

# A Multilayer Topic-Group based P2P Network

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## Abstract

Considering that large and various contents are shared over thousands of peers across a P2P network, one challenging problem is to locate the target content in such a large and unorganized environment. Hence, a P2P system designed with the content classification and managed distribution is more efficient and reliable than the mass and unclassified ones. We propose a MLTG (MultiLayer Topic-Group) based P2P Network. Two core concepts are integrated into the system structure: topic-group and hierarchic layer. Peers act as Local Peers, Delegate Peers and Super-Peers. These peers spread on different hierarchic layers and the system distributes the correlative resources among the same groups. Compared with the traditional P2P schemes, the MLTG is out-performed significantly. From the experiments, it saves up to 90% of query cost for the case of a single keyword query. When the query consists of topic and keywords, it saves up to 93% of cost. MLTG guarantees the enhancement of successful search and lower consumption of bandwidth. It also makes the system more available, reliable and efficient.

Keywords — Peer-to-Peer, Bloom Filter, Topic-Group, Hierarchic System, Content Delivery

## 1. Introduction

Peer-to-Peer (P2P) network has become more and more popular for real-time application, distributed computing, connect sharing in recent years. Although P2P system are adopted widely and many researches try to design efficient searching schemes, such as Napster, Gnutella, Chord, CAN, FastTrack, and KaZaA, one primary problem is how to quickly and efficiently discover and locate the target content.

P2P network could be classified to three types: content-filter based P2P networks, interest-group or cluster based P2P networks, and hierarchic index based P2P networks. The first is content-filter based P2P network (e.g. [3][4]). Each managed peer with a filtering index acts as a proxy and records the results of query hit. More popular and important contents will be published. The rejected ones, however, will be filtered out. The second is interest-group or cluster based P2P network (e.g. [5][6]). It separates the peers into several groups according to the similar or same interest topics. Users will quickly find the resources in the specific groups. However, the discovery and searching processes usually consume most of network bandwidth. The last one is

hierarchic index based P2P network (e.g. [7][8]). It divides the peers into multiple levels of clusters, and the managed peer with a distributed summary index acts as a switch and determines the propagation of queries.

Although dividing peers into clusters reduce the traffic over the network, it still has consumption between clusters. Hence, we propose a MLTG (MultiLayer Topic-Group) based P2P network. As shown in Figure 1, it is the topic-group approach and hierarchic layer design. There are various topic-groups in the P2P network, and these are made by the sharing resources of peers instead of human involvement. Besides, a topic-group consists of not only peers but also several sub-groups. The peers or groups with the relevant resources will be assigned to the same area. Peers act as Local Peers, Delegate Peers and Super-Peers in different layers. Each of them has its summary, and each layer of summaries would cover more information than the lower ones.

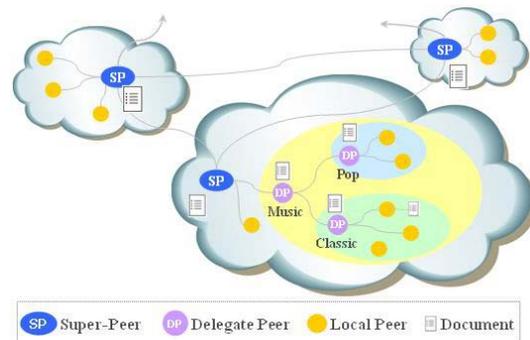


Figure 1. MLTG based P2P network.

Though MLTG would consume extra bandwidth to manage the hierarchic architecture with topic-groups, it still works very efficiently and reliably. Compared with the traditional P2P schemes, the MLTG is out-performed significantly. As the experiments, MLTG saves up to 90% of query cost for the case of a single keyword query. When the query consists of topic and keywords, MLTG saves up to 93% of cost. Besides, we examine the query cost with different values of Group Threshold and work various groups in whole system; and then, we find the query cost (the number of messages) is relative with the values of Group Threshold and the number of peers; namely, it does not guarantee that the more various groups are the more efficient; instead, the suitable number of groups has the best performance.

