Computing and Informatics, Vol. 30, 2011, 467–489

AN ENHANCED DOUBLE-LAYERED P2P SYSTEM FOR THE RELIABILITY IN DYNAMIC MOBILE ENVIRONMENTS

Ji-Hoon Kim, Jin-Woo Song, Taek-Hun Kim, Sung-Bong Yang

Department of Computer Science
Yonsei University
134 Shinchon-Dong, Seodaemoon-Gu
Seoul, 120-749, Korea
e-mail: {barampow, fantaros, kimthun, yang}@cs.yonsei.ac.kr

Abstract. The double-layered peer-to-peer (P2P) systems were introduced to reduce the network traffic in MANET. The peers in the systems are classified into *super peers* and *sub-peers*. Super peers manage their neighboring sub-peers. The network communications in the systems are done mostly among super peers. In case when a pair of neighboring super peers is too far to communicate, one or two of their sub-peers bridges the super peers. However, the double-layered systems need to improve the reliability that guarantees communications among peers. In this paper, we propose a new double-layered P2P system in which super peers are selected based on their mobility. We also propose two reliability improvement schemes, the avoidance scheme and the role changing scheme. They are applied to the proposed system to enhance the reliability of the system. The proposed system is implemented in the dynamic mobile P2P environment where peers may join and leave the network dynamically and the number of peers varies. The various experiments are done with the Network Simulator-2 v2.33. The experimental results show that the proposed system with the two schemes improved the reliability over other double-layered systems in terms of the failure rate by up to 25 %, while increasing the network traffic marginally.

Keywords: Double-layered P2P systems, reliability, MANET, dynamic mobile environment, file search

1 INTRODUCTION

As mobile technologies advance, researches on file sharing among peers have extended toward the mobile environments. Due to the nature of mobile networks, there are such limitations as power, mobility, communication range, and capacity [1]. For these reasons, a client/server-based infrastructure system is not suitable for the mobile environment. Instead, MANET (Mobile Ad-hoc NETwork) in which no infrastructure could be available was introduced, and many researches and studies were also introduced as the great efforts to overcome these limitations. We may classify the P2P systems in MANET into two types according to the roles of peers in the network; they are a single-layered system and a double-layered system. *A single-layered system* allows each peer to have the same role in the communications. One of the typical single-layered systems is ORION (Optimized Routing Independent Overlay Network) [1]. ORION suffers from too much network traffic, because its communications are based on flooding among all the peers. *A double-layered system* has two layers in its structure; super peers are in the upper layer while sub-peers are in the lower layer, and each super peer manages its neighboring sub-peers. Various double-layered systems were developed to reduce the network traffic by avoiding flooding [2]. In the double layered systems, super peers have information about their sub-peers and the communications are done mostly among super peers to reduce the network traffic.

In mobile networks, the reliability that guarantees communication among peers is one of the crucial factors to be considered [3]. Also, for high quality P2P services, the systems need additional requirements such as context-awareness, user-driven adaptability, service continuity, and on-demand code distribution [4]. In this paper, we propose a new double-layered P2P system in which super peers are selected based on their mobility. In the proposed system, peers with lower mobility become super peers. We call it the *MOB* (MObility-Based) *system*. We also propose two reliability improvement schemes, the avoidance scheme and the role changing scheme. They are applied to the MOB system to enhance the reliability of the system.

Most of the previous P2P systems are evaluated under the "static" mobile P2P environment in which the number of peers is fixed and there are no dynamic joins and leaves. Moreover, there are many systems that do not even consider the mobility of peers. In this paper, the MOB system is implemented in the "dynamic" mobile P2P environment where peers may join and leave the network dynamically and the number of peers varies.

We evaluate the failure rates of the MOB system with and without the reliability improvement schemes for file searches in the dynamic mobile environment and compare them with those of the Greedy system and the MIS system in [2]. The various experiments are done with the Network Simulator-2 (NS-2) v2.33 [5]. The experimental results show that the average failure rate of the MOB system with the proposed schemes decrease by 25 % over the Greedy system and by 18 % over the MIS system. The network traffic costs of the MOB system and other double-layered systems are also analyzed. When applying the proposed schemes to each system, the average network traffic cost of the MOB system is higher than that of the MIS system by only 0.01 %, but much lower than that of the Greedy system (by 35 %). The overall performance of the MOB system with the proposed schemes is better than other systems, although its average network traffic cost is slightly higher than that of the MIS with the schemes.

The rest of this paper is organized as follows. The related work is provided in Section 2. The dynamic mobile P2P environment is explained in Section 3. The MOB system and the two reliability improvement schemes are described in Section 4. The experimental results are given in Section 5. The conclusions are made in Section 6.

2 RELATED WORK

2.1 The Double-layered P2P Systems

A double-layered system has two layers, the upper layer and the lower layer. The peers in the upper layer are called *super peers*. Each super peer manages some neighboring peers in the lower layer, called *sub-peers*. Most communications are taking place among super peers in the upper level as well as some sub-peers in the lower layer. When two neighboring super peers are out of the communication range, one or two of their sub-peers plays a role of a bridge between the super peers. Each super peer maintains a table whose entry contains the *ID*, *address*, and *file list* of each of its sub-peers.

There are two double-layered systems, the MIS (Maximal Independent Set) and the Greedy systems proposed in [2]. Each has a different way of selecting super peers. The MIS system uses random numbers for selecting super peers. Its super peer selection mimics the Luby's randomized maximal independent set algorithm in [6]. Each peer chooses a random number at once. Then among the peers who are within the communication range, a peer who has the largest random number is selected as a super peer. Each super peer finds its *neighboring peers* – the peers within its communication range – to form *a cluster*; it can be viewed as a group of peers in which a super peer manages its sub-peers. Afterwards, the same selection process is repeated with the rest of peers until all peers become either super peers or sub-peers.

The Greedy system is almost the same as the MIS system except that the number of neighboring peers – the *degree* of a peer – is used for selecting super peers. The Greedy system selects super peers based on the greedy set-cover algorithm in [7]. Among the peers who are within the communication range, a peer with the largest degree is selected as a super peer. The neighboring peers to super peers become their sub-peers. The same process is repeated with the rest of peers who are not yet determined to be either super peers or sub-peers until all peers become either super peers or sub-peers. In both systems a pair of super peers communicates with each other via at most two neighboring sub-peers, called *relay sub-peers*. Note that a sub-peer belongs to only one super peer in a double-layered system. We have analyzed more thoroughly the performances of double-layered systems with various metrics and the results can be given in [8]. We also proposed a new double-layered system and routing schemes for better energy efficiency in [9] and [10].

2.2 Reliability Schemes on Other Systems

Sung et al. proposed two reliability improvement schemes, *the configuration scheme* and *the routing scheme*, for the ORION system [3]. Their system has the routing table that contains the information of peers who have the target items. The configuration scheme is to configure a mobile network. The routing scheme focuses on reliable communications among peers in the network. It contains an efficient discovery mechanism as well as a reliable transfer mechanism.

Kei Takeshita et al. proposed a scheme based on DHT (Distributed Hash Table) in the dynamic mobile P2P environment [11]. They used hashing for sharing pointers that indicate the files in the same cluster. The scheme improves the searching performance in the MADPastry [12] environment in which a network is clustered.

