An Efficient Peer-to-Peer Lookup Protocol for Location-Aware Mobile Ad Hoc Networks

Dae-Woong Kim and Chan-Ik Park

Department of Computer Science and Engineering/PIRL
Pohang University of Science and Technology
Pohang, Kyungbuk 790-784, Republic of Korea
{woong, cipark}@postech.ac.kr

Abstract

The rapid increase in the usage of mobile devices and the development of wireless technology bring to the needs of service lookup (i.e. discovery) methods in mobile networks. If a geographical distributed hash table (DHT) is directly applied to a location-aware mobile ad hoc network, the key redistribution overhead could be severe. To reduce the key redistribution overhead, we propose a novel peer-to-peer lookup protocol, two-phase geographical distributed hash table. The proposed protocol causes the home consistency problem because it uses two DHTs in tandem: We also provide a solution to the problem so that a query for a key can be routed correctly to the node which is currently responsible for the key.

1 Introduction

A peer-to-peer (P2P) network is an overlay network in which nodes share their resources and services by directly exchanging one another without explicit servers. Since resources are distributed among nodes, an essential problem of P2P applications is the efficient location of the node that has a desired resource [5].

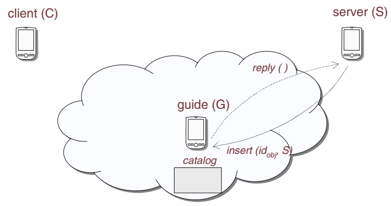
In mobile ad hoc networks (MANETs), broadcast schemes are usually used to discover communication paths, which limits the scalability. Each node in location-aware MANET can determine its current position using a mechanism such as GPS. A position-based routing protocol where each node makes forwarding decisions based on the geographical position of a packet's destination and its nearby nodes has two advantages. It scales well since nodes need not maintain explicit routes, and its routing is very efficient using location information [3].

This paper focuses on efficient P2P lookup protocols well-suited for location-aware MANETs. The proposed DHT model, *two-phase geographical DHT*, has two distinguished characteristics: (a) Each node uses its geographical position as its identifier to maximize the efficiency of overlay routing. (b) Two DHTs are exploited in tandem so that every lookup or insert process is split into two phases to reduce the key redistribution overhead due to node mobility. To the best of our knowledge, little has ever been published about the multi-phase DHT. We also address the *home consistency problem* of two-phase DHTs and provide an solution to it so that a query for a key will be routed correctly to the node which is currently responsible for the key [4].

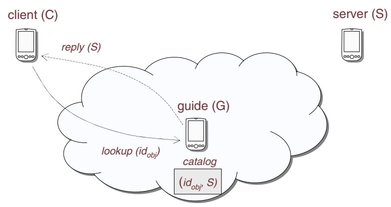
To simplify the exposition, we assume a distributed object sharing system, where a DHT protocol maps the identifier of an object onto the identifier of the node which stores the object. A *server* stores objects, and for each object, it informs a *guide* of the object as shown in Figure 1. A *client* wants an object so that it refers to a *guide* to find out which server holds the object. A *guide* acts as a directory: It maintains a *catalog* and informs a client which server can offer the requested object. A *catalog* contains (key, value) pairs where the key is an object identifier and the value is the identifier of the server which holds the object. A guide is said to be *responsible* for a key or be the *home* of the key, if the (key, value) pair should be maintained by the guide. The *territory* of a guide is the whole key space for which a guide is responsible.

2 Single-phase Geographical DHT

The single-phase geographical DHT is well tailored to a location-aware P2P system where nodes are not likely to change their geographical positions. Both GeoPeer [1] and Mithos [6], which assume wired internet environments, are single-phase geographical DHTs. In the proposed single-phase geographical DHT, nodes self-organize into a Delau-