The rest of this paper is as follows: Section 2 gives an overview of the MLTG system. Section 3 expands on the performance analysis. Section 4 presents our experiment

environment and discusses evaluation results. The conclusion and future works are given in Section 5.

## 2. MLTG System Architecture

A MLTG (MultiLayer Topic-Group) based P2P Network is an hierarchical architecture that uses groups of multiple layers according to the popular keywords or topics; consequently, **topic-group** and **hierarchic layer** are integrated into the system structure. Peers act as Local Peers, Delegate Peers and Super-Peers. These peers spread on different hierarchic layers in MLTG system. Each peer has its own summary index, and each layer of summaries covers more information than the lower ones. MLTG is a self-organized architecture when peers join and leave, and supports dynamic reconfiguration to scale against the growth of the network.

### 2.1. Topic-Group and Hierarchic Layer

Two core concepts are integrated into the system: **topic-group** and **hierarchic layer**. A topic-group consists of not only peers but also several sub-groups. Peers or groups with the correlative topics of resources will be classified into an independent area.

In order to decide new topic-groups, MLTG generates the documents with a set of keywords (topics and keyword-sets) from the files. The more popular keywords become topics; the others become the keyword-sets. Therefore, each Local Peer in the same group has to provide a single topic. The Delegate Peers or Super-Peers calculate how frequently a topic appears in this group and determine whether a new group would be generated. In other words, the topic-group is a special area which gathers not only the same or similar topic of sharing resource from Local Peers but the correlative resources of the sup-groups. Thus, the number of topic-groups is relative to the number of topics.

### 2.2. Encoded-Keyword Summary

To guarantee the successful search of an exiting file, we use an Encoded-Keyword Summary scheme. As shown in Figure 2, the special and brief summary is a Bloom Filter [2], which is a bit vector of fixed length with a family of independent hash function. Each summary represents the storage information of peers;

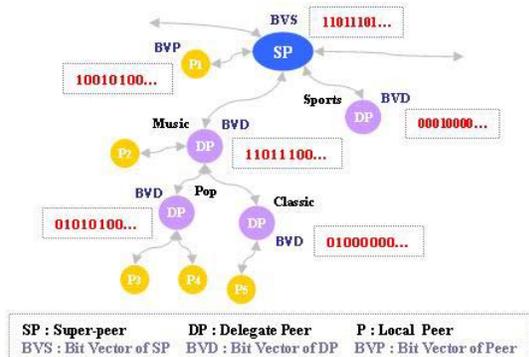


Figure 2. The Encoded-Keyword Summary in MLTG thus, each Super-Peer, Delegate Peer and Local Peer has

its own summary: Bit Vector of Super-Peer (BVS), Bit Vector of Delegate Peer (BVD) and Bit Vector of Local Peer (BVP).

In MLTG, each Local Peer summarizes the set of keywords from files in its document. Delegate Peers and Super-Peers generate their summaries by merging (OR operator) the summaries in the Local Peers or ones in the low layer of Delegate Peers. The higher layer of summaries would contain the lower ones. The higher layer of summaries is a general document of storage information, and the lower ones is a specific. Hence, the higher layer of peers would easily and quickly find which keywords are stored in the low ones, and propagate the query to them. When searching, the system compares the bit vector representing the query keywords with summaries. If at least bit of them is not set, the query is not a member of summary; instead, if all of the bits are set, the query belongs to summary.

### 2.3. MLTG Design Overview

There are three different types of peers in a MLTG based P2P Network: Super-Peer (SP), Delegate Peer (DP) and Local Peer (P).

