A Category Overlay Infrastructure for Peer-to-Peer Content Search

Xin Liu, Jun Wang and Son T. Vuong
Department of Computer Science, University of British Columbia
Vancouver, BC, Canada
{liu, jwang, vuong}@cs.ubc.ca

Abstract

For a Peer-to-Peer (P2P) system which contains huge amount of data, an efficient content search technique is definitely necessary. In this paper, we present a novel category overlay search infrastructure which can sit on top of existing unstructured P2P systems, such as Gnutella. The intuition behind our work is that by clustering the whole peer group into clusters and mapping the predefined category domain to clusters, multiple category overlays can be constructed and a search can be restricted within only some specific overlays, thus the search efficiency can be improved dramatically. Our preliminary simulation shows that this infrastructure can provide efficient search service, even in a highly dynamic network environment.

1. Introduction

Peer-to-Peer systems have recently become more and more popular to share huge amount of data. The key to the usability of these systems is how to search for desired contents efficiently. Unstructured P2P systems such as Gnutella [4] and KaZaa [5] use flooding as their essential search techniques. Although flooding is simple and works well in a highly dynamic network environment, it will inevitably generate huge amount of redundant messages, which makes it not scalable. Structured P2P systems such as Chord [11], CAN [9] and Tapestry [16] use Distributed Hash Table (DHT) based search techniques, which can guarantee to locate content within a bounded number of hops. But these techniques tightly control both the placement of data and the topology of network, which results in a high maintenance cost. Furthermore, they can only support search by identifier and lack the flexibility of keyword searching.

The emergence of some hybrid infrastructures such as pSearch [13] and YAPPERS [3], which combine the advantages from both unstructured P2P and DHT camps, reveals the possibility of creating a scalable yet reliable P2P system. Inspired by these works, we propose a new P2P searching strategy, which is essentially a hybrid approach, where a pure/unstructured P2P system (such as Gnutella) and its associated searching scheme are serving as the base, and sitting on top of it are multiple Category Overlays.

The idea is to cluster the whole peer group into clusters, and for each cluster, nodes are selected to take care of each of predefined categories (we call this mapping). By doing this, multiple Category Overlays can be constructed over the clusters. A query in our system is a tuple, which consists of one or more categories and a list of keywords. Search starts from locating the node which is in charge of the category in a cluster, and then propagating queries only within some specific overlays. Each overlay contains at most N nodes, where N is the number of clusters. Therefore, as long as query is routed within an overlay, very few nodes (comparing with all the nodes in the system) will be visited.

The primary contribution of this work is architectural. Our goal is to propose a P2P search infrastructure which can provide efficient search service with a relative low maintenance cost, thus it can work well in a highly dynamic P2P environment. The three main components of this work are: a novel clustering algorithm to cluster the peer group, a mapping scheme to build Category Overlay, and a Category Overlay Search algorithm. Preliminary simulation shows that our infrastructure can provide effective searching service even under a highly dynamic network environment.

The rest of this paper is structured as follows. Related work is provided in Section 2. In Section 3, our clustering algorithm and basic Cluster Search are presented. The mapping scheme to build Category Overlay, the maintenance mechanism and the Category Overlay Search algorithm are detailed in Section 4. The simulation setup and results for a preliminary performance evaluation are presented in Section 5. Finally, we conclude this paper and outline directions for future work in Section 6.

2. Related Work

Perhaps the most famous unstructured P2P systems are Gnutella [4] and KaZaa [5]. They attract large populations due to their flexibility and usability. Flooding is the
essential search technique used in those systems. However, flooding generates huge redundant traffic and is therefore not a scalable solution. Many techniques are proposed to either restrict the flooding or to eliminate it. [15] proposes Iterative Deepening, Directed BFS and Local Indices to limit or reduce the number of nodes visited through flooding. [1] further improves Gnutella searching by introducing ideas like Topology Adaptation, Replication, Flow Control, etc. The goal is to balance Gnutella systems (both from traffic and structure’s point of view). But there is not too much we can do if flooding is still the primary search technique.

Other approaches like [14] and Guess [2] use heuristics or probability based Random Walk to replace flooding. The idea is to use previous knowledge to predict current or future location of certain contents and [8] gives a quite decent analysis of that. These approaches are able to locate popular contents effectively, but they show poor performance when querying unpopular information.

