An Energy Efficient Hole Detour Scheme Using Probability Based on Virtual Position in WSNs

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Abstract

Holes are generated due to limited precision of deployment, and thus bypassing holes is one important issue of Wireless Sensor Networks (WSNs). In existing routing schemes using an optimal path, intermediate nodes in the path may deplete their energy quickly, which results in expansion of holes. The Ant Colony Optimization (ACO) algorithm solves this problem by balancing the traffic of data transmitted in the optimal path with transition probability. Ant Colony optimization based Location aware Routing (ACLR) is a hole detour scheme that uses nodes residual energy in transition probability to route data packets in a more energy-efficient way. The problem of ACLR is that it causes unbalanced energy consumption when local minimums occur because a packet may be retransmitted many times by one sensor node. In addition, ACLR also limits the number of nodes used for routing data. In this paper, we propose an algorithm that uses the node’s virtual position, calculated by neighbor nodes coordinates, when computing distances between sensor nodes. By using a node’s virtual positions, a routing scheme using Probability based on Virtual Position (PViP) reduces the number of backoff processes and has more neighbor nodes compared to ACLR. This will enhance the delay performance. As a result, it can balance energy consumption among nodes, improve the network lifetime by up to 7.3%, and the transmission delay by up to 2.7%.

Keywords: Hole Detour, Virtual Position, Delay, Lifetime, Energy Efficiency, Wireless Sensor Networks (WSNs)

1. Introduction

WSNs consist of a large number of low powered nodes and deployed in diverse and complex environment [1]. Hence, either a void in deployment or node failures can cause routing holes which often result in failures in routing [2]. Bypassing the holes is one important issue of WSNs [3, 4]. Since each node has limited energy, its energy consumption must be minimized to prolong the network lifetime. In existing schemes, an optimal path is usually chosen for transmitting data packets in every routing process. Therefore, intermediate nodes in the optimal path deplete their energy sooner, which results in imbalanced energy consumption. Dispersing the energy consumption into multiple paths can extend network lifetime significantly.
Many hole-bypassing schemes have been proposed to route data packets more efficiently in terms of energy use [5, 6]. Hole bypassing schemes proactively identifies the size and shape of the hole to save energy by reducing unnecessary data transmissions. However, these schemes always choose the optimal path to bypass the hole, and result in imbalanced energy consumption. To resolve these problems, some other schemes achieve balanced energy consumption by changing current path to one of the candidate paths, based on the residual energy and locations of nodes [7, 8]. However, these schemes tend to extend the sizes of holes. So, other works have proposed the schemes to slow down the hole spread speed [9, 10]. In these approaches, transition probability was used to distribute energy consumption by choosing different nodes at different times of transmitting data.

Ant Colony optimization based Location aware Routing (ACLR) is a scheme based on Ant Colony Optimization (ACO) transition probability, the scheme includes the amount of pheromones, the shortest path to the destination and the residual energy of nodes. The advantage of ACLR is that it can find the shortest path for routing the data packets in an energy efficient manner when node energy is not the same. However, it causes unbalanced energy consumption when local minimums occur because a packet may be retransmitted many times by one sensor node. In addition, ACLR also limits the number of nodes used for routing data.

In consideration of the aforementioned limitations, a scheme that could increase the data transmission reliability and energy-efficient routing is highly desired. Therefore, we propose the routing scheme using Probability based on Virtual Position (PViP) that uses the EViP nodes virtual position in ACLR. PViP uses the virtual positions of nodes instead of their geographic positions when calculating the transition probabilities. The virtual position of a node is calculated as the average of its one-hop neighbor’s node location. After calculating the virtual position the new position would be closer to the node that has more residual energy. Then, the nodes virtual positions are used to calculate distances between sensor nodes. By using node virtual positions, PViP reduces the backoff process, and has more neighbor nodes compared with ACLR. As a result, their use can balance energy consumption among nodes. From the simulation results, PViP improves network lifetime and delay by up to 7.3% and up to 2.7%, respectively.

The rest of the paper is organized as follows. Section 2 reviews existing energy-efficient hole detour schemes like ACO based schemes and schemes using virtual positions. The proposed scheme is presented in section 3. We then compare the results of our scheme and other schemes. Concluding remarks and further suggestions are found in Section 5.

2. Related Work

This section discusses the energy considered hole bypass schemes. The ACLR [10] scheme uses the nodes residual energy to distribute the energy consumption to other detour paths. The transition probability includes the amount of pheromones, the distance from neighbor to destination node, and neighbor nodes residual energy using Eq. (1).

\[ P_{ij} = \frac{[\psi_{ij}(t)]^{\alpha} [\xi_{ij}(t)]^{\beta} [\eta_{ij}(t)]^\gamma}{\sum_{s \in C(i)} [\psi_{i(s)}(t)]^{\alpha} [\xi_{i(s)}(t)]^{\beta} [\eta_{i(s)}(t)]^\gamma} \]  

