RESEARCH ARTICLE OPEN ACCESS

End-To-End Routing Analysis Through Greedy Forwarding In Wireless Sensor Networks With High Quality Links

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Abstract:

Greedy forwarding is a artless yet proficient system labouring by many routing protocols. It is ideal to appreciate point-to-point routing in wireless sensor networks because packets can be delivered by only keeping a small set of neighbours' information irrespective of network size. It has been well employed by terrestrial routing, which adopts that a packet can be moved nearer to the destination in the network topology if it is forwarded geologically nearer to the destination in the bodily space. This assumption, however, may main packets to the resident least where no neighbours of the sender are nearer to the endpoint or low-quality routes that embrace long distance hops of low packet greeting ratio. To address the resident least problem, we suggest a topology alert routing (TAR) protocol that well encodes a network topology into a low-dimensional virtual coordinate space where hop spaces between pairwise nodes are conserved. Based on exact hop distance contrast, TAR can elevation greedy forwarding to catch the right national that is one hop earlier to the destination and reach high success ratio of packet delivery without position data. Further, we recover the routing worth by inserting a network topology based on the metric of expected transmission count (ETX). ETX inserting exactly encodes both a network's topological structure and network quality to nodes' small size virtual coordinates, which helps greedy forwarding to guide a packet along the optimal path that has the least number of broadcasts. We estimate our methods through both reproductions and experimentations, showing that routing presentation are enhanced in terms of routing achievement ratio and routing cost.

Keywords **—Sensor networks, routing, link quality, topology embedding.**

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1. INTRODUCTION

As an alternative of concentrating on data gathering in wireless sensor networks (WSNs)
where tree-based many-to-one routing original is expected, a increasing number of submissions need more supple point-to-point routing support [1]. In a WSN, it is excessive to implement the table-driven shortest path routing (SPR), which needs per-destination conditions preserved by separate nodes. When the networkscales to thousands of nodes, the great size routing tables holding thousands of admissions may not be reasonable to resource-constrained sensors. The battle between the greatsize network with a random arrangement and the small routing table reasonable to a sensor node increases ultimate experiments to point-to-point routing in WSNs. To address the issue, terrestrial routing (GR) arises as an ideal nominee [2], [3], [4], [5]. In GR, packets of a node are greedily forwarded to a neighbour that is geologically nearer to the destination, and lastly delivered to the destination after sequential hop by hop forwarding. GR accepts greedy forwarding (GF), a confined

algorithm that trusts on possession a small routing state composed of the locations of the destination, the recent node, and its close neighbours. Hence, it is suited for sensors' limited memory. On the additional, GR needs nodes' position information. Although a number of localization procedures have been future to infer nodes' positions with a few GPS-enabled presenters [5], correct localization is still subject to errors leading to route failures [6]. In addition, greedy forwarding based on resident information cannot confirm global best and packets might never reach the favourite destination.

In this perception, we introduce a Topology Aware Routing (TAR) procedure that guides the GF along the near optimal paths in terms of global metrics. The topology awareness is attained via building a virtual coordinate space (VCS) where the equal distance between two arbitrary nodes are returns the authentic distance in conforming global metric space. We decrease the dimensionality of VCS by introducing a multidimensional scaling (MDS) method. We further insert a WSN into a Euclidean space where the equal distancebetween two arbitrary nodes is relative to the number of expected transmissions for a packet to be efficaciously delivered between the two nodes. TAR routing procedure accepts the metric of ETX [7] instead of that of least hop count and succeeds high presentation.

The relaxation of the paper is organized as follows: In Section 2, a summary of correlated work is offered. The meaning of topology inserting problem is offered in Section 3. Part 4 grants the TAR procedure and its ability to evade local modicums. We establish the integration of ETX distance in TAR in Part 5. Presentation estimation is offered in Sector 6 and we finally complete this concept in Sector 7.