Hierarchical architecture is also proposed to reduce the number of nodes involved in the searching. KaZaa and the newer release of Gnutella both adopt the idea of “Super-Node” or “Ultra-Node”. These powerful nodes maintain the indices for the contents on other nodes and therefore searching can be carried out only among those nodes. However, it introduces a serious problem – single point of failure.

DHT, on the other hand, is designed to locate objects with complete identifiers. [13] proposes free-text search schemes based on DHT. The basic idea is to treat each keyword as a key and publish links to object based on these keys. However, searching requires a Join and Select Operation on all the links relevant to the queried keywords. In order to do that, large amount of data must be transferred from one node to another, and as [6] suggests, the traffic load soon makes this approach infeasible. Systems like [12] try to avoid the Join by storing, for each piece of content, a complete Keyword list on all the relevant nodes. The challenge is to reduce the overhead of publish and storage. [10] chooses SkipNet as the base architecture and try to perform multi-level Join in order to decrease the amount of data being moved. However, in a highly dynamic environment, the cost of DHT maintenance could be very high. Therefore, it is not appropriate to put DHT at the bottom level of a searching overlay.

Hybrid architecture becomes the trend of recent research due to its potential of keeping the flexibility, connectivity and low maintenance cost. [7] is layering pure P2P and DHT in parallel. It is an explicit solution to deal with the ineffective search of unpopular contents. YAPPERS [3], on the other hand, brings the idea of clustering nodes directly on top of unstructured system. It is by far the most similar system to ours. But their solution uses hashing to locate content within a certain range and the clustering stays at the conceptual level. Maintenance cost is certainly overwhelming. pSearch [13] and [17] go even further by applying Latent Semantic Indexing (LSI) and therefore introduces semantics into search. However, the choice of using DHT as the bottom layer makes them inappropriate to be deployed in dynamic P2P environment.

3. Clustering Algorithm and Cluster Search

This section introduces our new clustering algorithm, which can operate directly on a pure P2P system and preserve its old architecture. We also present a simple Cluster Search algorithm which serves as basic search scheme when the Category Overlay Search (will be discussed in section 4) fails.

3.1. Overview

Due to the degrees of nodes and the complexity of the system topology, searching directly on Gnutella-like systems is usually hard to control and optimize. One way to reduce the complexity is to organize the network in some way so that the basic operating unit (ounit) becomes an aggregation of a set of nodes. For example, Super Node or Super Node group is an operating unit. Then searching can be divided into two parts: intra-ounit search and inter-ounit search. We choose Tree-based Clusters as the ouunits in our system. Figure 1 shows a portion of such a clustered system that sits on top of Gnutella. All the links are therefore Gnutella links. Solid links are used to build the Tree structures, and dashed links are other Gnutella links. Each cluster is of tree type, which has a central node and all other member nodes are within N hops distance, we call this N hops distance as Cluster Range Limit and the hops distance from each member node to central node as the node’s Range. For simplicity and clarity, we discuss our cluster algorithm more clearly, we define terminologies as follows:

- **Core Node**: Root of the tree (central node).
- **Master Node**: Children of the Core Nodes.
- **Slave Node**: Children of the Master Nodes.
- **Range**: The hops distance from current node to Core.
- **Cluster Range Limit**: The maximal hop distance from cluster member to Core Node.

- **Primary Link**: Gnutella link
- **Primary Cluster Link**: Primary Link that is a tree branch.
- **Primary Index Link**: Primary Link that connects member nodes in the cluster, but is not a tree branch.
- **Inter-Cluster Primary Link**: Primary Link connects different trees.
- **Local Member List**: Each node’s view of the current cluster membership and topology for its own cluster.
- **Reachable Clusters Set**: The set of clusters which can be reached through Primary Cluster Links and Inter-Cluster Primary Links from current node.
3.2. Cluster Creation and Maintenance

This section describes our approaches to create and maintain clusters. For clarity, we choose Gnutella as the underlying P2P system.

