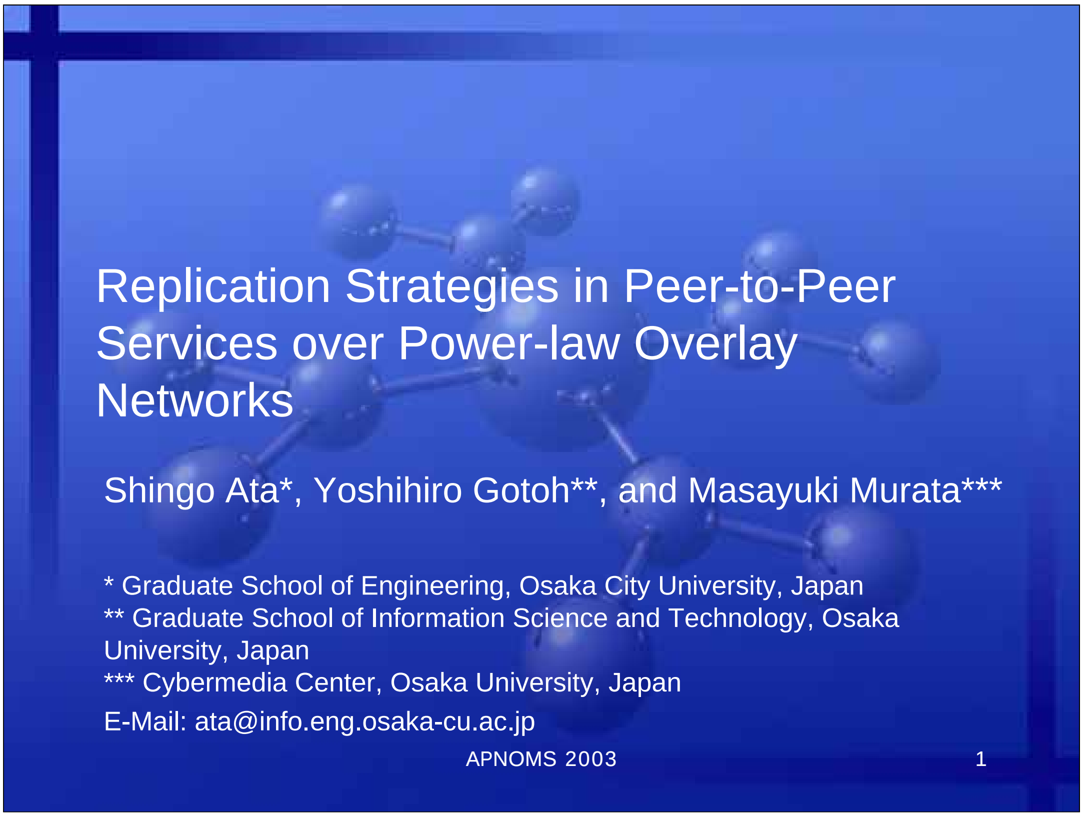
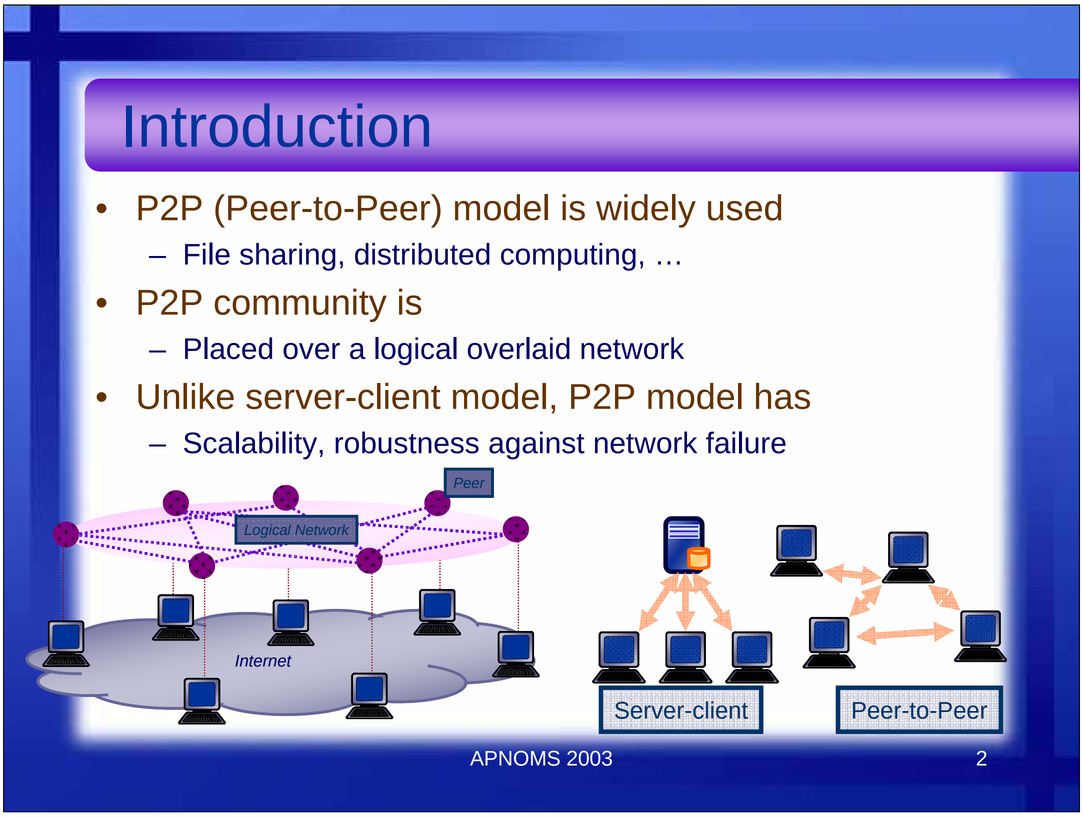


Abstract

Many services have recently been offered based on a peer-to-peer (P2P) communication model. The robustness of the P2P network against frequent peer failure must be considered. Replication of the content is one of the most useful techniques to increase robustness. However, the overall effectiveness of replication is heavily dependent on the topology of the logical network.

