Dynamic Routing and Location Services in Metrics of Low Doubling Dimension

Goran Konjevod
Arizona State University
goran@asu.edu

Andréa W. Richa
Arizona State University
aricha@asu.edu

Donglin Xia
Arizona State University
dxia@asu.edu

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A routing scheme on the graph $G = (V, E)$ is a distributed algorithm that allows any source node to send packets to any destination node along the links of E. A routing scheme on a metric space (M, d) builds a graph $G = (M, E)$ by distributedly selecting the edges (u, v) to be in E and routes only along the edges of E. The *stretch* of a routing path is its length divided by the length of the shortest path between its endpoints. The *stretch* of a routing scheme is the maximum stretch of a routing path. A routing scheme is *compact* if the routing table and packet header size are both polylog$(|M|)$.

Compact routing research has recently focused on graphs of low doubling dimension [10, 3, 8, 2, 5, 6, 7, 9], (the *doubling dimension* of a metric space is the minimum α such that any ball of radius r can be covered by at most 2^α balls of radius $r/2$.) However, all of these schemes are static and assume a fixed metric. Moreover, they assume a centralized pre-configuration procedure to build the routing tables.

We finally cross the gap from static to dynamic (optimal stretch) compact routing schemes, thus widening the applicability of such schemes to more realistic dynamic scenarios. We describe the *first fully dynamic* distributed compact routing schemes with optimal-stretch in both labeled ($1 + \epsilon$ stretch) and name-independent models ($9 + \epsilon$ stretch). More precisely, our schemes work on a dynamic set of nodes V in a metric of doubling dimension $\alpha = O(\log \log \Delta)$ (where Δ is the normalized diameter of the graph), use routing tables, label and packet headers of size polylogarithmic in the network size and the normalized diameter. The number of messages, amortized per operation, grows polylogarithmically with the network size and Δ. We support node join, leave and move operations. Finally, the move operation is locality-sensitive, in that the cost of the movement of a node is proportional to the distance moved.

An important application of our result is the design of dynamic Distributed Hash Tables (DHTs) for highly-scalable peer-to-peer systems. A DHT (or object/service location scheme) is a dictionary data structure implemented in a distributed way, thus allowing efficient object location (lookup), where objects may be data items (files), nodes, or services.

If each node publishes its own name as an object, DHT design reduces to compact name-independent routing on the shortest-path metric induced by the network: the dynamic graph G maintained by the routing scheme will correspond to the DHT overlay network. Our routing scheme generalizes to DHTs where nodes may hold multiple (copies of) objects and where the network may contain duplicates of any object. We also achieve *constant stretch*, *polylogarithmic degree and storage space*, and *locality-sensitive* node move/join/leave and publish/unpublish operations.

Another application of our routing scheme is *locating nodes in mobile ad-hoc networks*, using our locality-sensitive protocols for adapting to node movement, as well as join and leave operations. Rigorous theoretical study of this problem had been limited to close-to-uniform node distributions [4, 1]. Thus, our results imply constant stretch, low degree compact node location schemes in mobile ad-hoc networks of low doubling dimension which adapt near-optimally to node move/join/leave operations.

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