3.2.1. Node Join and Leave. The first node of Gnutella will become the Core Node and create the first cluster.

As node \( N_X \) joins/rejoins Gnutella, it immediately builds one or more Primary Links (Gnutella Links). Based on its preference, \( N_X \) selects one Primary Link and applies for cluster membership. Suppose the Primary Link that node \( N_X \) chose is connected to node \( N_Y \). If \( N_Y \)'s Range is less than Cluster Range Limit, then \( N_X \) will join in \( N_Y \)'s cluster and \( N_Y \) will be \( N_X \)'s parent. Also, \( N_X \) will receive a Local Member List from \( N_Y \). Otherwise (\( N_Y \)'s Range is bigger or equal to Cluster Range Limit), \( N_X \) will try other Primary Links until it checks all the links, and in this case, it builds its own cluster and becomes a Core Node. (This basic algorithm works, but it will inevitably create many very small clusters, which is not good for search. Section 3.4 will describe some optimizations).

Node leaving is a little bit more complicated than join activity. Note that closing a Primary Cluster Link is also treated as leaving cluster. Leaving of node \( N_Y \) may or may not affect other nodes, depending on its role in the cluster. If \( N_Y \) is a Slave Node, then it can leave by only notifying its Parent Node. If \( N_Y \) is a Master Node, then it should notify its Parent Node as well as all its Child Nodes. Upon receiving the notification, every Child Node picks up another Master Node in the cluster and sends a Switch request. In most case, this request will be approved unless the target node is overloaded. However, if \( N_Y \) is a Core Node, it has to decide a successor before it departs. The successor then notifies all the Master Nodes and confirms its new role. It also notifies its Child Nodes and changes them to be Master Nodes.

3.2.2. Node Failure. Node detecting any failure should report to the Parent Node of the failed node and that Parent Node needs to verify the claim before it takes any action. Simultaneous failure of the Parent Node can be reported directly to the Core Node. In order to deal with the failure of Core Node, a Core Node candidate should be determined in advance. After determining the failure, same actions as described in node leave are performed except it is now the Parent Node’s duty to do the notification.

3.2.3. Cluster Membership Consistency Resolution. All the operations we described above only involve the direct participants of those events (by events, we mean node join, leave or failure). Therefore, in a dynamic P2P environment, the majority nodes of cluster will inevitably have some inconsistency between their Local Member List and the actual Membership.

This inconsistency problem can not be ignored because a high level of inconsistency can easily make the whole system unusable. However, maintaining very high level or even 100% consistency, like many other systems do, generates huge network traffic and is therefore not a realistic solution. So we decide instead of broadcasting each individual event, each node only send an event aggregation report to its parent or child on demand and/or on regular basis. The report includes all the events it sees or hears since the last report. It also reports the changes of its Reachable Clusters Set. A timestamp is attached to each event so that the receiving node can make correct updates.

But in case the environment is extremely dynamic, our simple reporting scheme might not be able to maintain consistency at a relatively high level. To solve this problem, we require the Core Node to broadcast Quarter Report which includes its entire Local Member List. Each node in the cluster will receive this report and update its Local Member List according to it. But this is an on demand report, which means it is sent only when Core Node notices some significant changes of cluster membership.

In the reporting process, Master Nodes and Core Nodes take more responsibility, which means their failure has bigger impacts. But we can always select more stable nodes to be Master/Core Nodes to minimize the impacts.

3.2.4. Inter-Cluster Maintenance. At this moment, Inter-cluster Primary Link is the only medium for two clusters to communicate. No special maintenance is necessary besides a “ping” facility at the Gnutella level. The only difference is that the node needs to send its Cluster ID along with the “ping” message.

3.3. Basic Cluster Searching and Publishing

The basic form of search is running on top of our Tree-based Clusters. Queries still need to go through Gnutella links and every node has to be visited to get complete results. However, it improves flooding effectiveness by
reducing huge amount of redundant messages. As mentioned before, this basic Cluster Search is also served as a backup facility to our more sophisticated Category Overlay Search.

3.3.1. Intra-Cluster Searching and Publishing. Figure 1 shows a case for Intra-Cluster Search. It is essentially a source-based broadcasting. Queries are propagated through only arrowed solid lines, or Primary Cluster Links. Due to the uniqueness of Primary Cluster Link, no redundant message is generated. Each query has a valid ID and this ID is kept on each node for a certain period to avoid redundant broadcasting.

Published, on the other hand, does not need communication. Users are required to provide a list of keywords (or meta-data) to the content which is being published. This list is stored in local database for future query.

