Parabola based Geographic Forwarding in Wireless Sensor Networks

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ABSTRACT

Due to power and communication capability limitations, communication between a source node and a destination node in a Wireless Sensor Network (WSN) that are not within each other's direct communication range needs to rely on the forwarding of other nodes. When it comes to the routing problem in WSNs with a void area (which is a hole that lacks of active nodes), researchers have proposed a variety of mechanisms. One of the solutions is to create a path along the perimeter of a geometric shape. However, it often results in long detour path although some nodes that can create a much short path exist. A improved solution is to find a landmark node. This method first finds a routing path from the source to the landmark, and then develops a routing path from the landmark to the destination. This method avoids long detour paths during forwarding. However, the selected forwarding nodes are mechanically fixed. These nodes suffer from a much higher traffic load, which results in a shorter lifetime and thus creates a larger void area. This article presents a mechanism based on virtual parabola generated using the locations of the source, the landmark, and the destination prior to the routing. During the forwarding process, more nodes will be evenly chosen based on the virtual parabola. Because of that, the new proposed scheme finds short routing path while maintaining more balanced energy consumption. The performance of the new proposed method is evaluated through simulations. The results demonstrate that the approach made improvement compared with both existing methods.

1. INTRODUCTION

Wireless Sensor Network (WSN) is a wireless network that consists of a large number of sensor nodes that are connected and communicate via wireless channels [4][5]. These networked nodes play strong roles in various operations, including surveillance, disaster search and rescue [1][2][3].

Due to power limitation and communication capability constraint, only when a source node and a destination node is within each other's communication range, they can direct send message to each other. Otherwise, communication between a source node and a destination node in Wireless Sensor Network (WSNs) that is not within each other's direct communication range needs to rely on the forwarding of other nodes.

Various existing routing and forwarding protocols have been proposed by researchers [6][7][11][12][13][14][15][16]. Geographic routing, which focuses on position-based routing protocol design, delivers packets to nodes in a network via multi-hops routing based on known position information. Technologies such as GPS (Global Positioning System) or virtual coordinates can be utilized to obtain the location information of sensors [17][18][19]. The assumption of geographic routing is that the source node knows the location of the destination node. The basic approach that can be adopted is that the source node selects one of its neighbors that is closest to the destination as the forwarding node. This greedy rule then is expected to be used by each of the subsequent forwarding nodes until the packet reaches the destination. This approach overcomes the flooding problem during forwarding. However, this method may not work as expected in WSNs with void areas (areas that have no active nodes). Because the node forwarding the packet around the void area may not have a neighbor that is closer to the destination. In WSNs, various reasons may cause the void area. For example, hackers gaining control of wireless nodes and turning them into zombies and making them inactive. Additionally, sensor nodes may die due to run out of power since they are battery power in most cases. Moreover, physical obstacles such as mountains or lakes can create void areas.

Many existing mechanisms have been proposed to solve the forwarding path-finding problem in WSNs with void areas. Initially, the Greedy Perimeter Stateless Routing (GPSR) protocol was proposed by Karp and Kung in their work [20]. Their approach successfully delivers packets as long as a path exists. When a packet is stuck at a node around a void area, the protocol attempts to get out of the local minimum by forwarding the packet around the void area. In such a method, sensors make local forwarding decisions based only on their own location, the locations of their neighbors, and the location of the destination [10]. GPSR guarantees success in finding a valid routing, but often results in longer detour path, leading to increased delay. Later, scholars in their work [7][34][25][26] proposed landmark based routing. The key idea is to find a suitable landmark node. This method first determines a routing path from the source to the landmark (the intermediate target node), and then develops a routing path from the landmark to the destination. The landmark based protocols avoid long detour paths when a void area blocks greedy forwarding. However, their shortcomings are also obvious. The fixed selected landmark nodes typically have much shorter lifetime due to heavier forwarding workload, which may cause the void area to grow bigger.

The concept of Green Computing has gained increased attention in WSNs in recent years. One important reason is that sensor nodes are typically battery-powered, making replacement or recharging challenging, especially if a WSN is deployed in rural areas. Therefore, many scholars are interested in the study of energy-efficient protocol design in WSNs[27][28]. Many of the recent routing and forwarding approaches also take energy efficiency into consideration regardless of their research focus. They either focus on protocols that minimize energy consumption [30], or switch idle nodes' to an off status as much as possible [29], or implement other approaches to reduce the utilization of energy consumption [31][32][33].

In this work, an energy-efficient parabola-based routing algorithm for WSNs with void areas is presented. The research goal is to find out the optimal routing paths that avoid long detour path while achieving a more balanced energy consumption, thus achieves a longer network lifetime. When a void area exists, the source node obtains the location information of the landmark node [7]. Assuming the source node also knows the location information of the destination, a virtual parabola can be constructed based on the locations of the source, landmark, and destination nodes. Subsequently, the forwarding is conducted along the virtual parabola. In this mechanism, the forwarding nodes are not fixed as in existing proactive mechanisms. Instead, the nodes along the parabola share the forwarding tasks to balance energy consumption, thereby extending the lifetime of the selected nodes. Experimental simulation results demonstrate that our proposed approach achieves better performance in prolonging the life time of selected nodes, while forwarding the data through a shorter path.

