Topological Cluster-based Geographic Routing in Multihop Ad Hoc Networks

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***Abstract*—Existing geographic routing algorithms face serious challenges due to location errors, nonplanarity issues and overhead of location service. To solve these issues, we propose Topological Cluster Based Geographic Routing that combines topology-based routing and geographic routing. It is a localized routing scheme where the geographic routing is performed on an overlay network of topological clusters. Preliminary results from simulations show that the overlay graph created by topological clustering has the potential to create planar graphs even with realistic wireless models. Hence, the typical Greedy-FACE-Greedy protocol used in geographic routing works in these overlay graphs and makes the geographic routing applicable in realistic wireless networks. Moreover, due to the topology-based multi-hop clustering which we apply in this work, the proposed routing has the potential to subside node localization errors and reduce the overhead of the location service.**

Keywords*—*geographic routing; multi-hop clustering; overlay graph; graph planarization; location fault tolerance.

I. Introduction

Efficient routing in mobile ad-hoc networks is a challenging task due to their highly dynamic network topology, bandwidth constrained links and resource constrained nodes. Routing protocols developed during the earlier stages were based on the topology information, which used the knowledge about the links between the nodes to establish and maintain end-to-end paths for routing. Topology-based routing has significant overhead in maintaining up-to-date paths between source and destination, if the topology changes frequently. Moreover, it has scalability issues, as the overhead increases according to the number of nodes in the network.

With the availability of small, inexpensive, and low-power Global Positioning System [1] receivers or other localization systems, routing based on the geographic information gained significant attention. In geographic routing, a node uses the position information of the sender S, its neighboring nodes, and the destination node D, to move the packet further toward the destination at each hop.

The simplest form of geographic routing is to greedily forward the message to the node which minimizes a local forwarding metric. A simple example of such a metric is the distance to the destination. In this case, the message is forwarded to the neighbor node which minimizes the distance to the destination.

In all greedy routing variants the message may arrive at a node, which compared to its neighbors is the best with respect to the routing metric applied. In this case, greedy routing has to stop and an alternative routing mode called void handling has to be used to circumvent the void regions.

Void handling based on routing in planar geometric graphs attracted a major amount of research effort due to its stateless property and guaranteed delivery in planar graph models [2], [3]. The planar graph algorithms uses graph traversal rules (right hand rule and face changes rules) to find a path from the source to the destination on planar graphs along the boundaries of the void regions.

Existing geographic greedy routing and void handling methods do not require the establishment and maintenance of end-to-end paths. Thus, compared to topological routing, changes in topology have less impact. However, the following shortcomings of geographic routing algorithms are known:

Localization errors: Location measurement is often noisy and incurs errors. Even small errors can lead to incorrect, non-recoverable geographic routing with noticeable performance degradation. Kim et al. [4] shows that location inaccuracy ($\leq 20\%$ of radio range) caused forwarding loops, and packet drops reaching up to 54 percent.

Void handling issues: The planar graph-based void handling guarantees message delivery only if the graph is planar. Hence a planarization step, prior to routing is required. However, localized planarization processes that work in realistic wireless models do not exist. Moreover, localization errors as discussed above, causes incorrect edge removal and may disconnect the planar subgraph [4]. Hence an efficient localized planarization algorithm that works in realistic wireless models with location fault tolerance is needed.

Location service: Geographic information of the destination node is required to send packets to the destination. Typically a location service maintains the up-to-date positions of the nodes in the network and the source directly asks the location service for destination position information. The overhead in maintaining a location service with up-to-date positions of all nodes in the network is very high; especially at high node mobility [5].

To address the above mentioned problems, we propose Topological Cluster Based Geographic Routing (Topogeo), which is a combination of small scale topology-based and

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large scale geographic-based routing. The principal idea behind the Topogeo routing is presented in Section II. Preliminary results of the Topogeo performance analysis on graph planarization are discussed in Section III. Finally, Section IV summarizes the findings of this work and provides an outlook on possible future research.

II. Topological Cluster Based Geographic Routing

Topogeo combines topology-based routing and geographic routing. Here, the geographic routing is performed on an overlay network of topological multi-hop clusters. The cluster heads constitute the vertices of the overlay graph. The cluster heads collect information about their neighboring clusters and establish links towards the neighboring cluster heads. These links constitute the edges of the overlay graphs. Since the cluster hop counts are limited and the cluster head keeps information only about the neighboring clusters, Topogeo remains a localized routing algorithm.

