Minimal Marking of Trap-Regions for Efficient Greedy Forwarding in WSNs

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Geographic routing has emerged as a promising routing paradigm for Wireless Sensor Networks (WSNs). Localized operation, stateless nature, and ability to operate in absence of unique node addresses, are some of the characteristics that make geographic routing particularly suitable for WSN applications. Greedy forwarding is a simpler and efficient form of geographic routing in which a packet is forwarded to a neighboring node that makes maximum positive progress towards the destination. However, in the presence of communication voids, greedy forwarding may fail at some dead-end – *a node that does not have any optimal neighbor for greedy forwarding.* The dead-end situation is usually handled by switching to some other supplementary routing methods like flooding, perimeter routing, or face routing, which are highly inefficient and hence should be avoided whenever possible. The overall performance of geographic routing methods which utilize greedy forwarding can be significantly improved by denying a packet originating in Greedily-Routable-Region (GRR) to enter into a dead-end region during routing. In this work, we propose a simple yet effective method called Minimal Marking of Trap-Regions (MMTR) for maximizing the GRR in WSNs. MMTR performs the on-demand marking of minimum nodes of a trap-region so as to transform a WSN into a dead-end free network for greedy forwarding. The proposed solution also addresses the hotspot problem observed along the border of dead-end region.

Keywords: Geographic routing, greedy forwarding, dead-end, trap-region, shadow region, hot-spot

1. INTRODUCTION

The advent of *Micro-Electro-Mechanical System* (MEMS) and *System on Chip* (SoC) technologies have enabled the fabrication of tiny, low-cost, autonomous, dispensable, battery-powered nodes equipped with sensors and actuators, low-power microcontrollers, and radio transceivers. These tiny nodes called *sensor nodes* can be *unobtrusively* deployed inside or near some phenomenon of interest and tasked to *collaboratively* gather relevant *sensory data* like temperature, pressure, humidity, light, sound, vibration, radiation, stress, chemical composition etc. Real-time and application-specific processing of these values reveals vital information about the phenomenon happening in the surrounding environment. A large number of these nodes are deployed in a sensor field to ensure area coverage and increase the fidelity of the collected data. The sensor nodes collaborate over short-range wireless links to form an *ad-hoc* wireless network called a *Wireless Sensor Network* (WSN). A typical WSN setup may have hundreds to thousands of sensor nodes depending upon the application requirement. The sensory data collected by the nodes is forwarded over multiple hops to a specially designated node called a *sink* node that acts as a gateway between WSN and the end-user space where the data is analyzed and interpreted in the application-specific context.

Some of the typical application areas of WSNs include (but not limited to) [Karl and Willig 2005]: disaster relief, surveillance, environment monitoring, habitat monitoring, smart buildings, structural health monitoring, facility management, industrial process automation, precision agriculture, health-care, logistics, critical infrastructure protection etc.

A sensor node is typically powered by an *on-board battery.* It is either impractical or impossible to replace or recharge the sensor node batteries after deployment [Anastasi et al. 2009]. On the other hand, a WSN should have a lifetime long enough to fulfill the application requirement which may extend up to several months to a few years. Once the battery of a node exhausts, it will be dead for ever leading to adverse situations to the extent of *network partitioning.* Hence, judicious energy usage is crucial for prolonging the lifetime of the network.

The deployment of sensor nodes comprising a WSN over a geographic region may either be deterministic or self-organizing [Tilak et al. 2002]. In deterministic deployment, the sensor nodes are *strategically* deployed according to the requirement of the application (structural health monitoring, smart homes, precision agriculture, critical infrastructure protection, industrial process monitoring and control, body area networks etc.). In self-organizing deployment, the nodes are scattered *randomly* over the deployment field (military applications, rescue and relief, habitat monitoring, surveillance etc.) and they self-organize to form an ad-hoc network. Random deployment is more realistic deployment model especially in case of scenarios requiring quick deployment or when the deployment environments are hostile or inaccessible.