The rest of the paper is organized as follows. In section 2, it reviews existing related works. In section 3, the problem is defined and the new scheme is presented, which is the key of this article. In section 4, the performance of the proposed mechanism is evaluated through simulated experiments. The conclusion is made in section 5.

2. RELATED WORK

In the early years, when geographic routing protocols began to be studied, greedy forwarding was the basic scheme. In greedy geographic routing, each node chooses one of their neighbors who is closest to the destination as its forwarding relay until the destination is reached. Soon after, a face routing mechanism called Compass routing was proposed in the work [21]. It ensures that the data is forwarded to the destination as long as path exists. This approach works for most network scenarios but not for all. In work [20], Karp and Kung proposed the Greedy Perimeter Stateless Routing (GPSR) algorithm. The proposed protocol consists of a normal greedy forwarding mode and a perimeter forwarding mode. The perimeter forwarding mode is activated when a void area blocks the greedy forwarding.

Ahmed Aboud, et al. in their work [22] proposed a geographic interest forwarding strategy for Named Data Networking (NDN)-based Internet of Things (IoTs). Their study introduced a new energy-efficient geographic forwarding mechanism. They provided support for push-based network traffic and utilized different forwarding technologies to balance the energy consumption across the network. In work [23], Shuai Gao et al. proposed a dual mode geographic interest forwarding scheme for multi-hop communications in WSNs. The scheme includes two forwarding modes. One mode focuses on energy efficiency and provides a flexible mode shifting with flooding scope control and broadcast storm prevention. Additionally, they employ energy weight factors to control and balance the energy consumption of forwarding relays.

Xuejie Liu et al. studied the Geographic forwarding problem in V-NDN (Vehicle Named Data Networking) [24]. They proposed GOFS (Geographic Opportunistic Forwarding Strategy), which is a mechanism that supports Geographic-tagged name-based information retrieval in V-NDN. The proposed method develops an opportunistic forwarding strategy by utilizing the position of interest and trajectories of vehicles in their decision-making process for forwarding.

F. Xing et al. proposed a mechanism HAGR which includes hole detection and hole advertisement algorithms. Then, they proposed a routing algorithm which uses the hole information[35]. Q. Fang et al. developed an approach to define and detect the hole, and then a routing algorithm was designed[36].

Some papers were working on the new algorithms to solve the challenge by geometric shape aided routing/forwarding. [8] proposed an algorithm based on the routing path created along a circle. The paper made improvement based on other existing work. However, the curvature of a circle is too much and it misses some ideal forwarding nodes, which is the limitation. Then a newer algorithm guided by an ellipse was proposed [9]. The paper also made improvement based on other existing work, but the curvature is too small and sometimes it is close to the greedy algorithm.

3. PARABOLA BASED FORWARDING

3.1 Background and Challenge

With the help of GPS, satellite based navigation systems, as well as algorithms for creating virtual coordinates, electronic devices including small mobile devices such as sensor nodes are able to obtain location information. Geographic routing and forwarding solutions that utilize the location information of sensor nodes are more efficient and scalable. With the awareness of location information, a node can verify, within its communication range, which node is closer to the destination, allowing it to select the closest neighbor nodes in a greedy modality.

The limitation of geographic routing and forwarding is that the greedy mechanism does not work for situations where a void area exists in a WSN. In order to address this issue, GPSR was proposed as presented in [20]. However, in such a mechanism, sensors make local forwarding decisions based only on their own location, the locations of their neighbors, and the location of the destination [10]. As a result, it often returns a longer detour path.

For instance, consider the example shown in Fig. 1. a source node denoted as S wants to send a packet to a destination node denoted as D. Based on GPSR, the message is forwarded to node p_1, then p_1 forwards the message to p_2, and then subsequently to p_3. All of those forwarding decisions are made simply based on the greedy rule. However, the greedy forwarding fails at p_3 because there is a void area. p_3 is unable to find any neighbor that is closer to the destination using the greedy forwarding approach. In this case, the perimeter routing mode is activated to send the message to Node B. After that, the greedy forwarding mode restarts and then the packet is forwarded to q_1, q_2, q_3, and so on. Throughout this process, a long detour forwarding path from S to B is obtained.

