S-Ring: A P2P-based Information Diffusion Environment Utilizing the Ring Topology

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Abstract: Recently user-generated content (UGC) has become major content of the Web and the real-time Web such as Twitter has become popular. Meanwhile, P2P-based information sharing systems have been used to realize scalable, fault-tolerant and sometimes anonymous information sharing. Although existing P2P-based information sharing systems are very useful, it seems that they do not have enough ability to realize the real-time Web. In this paper, we propose an information diffusion environment which uses a ring topology to realize the real-time Web in a P2P manner. The ring topology makes it possible to effectively collect the feedback from users at the same time when each piece of UGC passes through user terminals. The proposed environment, named S-Ring, enables consumers to get trusted information passively as easy and simple as watching TV on a timely basis. We will show the positive feasibility of S-Ring based on our findings from analysis of a previous study on Twitter. Furthermore, the results of simulations provide insights about trade-offs between time required for information distribution and network resource consumed in the ring networks.

1. Introduction

Recently user-generated content (UGC) has become major content of the Web[1]. Generally UGC is shared among consumers by using the conventional client-server architecture. Content distribution networks (CDNs) have enabled a large number of consumers to download vast amounts of information like high quality videos simultaneously[2]. Additionally, with the help of cloud computing, the real-time Web such as Twitter which enables users to receive information as soon as it is published has become popular. In particular, when serious incidents or natural disasters have happened, it is not unusual that information about them is published earlier than traditional media like TV and radio. For instance, immediately after the Great East Japan Earthquake, Twitter particularly made a significant contribution to share information[3]. Meanwhile, P2P-based information sharing systems have been used to realize scalable, fault-tolerant and sometimes anonymous information sharing[4]. Although these P2P-based information sharing systems are very useful, it seems that they do not have enough ability to realize the real-time Web.

In this paper, we propose an information diffusion environment which uses a ring topology to realize the real-time Web in a P2P manner. The proposed environment is named S-Ring coming from rings organized by the information stream. S-Ring is a new P2P-based information diffusion environment which enables consumers to get trusted information passively as easy and simple as watching TV on a timely basis. In S-Ring, users are clustered in accordance with their interests and user terminals organize a ring network. UGC is delivered to all user terminals along the network and users can watch and/or listen to them passively. UGC which is offensive to public order and morals will be deleted based on the feedback from users. The ring topology makes it possible to collect the feedback from users at the same time when each piece of UGC passes through user terminals.

In addition, we will show the positive feasibility of S-Ring based on our findings from analysis of a previous study on Twitter. Furthermore, the results of simulations provide insights about trade-offs between time required for information distribution and network resource consumed in ring networks. In the simulation, simple ring networks and Chord-based networks are compared as implementation candidates of the P2P ring network.

Major contributions of this work can be summarized as follows:

- We propose a new P2P-based information diffusion environment utilizing the ring topology which enables users to get information passively and reflect their feedback to the information on a timely basis;
- We reveal the trade-offs between information diffusion time and network resource consumption in the ring topology through fundamental simulations comparing a simple ring topology and a Chord-based topology.

The rest of the paper is organized as follows. Section 2 provides the positive feasibility of S-Ring referring to Twitter. In Section 3, S-Ring is proposed. The simulation results are shown in Section 4. Finally, Section 5 concludes the paper and gives an outlook on the future work.

2. S-Ring and Twitter

In this section we analyze and discuss a previous study on Twit-

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ter to show the feasibility of S-Ring. Twitter has employed the client-server architecture while S-Ring employed the P2P architecture. Although these two are totally different from each other in their architecture, Twitter bears an important resemblance to S-Ring in terms of information acquisition which is unexpected for consumers.

2.1 Analogy between S-Ring and Twitter

Twitter is one of the most popular microblogging services. Users can send posts of up to 140 characters, called "tweets", and subscribe to other users' tweets. This action to subscribe is called "follow" and subscribing users are called "followers". Generally Twitter is also regarded as an online social networking service because of this following-followed relationships.

Users of Twitter are not limited to only individuals but also organizations such as companies and universities[5]. Automatic programs are also handled as users. That kind of programs post popular tweets, tweets in specific fields, and so on. In addition, Twitter has the function, called "retweet", which enables users to diffuse information they credited to their followers. These facts mean that users can get information from other users whom they are not directly following to.

