# Stochastic Routing in Wireless Sensor Networks

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***Abstract*—We propose a new location-based stochastic routing approach that is well-suited for wireless sensor networks deployed for public safety applications such as emergency evacuations or search and rescue operations. We first introduce a new modeling and evaluation framework based on Markov chains for randomized routing. Based on this evaluation framework, we study the load balancing and routing performance aspects of i) a near-optimal solution using the complete topology information, ii) a heuristic algorithm that uses only local neighborhood information. Numerical studies using the evaluation framework show that our heuristic routing approach scales well with both network size and density, considering the combined problem of routing and load balancing.**

## I. Introduction

Public safety applications, such as emergency evacuation (of buildings or urban areas) or search and rescue operation after a large-scale natural disaster, can significantly benefit from an earlier deployment of a wireless sensor network (WSN). In this context, the major use of the deployed WSN would be to allow gathering location-specific information from the field and transmitting data to nodes at specific locations for directives and announcements. For instance, in an emergency evacuation application, some sensors may be equipped with appropriate actuators, and the overall information about the field can be compiled and conveyed to those for location-specific dynamic evacuation directives.

Location-based, or geographic, routing is well-suited for such sensor network deployments, where nodes are stationary and the communication paradigm is location-centric as opposed to traditional node-centric addressing. Though the nodes are stationary, there may be frequent node failures, especially during emergency situations, which renders proactive routing methods inefficient and even inapplicable due to stringent energy and latency requirements.

There are two extremes in geographic routing; the greedy strategy and the robust strategy. Greedy strategies may suffer from failures to route packets to destination, while robust strategies need very high flooding rates to ensure guaranteed and rapid delivery of data. Our approach is a combination of the two, where we utilize an adjusted level of greediness as packets travel from source to destination. We provide an overview of related work and contrast those to our approach in the next section.

### A. Related Work

Geographic routing protocols are mostly based on the greedy routing principle. Many of these propose methods to overcome the mentioned drawback of greedy routing, i.e. to work around holes (voids) and avoid *dead-ends* in the topology to reach the destination. GRAViTy [1] is one such approach, which uses backtracking from dead-ends and learning from previous routes to optimize subsequent paths in greedy routing. GPRS [2] and GOAFR$^+$ [3] utilize face (or perimeter) routing to go around voids in the topology. All of these protocols use single path routing with deterministic selection of the next hop, and they may suffer from an unbalanced distribution of energy dissipation among sensor nodes in the network. Iterative use of the same routing path, due to the greedy and deterministic selection of next hop, increases the stress on those relaying nodes. Generally speaking, randomized routing is a well-studied approach to overcome this problem, but is mostly overlooked in the geographic routing domain.

Those that utilize randomized routing mostly consider an unknown destination location and employ a pure random walk to discover the destination. Among those, [4] provides an analysis of pure random walks on sensor networks with regular deployment, such as triangular, hexagonal, or square-based topologies. In [5], authors also consider unbiased random walk on a regular deployment of nodes, forming a hexagonal lattice pattern. Another use of unbiased random walks is presented in [6] in order to detect outlier data in sensor networks. Zhang et al. [7] utilize the random walk approach in a rather different context in sensor networks, i.e. in order to enhance the source-location privacy by introducing *phantom* sources in between the actual data source and the sink. A random walk is initiated at the actual source and terminated after a predefined hop count, where the phantom source is created. Data is then sent to the sink by the phantom source using a given routing protocol. An overview and comparison of different random walk strategies for ad hoc networks is given in [8]. None of those approaches consider a given destination location, hence there is no bias toward a target in the probabilities of the random walk.

Geographical Random Forwarding (GeRaF) [9] introduces a new concept of *receiver contention* for packet forwarding. In this scheme, the relaying node does not specify the next hop but the receiving neighbors decide which one should relay the packet based on the location, similar to the greedy approach. The paper presents an analysis of this scheme, but does not fully address how contention among receivers is resolved in a distributed manner. Probabilistic Geographic Routing (PGR) [10] is similar to our approach in the sense that it assigns probabilities to a few candidate relaying nodes, but the assignment is uniform along the routing path, unlike our approach where the probability assignment scheme (bias)