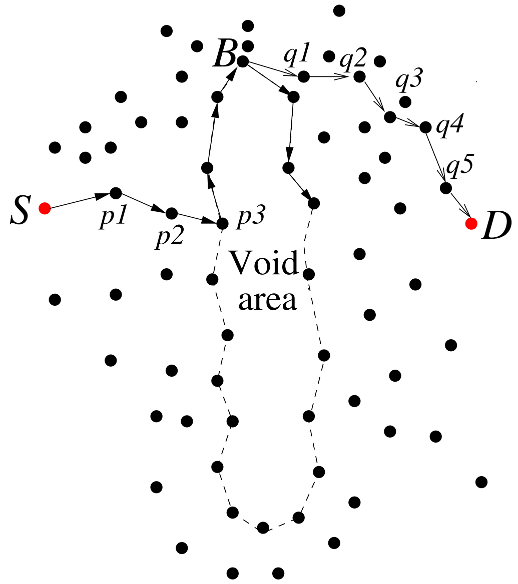

Fig. 1: A long detour path created by GPSR

While location awareness plays a crucial role in geographic-based routing, GPSR does not fully utilize the locations of sensor nodes. To take full advantage of location information, researchers have developed landmark-based forwarding protocols. In these protocols, landmark nodes are predetermined, e.g., ITGR[7]. During the initial routing phase, the source node sends the packet to the landmark, and then the packet is forwarded from the landmark to the final destination node. As depicted in Fig. 2, differences from the parameter routing used in GPSR, landmark-based routing and forwarding protocol are capable of avoiding long detour paths. However, the nodes selected as part of the routing path are typically fixed due to the proactive forwarding nature. These nodes consume more energy and bandwidth, resulting in faster power depletion. This may cause more nodes to be inactive and thus make the void area larger. The possibility of an increased void area or changes in the working status of sensor nodes between on and off, can trigger the routing algorithm to reorganize the network, leading to high complexity.

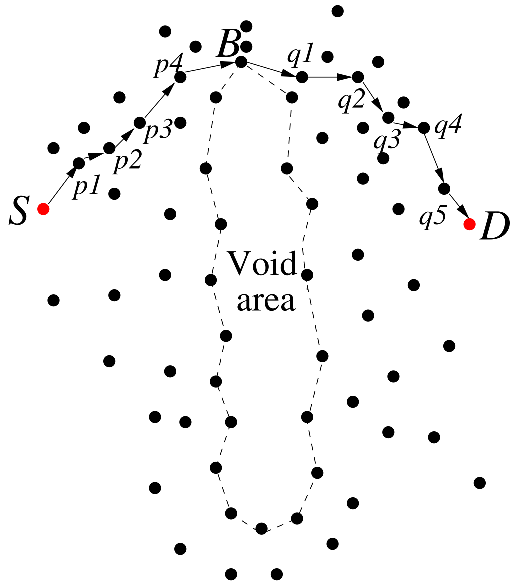

Fig. 2: A path created by landmark routing

This article presents a novel forwarding algorithm for WSNs with void area. The goal is to find out optimal routing paths that avoid long detour path while achieving a more balanced energy consumption by distributing the forwarding task to more nodes. Compared with existing approach, the new solution achieves short paths and a longer network lifetime.

3.2 Outline of the Approach

A WSN where all sensor nodes are static and deployed in a two dimensional area is considered in this study. As shown in Fig. 1 and Fig. 2, GPSR and landmark based forwarding mechanism both have limitations. One finds long detour path that leads to more delay while the other finds path with constant nodes which leads to increased void area and shorter network lifetime.
In order to overcome the above mentioned limitations, this study proposes a new approach. On one side, it is able to balance the energy utilization in a group of sensors instead of a fixed set, which prolong the nodes' lifetime. On the other side, it does not generate a long detour forwarding path. In landmark based routing, the source node S knows the location of landmark node B. This study makes the same assumption, where source node S knows the coordinates of landmark node B and final destination D [7]. Based on that location awareness, S is able to construct a virtual parabola P using the three points S, B and D. Then the forwarding nodes will be selected based on the virtual parabola P. Specifically, to balance workload, the forwarding nodes will be chosen from inside and outside of P alternatively. For example, as shown in Fig. 3, S forwards a packet to p_1, which is inside P. Then p_1 forwards the packet to p_2, which is outside P. Then p_2 forwards the packet to p_3, which is inside P, and then p_3 forwards the packet to p_4, which is outside P. In such an approach, the source node S does not create a proactive path. On the contrary, the path created based on a virtual parabola reactively. In case any node fails, the approach can be executed in a manner of distributed network, meaning that no reshuffle takes place in the approach.

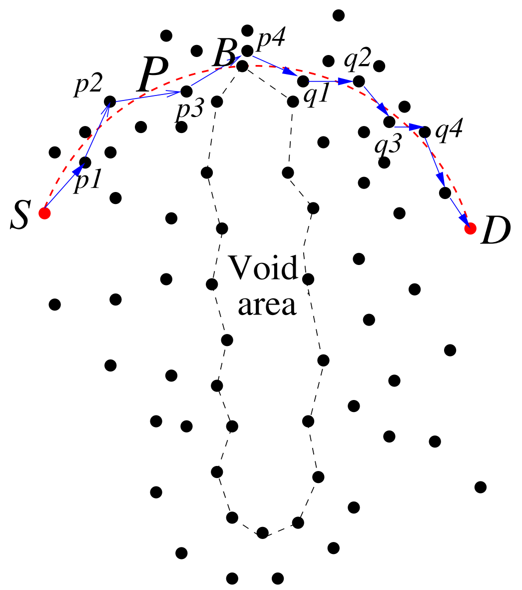

Fig. 3: The forwarding based on a virtual parabola

3.3 Description of the approach

Let $S(x_s, y_s)$, $B(x_b, y_b)$, and $D(x_d, y_d)$ denote the coordinates of nodes$S$, B, and D, respectively. Suppose S would create a parabola by the three points, whose equation is $y = ax^2+bx+c$. Because all the three points are located in the parabola, their coordinates satisfy:

$$y_s = ax_s^2 + bx_s + c \quad (1)$$

$$y_b = ax_b^2 + bx_b + c \quad (2)$$

$$y_d = ax_d^2 + bx_d + c \quad (3)$$

Then by calculation, a, b and c are:

$$a = \frac{x_d(y_s-y_b)+x_s(y_b-y_d)+x_b(y_d-y_s)}{(x_s-x_b)(x_s-x_d)(x_b-x_d}$$
$$b = \frac{x_d^2(y_s-y_b)+x_s^2(y_b-y_d)+x_b^2(y_d-y_s)}{(x_s-x_b)(x_s-x_d)(x_b-x_d}$$
$$c = \frac{x_d x_d(y_s-y_b)+x_s x_d(y_b-y_d)+x_b(y_d-y_s)}{(x_s-x_b)(x_s-x_d)(x_b-x_d}$$

Let

$$G(x, y) = ax^2 + bx + c - y \quad (4)$$

To determine whether a node $p(x_p, y_p)$ is inside or outside the parabola P, three cases are considered:

—Case 1: $G(x_p, y_p) > 0$, indicating p is outside the parabola;
—Case 2: $G(x_p, y_p) = 0$, indicating p is in the parabola;
—Case 3: $G(x_p, y_p) < 0$, indicating p is inside the parabola.

Case 1 and case 2 are combined to simplify the cases. This combination does not affect the routing result.
In the proposed algorithm, when a node forwards a packet to the next hop, the next hop node is chosen either inside or outside the parabola P. For a node p' with coordinates $p'(x_{p'}, y_{p'})$, its coordinates are substituted to (4). if the value is positive, the node p' is considered as outside the parabola P; otherwise it is considered as inside the parabola P.

$$G(x, y) : \begin{cases} \geq 0, \ p' \ is \ outside \ \mathrm{P} \\ < 0, \ p' \ is \ inside \ \mathrm{P} \end{cases} \quad (5)$$

When a source node S initializes the forwarding of a packet targeted at destination D, GPSR is initially used for the forwarding. Suppose the node of next hop is p_1. If p_1 is inside the parabola P as in Fig. 4, then p_1 will use left-hand rule and equation (4) to find out the next hop p_2 outside P. Further, p_2 will use equation (4) to find out its next hop inside P. On the other side, if p_1 is outside the parabola P as in Fig. 5, then p_1 will find out the next hop p_2 inside P accordingly.

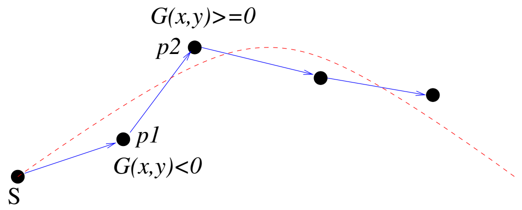

Fig. 4: The case when the node of next hop is outside the parabola

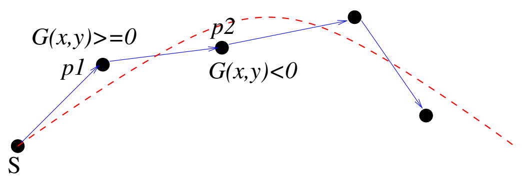

Fig. 5: The case when the node of next hop is inside the parabola

3.4 Algorithms

Suppose the current node is p_i. It calculates $G(x_i, y_i)$ with its coordinates (x_i, y_i) according to (5). If $G(x_i, y_i) \geq 0$, it means the current node p_i is outside of the parabola P, then it finds the first node p_{i+1} inside the parabola P as its next hop by right-hand rule. If the distance from p_{i+1} to D is closer than the distance from p_i to D, then p_{i+1} is the next hop of p_i. otherwise parabola based forwarding is not adopted. Node p_i calls GPSR instead. If $G(x_i, y_i) \leq 0$, it means the the current node p_i is inside the parabola P, then it finds the first node p_{i+1} outside the parabola P as its next hop by left-hand rule. After that, p_i calculates its distance to D and compares the distance with distance from p_{i+1} to D to figure out the next hop node accordingly. The approach can be summarized as shown in algorithm 1.
The entire routing with parabola based forwarding starts from node S. As shown in algorithm 2, because node S knows its own coordinates and the location information of B and D, node S figures out a virtual parabola P at first. Then node S forwards the packet and the information of the virtual parabola to its next node p_i by GPSR, meaning P finds out one its neighbors p_i that is along the parabola and closest to the destination. The routing process ends when p_i is the destination node D. Otherwise,

Algorithm 1 $Finding\_next\_forwarding\_node()$

The current node p_i calculates $G(x_i, y_i)$ according (5)
Case 1: $G(x_i, y_i) \geq 0$
  by right-hand rule, find the first p_{i+1} satisfying $G(x_{i+1}, y_{i+1}) \leq 0$
    If distance(p_{i+1}, D) is $\leq$ distance(p_i, D)
      p_{i+1} is next hop of p_i
      p_i conducts GPSR to find next hop p_{i+1}
Case 2: $G(x_i, y_i) \leq 0$
  by left-hand rule, find the first p_{i+1} satisfying $G(x_{i+1}, y_{i+1}) \geq 0$
    If distance(p_{i+1}, D) is $\leq$ distance(p_i, D)
      p_{i+1} is next hop of p_i
      p_i conducts GPSR to find next hop p_{i+1}

p_i calculates and identifies its next hop node p_{i+1} based on algorithm 1. Then p_i forwards the packet and the information of the virtual parabola to p_{i+1}. This process is repeated until the packet arrives destination node D. If such node that is along the parabola and closest to the destination does not exist, then the forwarding will adopt GPSR.