The MADPastry uses AODV (Ad-hoc On Demand Vector) as a routing protocol. The MADPastry guarantees $O(log_b N)$ hop count for forwarding the messages, where N is the number of peers and b is a configuration parameter with a typical value 4. However, it is just a logical cost estimated only on the application layer, not on the network layer. Therefore, it is not suitable for mobile networks because the hop counts should be measured "physically" on the network layer; one hop on the application layer should be implemented multi-hops on the network layer in reality. Their scheme makes up such disadvantage in having inaccurate information about files by sharing the pointers periodically that refer to the file locations, so it is simple and easy to apply.

3 THE DYNAMIC MOBILE P2P ENVIRONMENTS

Most of the mobile P2P systems in [1] and [2] were evaluated with a fixed number of peers only within a given network area. However, such a static mobile environment does not reflect a realistic one. The dynamic mobile P2P environment, on the other hand, allows peers to turn their power off to leave the network or on to newly join the network. In addition, peers may move freely; they can even get out of the network area or are allowed to get into the network from outside. Other researches in [13, 14, 15, 16] described the definition of dynamic environments in MANETs, but they considered only peers' movements with various speed and direction as the most important factors for dynamic environments. Unfortunately they ignored peer's join/leave that is one of the critical factors for dynamic environments.

Sometimes peers may not even give any notice to the system that they have just joined or left. Some of these cases may cause communication failure due to wrong information in the routing tables of the related peers. Figure 1 illustrates a portion of a network for a double-layered system in the dynamic mobile P2P environment.

There are three clusters each of which has a super peer and its own sub-peers. Each super peer forwards messages to neighboring super peers via relay sub-peers because neighboring super peers are out of the communication range.

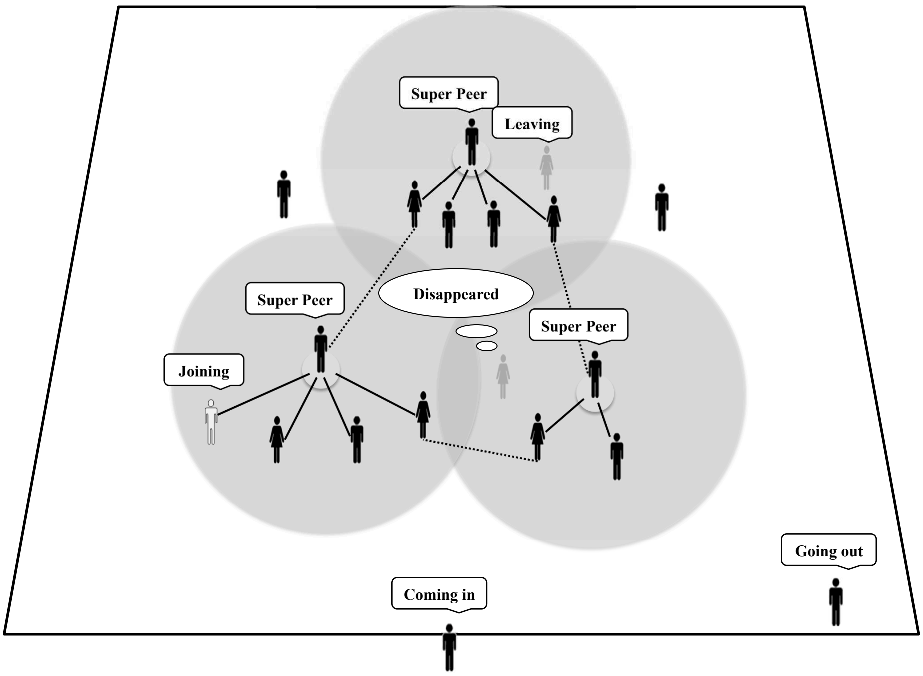


Fig. 1. A double-layered system in the dynamic mobile P2P environment

4 THE MOBILITY-BASED DOUBLE-LAYERED SYSTEM AND THE RELIABILITY IMPROVEMENT SCHEMES

Improving the reliability is a very important issue not only for the double-layered systems but also for other multicasting-based systems in [17, 18, 19]. In this section, we describe a new double-layered system and two reliability improvement schemes. They try to maintain clusters stably and fix disconnections due to sudden disappearances of peers by turning off the power or by moving out of the communication range during file searches.

4.1 The Mobility-Based Double-Layered System

In mobile networks, peer's mobility is one of the most important factors to be considered. The performances of double-layered systems depend on how to effectively establish clusters and how long clusters can be maintained without breaking apart due to the dynamic nature of the environments. If super peers move too fast, clusters may be broken because their sub-peers cannot communicate with their own super peers. Therefore, selecting super peers for more stable clusters is a very important issue in the double-layered architecture. Hence we propose the MOB system in which the mobility of peers is considered for selecting super peers to improve the reliability of the system in mobile networks where peers may move around with various types of mobility. In this system, a peer who has the lowest mobility among neighboring peers is selected as a super peer, since high mobility of a sub-peer may cause the reliability problem only locally while that of a super peer may widen the problem to all of its sub-peers as well as neighboring super peers. In a double-layered system, super peers are selected periodically to reflect peers' movements in the system; that is, the network is reconstructed periodically. During a period, each peer is supposed to compute the value of its own mobility as follows. Assume that we express a location of a peer with the x and y coordinates.

$$m(t_s, t_n) = \left| \frac{\sum_{i=s+1}^{n} \sqrt{(x_{i-1} - x_i)^2 + (y_{i-1} - y_i)^2}}{t_s - t_n} \right|. \tag{1}$$

During a period between two consecutive super peer selections, there are n measurements of the location of each peer at times t_0, t_1, ..., t_n. The location of a peer at t_i is denoted as (x_i, y_i), and (x_0, y_0) is the initial location of a peer. For the next super peer selection, each peer compares its mobility $m(t_0, t_n)$ with that of other peers within its communication range. After the comparison, the peer which has the lowest value of $m(t_0, t_n)$ becomes a super peer. Figure 2 shows an example of calculating the mobility of a peer from t_0 to t_5.

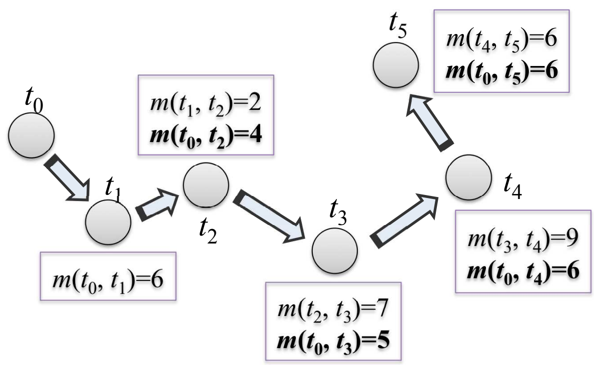


Fig. 2. The values of the mobility of a peer

Other peers within the super peer's communication range become its sub-peers. These processes are repeated until all the rest of peers become either super peers or sub-peers in the network. Super peers and sub-peers maintain their roles until the next super peer selection stage. This system improves the reliability by enhancing the stability of clusters.

4.2 Reliability Improvement Schemes

We proposed two reliability improvement schemes in the dynamic mobile environments including the cases when a pair of peers is out of the communication range and when some relay sub-peers become disabled or move too far away. To cope with these cases, two reliability improvement schemes are applied to both super peers and sub-peers in the systems.