As shown in Figure 3, a Super-Peer has two tables and a summary: SP Document (SPDoc), Routing Table (RT) and Bit Vector of Super-Peer (BVS). It maintains an area which is a domain-wise or geographical division locality in the Network. Besides, when a topic is getting more popular, a Super-Peer will generate a new topic-group and randomly pick out a Delegate Peer from Local Peers with the same topic. Besides, it is responsible for redirecting search and propagating the queries to the low layer of peers or neighbor Super-Peers. Similarly, a Delegate Peer has a table (DPDoc), summary (BVD) and DP Topic. It plays the same role as a Super-Peer. Finally, a Local Peers has a table and summary: Peer Document (PDoc) and Bit Vector of Peer (BVP). It manages a document of index entries with a set of keywords from the files, and verifies whether the PDoc would find the keywords of queries. Most important of all, each Local Peer in a Delegate Peer or Super-Peer is unique. We would find that the same Local Peer is not in the same topic-group. In MLTG, a Local Peer is comparable to a client and connects with Delegate Peers or Super-Peers. But, a node is the sharing of device files (PC, notebook, etc).

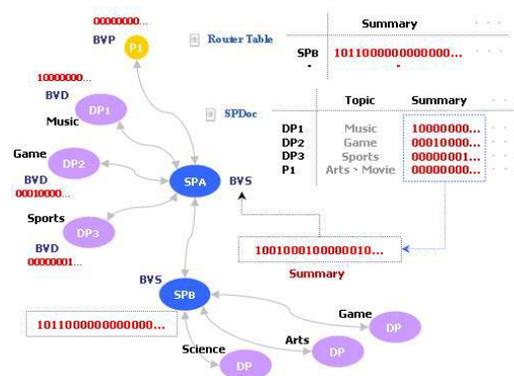


Figure 3. The Super-Peer in MLTG

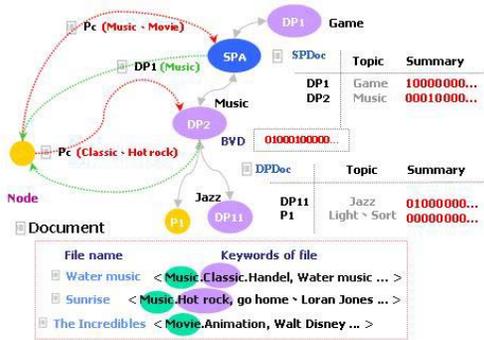


Figure 4. A process of joining request and response.

When a new node joins MLTG, it will pick out keywords from the metadata fields of sharing files and determine which of the keywords are topics or keyword-sets. As shown in Figure 4, the node contacts any existing peer to get the Super-Peer and sends a linking request to SP. The Super-Peer verifies whether the topics in the request are as same as in the SP Document. If found, the Super-Peer sends a message to this node and the message contains a set of addresses of Delegate Peers whose topics are as same as the request. If not, the Super-Peer only sends a linking message and tells a new node to connect with it. Similarly, the node sends a linking request to suitable Delegate Peers whose addresses are in the message received from Super-Peer or high layers of Delegate Peers. Otherwise, the node connects with the Super-Peer or Delegate Peer and sends storage information to them. After the linking process, a new node would join one or more groups.

#### 2.4. Searching Scheme

A MLTG based P2P Network provides the multilayer searching processes for keywords. Different layer of peers are responsible for their searching process. The higher layers of Delegate Peers or Super-Peers have summaries with extensive storage information, so they provide the preliminary search and propagate the queries to the approximate peers. The lower layers of Delegate Peers have exact storage information; thus, they supply the distinct search and propagate the queries to the accurate peers. Finally, the Local Peers compare the query with their documents and determine whether the queries are in the sharing files.

### 3. Performance Analysis

We analyze the performance model in MLTG by two methods: the search cost (search time) and query cost (the number of messages).

