside its queue when the traffic load made by the application and the node has already committed to forward.

The main goals of this paper design a new efficiency routing protocol that will enhancement and extend the lifetime of the WSNs through limiting energy cost as well as the egalitarian distribution of power consumption with minimizing data packet delivery time. To realize this, the new method uses the LPA-star algorithm with all aforementioned routing criteria (residual energy, distance to the BS and traffic load amount) for each sensor node to find an optimum forwarding path from the source node to the BS. The candidate node to represent the optimum routing path depends on the largest key-value which used the evaluation function ($k1(n)$) to find the largest $k1$ -value. The node has the largest $k2$ -value selected when there is more than one node with the same largest $k1$ -value. The evaluation functions we used are given as:

$$k(n) = (k1(n), k2(n)) \quad (7)$$

$$k1(n) = g(n) + (1/h(n)) \quad (8)$$

$$k2(n) = g(n) \quad (9)$$

Where $h(n)$ is the distance from node n to the BS and $g(n)$ is the cost for node n , which takes value $[0...1]$ and determine by the fitness function. The fitness evaluation function is considered for the amount of residual energy and the traffic load of node n to determine the optimum cost value for the node n . The cost function $g(n)$ we used is given as:

$$g(n) = \alpha \left(\frac{Re(n)}{Et(n)} \right) + \beta \left(\frac{Bf(n)}{Bt(n)} \right) \quad (10)$$

Whereas $Re(n)$ and $Et(n)$ are refer to the initial and residual energy of node n respectively, and $Bf(n)$ and $Bt(n)$ are refer to the current and maximum traffic loads of node n respectively. α and β are constant values.

The candidate node that has the maximize power and lowest traffic load amount as well as the shortest distance to the BS (minimum hop counts) will be selected as the better node for the routing path to the BS. As a result, these parameters play a vital role for balance the energy consumption and the appropriate distribution of network load for all nodes in order to prolog the network lifetime.

Our routing protocol for the proposed model check the existing nodes in the optimum path with their neighbors after every packet sends and re-use the same path while its nodes still have the largest key-value. Furthermore, our method gets to benefit from the previous path to recalculate the new optimum path from current node that have changed in which key-value to the BS by select its neighbors that have the largest key-value without re-running from the start nodes.

The proposed method depended on the threshold value for node energy. The communication between the sensor node and the BS through routing path will break while the sensor node energy is least than the threshold value. Therefore, the proposed algorithm tries to find alternate route path by running the algorithm from the start node to avoid choose the low energy nodes in order to prolong the network lifetime. The flow chart of proposed method to find optimum routing path from start node to the BS is shown in Figure 3.

5. Performance Evaluation

In this section, the performance of the proposed algorithm is investigated against the EERP protocol in [17] to demonstrate optimization methods in terms of average residual energy as well as maximizing network lifetime.

5.1. Simulation Evaluation

We adopt MATLAB for executing the simulation. The simulation area is $200 \times 200 \text{ m}^2$ with 50 sensor nodes randomly deployed in this topographical area. The initial energy for every sensor node in the network is set to 5 Joules, with maximum sensed transmission range at 80m. The traffic load is generated randomly between $[0...10]$ for each sensor node. There is a single base station located at the top right-hand corner of the simulated area (200m, 200 m).

Furthermore; a radio model discussed in [28] is used for the proposed method. Based on this model; the sender node expends energy to run radio electronics and a power amplifier. On the other hand, the receiver node spends energy to run the radio electronics. In order to transmit number of bits per packet (k) over the distance (d) between sender and receiver nodes, the dissipate energy of a node is characterized by:

$$E_n T(k) = E_{elec} * k + E_{amp} * k * d^2 \quad (11)$$

And the power consumption of a node for receiving this message is characterized by the expressions:

$$E_n R(k) = E_{elec} * k \quad (12)$$

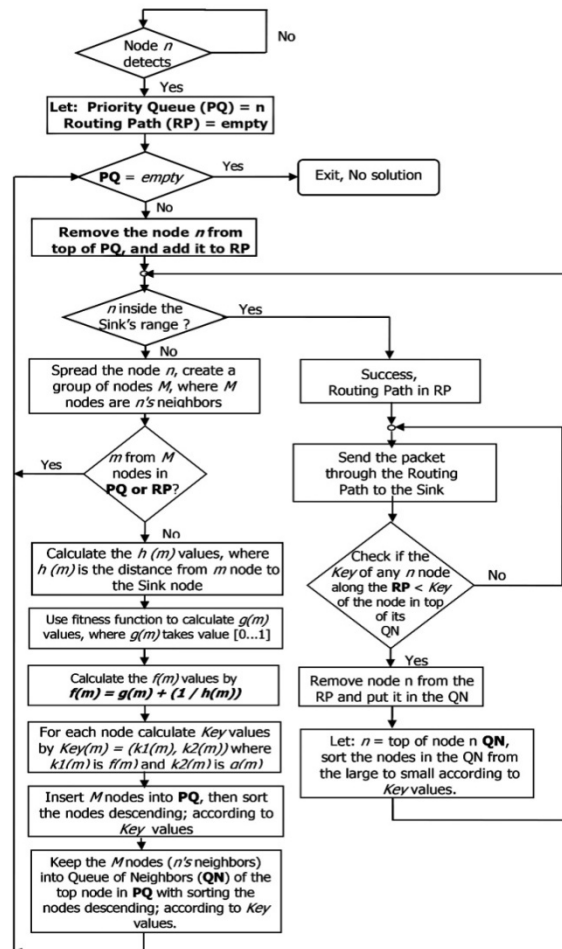


Figure 3. Flow-chart of the LPA-star search algorithm

The electronics energy E_{elec} is affected by several factors such as filtering, modulation, digital coding, and spreading of the signal. In addition, the amplifier energy E_{amp} is influenced by factors like the distance d between sender and receiver nodes and acceptable bit-error rate. Simulations are made using values 100 pJ/bit/m^2 and 50 nJ/bit for E_{elec} and E_{amp} respectively. The simulation parameters are presented in Table 1 which follows.

