

Routing Hole Handling Techniques for Wireless Sensor Networks: A Review

B H, Swathi¹, H L, Gururaj²

1- Vidyavardhaka College of Engineering(email2swathibharish@gmail.com)

2 - Vidyavardhaka College of Engineering

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Abstract: A Wireless Sensor Network consists of several tiny devices which have the capability to sense and compute the environmental phenomenon. These sensor nodes are deployed in remote areas without any physical protections. A Wireless Sensor Network can have various types of anomalies due to some random deployment of nodes, obstruction and physical destructions. These anomalies can diminish the sensing and communication functionalities of the network. Many kinds of holes can be formed in a sensor network that creates geographically correlated areas. These holes are also responsible for creating communication voids. These voids do not let the packets to reach the destination and minimises the expected network performance. Hence it ought to be resolved. In this paper we presented different kinds of holes that infect the sensor network, their characteristics and the effects on successful communication within the sensor network. Later we presented a detailed review on different routing hole handling techniques available in literature, their possible strengths and short comes. At last we also presented a qualitative comparison of these routing hole handling techniques.

Keywords: Wireless Sensor Networks (WSNs), Geographic routing, greedy forwarding, sensor nodes, routing holes

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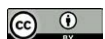
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1. Introduction

Now a days, Micro Electrical Mechanical System (MEMS) [32][33] and Wireless Communication Technology is gaining global attention in research area of Wireless Sensor Networks (WSNs). A sensor network consists of several tiny and economical nodes [10]. These sensor nodes are organized in such a way that they can sense some phenomenon, evaluate and store the sensed information and can communicate with the other nodes. These sensor networks can be used in several applications like military applications, intrusion detection, environmental monitoring, hazard detection, health related applications, meteorology, agriculture, industry applications, infrastructure monitoring and many other [14]. Even though

they have many useful applications it suffers from some constraints like low processing speed, limited bandwidth, less memory and limited battery. These constraints present various operational, management and design issues[7][25].

The main task of a sensor node in WSNs is to sense the particular phenomenon and carryout communication among the sensor nodes. To achieve the expected communication between these nodes, the nodes should be deployed in such a way that it should cover 100% of the target field. Various types of anomalies can occur during the deployment of nodes and above mentioned constraints can cause a sensor node to fail. The area with a failed node causes a hole in the network which is a major issue that ought to be solved. Because, occurrence of the holes causes the communication delay and



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potentially degrades the quality of the service in WSNs. There are various reasons behind the creation of holes in the sensor networks. Holes may occur during the deployment stage of the network, during continuous operation or by some environmental phenomenon [8]. These routing holes lead to performance degradation of network and the communication between nodes becomes weak. Hence routing of packet in such scenario is the great challenge. Therefore identifying and recovering a hole is very important [3][12].

Geographic routing is an efficient and widely accepted routing approach to resolve the routing hole problem [17][40]. In geographic routing, packets are delivered to the intended destination using the location or the geographic position of the destination rather than logical or identity of the destination. There is no need to maintain entire routes information from source node to destination node. Nodes need not to store routing tables [42][43]. Because it uses only one-hop geographic information of neighbour node. It also supports geocasting services. Because of its stateless and localized features the geographic routing approach is considered as scalable and simple. Performances of various geographic routing protocols are described in literature [1]. In 1980's geographic routing approach was basically proposed for packet radio networks which is also known as location based routing, position based routing or directional routing approach. As the applications of self configuring localization mechanism and Global Positioning System (GPS) are increasing, it is gaining more attention and providing efficient solution for WSNs, Underwater sensor [41][50], Vehicular AdHoc Networks (VANETs) [34][35][36], Mobile AdHoc Networks (MANETs) [37][38][46] and Wireless Mesh Networks (WMNs) [12][16][39].

The remaining part of the paper is structured as follows: In section 2 we have discussed the categories of hole in wireless sensor networks and the basic principles of geographic routing approaches. Section 3 provides an elaborated description about the hole detection and recovery approaches especially on routing holes with respect to various literature works. Summarization of different techniques is done in section 4. And finally section 6 concludes.

2. Categories of holes in WSNs

This section presents different types of holes that a WSNs can have and the basic principles of hole avoiding strategies.

