Rapid Information Delivery over Unstructured Overlay Network

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Summary
It is difficult to propagate disaster management information rapidly among clients when some local network breakdown takes place. By applying percolation theory to propagate newly defined reverse-query messages over the unstructured P2P network, we propose novel information delivery network architecture built over existing unstructured P2P network. We analyzed our algorithm and examine the validity of our model, that will cover more than 80% of all the clients ,with relaying reverse-query messages under probability as low as 10%, being effective drastically to reduce the total traffic generated by query propagation. This architecture can be a solution for presenting information to many people in the devastated area over the Internet in case of natural calamity.

Key words:
Overlay Network, Percolation Theory, CDN, Power-law distribution.

1. Introduction

It has been more than 10 years since the Great Hanshin-Awaji Earthquake took place in Japan. Today, how to secure the communication infrastructure in case of such a natural disaster draws increasing attention, because it is inevitable that we will be suffering from big earthquake in the coming future.

On the other hand, domestic network infrastructure expands rapidly thanks to governmental e-Japan strategy. Today, number of broadband users sums up to 20 million and overall penetration rate for households counts for more than 40%. With the emergence of such broadband communication infrastructure, people can enjoy any type of contents at any time over the network.

However, when it comes to the matter of how we should deliver broadband contents that contains disaster management information over the Internet, the total throughput will be determined by any bottleneck somewhere between contents provider to consumers. For example, even a user purchases 100Mbps optical fiber service, one's requested contents comes from distant server only 100Kbps because of narrow path somewhere over the Internet. Most of proxy servers distributed over the Internet are aimed for static contents like homepage objects, and are not tuned for broadband stream contents.

For instance, once many users try to pull large video streams at the same time, it is clear that backbone network is easily falls into overflow. This requires a new contents delivery technology which supports a huge simultaneous access transaction for broadband objects.

For this purpose, to deliver broadband contents over the Internet, CDN(Contents Delivery Network) architecture [1], [2] and contents distribution algorithm for replication [3], [4] are actively studied. But such CDN solutions for large scale contents delivery faces difficulty because the number of acceptable simultaneous access is almost determined by hardware specification of cache servers, and this falls into optimal cache server distribution problem with considering dynamic request load balance under the exact forecast of contents popularity and hardware availability.

This is also regarded as a big issue for realizing broadcast type traffic over the Internet, which could be a solution for sharing disaster management information. Existing technique to handle telephone call over the telephone network is specific for point to point traffic, and it is not applicable for clearing simultaneous access to a contents sever, that makes it difficult to deliver broadband contents to many clients.

This study aimed for overcoming this problem by building our proposed overlay network over the Internet, and to manage generated traffic under our control, to share information toward disaster management among mobile phones and navigation system installed on cars.

We develop a new contents delivery network for broadband contents based on the fact that many link status on the Internet follows power law distribution [5]. For example, one of the most popular pure P2P network Gnutella has been analyzed that its nodes' outgoing degree can be expressed as $P(k) \sim k^{-\tau} (\tau \geq 0)$ [6]. However, such an unstructured network is not manageable in nature, and makes it difficult to apply for contents delivery for its fundamental network architecture.

Manuscript received January 25, 2006.
Manuscript revised January 30 , 2006.

In this paper, we employ percolation theory [7] that is mainly studied in physics, to model the "percolating information" for contents delivery over the pure P2P network. In other words, the query message released by client seeking for requested contents is not merely used for this purpose, but we define a new "reverse-query" message to find any client who needs a certain contents and try to apply the percolation theory to manage the generated traffic. This will lead to reduce the explosive P2P query traffic while maintaining fairly high clients cover rate over our proposed overlay network. We will expect rapid information propagation among clients who joins this overlay network. An outlook of our model is shown in Fig.1.

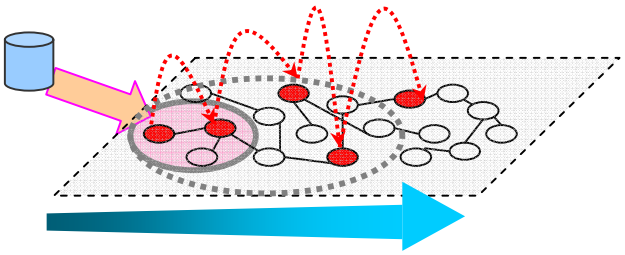

Fig. 1 Message Propagation over the P2P Network

2. P2P Network

2.1 P2P Network Problems

Recently, file sharing application over P2P network has been pervasive and it plays an important role as contents distribution infrastructure.