As topology of networks, including the Internet and P2P, follows a Power-Law distribution pattern, we first investigate the effect of the logical network topology (especially of the Power-Law characteristics) on replication methods. Based on these observations, we propose a query forwarding method that considers the characteristics of the network topology in order to improve the performance of the P2P service. Our simulation results show that our proposed method can greatly improve the query performance by considering the characteristics of Power-Law. Our method reduces the average hop count in finding replicas by up to 60% compared with the random forwarding method.

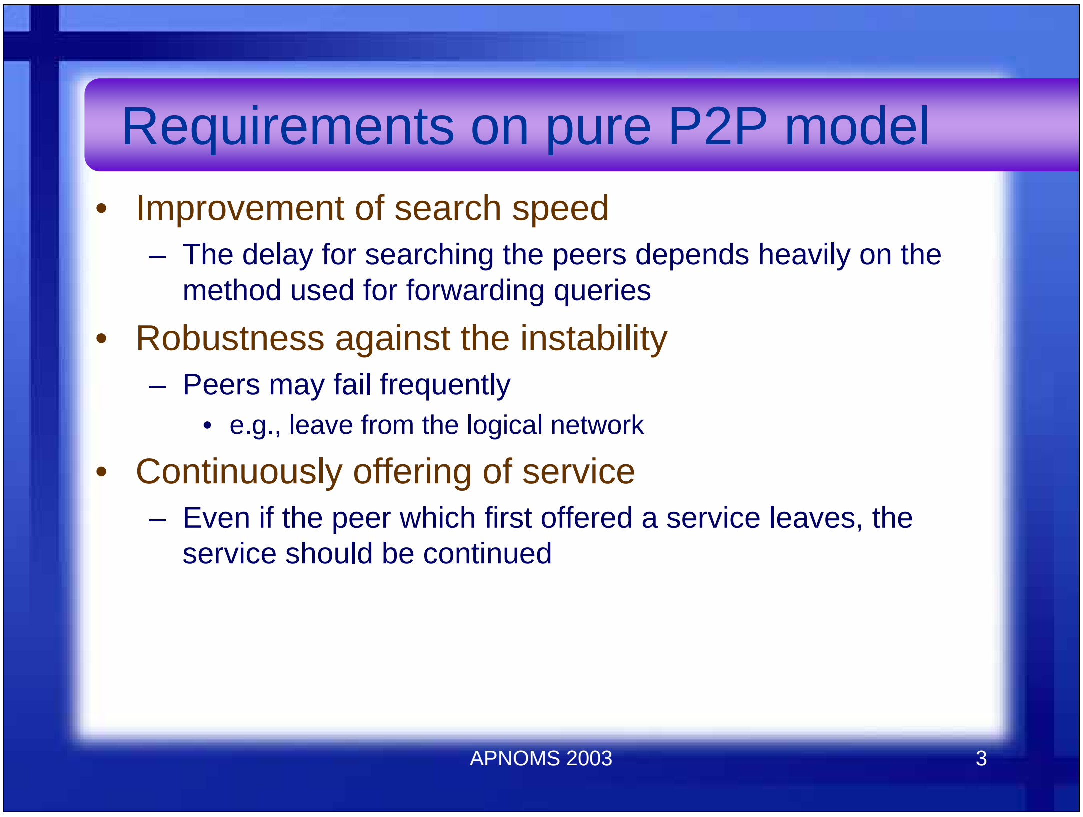


1. Introduction

The Peer-to-Peer (P2P) model has recently attracted attention as a new network model, which is used in e.g., file sharing and distributed computing.

Unlike the server-client model, which is conventionally used today, P2P model does not need a special node (i.e., a server) to provide services. The nodes participating in the P2P service are called ``peers,'' and these construct a logical community (we call it the P2P community). All the peers are treated equally in the P2P community. Sometimes a peer offers a service (i.e., acts as a server in the server-client model), and sometimes it receives a

service (i.e., a client). The actual capability of the P2P community can be regarded as the aggregation of all the services provided by all the participating peers in the community. Unlike the server-client model, services are not centralized in a special node but distributed to the smaller peers. Moreover, since peers operate autonomously, the P2P model has advantages in terms of both scalability and robustness against network failure.



In pure P2P model, we need to consider the following aspects.

1. Improvement of the search speed:

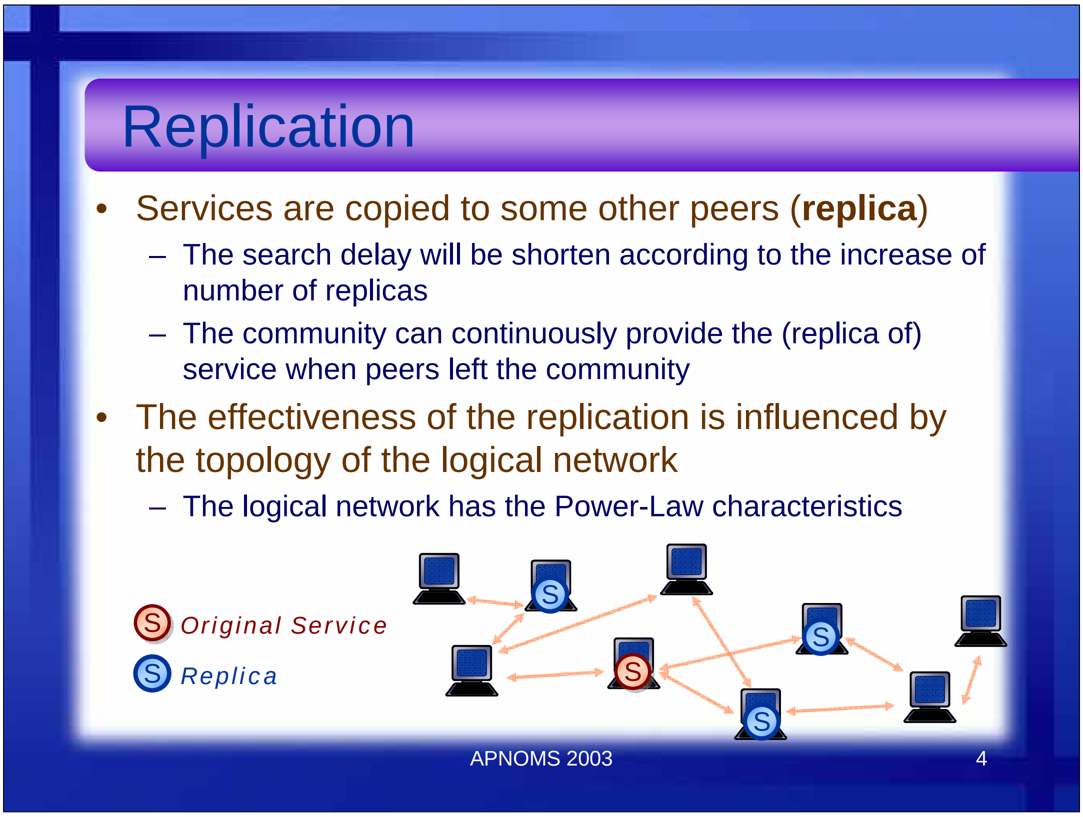
As mentioned above, the forwarding of the query in the pure model is performed on a hop-by-hop basis. The delay for searching the peers depends heavily on the method used for forwarding queries.