Using topology-based multi-hop clustering to create a robust overlay graph for geometric routing, is a novel idea. Geographic routing performed on an overlay graph of cluster heads (CH) was already reported; for instance in [4], [6]–[8]. Contrary to these works that create geographic clusters or geographic cells, our work is based on the idea of topological clustering. Terminode Routing [9] combines hierarchical and geographic routing. The hierarchy created in Terminodes is by using anchor nodes, where, as in Topogeo the hierarchy is created by topological clustering. Moreover, Topogeo is a localized geographic routing, where as Terminodes needs a global map of the anchor nodes or path discovery protocols to obtain the anchored path.

Topological Cluster Based Geographic Routing has three different processes, namely 1) Multi-hop clustering and cluster head selection 2) Overlay network formation and 3) Topogeo routing. Topogeo uses any multi-hop clustering algorithm, e.g, k-hop connectivity ID algorithm [3], for clustering and cluster head selection. After the clustering process, virtual nodes are created at the center of gravity of the clusters. These nodes are chosen as the vertices of the overlay graph, as they are more location fault tolerant than the real cluster heads. In principle, a node close to the location of virtual cluster head (VCH) or the real cluster head itself serves the functions of the VCH. Now, virtual links are created between neighboring VCHs. After the overlay graph formation, the Topogeo routing process is executed.

Topogeo routing uses topological information of the cluster member nodes for routing within the clusters. During the clustering process, each cluster head collects topology information about its member nodes. The cluster member nodes keep information about the path to reach their cluster head. This information is used for the topology-based intra-cluster routing. For routing beyond the source node's cluster, Topogeo uses geographic routing. In geographic routing, the typical Greedy-Face-Greedy type protocol [2] is used to route packet along the edges of the overlay graph. In the greedy-forwarding

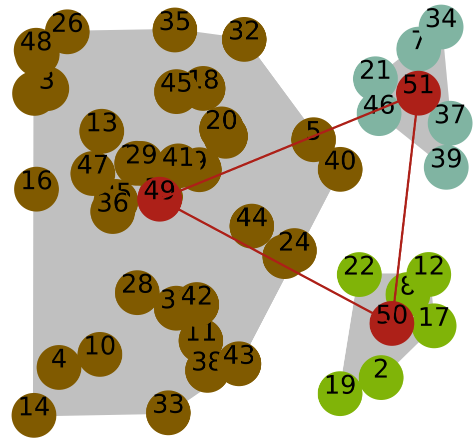

Fig. 1: Overlay graph created with 2-hop clustering for illustration

mode of the protocol, each cluster head forwards the packets to its neighboring cluster head based on any forwarding criterion that guarantees loop-free paths; e.g., the most-advance based forwarding [10] criterion. When the packets get stuck at voids during greedy-forwarding, they use the planar graph traversal based on Face routing [3] for void handling. This helps the packets to circumvent the void region. Once they circumvent the void region, the routing is switched back to the greedy forwarding mode. When the packets reach the cluster head of destination node, the local topology routing protocol is used to forward the packets to the recipient node.

Planar-graph-based void handling guarantees message delivery only if the graph is planar. Hence a planarization step that works in realistic wireless models is needed. Topogeo creates an overlay graph that is almost 100% planar, even with realistic wireless models such as Log normal Shadowing model [11] as observed in our experiments. The planarity of the overlay graph is achieved with the multi-hop clustering step.

Figure 1 shows a small network created with 50 nodes and average node degree 9.4 (3π) for illustration. The edges of the original network are not shown in the figure for better visualization of the overlay graph. On performing 2-hop clustering, three clusters are formed with the cluster member nodes displayed in three different colors, along with their node ids. The silver colored area shown in the background of clusters, is the convex hull region of their member nodes. The vertices of the overlay graph are shown in brick-red colored circles and the edges in brick-red colored line segments.

Topogeo addresses the shortcomings of localized geographic routing discussed in Section I as follows. It is location fault tolerant, as Geographic routing is performed at the cluster head level rather than at the node level. Hence the location and link errors of individual nodes do not directly reflect on the routing decisions in the overlay graphs; especially in dense networks having several gateway nodes between each clusters or cells. Moreover, the virtual cluster head creation and large cluster formation, subside the discrepancy in the location of nodes which will be validated in our future experiments.