From this point of view, S-Ring and Twitter are analogous. Both S-Ring and Twitter can provide unexpected information to users passively. Consequently, it can be said that findings from Twitter are meaningful to discuss the feasibility of S-Ring.

2.2 Analysis and Discussion

The following analysis results are based on a previous study on Twitter by Haewoon et al. [6]. According to the paper, 41.7 million user profiles are collected. There exist 1.47 billion directed following-followed relationships. Spam tweets are removed and 106 millions tweets including retweets are used for the analysis.

First concern is about users of Twitter. If the number of followings and followers are plotted as the complementary cumulative distribution function (CCDF), the lines fit to a power-law distribution with the exponent of 2.276 roughly. Most real networks including social networks have a power-law exponent between 2 and 3. Users who have more than 10^5 followers have many more followers than the power-law distribution prediction. Moreover, there are only 40 users with more than a million followers and all of them are either celebrities or mass media.

Because an enormous number of users have a common interest in information posted by celebrities and mass media, these information should be treated distinctively from other information in S-Ring. To distribute information to an enormous number of users, the P2P streaming model must be the best way as used in P2P TVs [7]. Adapting the P2P streaming model may make S-Ring difficult to collect the feedback from users. Thus only a few trusted celebrities and mass media should be treated as an exception.

Next concern is about retweet. Recall that retweet is one of the factors which gives Twitter a resemblance to S-Ring. Retweet forms trees of pathways of information distribution from a node which posted information to other nodes who received it if following-followed relationships are regarded as directed

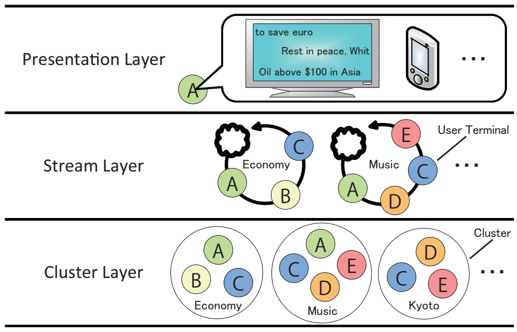


Fig. 1 The three-layer model of S-Ring

graphs. The trees whose height is 1 are the most common claiming 95.8%. All retweet trees but for a handful have a height which is lower than 6, and no tree goes beyond 11 hops. Furthermore half of retweets occur within an hour, and 75% under a day. However, about 10% of retweets take place a month later.

If we regard the number of retweet as an indicator of information's popularity, it can be said that information which has high popularity does not exist in large amounts. Even if a threshold of popularity was more than 2 hop, only 4.2% of whole information has popularity. Besides, each piece of information has different lifetime. Short-life information should be handled differently from long-life information so that users can recognize a property of information easily.

3. S-Ring

S-Ring enables users to get information as easy and simple as watching TV on a timely basis. P2P principles provide the features of scalability and fault-tolerance for S-Ring. The ring topology of S-Ring makes it possible to collect feedback from users and reflect the feedback to the information effectively.

3.1 Architecture

The architecture of S-Ring consists of three layers. The three-layer model of S-Ring is illustrated in **Fig. 1**. The small circles indicate user terminals such as computers and smartphones. The role of each layer is described below.

3.1.1 Cluster Layer

The cluster layer defines user groups. Users are clustered in accordance with their interests. Note that users can belong to multiple groups at the same time. The large circles surrounding user terminals indicate clusters of user terminals. User terminals marked by the same label represent the same user terminal.

We do not feature clustering methods because it is not the central topic of this paper to cluster users; users shall be clustered in some fashion. There are many well-known soft clustering methods[8].

3.1.2 Stream Layer

The stream layer defines the information stream in each of clusters. Terminals of users in respective clusters organize a ring network and distribute information along the network. This flow of information among user terminals is named the "information stream". Each ring network represents the information stream for each of the clusters. Further details of the information stream is provided in the next section (3.2).