2. Robustness against the instability of the logical network:

Since peers in a P2P logical network are run by the application software, it is important to consider the robustness against frequent peer failures. This includes the peers that leave the logical network as this directly affects the stability of the logical network.

3. Continuously offering of service:

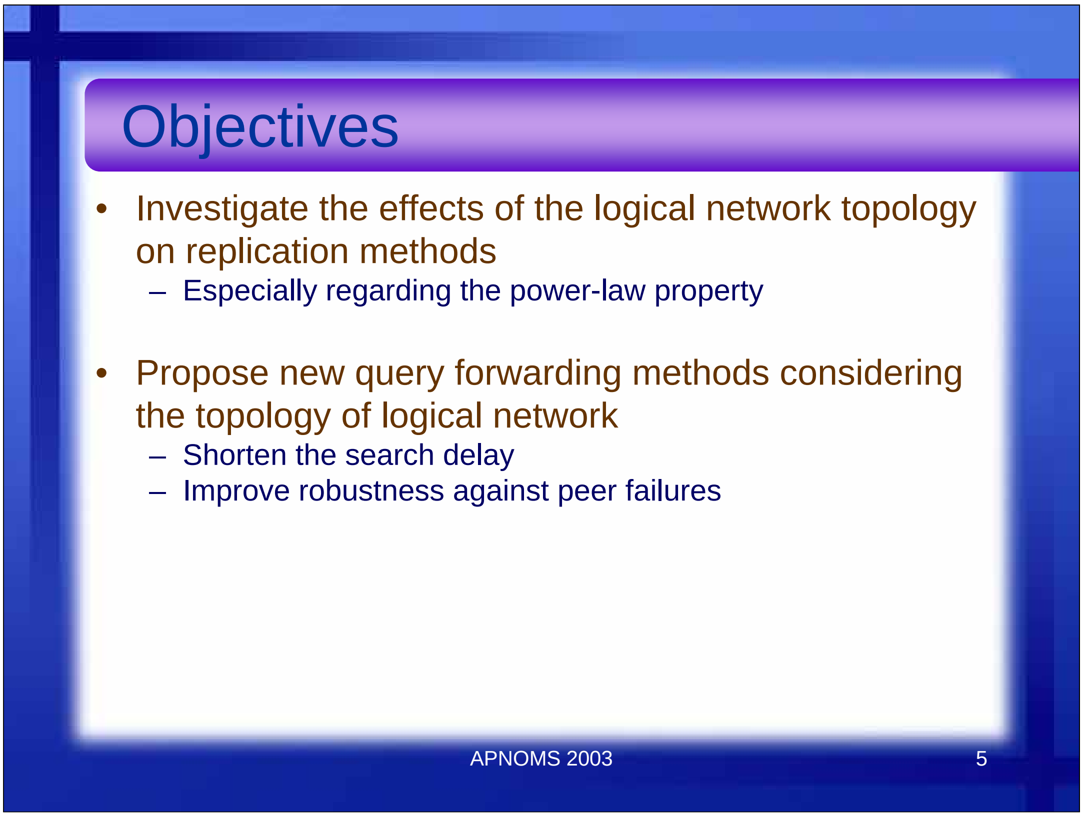
A stable service is desirable so that even if the peer which first offered a service leaves, the service can continue to be available.



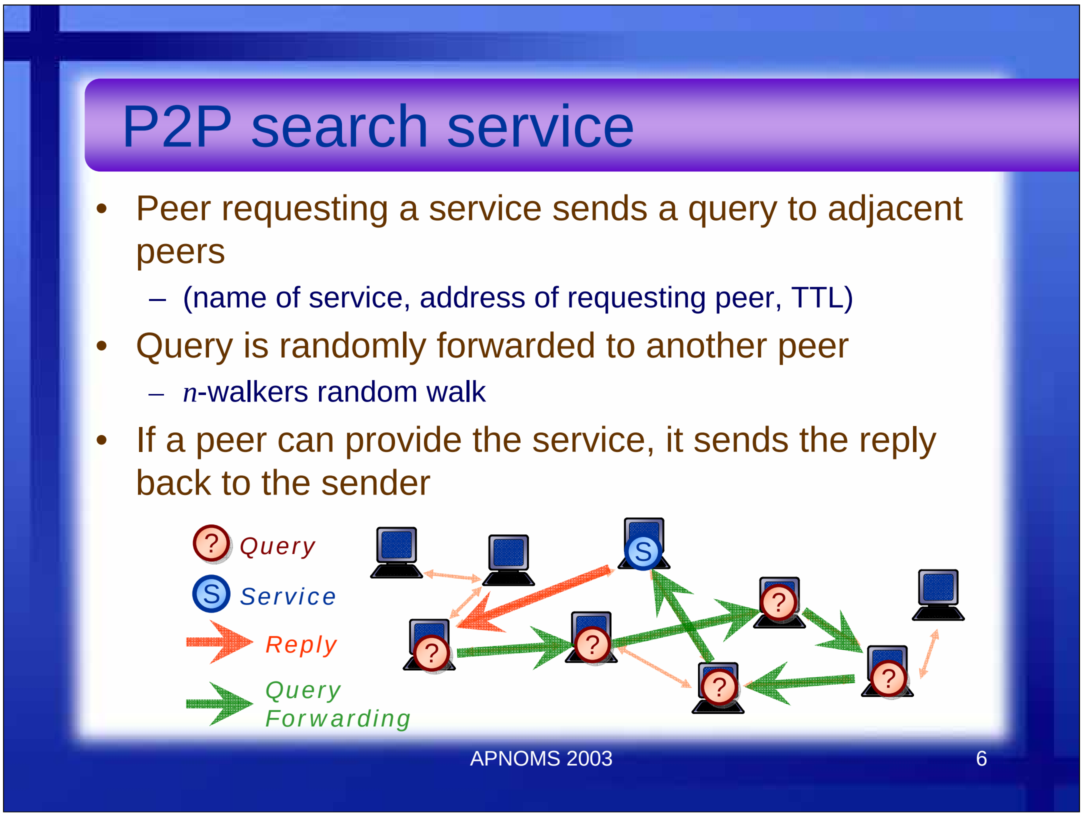
Replication [1] was proposed as a solution to the above problems. Services are copied to some other peers. The peer with the copied service (called *replica*) can also offer the service. As the number of relevant peers has increased, the delay in finding the peers should be shortened. Moreover, although the peer which originally had the target service has left the community, the service can still be offered by other peers holding the replica. The