\( P_{ij} \) is the probability of node \( i \) to choose node \( j \). \( \psi_{ij} \) is the pheromone between \( s_i \) and \( s_j \). The \( \xi_{ij}(t) \) defines the neighbor node that belongs to the short path to the destination.
and $\eta_{ij}(t)$ finds the neighbor node that has more residual energy. $\alpha$, $\beta$ and $\gamma$ are adjustable weights, as the value of $\alpha$ increases, the chance for ants to choose the route with a higher pheromone rises and the value of $\beta$ increases, the chance for ants to choose the route with a shorter length rises. The value of $\gamma$ increases the chance for ants to choose the node with more residual energy rises. However, ACLR calculates the distance between nodes by geographic position; it limits the number of nodes used for routing data and results in local minimum. When local minimum occurs at node $j$, node $j$ retransmits the data packet to node $i$ that has previously received the data packet. Then, node $i$ finds another neighbor node to detour the local minimum in order to transmit the data packet. The advantage for ACLR is because the next hop number of a neighbor node is limited to the destination direction, it could prevent the wrong data forwarding to other directions. It could also find the shortest route to the destination and route data packet efficiently by using nodes residual energy. However, because of backoff retransmission and limited neighbor nodes it could cause imbalanced energy consumption.

In EViP [8], all nodes calculate their virtual positions before forwarding data packets. When the network topology is created, nodes calculate the average of their one-hop neighbor coordinates and forward a packet to a destination. After sending several packets, if the residual energy of a node is lower than a threshold, it will calculate a new virtual position using Eq. (2) [11].

$$\left(x_A, y_A\right) = \left((\frac{\alpha_{A,1}x_{A,1} + \alpha_{A,n}x_{A,n}}{\alpha_{A,1} + \cdots + \alpha_{A,n}}), (\frac{\alpha_{A,1}y_{A,1} + \alpha_{A,n}y_{A,n}}{\alpha_{A,1} + \cdots + \alpha_{A,n}})\right).$$  \hfill (2)

Eq. (2) is a weighted average expression appearing in many references [12, 13]. Where $\alpha$ is the residual energy weight ($0 \leq \alpha_{A,j} \leq 1$); $x_{A,1}$ is the $x$ coordinate of the first neighbor of node $A$; and $y_{A,1}$ is the $y$ coordinate of the same node. EViP calculates the average of all coordinates weighted with residual energy. After consuming energy to forward data packets, the remaining energy of a node will reach a threshold. At this moment, it uses Eq. (2) to calculate its virtual position. The residual energy of node $A$ can be lower than its neighbors, thus its new virtual position will be directed toward nodes having more residual energy. Because the energy weight of node $A$ is less than that of its neighbors, it can make a new path with new nodes having greater residual energy. However, after calculating the virtual position, if the local minimum still occurs, the data packet cannot be transmitted.

3. Proposed Scheme

This section describes our method that combines the ACLR and EViP’s virtual positions. Subsection 3.1 explains the motivation and the proposed scheme PViP is illustrated in subsection 3.2.

3.1. Motivation

ACLR shows a significant regulation in selecting next hops. When node $i$ that has the data packet tries to select the next hop node $j$ as $C(s_i) = \{s_j | s_j \in N(s_i), d_{j\beta} \leq d_{j\delta}\}$, where $d_{j\beta}$ is a distance between node $j$ and destination. and $d_{j\delta}$ is a distance between node $i$ and destination. Node $i$’s next hop candidate neighbor node set is $C(S_i)$ and $N(S_i)$ is the set of one hop neighbor nodes. Using the nodes geographic position, it limits the next hop candidates and causes the local minimum around the hole during the packet delivery.
For example, Figure 1 shows the local minimum at node A, because the distance from node A to destination (dotted line) is longer than that of node B and C (line). Therefore, $C(S_A)$ is an empty set, and indicates no next hop candidate for data routing.

(a) ACLR  

(b) EViP  

Figure 1. An Example of Local Minimum in ACLR and EViP

In ACLR, when a local minimum occurs as in Fig. 1(a), it uses the backoff retransmitting process to bypass the hole and transmits the data packet. If EViP has the problem that the nodes virtual position is same after calculation as in Fig. 1(b), the data transmission will be failed.

Backoff retransmission and limited neighbor nodes in ACLR cause unbalanced energy consumption. EViP also has the problem that after calculating the virtual position, if the local minimum still occurs, it cannot transmit the data packet. Therefore, we need a scheme that reduces the backoff retransmitting process and uses more neighbor nodes to route the data packet more energy efficiently and also improves the success rate of transmitting.

3.2. Routing Scheme using Probability based on Virtual Position (PViP)

In this paper, we propose the PViP scheme that combines ACLR and EViP’s virtual position. PViP calculates the distance between nodes using virtual position instead of geographic position when calculating the transition probability. In this way backoff retransmitting rate is to reduce and improves the success rate of transmitting, therefore the network lifetime is extended. The residual energy of node A in Fig.1 might be lower than that of its other neighbors, therefore the new virtual position of node A will reorient toward the nodes that have more residual energy. Because the energy weight of node A is less than that of its neighbors, it is able to make a new path with a new node that has greater residual energy.