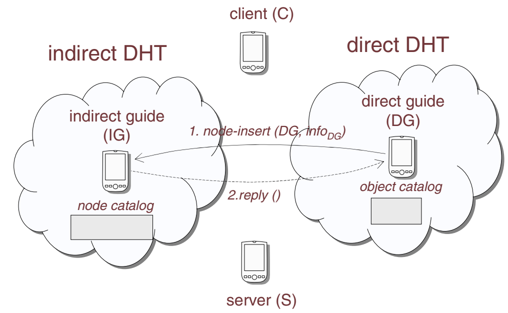


(a) Insertion of a key

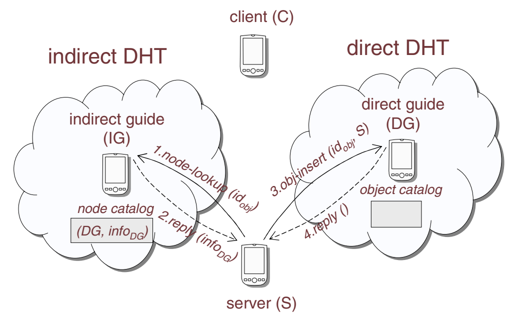


(b) Lookup of a key

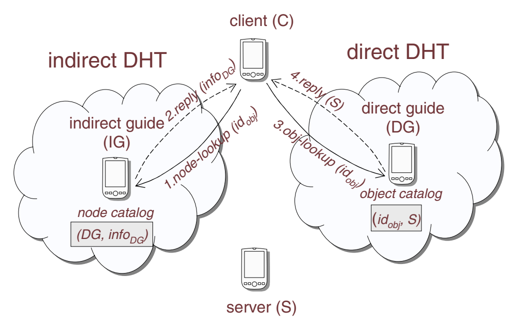
Figure 1. Illustration of single-phase DHT



(a) Insertion of a node information



(b) Insertion of a key



(c) Lookup of a key

Figure 2. Illustration of two-phase DHT

nay triangulation. Given a region $\mathcal{R}$, the geographical location vector $\mathbf{m}_i$ of a node m_i corresponds to its identifier. In other words, a node identifier can be represented by its two coordinates (m_{ix}, m_{iy}) in the region $\mathcal{R}$. An object identifier can be also represented by a point in $\mathcal{R}$.

For a point $p \in v(m_i) \subset \mathcal{R}$, where $v(m_i)$ is the Voronoi polygon of m_i, m_i is the guide of the point p. In the single-phase geographical DHT, routing among overlay nodes means routing in a Delaunay triangulation. There are a lot of routing algorithms based on a Delaunay triangulation, which can be used in MANET: compass, randomized compass, or greedy [2].

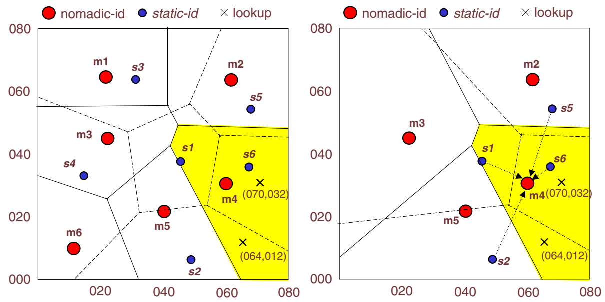
A network based on a Delaunay triangulation has the following desirable characteristics [6]: (1) A Delaunay triangulation enables locality-aware connectivity. (2) The average node degree of a Delaunay triangulation is at most six. (3) A node needs not know all the nodes in the overlay network but needs a local Delaunay triangulation including only its nearby nodes. However, the single-phase geographical DHT has some critical drawbacks: Since the identifier of a node corresponds to its physical location, and nodes can move freely, the territory of a node changes as the node or its neighbors move. This implies that some (key, value) pairs should be moved from node to node according to the topology change.

3 Two-phase Geographical DHT

In the proposed system, *two-phase geographical DHT*, two DHTs are exploited in tandem. The first one, *indirect DHT*, is a single-phase geographical DHT and the second one, *direct DHT*, is a single-phase non-geographical DHT. Figure 2 illustrates the abstract view of the key location operation in the two-phase geographical DHT. Assume the number of overlay nodes is n and each node p_i has one nomadic identifier m_i as an indirect guide and one static identifier s_i as a direct guide. Figure 3(a) shows the overlapped Vornonoi diagrams of the indirect DHT of six indirect guides $m_1, \ldots, m_6$ and the direct DHT of six direct guides $s_1, \ldots, s_6$.

