# CIVILIZING UNINTEREPTED ROUTING PERFORMANCE OF GREEDY FORWARDING IN SENSOR NETWORKS

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**ABSTRACT:**

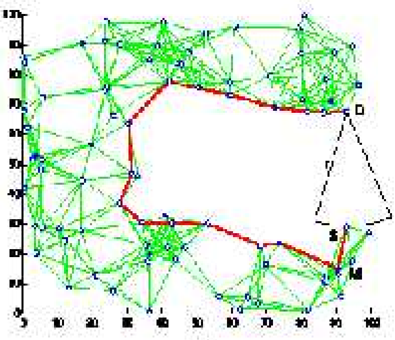
***Greedy forwarding is a simple yet efficient technique employed by many routing protocols. It is ideal to realize point-to-point routing in wireless sensor networks because packets can be delivered by only maintaining a small set of neighbors' information regardless of network size. It has been successfully employed by geographic routing, which assumes that a packet can be moved closer to the destination in the network topology if it is forwarded geographically closer to the destination in the physical space. To address the local minimum problem, proposed a topology aware routing (TAR) protocol that efficiently encodes a network topology into a low-dimensional virtual coordinate space where hop distances between pair wise nodes are preserved. Based on precise hop distance comparison, TAR can assist greedy forwarding to find the right neighbor that is one hop closer to the destination and achieve high success ratio of packet delivery without location information. Further, To improve the routing quality by embedding a network topology based on the metric of expected transmission count (ETX). ETX embedding accurately encodes both a network's topological structure and channel quality to nodes small size virtual coordinates, which helps greedy forwarding to guide a packet along the optimal path that has the fewest number of transmissions. The evaluatutionof this approaches through both simulations and experiments, showing that routing performance are improved in terms of routing success ratio and routing cost.***

**INTRODUCTION:**

Instead of focusing on data collection in wireless sensor networks (WSNs) where tree-based many-to-one routing primitive is assumed, a growing number of applications (e.g., data-centric storage) require more flexible point-to-point routing support. In a WSN, it is prohibitive to implement the table-driven shortest path routing (SPR), which requires per-destination states maintained by individual nodes. When the network scales to thousands of nodes, the large size routing tables containing thousands of entries may not be affordable to resource-constrained sensors. The conflict between the large size network with a random structure and the small routing table affordable to a sensor node raises fundamental challenges to point-to-point routing in WSNs. To address the issue, geographic routing (GR) arises as an ideal candidate. In GR, packets of a node are greedily forwarded to a neighbor that is geographically closer to the destination, and finally delivered to the destination after consecutive hop by hop forwarding. GR adopts greedy forwarding (GF), a localized algorithm that relies on keeping a small routing state composed of the positions of the destination, the current node, and its immediate neighbors. Hence, it is suited for sensors' limited memory. On the other hand, GR requires nodes' location information. Although a number of localization algorithms have been proposed to infer nodes' locations with a few GPS-enabled anchors, accurate localization is still subject to errors leading to route failures .In addition, greedy forwarding based on local information cannot ensure global optimum and packets might never reach the desired destination.

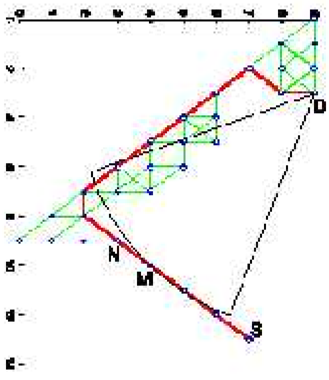
## 1. GF ALGORITHM AND EMBEDDING A NETWORK TOPOLOGY

The technique present the local minimum problem in GF algorithm. Second, one is to show how to achieve the shortest path routing through scalable GF instead of the table-driven method. The benefit is that there is no need to store a large-size routing table in a node. Third, the definition of embedding a network topology to a low dimensional Euclidian space is presented, which could be used to reduce the routing state space of GF. Finally we present the multidimensional Scaling method that is used to embed a network topology. Greedy forwarding is a powerful algorithm that guarantees convergence to a solution through its greedy search mechanism. In addition, the route can be computed when needed, eliminating the overhead for updating the routing table. GR protocols apply the GF algorithm on node locations. A distribution of wireless sensor nodes in a square field is shown in Fig. 1a.