Sensor nodes measure one or more physical properties of their surrounding environments and record the data after application-specific processing. The data gathered by sensor nodes is reported to the sink node in either of the data-delivery models: *continuous*, *event-driven*, *observer-initiated*, or *hybrid* [Tilak et al. 2002]. Other than sensory data, other common traffic sources in a WSN are: data requests, coordination messages and software updates etc. Short-range multi-hop communication over RF is known to be more energy-efficient and robust [Pottie and Kaiser 2000] as compared to its long-range single-hop counterpart. Since energy efficiency is the most crucial design issue in WSNs, multi-hop communication has been extensively studied in the literature.

Except for local coordination, the sink node is almost always at one end (either as source or destination) of the communication. This communication pattern leads to the problems of "*funneling effect*" and "*hot-spot problem*" [Li and Mohapatra 2007] where the nodes nearer to the sink node tend to exhaust their energy and *die* earlier than other nodes. Application-specific data aggregation and fusion of in-transit data at nodes nearer to the data source, is a common technique to reduce the traffic in WSNs.

Location awareness is a fundamental requirement in many WSN applications, because data without associated spatial and temporal attributes of its originating node may not be as useful. The location and timing of an event is as important as the detection of the event itself [Li and Mohapatra 2007]. A node may estimate its location (either absolute or relative) using techniques like GPS or some other localization mechanism [Hightower and Borriello 2001].

Resource-constrained sensor nodes are not adequately equipped to handle large routing tables (proactive protocols) or control traffics (reactive protocols) of traditional routing protocols [Cadger et al. 2013]. Further, a node may be unavailable for routing due to transient failure, temporary radio obstruction, or duty-cycling.

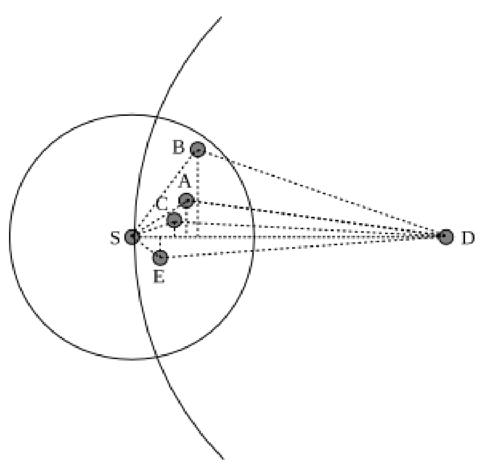
Geographic routing technique exhibits many properties particularly desirable in resource-constrained WSNs. Some of these characteristics are: localized operation, stateless nature, scalability and robustness in highly dynamic network conditions. Moreover, geographic routing can operate in the absence of unique node addresses. Geographic routing techniques assume that each node is informed about its own location and the location of the sink node. Geographic routing techniques utilize the geographic location information of the current node, its neighbors and the destination node to select the next best hop in the routing process. Greedy forwarding is the simplest yet efficient form of geographic routing in which a packet is greedily forwarded towards the destination. In this paper, we investigate in detail the greedy forwarding and propose a scheme to induce condition favoring greedy forwarding in as-larger-as-possible portion of the WSN.

The rest of the paper is organized in five sections. Section-2 covers the state-of-the-art work related to geographic routing with special emphasis on void handling approaches. Section-3 outlines the presumed system model and terminology used in this work. Section-4 describes the proposed scheme in detail. Section-5 covers the simulation results and their explanation. The paper is concluded in section-6.