details of this replication are described in the Section 2.

Replication has advantages, such as an improvement in handling peer failures, and the shortening of the search time. However, the effectiveness of the replication seems to be influenced by the topology of the community's logical network. Recent studies have shown that the Internet displays the characteristics of Power-Law [2] and Small-World [3]. The logical network of the P2P community also shows evidence of Power-Law behavior [4]. This property means that peers in the logical network are not connected randomly, but most are connected to a limited number of peers. These peers have a big influence on the stability of the logical network.



In this paper, we first investigate the effects of the logical network topology (especially regarding Power-Law) on replication methods. Based on our observations, we next propose a new query forwarding method that considers the Power-Law property of the logical topology, in order to improve the performance of the P2P service. In our method, queries are transmitted with different probabilities, depending on the degree of each adjacent node. Through simulation experiments, we evaluate the effect of our forwarding method on the replication. Our numerical results show that our new forwarding methods can discover more requested services with the shorter delay.

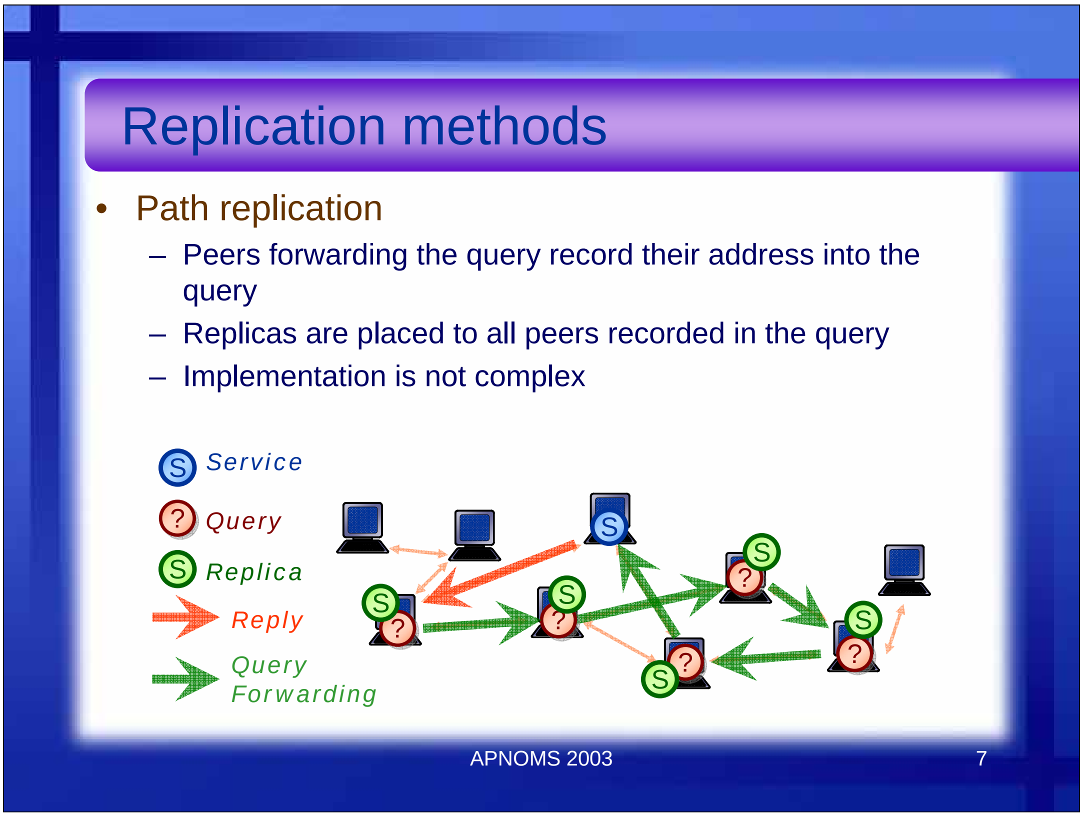


2. P2P Search Service

We describe the search service in our pure P2P network. The service uses a distributed search method to find the relevant resource. Peers in the P2P community connect to each other, and this constitutes the logical overlaid network. A typical search process is as follows (see, e.g., [1]). When a peer requires a service it sends a *query* to its adjacent peers. This query message contains the name of the service (e.g., the file name), the address of the service-request peer, and the TTL (Time To Live) field. A peer that receives the query first checks whether it can offer the service itself. If it can, it sends the *reply* with its address back to the sender peer. Otherwise, it forwards the query to its adjacent peers. Before forwarding, the peer decreases the value of the TTL field by one, or if the TTL value is zero it discards the query. This mechanism is effective for avoiding a loop in forwarding queries. When the sender peer receives the reply message, it directly connects to the peer specified in the reply so it can receive the requested service.