4.2.1 The Avoidance Scheme

The avoidance scheme searches an alternative route by avoiding a "disabled" or "gone too far" peer to maintain proper communications. We illustrate the scheme with an example in Figure 3. Assume that peer A requests a file that peer M owns. The route A-B-C-F-J-K-L-M is assumed to be established at the previous super peer selection stage. After a few seconds, peers may move around with their own speeds and directions. Figure 3 a) shows that C moved away from F so that the link between C and F becomes disconnected. In Figure 3 b) an alternative route A-B-D-E-F-J-K-L-M is established. Similarly when C is disabled as in Figure 3 c), this scheme tries to find an alternative route as in Figure 3 d).

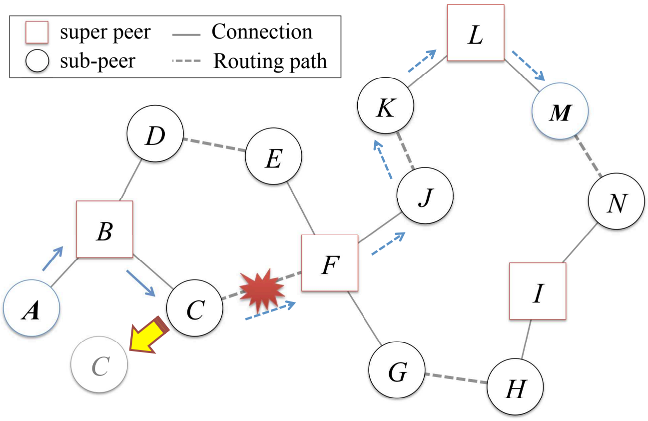
The avoidance scheme can discover a new route because all possible routes are searched when reconstructing the network periodically. However, more packets should be transmitted for queries because detours should be found.

4.2.2 The Role Changing Scheme

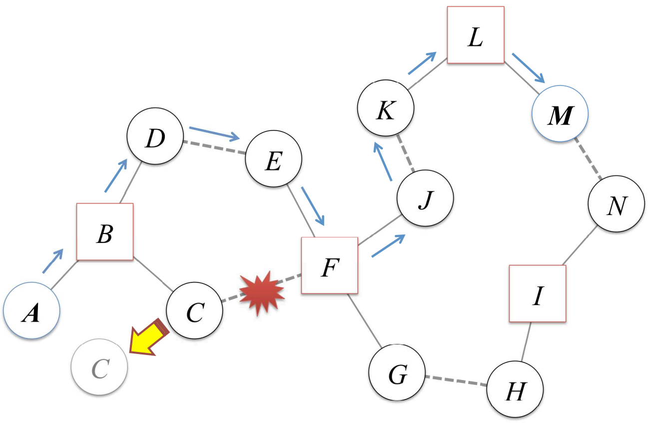
When a super peer becomes disabled or moved too far from the communication range, a relay sub-peer cannot play a role of a bridge any more. In addition, when one of its sub-peers requests a file, the request message is transmitted nowhere because there is no super peer to ask. Unfortunately, the avoidance scheme cannot handle these problems. To resolve the problems, therefore, we promote a sub-peer who requests a file or has a query to be forwarded to its super peer to a new super peer so that it can establish new route(s) with other super peers nearby.

We illustrate the role changing scheme with Figures 4 a) and 4 b) from the situation shown in Figure 3 d). Sub-peer A requests a file owned by peer M. When the request query reaches at E, E tries to forward it to its super peer F; but F moved too far from the communication range of E, or became disabled. The role changing scheme detects the problem and promotes E to a super peer. E then finds a sub-peer K managed by super peer L. A new route between E and L can be established via sub-peer K.

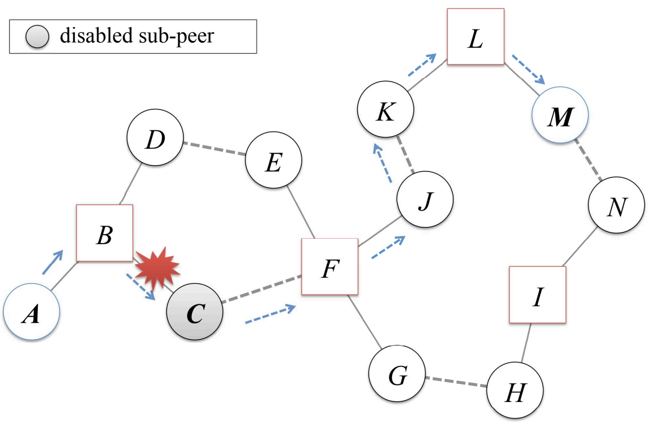
Figure 4 c) shows the other case when a super peer who manages a requesting sub-peer becomes disabled. Sub-peer A requests a file in K, but it fails to com-


super peer
sub-peer
Connection
Routing path
L
K
M
D
E
J
N
B
F
I
A
C
C
G
H

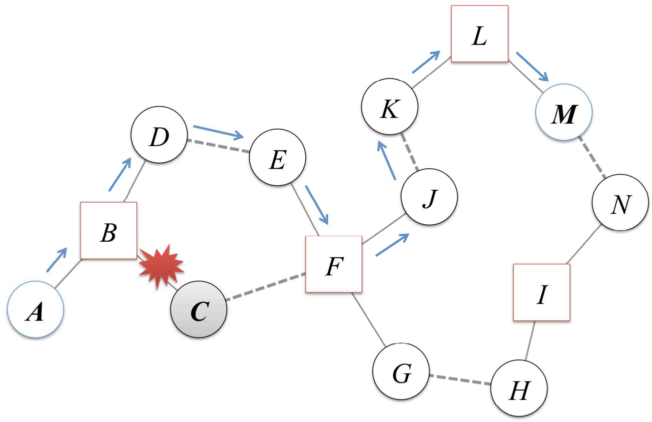
a)


L
K
M
D
E
J
N
B
F
I
A
C
C
G
H

b)


disabled sub-peer
L
K
M
D
E
J
N
B
F
I
A
C
G
H

c)



d)

Fig. 3. The avoidance scheme

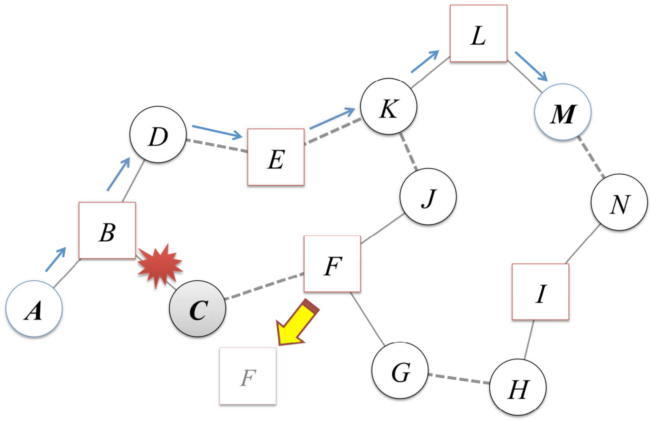
municate with its super peer B. In this case, as shown in Figure 4 d), A becomes a super peer, and then tries to establish new connections among neighboring peers. Therefore, new routing information between A and G is established via C. The role changing scheme finds new alternative routes in real-time to improve the reliability, but the cost of fixing the routes do increase the network traffic. Note that unlike the avoidance scheme, the role changing scheme is implemented whenever the system detects the problems.