2.1 Holes for WSNs

A wireless sensor network can have different types of holes including coverage hole, jamming hole, routing hole, and sink hole/black hole/warm hole. Coverage hole can occur due to the failure of node, due to power exhaustion, fault in network topology and random deployment of sensor nodes that create voids. This leads to coverage hole and routing hole within the sensor network [15][21][23][51][52]. Sometimes the nodes in the network may not be able to communicate with each other according to the designed goal to reach their objectives. This happens if a node cannot sense or relay the sensed information to the destination. These types of holes are called as routing hole [19]. Routing hole can also occur if a fresh sensor node is replaced in the place of a faulty sensor node. Because it may change the routing path in the network. A jammer is used to interrupt the communication between the nodes. The jammer can block the radio frequencies by using high-frequency signals. These are called as jamming holes. Jamming holes may also occur when the malicious node tries to jam the communication between the nodes [22]. Other holes like sink hole/black hole can occur due to the denial of service attack where the malicious node may mislead the packet on routing path [6][20][24].

2.2 Basic principles of Geographic routing approach

Geographic routing approach has been proposed and widely accepted method to overcome from the routing issues since it is scalable and uses localized information [44][45][47][48]. To overcome from the issues of routing holes, geographic routing uses two well known fault tolerance mechanisms namely, greedy forwarding and face routing [4][9][26][27][28].

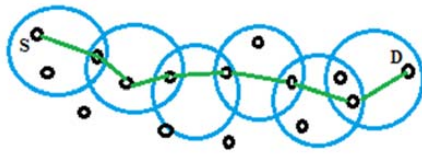


Fig.1 Example for greedy forwarding

The greedy forwarding is the simple and basic approach. Here at each hop, positive progress is carried out to route the packet to the neighbour node which is located closer to the intended destination node. When a current node is not able to identify a neighbouring node located closer to the destination node than itself it should drop the packet which is being forwarded. That is, a source node fails to identify a next-hop using positive progress towards the destination. This unenviable phenomenon is called as local minimum or local maximum phenomenon. It is often referred as communication void. [11][13][16][19][24][25].

Fig.1 depicts the example of greedy forwarding approach. The blue circles in the diagram represent range of transmission of a node. The black small circles represent the nodes and a green line indicates the packet routing path. The node S indicates the source and it follows the principle of greedy forwarding and sends the packet to the node which is nearer to the destination D than itself. A node which receives the packet will carry out the same procedure. The Fig.1 is a just an idealized scenario but it is somewhat impossible in real networks because of the dynamic nature of the network. Hence it is not possible to identify a nearest node of a destination. Hence the packet might be dropped even though there is a path from the source node to destination node. Hence it leads the node into local maximum phenomenon. Even though greedy forwarding is well understandable, easy to implement and being more efficient it suffers from this major drawback [4].

The face routing approach is basically inherited from Compass routing II [28]. This approach is come up as a healing mechanism from local maximum phenomenon and as a well known routing approach. By combining the possible strengths of both greedy forwarding method and face routing method the disadvantages of greedy forwarding can be minimized. Face routing uses

a process called Planarization to construct planer sub graphs. A planer graph is one which consists of no crossing links and contains sequence of polygonal areas separated by faces or edges. These planner graphs can be obtained by using Gabriel Graph (GG) or Relative Neighbourhood Graph (RNG) [4][16].

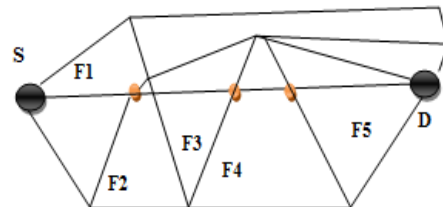


Fig.2 Example for face routing approach

Face routing uses right hand or left hand rule to traverse these planer sub-graphs. A basic operation of face routing is shown in Fig.2. The node S represents the sender and the node D represents the destination. The thin black lines represent the faces which are obtained by planarization algorithm. The small circle indicates a point which intersects the edges of the graph [19]. The traversed faces on the routing path from S to D are numbered sequentially F1 to F5. The routing starts from source node S and it uses right hand rule to traverse face F1 with the point closest to the D which intersects the S-D line being the point where the next face is traversed. F2 is then traversed before the point closest to D that intersects the line S-D is discovered. When it completes the traversal of entire face, the algorithm goes to the any one of the intersection which is closest to the destination and continues to do so until eventually the D is reached. The major advantage with face routing is guarantee delivery of packets. However its possible inefficiency is the major drawback [4].

3. Routing hole avoidance techniques

This section provides a overview of the various types of techniques which are used to bypass routing hole in wireless sensor networks using geographic routing approach.

3.1 Greedy Perimeter Stateless Routing

Greedy Perimeter Stateless Routing (GPSR) [19] was mainly proposed to increase the scalability under the scenarios of increasing rate of nodes in the network and increasing rate of mobility. It uses greedy forwarding to send the packets from source to destination as illustrated in section 3. Packet forwarding decisions can be made by using the location of router and location of destination. As a result, an intermediate packet sending node can choose packet's next hop by making locally optimal and greedy choice. Means, if a node has a radio neighbour location information, it can choose that node as a next hop by using local optimal choice if the neighbour node geographically nearer to the destination.