Each indirect guide computes two local Voronoi diagrams. Let M_{m_i} be the set of the direct neighbors of an indirect guide m_i. First, m_i calculates a local Voronoi diagram $V(M_{m_i}) = \{v_M(m_j|m_i) \mid m_j \in M_{m_i}\}$, where the set given by $v_M(m_j|m_i) = \{\mathbf{x} \in \mathcal{R} \mid ||\mathbf{x} - \mathbf{m}_j|| \leq ||\mathbf{x} - \mathbf{m}_k||$ for $k \neq j, m_j, m_k \in M_{m_i}\}$ is the local version of Voronoi polygon of m_j computed at m_i. In Figure 3(b), the solid lines depict the local Voronoi diagram of indirect DHT computed at m_4.

When the *node catalog* of m_i is defined to be the set



(a) Overlap of two DHTs (b) Local view of m_4

Figure 3. An example of deploying an two-phase geographical DHT. The solid lines and dashed lines depict the Voronoi diagrams of static-ids and nomadic-ids respectively

$S_{m_i} = \{s_j \mid v_S(s_j) \cap v_M(m_i) \neq \emptyset$ for $j \in I_n\}$. An indirect guide m_i also calculates a local Voronoi diagram $V(S_{m_i})$.

In Figure 3(b), the dashed lines show the local Voronoi diagram for direct DHT computed at m_4. To figure out the correct direct guide which is responsible for an incoming query message with an object identifier $o \in v_M(m_i)$, an indirect guide m_i must know the static-id of every direct guide whose territory overlaps with its territory. Thus, m_4 should store the entries of the four direct guides s_5, s_1, s_6 and s_2 into its node catalog.

If the queries for the keys (070, 030) and (064, 012) occur, they will be routed to m_4, and m_4 can find out that s_6 and s_2 are responsible for the keys (070, 030) and (064, 012) respectively.

4 Home Consistency Problem

The property, *home consistency*, can be defined as follows: a query for a key *k* must be routed correctly to the node which are currently responsible for the key [4]. In the *two-phase geographical DHT*, a query for *k* is routed to the indirect guide whose nomadic-id is closest to *k* and the indirect guide figures out where the (k, v) pair should be currently stored. Thus each indirect guide must contain sufficient and correct information of the corresponding direct guides to ensure home consistency.

The detailed process of the proposed solution to the home consistency problem is described as follows:

1. The newly joining node with static-id s reports its information to the indirect guide m that is closest to its static-id s, that is, $s \in v_M(m)$.

2. m calculates the local Voronoi diagrams $V(M_m)$ and $V(S_m)$ of its local nomadic-id set M_m and its local static-id set S_m respectively.

3. m figures out the set $\mathcal{N}_m(s) \subset M_m$ such that the territory of each element overlaps that of s, that is, $\mathcal{N}_m(s) = \{m_j \in M_m \mid v_S(s|m) \cap v_M(m_j|m) \neq \emptyset\}$.

4. m delivers the information of s to all its neighbors.

5. Receiving the information of s, each neighbor m_k performs the step 2, 3 and 4.

5 Conclusion and Future Work

In this paper, we introduce a single-phase geographical DHT and propose a novel peer-to-peer lookup protocol, two-phase geographical DHT. In the proposed system, two distributed hash tables are exploited in tandem, therefore a key location is executed in two phases. The direct DHT uses static-ids as node identifier so that no key redistribution occurs due to node mobility. The indirect DHT inherits the drawbacks of geographical DHTs. In other words, node territories change according to the node mobility. However, because the (node) catalog size per node is very small $O(1)$, it is expected that the drawbacks make little difference to the performance. The proposed protocol has double times long routing path length than that of the single-phase geographical DHT. However, it could achieve high performance by reducing the key redistribution overhead in an environment where the node mobility is high or a large number of keys exist. We also address the home consistency problem in the proposed protocol and provides a solution to it. Currently, we are developing a simulation environment to evaluate and verify the proposed protocol.

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