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Geographic routing on Virtual Raw Anchor Coordinate systems

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ABSTRACT

In this manuscript, we present geographic routing algorithms with delivery guarantees on a virtual coordinate system, namely Virtual Raw Anchor Coordinates (VRAC). Proposed algorithms can be seen as a variant of GFG (Greedy Face Greedy of Bose et al.) algorithm and based on combinatorial and geometric properties derived in the Virtual Raw Anchor Coordinate system. We utilize a local planarization algorithm of a geometric graph, which is based on the Schnyder's characterization of planar graphs. The new approach is combinatorial in the sense that the nodes are ordered with respect to three distinct order relations satisfying suitable properties. The coordinate system that motivated the development of this routing algorithm is VRAC, which localizes the nodes with the raw distances from three fixed anchors. Since the positions of the anchors are not known, the VRAC coordinate system does not correspond to the Euclidean location of nodes, yet leaving sufficient information to define necessary combinatorial and geometric constructs for routing with guaranteed delivery. In particular, the routing algorithm avoids the references to geographical arguments and makes use only of the order relations on the nodes. We expect that our approach will foster further research on building efficient order relations, that will prove to be useful in practical implementation of geographic routing algorithms. In particular, we expect that further work will prove that the geographic routing based on a raw anchor based positioning system is more robust in the presence of distance measurement errors.

1. Introduction

Geographic routing is a routing paradigm proposed for wireless ad-hoc networks, independently in Greedy Perimeter Stateless Routing (GPSR) [1] and Greedy Face Greedy (GFG) [2]. Main motivation of geographic routing is to avoid the construction and maintenance of routing tables, which can be expensive in a wireless networking environment. Geographic routing uses geographic positions of nodes as addresses in the routing layer and makes routing decisions, only based on the geographic positions of neighboring nodes and the destination node (i.e. with local neighborhood knowledge only). Therefore it is not required to discover and maintain routes, as in on-demand routing protocols like AODV [3]. Consequently, geographic routing does not require to adapt to potential changes in the network topology, keeping protocol overhead minimal.

Routing algorithms model networks as graph representations (namely a connectivity graph) with nodes representing vertices and communication links between nodes representing edges. Once the nodes are associated with geographic po-

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sitions (coordinate) based on some localization mechanism, connectivity graph becomes a geometric graph on a respective geometric space (also referred to as an embedded graph). For instance, if nodes are assigned three dimensional coordinates, connectivity graph happens to be a geometric graph on the Euclidean three dimensional space. Geographic routing algorithms are performed over geometric connectivity graphs. In the simplest form, geographic routing forwards the message to the closest neighbor towards the destination, which is referred to as *greedy forwarding*. Depending on the node distribution it is possible to have multiple nodes, which are closer to the destination, namely the greedy neighbors. Greedy neighbors are determined based on the underlying distance function (metric) on the respective geometric space, for instance, Euclidean distance in the Euclidean space. Despite the simplicity and efficiency of greedy forwarding [4], it can reach a node, such that no further progress can be made towards the destination (namely *local-minimum or a void*).

In order to recover from a local-minimum, *face routing* (or perimeter routing) was proposed in [2,1]. Face routing considers a planarized sub graph of the connectivity graph and routes the message along the faces (bounded or unbounded regions) of it in a systematic way. Face routing phase continues either until it reaches the destination or a node where greedy forwarding can resume. During the face routing phase, message header carries the coordinates of the *local-minimum*, which is used to make the face routing decisions. The celebrated *right hand rule* for maze solving is used to perform face traversal, where it forwards the message to the first clockwise or counter-clockwise neighbor. The message has to switch the current face, when it crosses the hypothetical line between the *local-minimum* and destination (this can be determined with information in the message it self), which we refer to as *face switching*. In GFG and GPSR they use a local planarization algorithm assuming a Unit Disk Graph (UDG) connectivity model. Both GFG and GPSR claims guaranteed delivery of messages. Later in [5], a comprehensive study on delivery guarantees was presented for different planar subgraphs and different face switching strategies. Moreover, they proved that face switching strategy in GFG ensures delivery guarantees in arbitrary planar graph.