2 RELATED WORKS

Topographical routing [2], [3], [4], [5] is good looking in WSNs because of its greater scalability: every node only wants to be awake of a minor set of its neighbours' positions irrespective of network size. Position willingness confines its submissions. In addition, a packet may be confined in the resident least. A GR protocol, thus, normally activates in two modes: topographical greedy-forwarding mode and supplementary void-handling mode. A main void-handling method labouring by GR protocols is expression routing, which travels the borders of faces in the linearized network graph [2], [3], [4], [5]. The face routing wants to be made upon graph planarization procedures such as CLDP [6], which eliminates cross links that will not detach the routable sub graph. While CLDP is able to linearize an arbitrary graph, the cost to analysis every link several periods is high. GDSTR [7] and GEM [8] thus modification to route on a tree instead of planar zing the network connectivity graph.Instead of reviewing how to get out of a dead end, some structures challenge to avoid dead ends in advance. In HAIR [9], a dead end enquires neighbouring nodes to mark itself as a whole node and tells them to find additional route to theendpoint. DUA [9] rejects voids by distance upgrading, and some protocols [10] use Tent rule and Bound Hole procedures to determine a void and build a spherical announcement area. While they optimize the plan of routing nearby voids, the resident retrieval cannot assurance global optimum. Different from them, we build a virtual coordinate space (VCS) in which the GF can guide packets along the best paths in a global view.

Virtual coordinate schemes arise as a result when position information is not offered [10], [11], [12]. The virtual coordinate of a node is calculated based on its spaces, usually in hops, to a set of reference points called anchors (orlandmarks). Because the coordinates are based on network connectivity rather than the physical distance, virtual coordinate schemes are more lenient to routing voids.

Inspired by the fact that the location of a point on a two-dimensional level can be uniquely described by its distances from at least three non-collinear reference pints, procedures only routine three anchors. Because a set of nodes within a region have the similar triplet ðx; y; zÞ coordinate, a positive ID-based method is used to deliver packets to the anticipated destination node.

LCR displays that the delivery ratio is rather acceptable when using four anchors with each located at a corner of a rectangular area. The alike idea of attaining virtual coordinates from a set of anchors is also labouring by BVR but a dissimilar forwarding metric and a scoped overflowing retrieval scheme have been future. Because the distance is measured in hops, the use of whole number to approximate continuous symmetrical space introduces quantization noise. This has been calculated in aligned VCS. Previous studies only use a minor number of anchors and thus fail to well represent a network topology. Due to the limited memory of sensors and the overhead acquired by packet headers the number of broadcasters cannot be large.

To apply more anchors for well abstracting a network topology, we adopt dimensionality reduction methods to decrease the dimensionality of VCS.To route on worthy links, some GR attitudes balance the forwarding distance and the link quality either by describing a beginning to eliminate low-quality radio links or by describing a new metric that can be exploited underneath the restrictions of both forwarding distance and radio link quality.

However, the greedy forwarding based on resident metrics fails to discovery the optimal end-to-end routing path because the resident metrics collective by the forwarding advance and the link quality between two neighbouring nodes cannot replicate the global communication frequency quality. On the dissimilar, the ETX distance is a global metric that describes the end-to-end communication quality and thus our combination of ETX in TAR can find the optimal path that clues to the smallest transmissions.

3 GREEDY FORWARDING AND EMBEDDING NETWORK TOPOLOGY

In this section, first, we present the indigenous least difficult in GF procedure. Second, we show how to succeed the shortest path routing through scalable GF instead of the table-driven technique. The advantage is that there is no need to store a large-size routing table in a node. Finally we present the Multidimensional Scaling technique that is used to embed a network topology.

Greedy forwarding is an influential procedure that assurances mergingmechanism. In addition, the route can be calculated when needed, excluding the overhead for updating the routing table.GR protocols smear the GF procedure on node positions. A delivery of wireless sensor nodes in a square field is shown in Fig. 1a. When packets of node S need to be greedily forwarded to endpoint D, node S is unable to find a neighbour that is nearer than itself to the endpoint D and hence the procedure is trapped in a resident minimum. As a result, packets cannot be delivered to the endpoint.