The example of the virtual position updating is presented in Figure 2. When the data packet is transmitted along the paths 10-11-16-21, node 16 will consume energy to send the data packet to node 21. Thus, node 16 has less residual energy than node 8. Therefore, EViP calculates the weight of node 16 and finds that it is less than that of node 8. Because, node 16 consume it’s energy for transmitting data packet. Finally, the virtual position of node 12 should be 12’ position. When transmitting a data packet in greedy forwarding, since the position of node 12’ is closer to the destination than node 16, the data packet will be sent to node 12’ and node 12’ transmits the data packet to the destination using the path 10-11-12’-8. The ACLR uses the pheromone to distribute the energy consumption of the optimal path; the probability for other paths could be very low. However, the proposed scheme uses the nodes residual energy threshold to
distribute energy consumption rather than pheromone. Therefore, it has greater energy efficiency compared to ACLR.

When PViP calculates the transition probability, it uses the distance from next hop neighbor nodes to the destination and their residual energy using Eq. (3).

\[ P_{ij} = \frac{[\xi_i(t)]^\alpha [\eta_i(t)]^\beta}{\sum_{j \in \mathcal{C}(S)} [\xi_j(t)]^\alpha [\eta_j(t)]^\beta}, \]  

where \( \alpha \) and \( \beta \) are adjustable weights, as the value of \( \alpha \) increases, the chance to choose the node that belongs to the shorter route, and when \( \beta \) increases the chance to choose the node that has greater residual energy rises. \( \xi_i(t) \) defines the neighbor node that belongs to the shortest path to the destination and the location is closer to the current node that has the data packet by Eq. (4) [10].

\[ \xi_{ij} = \left( \frac{d_{od}}{d_{oi}+d_{ij}+d_{jd}} \right) \cdot \left( 1 - \frac{d_{ij}}{\sum_{\eta \in \mathcal{C}(S)} d_{ij}} \right), \]  

where \( d_{ij} \) is the distance between nodes \( i \) and \( j \), \( d_{od} \) is the distance from source node to destination node, \( d_{oi} \) is distance between source node and node \( i \), also \( d_{jd} \) is distance between node \( j \) and destination node [10].

\[ \eta_{ij}(t) = \frac{e_i(t)}{\sum_{i \in \mathcal{C}(S)} e_i(t)}, \]  

where \( \eta_{ij}(t) \) defines the neighbor node that has greater residual energy. In Eq. (5), \( e_i(t) \) denotes node \( i \) residual energy at time \( t \).

When the local minimum occurs, PViP could change the nodes position with virtual position that uses the mean of nodes coordinate to transmit the data packet. For example in Figure 3, when computing the virtual position of node \( A \), as the distance of node \( A \) becomes greater than its previous one, node \( A \) could select node \( B \) or \( C \) as a next hop neighbor. That causes its neighbors to ignore the local minimum when routing the packets. If the local minimum occurs again, it uses the backoff retransmitting processes such as ACLR.
4. Performance Evaluation

We implement the simulation by using C# to analyze the performance of our proposed scheme. We use two mechanisms to guarantee the reliability of the simulation. First, we develop the simulation in accordance with the same environment [10]. And obtain the same trends from the graphs representing the network lifetime. Second, all experiments are repeated 100 times and we get the average value [14]. The detailed simulation environments are as follows. We randomly deploy 100 ~ 200 nodes that has 30m transmission ranges in the network with an area of 200×300m² and compared the network life time and data transmission delay. The ratios of the amount of energy used for transmitting, receiving, and listening status are 1.7:1.2:1, respectively [15]. The initial energy of each node is set to 100. We have measured the network lifetime when at least one node runs out of energy [16].

![Figure 4. Network Lifetime](image1)

![Figure 5. Data Transmission Delay](image2)

We first compare the network lifetimes of two schemes and measure as a round, when one node runs out of its energy is one round. In Figure 4 shows that PViP improves the network lifetime by up to 7.3% and average 5% compared to ACLR only. Because of back off retransmission, limited neighbor nodes have the unbalanced energy consumption problem. PViP reduces the back off process and have more neighbor nodes compared to ACLR. As a result, this scheme can balance energy consumption among nodes and improve network lifetime. Therefore, it also chooses the one optimal path to bypass the hole and the hole gets bigger. However, the proposed scheme uses the other bypassing routes, but the optimal path prolongs the network lifetime.

Figure 5 shows the performance of the average data transmission delay (number of hops) in ACLR and PViP. When the nodes densities increase, we see that the data transmission delay is increased. PViP also improve the delay performance approaching 2.7% and average 2% compared to the ACLR. However, this result is almost similar. The reason for similarity is that both schemes do not use the optimal path, sometimes there is a probability of using the long path to the destination.

5. Conclusion

In this paper, we proposed the PViP algorithm that which can balance the nodes energy consumption and reduce data transmission delay. The ACLR causes unbalanced energy consumption, when local minimums occur because a packet maybe retransmitted many times by one sensor node. In addition, ACLR limits the number of nodes used for routing data. Also, EViP cannot transmit the data packet if the virtual position is still local minimum. However, PViP reduces the back off process and has more neighbor
nodes compared to ACLR. As a result, PViP can balance energy consumption among nodes.

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