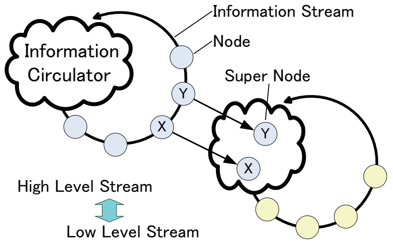


Fig. 2 The structure of the Information Stream

3.1.3 Presentation Layer

The presentation layer defines methods to provide information to users. Presentation methods would vary according to the difference of types of user terminals such as smartphones, tablets and desktop PCs. Although S-Ring does not strictly define how diffused information must be presented, presentation methods are expected to enable users to watch and/or listen to information passively. Presentation methods also should express which clusters information came from. Users might belong to several clusters and information is delivered from each of the clusters. Even if the same information is posted, it will be public or foreclosed by the difference in clusters. This means that credibility of information depends on not only who posted it but also which clusters it came from. For an extreme example, if a piece of information which says "Japan did default" is diffused in a joking cluster, most users will never believe it and just skip it. In contrast, if it is diffused in an economic cluster, users will be surprised and try to check if it is true or not in some way.

3.2 Information Stream

As explained in the previous section, in the stream layer, clustered user terminals organize ring networks and information diffusion occurs forming the information stream along the network. The information stream is the heart of our research. The structure of the information stream is illustrated in **Fig. 2**. Note that this is an abstracted ring network. Examples of real implementations are simple ring networks and Chord-based networks as presented in Section 4. User terminals such as computers and smartphones are indicated by circles, hereinafter called nodes. Super nodes are elected from nodes based on some conditions and organize the information circulator. The conditions could be the performance of CPU and network and/or duration time of online. While an information circulator can be organized by only one super node, it should be organized by multiple of super nodes to deal with network failures and sudden defection of super nodes. Super nodes and normal nodes then organize an overlay network. This overlay network is a P2P-based network and its topology is the ring.

The information circulator manages the information stream. Once pieces of information posted by nodes arrive the information circulator, each piece of information starts out from and arrives back in the information circulator as the information stream. During that time, information flows among user terminals along the network and users can watch and/or listen to them passively. In addition, information which is offensive to public order and morals will be deleted by the information circulator based on the feedback from users. Feedbacks are attached with corresponding

Algorithm 1 Procedures for node

1: **procedure** onReceive(*info*)
2:     **if** *info* is not already received **then**
3:         notice(*info*)
4:         **for** $i \leftarrow 0$, *receivers*.length **do**
5:             send(*receivers[i]*, *info*)
6:         **end for**
7:     **end if**
8: **end procedure**

9: **procedure** evaluateInfo(*info*, *eval*)
10:     *info*.add(*eval*)
11: **end procedure**

12: **procedure** postInfo(*info*)
13:     **for** $i \leftarrow 0$, *receivers*.length **do**
14:         send(*receivers[i]*, *info*)
15:     **end for**
16: **end procedure**

pieces of information and collected at the same time when each piece of information passes through user terminals.

The simplified algorithm for nodes is indicated in **Algorithm 1**. Once information arrives from other nodes, onReceive() is called. In the procedure, information which is already received is not processed and new information is passed to notice() so that presentation methods in the presentation layer can provide it to users. Users may evaluate the information in some cases. Subsequently, the information is transmitted to receivers. How to determine receivers is highly dependent on network topologies. Note that user evaluation can occur simultaneously when the transmission is ongoing. In that case, the feedback is only transmitted to receivers which do not have received the information yet. The feedback will be transmitted to the remaining receivers if the information come up again because of its TTL value is still valid. Each piece of information has a TTL value which determines its lifetime. This means that the condition expression at line 2 is evaluated based on an identifier of information and its TTL value. Additionally users can post new information as well by calling postInfo() .

The simplified algorithm for the information circulator is indicated in **Algorithm 2**. A TTL value of information is decreased firstly when the information arrived in the information circulator. Then the feedbacks from users are tallied. The TTL value of the information is prolonged or the information is defeated if necessary according to the tally. Information which is still valid is transmitted to receivers and other information is finally deleted. Note that a piece of information may arrive back in the information circulator with some replicas which are duplicated in the diffusion process; a node transmits a piece of information to receivers in the diffusion process and each transmitted piece can be regarded as replicas of the original piece. In that case, all pieces containing the same information are merged to one piece in the tallying process. More realistically, the information circulator will collect just a certain number of pieces to merge them to one and tally the feedbacks. Then, other pieces which come in later will be dropped to deal with sudden logoff of nodes which can lead to disappearance of replicas.