3.3.2. Inter-Cluster Searching. Figure 1 also presents a case for Inter-Cluster Search. Node NX is broadcasting a query to its cluster CX. All the nodes on the path from NX to the Core Node NZ (NX, NY and NZ in this case) need to select and forward the query to their reachable clusters. For example, NY knows cluster CZ is reachable through Node NM, then it asks NM to forward the query to CZ (Query is forward to other clusters only through Inter-Cluster Primary Link). NY also informs NZ that it is not necessary for NZ to forward to CZ.

3.4. Cluster Restriction and Optimization

The basic cluster creation algorithm is able to build clusters on top of Gnutella, however, the cluster sizes could be distributed widely, and some clusters may have very small sizes. To make the clusters denser and eliminate the very small clusters, we use following optimizations:

- **Cluster Size Limit**: Cluster has a size limit. Once a cluster reaches this limit, it will reject any join request until some members leave. We suggest that Cluster Size Limit should be no less than the number of Categories.
- **Cluster Size Full Fraction**: when a node wants to join a cluster but only knows boundary nodes, instead of being forced to create a new cluster, a boundary node can forward this request to its parent. If the cluster size is less than the Full Frac, the node can join this cluster. The higher the Full Fraction is set, the less clusters will be created. In our simulation, we set Full Fraction to 0.9 and the result is quite good.
- **Core Qualification**: a node which wants to be a Core should satisfy some conditions, such as computation power, high bandwidth, long stay period, etc.
- **Cluster Merge**: the Core Node of each cluster will periodically check its size. If its size is below the Cluster Size Low Bounder, the Core Node will try to find another suitable cluster and merge into that cluster.

4. Category Overlay

This section presents our simple yet effective Category Mapping scheme which is used to build our Category Overlay. Then we describe several techniques used to solve the Category Table Inconsistency problem. Finally, we give our Category Overlay Search algorithm. Note that in this paper, we don’t discuss how to find relatively good categories, which is beyond the scope of this paper. But we think Google directory could be a good candidate.

4.1. Mapping Category domain to Clusters

Mapping a category domain to a P2P system domain by preserving most of the benefits as well as introducing little traffic overhead is not a trivial issue (by Category Mapping, we mean that which node is in charge of which category). Our current mapping scheme is simple yet effective; some more sophisticated and better schemes could be our future work.

Our mapping scheme works as follows: when a new cluster is created, the Core Node will take all of the categories, in another word, all of the categories are mapped to the Core Node. Latter, when a new node join in as a child of Core Node or Core Node find that its overhead is too high, it will migrate some categories to its children. Also, any member node of a cluster can migrate some of its categories to other members if it finds that its overhead is too high (node NY migrate Category CA to node NZ, we mean that before migration, node NY is in charge of Category CA; while after migration, node NZ is in charge of Category CA).

Figure 2 shows the architecture with categories being mapped to clusters. Each node is in charge of 0 or more categories. If a node is in charge of some categories, we call it Agent Node of those categories. By “in charge of” we mean it stores all the meta-data for the contents in a certain category within the cluster. Therefore, searching within a cluster becomes locating the Agent Node and then performing searching locally. Each node also has a table that stores its local view of the category mappings and we call it Category Table. It looks like a hash table where the key is a Category and the value is its Agent Node. Note that every Category has a correspondent entry in this table.

To make our description more clearly, we define some terminologies as follows:

- **Content Index Table**: Data structure that stores the keyword lists (meta-data) for all the contents, within a cluster, of a certain category.
- **Category Agent Node**: Node which is in charge of a certain category. It maintains the Content Index Table for that category. In this paper, we also simply call it Agent Node.
inconsistency between nodes. But for a certain node, the migration of Maintenance schemes. The idea is to ship a Category from Migration. It serves as a basic building block for other introducing a new concept and operation - Category 4.2.1. Category Migration. structures.

inevitable. This section discusses how to maintain the request can only involve a certain Category, as well as all Agent Nodes for the same Category, so 

Inter-Cluster Shortcut Links

Figure 2. Mapping categories to clusters

- Category Table: Local table that maps Categories to their Agent Nodes. Each entry in this table is a tuple: (Category, its Agent Node, Timestamp). Note that every Category has a correspondent entry in this table and each node has this table.

- Inter-Cluster Shortcut Link: Virtual link used to connect nodes in different clusters. It exists only between two nodes that are Agent Nodes for the same Category.

- Neighbourhood Category List: For any category \( C_A \) and node \( N_X \), it is a list recording all the nodes that \( N_X \) is able to contact through Inter-Cluster Shortcut Links.