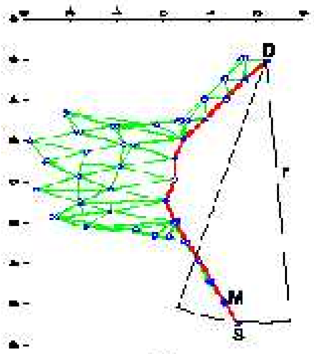

(a)

Fig. 1. (a) In GR, node S cannot find any other node that is geographically closer to the destination D.




(b)

(b) Using hop distances to two randomly selected anchors as the virtual coordinates, node S can deliver packets to node M but cannot go beyond that. The cone represents the distance from node D to M, which implies that node N is farther than node M as it locates outside the cone.




(o)

(c) With topology embedding, hop distances between pair wise nodes are preserved.

When packets of node S need to be greedily forwarded to destination D, node S is unable to find a neighbor that is closer than itself to the destination D and hence the algorithm is trapped in a local minimum. As a result, packets cannot be delivered to the destination. GF can guarantee delivery and achieve the same routing performance as the shortest path routing if hop distances between pairwise nodes can be precisely recovered from their local routing states. A naive approach is to maintain per-destination states in each node. The per-destination states maintained by node i in a network of size N can be viewed as a N-dimensional virtual coordinate xi ¼ ½xi1; xi2; . . . ; xiN _T ; where xij is the hop distance from node i to j. Based on the per-destination states, the hop distance between any pair of nodes m and d can be easily obtained as xmd, which provides sufficient support for GF to follow the path of the

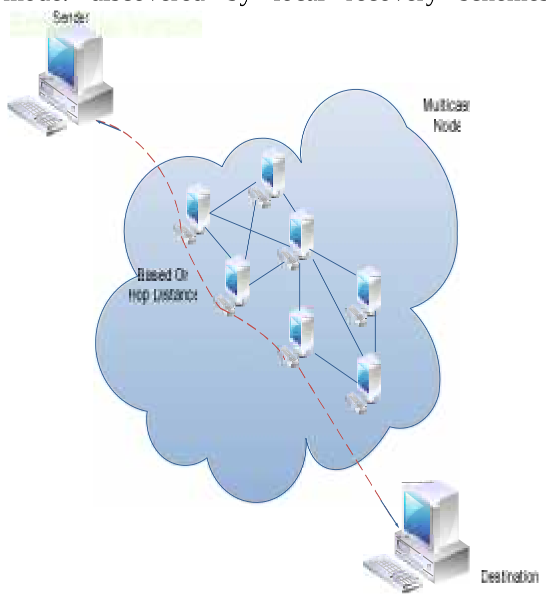
fewest hops. High routing performance can be easily achieved based on the N-dimensional per-destination states. The challenge is how to achieve high routing performance based on smaller routing states. Using smaller routing states might cause the GF to converge to a local minimum, which is referred to as the local minimum problem. For example, instead of keeping hop distances to all nodes in a network, a node can construct its virtual coordinate based on its minimum hop counts from some selected nodes, which are called anchors. As the number of anchors increases, the VCS is expanded and a node would have a higher chance to find a neighbor that is one hop closer to the destination. It shows that the local minimum problem cannot be completely addressed by using a small number of anchors. When packets are delivered to node M, it cannot find any neighbor that is closer than itself to destination D. Although node N has a shorter hop distance than node M, it has a longer geometric distance in the VCS. The problem of local minimum vanishes if we use all the nodes as anchors. However, the size of the virtual coordinates would be too large (i.e., N dimensional in a network of N nodes). A viable solution is to “losslessly compress” the N-dimensional per-destination states to low-dimensional routing states from which hop distances between pair wise nodes can be precisely recovered.. Embed a Network Topology to a Low-Dimensional Euclidean Space The compression problem can be generalized as an embedding problem, which embeds a N-dimensional hop distance metric space to a m-dimensional Euclidean space, where m _ N. An embedding problem can be formalized as follows:

Let define a metric space. Here, X is a set of nodes and _ is a metric that defines a distance function between nodes in X. Let ðP; dÞ define a Euclidean space where P is a set of points mapped from nodes

in the set X and d is a metric that defines the function of 2-norm Euclidean distances
between pair wise points in P. For pi; pj 2 P, we have di;j ¼ jpi _ pjj. Definition1. An embedding of metric space ðX; _Þ into a Euclidean space Embedding a network topology to a Euclidean space can be intuitively explained as given hop distances between pair wise nodes in a network, finding nodes' coordinates in a m-dimensional Euclidean space such that the hop distances between pair wise nodes can be inferred from
the 2-norm Euclidean distances in the mapped space. The objective of the embedding is to find the minimal m such that dij ¼ 'ð_ijÞ, i.e., to embed a hop distance metric space into the lowest dimensional Euclidean space in which hop distances between pairwise nodes can still be precisely recovered. The exact embedding is presented in the supplement, which can be found on the Computer Society Digital Library at Instead of an exact embedding, a network topology can
be approximately embedded into a Euclidean space by relaxing condition . We define an efficient expression of a network topology below. Definition 2. An efficient expression of a network topology is to embed the network topology into a m-dimensional Euclidean space such that
1. m is minimized;
2. differences between hop distances of the network topology and Euclidean distances of the embedded space are minimized. The double minimums in the definition above cannot be
achieved simultaneously. The contradiction between the accuracy of the embedding and the small dimensionality of the embedded space reflects the inherent trade-off between the accuracy of a network expression and the size of the expression. We show that the embedding can be achieved by using multidimensional scaling Embed a Network Topology through Multidimensional Scaling Multidimensional scaling [24] is a set of dimensionality reduction techniques that are used to discover meaningful low-dimensional structures hidden in the high-dimensional observations. The MDS can be generalized as assigning coordinates to data points such that Euclidean Fig. 1. (a) In GR, node S cannot find any other node that is geographically closer to the destination D. (b) Using hop distances to two randomly selected anchors as the virtual coordinates, node S can deliver packets to node M but cannot go beyond that. The cone represents the distance from node D to M, which implies that node N is farther than node M as it locates outside the cone. (c) With topology embedding, hop distances between pair wise nodes are preserved.
distances estimated from the coordinates can best fit measured distances. Fig. 1c shows that the dimensionality of the VCS is reduced from N to 2 by using MDS and the geometric distances inferred from virtual coordinates still well reflect hop distances between pairwise nodes. Because the VCS is constructed based on hop distances, routing in the VCS follows the shortest path between two nodes.

## 2. TOPOLOGY AWARE ROUTING

The technique presents the TAR algorithm. TAR adopts MDS to embed a network topology to a low-dimensional Euclidean space where the hop distances between pair wise
nodes are preserved. We first present a centralized version and then show how to deploy it in a distributed fashion through anchor sampling. Before we proceed to the detailed description of TAR routing protocol, we clarify the
objectives of proposed TAR below:
1. We target to improve the point-to-point routing performance of a WSN comprising a large number of randomly deployed stationary nodes. This covers the main category of WSNs that have limited dynamics caused by node failures.
2. Different from prior works, we focus on improving the routing performance of GF instead of optimizing the complementary recovery schemes that are invoked when GF fails. GF is in average more efficient than routing in recovery mode. discovered by local recovery schemes.




### 2.1. CENTRALIZED MULTIDIMENSIONAL SCALING

We have introduced the idea of using MDS to reduce dimensionality of VCS. In practice, we can use following steps to reduce the dimensionality of the virtual coordinate space by utilizing the MDS embedding:
1. The base station floods a topology request packet to the entire network to collect connectivity information between nodes. Efficient flooding algorithms such as the multipoint relaying (MPR) [25] can be adopted. They are shown to cover the entire network with a few number of broadcasts. A small set of selected multipoint relays are responsible for relaying the topology request

packet and reporting two hop neighbor information back to the base station.