2. RELATED WORK

Location-Aided Routing (LAR) [Ko and Vaidya 2000] is one of the early protocols proposed that utilizes location information of the nodes to limit the propagation of route request packets in direct source routing (DSR) to a geographic region where it is most likely for the destination to be located. Geographic adaptive fidelity (GAF) [Xu et al. 2001] is an energy-aware location-based topology maintenance algorithm in which each node uses its GPS-determined location information to associate itself with a point in a virtual grid. Nodes that associate themselves with the same point on the grid are considered equivalent in terms of routing cost. The redundant equivalent nodes are kept in sleep state to prolong the lifetime of the network. Geographical and Energy Aware Routing (GEAR) [Yu et al. 2001] uses the geographical information of the nodes to optimize the performance of directed diffusion [Intanagonwiwat et al. 2000] by restricting the number of interests by considering only the relevant geographic region rather than flooding them throughout the network. The schemes like LAR, GAF, GEAR etc., do not use the location information of the nodes for packet forwarding decision, but to compliment some of the existing routing techniques, hence, are not geographic routing protocols in a true sense.

In geographic routing, the node utilizes the location information of its neighbors and the destination nodes to choose the next hop in routing. A majority of geographic routing schemes operate in two modes: greedy forwarding and detouring mode. Greedy forwarding has been perceived as a simpler and efficient form of geographic routing with worst-case complexity of $\Omega(d^2)$ [Kuhn et al. 2008], where d is the Euclidean distance between the source and the destination of the packet. Greedy forwarding was earlier proposed as Cartesian routing [Finn 1987] for routing in large-scale internet. In greedy forwarding, the current node chooses a neighbor as the next routing hop in a way so as to make a maximum positive progress towards the destination of the packet. The notion of progress is realized using some optimization criteria defined in terms of Euclidean distance, projected distance, or direction towards the destination. In greedy mode, Greedy-Face-Greedy (GFG) [Bose et al. 1999], Greedy Perimeter Stateless Routing (GPSR) [Karp and Kung 2000], Cartesian routing [Finn 1987], GOAFR [Kuhn et al. 2003], Geographic Distance Routing (GEDIR) [Stojmenovic and Lin 2001], choose the neighbor with minimum Euclidean distance to the destination as the next hop (node A is the Fig.1), MFR (Most Forward within Radius) [Takagi and Kleinrock 1984] selects the neighbor with the shortest projected distance (on the straight line joining the current node and the destination) to the destination (node B in Fig.1), while compass routing [Kranakis et al. 1999], GeoRoutIng around obstaCles (GRIC) [Powell and Nikoletseas 2007] choose the node that makes the least deviation angle with the line joining the current node and the destination node (node C in Fig.1). In Nearest with Forward Progress (NFP) [Hou and Li 1986], the sender forwards the packet to the nearest neighbor that is closer to the destination (node E in Fig.1). The objective of NFP is to minimize the transmission power and reduce the probability of packet collisions.



. Figure 1:Notions of progress.

Greedy forwarding guarantees loop-free operation and yields a nearly optimal route in densely deployed networks. This is due to the fact that except in degenerate cases the routing path tends to stay close to the line connecting the source and the destination [Kuhn et al. 2008]. The only drawback of greedy forwarding is that it fails at *dead-end* (also called local minimum or concave node) that doesn't have any neighbor closer to the destination than itself. Dead-end nodes appear at boundaries of the *voids* or holes uncovered areas or obstacles to radio waves in a given direction. Every dead-end node has an associated *trap-region* the connected subgraph of the WSN in which greedy forwarding culminates at that particular dead-end. When the greedy forwarding fails, the routing mode switches to *recovery mode* that continues until the greedy forwarding technique is again feasible. The recovery mode solutions are classified as [Chen and Varshney 2007]: flooding based, planar graph based, spanning tree based and geometric based. Flooding based recovery [Stojmenovic and Lin 2001] use repeated broadcasts to route packets out of the dead-end regions. The first geographic routing algorithm that guaranteed packets delivery was Face Routing [Kuhn et al. 2008] that routes the packet around voids in the network by forwarding it along a *face* of the planarized network graph. In this approach, faces on a planar graph are traversed using a technique known as the 'right hand rule' in which the algorithm switches to the adjacent face at an edge that intersects the line connecting the source and the destination. In worst case, these algorithms take $\Omega(n)$ steps before arriving at the destination [Kuhn et al. 2008], where n is the number of network nodes. Variants of face routing were proposed as Bounded Face Routing (BFR) and Adaptive Face Routing (AFR) [Kuhn et al. 2002]. GFG [Bose et al. 1999] begins to operate in greedy mode and switches to the Compass II (face) algorithm when the local minimum is encountered. The routing modes switches back to greedy mode when the dead-end is traversed. Integrated Location Service and Routing (ILSR) [Li et al. 2012] is an extension of GFG scheme optimized for mobile sink nodes. ILSR uses restricted flooding for updating the location information about the neighbors whenever a next-hop change is observed by a node. Geographic Landmark Routing (GLR) handles the problem of voids through the discovery of paths that bypass voids [Na and Kim 2006] by remembering the landmark nodes - nodes at which the recovery scheme is terminated and greedy routing resumed.