The greedy forwarding only depends on the information about the immediate neighbour of the packet forwarder node. It doesn't require state information. Hence GPSR is stateless. It is dependent on the density of the nodes but not on the total number of destination nodes in WSNs. The disadvantage of greedy forwarding is that it suffers from local minimum phenomenon which is shown in Fig. 3.

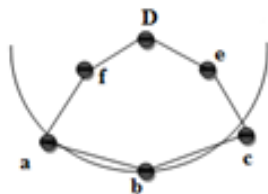


Fig.3 Failure of greedy forwarding, nodes a and c are geographically farther from destination D, node b is a local minimum in its proximity to node D.

Here, the node b has a packet to send to the destination node D. Node b is nearer to destination node D than its neighbour nodes a and c. The arc about the node indicates the range of the node. The distance between D and b is equal to the radius of D. Even though D has two paths (b->c->e->D) and (b->a->f->D), the node b doesn't choose a or c based on greedy forwarding. Node b is a local minimum to D in this situation and some other strategies must be chosen to route the packets.

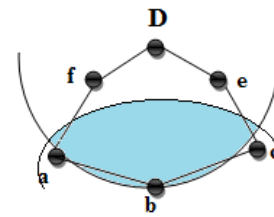


Fig.4 Node b's void with respect to D.

The intersection between the circular range of node b and the radius of D is empty without any neighbouring nodes. It is illustrated in Fig.4. From the node b's perspective the shaded area without any nodes is a void.

Perimeter forwarding approach will be applied in such cases when greedy forwarding method fails to forward the current sending packet. It is also called as face routing approach [8]. Perimeter forwarding can be applied for planarized graph where as greedy forwarding can be applied on full network graph. Planar graph uses both interior faces and exterior faces to transmit the packet using right hand rule. Fig.5 shows an example for perimeter forwarding. In the figure, each traversed face is penetrated by aD. The first two and last faces indicates interior faces, third is the exterior face.

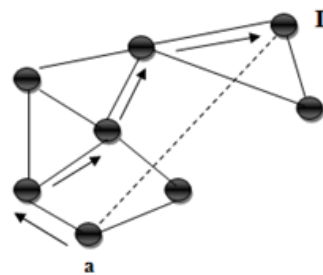


Fig.5 Example for Perimeter forwarding

In static network topology, the no-crossing heuristic identifies the maximum number of routes but it is difficult to identify a reachable route to node. Hence planer graph can be used to remove crossing links. But the graph must not be separated by removal of crossing edges. The Relative Neighbourhood Graph (RNG) and Gabriel Graph (GG) are the two well known and commonly used planar graphs which shown in Fig.6 and Fig.7 respectively.

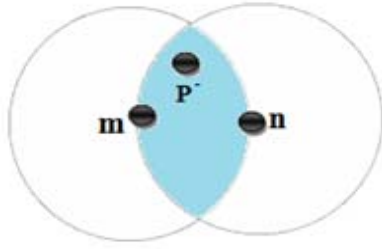


Fig.6 RNG graph

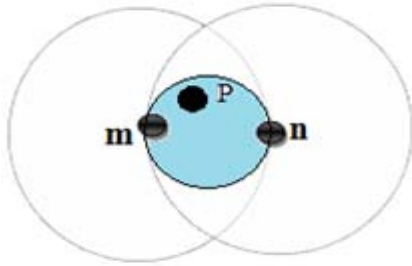


Fig.7 Gabriel Graph

RNG is defined as “An edge $E_{m,n}$ exists between vertices m and n if the distance between the vertex is less than or equal to the distance between every other vertex p and whichever of m and n is farther from vertex p ”. In equation form.

$$\forall p \neq m, n: d(m, n) \leq \max[d(m, p), d(n, p)] \quad (1)$$

A RNG graph can be constructed by removing the crossing links as illustrated in Algorithm 1.

Algorithm : 1 Relative Neighbourhood Graph

1. for all $n \in N$ do
2. for all $p \in N$ do
3. if $p = n$ then
4. continue
5. else if $d(m, p) > \max[d(m, p), d(n, p)]$ then
6. remove edge(m, n)
7. break
8. end if
9. end for
10. end for

GG is defined as- "An edge $E_{m,n}$ exists between vertices m and n if there is no vertex p is there within the circular region whose diameter is mn ". In equation form

$$\forall p \neq m, n: d^2(m, n) \leq [d^2(m, p), d^2(n, p)] \quad (2)$$

GG graph can be constructed by removing the crossing links as in the Algorithm-2 .