2. When the base station obtains the global network topology, it uses Dijkstra algorithm to compute hop distances between pair wise nodes.

3. Based on the hop distances between pair wise nodes, the base station uses MDS to embed the network topology into a Euclidean space where each node is assigned a virtual coordinate.

4. The base station then sends the virtual coordinates to corresponding multipoint relays and let them broadcast the virtual coordinates to their one-hop neighbors. The centralized algorithm incurs overhead for detecting the entire network topology. In the next section, we introduce a distributed embedding procedure in which the base station only needs to collect information from a set of selected anchors.

## 2.2. DISTRIBUTED MULTIDIMENSIONAL SCALING

We embed a network topology in a distributed fashion by sampling a portion of nodes in the network. In a network of size N, M nodes are randomly selected as anchors. Each anchor k floods a beacon message that contains a hop counter initialized to zero. Based on the received messages sent out by all M anchors, node i constructs its hop distance vector as Here the shortest hop distance from node i to anchor j.

When sufficient anchors are uniformly distributed, it is possible to infer the network topology through anchor sampling and we can achieve reasonable embedding accuracy based on partial observations. Weprovide an analysis in the supplement, which can be found on the Computer Society. In order to achieve high embedding accuracy while preserving low dimensionality of the embedded space, TAR uses sufficient number of anchors to abstract the network topology first and then reduces the dimensionality as follows:

1. Each anchor sends its hop distance vector xi to the base station and the base station constructs anchors' hop distance matrix X as X ¼ ½x1; x2; . . .

Based on the matrix X, we use MDS to embed the hop distance metric space to a low- dimensional Euclidean space such that each anchor is assigned a virtual coordinate kj of m-dimension where m _ M.

2. The virtual coordinates of anchors are flooded by the base station. Each non anchor node calculates its virtual coordinate by itself using the least square fitting method to ensure that the differences between hop distances and the corresponding Euclidean distances from the node to all anchors are minimized. The performance evaluation in Section 6 shows that the hop distance between any pair wise nodes can be accurately inferred from the virtual coordinates, despite the fact that the virtual coordinates are constructed from the partial observations on anchors. The entire topology of a network can be sampled from a set of anchors because of two reasons:

1. Randomly selected beacons are uniformly distributed in the network, which makes them good candidates to represent the structure of a network topology.

2. Neighboring nodes have similar hop distances to the third node due to the triangular inequality. Wealthy topological information can be preserved by only using hop distances to a few anchors because the hop distances to other nodes close to anchors are often redundant. After the above embedding, the complete TAR protocol proceeds as GF in finding the best route.

## 3. ETX-BASED GREEDY FORWARDING

Both TAR and GR assume that wireless channels between neighboring nodes have perfect reception, i.e., packets can always be successfully delivered. Based on this assumption, the optimal routing path between the source and the destination is the path with the fewest hops. However, radio signals attenuate in transmission and are susceptible to environmental interference, which may lead to corruption of packets. In such a case, packets need to be retransmitted for several times before they can be successfully delivered. When we aim to find the shortest path, each individual hop usually has long transmission distance and low quality. Consequently, the GF fails to find the optimal path comprising high-quality links. In this section, we further improve the end-to-end routing performance of GF by embedding a WSN into a Euclidean space where two nodes' geometric distance in the space is proportional to the number of expected transmissions for a packet to be successfully delivered between the two nodes.