Message forwarding in the pure model is performed on a hop-by-hop basis. The search delay depends on the method used for forwarding queries. There are several methods that can be used [1]. The simple approach is the peer that receives the query passes it to another peer picked randomly from among the adjacent peers. This is called the *random walk* approach. A peer asks for the service from all the peers belonging to the community one at a time. The weakness of this approach is that it takes a lot of time to wait for the replies. ***n-walkers random walk*** is one of the derived versions from the random walk approach. In n-walkers random walk, n of queries are sent simultaneously by the sender peer. A peer receiving a query simply forwards to another peer, which is the same action as in the random walk. n-walkers random walk has a clear tradeoff between the value of n and the delay in searching: When the value of n increases, the expected number of peers forwarding the query decreases linearly. On the other hand, a large value of n demands a large volume of message traffic, which decreases the possible usage of the link bandwidth. The authors in [1] investigated the effectiveness of n-walkers random walk, and showed that between 16 and 64 queries is reasonable as the value of n irrespective of the network size.

We used the 16-walkers random walk approach in our experimental evaluations.



3. Replication Methods

In the replication, the key question to ask is ``how do we distribute the replicas?" In [1], three replication methods are proposed. These are **Owner Replication**, **Random Replication**, and **Path Replication**.

3.1 Owner Replication

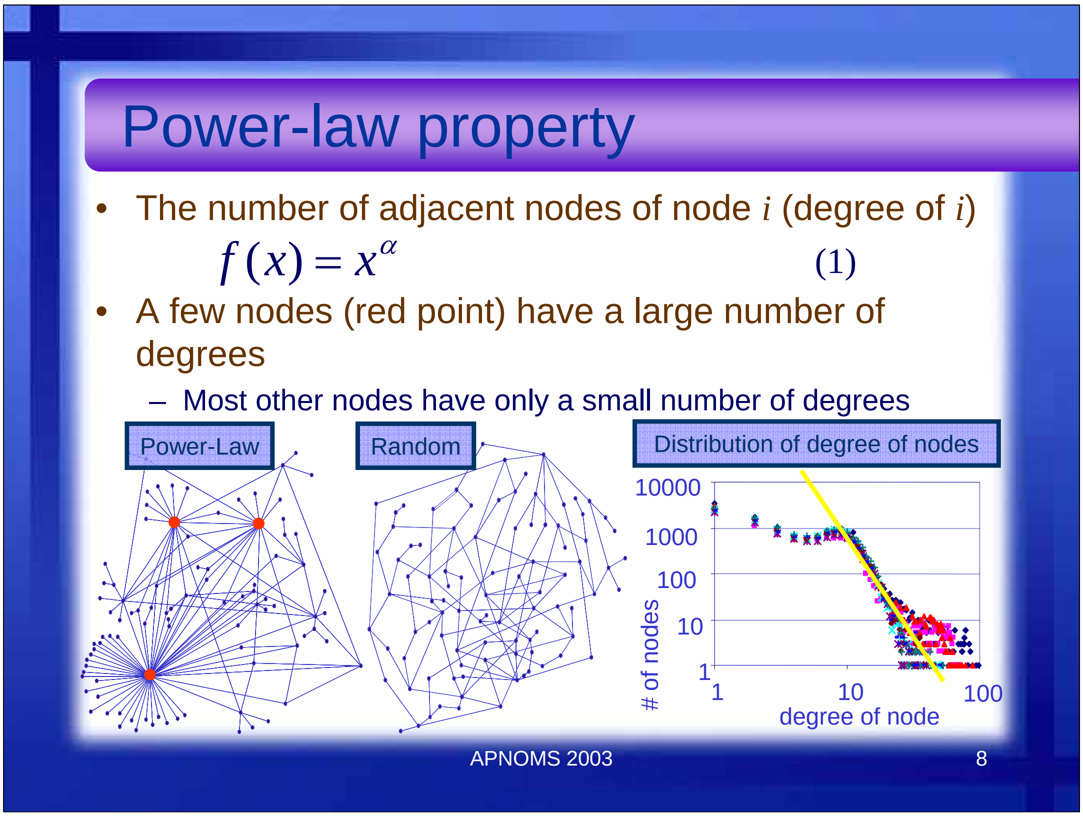
In the owner replication method, the peer which received the service keeps a copy so it can offer the service itself if requested by other peers in the future. In other words, the receiver peer also becomes a service provider. The number of replicas will increase in proportion to the number of requests for the service. Nevertheless, it is insufficient for fully improve performance.

3.2 Random Replication

In random replication, replicas are randomly distributed amongst other peers. If we use random forwarding n-walkers random walk, Random Replication is the most effective approach for achieving both smaller search delays and smaller deviations in searches. However, to perform random replication, the peer must know the information of all the peers in the logical network. This is not easy to implement, because a peer can only know information about its adjacent peers (i.e., not all the peers in the logical network).

3.3 Path Replication

Path replication is another approach for distributing multiple replicas for each service. As the peers forward the query they record their address into the message. The service-providing peer receives the query which contains information about the sequence of peers (i.e., forwarding route) that forwarded the message. The provider peer can then send a reply and replica of the service in the reverse direction of the forwarding route. Simulation results have shown that path replication achieves a similar performance to random replication [1], while implementation is less complex than the random replication. For this reason, we use path replication as the replication method in this paper.