Algorithm 2 $Parabola\_based\_forwarding()$

1: If current node S successfully figures out a virtual parabola P by S, B and D.
2: S forwards the packet and the parabola P to its next hop p_i.
3: If p_i is D, end
4: p_i calls algorithm 1 to find its next hop p_{i+1} and forwards the packet and the parabola P to its next hop p_{i+1}.
5: p_i=p_{i+1}, go to step 3
6: Else
7: S conducts GPSR to forward the packet

3.5 Recursive routing protocol for WSNs with multiple landmarks or holes

ITGR [7] is a method that can be used to determine the landmarks prior to the routing. It provides the situation when there are multiple landmarks in a path from a source node to a destination node, which may happen in two situations. One is that a void area (or hole) has multiple landmarks, the other is that there are multiple holes with multiple landmarks in the path. In [7], the multiple landmarks are called ITGR list. The proposed parabola based routing protocol is called recursively until the packet reaches the destination. Fig. 6 illustrates a situation that a hole has multiple landmarks. When S intends to send a packet to D, the ITGR list is retrieved, i.e., $< L_1, L_2, L_3 ... >$. When the algorithm is called, it retrieves the first element denoted as L_1 from the ITGR list, and uses three points S, L_1, D to create a virtual parabola P_1 (red curve shows part of parabola in Fig. 6) and uses the partial parabola P_1, say arc $\widehat{SL_1}$ to guide the routing. Then L_1 is considered as the new source. In this step, the algorithm retrieves the first element (say L_2 this time) from the remaining ITGR list. Then a virtual guiding parabola P_2 was drawn with L_1, L_2 and D. Then the routing is along the arc $\widehat{L_1L_2}$, which is the partial parabola P_2(blue parabola in Fig. 6). In this way, the next routing is along the arc $\widehat{L_2L_3}$, which is the part of guiding parabola P_3(cyan parabola in Fig. 6). The process stops until the packet reaches the destination node D. Finally, the generated routing path is $< S, ...L_1, ...L_2, ...L_3, ..., D >$. In this mechanism, the arcs $\widehat{SL_1}$, $\widehat{L_1L_2}$, etc. are used to guide the forwarding relay selection. Each piece includes two adjacent landmarks, making a short path of each local routing. As such, a shorter path is generated instead of a long detour path. During the routing and forwarding procedure, when a node runs out of power, an alternative node along an arc will be replaced its role in forwarding, by which the life time of the network is increased. Therefore, in the proposed mechanism, both short path and long life time are ensured. Fig. 7 shows the scenario with multiple void areas and multiple landmarks, it is implemented in the same way and with the same objectives.

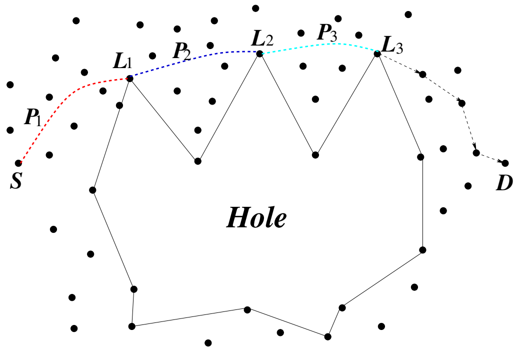

Fig. 6: The case when a hole has multiple landmarks

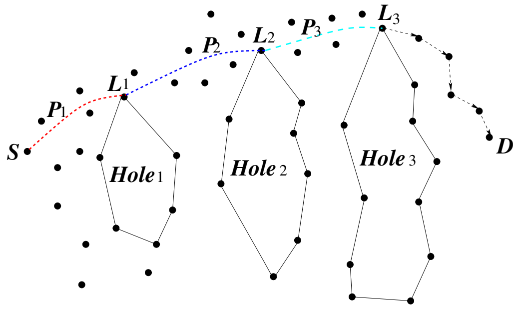

Fig. 7: The case when a routing path meets multiple holes

The recursive call is $\tau = I.dequeue()$, by which the nodes are removed from I, making I smaller and smaller and eventually empty. The recursive call moves toward to the termination condition and eventually results in the end of recursive call, thus the recursive algorithm is robust. The process is depicted in detail in algorithm 3.