P2P network holds such technical problems in nature as:

- Interoperability between peers
- Scalability and reliability without center server
- How to keep anonymity and privacy
- Adhoc join and leave behavior

When we apply P2P network for contents delivery, under the pure P2P architecture which has no center server, it is major concern how to find available resources and required contents from all over the network. In this field of study, such projects as CAN[8], Chord [9], Pastry [10], Tapestry [11] are trying to employ Distributed Hash Table (DHT)[12].

However, in order to apply for commercial services, there exists more problems in this DHT solution.

- When peers join/leave the network, they have to takeover management table to some other peers, results in heavy overhead.
- Network structure becomes complicated.

In addition, traffic generated by those P2P nodes has been increasing more and more, whose amount of load gives serious impact to today's ISP backbone network. If we can manage such huge traffic, it will be a good news for Internet backbone operators. There are several ways to detect P2P traffic as: "by signature pattern", "by application layer", "by flow parameter" [13]. However, those solutions are to insert gateway devices into the network and force to control the bandwidth upon detected information. This requires additional hardware costs and could be regarded as degrading usability for users.

2.2 Query Traffic

In this study, we propose a new network architecture for broadband contents delivery which can solve problems shown above and applicable for quasi-broadcast platform over the internet.

To estimate the amount of total traffic for retrieval query sent by each client, there is a report from [14].

And for modeling method of network with a power law link distribution, there is an algorithm by [5] with preferential attachment model. However, this method focuses mainly on the growth of network itself and analyzing dynamic traffic behaviour has been still left for further study. Also, validation of those theoretical network structure and real P2P network on the Internet is not fully analyzed yet.

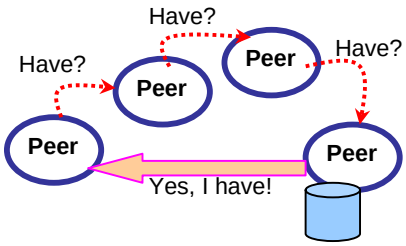

Fig. 2 Do-you-have? Query

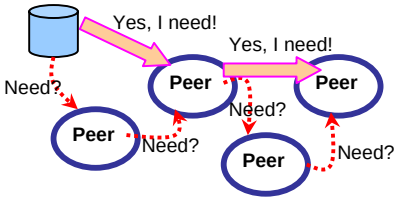

Fig. 3 Do-you-need? Query (= Reverse-query)

Percolation theory is introduced in [7]. Sarchar [15] applied this percolation theory for propagating retrieval query over the network ("Do-you-have"model), but this study conclude query transfer has finished when the query

reaches any giant node on the P2P network, which does not meet our objective. In our study, we spread information of contents attributes in the form of deliverying "reverse-query" ("Do-you-need" model) and those who have interests in the contents will try to download the contents from its previous peers. This concept will lead to a new contents delivery platform of Reverse-query mechanism. Fig.2 shows basic concepts of "Do-you-have"query and Fig.3 shows "Do-you-need" query.

3. Reverse-query Mechanism

3.1 Proposed Method

This study basically deals with information propagation by managing traffic generation from provider's side, that is, completely different from existing model which throws "Do-you-have what I need?" query from receivers' side, but throws reverse-query as "Do-you-need this contents?" to all over the network. Our mechanism lets us propagate necessary information to all peers on the network while controlling the amount of generated traffic. This is fairly new concept of push-type contents delivery platform

3.2 Algorithm

In this study, we propose the new algorithm that propagates reverse-query message and contents by applying percolation theory to P2P network.

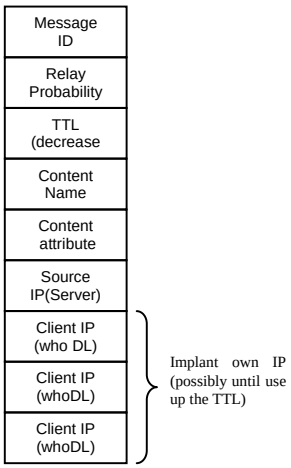

Fig. 4 Reverse-query message structure

The message structure is shown in Fig.4, Message ID, relay probability; TTL, contents name, attributes and source node IP are kept in the header of the message, followed by clients node IP who downloaded the contents. Those elements are minimum set of information that is to implement our proposed mechanism. Here is an example of each nodes' procedure.