Algorithm 2 Procedures for the information circulator

```
procedure onReceive(info)
    info.decreaseTTL()
    tallyEvaluation(info)
    if info is still valid then
        for i ← 0, receivers.length do
            send(receivers[i], info)
        end for
    else
        info.delete()
    end if
end procedure

procedure prolongInfoLife(info, additionalTTL)
    info.addTTL(additionalTTL)
end procedure
```

3.3 Efficient Distribution

How to distribute information efficiently is an important issue. If it requires enormous time to distribute information to all users, no users will hope to use the system and the system will fall into discredit.

One simple way to distribute information efficiently is layering of ring networks. As seen in Fig. 2, if time required for information distribution is getting longer, new super nodes are selected (X and Y) and organize a new ring network as the information circulator. However, to restructure ring networks into layered ring networks costs much obviously and is quite difficult to manage. Dynamic network restructuring should be better to avoid if possible. A discussion about layering of networks is made based on the simulation results in Section 4.4.

The principle of S-Ring that information is transmitted along ring networks signifies that it is not realistic to transmit vast amounts of information like high quality videos directly. For handling that kind of information, a combination of S-Ring and content distribution networks (CDNs) is one of the most potent solutions. This means that each piece of information is divided into a header and its body, and only headers are distributed in S-Ring. For instance, a pair of title and URI may be distributed and the body of the information may be located in the Web. If web servers can be used, CDNs postulating the Web such as OpenWeb[9] would be proper. Alternatively, CDNs postulating P2P[10] would be proper if web servers cannot be used or are not allowed to be used for some reason.

In the future, if the next generation network (NGN) has been well-wired, it may bear a chance of transmitting vast amounts of information directly.

3.4 Popularity of Information

Popularity of information can be defined as how many users feel the information is useful. If a piece of information is only useful for few users, it could have no popularity. In contrast, if a piece of information is useful for a large majority of users, it could have extremely high popularity.

In S-Ring, information is expected to have some popularity. This is because the information stream passes through all of user terminals in each cluster. Though all users can post information freely, the feedback from users and the TTL mechanism will foreclose information which has no popularity.

It should be pointed out that popularity is heavily dependent on the kind of clusters as mentioned before. Even if the same information is posted, the information will be popular or foreclosed in accordance with the characteristics of each cluster.

4. Fundamental Simulation

To investigate characteristics of the ring network, simulations which compare simple ring networks with Chord-based networks have been done. These two are prospective candidates for realizing the ring network in S-Ring.

4.1 Simulation Setting

Settings for the simulation are as follows.

Unit time

As seen in Algorithm 1, the most time-consuming process is clearly the part of line 4 to 6 which transmits information to other nodes. Therefore the unit time in the simulation is defined as time required for transmitting a piece of information to another node. In other words, a node can transmit information to only one node in a time unit. Of course different nodes can work simultaneously in the same time unit.

Number of nodes

The number of nodes is fixed to 2^{10}, 2^{13}, or 2^{16}. One of them works as a super node and others work as normal nodes. Although the information circulator will be organized by more than one super node in reality, in this simulation, the information circulator is organized by only one super node to simplify the simulation.

Length of a successor list

Successors are nodes which come after a node in a ring network according to the direction of the information stream. If the length of a successor list is 1, a node only knows the next node in a ring network. If the length is 2, a node knows the next node and the node after the next node. The same goes for the following. The length of a successor list ranges from 1 to 10.

Topology

Two network topologies are arranged. One is a simple ring network and the other is Chord. Simple ring networks use only successor lists to diffuse information. Chord-based networks use both successor lists and the finger tables. The finger tables are special shortcuts to other nodes which are away from a node[11]. Typical algorithm of Chord is used to make the finger tables. Some nodes in a successor list may overlap with nodes in a finger table. In that case, nodes of finger tables which also appear in successor lists are not used for information diffusion.