Table 1. Simulation Parameters

Parameter	Value
Topographical Area	$200 \times 200 \text{ m}^2$
Location of BS (meters)	(200×200)
Number of nodes	50
Transmission range (meters)	80
Initial energy of node	5 J
E _{amp}	100 pJ/bit/m^2
E _{elec}	50 nJ/bit
Data Packet size	4k bit
Number of transmission packets	2×10^4
Maximum traffic node's	10
α, β	0.65, 0.35

5.2. Simulation Results

The number of nodes still live is given as a function of rounds by using the two different approaches presented in Figure 4. The graph indicates that the proposed method outperforms the EERP protocol. When all packets are sent, the network lifetime increased with the LPA-star algorithm by roughly 25% over that obtained from EERP protocol. Furthermore, we can see that the number of active nodes of the LPA-star algorithm is consistently higher than that of the EERP protocol.

The different duration of time corresponding to the first dead node, computed using two different approaches is listed in Table 2. Obviously, the time before the first node dies in the proposed method is much greater than that taken by the first node to die in the EERP method.

From Figure 4 and Table 2, it is clear that the proposed method outperforms the EERP method in terms of maximization of network lifetime and balancing energy consumption.

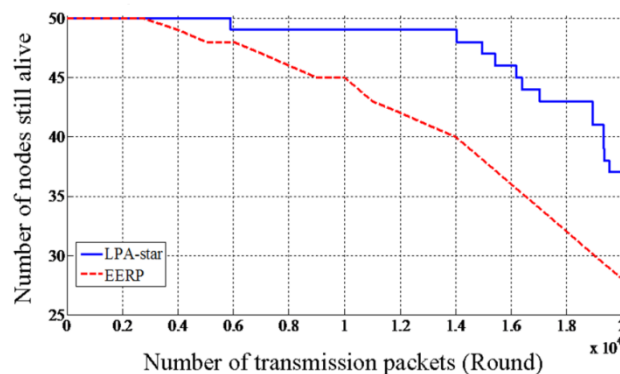


Figure 4. Number of nodes still alive as a function of rounds based on the two approaches (LPA-star and EERP)

Table 2. Number of Rounds with the First Dead Node

Approaches	EERP	LPA-star
Round first node dies	2743	5895

The simulation results in Figure 5 show the average remaining energy of the network for both protocols as a function of transmission rounds. Our proposed method always repeatedly re-uses optimum paths with minimum hop count while the energy nodes in the route path are better than their alternative nodes to route the data packets. Therefore, the proposed method performs better than the EERP protocol in terms of saving node energy. This indicates that a good energy balance is achieved in a WSN through our proposed method.

Many applications in WSNs require a timely response, including for example fire alarm systems. The delay in transmission of a data packet from the sensing nodes to the base station depends on the transmission time, and it should be short, which leads to a fast response with high quality of service. The comparison between two different approaches is shown in Figure 6.

it can be seen that the proposed algorithm has the shortest delay more 50% than that obtained by the EERP protocol.

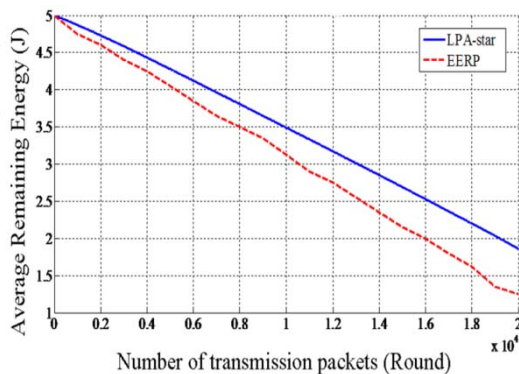


Figure 5. Average network remaining energy as a function of transmission round

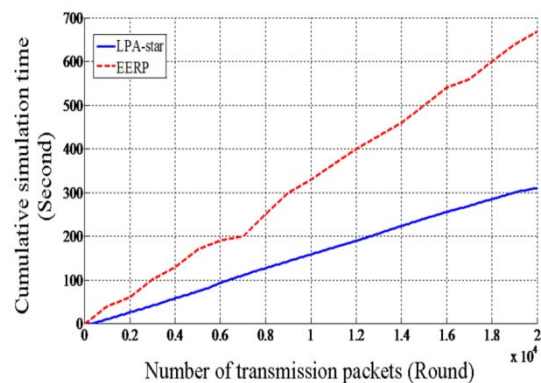


Figure 6. delay in transmission of a data packet in the two approaches (LPA-star and EERP)

6. Conclusion

Energy resource constraints are one of the most critical challenges for wireless sensor networks (WSNs). In spite of the fact routing selection is quite difficult as a result of energy constrained, but this is strongly related to extending network lifetime. Uneven energy consumption is an innate problem in WSN which lead to reduce the network lifetime. To prolong the lifetime of the whole network and eliminate the chance of network partition, we have proposed a new efficient routing protocol called LPA-star protocol. The new method uses the LPA-star algorithm to repeatedly find an optimum routing path. The optimum path can be selected by favoring the highest residual energy, minimum hop count and lowest traffic load. The LPA-star protocol always reuses the part of the previous search operation to recomputed the new optimum routing path without running the algorithm from the scratch. Simulation results show the appropriateness and better performance of new protocol against EERP protocol with regards to enhancement of the WSNs lifetime and balanced energy consumption with fast data transmission across the network.

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