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In Topogeo, the location service keeps and maintains the position information only for virtual cluster heads. For each individual node in the network, now only the node's cluster head id is stored in the location service. Hence the location service need not update information of each node in the network while it has a position change. Location information about a node only needs to be updated when it changes its cluster. Moreover, individual node movements do not change the position of virtual cluster heads significantly and hence the virtual cluster head position update is less frequent.

The overlay graph created by Topogeo has almost no intersections even with realistic wireless models. Hence the non-planarity issues of planar-graph-based void handling in realistic wireless models is solved and FACE routing works with guaranteed delivery in such overlay graphs.

III. Experimental Analysis and Preliminary Results

We have implemented the multi-hop clustering algorithms such as k-CONID (k-hop connectivity ID) algorithm [3] and Max-Min D-Cluster algorithm [12] for clustering and cluster head selection process. After this process, the virtual nodes and virtual links of the overlay graph are created. The third process, the Topogeo routing, works on any existing topology-based and geometric routing algorithms for intra-cluster and inter-cluster routing respectively. The evaluation of Topogeo performance on its ability to solve the shortcomings of localized geographic routing discussed in Section I is independent of the implementation of Topogeo routing process.

To make statistical estimations on the planarity of the overlay graphs, we conduct various experiments on different test networks. We use the ShoX network simulator [13] for network creation and overlay graph formation. Networks with field sizes 500×500 containing 100 to 500 nodes, and another one with 2500×2500 containing 2500 to 12500 nodes, are used in these experiments. For each field size, 100 different network configurations are created for a specific average node degree value. We use more than 1000 different networks in total for the evaluation.

We use the Log normal shadowing (LNS) model [11] for our experiments. The path loss at a distance d expressed in decibel by the LNS model is given as:

$$PL(d)[dB] = PL(d_0)[dB] + 10\gamma \log_{10} \frac{d_0}{d} + X_\sigma[dB], \text{ where} \quad (1)$$

γ is the path loss exponent, X_σ is a zero-mean Gaussian random variable with variance σ^2, and $PL(d_0)$ is the reference path loss at a reference distance d_0. We choose realistic values $\gamma = 3.25$ and $\sigma = 2.5$ for our experiments. We assume $P_{tx} = 15\ dBm$ and the reference path loss $PL(d_0) = 40\ dBm$ for the reference distance $d_0 = 1\ m$. We set the receiver sensitivity at 80 dBm.

The preliminary results obtained on the planarity of the overlay graphs show that overlay graphs created from multi-hop clustering are almost 100% planar especially at higher hop counts. We are working on the strategies to create overlay graphs that are planar even at lower hop counts.

To compare the performance of the Topogeo planarization, a Gabriel Graph (GG) [2] based planarization algorithm is also implemented. GG creates a planar graph locally from the full graph. It provably yields a connected planar graph on Unit Disk Graphs. When the GG based planarization algorithm is performed on the LNS model, more than 80% of the test cases produced are nonplanar graphs, where as almost 100% graphs are planar with Topogeo.

IV. Conclusion and Future Work

We proposed Topological Cluster-based Geographic Routing, a new routing scheme which combines topology-based routing and geographic routing. The geographic routing is performed on an overlay network created from multi-hop clustering. For routing within the clusters, Topogeo uses topology information and for inter-cluster routing, it uses the typical Greedy-FACE-Greedy routing scheme. The Greedy-FACE-Greedy routing guarantees message delivery only if the network graph is planar. Nevertheless, localized planarization processes that work in realistic wireless models have not yet been found. The preliminary results obtained from simulations show that the overlay graphs created by the multi-hop clustering are almost 100% planar even with realistic wireless models like Log Normal Shadowing model. Hence the Greedy-FACE-Greedy routing works in these overlay graphs and makes the geographic routing applicable in realistic wireless networks. More investigation on multi-hop clustering algorithms that create overlay planar graphs using local information need to be done. This work shows that the geometric properties of the overlay graph produced from topological clustering, is an area worth exploring more.

Due to the multi-hop clustering, it is evident that individual node localization errors do not affect the performance of Topogeo routing and the overhead of a location service is reduced significantly. We are currently working in this direction to provide more quantitative results in future. We are also working towards the implementation of Topogeo routing process.

Acknowledgment

Emi Mathews acknowledges with appreciation, the research fellowship from the International Graduate School, Dynamic Intelligent Systems, University of Paderborn, Germany.

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