

A Case for Lightweight SuperPeer Topologies

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Abstract: The usage of SuperPeers has been proposed to improve the performance of both Structured and Unstructured Peer-to-Peer (P2P) networks. In this paper we explore a network-aware class of Lightweight SuperPeer Topologies (LSTs). The proposed LST is based on the geometric principle of Yao-Graphs, a class of graphs allowing the development of simple and efficient broadcast algorithms. The pre-requisite of the LST approach is a function for mapping nodes in a network into a geometric space. In this paper we use the "Highways" proximity clustering and geometric placement model, introduced by one of the authors for this purpose. LST is evaluated based on PlanetLab measurements.

1 Introduction

In a hierarchical P2P network, so-called SuperPeers are selected based on metrics like connectivity, CPU capacity or reliability to build a SuperPeer layer used for e.g. the scalable distribution of search request. *Normal* peers are clustered at dedicated SuperPeers. In this paper we are proposing network-aware *Lightweight SuperPeer Topologies* (LST) for hierarchical P2P Networks. LST are designed to have lower complexity and management overhead than *Structured* P2P networks, and are based on the geometric principle of *Yao-Graphs* [Yao82]. *Yao-Graphs* are used since they represent a geometric structure containing the *Euclidean Minimum Spanning Tree* (EMST), and their structure is relatively lightweight. Since the pre-requisite of LST is mapping nodes in a network into a geometric space, we use the *Highways* [LCP04] proximity clustering scheme, introduced by one of the authors, for the *network-aware* assignment of geometric co-ordinates to SuperPeers. As the expected result, the application-layer multicast of multimedia data or search requests between SuperPeers performs well, because of the EMST and the network-aware LST construction. We evaluate the impact of the proposed model based on the PlanetLab testbed [pla].

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2 LST construction and the *Highways* Principle

The basic idea of *Yao-Graphs* and the construction principle used by LST is to cut the space around a set of points in R^2 into sectors of equal angle θ (e.g. $\theta < \pi/3$) and to connect each point to its closest neighbour (with regard to euclidean distance) in each of its sectors. The following result presented in [Yao82] motivates our usage of these graphs.

Lemma 1 (Yao-Graphs) *Let P be a point set in R^2 . Let G be the undirected Yao-Graph for P with $\theta < \pi/3$. Then, the Euclidean minimum spanning tree of P is a subgraph of the Yao-Graph G .*

Moreover, these graphs have been the first solution to break the $O(n^2)$ time complexity barrier for calculating the EMST for a connected graph containing n nodes [Yao82]¹. With the aim to minimise management overhead, the above described construction principle results in a directed *Yao-Graph*, which can still be used as an approximation of the EMST of a set of points following the observations provided in [CEF⁺03]. The network-aware LST construction is based on ideas extend from *Highways* [LCP04], using a landmark-based distance estimation principle for clustering landmarks and nodes based on a cluster size estimated e.g. by RTT distance. In principle, landmark-based schemes provide a network distance estimation based on euclidean distances in a hyperspace in which the hosts are embedded [KZ04]. After the calculation of geometric co-ordinates for the SuperPeers, it is possible to exploit *Yao-Graphs* to achieve a global characteristic of the SuperPeer topology (i.e. the EMST property) by applying a simple local construction algorithm. For the construction of a SuperPeer topology based on a *Yao-Graph* we implemented the following algorithm:

1. To be able to join the P2P network, a node has to know at least one node which is already a member of the P2P network, and can be used for a standard join procedure [LNS01].
2. As a new part of the join procedure, an overlay network address in the form of a geometric co-ordinate is calculated, using the *Highways* scheme and is assigned to the joining node.
3. The decision is made if the new node becomes a SuperPeer. The decision is based on metrics like connectivity, CPU capacity or reliability.
 - a) If the node is a SuperPeer candidate, the co-ordinate of the node is used to guide the new SuperPeer through the SuperPeers topology using a geometric routing principle (e.g. compass routing [KSU99]). As soon as the new SuperPeer has reached its hyperspace location, the SuperPeer topology is locally updated, by inserting the new node and updating the *Yao-Graph* neighbour relation.
 - b) If the new node is not a SuperPeer candidate, it is routed like a message through the LST until it has reached the SuperPeer with the geometrically closest co-ordinate that is capable of accepting a further client.

¹Calculating the MST of a weighted graph containing n nodes, connected by m edges requires $O(m \log n)$ time, using for example Kruskal's algorithm. In a two dimensional geometric representation of the graph, the calculation of the EMST can be done in $O(n \log n)$ time [SH75].