Step1 : Message Distribution
The server which holds contents to be delivered generates a "do-you-need" message and sends it to some randomly selected peers.

Step2: Bond Percolation
Following the step1, the first receiver peer A compares the attribute of the contents with its own preferences, and if they match, peer A tries to pull the contents file from the initial server. Following this operation, peer A revise the "do-you-need" message to implant its own IP showing it is retrieving the contents now, and forward it to some randomly selected neighbors.
In case of peer A's favor does not match the contents attribute, peer A is expected to just forward the message to some randomly selected its neighbors.
By repeating this operation, the "do-you-need" message" covers whole peers within a certain period of time.

Step3: Contents Extraction
Suppose peer B receives the "do-you-need" message" from peer A. Peer B compares the attribute of the contents with its own tastes as peer A in Step2, and if they match, peer B also tries to pull the contents from the previous peers listed in the relay chain. (This case, it is probably from peer A)

When we choose the relay probability to be just above the percolation threshold of underlying power law network, the message can be propagated all over the peers [15].

3.3 Analysis

In this chapter, we will evaluate the feasibility of our proposed mechanism.

3.3.1 Basic Model

First, let us suppose two typical cases based on each node's behavior.
(1) Transfer All Queries
Each node forward the received query to its all neighbor nodes. The necessary number of forwarding hops to cover the whole network is dependent on the shape of network, however, it is clear that minimum number is 1 (= star shape architecture that all nodes are reachable just 1 hop from the origin) and maximum number is half the radius of network. The size of existing P2P network is studied by the method proposed in [16].

(2) Transfer Queries According to Relay Probability

Consider the probability that query is transfered between node a and b. Let p to be the probability that a link exists between those two nodes. Then, the query will be transfered from a to b:

(i) a -> b

is p because a and b are directly connected.

(ii) a -> c -> b

Let the probability that c transfers query to be α , then the query will be transferred a -> b

$$\alpha \bullet (1-p) \bullet p \tag{1}$$

and the probability that query will not be transferred a -> b is

$$(1-\alpha) \bullet (1-p) \bullet p \tag{2}$$

(iii) a -> c -> d -> b

In the same way, let the probability c and d transfers query to be α , then the query will be transferred a -> b

$$\alpha^2 \bullet (1-p)^2 \bullet p \tag{3}$$

This can be extended to n nodes case between a and b

$$\alpha^n \bullet (1-p)^n \bullet p \tag{4}$$

3.3.2 Percolation on Generalized Random Graph

The percolation behavior on generalized random graph can be led as follows [17].

Suppose the degree distribution of each node to be p(k), then the general function of this distribution can be defined as:

$$G_0(x) = \sum_{k=0}^{\infty} p(k) x^k \tag{5}$$

Suppose the vertex distribution of connected component on generalized random graph holds general function $H_0(x)$, and general function for the size of connected component from a certain branch to be $H_1(x)$. Then the average size of connected component $<| c_0 |>$ to be

$$<| C_0 |> = H_0^{'}(1) = 1 + G_0^{'}(1) H_1^{'}(1)$$

$$= 1 + \frac{G_0^{'}(1)}{1 - G_1^{'}(1)} \tag{6}$$

The state transition will take place when right-hand side becomes 0,

$$G_1^{'}(1) = 1 \Leftrightarrow \sum_k k(k-2) p(k) = 0$$

$$\Leftrightarrow \frac{< k^2 >}{< k >} = 2 \tag{7}$$

Here, the percolation threshold can be

$$q_c = \frac{1}{\frac{< k^2 >}{k} - 1} \tag{8}$$

If we assume our delivery platform to be generalized random graph, we can say that almost all node can receive the transferred messages when each node relays received messages more than q_c.

3.3.3 Percolation on Power law Overlay Network

The percolation behavior on the power law overlay network can be led as follows.

(1) From Origin to the First Neighbor

We will consider the number of vertex that is 1 hop away from the origin.

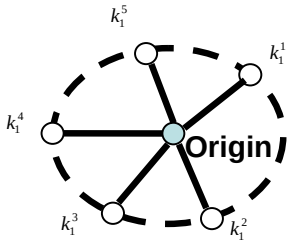

Fig. 5 First neighbors

Let us employ the expression k_m^n, which shows the degree of vertex to be m hops away from origin (lower right) and nth vertex out of the set of m vertexes (upper right). Fig.5 shows an example.