- Category Overlay: Overlay network that consists of all the Agent Nodes of a certain Category, as well as all Inter-Cluster Shortcut Links among them.

4.2. Category Table Maintenance

If all of nodes’ Category Tables are consistent, a search request can only involve Agent Nodes for one or more relevant Categories. But for a certain node, the Category Table is its local view of the category mappings, so the inconsistency between nodes’ Category Tables is inevitable. This section discusses how to maintain the consistency in Category Tables and other associated data structures.

4.2.1. Category Migration. We start our discussion by introducing a new concept and operation - Category Migration. It serves as a basic building block for other maintenance schemes. The idea is to ship a Category from its Agent Node to another node.

Assuming the Agent Node \( N_X \) for Category \( C_A \) wants to migrate \( C_A \) to another node \( N_Y \). \( N_X \) first needs to send \( C_A \)’s Content Index Table to \( N_Y \). Then both \( N_X \) and \( N_Y \) update their Category Tables to reflect the changes. \( N_X \) sends \( C_A \)’s Neighbourhood Category List to \( N_Y \) as well, because from now on, \( N_Y \) is the new neighbour for the nodes in this list, not \( N_X \). Recall this list is to associate different Agent Nodes for the same Category, so \( N_Y \) needs to inform all of Agent Nodes in this list. Moreover, \( N_X \), \( N_Y \) and all \( N_Y \)’s ancestors should record this migration event, which will be reported to other nodes during consistency resolution.

4.2.2. Node Join and Leave. Our revised Join is of little difference from the original one described in section 3.2.1. However, the new Parent Node needs to send back its Category Table along with Local Member List. Category Migration is allowed but is optional at this stage. New node tends to be less stable and therefore it usually should not take too much responsibility.

Without considering Category Migration, leaving is also the same as its basic version. It starts with selecting a “random” (or a stable yet under-loaded) node to perform Migration. In this case, Category Migration is mandatory. Then it can follow the steps described in section 3.2.1.

4.2.3. Node Failure Recovery. What happens when a node is disconnected from the system because of failure? One simple solution is to ignore it. If the lost Category is queried, then the new Agent Node (usually the Parent node of the failure node) should ask every node in the cluster to re-publish all the contents of that Category. Moreover, the new Agent Node also needs to learn the Neighbourhood Category List, which might take a little bit of time. This approach works, but is not suitable to a dynamic P2P environment for performance reasons.

Our solution is to back up Content Index Table for each Category. The selection of back-up node is random and thereby decreasing the probability of backing up too many tables on a single node. The back-up table is updated based on the frequency of publishing.

When Category lost is detected, the Parent Node (or the new Agent Node) then asks for a copy of the table from the back-up node of that Category, along with the Neighbourhood Category List. If back-up node cannot be located, then we can always switch back to the simple solution.

4.2.4. Intra-Cluster Category Table Consistency Resolution. Introducing Category Migration unavoidably brings new inconsistency problems. If we take an insight look at Category Migration, we see that only local Category Table on both participating nodes can reflect the update. All other cluster members will not be informed of the change. If the environment is very dynamic, then the inconsistency level could quickly rise to a point where Category Table may even slow down the searching.

To solve this inconsistency problem, we introduce a
pair-wise report scheme, in which each node sends a category report to its randomly selected neighbour periodically. This report contains the latest N updates (or Category Migration events) known to the reporter, as well as M random entries in the reporter’s Category Table. Upon receiving the report, a node needs to update its own Category Table and record the update, based on the accompanied timestamps. Core Node and Master Nodes are playing the same role as other nodes. The time interval between two reports is a local decision and is depending on the updating frequency.

However, this approach is not able to remove the inconsistency completely and the aggregation of inconsistency may cause a disaster. The reason is simple, each update starts from very few nodes and it does take quite a bit of time before all the nodes in the network can learn about this. Therefore we introduce a cluster wide update request, sent by the Core Node to all other nodes (through Primary Cluster Link). Each node then replies with its N latest changes, as well as M random entries in its Category Table. After receiving enough replies, Core Node then sends a complete Category Table to all the member nodes. This is an expensive operation and it should not execute unless many member nodes complain about the degrading of searching speed. A light weight version can also be implemented, in which the report only involve one Master Node, all its Slave Nodes and the Core Node.