4. Effect of Power-Law Property of Logical P2P Topology on Replication

4.1 Outline of Power-Law Property

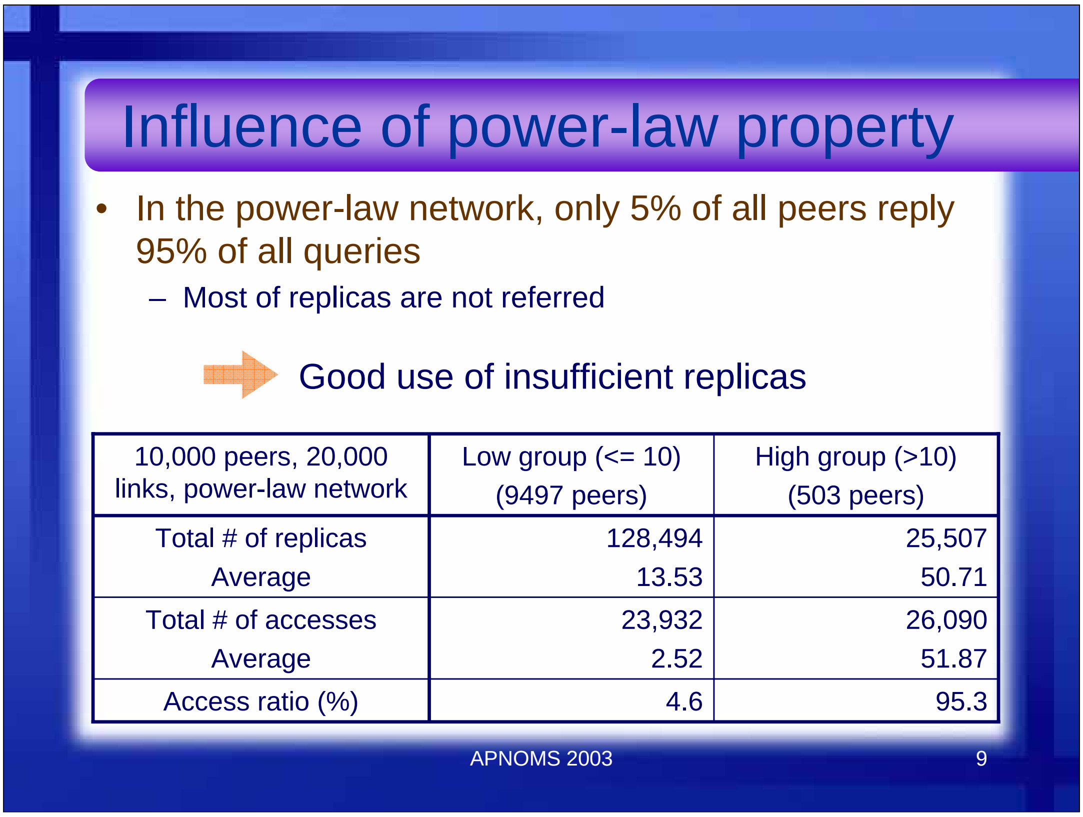
Recent studies have shown that the Internet has the characteristic of Power-Law [2] and the logical network of P2P community also follows the nature of Power-Law [4]. This property means that peers in the logical network are not connected randomly, but most of peers are connected to limited number of peers. Such peers make a big influence on the stability of the logical network.

Suppose the node *i* is on the network. We define the number of adjacent nodes of the node *i* as ``degree of *i*,'' which is denoted by x_i. If x_i follows the function f(x) defined in Eq. (1), x_i satisfies the Power-Law property.

The effect of the Power-Law property to the communication quality have been studied in some literatures (e.g.,[5][6]). In the Power-Law network, a few nodes have a large number of degrees while most other nodes have only a small number of degrees. For example, our observation have shown that 5% of nodes have high degrees larger than 10, and 50% of nodes only have a single degree. Therefore, when we randomly select a node in the Power-Law and random network respectively, the degree of the node in the Power-Law network is almostly smaller than the one in the random network. That is, the impact of a node failure on the Power-Law network is smaller than the impact on the random network in most cases [5]. However, if the node with high degree fails, the Power-Law logical network becomes easily unstable. Intentional attacks to the nodes with high degrees will cause a serious damage to the logical network [6].

In respect of the query performance, the Power-Law network has a tendency to follow character of the Small-World [3], in which the message can be forwarded to much more nodes with small number of hops by sending nodes with higher degrees. By using this phenomenon, the query message can be advertised to other peers faster by sending the query message to the peers having higher degrees aggressively.

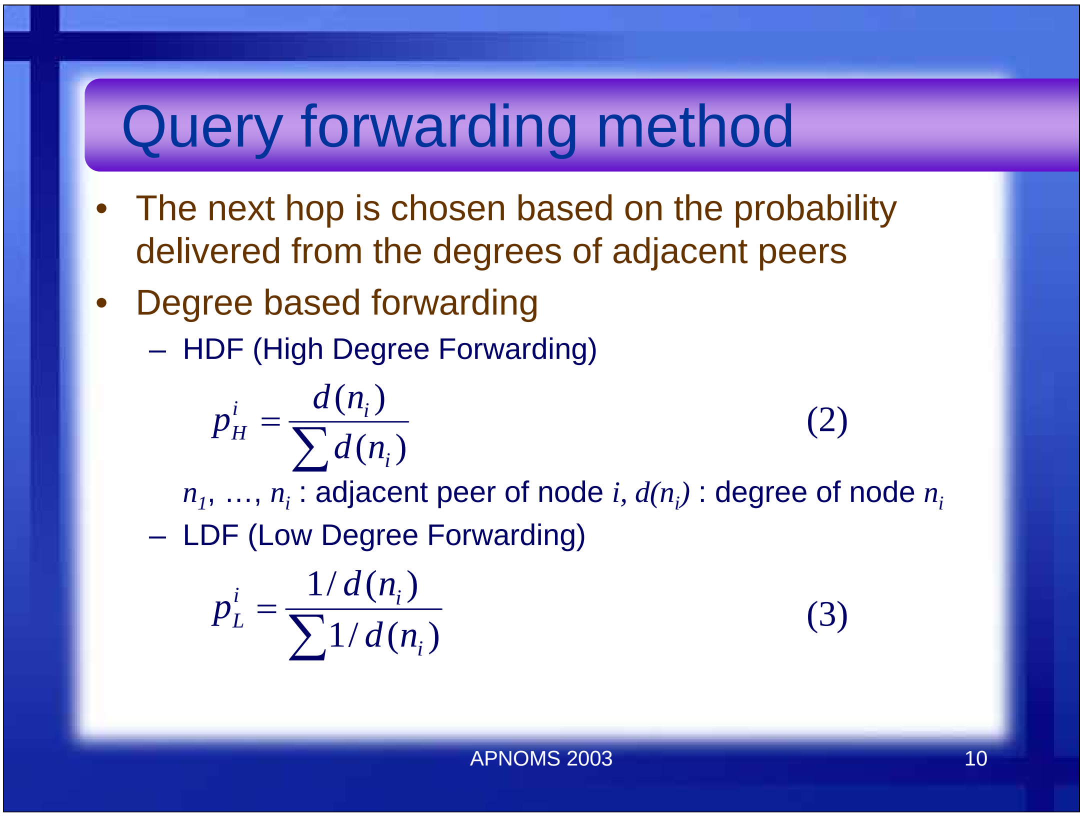
Although the influence of the Power-Law property to the query forwarding have been studied so far, the influence to the replication is not clear yet. In [1] authors have only investigated the effects of the replication in the random network topology, i.e., the effects in the Power-Law network topology have not been shown. However, the similar aspects shown in the query forwarding may be expected in the replication.