Then, remember the assumption that every node on the network has degree according to power law. This assumption is observed from real P2P network [6]. When we assume the origin holds connection with k_0 vertexes, then the number of vertex that can be reachable within 1 hop from origin is

$$k_1^1 - 1 \tag{9}$$

As there are k_0 vertexes as a whole, then the total number of reachable vertexes is

$$\sum_{i=1}^{k_0} (k_1^i - 1) \tag{10}$$

(2) Duplicated First Neighbor

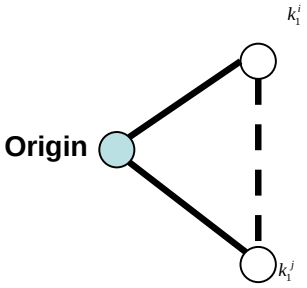

Fig. 6 Duplicated path

Then, we will reduce the duplicated number in the case of graph of Fig.6.

In the Fig.6, we need to subtract the paths k_i to k_j and k_j to k_i, because both k_i and k_j are counted as just 1 hop away from the origin.

The expected value for the number of vertex, that k_i is 2 hops away from the origin is

$$\sum_i \frac{k_1^i - 1}{n-2}(k_0 - 1) \tag{11}$$

Let the total number of vertexes D, which is reachable within 1 hop from origin can be expressed from (10) and (11)

$$D = \sum_{i=1}^{k_0}(k_1^i - 1) - \sum_i \frac{k_1^i - 1}{n-2}(k_0 - 1) \tag{12}$$

As this number is overestimated, it is enough to employ this equation to calculate the reachability from the origin.

(3) Distant Neighbor

The number of vertex V_m that m hops away from the origin can be expressed as

$$V_m = \sum_i \frac{k_2^i - 1}{n-m}(D + k_0^1) \tag{13}$$

By using recursive equation, the number of vertex n hops away from origin can be obtained in the same way. When we want to deliver a certain message to more than 80 % of nodes on the overlay network by applying (4), it is enough to deliver the message as:

$$\alpha^{V_m} \bullet (1-p)^{V_m} \bullet p \geq 0.8 \tag{14}$$

In the next chapter, we have investigated the dynamics of α upon mathematical simulation.

4. Evaluation

4.1 Simulation

In order to evaluate our proposed model, we prepared a random network with a power law link distribution generated by Pajek [18], and implemented our algorithm on R environment. This overlay network is generated based on generalized BA model, which presumes that every vertex has at least some baseline probability of gaining an edge, to generate edges by mixture of preferential attachment and uniform attachment [19].

For generating condition, we set the total number of nodes N=1000, M_0=3, TTL=5 to 25 and average degree = 2.0 to 3.5.

In order to evaluate the results, we counted the number of generated messages (= reverse-query) and cover rate (=how much of nodes receives the reverse-query) upon relay probability implanted in the reverse query message.

4.2 Results

Fig.7 and Fig.8 shows typical examples of message propagation over this generated overlay network. In those three examples, we fixed the average degree of nodes to be 2.7 and compared the effects of TTL.

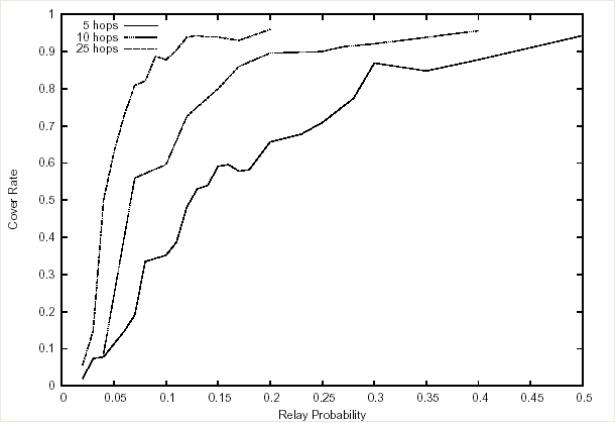

Fig. 7 Simulation Results (1) (Ave.Degree = 2.7)