4.2.5. Inter-Cluster Category List Maintenance. Category Table inconsistency is not the only by-product of Category Migration or Lost. If node $N_X$ is not the Agent Node for Category $C_A$ in cluster 1, but node $N_Y$ in cluster 2 still believes $N_X$ is the Agent Node because $N_X$ is still in $N_Y$’s Neighbourhood Category List for $C_A$. Then when next time $C_A$ is queried, $N_Y$ will still forward the query to $N_X$, which may not be able to provide any useful response. It is a big waste and will eliminate the meaning of Category Overlay. So we still need to maintain the consistency of Neighbourhood Category List.

As before, the maintenance of these overlays will not base on the occurrence of individual events. To minimize the communication overhead, we choose periodical reporting between each pair of connected nodes. When a node $N_X$ needs to report, it selects a node from any of the Neighbourhood Category Lists stored on it. The selection of the target node should be fair. Therefore, we first randomly select a cluster and then select a node inside that cluster. After selecting the node $N_Y$, $N_X$ then sends all the Category IDs that it maintains to $N_Y$. Upon receiving this message, $N_Y$ replies with a list of Agent Nodes, in $N_Y$’s cluster, which are currently maintaining the Categories contained in $N_Y$’s message. $N_X$ then makes proper updates to its Neighbourhood Category Lists. The idea behind this algorithm is that a node should know more about Categories in its own cluster than in other clusters.

4.3. Category Overlay Searching and Publishing

Our Basic Cluster Searching and Publishing uses only Gnutella topology and therefore is quite reliable. However, the restricted flooding can not provide the efficiency that we are looking for. Here we introduce a new approach to search over virtual networks, or Category Overlays. We name it as Category Overlay Search.

4.3.1. Intra-Cluster Searching and Publishing. With Category Mapping, the metadata for all the contents that belong to the same Category will be put on a single Node. Therefore, instead of using source-based broadcasting as section 3.3 describes, our Category Overlay Search tries its best to locate the Agent Node directly.

It works as following (assuming we are searching a content in Category $C_A$): The query initiator $N_X$ first looks up its Category Table to find the Agent Node for Category $C_A$. Suppose the found Agent Node is node $N_Y$. Then initiator $N_X$ contacts node $N_Y$. If $N_Y$ is alive and is the correct Agent Node, then $N_X$ search in its Content Index Table and return results to $N_X$. If $N_Y$ is not the right Agent Node or $N_Y$ is dead, then $N_X$ contacts the Parent Node of $N_Y$, say $N_Z$. If still no positive response comes back, $N_X$ then contacts $N_Z$’s Parent Node until it reaches the Core Node. If Core Node still can not find the right Agent Node or Core Node is dead, then searching switched back to the basic mode: Basic Intra-Cluster Search (described in section 3.3), and $N_X$ initiate Inter-Cluster Searching (will be described in next section).

Publishing takes the same step except that the query does not need to go out of the cluster and the keyword list will be sent to the Agent Node.

4.3.2. Inter-Cluster Search on the Category Overlay. As mentioned in section 4.1, the Category Overlay was defined as an unstructured virtual network that connects all the Agent Nodes of a certain Category. Therefore in our system, the total number of Category Overlays is less than or equal to the number of Categories (some Categories might share a common Overlay). The links on these overlays are called Inter-Cluster Shortcut Links. Ideally, a query will only be propagated through those Inter-Cluster Shortcut Links and the number of nodes and messages involved in each query are decreased by a magnitude of hundreds (depending on the average size of clusters).

Assume Node $N_X$ is the Agent Node for Category $C_A$ and $N_X$ is initiating Inter-Cluster searching. $N_X$ first sends the query to all the nodes on $C_A$’s Category Overlay (nodes are stored in $C_A$’s Neighbourhood Category List). If not enough nodes send back replies, $N_X$ then selects another Category $C_B$ that $N_X$ is maintaining and tries to send query through $C_B$’s Overlay. If $N_X$ still does not receive enough replies or there is no such $C_B$ existing, then $N_X$ chooses another node $N_Y$ in the same cluster and asks $N_Y$ to help searching. If $N_X$ is still not satisfied, then $N_X$
will send the query to Core Node and switch back to the basic Inter-Cluster Searching mode.

