Hierarchical Query Routing in P2P Information Filtering Systems

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Abstract *In recent years, various P2P network applications, Napster, Gnutella, WinMX, Winny and many others, have been developed. But it is difficult to find out suitable information resources and to guarantee practical response time by using distributed systems with simple search functions. Furthermore, most of applications are based on overlay networks with unstable network topology and query messages consume huge bandwidth in the internet. Therefore, P2P information retrieval systems have been changing from filename-based queries to contents-oriented queries with advanced data structures. We also proposed the topic-oriented search mechanism by using heuristic peer host selection functions with several parameters. We extended JXTA-like query routing protocols in order to handle characteristics of resources and queries. Our proposed hierarchy routing mechanism has the tradeoff between the cost of query forwarding and the amount of storage for routing information. Therefore, in order to evaluate the characteristics of hierarchical peer clusters, we analyze mathematical model with Palm-probability and Poisson-Voronoi-Clustering.*

1 Introduction

Various applications of peer-to-peer (P2P) systems using direct connections are becoming popular, P2P network applications are extremely important from the view points of scalability and flexibility in the internet [1,3]. However, the first generation of P2P file sharing applications gave negative impressions and they did not provide sufficient query processing functions and convenient user interface. Therefore, many researchers and developers try to extend search mechanisms, sharing performance by extending index data structures, implementing query routing functions and tables, utilizing metadata with additional attribute values and various information processing techniques.

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We classify four types of P2P file-sharing architectures and we focus on the fourth one, which is based on query routing protocol.

i) *Client-Server type controlled P2P system*
ii) *Pure P2P system using broadcast query messages*
iii) *P2P system with advanced index structures*
iv) *P2P system with query message routing tables*

JXTA has been developed by Sun Microsystems [8], and it provides XML descriptions called Query Routing Protocol (QRP). However, JXTA has some difficulties in managing metadata of query messages and query processing cost. Therefore, we try to improve several disadvantageous problems of JXTA and propose the topic-driven routing system which adopts standardized metadata (e.g MPEG-7, Dublin Core) for defining information resources [4–6]. In this paper, routing table stored in each cluster is called as *TRT (Term Routing Tree)*.

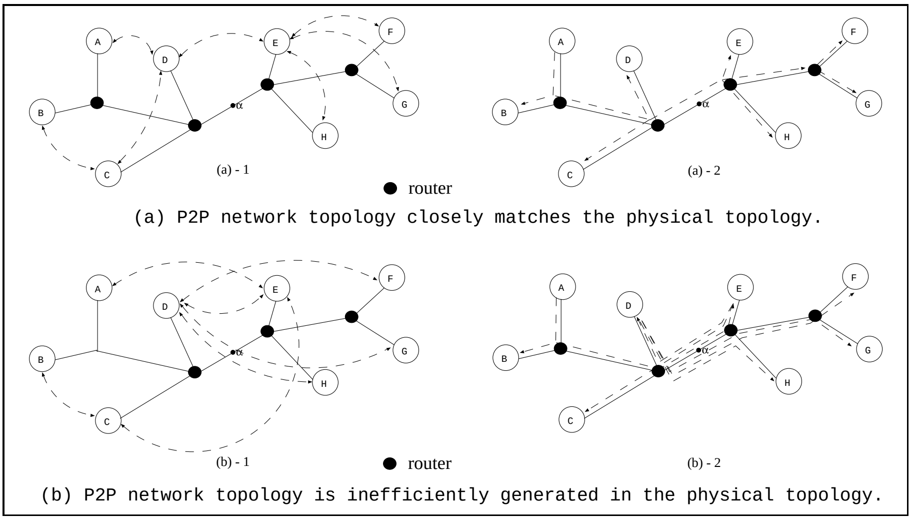
In our previous studies, we proposed QR (Query Routing) protocol with topic-oriented query processing. QR stores the plain attributes of information resources and the peer-host addresses at full length, QR protocol reduces the number of flooding messages in P2P network. But it is difficult to reduce the complexity of query routing tables.