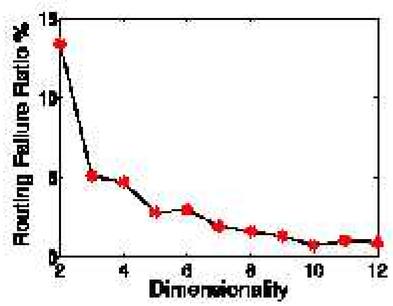



Fig. 2. Impact of virtual coordinates' dimensionality.

where Pij is the packet loss ratio from node i to j . Suppose two nodes x1 and xn has the routing path comprising intermediate nodes x2; x3; . . . ; n_1.We have the ETX of the routing path l as

We define the ETX distance between pairwise nodes xi and xj as the minimal. where L is the set of routing paths connecting nodes xi and xj. The routing path with the shortest ETX distance is the optimal one because packets can be successfully delivered with the fewest number of transmissions including retransmissions. In order to help greedy forwarding to find the routing path with the shortest ETX distance, each anchor initiates a flooding of a beacon message with initial ETX of zero. A multipoint relay is responsible for forwarding ETX distances calculated by itself and its one-hop neighbors. A multipoint relay thus needs to collect ETX distances of its one-hop neighbors before its broadcast. With these ETX distances to all anchors, we apply the same method introduced before to embed a network to the Euclidean space based on the ETX distances.

## 4. PERFORMANCE EVALUATION

To evaluate our TAR, we compare it with the a simplified variant of GFG evaluation focuses on the effectiveness of the constructed coordinates to support the greedy forwarding, i.e., the routing success ratio of greedy forwarding given a node coordinate assignment of a network. To clearly evaluate the effectiveness of various coordinate assignment schemes, we only use the GF and do not resort to any recovery solution for the local minimum when measuring the routing success ratio. We use three configurations to simulate three representative WSN deployments: an open flat area, a C shape network, and a street layout. The random selection of 1,000 pair wise nodes as sources and destinations to test GF based on nodes' coordinates assigned by one of the three routing protocols. The routing failure ratio, which is defined as the percentage that a packet cannot be delivered by the GF from the source to the destination, is used to measure the effectiveness of the three routing protocols.

To investigate how the dimensionality affects the routing failure ratio, we use the C shape network with transmission range of 18 m as the test bed. Fig. 2 shows that the routing

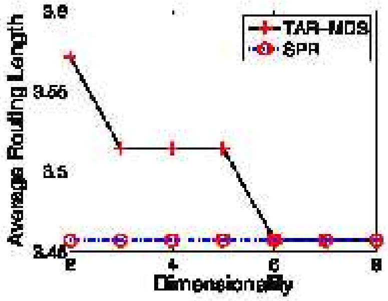


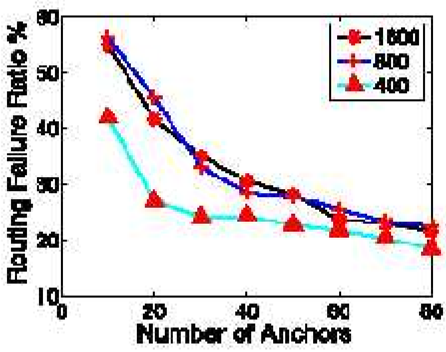

Fig. 3. Routing quality of TAR-MDS.

failure ratio of TAR-MDS can be significantly decreased if we increase the dimensionality of nodes' coordinates from 2 to 6. After that, the routing failure ratio eventually converges to zero. The routing failure ratio decreases with the increase of virtual coordinates' dimensionality because higher dimensional virtual coordinates preserve higher fidelity of the network topology in the embedding. The figure also demonstrates that a low routing failure ratio can be achieved at a fairly low dimensionality. Fig. 3 shows that TAR has the same average number of hops per routing (i.e., 3.45) as the shortest path routing when the dimensionality is increased to 6. In the same configuration, the average number of hops obtained by GPSR with face routing is 5.37, which implies that TARMDS can save energy for each packet delivery.

### 4.1. IMPACT OF ANCHOR SET SIZE IN TAR-DMDS IN A DISTRIBUTED TAR (TAR-DMDS)

we are interested in the impact of anchor set size on the routing performance. All the three approaches (i.e., TAR-DMDS, BVR, and LCR) share the similarity in that nodes' coordinates are constructed based on hop distances to a set of anchors. The relationship between the routing failure ratio and the anchor set size in the C shape network topology. This figure shows that a small number of anchors is insufficient to represent the network topology and certain number of anchors (more than 30 in this configuration) are required to achieve a relatively low routing failure ratio.