5. Simulation

To evaluate the performance of Category Overlay Search running over an unstructured P2P network, we implemented an overlay simulator in C++. In this work, we examine the searching efficiency with respect to the expected number of nodes contacted within each cluster. In other words, we only present the results relevant to the Intra-Cluster Search. For Inter-Cluster Search, assuming the expected number for Intra-Cluster Search is X and we have Y clusters, then the average number of nodes visited will be less than \( X \times Y \).

5.1. Cluster Size Distribution

We first experiment our clustering algorithm and check whether it is able to produce “similar” clusters. Similarity is important to balance workload and improve searching efficiency and quality. In the simulation, we first generate 10,000 nodes, and then let them randomly join the system. We set the Cluster Range Limit to 2, the Cluster_Size_Limit to 300, the Full_Fraction to 0.9 and the Cluster_Size_Low_Bounder to 30. According to the Core Qualification optimization, we simply set the success possibility of a node being Core to 0.2. We ran the simulation 100 times, and then compute the average result.

Figure 3 is the simulation result. 22 clusters are in the 271-300 size range, 7 clusters are in the 241-270 range, and 5 clusters are in the 121-150 range. No cluster’s size is below 30. The clusters are similar in size and most of them have sizes close to Cluster_Size_Limit.

5.2. Cluster Category Table Consistency

We define the consistency of a Category Table as the ratio of its correct Category-to-Agent mappings to the table size. This value determines how quickly an Agent Node can be located. For each cluster, we compute the mean value of all its member nodes’ consistency ratio.

According to the result of previous section, we choose 3 typical cluster sizes (that is: 300, 250, 150) to perform the simulation. The Cluster Range Limit is set to 2, and the Category size is set to 300. Each node sends a pair-wise report to its randomly selected neighbour in every 30 seconds. Each report includes 10 most recent updates plus 5 random table entries. In every 8 minutes, Core Node broadcasts a cluster wide report.

To simulate the dynamic behaviours, in every 6 seconds, a randomly selected node will migrate one category to a neighbour, and a randomly selected node will leave or re-join the cluster. Therefore, 20 events that causes inconsistency occur in one minute and for a 300 nodes cluster, we believe it is good enough to reflect a system running in a highly dynamic environment. Same as the cluster size simulation, we ran each simulation 100 times, and then compute the average.

Figure 4 is the simulation result of the cluster Category Table consistency. From the result, we see the consistency is retained at about 70 ~ 90% for all of the 3 cluster sizes. This is a promising result because the consistency at this level suggests low “agent node miss” to searching. Our result in next section supports this argument.

5.3. Intra-Cluster Category Overlay Search

As the previous simulation, we also choose 3 typical cluster sizes (300, 250, 150) to do this simulation. Other cluster and event settings remain the same. A query for a random Category is issued by a random node in every second. The number of nodes contacted before reaching the correct Agent Node is recorded. If a query reaches the Core Node and still cannot find the right Agent Node, then we record it as NF (Not Found). However, in this case, we can always switch back to the Basic Cluster Search. The simulation runs for 60 minutes and we therefore do 9,600 searches.

Figure 5 shows the simulation result. For all three clusters, the number of contacts before reaching the correct Agent Node is relatively low, indicating a good performance.
cluster sizes (300, 250, 150), about 90% search will successfully find the correct Agent Node, and most of successful searches will be return in only 1 node contacted. It suggests that with 70-90% consistency, our Intra-Cluster search is able to locate most of the Agent Nodes with 1 contact.

6. Conclusion

In this paper, we have studied the possibility of building a practical P2P Search Infrastructure that is able to not only achieve great efficiency, but also preserve most nice features of unstructured P2P systems (e.g. good fault tolerance, availability, flexibility). We have presented our design and evaluation of an ad-hoc Search infrastructure and algorithm, called Category Overlay Search, for efficiently locating categorized data directly on top of unstructured/pure P2P system. The efficiency of search is improved by propagating queries only in relevant Overlays and the reliability is ensured by sticking closely to the facility of underlying system and using pair-wise and cluster wise – 2 sets of maintenance scheme to refresh local knowledge.

There are several interesting future directions that we intend to pursue. First is a new Inter-Cluster Search that can further reduce flooding. It can take the advantage of the fact that contents on each Overlay tend to have close semantic meaning and may have small keyword domain. Another direction is to design cluster wide policies to control cluster membership. It encourages nodes to stay longer and to share more resources.

References