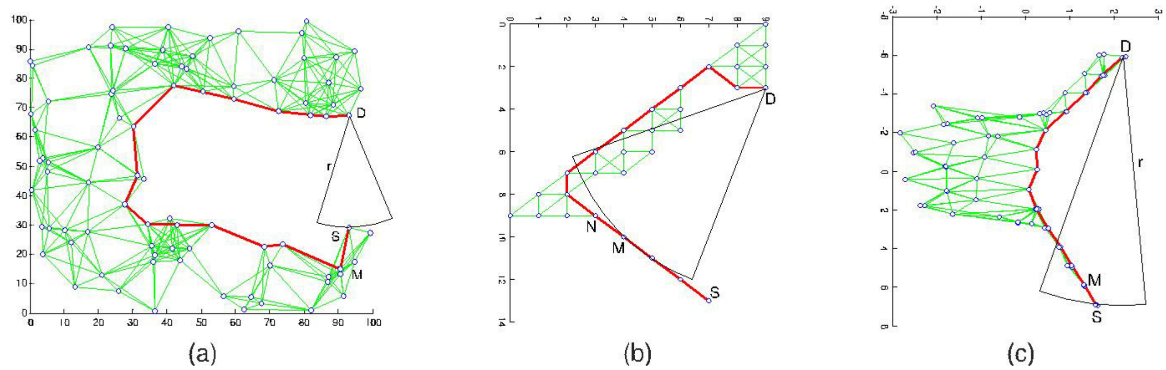

Fig. 1. (a) In GR, node S cannot find any other node that is geographically closer to the destination D. (b) Using hop distances to two randomly selected anchors as the virtual coordinates, node S can deliver packets to node M but cannot go beyond that. The cone represents the distance from node D to M, which implies that node N is farther than node M as it locates outside the cone. (c) With topology embedding, hop distances between pairwise nodes are preserved.

Greedy Forwarding can assurance delivery and succeed the same routing presentation as the shortest path routing if hop distances between pairwise nodes can be exactly improved from their resident routing positions. A naive method is to keep 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 and the hop space from node i to j. Based on the per-destination states, the hop space between any pair of nodes m and d can be easilyobtained as x_{md}, which provides sufficient support for GF to survey the path of the scarcest hops.

High routing performance can be easily succeed based on the N-dimensional per-destination states. The challenge is how to succeed high routing performance based on smaller routing states. Using smaller routing states might cause the GF to congregate to a resident minimum, which is referred to as the local minimum difficult. For example, instead of trust hop distances to all nodes in a network, anode can build its virtual coordinate based on its minimum hop computations from some nominated nodes, which are called anchors. As the number of anchors rises, the VCS is extended and a node would have a higher chance to find a neighbour that is one hop nearer to the endpoint. Fig. 1b shows that the native minimum difficult cannot be completely addressed by using a minor number anchors. When packets are delivered to node M, it cannot find any neighbour that is nearer than itself to endpoint D. Although node N has a shorter hop distance than node M, it has a lengthiersymmetrical distance in the VCS. The difficult of local least disappears 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 feasible solution is to “listlessly compress” the N dimensional per-destination situations to low- dimensional routing states from which hop distances between pairwise nodes can be exactly improved.

3.1 Embed a Network Topology to a Low-Dimensional Euclidean Space

The compression difficult can be widespread as an embedding difficult, which embeds a N-dimensional hop space metric distance to a m-dimensional Euclidean space.

Classification 1. An embedding of metric space ðX; _Þ into a Euclidean space ðP; dÞ is a mapping _ : X ! P , ’ : _ð_Þ ! dð_Þ such that

1. $\mathbf{p}_i$¼_ð$\mathbf{x}_i$Þ;
2. $\mathbf{d}_{ij}$¼’ð_$_{ij}$Þ.

Embedding a network topology to a Euclidean space can be intuitively explained as given hop distances between pairwise nodes in a network, discovery nodes’ coordinates in a m-dimensional Euclidean space such that the node to node distancesbetween pairwise nodes can be conditional from the 2-norm Euclidean distances in the planned space. The detached of the embedding is to find the nominal m such that to embed a hop space metric space into the lowest dimensional Euclidean space in which hop distances between pairwise nodes can still be exactly improved.

As an alternative of an exact embedding, a network topology can be nearly embedded into a Euclidean space by soothing condition 2. We define an effectual appearance of a network distance between two arbitrary nodes are returns the authentic topology below.

Classification 2. An effectual appearance of a network topology is to embed the network topology into a m-dimensional Euclidean space such that

2.1 m is minimalized;

2.2 differences between hop spaces of the network topology and Euclidean distances of the embedded distance are minimized.

The double minimums in the description above cannot be succeeded simultaneously. The inconsistency between exactness of the embedding and the small dimensionality of the embedded space reflects the integral trade-off between the precision of a network appearance and the size of the appearance. We show that the embedding can be succeeded by using multidimensional scaling [14] in the following section.

3.2 Embed a Network Topology through Multidimensional Scaling

Multidimensional scaling [14] is a set of dimensionality decrease methods that are used to discover meaningful low-dimensional structures secreted in the high-dimensional explanations. The MDS can be widespread as allocating coordinates to data points such that Euclidean spaces calculated from the coordinates can greatest fit measured spaces. We deliver a diminutive assumption in the addition, which can be found on the Computer Society to show how the MDS can be used to embed the hop space metric distance into a Euclidean space. The result shows that a node’s N-dimensional coordinate can be stated as rank-ordered set of Particular values attained by particular value decomposition. 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.