4. SIMULATIONS

In this section, the proposed method is evaluated through simulations. MATLAB is adopted to evaluate the new mechanism. The simulation assumes the sensor nodes are distributed in a simulated noiseless radio network environment. A simulated topology with 1000x1000 meters is created that consists of a number of randomly distributed nodes. The radio signal range of sensor nodes is set to 50 meters. The experiments generate networks

Algorithm 3 *Recursive_routing*

1: Retrieve the ITGR list I
  if I is empty
    send the packet to destination D using greedy-based forwarding;
    exit;
  end
2: else
  τ = I.dequeue();
  create a virtual parabola by this node, τ and D;
  call $Finding\_next\_forwarding\_node$();
  $\tau.Parabola\_based\_forwarding$()
end

with different size, where the number of nodes varied from 100 to 500 with a increment of 25 each time. Random coordinates are generated for those nodes to simulate a random nodes distribution. The void areas were also automatically generated based on the distribution of the nodes. If a node a sends a packet to node b, ITGR [7] will be called at first to detect whether hole(s) exist between a and b. If yes, then a virtual parabola will be created and the nodes along the virtual parabola conduct the forwarding. Otherwise, a simple greedy will be conducted, which is one of the modes in GPSR. This article focuses on the high level algorithm design, and thus physical parameters are not involved in the simulation, which is similar to some peer research focused on the length of path.
The proposed PARA (Parabola based forwarding) approach is compared with two other existing approaches. One is LM presented in [34], which is a typical landmark based algorithm. The other one is GPSR presented in [20]. Particularly, the study compares the percentage of remaining alive sensors over time and the average length of forwarding path over time. The study assumes that once a node conducts a forwarding, 1% energy will be consumed, and if a node is dead once it runs out of its power. The time was changed from 0 to 1000 seconds with increment of 50. For each moment, then the experiments were conducted with the change of the time. Overall, the experiments create the typologies of 100, 125, 150, 175, ..., 500 nodes. For each size n, the experiments randomly choose $10\% * n$ pair of nodes and set then as source and destination nodes to send packets. For example, when n is 100, the simulation randomly chooses 10 pairs of nodes to send packets once every 5 seconds. For the same size 100, after 50 seconds, the experiments reshuffle all the source and destination nodes in the topology and do the packet sending again. Then after 50 seconds, the experiments do the same thing again. For the same topology, the three approaches, the propsoed parabola based approach, LM[34], and GPSR[20] are conducted with the same setting. Then the average results are presented in the figures below.

Fig. 8 demonstrates that when the time is longer, the algorithm PARA maintains more alive sensors. In GPSR, more nodes die fast because GPSR requires more nodes to attend the forwarding and thus they run out of their battery fast. PARA is also better than LM in terms of the alive nodes.

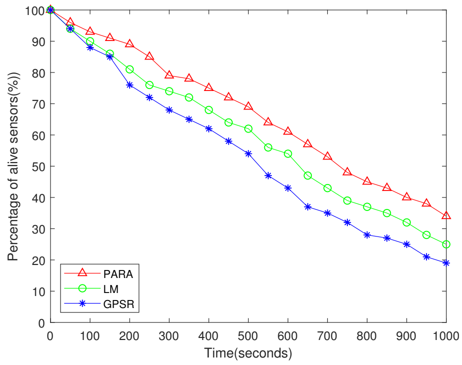

Fig. 8: The percentage of alive sensors over time

Fig. 9 displays the average length of path obtained by three different forwarding algorithms. The results show that GPSR obtained the longest path because it had no mechanism to avoid long detour path when encountering a void area. Instead, it performed perimeter routing, which led to a long path. The proposed PARA approach generated shorter average path because PARA uses landmarks and virtual parabola to guide the forwarding, thus lowering the length of the path. The path length returned by PARA is similar to the length of LM, which is a landmark based routing.

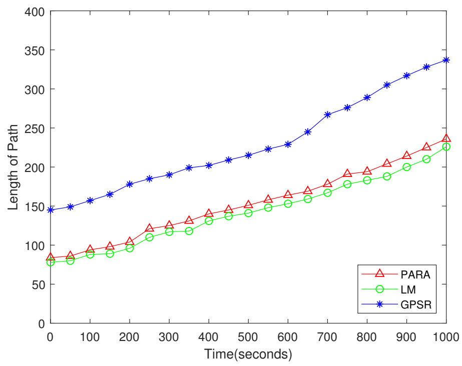

Fig. 9: The length of path over time

Fig. 10 demonstrates the length of paths generated by recursive calling, which is incurred by a hole with multiple landmarks or multiple holes with multiple landmarks. Similar to the average length of path obtained in the circumstance of a single hole, the scheme PARA generates shorter paths while GPSR results in longer paths in multiple landmarks as well. In such a situation, the recursive call is performed as Algorithm 3 in PARA. The forwarding path returned by GPSR was much longer than that of the other two because GPSR resulted in multiple long detour paths when there are multiple holes. The result of LM is similar to PARA.

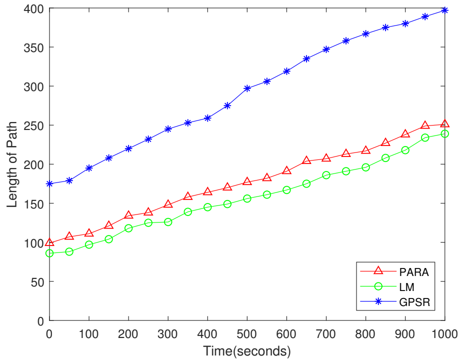

Fig. 10: The length of path over time of recursive calling

With regard to the alive sensors, PARA evenly allocates the forwarding tasks to nodes along the parabola, thus the situation that some nodes afford much forwarding and run out of energy quickly does not exist in PARA. Therefore, PARA maintains the highest percentage of alive sensors over time of recursive calling as shown in Fig. 11. The LM and GPSR have lower percentages, especially in GPSR, and multiple landmarks result in many long detour paths by this scheme and thus more sensor nodes die with insufficient energy.