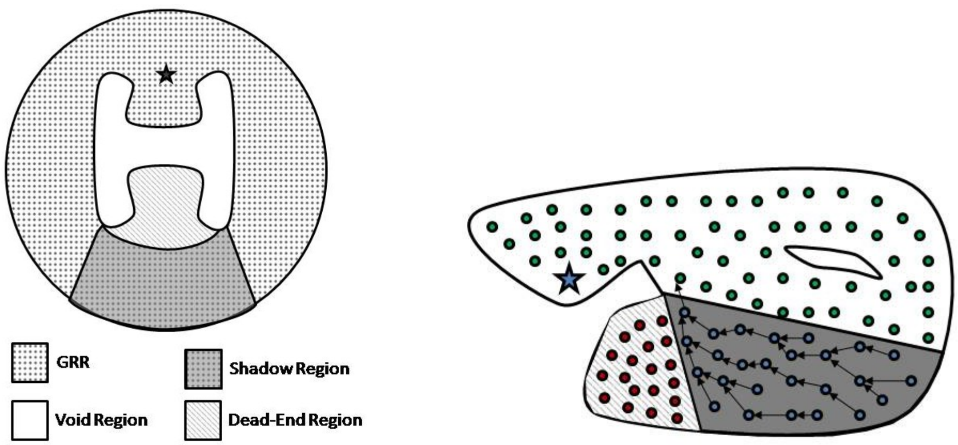
In real implementations, WSNs' connectivity graphs usually contain many crossing edges. Greedy routing can work on such network graphs, but face routing operation requires a planar subgraph of the full network graph. Graphs planarization uses planar graph structures like Delaunay Triangulation (DT), Relative Neighborhood Graph (RNG) and the Gabriel Graph (GG) [Bose et al. 1999]. RNG and GG assume Unit Disk Graph (UDG) model for wireless connectivity (all nodes have perfectly circular radio ranges of radius 1, centered at their own positions). UDG assumption is often violated in practice because of obstructions and the physical characteristics of real radios [Kim et al. 2005b]. Cross-Link Detection Protocol (CLDP) [Kim et al. 2005a] guarantees to produce a planarized subgraph where the nodes independently probe each of their links using a right-hand rule to remove cross-linked edges. CLDP uses a two-phase locking protocol to ensure that no more than one link is removed at any given time from any given face. While CLDP is able to planarize an arbitrary graph, every single link in the network has to be probed multiple times, and has a high cost.

Spanning tree based schemes like Greedy Distributed Spanning Tree Routing (GDSTR) [Leong et al. 2006], aggregates the locations covered by subtrees using convex hulls to decide which direction in the tree is closer to the destination.

BOUNDHOLE [Fang et al. 2006] was the first algorithm to use geometric aspects of the network to identify holes - the areas of the network consisting of all stuck nodes. A path can be found either reactively (i.e., when greedy forwarding fails) or proactively and stored locally along the boundaries of holes. The BOUNDHOLE protocol uses a rule called TENT rule to identify a hole around a dead-end node.