First, we find the search cost is relative with the height of architecture in MLTG. We assume  $N_{Node}$  nodes will join to the Super-Peer and each node has  $N_{File}$  files. In the best case if the architecture of MLTG is a balance tree, the search cost is expressed as below:

$$O(\text{depth of layer}) = O(\log N_{Node})$$

In the worst case if the architecture of MLTG is a single chain, the search cost is expressed as below:

$$O(\text{depth of layer}) = O(N_{Node})$$

Thus, the search cost is between  $O(\log n)$  and  $O(n)$ .

In order to measure the query cost, we assume  $N_{Peer(i)}$  is the number of Local Peers in each layer  $i$ . When searching, the node sends a query message to Super-Peer, and Super-Peer propagates this message to Delegate Peers. The query cost must be relative to the number of Super-Peers and Delegate Peers. Each of them has its document which stores index entries of files' sharing resources. Therefore, we have to estimate the number of index entries in groups of layer  $i$  and the notation is  $N_{Doc(i)}$ . We assume that  $N_{GjDoc(i)}$  is the number of index entries in the Group  $j$  of layer  $i$ ,  $N_{Groupj(i+1)}$  is the number of sub-groups in the Group  $j$ , and  $N_{GPeerj(i)}$  is the number of Local Peers which connect to the Group  $j$ . Thus,  $N_{GjDoc(i)}$  would be expressed as an equation:

$$N_{GjDoc(i)} = N_{Groupj(i+1)} + N_{GPeerj(i)}$$

And then, the number of index entries of the documents in the groups of layer  $i$  would be expressed as an equation:

$$N_{Doc(i)} = N_{Group(i+1)} + (1 - P_{JoinGroup(i+1)}) \times N_{Peer(i)}$$

and

$$P_{JoinGroup(i)} = \frac{SUM(JG)_{i-1} (\geq G)}{(N_{Group(i)} + N_{Group(i-1)})^{N_{Peer(i-1)}}$$

A special notation, which designates the total events when the number of Local Peers in each group of layer  $i$  is more than Group Threshold ( $G$ ), is

$$SUM(JG)_{i-1} (\geq G) = \sum_{a=G} \sum_{b=G} \dots \sum_{c=G} C_a^n C_b^{n-a} \dots + \dots$$

$$\text{, where } n: N_{Peer(i-1)} \\ G: \text{Group Threshold}$$

$$\text{Therefore, } N_{Doc(i)} \text{ would be expressed as an equation: } \\ \begin{cases} N_{Group(i+1)} + (1 - P_{JoinGroup(i+1)}) \times N_{Peer(i)}, & 0 \leq i < \text{MaxLayer} \\ N_{Peer(i)}, & i = \text{MaxLayer} \end{cases}$$

As noted previously, we find the number of index entries of the documents in the groups of layer  $i$  is in direct proportion of the number of groups and Local Peers.

Then, we measure query cost in each layer, and assume that the hit rate of Query is  $Hit(Q)$ . The brief equation is expressed as below:

$$QM_{(i)} = N_{Doc(i)} \times Hit(Q)$$

And then, total query cost in each SP would be expressed as an equation:

$$QM_{(total)} = \sum_{i=0}^{\text{MaxLayer}} QM_i = \sum_{i=0}^{\text{MaxLayer}} (N_{Doc(i)} \times Hit(Q))$$

In the previous equation, we find query cost is relative with the number of groups and Local Peers.

In conclusion, we find the search cost (search time) is between  $O(\log n)$  and  $O(n)$ , where  $n$  is number of nodes which join to the Super-Peer. In each Super-Peer, the query cost is relative to the number of groups and Local Peers. The number of groups is inverse proportion of Group Threshold ( $G$ ). Thus, we estimate the performance

of MLTG by Group Threshold and the number of nodes.

## 4. Experiments

In this section, we present our experiments for a MLTG based P2P Network. Based on the analytical model, we designed an experiment environment. The emulation was a test-bed implemented by C++ and communicated by socket. Furthermore, the main assumptions behind the MLTG architecture are: (1) each Super-Peers and Delegate Peers have their own backup peers. The backup peer takes over the role at a time when these are not available; and (2) each node has to pick out some of keywords from the metadata fields of files and determine whether the keywords are topics or keyword-sets. We attempt to validate these assumptions with some experiments.