In this paper, we apply generalization techniques of data mining to our proposed QR protocol, and we evaluate the performance of HQR (Hierarchical Query Routing) depending on the level of hierarchical structures.

2 Problem of Complex Overlay Network in P2P System [4]

In order to share and transfer information resources, several types of distributed search systems over P2P network have been developed [1,3]. For instance, Napster shares information resources based on a server/client system, Gnutella and Freenet share resources over pure P2P networks without any central servers. We also proposed hybrid type of file exchanging systems which are based on an integration of web warehouses and pure P2P clients [4]. However, it is not effective for many users to discover appropriate information resources by using simple queries with file-names and path-names. Furthermore, from view points of network technologies, we have to resolve other important problems of P2P systems, such as scalability of search transactions between peer hosts, optimal configuration of P2P network topology and unstable traffic of extremely frequent ping packets. Here, we briefly describe the unstable overlay network, as a typical problem in P2P systems.

In Figures 1-(a)-1 and 1-(b)-1, we argue the importance of a “properly fitting” overlay topology. The solid lines show the underlying physical network connections that connect eight hosts in a Gnutella-like network, and dotted lines present the application’s overlay topology.



(a) P2P network topology closely matches the physical topology.

(b) P2P network topology is inefficiently generated in the physical topology.

Figure 1: Mapping the overlay network topology to the physical network infrastructure.

In Figure 1-(a)-1, the overlay topology closely matches the physical network, and as shown in Figure 1-(a)-2, a broadcast packet from host A involves only one connection over the physical link α. On the other hand, in Figure 1-(b)-1, the overlay topology is inefficiently mapped to the physical networks, and as shown in Figure 1-(b)-2, the same broadcast packet involves six redundant connections over the same link α. Therefore, we have to reduce redundant packets by constructing optimal topology of P2P network depending on the network architecture.

3 Algorithm of HQR

In order to resolve the above problems in Section 2, we try to improve techniques of query routing mechanism between peer hosts. Then, we introduce QR algorithm and propose HQR algorithm [5].

3.1 QR Algorithm

Query description based on resource characteristics

The topic driven query routing requires metadata of information resources to handle resource characteristics. In our previous studies, we proposed addition of standardized metadata (e.g., MPEG-7) to QRP (Query Routing Protocol) of JXTA search. Typical statements of MPEG-7 are as follows:

1. MPEG-7: resource information

2. Creation_Meta_Information: information of data creation
3. Multimedia_Content: format, extension and so on
4. Usage_Meta_Information: author's copyright and other properties

QR adopts a query routing system in order to reduce the number of broadcasting query messages. On the other hand, QR has a problem that the size of routing tables will be increasing monotonously.

3.2 HQR Algorithm

In order to reduce the size of query routing tables, we propose a hierarchical routing mechanism based-on the concept of hierarchical query routing(HQR). QR only stores the attributes of data and the peer-addresses at full length. On the other, HQR aggregates the attributes of data into the hierarchical structure and stores peer-addresses associated to neighbors.

Routing algorithm of HQR

1. The consumer host C sends requests, and C also checks the query in his own registers, and it forwards the query to suitable peer host A.
2. The peer host A receives the query and checks the query-uid (query-unique ID). If A has never received the message with query-uid, A checks the query in his own registers including hierarchical routing information. Moreover if he discovers a suitable information resource in his registers or the hierarchical routing table, A sends back a reply message, which includes the address of P having information resource, to the host C and forwards a request to the suitable peer host P. If the query does not match the information in his registers, A forwards a query to its neighbor and reduces TTL of the query. This operations are repeated until $TTL = 0$.
3. When C receives a reply message, it checks the validness of information resource and stores the address in his query routing table. This content information and address realize effective routing operations.

In the both of QR and HQR systems, the tradeoff between the cost of query forwarding and the size of storage for routing information have been studied by using simulation models [5].

4 Performance evaluation of hierarchical query routing protocol

In this paper, in order to evaluate the performance of analytical model of QR and HQR systems, we look back the previous studies of traditional network routing problems [2, 7].