The recovery schemes are complex and highly inefficient as compared to greedy forwarding. Hence, it is desirable to induce conditions favorable for greedy forwarding throughout the WSN, if possible. In [Tan and Kermarrec 2012], Tan and Kermarrec proposed to decompose the entire network into minimum number of Greedily Routable Components (GRCs) where greedy forwarding is guaranteed to work within each such component. Dead-end free topology maintenance protocol DFTM [Chou et al. 2011] constructs a dead-end free topology using a minimum number of active nodes by making use of Voronoi diagrams. Proactive identification of obstacles to improve the performance of greedy forwarding was proposed by Moraru et al. in [Moraru et al. 2007] and [Moraru et al. 2008]. A node is marked as non-optimal for greedy forwarding in [Moraru et al. 2007] if the ratio between the number of times the greedy and perimeter modes previously used by the node is below a threshold value. A node is considered as non-optimal in [Moraru et al. 2008] if it does not have any optimal neighbor which can be used as next hop in greedy forwarding. Huc et al. [Huc et al. 2009] extended the work in [Moraru et al. 2008] to all-to-all traffic pattern.

All the packets originating in the shadow region tend to route along the border of its dead-end region thereby creating a funnelling effect [Li and Mohapatra 2007] as shown in Figure.2(b), that ultimately leads to network partitioning.



(a) WSN Regions classification

(b) Funnelling effect observed in trap-region

. Figure 2:Various Regions in a WSN w.r.t. Greedy Forwarding

3. SYSTEM MODEL AND TERMINOLOGY

For the purpose of this work we assume a system model similar to [Kuhn et al. 2008]. The sensor nodes are deployed in a Euclidean plane $\mathbb{R}^2$, and each node is aware of its geographic location. Every node has the same transmission range, without loss of generality normalized to 1. A WSN is modeled as an undirected graph $G(V, E)$, where V is the set of vertices representing the sensor nodes and E is the set of edges representing the wireless communication links. The links between nodes are symmetric i.e. if u is a neighbor of v then v is also a neighbor of u. Graph G is also assumed to be a bounded degree unit disk graph with parameter k i.e. none of its nodes has degree (number of incident edges) greater than k. There is no global addressing scheme for nodes and a node is identified by its location only. To ensure that every sensor node in the WSN has a unique location, a cluster of adjacent nodes is formed such that distance between any two nodes of the cluster is not more than a constant minimum bond of $\Omega(1)$[Kuhn et al. 2008] model. The redundant nodes of such a cluster are kept in sleep mode. There is only one static sink node in the WSN, the location of which is known to all the sensor nodes. The energy model assumed in this work is similar to [Heinzelman et al. 2000]. The energy consumed to transmit a k-bit packet over a distance d is given by $E_{Tx}(k, d) = E_{elec} * k + \varepsilon_{amp} * k * d^2$ where E_{elec} is the energy consumption per bit for the transceiver circuitry, and ε_{amp} is the energy consumed by the power amplifier for transmitting one bit per unit distance. The propagation loss exponent α is taken as 2. The energy consumed by the node in receiving a k-bit packet is given by $E_{Rx}(k) = E_{elec} * k$. A node v connected to a node u through a direct wireless link is called a neighbor of u. The set of adjacent neighbors called adjacency set of a node v is represented by $adj(v)$. The Euclidean distance between two nodes u and v is represented by $\overline{|uv|}$.

Definition 1. ***Greedy Forwarding Set*** *(GFS) of node u towards destination d is the set of its adjacent nodes which are closer to d than the node u itself. i.e.* $\mathcal{GFS}_d(u) = \{v : v \in adj(u) \wedge \overline{|vd|} < \overline{|ud|}\}$.