4.2 Influence of Power-Law Property to Replication

We use the Power-Law topology consisting 10,000 peers and 20,000 links generated by the BRITE [7] topology generator using BA (Barabasi-Albert) model [8]. The number of target services is set to 100, and 16 random walk is used for the search method. The value of TTL field is set to 500. Of course, the appropriate value of TTL should be existed on this simulation condition. Choosing the appropriate TTL value is our future research topic.

Because the peer having the more degrees receives the more query messages, the frequencies of access of replicas may differ according to the number of degrees of the peer owning the replica. Here, we investigate the effect of degrees on the frequency of access of replicas. We classify all peers into two groups: **high group** in where peers have many degrees (> 10), and **low group** in small number of degrees (<= 10). This table summarizes the statistics of two groups. In this table, the second row is the number of peers classified for each group. The third and fourth rows are total and average number of replicas owned by peers respectively. The fifth and sixth rows are total and average number of times accessed replicas. The last row is what percentage of all accesses is made by peers belonging to the group. As shown in this table, replicas on peers in the **high group** are accessed more than 20 times as large as those of **low group** peers, while the number of replicas is less than four times. The most interesting result is that only 5% of all peers reply 95% of all queries. That is, in the Power-Law network, most of peers (95% in this result) could not provide the capability of replication efficiently. We consider that in the good use of such inefficient replicas the effective of the replication can be much improved.



5. Query Forwarding Method

As we stated before, the importance of peers strongly depends on their degrees. So we should consider the replication methods taking the effect of degrees into consideration. In this section, we propose query message forwarding methods according to the number of degrees of adjacent peers. In the path replication used in this thesis, replicas are created along the search path on which the query message is passed. The effects of query forwarding method appear to both the search performance and the utilization of replicas. We consider an efficient replication with managing query transmission method.

In n-walkers random walk used in the previous section, the peer chose the next hop peer from its adjacent peers. On the other hand, in the proposed methods, the next hop is chosen based on the probability delivered from the degrees of adjacent peers. In our methods, we assume each peer can retrieve the degrees of adjacent peers. We call adjacent peers $n_1, \ldots, n_d$, and their degrees $d(n_1), \ldots, d(n_d)$.

5.1 Degree based Query Forwarding Methods

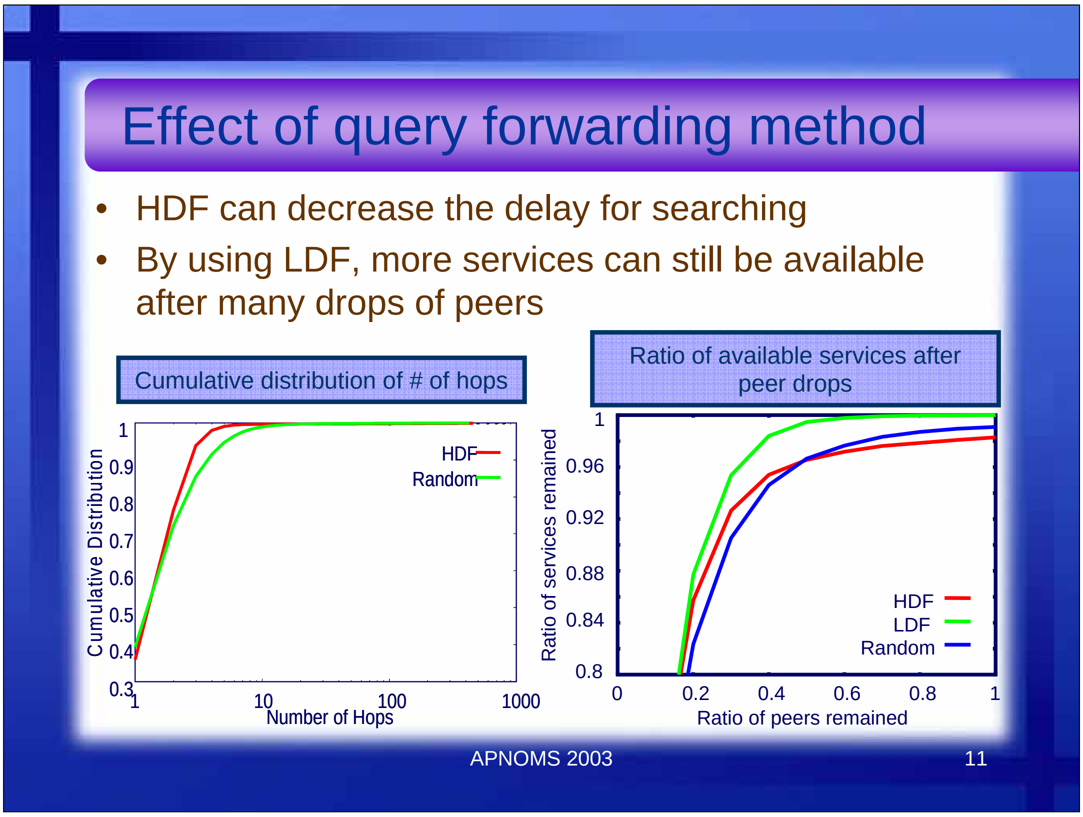
The original n-walkers random walk uses the random selection policy for choosing the next hop peer when there are multiple adjacent peers connected with the peer. Results shown in the previous section have illustrated such random policy is not much efficient in terms of both the query speed and the utilization of replicas. From this reason, we propose new query forwarding methods to improve the above-mentioned performance by taking the degree of peers into consideration. Note here that we refer **Random** as the original n-walkers random walk.