Algorithm : 2 Gabriel Graph

1. $c =$ centrepoint of edge mn
2. for all $n \in N$ do
3. for all $p \in N$ do
4. if $p = n$ then
5. continue
6. else if $d(c, p) < d(m, c)$ then
7. remove edge(m, n)
8. break
9. end if
10. end for
11. end for

The well known Right hand rule is depicted in Fig.8. It states that when a packet sent from c to node a , it traverse the next edge (a, b) sequentially in counter clock wise about a from edge (a, c). The right hand rule will traverse the interior part of a closed polygon region or a face in clock wise order. In Fig.8 the nodes a, b, c creates a triangle in the order ($c \rightarrow a \rightarrow b \rightarrow c$).

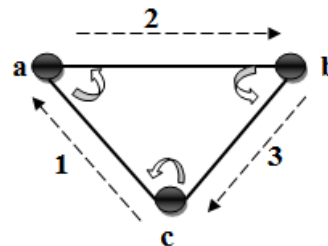


Fig.8 Right hand rule

The disadvantage of GPSR is that, even though it bypasses holes in the network which are caused by local minimum phenomenon, it has to maintain planar graph on each node which leads to overhead on nodes. Because, these information is used by only those nodes which are affected by local minimum phenomenon.

3.2 Compass Routing II

Karnakis et al.[28] proposed the Compass Routing II algorithm. It guarantees the packet delivery to destination node even if the node is in a local minimum problem in greedy forwarding. It uses face routing with least deviation angle of the link between the current node and the destination node when it is trying to forward a packet to the next hop. As Compass Routing II [28], FACE-I and FACE-II algorithms are proposed [29] that guarantees the packet delivery. It also uses Gabriel Graph(GG) to construct planer sub graph and then uses right hand rule to traversal the faces. FACE-I is modified in FACE-II in which the traversal of face will follow the next edge wherever that link crosses the line from source node to destination node. The routing hole issue can be solved by always using the face routing.

3.3 Greedy Other Adaptive Face Routing

Greedy Other Adaptive Face Routing (GOAFR, GOAFR+) [30] was introduced as the extension of Compass Routing II. It has come up with the fall back scheme to come back to the perimeter forwarding mode without exploring the entire face boundary if it is not necessary. Same as [19],[28] it constructs the planar sub graph using Gabriel Graph. It begins with greedy forwarding mode and whenever it encounters a local minimum phenomenon, it will switch to face routing mode. It uses two counters. First is to keep track of the number of attended nodes during face routing that are closer to the destination node. Another one is to keep track of the number of nodes which are far from the destination node. These two counters are used to decide whether it has to continue in the face routing or fall back to greedy mode. Algorithm 3 illustrates the steps involved in GOAFR+.

Algorithm : 3 Greedy Other Adaptive Face Routing

Require: Choose Algorithm parameters to ρ, σ before the beginning of algorithm and remains same during execution and set the conditions $1 \leq \rho_0 < \rho$ and $0 < \sigma$ and also two counters x, y

1. Initiate from source node S and Z as a circle with centre D where $r_D = \rho_0 |SD|$
2. Continue greedy forwarding until it reaches D or occurrence of local minimum // Terminate if true.
3. Begin face routing and explore the boundary of F_i face has a line $a_i D$ //where a_i is the current local minimum
4. If visited node is nearer to D then repeat step 2. Otherwise report node S as graph has disconnected.
5. Use x to indicate the node nearer to D than a_i and y to indicate node which is far from D than a_i and has to take some special actions if following cases meet

Case1: If Z hits for the first time, go back and explore the F_i 's boundary in the reverse direction

Case2: If Z hits for the second time and there is no visited node nearer to D than a_i increase radius of Z ($r_z := \rho r_z$) repeat step 2 if it began from a_i . Otherwise repeat with step 2.

Case3: If $x > \sigma y$, then it says that the number of visited nodes which are nearer to D are more than the nodes which are not. Repeat step 2.

Consider the Fig.9 which illustrate GOAFR+ algorithm with parameter σ, x, y where x and y are the counters and σ is the condition for fall back which is set to be $1/4 \leq \sigma \leq 1/2$.