Definition 2. *A node v is said to be a* ***dead-end node*** *towards destination d if its greedy forwarding set towards d is null i.e.* $\mathcal{GFS}_d(u) = \varnothing$. *A dead-end node is a non-potential relay node w.r.t. greedy forwarding.*

Definition 3. *A node is a* ***non-potential relay node*** *w.r.t. greedy forwarding if it is either a dead-end node or all nodes in its greedy forwarding sets are also non-potential relay nodes.*

The set of all non-potential relay nodes $\mathcal{NPR}(G)$ in WSN graph G is recursively defined as: $\mathcal{NPR}(G) = \{v : v \text{ is a dead-end, OR } \mathcal{GFS}_d(v) \subset \mathcal{NPR}(G)\}$

If a node u selects the node v as its next hop during greedy forwarding towards destination d, we represent it as $u \xrightarrow{gf_d} v$. $\xrightarrow{gf_d^*}$ is the transitive closure of $\xrightarrow{gf_d}$ operator i.e. if $x_1 \xrightarrow{gf_d} x_2$, $x_2 \xrightarrow{gf_d} x_3, \ldots, x_{n-1} \xrightarrow{gf_d} x_n$, then $x_1 \xrightarrow{gf_d^*} x_n$.

Definition 4. *A* ***trap region*** *of a dead-end node u is a connected subgraph of WSN in which greedy forwarding towards destination d culminates at u, i.e.* $\mathcal{TR}(u) = \{v : v \xrightarrow{gf_d^*} u\}$.

Definition 5. *A* ***dead-end region*** *of a trap region is a consists of nodes in the trap region which do not have any optimal neighbor, i.e.* $\mathcal{DR}(u) = \{v : v \xrightarrow{gf_d^*} u \wedge \mathcal{GFS}_d(v) \subset \mathcal{NPR}(G)\}$, *where u is a dead-end.*

Definition 6. *A* ***shadow region*** *of a trap-region is a connected subgraph consisting of nodes which have at least one optimal neighbor for greedy forwarding towards the destination d. A shadow region consists of nodes of the trap region excluding the nodes in its dead-end region.*

Definition 7. *A subgraph of a WSN is called a* ***Greedily Routable Region****(GRR) w.r.t. destination d, if each of its node u has a greedy path upto destination d.* $\mathcal{GRR}_d(G) = \{v : v \xrightarrow{gf_d^*} d\}$

Fig.2(a) shows various regions relevant in a WSN.

4. PROPOSED SCHEME

The scope of greedy forwarding in a WSN can be expanded by segregating various regions i.e. $\mathcal{GRR}$, $\mathcal{TR}$, $\mathcal{DR}$, $\mathcal{SR}$ of a WSN. Each node in the network maintains two flag variables viz. *is_optimal* and *is_shadow*, indicating the regions in which the node is located. Initially, all the

Table I. Conditions for Various Regions

is_optimal	*is_shadow*	**Region**
×	**true**	Trap Region
false	**true**	Dead End Region
true	**true**	Shadow Region
true	**false**	Greedy Routable Region

nodes are marked as "optimal" for greedy forwarding. Whenever a dead-end node is encountered during greedy forwarding, it is marked as non-optimal. If all the neighbors of a node are non-optimal, it is also marked as non-optimal. If the most optimal node of a node is marked as non-optimal but it has another optimal (albeit to a less degree) neighbor, the node is marked as a shadow-region node. The recursive application of above rules will transform the entire WSN into two types of non-overlapping regions: one contiguous Greedy Routable Region (GRR), and several ($\geqslant 0$) trap regions. Each trap region is again divided into two types of non-overlapping regions: one contiguous dead-end region and several ($\geqslant 0$) shadow regions. Or $G = \mathcal{GRR} \cup \mathcal{TR}$ and $\mathcal{TR} = \mathcal{DR} \cup \mathcal{SR}$. Fig. 2. shows the greedily routable region, void region, dead-end region, and shadow region of a WSN. Table-I. summarizes the inferences about the location of a node depending upon the truth values of its flag variables. The node marking is done on-demand during routing without any overhead of control messages or information piggybacking.