4 TOPOLOGY AWARE ROUTING

In this conception, we present the TAR procedure. TAR admits MDS to embed a network topology to a low-dimensional Euclidean space where the hop spaces between pairwise nodes are conserved. We first present a integrated version and then show how to arrange it in a circulated style through anchor selection. Before we progress to the exhaustive explanation of TAR routing protocol, we explain the purposes of our proposed TAR below:

1. Our aim is to improve the point-to-point routing performance of a WSN encompassing a huge number of randomly arranged fixed nodes. This covers the main classification of WSNs that have restricted dynamics affected by node disasters.

2. Dissimilar from preceding works, we concentration on enlightening the routing performance of GF instead of optimizing the consistent recovery constructions that are appealed when Greedy Forwarding fails. Greedy Forwarding is in average extra effective than routing in retrieval mode. Therefore, our objective is to reduce the need of resorting to recovery schemes. In addition, we aim to provide better routing paths than that discovered by local recovery schemes.

4.1 Centralized Multidimensional Scaling

We have familiarised the knowledge of using MDS to decrease dimensionality of VCS. In preparation, we can custom next steps to decrease the dimensionality of the virtual coordinate space by consuming the MDS set in:

1. The base station downpours a topology invitation packet to the whole network to gather connectivity evidence between nodes. Resourceful flooding procedures such as the multipoint transferring (MPR) [14] can be accepted. They are exposed to safeguard the entire network with a few number of broadcasts.

   A small set of individual multipoint relays are answerable for relaying the topology request packet and commentary two-hop neighbour information back to the base station.

2. When the base station attains the worldwide network topology, it usages Dijkstra algorithm to calculate hop spaces among pairwise nodes.

3. Based on the hop places among pairwise nodes, the base station uses MDS to embed the network topology into a Euclidean space where all node is consigned a virtual organize.

4. The base station then sends the virtual coordinates to matching multipoint relays and let them broadcast the virtual directs to their one-hop neighbours.

The centralized procedure suffers above for perceiving the whole network topology. In the next section, we introduce a distributed implanting technique in which the base station only requirements to collect information from a set of selected anchors.

4.2 Distributed Multidimensional Scaling

We embed a network topology in a distributed style by sampling a portion of nodes in the network. In a network of size N, M nodes are arbitrarily selected as anchors. Each anchor k floods a beacon communication that covers a hop counter modified to zero. Based on the established messages sent out by all M anchors. When sufficient anchors are equivalently circulated, it is imaginable to gather the network topology through anchor sampling and we can succeed judicious embedding accurateness based on incomplete observations. We provide an analysis in the addition, which can be found on the Computer Society Digital Library to illustrate the relationship between the embedding accuratenessand the size of anchor set. As analysed in the addition, which can be found on the Computer Society Digital Library a dense and uniform anchor circulation is helpful to minimize the space estimation error. However, increasing anchor density will lead to higher dimensionality of the embedded space. In order to succeed high embedding exactness while conserving low dimensionality of the embedded distance, TAR uses adequate number of anchors to abstract the network topology first and then decreases the dimensionality as follows:

Step one. Each anchor sends its hop space vector x_i to the base station and the base station builds anchors' we use MDS to embed the hop space metric distance to a low-dimensional Euclidean space such that each anchor is allocated a virtual coordinate of m-dimension.

Step two. The virtual coordinates of anchors are flooded by the base station. Each non-anchor node estimates its virtual coordinate by itself using the smallest square suitable technique to confirm that the variances between hop spaces and the corresponding Euclidean spaces from the node to all anchors are minimized.

The performance calculation in Section 6 shows that the hop space between any pairwise nodes can be exactly contingent from the virtual coordinates, despite the fact that the virtual coordinates are built from the incomplete explanations on anchors. The whole topology of a network can be sampled from a set of anchors because of two reasons:

1. Randomly selected beacons are uniformly circulated in the network, which makes them good nominees to symbolise the structure of a network topology.

2. Neighbouring nodes have like hop spaces to the third node due to the triangular dissimilarity. Wealthy topological information can be conserved by only using hop spaces to a few anchors because the hop distances to other nodes close to anchors are often redundant.

After the above embedding, the whole TAR protocol continues as GF in finding the best route.