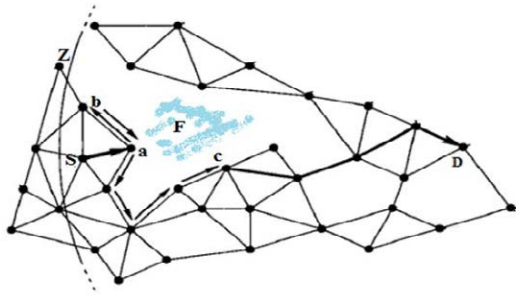


Fig.9 Example for GOAFR+

The node S begins to forward packet in greedy mode. The packet reaches node a, when it doesn't get any neighbour node nearer to the destination and it will move to face routing. It begins exploring the boundaries of face F. At node b, the algorithm reaches the boundary of the circle Z and come back to exploring the face F in opposite direction. Counters x , y keep on updating after each step. At node c, the number of nodes visited so far which are nearer to the destination D is two. Hence the counter value $a=2$. The number of nodes visited that are far away to the node D is four. Hence counter value $b=4$. So the fall back condition is true, i.e., $a > \sigma b$. Therefore, the algorithm fall back to greedy forwarding mode and continues the process until it reaches the destination.

3.4 Geographic and Energy Aware Routing

Geographic and Energy Aware Routing (GEAR) [27] was proposed to forward a packet to the intended destination. It works in two steps of operation. In first step, the packet will be forwarded to the destination by making use of energy aware next-hop neighbour selection. In second step, the packets are distributed inside the region using recursive geographical or restricted flooding. In first step, two types of costs are maintained by each node. They are estimated cost and a learned cost for reach ability of the destination node via its neighbour nodes. The one-hop neighbour information is used to obtain the learned cost of a region and by adding it to the particular selected neighbour cost a node can calculates its learned cost.

The estimated cost is used as default cost if there is no learned cost is available. The estimated cost depends on the distance to the destination node and the residual energy of a node. The

presence of hole in the network will reflects the variation of the routing path on the new learned cost which encounters the routing hole. If there is no hole appears, the learned cost is equal to the estimated cost. The recursive geographical forwarding is used in case of high density sensor network instead of restricted flooding. The advantage of GEAR is that it works well in the small sensor area network.

3.5 Intermediate Node Forwarding

A probabilistic approach called Intermediate Node Forwarding was introduced by De. Couto et al.[31] to forward packets around routing hole by assuming unequal radio ranges. When packet drop occurs due to local minimum the source node will get the feedback using Negative Acknowledgement (NAKs).

When the sender gets the information about the packet drop, it will select any location randomly from a disk that is one quarter distance between the sender node and the destination node, which is centred at the middle point of the distance between the sender and the destination. If the packet is dropped by the chosen node to be doubled along with another randomly selected intermediate geographic location. The disadvantage of this approach is, the protocol overhead may occur due to NAKs.

3.6 Boundhole

Qing Fang et al.[18] proposed an approach to define the nodes as stuck nodes that are caused by the local minimum phenomenon. A local rule called TENT rule is developed for each node of the network to verify the presence of the stuck node. If the node is identified as stuck node, then it uses BOUNDHOLE-a distributed algorithm to identify the holes. Similar to the planar graph of the perimeter routing, the boundary information which is stored locally is used to get rid from the local minimum phenomenon. It computes and stores information of holes only at the region of routing hole. In order to identify the stuck node the TENT rule can be implemented.

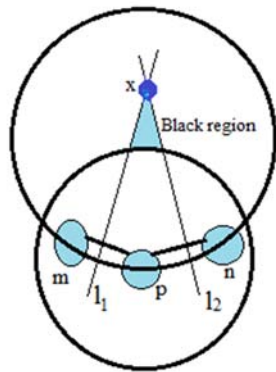


Fig.10 The TENT rule to identify a void

As depicted in Fig.10 for each node p, we order its entire one-hop neighbour in counter clockwise. The adjacent nodes m and n have a perpendicular bisector mp and np which intersects the point X. If the point X is in the range of p there is no stuck node. Because m and n are adjacent and there is no node within the black region. Hence node p cannot be a stuck node with the cone pm and pn. Conversely, if X is in the outside of the communication range there will be a stuck node at p. So TENT rule is necessary to identify the void node.

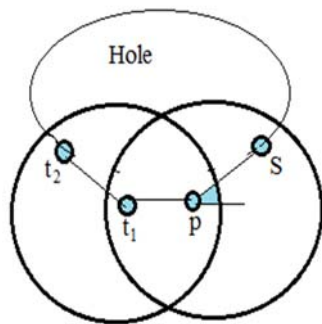


Fig.11 BOUNHOLE approach

After the identification of the of the stuck node, the BOUNHOLE approach is used by the node p. The Fig. 11 shows the basic idea. The nodes s, p, t1, t2 bounds the hole. This approach begins from stuck node p and sweep

in the direction of stuck node. It sends packet to a neighbour node t1 in clockwise direction. The t2 receives the packet from t1 and t2 passes it to s. In general this process repeats until the packet reaches back to p by marking the boundary of the hole. Hence similar to the perimeter routing it creates a conduit for the stuck packets that are routed in the void area.