5 EXPERIMENTAL RESULTS

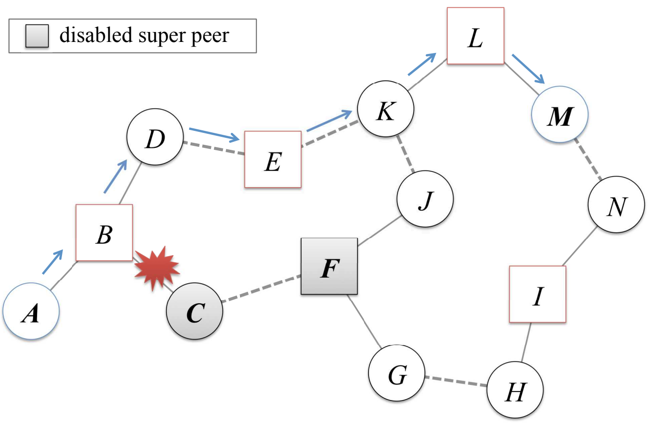
5.1 Experimental Environment

In this section, we evaluate the failure rate and the network traffic during file searches for the double-layered systems; the MOB system, the MIS system, and the Greedy system. The *failure rate* is the ratio of failed file searches to all file searches. The *network traffic cost* denotes the total size of packets for processing file search queries and updating the network. The experiments are done using a mobile network simulation tool, NS-2 v2.33, and the parameters of the experiments are given in Table 1.

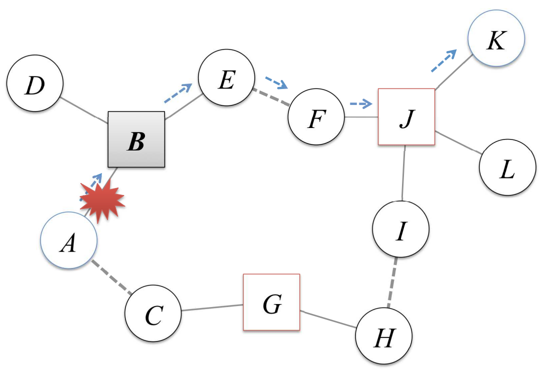
A peer may be located in a network area of $1\,000\,\mathrm{m} \times 1\,000\,\mathrm{m}$ or out of the area. The movements of peers are based on the random waypoint model in [20]. The maximum speed of each peer is $2 \sim 10\,\mathrm{m/sec}$, and all peers are able to move anywhere. Peers outside of the area are excluded from the experiments. The communication range is 200 m with the two ray ground propagation model. Each peer has five files and some files can be stored in other peers redundantly. In the experiments 1 000 queries from peers in the network are assumed to be processed during the simulation period. We assume that the basic packet size of a message for the double-layered


L
K
M
D
E
J
N
B
F
I
A
C
F
G
H

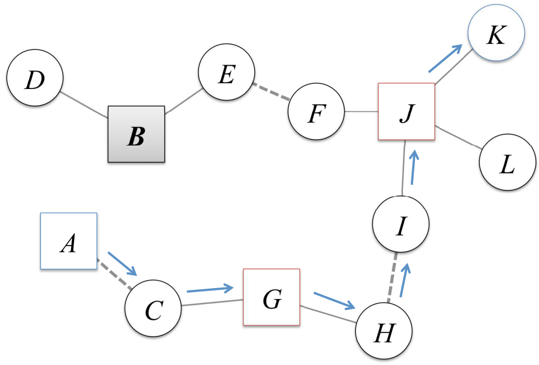
a)


disabled super peer
L
K
M
D
E
J
N
B
F
I
A
C
G
H

b)


K
D
E
F
J
B
L
A
I
C
G
H

c)



d)

Fig. 4. The role changing scheme

Parameters	**Values**
Simulation period	1 000 sec
Maximum number of peers	100
Network area	1 000 m × 1 000 m
Communication range	200 m
Maximum speed of a peer	2 ∼ 10 m/sec
Percentage of peers who join/leave	5 ∼ 30 % of the total number of peers
File request query period	1 sec
Number of files in a peer	5
Channel type	Channel/WirelessChannel
Propagation model	Propagation/TwoRayGround
Network interface	Phy/WirelessPhy
Mac interface	Mac/802.11

Table 1. Experimental Environment

systems is 28 bytes based on UDP (User Datagram Protocol) packet. In case when exchanging the routing information, it is needed for additional five bytes (four bytes for the IP address of a neighboring peer and one byte for extra link information) are needed. During a super peer selection stage, peers exchange their own values such as mobility values, random numbers, or degrees depending on the systems. We need one more byte for the value in a packet. The size of a packet for sending a query is 40 bytes including four bytes for each of the source *IP address*, *the destination IP address*, and *the file name*. Under the above environment, we used 20 test sets of input to experiment, and then analyzed the results to evaluate the performance of each system for 1 000 seconds.

5.2 Performance of the MOB System

We evaluated and compared the systems when the period to update the network is set to 100 seconds and 5 % of peers join or leave. Figure 5 shows the failure rate of each system with these settings.

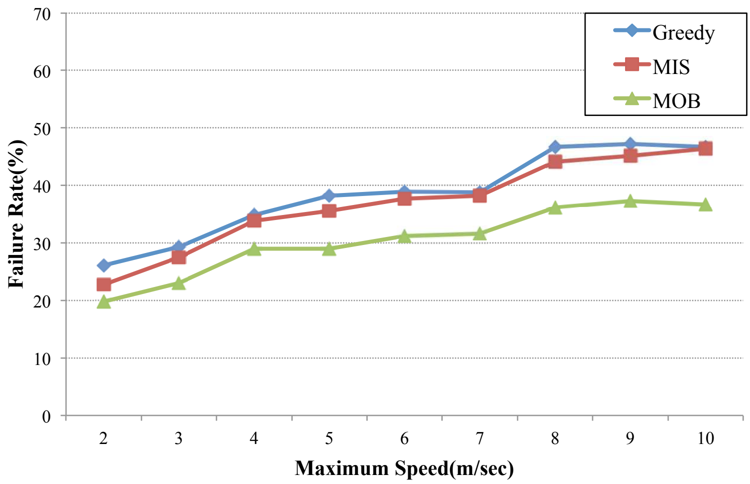


Fig. 5. The failure rates as the maximum speed increases

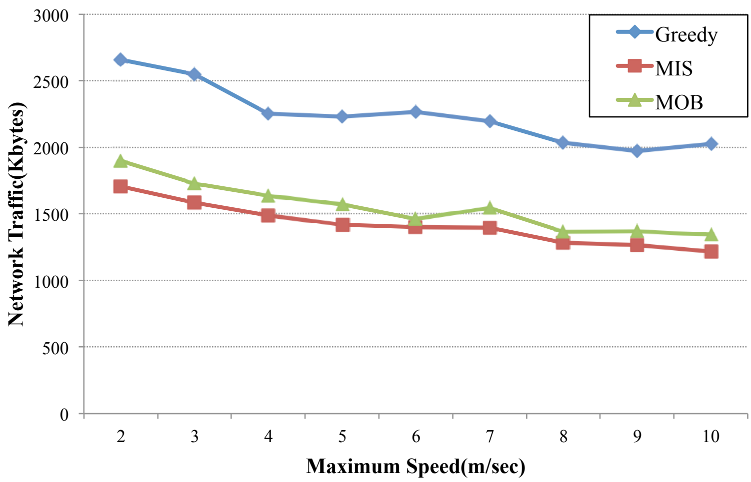


Fig. 6. The network traffic costs as the maximum speed increases

The MOB system shows lower failure rate than the MIS and Greedy systems. Since in the MOB system a peer who has the lowest mobility among its neighboring peers becomes a super peer, the connection between a super peer and each of its sub-peers is more robust. Therefore, the clusters in the MOB system can be maintained longer than those in other systems.