3 Testbed Experiments and Evaluations

To evaluate LST we conducted simulation experiments based on PlanetLab measurement data [pla]. Since quite a number of nodes reside within each site of the PlanetLab testbed, we randomly choose one of them as a representative SuperPeer. We performed experiments simulating to four different SuperPeer layer sizes 40, 60, and 81 for LST. In the experiments, we first simulated a join procedure using *Highways* to assign geometric coordinates, with the best performing parameters as observed in [LCP04]. The used cluster size was of RTT distance 60 ms from the cluster's centroid. After this step, the SuperPeers are integrated into a *Yao-Graph* topology. Once the SuperPeers in each corresponding ex-

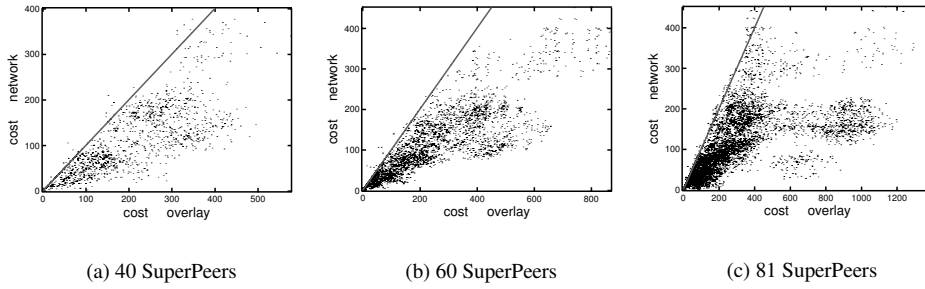


Figure 1: *Overlay Performance for LST with 40,60, and 81 SuperPeers*

perimental set have been integrated into the topology, we used the following measurements to estimate the quality of the P2P structure:

Diameter of the topology is the longest shortest-path length (in terms of hops) between any pair of nodes in the system. It represents an upper bound on the search path length which is the primary factor for the scalability. In our measurements, the average LST Diameter ranges from 3 to 5.7 and its standard deviation ranges from 1.8 to 3.4.

Overlay Performance is measured by a comparison of the network cost of direct IP communication between each two SuperPeers, utilizing the underlying network, and the cost of using the LST SuperPeer topology. The routing algorithm used on top of the LST was compass routing [KSU99]. Results are presented in Figure 1. LST overlay cost is on the X-axis while network cost on the Y-axis. In a very few of the cases, communication via the LST out-performs the direct IP-based communications in the underlying network.

In/Out Degree of a Node represents the number of SuperPeer connections or neighbours that must be maintained by a single SuperPeer. The average In-Degree for all the experiments was equal to the average Out-Degree, but In-Degree shows larger variance. The average Degree ranges from 3.7 to 5.2. The SuperPeers have a bounded Out-Degree of about 6 in our case, and a high percentage does not have a high In-Degree. In general, the In-Degree and Out-Degree of a SuperPeer in the constructed *Yao-Graph* topologies can be bounded through the dimension of the geometric target space and/or by using the principle of the *Sparsified Yao-Graph*.

4 Conclusion and Future Work

In this paper, we have proposed Lightweight Structured SuperPeer topologies (LST) for hierarchical P2P networks, and we have provided an initial evaluation of LST. The key intent for our geometric approach is that computing a minimum spanning tree of a fully meshed graph with n nodes requires in general $O(n^2)$ time, but only $O(n \log n)$ for a set of n points in a two-dimensional geometric space [SH75]. One of the advantages using *Yao-Graphs* in this context, is the possibility to archive a global characteristic of the LST (i.e. the EMST property) by applying a comparable simple local construction algorithm. The diameter and average number of hops of LST are reasonable small, and the Out-Degree and In-Degree of a SuperPeer can be bounded via the dimension of the geometric target space respectively using the principle of *undirected* or *sparsified Yao-Graphs*. Thus, we have demonstrated the construction of a network-ware SuperPeer topology through the assignment of accurate geometric co-ordinates to the SuperPeer layer of a P2P Network using *Highways*. An important part of future work will be to study the impact of higher dimensions and evaluating different schemes for the network-aware assignment of geometric co-ordinates. A comparison with *Random-Graph* based topologies and a comparison with P2P overlay multicasting schemes such as *Scribe* [CDKR03] will be also a subject of future work.

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