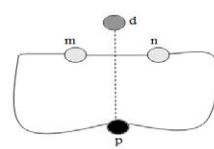


Fig.12 (i)

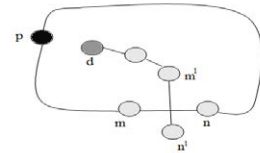


Fig.12 (ii)

Fig.12 An example to illustrate how the approach utilizes hole surrounded path. Fig-12(i) The destination node d lies outside the hole Fig-12(ii) The destination node d lies inside the hole.

Consider the Fig.12 (i) where node p is a void node where the packet is stuck when it is in the greedy forwarding mode. The boundary of the hole may contain both void and non void nodes. Hence according to the BOUNHOLE approach the node p must be on the boundary. The void node forwards the packet on this boundary. The packet is forwarded greedily again if the routed packet is received by the closest node of the destination d than p. The example is shown the Fig.12 (i). Here the destination d is in the outside region the hole and a node m that is nearer to the destination d must exit than p. Suppose if we join the line pd, it crosses the edge mn which is a hole boundary. The packet will always reach the destination because both node m and n are closer to node d and p. If the node d is inside the hole region then restricted flooding can be applied and it is depicted in Fig12(ii). The disadvantage of BOUNHOLE is it impose higher load on nodes which are the boundaries of hole.

3.7 Curved Stick

Ahmed Mostefaoui et.al [2] proposed a novel approach to overcome the disadvantages of BOUNHOLE called Curved Stick (CS). The basic idea of Curved Stick (CS) method is to characterize the nodes which are responsible for

a communication intersection situation which is depicted Fig.13. A communication intersection says that, it is a situation when a edge E1,2 is on the boundary of the nodes N1 and N2 that crosses by an edge E3,4 where N1 and N2 are not visible to N3 . Hence the basic idea behind this is to overcome from the false boundary identification problem of BOUNDHOLE problem. It uses Curved Stick to select the next hop rather than sweeping line.

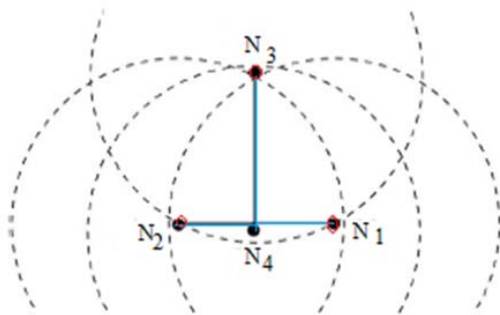


Fig.13: Communication intersection Problem

The CS routing algorithm works mainly in three phases a) Engaging phase b) CS boundary traversal and c) Termination phase

The engaging phase is similar to the greedy forwarding approach. The packets between the nodes use the geographical information to reach the destination. If the packet cannot be delivered to the destination then it encounters local minimum phenomenon. As shown in Fig-14 Ninit is the initiator node where the message got stuck. Then it implements the CS boundary traversal phase.

In this phase, every attended node collects the initiator's location information from the earlier attended hop node. It uses this information as an input. Initially, the visited node figure outs its distance to the destination and from the initiator node to the destination. The packet will considered as local minimum problem free if its distance is closer to the destination than the initiator node. If it is out of local minimum problem then it can use greedy forwarding approach. Otherwise CS rule can be applied.

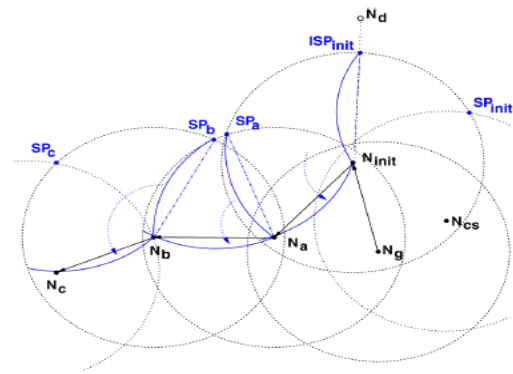


Fig.14 Curved Stick Rule

The termination phase can takes place only in two cases. In the first case, the destination must have received the packet. In the second case, the packet uses the CS rule to travel on the entire boundary and gets back to Ninit. Here, the curved stick is swept by the initiator. If the node is hit, it is considered as the next hop node and the CS rule will continue. If not the Ninit cannot implement CS rule and it says that there is no route from the source to destination and the initiator indicates the source node that the packet cannot be sent. They presented a hop count reduction method which can be applied when there are multiple sweeping direction. However CS rule can bypass hole but still it suffers from local minimum problem. The disadvantage of this CS rule is that it can be applicable only for two- dimensional network and it still suffers from local minimum problem. Algorithm 4 illustrate the Curve Stick routing.