Figure 6 shows the network traffic costs of each system while the maximum speed of a peer varies from 2 to 10 m/sec. The Greedy system has the highest traffic costs for all the speeds because a super peer in the Greedy system has more sub-peers than those in other systems; that is, there are many connections like spider's threads among peers, so exchanging routing information is more expensive. Moreover, the Greedy system needs to broadcast twice to select super peers while the MIS and MOB systems do only once. The costs of the MOB system are a little bit higher than those of the MIS system; but the MIS system suffers higher failure rates and hence some packets of queries might have been dropped, and the difference between the traffic costs of these two systems is only 110 KB on the average. As shown in Figures 5 and 6, the MOB system improves the reliability over other systems in terms of the failure rate without increasing traffic costs too much for all the range of the maximum speeds of a peer. In this experiment the MOB improves the reliability by up to 10 % over the MIS and Greedy systems on the average.

We have also tested when 0 % to 20 % of all the peers in the network join or leave. The period to update the routing information is set to 100 seconds, and the maximum speed of a peer is 5 m/sec. Figures 7 and 8 compare the failure rates and the network traffic costs of the systems, respectively. Note that there are additional costs when a peer joins for communicating with other neighboring peers.

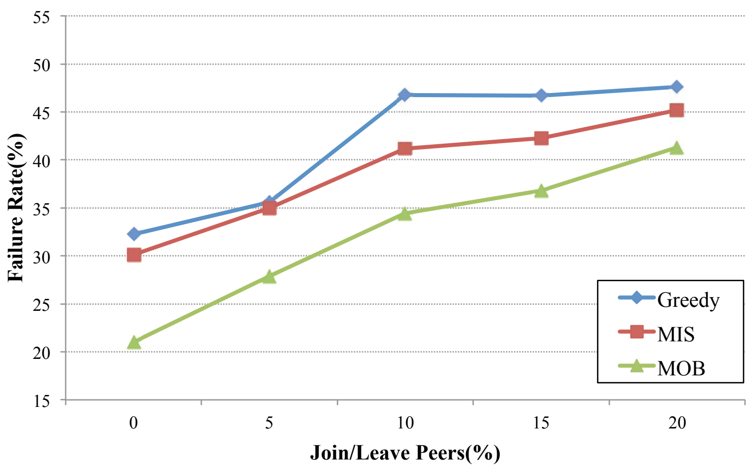


Fig. 7. The failure rates as the percentage of join/leave peers increases

As the number of peers who leave the network increases, so does the failure rate, because they cause the links to be disconnected in the network. On the other hand, as the number of peers who join the network increases, so do the network traffic costs, because the appropriate routing information should be updated. As shown

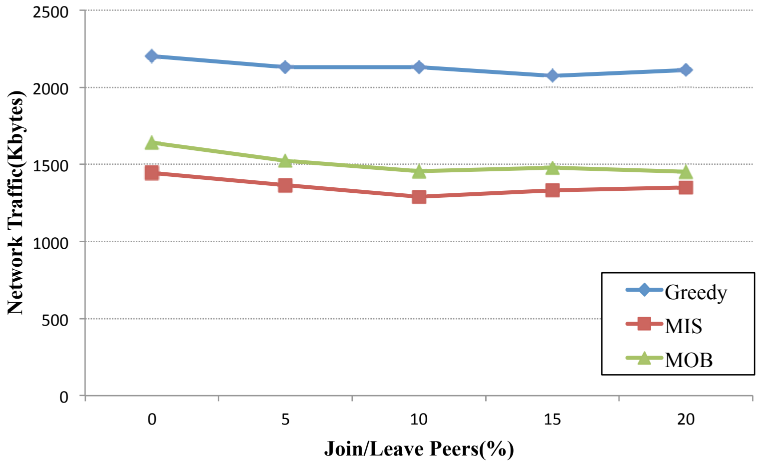


Fig. 8. The network traffic costs as the percentage of join/leave peers increases

in Figure 7, the MOB system shows lower failure rates than others by up to 10 % on the average. The experimental results in Figures 5 and 6 are quite similar to those in Figures 7 and 8, respectively. Hence the analyses of the results are quite the same as before. Although the MOB system improved the reliability, the failure rate increases as both the number of peers who join or leave and the maximum speed of a peer increase. Next we show that the MOB system with two reliability improvement schemes further reduces the failure rates.

5.3 Performance of the Reliability Improvement Schemes

In this section we compare the failure rates and the network traffic costs of the MOB system with and without the two reliability improvement schemes. We tested when a peer has the maximum speed with 5 m/sec and the update period is 100 seconds. There are four different systems for the experiment; they are the systems without applying any scheme, with the avoidance scheme, with the role changing scheme, and with both schemes. Figures 9 and 10 show the failure rates and the network traffic costs for these four systems.

As shown in Figure 9, applying the avoidance scheme alone to the MOB system improves the failure rate slightly. The reason is that the avoidance scheme could not handle the problems when super peers leave the network or move too far from their relay sub-peers. On the other hand, applying the role changing scheme could resolve these problems and improves the failure rates noticeably. However, the network traffic costs had increased due to finding neighboring peers and establishing new connections. The MOB system with both schemes shows the best performance in terms of the failure rate by about 20 % comparing with the system without any scheme. We tested the systems as the percentage of peers who join or leave varies

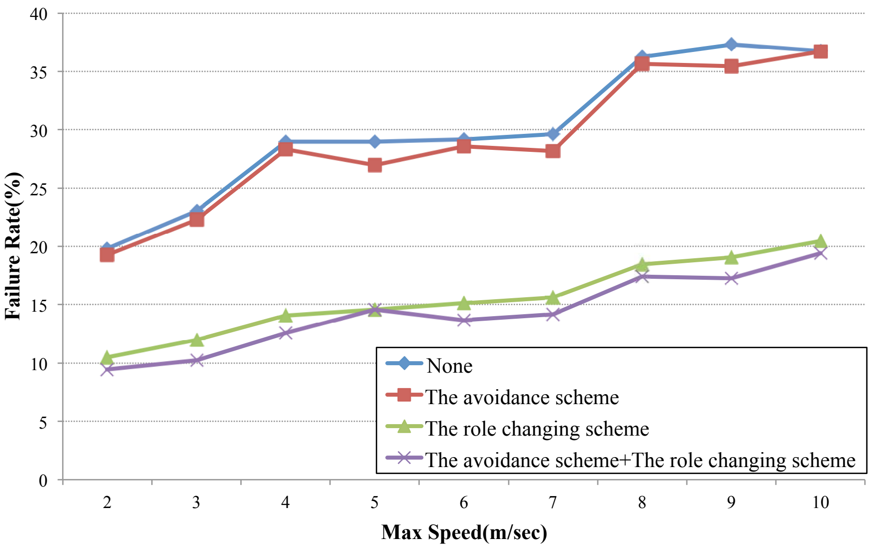


Fig. 9. The failure rates of the MOB systems as the maximum speed increases

from 0 % to 20 %. The experimental results are given in Figures 11 and 12 and are quite similar to those in Figures 9 and 10.