### 4.1. Experiment Environment and Parameters

We construct the system with two kinds of servers: Environment Manager Server and SP Application Server. These Servers are actual devices in our experiment test-bed. The Environment Manager Server controls the MLTG P2P network. It also manages and observes each of SP Application Servers. The SP Application Server plays a role of a Super-Peer and represents an area of a geographical division. It manages the topology of topic-groups and simulates the real status of the network; besides, there are thousands of threads with processes that emulate the actions of Delegate Peers or Local Peers.

We work an Environment Manager Server and four SP Application Servers. There are one thousand keywords which are randomly chosen from ODP [1] in the system and we select some of them for files in each node. The false positive rate of the Bloom filter is 0.0001. As a well defined linear function of Bloom filters, we determine that the number of hash functions is 10 and the size of summary (bit vector) is 1.797 KB.

We perform experiment by using several kinds of the number of nodes and Group Threshold as initiating the system. Additionally, by using different values of Group Threshold, we observe the topology and record the status of each topic-group in each Super-Peer. We carry out experiments with different types of queries. We observe the query cost when one hundred nodes send the query message with keywords. Finally, the Parameters are summarized in Table 1.

Table 1: Environment Parameters.

Parameter Name	Value
Number of Super-Peers ( $N_{sp}$ )	4
Number of nodes in each SP ( $N_{node}$ )	100 - 600
Number of the files in each node ( $N_{file}$ )	10
Number of keywords in each file	10
Group Threshold ( $G$ )	10 - 30
Number of query nodes ( $N_{qn}$ )	100
Type of keywords in each query	single / various

## 4.2. Experiment Results

In this paper, we present selected results from three experiments.

### ◆ Experiment 1

We performed an experiment by comparing MLTG and traditional P2P schemes with a flooding message.

In Figure 5, the cumulative query cost (the number of messages) is relative to the number of nodes. However, MLTG is out-performed significantly. In an average status, it saves up to 90% of query cost for the case of a single keyword query. When the query consists of topic and keywords, MLTG saves up to 93% of cost. Hence, MLTG guarantees enhancement of successful search and lower consumption of bandwidth.

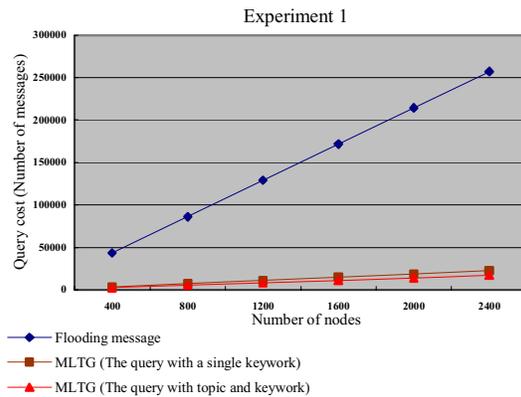


Figure 5. A flooding message vs. MLTG with different types of queries.

### ◆ Experiment 2

We performed an experiment in diverse values of Group Threshold by working the different number of nodes. The experimental results are shown in Figure 6.

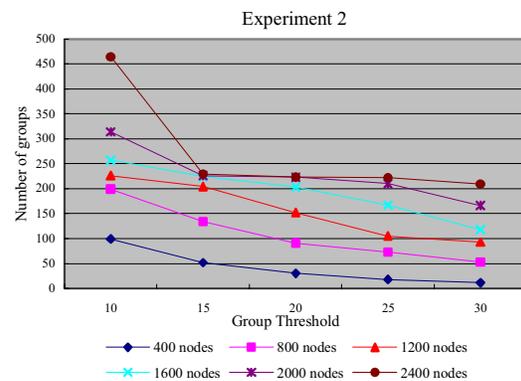


Figure 6. Evaluation of Group Threshold.