A packet originating in a $\mathcal{GRR}$ is routed using normal greedy approach. All the packets originating in the $\mathcal{SR}$ tend to travel along the border of the dead-end region creating a funneling effect (Figure 3.) and hotspot, thereby leading to rapid depletion of energies of border nodes. To mitigate the hotspot effect, the greedy optimization criterion in the shadow region is modified to prefer nodes in $\mathcal{GFS}_d(u)$ having maximum residual energy. The packets originating in a dead-end region are routed using perimeter/ face routing until an optimal node is found along the path, where the greedy routing resumes.

Algorithm - *GreedyForward (Node u, Node d, Packet p)*
To choose the next hop and mark the regions of a WSN.
Inputs - Current node u, Destination d, and Packet p

```
U ← {v : v ∈ GFS_d(u) ∧ v.is_optimal
If U = ∅
Then
    u.is_optimal ← false
    u.is_shadow ← true
    V ← {v : v ∈ GFS_d(u) ∧ v.is_optimal}
    If V = ∅
    Then
        Switch to recovery mode
    Else
        next_hop ← w : w ∈ V ∧ |w d| = min_{v∈V}(|v d|)
        Forward p to next_hop
    EndIf
Else
    most_optimal ← w : w ∈ U ∧ |w d| = min_{v∈V}(|v d|)
    If most_optimal.is_shadow
    Then
        u.is_shadow ← true
    EndIf
    next_hop ← w : w ∈ U ∧ w.res_energy = max_{v∈V}(v.res_energy)
    Forward packet to next_hop
EndIf
```

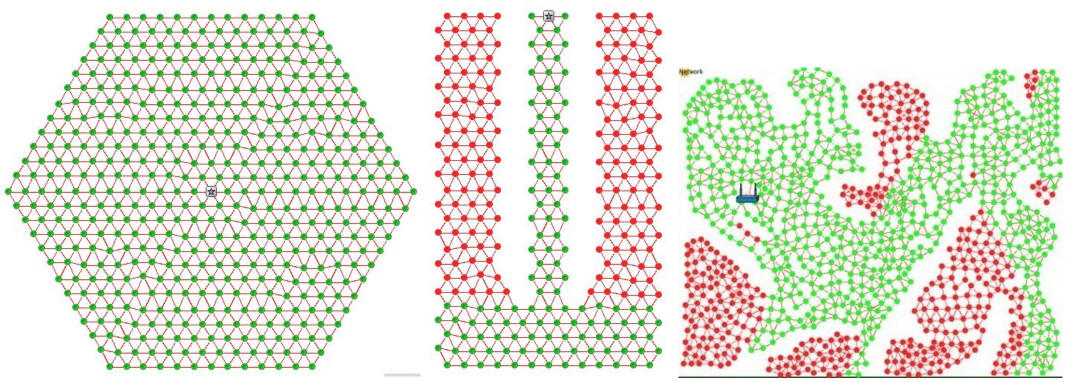
5. SIMULATION AND RESULTS

The proposed scheme is simulated in OmNet++ simulator. Simulation parameters used in this work are as mentioned in Table-II. A number of simulation runs with different node densities are carried out.

The comparison is done with GPSR and the scheme proposed in [Moraru et al. 2008] denoted by MLNR. We define a performance metric ρ_g as fraction of total packets routed to sink node using greedy mode only.