To further verify the performance of the MOB system with both schemes, we experimented under various environments by changing the network update period from 50 seconds to 250 seconds with an interval of 50 seconds when the average maximum speed of peers is 5 m/sec and 5 % of all the peers join or leave the network. Note that all the routing information is updated at the beginning of each period. Figure 13 shows the failure rates of the MOB systems with and without two schemes.

As the update period increases, so does the failure rate because more disconnections could not be fixed and more search queries failed to reach the destinations as well. If the update period gets shorter, however, the network traffic costs rise. Figure 14 shows such a phenomenon.

The results in Figures 13 and 14 show that the MOB system with both schemes does improve the system reliability as the update period varies. Although its network traffic costs are higher than the system without applying the two schemes, such overheads are not unbearable.

5.4 Overall Performance

Finally, we also tested the MIS and the Greedy systems with and without the reliability improvement schemes under the environments that the percentage of joining and leaving peers varies from 0 % to 20 % and the peers' maximum speed varies from 2 m/sec to 10 m/sec. The experiment results of all the cases are averaged

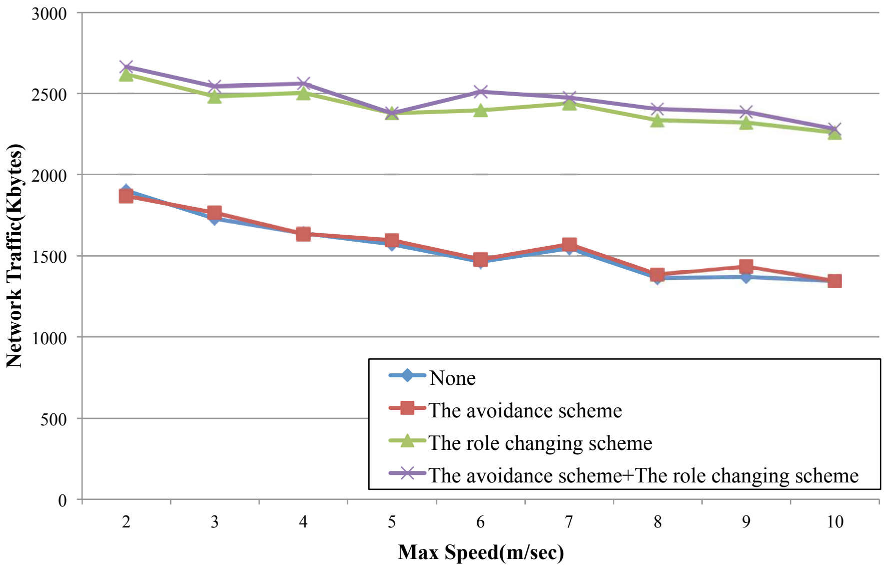


Fig. 10. The network traffic costs of the MOB systems as the maximum speed increases

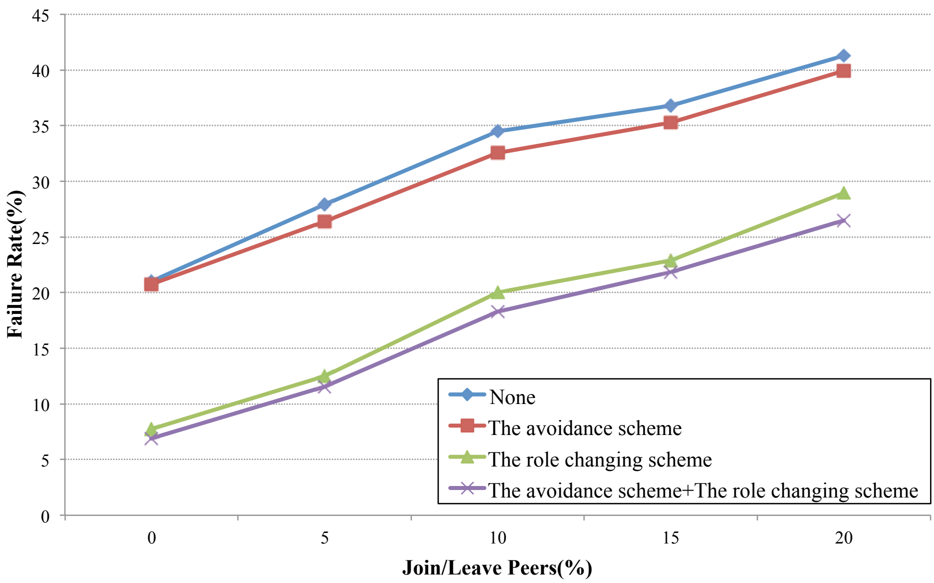


Fig. 11. The failure rates of the MOB systems with the proposed schemes as the number of join/leave peers increases

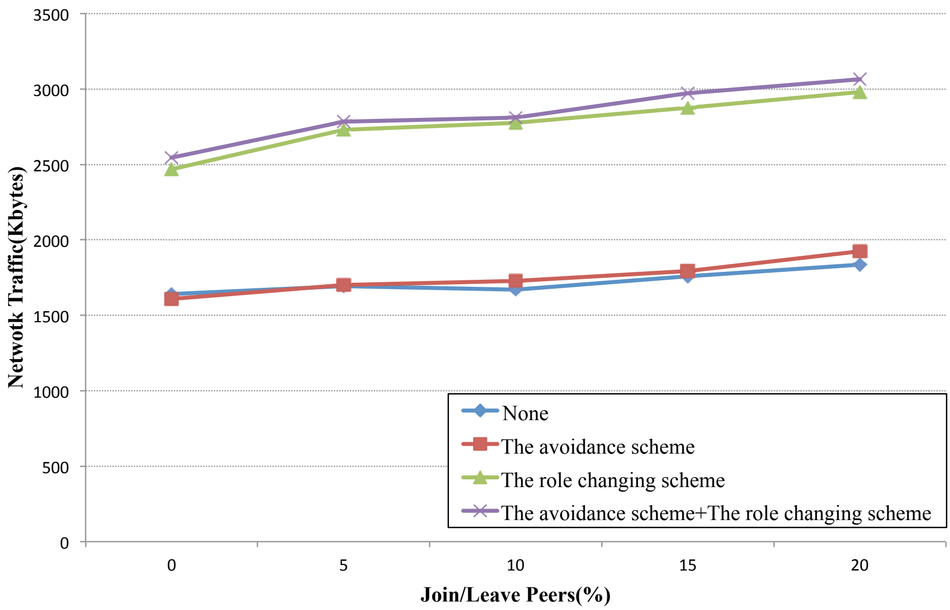


Fig. 12. The network traffic costs of the MOB systems with proposed schemes as the number of join/leave peers increases