Note that, in the network organization phase, a route which steps over the information circulator is not allowed because all of the information stream must be under the control of the information circulator. If such routes are going to be made according to successor lists and/or finger tables, the destinations of the routes are replaced with the information circulator.

4.2 Simulation Scenario

At the beginning of simulation, nodes are generated and a network is organized according to the settings. Then a piece of infor-

Table 1 Number of required samples

# of nodes	2^{10}	2^{13}	2^{16}
# of required samples	279.6	367.0	381.9

mation starts flowing from the information circulator and elapsed-time counters start. For each time unit, transmissions which have occurred and the number of nodes which have received the piece of information are recorded.

In the information transmission phase, each node tries to transmit a piece of information in order, from the farthest node in candidates, to receivers which do not have received the information yet. This is because the results of preliminary experiments show that farthest-first transmission is the most suitable from the view point of time required for information diffusion.

4.3 Result

4.3.1 Collection of Feedbacks

It is an important issue to know how many feedbacks can be collected. Although the ideal feedback is a unified feedback which is collected from all users, not all information pieces can arrive at the information circulator because some duplicated information pieces are not transmitted to other nodes in the cause of the condition expression at line 2 in Algorithm 1. Consequently, it is impossible for S-Ring to collect feedbacks from all users except in the case of employing a simple ring network where the length of successor lists is 1.

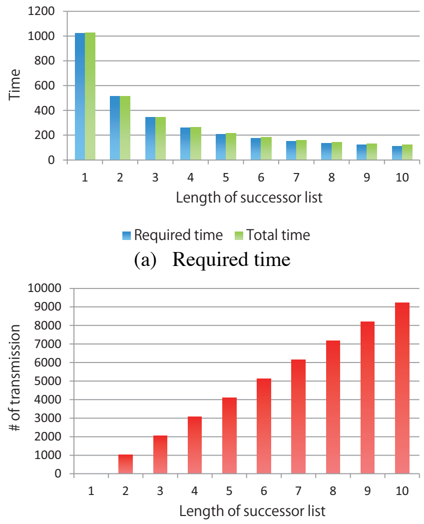
Table 1 shows the thresholds of required samples to guarantee a level of statistical significance. These thresholds are calculated under the common assumption in statistics that the maximum error is 0.05, the confidence coefficient is 1.96, and the population proportion is 0.5. If collected feedbacks exceeds the thresholds, the feedbacks can be treated as a unified feedback of all users with a 95% confidence level.

Table 2 shows the maximum number of collectable feedbacks when all users assessed a piece of information. Simple networks could not exceed the threshold under the condition of 2^{10} nodes and the successor lists having a length of more than 4. On the other hand, Chord-based networks exceed the thresholds in any conditions. Additionally, simple networks are strongly affected by the length of successor lists, but Chord-based networks are not.

4.3.2 Required Time and Network Resource

How fast information is diffused is another important issue. Recall that half of retweets occur within an hour. S-Ring should also diffuse information within around an hour so that users can access the information as fast as Twitter.

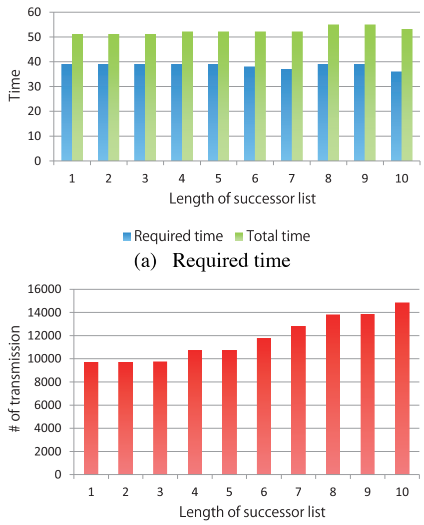
Fig. 3 shows the results in case when a piece of information is diffused in simple ring networks which consist of 2^{10} nodes. In Fig. 3 (a), total time indicates time elapsed until all of the nodes have completed the diffusion process and required time indicates time elapsed until all of the nodes get the piece of information. Note that total time is always longer than required time because total time includes process time of redundant transmission after all of the nodes get information. As the length of successor list is getting longer, the required time and the total time get to be shrinking rapidly like a power-law curve. Moreover there is little



(a) Required time

(b) Redundant transmission

Fig. 3 2^{10} nodes - simple ring - static



(a) Required time

(b) Redundant transmission

Fig. 4 2^{10} nodes - Chord - static

difference between the required time and the total time.