4.1 Size of hierarchical query routing table

We introduce the peer-cluster structure and the TRT as a structure of hierarchical routing tables in order to decide directions of forwarding query messages. By using a HQR mechanism, the network is divided into independent routing areas as *Clusters* in order to reduce the number of peer hosts all over network.

d_c is defined as the total number of layers in the hierarchical structure of peer-cluster, δ_c is defined as the depth of the particular layer ($0 \leq \delta_c \leq d_c$). Array A is used to define the relationship between a parent cluster and a child cluster. Here, A_x^y stand for the y-th child-cluster on layer level x for its parent cluster. Cluster is generally defined as $C^{A_1^i \cdots A_{\delta_c}^j}$. Peers in the network correspond to clusters in the lowest layer ($\delta_c = d_c$).

$$C \equiv \begin{cases} C^r & , \quad \delta_c = 0 \\ C^{A_1^i \cdots A_{\delta_c}^j} & , \; 0 < \delta_c \leq d_c \end{cases} \tag{1}$$

Parent function p is defined as:

$$p(C^{A_1^i \cdots A_\delta^j A_{\delta+1}^k}) = C^{A_1^i \cdots A_\delta^j} \tag{2}$$

Several peers are divided into clusters according to the features and the allocation of information resources. Peer hosts have routing information about their routing areas. Herewith, QR and HQR protocols can reduce the size of the routing table stored addresses of neighbor hosts and for routing direction. Therefore, network administrators have to maintain optimal routing tables under the topology of P2P network connections. An example of the cluster structure can be seen in Figure 2. The bottom layer π_3 corresponds to the physical network. In the higher layers(π_2, π_1), peers are combined to clusters.

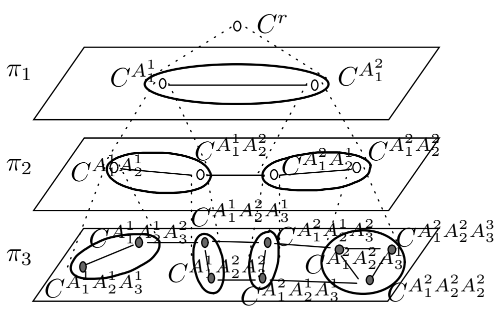


Figure 2: Example of peer-cluster

By the way, each attribute is defined as t and there are various kinds of information attributes. Therefore, the tree-structure of information attribute is not unique. Root of respective tree-structures are defined as r_k. Then, d_{r_k} is defined as the total number of layers in the hierarchical structure of TRT, δ_{r_k} is defined as the depth of the particular layer ($0 \leq \delta_{r_k} \leq d_{r_k}$). Array B is used to define the relationship between a parent cluster and a child cluster. Here, B_x^y stands for the y-th child-cluster on layer level x for its parent cluster. Cluster is generally defined as $t^{r_k B_1^m \cdots B_{\delta_{r_k}}^n}$. Thus, it is possible to write:

$$t \equiv \begin{cases} t^{r_k} & , \quad \delta_{r_k} = 0 \\ t^{r_k B_1^m \cdots B_{\delta_{r_k}}^n} & , \; 0 < \delta_{r_k} \leq d_{r_k} \end{cases} \tag{3}$$

TRT is the set of t. Each layer corresponds to π_{δ_k}, and the following Formula is written:

$$\pi_{\delta_k} = \{t^{r_k B_1^1 \cdots B_{\delta_{r_k}}^1}, \ldots, t^{r_k B_1^m \cdots B_{\delta_{r_k}}^n}\} \tag{4}$$

The typical structure of TRT is seen in Figure 3.