Algorithm : 4 CS Routing Algorithm

```

1. if (Msg.Init.ID = null) then //where Msg is the message from previous hop
2.   use greedy forwarding
3.   select the next hop based on greedy forwarding
4.   if (stuck node occurs) then
5.     set Msg.Init.ID to MyID
6.     select next hop using CS rule
7.   end if
8. else
9.   if Msg.Init.ID ≠ MyID then
10.    calculate:  $d(N_{cur}, N_d)$  and  $d(N_{mit}, N_d)$  // where  $N_{cur}$ 
        is the current node and  $N_d$  is the destination node
11.    if  $d(N_{cur}, N_d) < d(N_{mit}, N_d)$  then //Free of
        local minimum phenomenon
12.      set Msg.Init.ID to null
13.      select next hop using greedy forwarding
14.    else
15.      select next hop using CS rule
16.    end if
17. else // message will be traversed entire boundary and returned
        to the initiator sweep the //curved stick from starting point
18.   if a node hits then
19.     select a next hop using CS rule
20.   else
21.     notify the source node that the message could not be reached
22.   end if
23. end if
24. end if

```

3.8 Long Range Sink

Moyses M. Lima et.al [5] have proposed an algorithm Long Range Sink(LRS) that considers the greater communication capability of sink node and the Received Signal Strength Indicator(RSSI) by constructing the packet forwarding path from source to destination. It uses the principle of forwarding the packet to the neighbour nodes that obtained the query with higher signal strength.

Initially it uses greedy forwarding technique along with LRS. When packets reaches to a hole region it will switch to hole-election mode. It performs data aggregation using hop-election mechanism to bypass the routing hole.

At the beginning sink sends the queries to every other nodes in a single hop communication. The RSSI technique is used to calculate the distance between sink and each node. All the information about the distance are exchanged between the neighbour nodes. The data of regular node will be aggregated to the list of aggregated data if it already contains any data that is related to the query of the sink node.

One hop neighbour of the sink node broadcasts the additional information to its immediate neighbour node. This additional information is used to identify the routing path from sink to the current node via the neighbour node that broadcasts the information. An initialization timer is used to keep track the performance of the data aggregation.

The nodes with lesser RSSI are omitted to avoid the participation of the nodes in a alternative hop-election. Whenever the initialization timer expires, a replay message is combined with both the node's distance information and aggregated data. Later, the node forwards this information to the neighbour node which is closer to the sink node. The message received by the neighbour of the sink aggregates the data with the list of aggregated data and forwards when the timer expires. The above process performs repeatedly until the packet reaches the sink node. When sink dispatches a query to the entire network it creates a eligible nodes table using which each node tries to identify whether it is in a hole region or not during the process of packet forwarding. If it is a hole node it chooses a new neighbour node towards the sink node using the extra information which is saved during the evaluation of distance. Then the hole node aggregates the packets from the hole region and sends packet via multiple hops toward sink.

3.9 Energy -aware Dual-path Geographic Routing

In this paper a new routing protocol Energy-aware Dual-path Geographic Routing (EDGR) is proposed by Haojun Huang et.al [26] to overcome from the more energy conservation and load balance issues of existing approaches. EDGR approach uses greedy mode to route the packet in two various routing paths instead of bypass mode. It creates dual routing paths using two node-disjoint anchor lists. Since it makes

the packet to travel through double sides of the holes, it shortens the path length for routing and balances the load. EDGR selects the node with higher residual energy as packet forwarders by using two node-disjoint anchor list. Hence the data packets are routed along two paths of the hole.

The EDGR works in two operation phases: obtaining anchor list and data dissemination phase. In the first phase two anchor lists are obtained by using adaptive approach based on the distance of nodes. In the second phase, the routing decisions are taken care by using geographic information, energy consumption characteristics and residual energy. Algorithm 5 illustrate the building of anchor list.

EDGR uses three types of packets namely: burst packet, beacon packet and data packets. Using burst packet, anchor lists can be identified. The beacon packets are used to exchange the residual energy and location information.

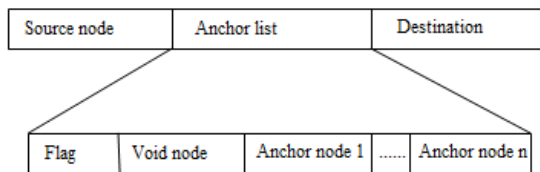


Fig-15 Burst packet format

The Fig.15 depicts the burst packet format. It has source and destination locations and a list of anchor nodes. This list consists of a sequence of anchor nodes. A flag field represents whether the data packet bypass the routing hole or not. It also uses right hand or left hand rule to traverse the hole. It also uses a temporary void node in every bypass mode. If the rules of anchor nodes are violated then the void node will be deleted. EDGR is also extended to three-dimensional (3D) sensor networks to achieve an efficient energy-aware routing approach to detour routing holes.