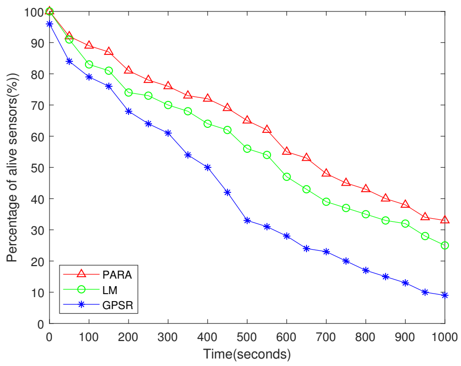

Fig. 11: The percentage of alive sensors over time of recursive calling

5. CONCLUSION

Two issues exist in forwarding in WSNs with void areas. One is the length of the returned forwarding path . The other is the energy consumption of sensor nodes, which is directly related to lifetime. A new forwarding approach based on the guide of a virtual parabola is presented in this article, which handles the two issues. In particular, it considers both landmark based geographic features to create short path and energy efficiency routing to make sensors' life time longer in forwarding. When a packet is intended to be sent to a destination node, the source node figures out a virtual parabola based on the coordinates of the source node, landmark node, and the destination node. Then the forwarding is carried out by the nodes inside and outside the parabola in turn, and thus the forwarding loads are shifted and balanced. Our proposed solution can find the short path and maintain a higher number of alive nodes compared with these landmark based approaches.
This study is focused on the algorithms. The future work may focus on the MAC layer to explore more physical parameters.

6. REFERENCES

[1] Chen, M., Leung, V.C., Mao, S. and Yuan, Y., 2007. Directional geographical routing for real-time video communications in wireless sensor networks. Computer Communications, 30(17), pp.3368-3383.

[2] Hurni, P. and Braun, T., 2008. Energy-efficient multipath routing in wireless sensor networks. In Ad-hoc, Mobile and Wireless Networks: 7th International Conference, ADHOC-NOW 2008 Sophia-Antipolis, France, September 10-12, 2008 Proceedings 7 (pp. 72-85). Springer Berlin Heidelberg.

[3] Young-Gwan, K. and Jae-Hong, Y., 2012, May. Position coodinate-based energy efficient routing protocol for Wireless Sensor Networks. In 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery (pp. 2193-2197). IEEE.

[4] Aboud, A., Touati, H. and Hnich, B., 2019. Efficient forwarding strategy in a NDN-based internet of things. Cluster Computing, 22, pp.805-818.

[5] Gao, S., Zhang, H. and Zhang, B., 2016. Energy efficient interest forwarding in NDN-based wireless sensor networks. Mobile Information Systems, 2016.

[6] Yang, J., Fei, Z. and Shen, J., 2015. Hole detection and shape-free representation and double landmarks based geographic routing in wireless sensor networks. Digital Communications and Networks, 1(1), pp.75-83.
Fascista, A., 2022. Toward integrated large-scale environmental monitoring using WSN/UAV/Crowdsensing: A review of applications, signal processing, and future perspectives. Sensors, 22(5), p.1824.

[7] Fei, Z., Yang, J. and Lu, H., 2015. Improving routing efficiency through intermediate target based geographic routing. Digital Communications and Networks, 1(3), pp.204-212.

[8] Yang, J., Guo, J., Shen, J. and Yan, M., 2020, May. Landmark based circle routing in wireless sensor networks. In 2020 5th International Conference on Computer and Communication Systems (ICCCS) (pp. 733-737). IEEE.

[9] Yang, J., 2022. An ellipse-guided routing algorithm in wireless sensor networks. Digital Communications and Networks, 8(5), pp.770-777.

[10] Ogier, R., Templin, F. and Lewis, M., 2004. Topology dissemination based on reverse-path forwarding (TBRPF) (No. rfc3684).

[11] Royer, E.M. and Perkins, C.E., 1999, August. Multicast operation of the ad-hoc on-demand distance vector routing protocol. In Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking (pp. 207-218)..

[12] Johnson, D., Hu, Y.C. and Maltz, D., 2007. The dynamic source routing protocol (DSR) for mobile ad hoc networks for IPv4 (No. rfc4728).

[13] Park, V.D. and Corson, M.S., 1997, April. A highly adaptive distributed routing algorithm for mobile wireless networks. In Proceedings of INFOCOM'97 (Vol. 3, pp. 1405-1413). IEEE.

[14] Haas, Z.J. and Pearlman, M.R., 1998. The performance of query control schemes for the zone routing protocol. ACM SIGCOMM Computer Communication Review, 28(4), pp.167-177.