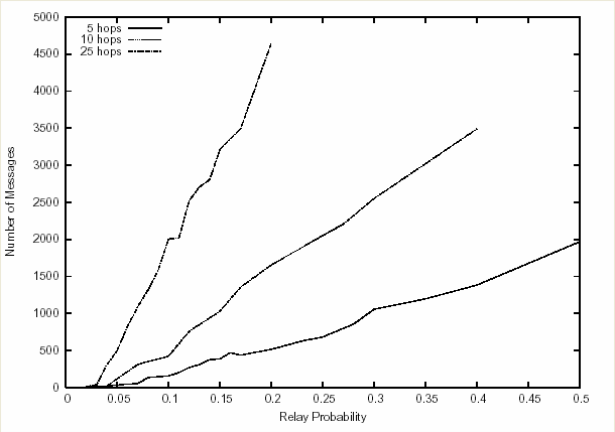

Fig. 8 Simulation Results (2) (Ave.Degree = 2.7)

In Fig.7, the outlook of those graphs looks quite similar, i.e., the propagating message will cover almost 80% of nodes upon certain relay probability, and Fig. 8 shows that the total traffic increases linearly. The only difference among those results is the scale of relay probability, which proves our proposed model will work even lower TTL.

In Fig.7 of TTL=5, the cover rate reaches more than 80% on relay probability of 0.3, while in TTL=25 shows relay probability of 0.07. By looking at equation (14), it is enough to set relay probability only 0.07 to cover 80% of nodes to deliver reverse-query message over the nodes joining this overlay network.

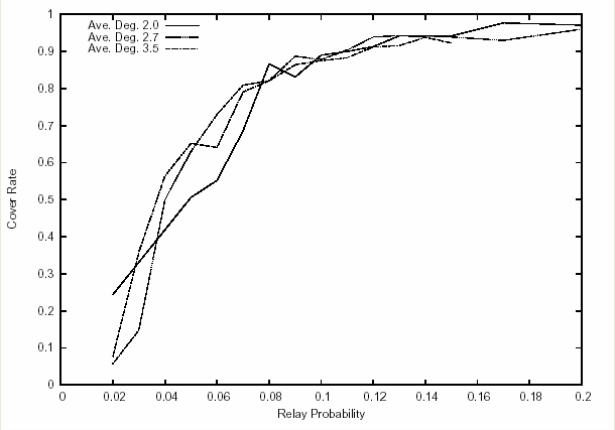

Fig. 9 Simulation Results (3) (Hop Count = 25)

Next, we tried to look into the effect of average degree of nodes in Fig.9. Though the link degree distribution in the real world is reported to be mostly 2 to 3 [20], we examined as the extreme case of average degree to 3.5. In both cases, TTL is maintained to 25. In Fig.9 of average degree 2.0, the leading edge of left side is slightly lower than that of average degree 2.7, but it does not make difference in terms of relay probability that covers 80% of all nodes. In Fig.9 of average degree 3.5, the result looks quite similar to that of average degree 2.7. This can be said because the message propagation is already saturated in case of Fig.9.

4.3 Validity

As we analyzed in the previous chapter, nodes which can be reachable from origin within n hops is expressed as equation (14). And if we set the relay probability optimally, the message will propagate to whole network as shown by simulation results. If we deliberately choose the relay probability, we can obtain the optimized condition that reducing the total number of generated messages while covering almost all the node over the network.

If we attach small video clip in the reverse-query message, it is possible to use this contents delivery mechanism as propagating electronic flyer all over the clients, making it as quasi-broadcast platform.
All the node does not necessarily have large memories, just buffering for few minutes and relay the data to its next peers who have interests in that contents' attributes.

As we observed in the simulation results, after several steps of relaying messages, the copy of message body will just go out from the overlay network, and this will lead to reduce the explosive P2P query traffic while maintaining fairly high clients cover rate over our proposed overlay network.

5. Conclusion

In this paper, we employ percolation theory to model the "message propagation" for contents delivery which contains disaster management information over the unstructured P2P network. We defined a new "reverse-query" message to find any client who needs a certain contents and try to apply the percolation theory to manage the generated traffic. We analyzed validity of our model through mathematical consideration and examined its dynamics by simulations. This can conclude that our proposal is effective to reduce the total amount of generated query traffic while maintaining high cover rate, which means we can provide robust network platform to propagate information rapidly among mobile phones and navigation systems over the Internet, because our model is sustainable for local breakdown.

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