Algorithm : 5 Building anchor list

Require: Source s , destination d

1. $list(s,d)=[flag,\emptyset]$
 2. s starts exchange of beacon packets
 3. s attaches $list(s,d)$ to a burst packet and sends to d
 4. **if** $\forall Vi$ in the bypass mode receive the packet **then** // Vi is any forwarder node
 5. UpdateList($Vi, list(s,d)$)
 6. **end if**
 7. **if** s gets a feedback packet from d **then**
 8. update $list(s,d)=[flag,a_1,\dots,a_j,\dots,a_m]$
 9. forward a burst packet via a_1,a_2,a_3,\dots,a_m
 10. **end if**
 11. **if** $\forall Vi = a_k \in \{a_1,\dots,a_m\}$ obtains the packet **then**
 12. forward the packet to a_{k+1}
 13. **else**
 14. **if** $\forall Vi$ is in the bypass mode **then** UpdateList($Vi, list(s,d)$)
 15. **end if**
 16. **function**(UpdateList($Vi, list(s,d)$))
 17. **if** $Vi \in list(s,d)$ **then**
 18. remove each node after Vi in $list(s,d)$
 19. **end if**
 20. **if** $Vi = V_{ij}$ or $Vi = V_{i-1}$ or V_{i+1} are in bypass mode **then**
 21. compute candidate Vi
 22. add Vi to $list(s,d)$
 23. send $list(s,d)$ to V_{i+1} following $flag$
 24. **end if**
 25. **if** $Vi == d$ **then**
 26. send $list(s,d)$ to s
 27. **end if**
 28. **end function**
-

4. Comparison of different routing hole bypassing techniques

Table 1 represents the comparison between the proposed hole handling techniques which are discussed in the previous section based on the mechanisms used to achieve fault forbearance

with respect to routing hole problem, their characteristics and maintenance of states are highlighted for each of the approaches.

Table 1: Comparison of some routing hole bypass techniques

Technique	Maintenance of state	Mechanism used to fault forbearance with routing holes	Delivery of packets	States	Complexity	Overhead	Scalability	Optimality of path	Distribution of information
GPSR	Planer graph and geographic information	Greedy forwarding, face routing, Right hand rule and planer graph using GG and RNG graph	Guaranty delivery	Stateless	Medium	Medium	Scalable	Not optimal	Localized
Compass Routing-II, Face-I, Face-II	Planar graph and Geographic information	Greedy forwarding, Face routing, Right hand rule and planer sub graph, Fall back mechanism	Guaranty delivery	Stateless	Medium	High	Not Scalable	Not optimal	Localized
GOAFR+	Planar graph and Geographic information	Greedy forwarding, Face routing, Right hand rule and planer graph	Guaranty delivery	Stateless	Medium	High	Not Scalable	Not optimal	Localized
Intermediate Node Forwarding	Geographic information	Negative acknowledgment packets	No guarantee delivery	Stateless	Medium	High	Not Scalable	Optimal	Global
GEAR	Learned cost and estimated cost	Learned cost helps to identify alternative path and limited flooding in region of interest	No guarantee delivery	State free	High	Low	Not scalable	Not optimal	Localized
BOUNDHOLE	Geographic information and holes boundary	TENT rule to detect holes and maintains information of boundary	Sometimes	Stateless	High	Medium	Scalable	Not optimal	Localized
Curved Stick(CS)	Geographic information	Hop count reduction method	No guarantee delivery	Stateless	High	High	Not scalable	Not optimal	Localized
LRS	Data aggregation on nodes	Hop-election	Sometimes	State free	Medium	High	Not scalable	Optimal	Localized
EDGR	Geographic information, Residual energy, energy consumption characteristics	Anchor list, Right hand rule, left hand rule	Guarantee delivery	Stateless	High	High	Scalable	Optimal	Localized

5. Conclusion

As routing holes present a serious problem on the performance of the sensor network, it has to be resolved. Geographic routing approach is one of the commonly used schemes to overcome from the holes problem. In this survey paper we discussed about the basic principles of geographic routing for WSNs. We have presented a detailed review on different routing hole handling techniques available in literature and their possible strengths and short comes. Later these approaches were compared in a qualitative manner, using nine criteria from various perspectives.

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