Table II. Simulation Parameters

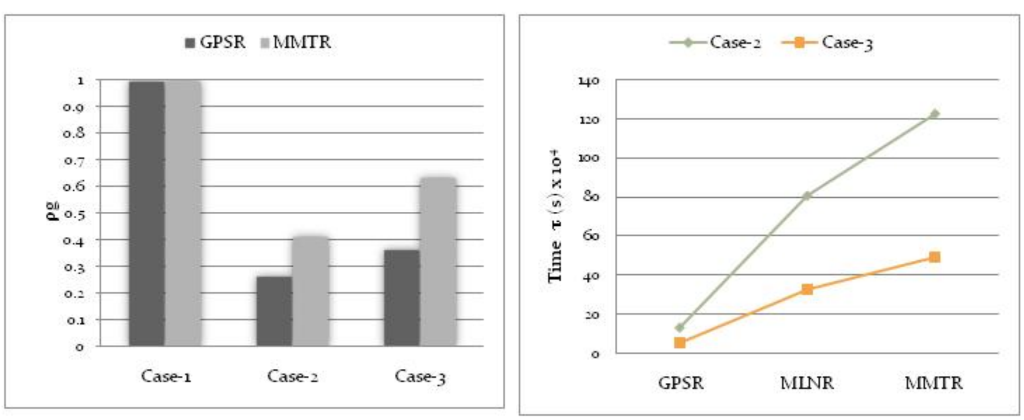
Deployment Terrain	$1000m \times 1000m$
Number of Nodes	Ranging from 100 to 1000
Node Placement	Random
Node Density	Uniform Distribution $0 \cdots 1$ *per* $900m^2$
Application Traffic	Constant Packet Rate @ 1 pkt/sec
Payload Size	16 byte
Channel Data Rate	250 kbps
Radio Range	60m



(a) GRR:100% (b) GRR:40%, DR:60% (c) GRR:60%, DR:40%

. Figure 3:Different WSN deployment scenarios

In a void-free deployment case (Fig. 3(a)), the performance of GPSR and MMTR is alike as all packets are routed using greedy mode. The scenario in Fig. 3(b) depicts a regular topology with void regions where 75 % of WSN is in trap-region, 15% in shadow region, 60% in dead-end region and 40% in GRR. In this case a difference of 15.5% is observed in ρ_g in GPSR and MMTR. The scenario represented by Fig. 3(c) is a random deployment in an irregular terrain with 60% of WSN is in trap-region, 20% in shadow region, 40% in dead-end region and 60% in GRR. In this scenario, 26.8% more packets are delivered in greedy mode in MMTR as compared to GPSR. The results of the simulation are shown in Fig. 4(a).



(a) No. of packets routed in greedy mode (b) Time until the first node dies

. Figure 4:Simulation Results

The energy consumption model to evaluate network lifetime is adapted from [Heinzelman et al. 2000]. The energy consumptions for transmit and receive operations are $E_{Tx}(k,d) = E_{elec} * k + \varepsilon_{amp} * k * d^2$ and $E_{Rx}(k) = E_{elec} * k$, the values for E_{elec} is taken as $50nJ/bit$ and ε_{amp} as $0.1nJ/bit/m^2$. Since we are concerned with the parameters affecting or affected by the routing only, we make idealistic assumptions about other network parameters. The power consumptions for CPU and sensor board are taken as $P_{CPU} = 50\mu J/s$, $P_{Sense} = 60\mu J/s$ respectively, $E_{Tx}(128, 60)$ is $52\mu J$ and $E_{Rx}(128)$ is $7\mu J$. Each node is powered by 2 AA size alkaline batteries (12000 J).

The performance metric for network lifetime is τ, "the time until first node depletes all its energy". It was observed that GPSR reports the first failure very early as compared to MLNR and MMTR (Fig.4(b)), due to the fact that the dead-end node of a trap-region is over-burdened during routing in both phases (greedy as well as perimeter). MMTR outperforms GPSR as well as MMTR because of energy-aware treatment in the shadow regions.

6. CONCLUSION

Greedy forwarding is a simple and efficient way of routing in large-scale ad-hoc networks like WSNs. The dead-end situation is the only limitation of greedy forwarding. In a densely deployed WSN with no dead-end node, the route of greedy forwarding tends to be the optimal route. Identification and tagging of the nodes that hinder the greedy forwarding, improves the overall performance of geographic routing. MMTR can improve the efficiency of GPSR by maximizing the Greedily Routable Region (GRR) in the WSN. Further, the funneling effect observed along the border of dead-end region in other node tagging schemes, is effectively alleviated by the proposed scheme.

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