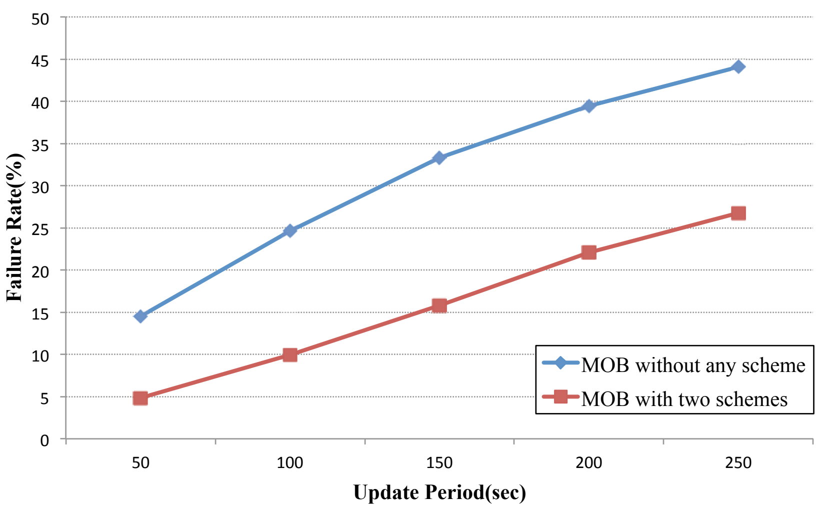


Fig. 13. The failure rates of the MOB systems as the update period increases

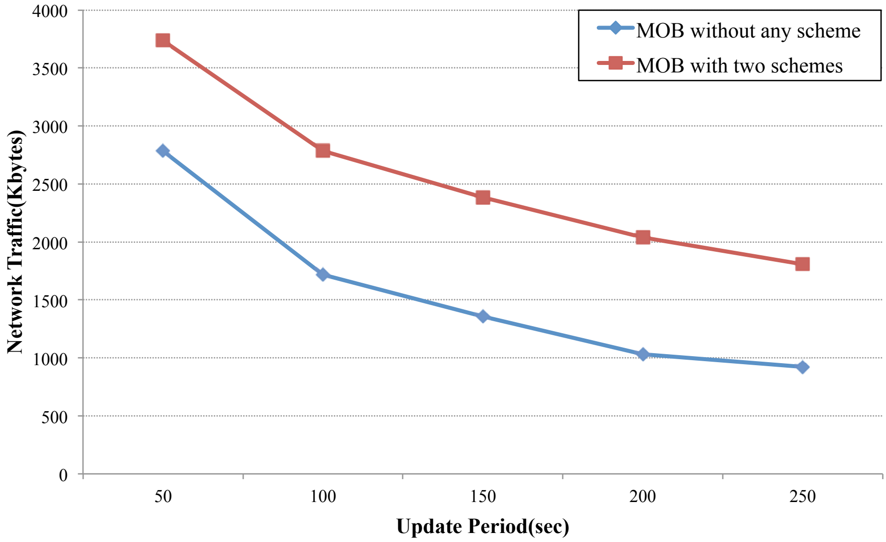


Fig. 14. The network traffic costs of the MOB systems as the update period increases

and are given in Figures 15 and 16 that show the failure rates and the network traffic costs, respectively. As in the figures, the MOB system with both schemes shows the lowest average failure rate even though there are additional network traffic costs to recover the alternative routes among peers. The MOB system with both schemes shows 16 % less failure rate than the MOB system without any scheme, 25 % and 18 % less failure rate than the Greedy system with and without schemes, and 18 % and 5 % less failure rate than the MIS system with and without schemes.

Figure 16 shows detailed analysis of the network traffic costs for each system; the cost for query processing and the cost for the network update are shown separately. When applying two schemes to each system, the average network traffic cost of the MOB system is higher than that of the MIS system by only 15 KB, but it is lower than that of the Greedy system by 927 KB. The average network traffic costs of the Greedy, MIS, and MOB systems with both schemes increase by 46 %, 65 %, and 52 % over the systems without the schemes, respectively. The overall performance of the MOB system with both schemes is better than other systems, although its average network traffic cost is slightly higher than that of the MIS with the schemes.

6 CONCLUSIONS

We have proposed a new double-layered system considering the mobility of peers in the dynamic mobile P2P environment. In the MOB system we select peers which

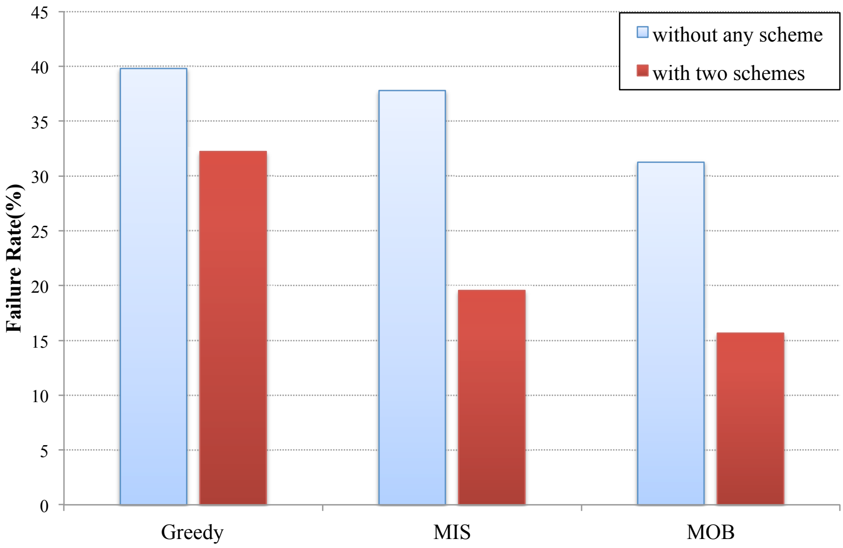


Fig. 15. The average failure rates of the systems

have lower mobility than other peers within the communication range as super peers. Therefore, clusters in the system are more stable compared with those in other double-layered system. The MOB system showed more enhanced reliability than other systems.

We also proposed two schemes to improve the reliability of the system further. The avoidance scheme searches alternative routes. The role changing scheme promotes sub-peers to super peers and recovers possible connections from the new super peers to other neighboring peers. The experimental results showed that the double-layered systems with these schemes had improved their failure rates. Consequently, when hybridizing the MOB system with the proposed schemes, the average failure rate was decreased by 25 % over the Greedy system and by 18 % over the MIS system.

Although the MOB system with the two proposed schemes improved the reliability in mobile networks, we plan to further study the improvement of the reliability with less update traffic costs. We will also study more robust systems and schemes with higher reliability that can be applied in various environments in the future.

Acknowledgement

This work was supported by the Korea Science and Engineering Foundation (KOSEF) for the research (2009-0073072).