We further investigate the relationship between the number of required anchors and the size of sampled network. We generate C shape network topologies with various number of nodes: 400, 800, and 1,600 nodes. The network of 400 nodes has the same node density as the network of 800 nodes and thus it has smaller size. A larger network usually needs more anchors but with certain number of anchors (e.g., 20 in 400 nodes, 40 in 800 nodes) the routing performance becomes stable. Impact of virtual coordinates' dimensionality.




Scalability of topology aware routing.

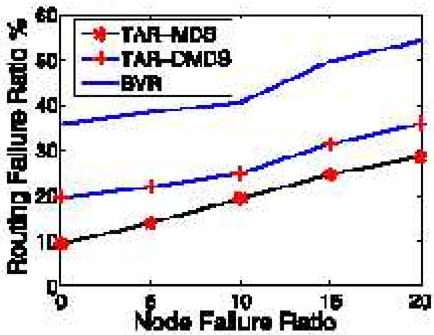
This requires us to estimate the anchor set size by simulation before network deployment. We show that it is only related to the complexity of the network topology. In the network of 800 nodes, we increase the number of nodes to 1,600 without changing the C shape. Fig. 5 shows that their routing failure ratios are close to each other. Therefore, we can conclude that the required size of sampling anchors mainly depends on the complexity of network topology instead of the total number of nodes in the network.

### 4.2. ROBUSTNESS OF TOPOLOGY AWARE ROUTING

In order to evaluate the robustness of topology aware routing, we use the street shape network topology as the test scenario. For each end-to-end packet delivery, certain percentage of nodes are randomly selected to turn off. We vary the percentage of failed nodes from 5 to 20 percent to investigate the resilience of topology aware routing to node failures. Fig. 6 shows that the routing failure ratios of both TARMDS and TAR-DMDS are increased as the node failure ratio increases. The TAR-MDS and TAR-DMDS fail to delivery packets because the routing paths discovered by them are broken due to node failures. However, we can observe that TAR-MDS and TAR-DMDS do show certain resilience to node failures based on the relative small slopes of the two curves. Because multiple paths exist between two nodes, failures of several nodes do not affect the routing performance. When a number of nodes are failed leading to new holes, the performance of VCS gradually degrades.

## 5. CONCLUSION

The technique introduces a new method to improve routing performance with small routing states. We solve the local minimum problem by embedding a network topology to a low-dimensional Euclidean space where hop distances between pairwise nodes can be recovered from nodes' virtual coordinates. Based on accurate hop distance comparison between neighboring nodes, the greedy forwarding can find the shortest path between two nodes. By further it show that the routing quality can be improved by embedding a network topology to a Euclidean space where the ETX can be recovered from nodes' virtual coordinates. Guided by the ETX distance, the greedy forwarding can find the optimal path of the fewest transmissions. We evaluate




. Robustness of topology aware routing.

our proposed approaches through both simulations and experiments, which show that they can improve the routing quality in terms of routing success ratio and routing costs.

## 7. FUTURE WORK:

The proposed technology of a topology aware routing (TAR) protocol that efficiently encodes a network topology into a low-dimensional virtual coordinate space where hop distances between pair wise nodes are preserved. Based on precise hop distance comparison, TAR can assist greedy forwarding to find the right neighbor that is one hop closer to the destination and achieve high success ratio of packet delivery without location information. Further, To improve the routing quality by embedding a network topology based on the metric of expected transmission count (ETX). ETX embedding accurately encodes both a network's topological structure and channel quality to nodes small size virtual coordinates, which helps greedy forwarding to guide a packet along the optimal path that has the fewest number of transmissions. evaluate our approaches through both simulations and experiments, showing that routing performance are improved in terms of routing success ratio and routing cost.