4.3 Overhead

The cost of attaining global best paths is the initial building overhead for the virtual coordinate distance. Matched with table-driven shortest path routing, the overhead is lower because hop spaces to a set of nominated anchors are measured instead of congregation hop spaces to all nodes in the network. In addition, by dimensionality decrease, a node only needs to maintain a small set of instant neighbour's low-dimensional virtual coordinates instead of maintaining a huge number of routing entries. Matched with GR, the flooding invites initial overhead for VCS building, which is similar to the overhead invited by localization procedures used in GR. The extra costs in our techniques come from the reconstruction of the VCS when network topology is meaningfully changed. In a sensor network, it is rare that a huge number of nodes in an area are all dead and new holes are produced. If it is frequent, the network cannot fullfill its application require because several areas are not capableto be observed.

The network dynamics are mainly affected by node malfunction, energy depletion, and agreement of duty-cycling MAC protocols. Calculation in Section 6 shows that our TAR is robust to node failures. Therefore, it works well with synchronous MAC protocols where nodes sometimes get up at the same time for replacing packets. Under asynchronous MAC protocols, we can adopt the asynchronous transmission scheme ADB [14] to succeed flooding. In data broadcast period, the sender will get up the receiver up by introduction broadcast as designed in asynchronous MAC protocols [14]. Therefore, nodes' episodic sleep does not caused the fundamental topology.

The rebuilding of VCS is rare and the overhead for VCS building is small with effective flooding structures as analysed in the addition, which can be found on the Computer Society Digital Library because a path exposed by our TAR has less hops than that exposed by GR, we reduce energy consumption for each end-to-end packet delivery and save energy in the long term.

5 ETX-BASED GREEDY FORWARDING

Both TAR and GR assume that wireless channels between neighbouring nodes have perfect reception, i.e., packets can continuously be efficaciously delivered. Based on this hypothesis, the optimal routing path between the source and the destination is the path with the smallest hops. However, radio signals diminish in broadcast and are liable to ecological intrusion, which may main to corruption of packets. In such a case, packets require to be retransmitted for many times before they can be success-fully delivered. When we target to find the shortest path, each separate hop usually has long broadcast distance and low quality. Subsequently, the GF fails to find the optimal path containing high-quality links.

In this segment, we further improve the end-to-end routing performance of GF by embedding a WSN into a Euclidean space where two nodes' symmetrical distance in the space is comparative to the number of probable transmissions for a packetto be efficaciously delivered between the two nodes. The routing path with the shortest ETX space is the optimal one because packets can be successfully delivered with the smallest number of broadcasts including retransmissions.

In order to help greedy forwarding to find the routing path with the shortest ETX distance, each anchor inductees a flooding of a beacon communication with first ETX of zero. A multipoint relay is answerable for forwarding ETX spaces estimated by itself and its one-hop neighbours. A multipoint relay thus requires to gather ETX distances of its one-hop neighbours before its transmission. With these ETX distances to all anchors, we smear the same technique introduced before to embed a network to the Euclidean space based on the ETX distances.

6 PERFORMANCE EVALUATION

To estimate our TAR, we compare it with the GPSR (a simplified different of GFG with differences shortened in [5]), the LCR, and the BVR.. Our estimation focuses on the effectiveness of the built virtual coordinates to support the greedy forwarding the routing achievement ratio of greedy forwarding given a node coordinate assignment of a network. To evidently estimate the success of various coordinate mission schemes, weonly use the GF and do not resort to any retrieval answer for the local minimum when measuring the routing achievement ratio. Weuse three configurations to pretend three representative. WSN deployments: an open flat area, a C shape network, and a street layout. The three topologies are illustrated in the addition, which can be found on the Computer Society Digital Library.

In every test, we arbitrarily select 1,000 pairwise nodes as sources and destinations to test GF based on nodes' coordinates allocated by one of the three routing protocols. The routing disappointment ratio, which is clear as the percentage that a packet cannot be delivered by the Greedy Forwarding from the source to the destination, is used to measure the efficiency of the three routing protocols.