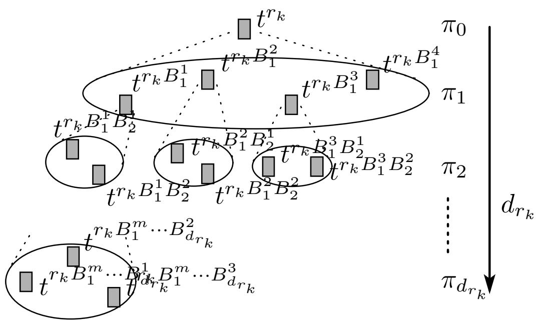


Figure 3: Generalization of TRT

In addition, a peer $C^{A_1^i \cdots A_{\delta_c}^j}$ manages content information stored in a parent cluster $C \supset C^{A_1^i \cdots A_{\delta_c}^j}$. (for $C^{A_1^1 A_2^1 A_3^1}$, independent clusters are $\odot$ in Figure 2) Resources in the network have various attributes, t corresponds to resource attributes. t is defined as a point in d-dimensional space. In other words, TRT consists of hierarchical tree of t.

In order to associate several t, *Poisson-Voronoi Tessellation* is useful. Let $\pi_{\delta_{r_k}}$ be a stationary point process with intensity λ_{δ_k}. Then the size of routing information in TRT depends on the total number of layers d_{r_k}. TRT with comparatively high layers can manage wide range of terms so that cost of handling routing information into TRT will be reduced. However, the protocol makes routing information fuzzy due to aggregating within wide range. Therefore it increases the frequency of query massage and the cost of query translation.

Each term of information resources t in the peer-cluster is represented by points, randomly distributed in R^d. Though, only the ones in a finite observation window W are analyzed to get a finite network. Term defined as $t^{r_k B_1^m \cdots B_{\delta_{r_k}}^n}$ is assembled

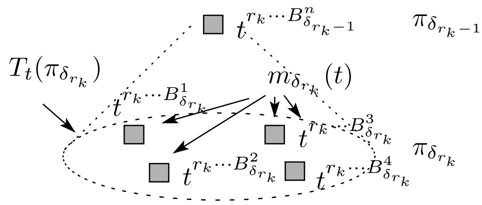


Figure 4: *Poisson-Voronoi clustering*

into its parent term $t^{r_k B_1^m \cdots B^{n'}_{\delta_{r_k-1}}}$. Term-Groups are modeled as *Voronoi Cell* $T_t(\pi_{\delta_{r_k}})$. Let $\pi_{\delta_{r_k}}$ be a homogeneous Poisson process with intensity $\lambda_{\delta_{r_k}}$ (see Figure 4).

According to mathematical definition, Each term t are assembled dependently on d-dimensional distance. However, attributes of all data are measured in numerical terms and it is impossible to represent t with coordinate data $(\tau_1, \tau_2, \ldots, \tau_d)$. Therefore, we determine that Each term t are assembled dependently on 2-dimensional distance calculated on allocation of storing peer in network.

Terms in the lowest point process $\pi_{d_{r_k}}$ are aggregated to the point in the point process $\pi_{d_{r_k}-1}$ dependently on $\int_{T_t(\pi_{d_{r_k}})}$. Terms in the other cluster $T_{t'}(\pi_{d_{r_k}})$ are aggregated in the same way. This operation is repeated from $\pi_{d_{r_k}-1}$ to $\pi_{d_{r_k}-2}$.

This aggregation process is iterative and the length of the routing database can finally be written
$NT_t = \sum_{i=1}^{i=d_{r_k}-1} \int_{T_t(\pi_i)} d\pi_{i+1} + \int_Z d\pi_1$.

The problem will then be to minimize the size of the routing database, averaged over all terms of the network.

$$\begin{aligned} D &= E_0^{\pi_0}[NT_0] \\ &= E_0^{\pi_0}\left[\sum_{i=1}^{d_{r_k}-1} \int_{T_0(\pi_i)} d\pi_{i+1} + \int_Z d\pi_1\right] \\ &= 1 + \lambda_1 + \sum_{i=1}^{d_{r_k}-1} \lambda_{i+1} E[|T_0(\pi_i)|] \\ &= 1 + \lambda_1 + \gamma \sum_{i=1}^{d_{r_k}-1} \frac{\lambda_{i+1}}{\lambda_i} \qquad (5) \end{aligned}$$

Formula (5) leads to the optimum hierarchical structure which minimizes the size of the routing table. We omit the detail discussion here, the optimum can be obtained, and the size of the routing table can be written for a given number of levels.