Fig. 3 (b) shows the number of redundant transmission of information. Redundant transmission means that a node transmitted a piece of information to another node which already has the same identity of the information. Although redundant transmission should be reduced to avoid wasting network resource in general, it will work particularly well to prevent the information stream from breaking when network failures occur and/or nodes go offline suddenly. The number of redundant transmissions increases linearly to the length of successor list.

Fig. 4 shows the results in case when a piece of information is diffused in Chord-based networks which consist of 2^{10} nodes. The required time does not depend on the length of successor list. This will be caused by overlaps of nodes in the successor lists and the finger tables. The total time takes a little bit longer than the required time and the redundant transmission increases gently as the length of successor list is getting longer.

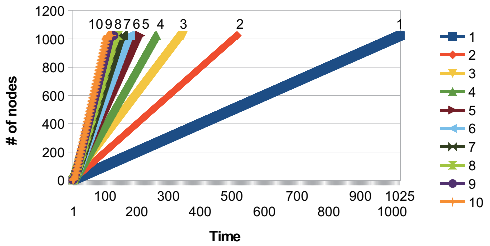
Instead of illustrating remaining graphs, other results are shown in **Table 3**, 4, and 5. They denote the same tendency as

Table 2 Maximum number of collectable feedbacks

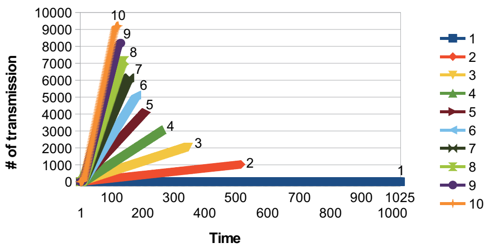
# of nodes	Topology	Length of successor list 1	2	3	4	5	6	7	8	9	10
2^{10}	Simple	1023	512	343	258	208	175	152	134	121	111
	Chord	526	526	526	526	526	526	526	526	526	524
2^{13}	Simple	8191	4096	2732	2050	1642	1370	1176	1030	918	828
	Chord	4116	4116	4116	4117	4117	4116	4114	4108	4108	4108
2^{16}	Simple	65535	32768	21847	16386	13111	10927	9368	8198	7289	6562
	Chord	32792	32792	32792	32783	32783	32783	32783	32784	32784	32792

Table 3 Required time

# of nodes	Topology	Length of successor list 1	2	3	4	5	6	7	8	9	10
2^{13}	Simple	8192	4097	2733	2051	1643	1371	1177	1031	919	829
	Chord	67	67	67	68	68	64	64	64	64	63
2^{16}	Simple	65536	32769	21848	16387	13112	10928	9369	8199	7290	6563
	Chord	102	102	102	102	102	98	98	100	100	99

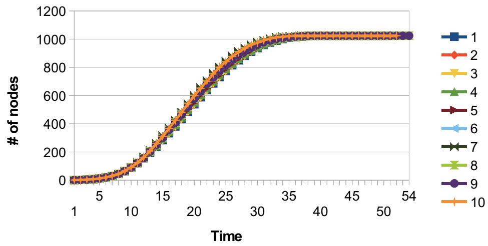


(a) Nodes with information

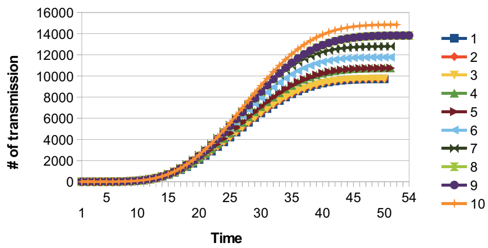


(b) Redundant transmission

Fig. 5 2^{10} nodes - simple ring - dynamic



(a) Nodes with information



(b) Redundant transmission

Fig. 6 2^{10} nodes - Chord - dynamic

the case when the number of nodes is 2^{10}.