[15] Nikaein, N., Bonnet, C. and Nikaein, N., 2001, September. Harp-hybrid ad hoc routing protocol. In Proceedings of international symposium on telecommunications (IST) (pp. 56-67).

[16] Joa-Ng, M. and Lu, I.T., 1999. A peer-to-peer zone-based two-level link state routing for mobile ad hoc networks. IEEE Journal on selected areas in communications, 17(8), pp.1415-1425.

[17] Basagni, S., Chlamtac, I., Syrotiuk, V.R. and Woodward, B.A., 1998, October. A distance routing effect algorithm for mobility (DREAM). In Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking (pp. 76-84).

[18] Ko, Y.B. and Vaidya, N.H., 1998, October. Location-aided routing (LAR) in mobile ad hoc networks. In Proceedings of the 4th annual ACM/IEEE international conference on Mobile computing and networking (pp. 66-75).

[19] Li, J., Jannotti, J., De Couto, D.S., Karger, D.R. and Morris, R., 2000, August. A scalable location service for geographic ad hoc routing. In Proceedings of the 6th annual international conference on Mobile computing and networking (pp. 120-130).

[20] B. Karp and H. Kung, GPSR: Greedy perimeter stateless routing for wireless networks, ACM/IEEE International Conf. on Mobile Computing and Networking,2000.

[21] Karp, B. and Kung, H.T., 2000, August. GPSR: Greedy perimeter stateless routing for wireless networks. In Proceedings of the 6th annual international conference on Mobile computing and networking (pp. 243-254).

[22] Aboud, A., Touati, H. and Hnich, B., 2019. Efficient forwarding strategy in a NDN-based internet of things. Cluster Computing, 22, pp.805-818.

[23] Gao, S., Zhang, H. and Zhang, B., 2016. Energy efficient interest forwarding in NDN-based wireless sensor networks. Mobile Information Systems, 2016.

[24] Liu, X., João Nicolau, M., Costa, A., Macedo, J. and Santos, A., 2016. A geographic opportunistic forwarding strategy for vehicular named data networking. In Intelligent Distributed Computing IX: Proceedings of the 9th International Symposium on Intelligent Distributed Computing–IDC'2015, Guimarães, Portugal, October 2015 (pp. 509-521). Springer International Publishing.

[25] Basiri, A., Amirian, P. and Winstanley, A., 2014. The Use of Quick Response (QR) Codes in Landmark-Based Pedestrian Navigation. International Journal of Navigation and Observation.

[26] Shawahna, A., Haque, M.E. and Tozal, M.E., 2017, April. Energy harvesting in wireless sensor network with efficient landmark selection using mobile actuator. In 2017 Annual IEEE International Systems Conference (SysCon) (pp. 1-8). IEEE.

[27] Zivkovic, M., Zivkovic, T., Venkatachalam, K. and Bacanin, N., 2021. Enhanced dragonfly algorithm adapted for wireless sensor network lifetime optimization. In Data Intelligence and Cognitive Informatics: Proceedings of ICDICI 2020 (pp. 803-817). Singapore: Springer Singapore.

[28] Zivkovic, M., Bacanin, N., Tuba, E., Strumberger, I., Bezdan, T. and Tuba, M., 2020, June. Wireless sensor networks life time optimization based on the improved firefly algorithm. In 2020 International Wireless Communications and Mobile Computing (IWCMC) (pp. 1176-1181). IEEE.

[29] Brinza, D. and Zelikovsky, A., 2006, June. Deeps: Deterministic energy-efficient protocol for sensor networks. In Seventh ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing (SNPD'06) (pp. 261-266). IEEE.

[30] Zhang, H. and Shen, H., 2009. Energy-efficient beaconless geographic routing in wireless sensor networks. IEEE transactions on parallel and distributed systems, 21(6), pp.881-896.

[31] Jiang, B., Huang, G., Wang, T., Gui, J. and Zhu, X., 2022. Trust based energy efficient data collection with unmanned aerial vehicle in edge network. Transactions on Emerging Telecommunications Technologies, 33(6), p.e3942.

[32] Al Aghbari, Z., Khedr, A.M., Osamy, W., Arif, I. and Agrawal, D.P., 2020. Routing in wireless sensor networks using optimization techniques: A survey. Wireless Personal Communications, 111, pp.2407-2434.

[33] Guleria, K. and Verma, A.K., 2019. Meta-heuristic ant colony optimization based unequal clustering for wireless sensor network. Wireless Personal Communications, 105, pp.891-911.

[34] Nguyen, A., Milosavljevic, N., Fang, Q., Gao, J. and Guibas, L.J., 2007, May. Landmark selection and greedy landmark-descent routing for sensor networks. In IEEE INFOCOM 2007-26th IEEE International Conference on Computer Communications (pp. 661-669). IEEE.

[35] Xing, F., Xu, Y., Zhao, M. and Harfoush, K., 2007, October. HAGR: Hole aware greedy routing for geometric ad hoc networks. In MILCOM 2007-IEEE Military Communications Conference (pp. 1-7). IEEE.

[36] Fang, Q., Gao, J. and Guibas, L.J., 2006. Locating and bypassing holes in sensor networks. Mobile networks and Applications, 11, pp.187-200.