In general, the number of groups gradually decreases except the value between 15 and 25 as 2400 nodes. Besides, there is the approximate number of groups in the two points. One is the value of Group Threshold 15 as 1600, 2000 and 2400 nodes; the other is the value of Group Threshold 20 as 2000 and 2400 nodes. This is because they cannot generate any lower layer of new topic-groups. By contrary, there is the greatest number of

groups in the value of Group Threshold 15 as 2400 nodes because it has generated topic-groups in the new layer.

#### ◆ Experiment 3

We performed an experiment in diverse values of Group Threshold by working the different number of nodes. It uses different types of queries (a query with a single keyword and with topic and keyword).

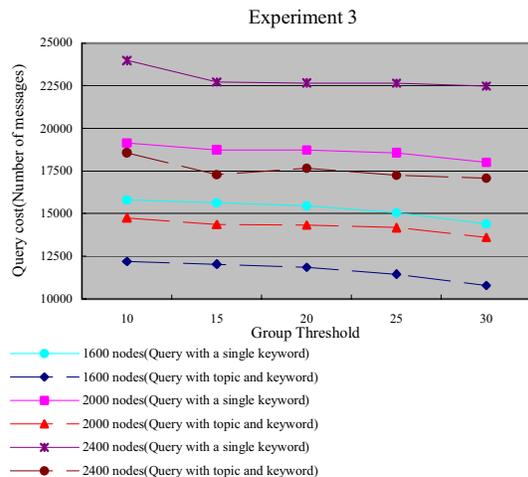


Figure 7. Evaluation of Group Threshold as comparing the different types of queries.

As showed in Figure 7, the number of Query cost slightly declines in the continuous lines. By contrary, the value of Group Threshold 15 is less query cost than the value 20 as 2000 and 2400 nodes in the dotted lines; accordingly, the value 15 has a better performance than the value 20. In conclusion, the query cost (the number of messages) is relative to Group Threshold and the number of peers. It has the best performance as the suitable number of groups. Besides, the query with topic and keyword has more efficient search than with a single keyword. It saves up to 20% of query cost.

## 5. Conclusion

We have proposed a MLTG (MultiLayer Topic-Group) based P2P Network. Two core concepts are integrated into the system structure: topic-group and hierarchic layer. According to the classification and distribution of sharing resources from peers, the MLTG not only guarantees enhancement of successful search and lower consumption of bandwidth; but also makes the system more available, efficient and reliable.

Compared with the traditional P2P schemes, the MLTG is out-performed significantly. In average case, it saves up to 90% of query cost as the query with a single keyword, and up to 93% of query cost when the query consists of the topic and keywords. Thus, more itemized queries are more enhanced search. Besides, we find that the query cost is relative to Group Threshold and the number of peers. However, it does not guarantee that the more groups are the more efficient; instead, the suitable number of groups has the best performance when there are a lot of peers in the system.

As for future developments, we would make good progress in MLTG. First of all, we still propagate the message between Super-Peers by flooding though we have a good solution to the consumption of bandwidth between peers or groups. Thus, it is a possible solution to make practical use of community management between Super-Peers. And then, it becomes possible that most bits of summaries are 1, especially in the Super-Peers. It would cause the flooding message and consumption of bandwidth.

Therefore, a possible solution is working with extra logical operators so that each higher layer of summaries would cover more storage information in the lower ones. In MLTG, it could build an attenuated summary instead of an original one. The system generates the summary and merges each bit in lower layers by using OR operator. It also builds by using AND operator and XOR operator. Hence, the MLTG could become more efficient for searching by using attenuated summaries even though the system meets the problem that most bits of summary in any Bloom filters are 1.

In conclusion, we believe that the multilayer topic-group based P2P network would work on the real-life distributed system and supply the most available, efficient and reliable network application in the future.

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