4.3.3 Diffusion Speed

Static aspects of the results have been described. Now we move on dynamic aspects of the results.

Fig. 5 shows the results in case when a piece of information is diffused in simple ring networks which consist of 2^{10} nodes. In Fig. 5 (a), how fast a piece of information is diffused to all of the nodes is indicated for each length of successor list. The plotted lines end at each of total time, that is, time elapsed until all of the nodes have completed the diffusion process. All of the lines increase linearly. Fig. 5 (b) shows how many redundant transmissions have occurred for each length of successor list. All of the lines also increase linearly.

Fig. 6 shows the results in the case when a piece of information is diffused in Chord-based networks which consist of 2^{10} nodes. They look like sigmoid curves as frequently produced in other information diffusion environments such as social networking services. Fig. 6 (a) represents that the diffusion speed is almost the same under any length of successor list. On the other hand, in the last half of Fig. 6 (b), gaps between the lengths of successor list are getting larger. When the lengths of successor list are 1, 2, and 3, the numbers of redundant transmission are almost the same.

Other results are not shown because they denote the same tendency as above and space does not permit.

4.4 Discussion

A network topology must be chosen so that information distribution can be done within around an hour as already stated. If a unit time is a second, information distribution must be done within around 3600 time units. In this case, some simple ring networks can satisfy the baseline as seen in Fig. 3 (a) and Table 3. However, if a unit time is 30 seconds, information distribution must be done within around 120 time units. Simple ring networks now cannot satisfy the baseline unless the number of nodes is confined under 2^{10} and/or the length of successor list is fixed more than 10. In contrast, all of the Chord-based networks can satisfy the both baseline in any case.

Besides, it seems that the number of redundant transmission in any Chord-based networks is enough or more than enough to prevent the information stream from breaking when network failures occur and/or nodes go offline suddenly. If redundant transmissions are not enough, S-Ring will not be able to deal with

Table 4 Total time

# of nodes	Topology	Length of successor list 1	2	3	4	5	6	7	8	9	10
2^{13}	Simple	8194	4100	2737	2056	1649	1378	1185	1040	929	840
	Chord	83	83	83	85	85	82	82	83	83	83
2^{16}	Simple	65538	32772	21852	16392	13118	10935	9377	8208	7300	6574
	Chord	120	120	120	121	121	118	119	122	122	122

Table 5 Redundant transmission

# of nodes	Topology	Length of successor list 1	2	3	4	5	6	7	8	9	10
2^{13}	Simple	1	8193	16385	24577	32769	40961	49153	57345	65537	73729
	Chord	102389	102390	102392	110583	110587	118778	126969	135160	135168	143359
2^{16}	Simple	1	65537	131073	196609	262145	327681	393217	458753	524289	589825
	Chord	1015794	1015795	1015797	1081332	1081336	1146871	1212406	1277941	1277949	1343484

the churn[12]. For this reason, and to avoid wasting network resource, Chord-based networks with the successor list having a length of 1, 2, or 3 will be the best candidate for S-Ring. Of course the number of required redundant transmissions depends on how nodes behave in actual operations and other external factors. Thus verification of this prediction must be needed through actual operations. In addition, with respect to the feedback, if the ideal feedback is really needed, existing P2P aggregation and voting methods[13] should be tested.

Finally, layering of networks has been supposed in Section 3.3. The results of simulations show that Chord-based networks can satisfy baselines without layering. Additionally, the network layering costs much and is quite difficult to manage as mentioned. Therefore, to use Chord-based networks or customize them should be a realistic way to implement S-Ring. If any problems occur regarding single-layer networks through actual operations, layering will be revisited considering other layering method[14].

5. Conclusion

In this paper, a new P2P-based information diffusion environment, named S-Ring, was proposed. S-Ring enables users to get trusted information passively as easy and simple as watching TV on a timely basis. The positive feasibility of S-Ring was shown based on our findings from analysis of a previous study on Twitter. The simulation results provided insights about trade-offs between time required for information distribution and network resource consumed in the ring networks. As future work, it is planed to implement some applications considering security and the usual problems of P2P applications such as churn, firewall, and NAT to verify the usefulness of S-Ring and its performance through actual operations.

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