5.1.1 HDF (High Degree Forwarding)

As shown in the previous slide, peers having large degrees make more replicas than small degree peers. If we intentionally choose the larger degree peers for forwarding the query message, the search delay is expected to be shorten. For this purpose, we define a new forwarding method called HDF (High Degree Forwarding). In HDF, the next hop peer is chosen by the probability which is weighted according to the degree of peers. The probability of choosing the next peer is given by p_{H}^{i}.

5.1.2 LDF (Low Degree Forwarding)

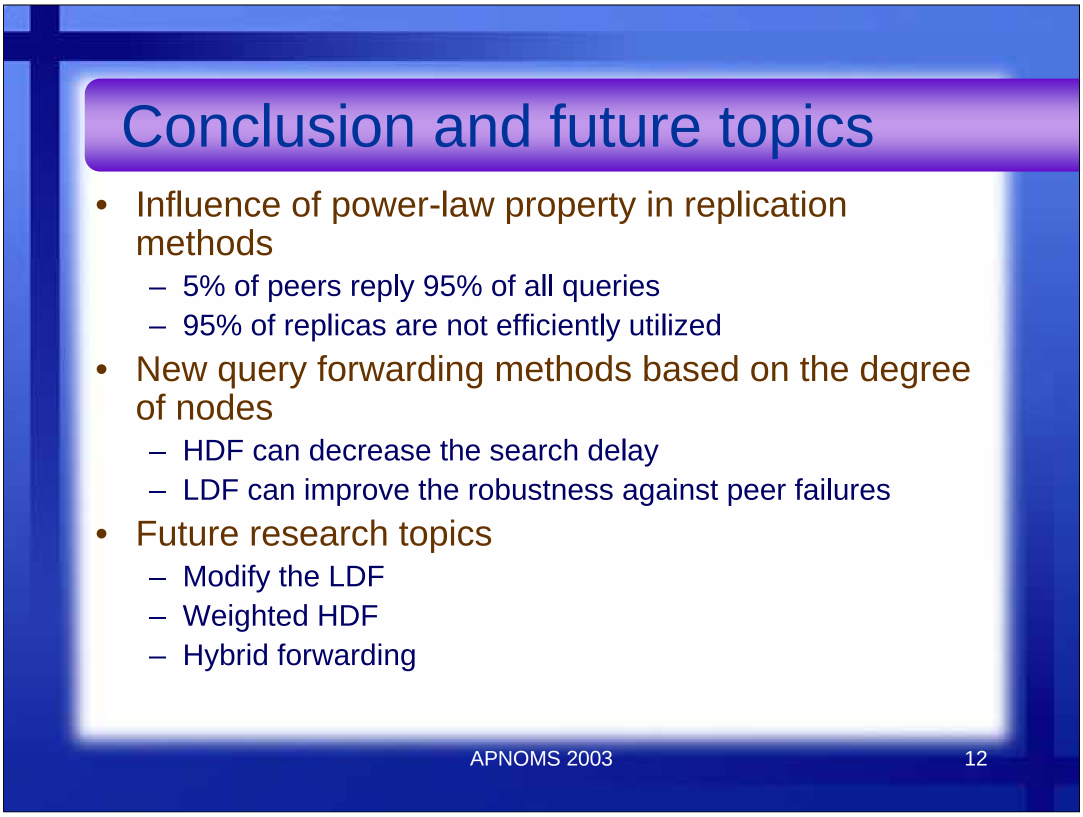
Results in the previous section have also shown that replicas on peers with smaller degrees have less reference frequencies. Conversely, when the reference frequency of the peer having a large degree becomes higher, the load of the peer is much heavier. This phenomenon implies that the P2P community becomes serious damaged, if the peer with large degree fails from community. To solve this problem, the frequency of references are entirely distributed by all peers joining the community. In this paper, we propose the LDF (Low Degree Forwarding) method for the query forwarding. In the LDF, peers with smaller degrees are intended for choosing as the next hop peer among adjacent peers. More specifically, the peer i chooses the next hop peer by the probability p_{L}^{i}, which is the reciprocal proportional function of the degree d_i.



5.2 Simulation Results

The left figure compares distributions of hop counts required for search between HDF and Random. This figure shows that HDF can decrease the hop counts. This is because HDF can reach high degree peers which has many replicas in short hops with nature of its forwarding method.

The right figure compares the ratio of available services after peer drops. We plot this figure by following steps: We first performed 20,000 queries for each forwarding methods. After 20,000 queries, we dropped a certain ratio of peers (e.g., 50%) randomly, and counted the number of services remained in the network. For example, when we dropped 6,000 of peers (= 60% of total peers), about 7% of services became unavailable in Random forwarding. From this figure, we can observe that by using LDF more services can still be available after many drops of peers. However, we notice the effect of LDF is limited because the LDF tends to make a local loop when some of adjacent nodes are high degreed. We are now developing the modification of LDF for this problem as the future research topic.



6. Conclusion

In this paper, we have focused on the effect of Power-Law property on the replication in the P2P services.

We first clarified the influence of Power-Law property in replication methods. In the Power-Law network, a few nodes have a large number of degrees while most other nodes have only a small number of degrees. Our observation have shown that 5% of peers have high degrees larger than 10, and 50% of peers only have a single degree. We have also shown that these 5% of peers reply 95% of all queries. We have found that the characteristic of network topology strongly affects the effect of replication (e.g., search speed, utilization of replicas).

Based on above observations, we next have proposed new query forwarding methods which takes degrees of nodes into considerations. We have proposed HDF (High Degree Forwarding) and LDF (Low Degree Forwarding) for the query forwarding methods. From our simulation results, we have observed that HDF can decrease the search delay instead of the degradation of the hit ratio, and the LDF can improve the robustness against peer failures compared with Random and HDF.

There are some future research topics. If we simply apply HDF to the query forwarding, the peer continuously tries to forward the query message to already visited peers with large degrees many times, and the peer becomes hard to receive the reply message when the degree of peer having the target service is small. For this problem, weighted HDF seems to be effective. Additionally, we need to modify the LDF for avoiding the local loop. To obtain the advantages in both LDF and HDF, the combination of these forwarding methods is also effective.

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