One of the practical challenges geometric routing faces is the coordinate assignment for nodes, namely localization. This is not trivial in wireless ad-hoc networks, considering the hardware capabilities of devices. For instance, Global Positioning System (GPS) hardware is expensive in terms of energy consumption. A typical solution is to equip a limited number of devices (so called anchor nodes) with location information called *anchors or beacons*, and let the rest of the nodes to derive their position based on the anchors. In order to calculate their position, non-anchor nodes have to measure the distances from anchor nodes (from minimum of three anchors in a two dimensional surface) and perform a basic geometric calculation like trilateration to compute their coordinates. An alternative to the anchor based localization was proposed in NoGeo [6], where nodes are assigned virtual coordinates. These coordinates do not correspond to their physical coordinates, yet suffice to perform geographic routing. Coordinate computation of NoGeo has to be done in an iterative manner and requires to perform several network wide broadcasts to communicate different information (like current coordinates) required in the coordinate construction. A similar but a computationally efficient distributed virtual coordinate construction was proposed in Anchor Free Localization (AFL) [7], where an iterative algorithm is proposed with message passing only within neighboring nodes. There are several other heuristic based algorithms for virtual coordinates construction problem can be found in literature. For instance in [8], the localization scheme executes a random process on the top of the network and the state of the process leads to coordinates.

In order to avoid the computation phase of localization, BVR [9] and GLIDER [10] have independently proposed a virtual coordinate scheme relying only on the raw measures from anchor nodes. Both these mechanisms assign nodes their coordinates, simply as a hop-count vector from the anchors. Therefore it does not require further computation, hence being efficient in terms of communication overhead and power consumption. In the same spirit, Virtual Raw Anchor Coordinate System (VRAC) [11] assigns raw distances (Euclidean distance) from a set of anchor nodes as the coordinate of a node. Consequently, VRAC does not qualify as a metric space, hence the of distance and angle are is not explicit. A local routing strategy was proposed for VRAC in [11] with guaranteed delivery in the case where the graph is dense enough. Furthermore, an anchor placement which ensures the planarized graph is a 2-spanner is also derived.

In this article, we present geographic routing algorithms with delivery guarantees on VRAC system. We derive important combinatorial properties from VRAC to formulate algorithms to planarize the graph and to perform greedy and face routing over it. We evaluate the routing stretch of our algorithm compared to GPSR assuming they have the perfect location information. Our algorithms achieve comparatively lower routing stretch, hence posing a trade-off between the efficiency of coordinate assignment and routing stretch. We believe that, with the efficiency of maintaining VRAC, our geographic routing algorithms could lead to a viable geographic routing solution for wireless ad-hoc networks with energy constrained devices.

2. Virtual Raw Anchor Coordinate system

Virtual Raw Anchor Coordinate space by definition, deviates from classical coordinate spaces. Most importantly, it does not follow the fundamental axioms required to define the *distance* and *angle*. This motivates us to explore combinatorial properties of VRAC which can be used in geographic routing. VRAC defines coordinates of each node u as $(u_1, u_2, u_3) = (d(u, A_1), d(u, A_2), d(u, A_3))$, see Fig. 1a. Moreover, we assume that all the nodes are inside the triangular region, $\widehat{A_1 A_2 A_3}$, formed by anchors A_1, A_2, A_3, see [12] for the explanation of why this is necessary and the description of possible further work to remove this assumption. In [13], authors proposed an interesting routing strategy in the Schnyder coordinates that does not make use of a distance function. VRAC is close in the spirit of this work, yet it avoids the computation of Schnyder coordinates (which is computed in a centralized manner) by assuming that the distances to the anchors are available.