6.1 Impact of Virtual Coordinates' Dimensionality in TAR-MDS

To examine how the dimensionality affects the routing failure ratio, we use the C shape network with broadcast range of 18 m as the test bed. The routing failure ratio of TAR-MDS can be meaningfully reduced if we increase the dimensionality of nodes' coordinates from 2 to 6. After that, the routing failure ratio finally joins to zero. The routing failure ratio reductions with the increase of virtual coordinates' dimensionality because higher dimensional virtual coordinates reservation higher fidelity of the network topology in the embedding. The figure also determines that a low routing failure ratio can be succeeded at a equally low dimensionality (6 in this experiment). TAR has the same average number of hops per routing as the shortest path routing when the dimensionality is increased to 6. In the same conformation, the average number of hops achieved by GPSR with face routing is 5.37, which suggests that TAR-MDS can save dynamism for every packet delivery.

6.2 Impact of Anchor Set Size in TAR-DMDS

In a circulated TAR (TAR-DMDS), we are attentive in the impact of anchor set size on the routing performance. All the three methods (i.e., TAR-DMDS, BVR, and LCR) share the comparison in that nodes' coordinates are built 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 minor number of anchors is inadequate to denote the network topology and confident number of anchors (more than 30 in this configuration) are needed to succeed a reasonably low routing failure ratio.

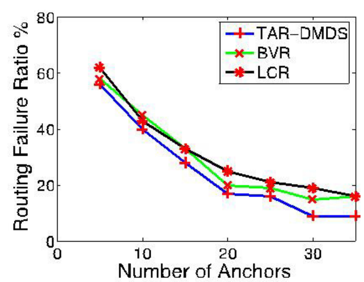

Fig. 2. Routing failure ratio versus # of anchors in a C shape network.

We further examine the relationship between the number of needed anchors and the size ofsampled network.We produce C shape network topologies with different number of nodes: 400, 800, and 1,600 nodes.The network of 400 nodes has the same node concentration as the network of 800 nodes and thus it has smaller size. A larger network usually needs more anchors but with convinced number of anchors (e.g., 20 in 400 nodes, 40 in 800 nodes) the routing performance becomes stable.This requires us to evaluation the anchor set size by reproduction before network disposition.We show that it is only connected to the complexity of the network topology. In the network of 800nodes, we increase the number of nodes to 1,600 without changing the C shape. Fig. 5 shows that their routing failure ratios are near to each other. Therefore, we can accomplish that the required sizeof sampling anchors mainly depends on the complexity of network topology instead of the total number of nodes in the network.

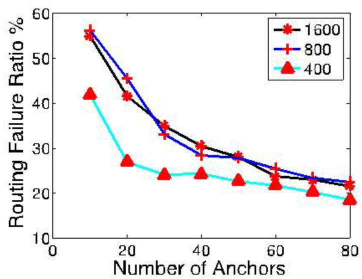

Fig. 3. Scalability of topology aware routing.

6.3 Robustness of Topology Aware Routing

In order to calculate the robustness of topology awake routing, we use the street shape network topology as the test development. For each end-to-end packet delivery, certain percentage of nodes are arbitrarily selected to turn off. We differ the percentage of failed nodes from 5 to 20 percent to examine the flexibility of topology attentive routing to node failures.Fig. 6 displays that the routing failure ratios of together TAR-MDS 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 exposed by them are broken due to node failures.

However, we can perceive that TAR-MDS and TAR-DMDS do show convinced flexibility to node failures based on the relation minor 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 prominent to new holes, the performance of VCS gradually degrades. More performance calculation results can be found in the addition, which can be found on the Computer Society Digital Library.

7 CONCLUSION

In this concept, we familiarise a technique to improve routing performance with minor routing states. We answer the local minimum difficult by embedding a network topology to a low-dimensional Euclidean space where hop spaces between pairwise nodes can be improved from nodes' virtual coordinates.

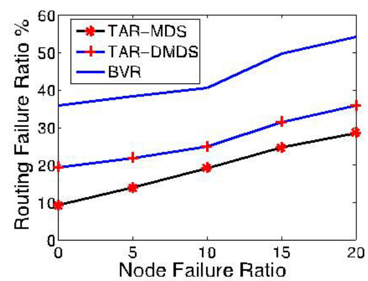

Fig. 4. Robustness of topology aware

Based on exact hop distance comparison between neighbouring nodes, the greedy forwarding can find the shortest path between two nodes. We further show that the routing eminence can be improved by embedding anetwork 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 smallest broadcasts. routing. We calculate ourproposed methods through both replications and tests, which show that they can improve the routing quality in terms of routing achieve ratio and routing costs.

ACKNOWLEDGMENTS

This work was held in part by the US National Science Foundation (NSF) under Grants CCF-0514078, CNS-0551464, and CNS-0721441. Guokai Zeng contributed in the initial stage of the work.

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