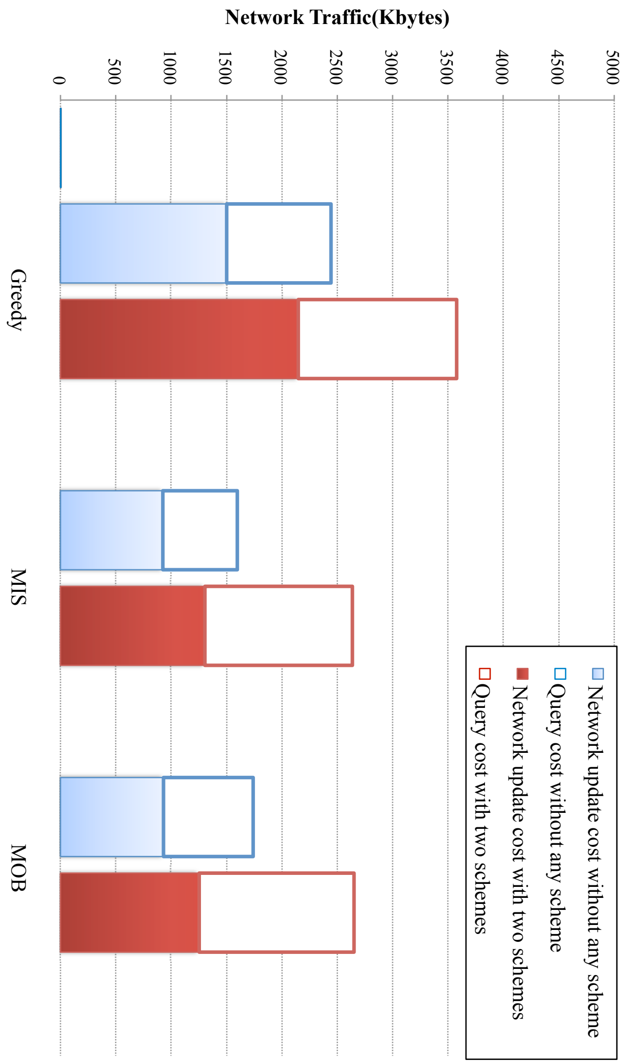


Fig. 16. The average network traffic costs of the systems

REFERENCES

[1] Klemm, A.—Lindemann, C.—Waldhorst, O.: A Special Purpose Peer-to-Peer File Sharing System for Mobile Ad Hoc Networks. In: Vehicular Technology Conference, Vol. 4, Oct. 2003, pp. 2758–2763.

[2] Han, J. S.—Song, J. W.—Lee, K. J.—Yang, S. B.: Mobile Peer-to-Peer System Using Super Peers for Mobile Environments. In: The International Conference on Information Networking, Jan. 2008, pp. 1–4.

[3] Sung, M. Y.—Lee, J. H.—Heo, Y. J.: Towards Reliable Peer-to-Peer Data Sharing over Mobile Ad Hoc Networks. In: Vehicular Technology Conference, Vol. 4, June 2005, pp. 2196–2200.

[4] Riva, O.—Nadeem, T.—Borcea, C.—Iftode, L.: Context-Aware Migratory Services in Ad Hoc Networks. IEEE Transactions on Mobile Computing, Vol. 6, 2007, No. 6, pp. 1313–1328.

[5] The network simulator – NS-2. Available on: `http://www.isi.edu/nsnam/ns/`.

[6] Luby, M.: A Simple Parallel Algorithm for the Maximal Independent Set Problem. SIAM Journal of Computing, Vol. 15, 1986, No. 4, pp. 1036–1053.

[7] Chvatal, V.: A Greedy Heuristic for the Set-Covering Problem. Math. of Oper. Res., Vol. 4, 1979, No. 3, pp. 233–235.

[8] Kim, J. H.—Lee, K. J.—Kim, T. H.—Yang, S. B.: Effective Routing Schemes for Double-Layered P2P Systems in MANET. Journal of Computing Science and Engineering, Vol. 5, 2011, No. 1, pp. 19–31.

[9] Han, J. S.—Song, J. W.—Kim, T. H.—Yang, S. B.: Double-layered Mobile P2P Systems Using Energy-Efficient Routing Schemes. In: Australasian Telecommunication Networks and Applications Conference, Dec. 2008, pp. 122–127.

[10] Lee, J. H.—Song, J. W.—Lee, Y. H.—Yang, S. B.: An Energy-Effective Routing Protocol for Mobile P2P Systems. In: International Symposium on Wireless and Pervasive Computing, Feb. 2009, pp. 1–5.

[11] Takeshita, K.—Sasabe, M.—Nakano, H.: Mobile P2P Networks for Highly Dynamic Environments. In: The Sixth Annual IEEE International Conference on Pervasive Computing and Communication 2008, pp. 453–457.

[12] Zahn, T.—Schiller, J.: MADPastry, A DHT Substrate for Practicably Sized MANETs. In: The Fifth Workshop on Applications and Services in Wireless Networks, Paris, June 2005.

[13] Li, Z.—Shen, H.: LORD: A Locality-Based Distributed Data Sharing System for Highly Dense and Dynamic MANETs. In: INFOCOM Workshops, April 2009, pp. 1–5.

[14] Liu, C.—Wu, J.: Adaptive Routing in Dynamic Ad Hoc Networks. In: Wireless Communications and Networking Conference, March 2008, pp. 2603–2608.

[15] Ding, Y.—Li, Q.—Li, F.: A Novel Method for Evaluating Trustworthiness Between Strangers in Large, Dynamic Ad Hoc Networks. In: Knowledge Discovery and Data Mining, Jan. 2009, pp. 280–283.

[16] Cheng, H.—Cao, J.—Wang, X.—Das, S. K.—Yang, S.: Stability-Aware Multi-Metric Clustering in Mobile Ad Hoc Networks with Group Mobility. Wireless Communications and Mobile Computing, Vol. 9, 2009, No. 6, pp. 759–771.

[17] Zhang, D.—Ray, S.—Kannan, R.—Sitharama, S.: A Recovery Algorithm for Reliable Multicasting in Reliable Networks. Parallel Processing, Oct. 2003, pp. 493–500.

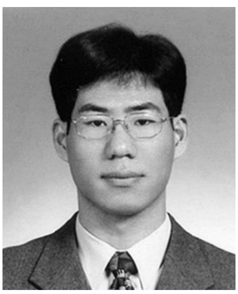
[18] Chumchu, P.—Seneviratne, A.: Multi-Level Reliable Mobile Multicast Supporting SRM (Scalable Reliable Multicast). In: Vehicular Technology Conference, Vol. 3, 2002, pp. 1410–1414.

[19] Kumar, V.—Venkataram, P.: Reliable Multicast Routing in Mobile Networks: A Neural-Network Approach. In: Institution of Electrical Engineers, Vol. 150, 2003, pp. 377–384.

[20] Broch, J.—Maltz, D. A.—Johnson, D. B.—Hu, Y.—Jetcheva, J.: A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols. In: The 4th Annual ACM/IEEE International Conference on Mobile Computing and Networking 1998, pp. 85–97.

Ji-Hoon Kim received the B. Sc. degree in Computer Science from Myongji University, Seoul, Korea, and the M. Sc. degree in Computer Science from Yonsei University, Seoul, Korea. His research interests include peer-to-peer computing and mobile computing.

Jin-Woo Song received the B. Sc. and M. Sc. degrees in Computer Science from Yonsei University, Seoul, Korea, in 2001 and 2003, respectively. He is currently a Ph. D. Candidate in Computer Science at Yonsei University. His research interests include peer-to-peer computing and mobile computing.



Taek-Hun Kim received Ph. D. degree in Computer Science from Yonsei University, Seoul, Korea, in 2005. He has been a Research Professor at the Department of Computer Science, Yonsei University, since 2006. His research interests include mobile computing, recommender systems, and personalization.

Sung-Bong Yang received Ph. D. degree in Computer Science from the University of Oklahoma in 1992. He has been a faculty member at the Department of Computer Science, Yonsei University, Seoul, Korea, since 1994. His research interests include Mobile Systems, Peer-to-Peer Computing, and 3D Graphics.