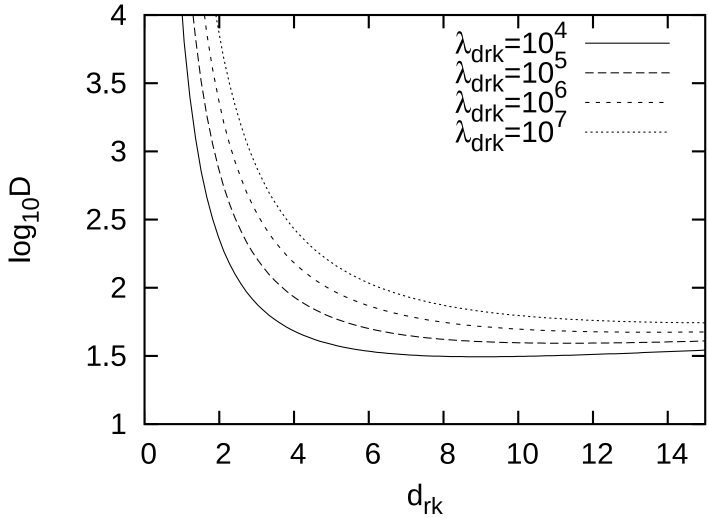


Figure 5: Characteristics of d_{r_k}, $\lambda_{d_{r_k}}$, D

$$D = 1 + d_{r_k}\gamma \left(\frac{\lambda_{d_{r_k}}}{\gamma}\right)^{\frac{1}{d_{r_k}}} \tag{6}$$

Fig. 5 shows the characteristics of equation (6) with D, $\lambda_{d_{r_k}}$ and d_{r_k}. Hence we can construct the HQR structure at the optimum:

$$d^*_{r_k} = log\left(\frac{\lambda_{d_{r_k}}}{\gamma}\right) \tag{7}$$

Consequently, it is possible to choose smaller values for the number of levels while still reducing the size of the routing table. It seems to be efficient to construct TRT which consists of lower hierarchical structure.

4.2 Number of query messages in HQR

Hierarchical routing information is based on generalized descriptions, it increases the number of attribute corresponding to a query message. Therefore, we also have performance analysis using the size of routing table and the number of forwarding query messages.

Firstly, M_{δ_c} is defined as the number of peer aggregated to peer-cluster in δ_c-th layer. $N_{h_{r_k}}$ is defined as the number of term aggregated to term-cluster in h_{r_k}-th layer. The query forwarding cost should be given by Formula (8).

$$Message\ Cost = M_{\delta_c} \cdot N_{h_{r_k}} \tag{8}$$

In this paper, we omit the detail discussions of analytical evaluations. But, by using analytical results, it is possible to decide appropriate number of layers in order to reduce the cost of query forwarding.

5 Conclusion

At present, we are trying to implement well-known standard metadata (e.g., MPEG-7) in XML-based logical expressions in our proposed P2P system. Firstly, we introduce our research of P2P, QRP (Query Routing Protocol) of JXTA search. In previous study, it is clear that our proposed HQR protocol utilizes effectively the aggregated routing information, and the complexity of routing tables can be reduced. But the query routing table causes different disadvantageous problem that the number of query messages increases in P2P network.

Therefore, in this paper, we propose the analytical model in order to evaluate characteristics of HQR protocol and the tradeoff between the query processing cost and the query. We try to evaluate the performance of HQR by using analytical models with Palm-probability to define the distribution of information resource and Poisson-Voronoi-clustering to make hierarchical clusters. Analyzing the model based on Poisson-Voronoi tessellation, we can clearly estimate the size of query routing tables in HQR system. We also evaluate the size of routing table and the number of query messages in the case of different generalizing levels. Consequently, we make clear that we can choose rather small number of aggregation levels in order to reduce the complexity of the routing table and distributed query processing cost.

Acknowledgments

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