A Performance Evaluation Framework for Mobile P2P Overlays under Churn

JUN LI[1,2],
[2]School of Mathematics and Computational Science
Anqing Normal University
Anqing, Anhui
CHINA
Jasonli376@gmail.com

GUOYIN ZHANG[1], XIANGHUI WANG[1]
[1]College of Computer Science and Technology
Harbin Engineering University
Harbin, Heilongjiang
CHINA
{zhangguoyin,wangxianghui}@hrbeu.edu.cn

Abstract - With the popular use of the mobile intelligence equipment, including smartphones and mobile tablets, mobile peer-to-peer (P2P) networks have become increasingly important. In recent years some mobile P2P overlays have been proposed. We propose a three-dimension evaluation framework for mobile P2P overlays under churn. Three P2P overlays, named as GIA, M-GIA, and KCCO(k-Clique Community Overlay), are chosen to be evaluated according to our framework. Two kinds of churn models are used to compare the performance of three P2P overlays for achieving more comprehensive results. Simulation results show that our framework could be used for performance evaluation of various overlays under different conditions, especially under high churn. With this framework, KCCO shows better suitability for mobile networks, because it gets much higher query success rate than other two overlays, and takes less average query delay than other overlays in most cases.

Key-Words: - performance evaluation, mobile peer-to-peer overlay, churn, k-clique, query success rate, average query delay.

1 Introduction

Recently, peer-to-peer (P2P) networks have been extensively studied and applied in a lot of realms, especially for file sharing, media streaming, and so on. With the wide use of intelligent mobile terminals, the research of mobile peer-to-peer networks came to be a hotspot due to the application of Mobile Ad-hoc Networks (MANETs).

There are four kinds of P2P network topologies: Centralized Topology, Decentralized Unstructured Topology, Decentralized Structured Topology, and Partially Decentralized Topology[1]. Although centralized topology is efficient for resource discovery because of the centralized directory, it is more likely to lead to single point failure. The famous MP3 sharing system Napster adopts this topology [2]. Decentralized Unstructured Topology use the random graph to organize nodes and support complex queries quite well. The typical case of this topology is Gnutella 0.4[3] and GIA [4]. Decentralized Structured Topology mainly uses Distributed Hash Table (DHT) technology to organize network nodes. DHT type of structure has good scalability, robustness, node ID distribution uniformity and self-organizing capacity. As the overlay network topology with a certainty, DHT can provide accurate findings. The most classic cases are the Chord [5] and CAN [6]. Partially Decentralized Topology (also known as the Hybrid Structure [7]) combines the advantages of both centralized structure and distributed structure, selecting high performance node as a super node (expressed as Super Nodes or Hubs). Each super node in the system stores information of some other nodes. Semi-distributed structure is of a hierarchical feature. The most typical case of this structure is KaZaa [8].

The construction of overlays is crucial for mobile P2P networks because mobile networks are more unsteady than fixed networks. Nodes of mobile P2P networks leave or crash more frequently so that the churn is more severe. So we developed a mobile P2P overlay called k-Clique Community Overlay (KCCO) in our previous paper[9]. In this paper, we setup a framework to evaluate the performance of KCCO and some other classic P2P overlays in mobile network under churn. Moreover, we distinguish the impact factors of different environment variables through the simulation experiments.

The remainder of this paper is organized as follows. In Section II, we review related work on performance evaluation of P2P networks. In Section 3 a performance evaluation framework under churn is provided. GIA, M-GIA [10], and KCCO are evaluated under two churn models in Section IV. Section V draws the conclusion.

2 Related works

We studied some papers about performance evaluation of P2P networks under churn. Next we will introduce these works separately.

A model [11] was presented for evaluating Gnutella topology evolution. It was based on the dataset collected by a crawler in Gnutella and analyzed in phase space. Both the theoretical study and the simulations has revealed that the lifetime of peers is much longer than that of connections which is nearly exponentially distributed.

The crash point [12] was defined to evaluate the impact of churn on structured P2P networks. When the query success ratio is less than fifty percent, it is called the crash point. Five structured P2P networks named as Chord, Tapestry [13], Kelips [14], Kademlia [15], and Koorde[16] are simulated to ascertain their crash points under high churn. Moreover, a strategy is developed to prevent the networks from crash.

Huang Qingfeng et al. [17] analyzed the four main factors which affect the churn handling cost of structured networks: the number of reverse neighbor nodes, the route table update strategy, the update speed and cost, and the query efficiency. One node's reverse neighbors are those nodes which take it as a neighbor node.

Supriya Krishnamurthy et al. [18] especially studied the performance of ring-based networks such as Chord under churn by using a method of physical kinetics [19]. Octavio Herrera and Taieb Znati [20] also proposed a churn framework which consists of four parts for Chord.

The probability of Merging or splitting operations caused by churn in Clustered P2P Overlays were studied [21] by utilizing a model named as barrels-and-balls. The results show that clustered P2P networks can be steady until extreme churn happens.

A joint research group from University of Oulu and Beijing University of Posts and Telecommunications published a series of papers [22-25] on evaluating performance of P2PP protocol [26] under churn in mobile networks including UMTS and WLAN. Modified Kademlia is adopted as the overlay. From network load to battery life, several metrics are thoroughly simulated and analyzed.

Di Wu et al. [27] used stochastic differential equations to analyze time evolution of P2P storage systems under churn. In their model every peer has three states: online, offline, and failure. Some performance metrics are formally deduced and confirmed by simulations.

Dong Yang et al. [28] proposed a three-dimension evaluation framework for P2P networks under churn. The framework includes three kinds of factors: the node inside factors, the node outside factors, and the influence of churn factors. Moreover, a previous churn model is modified to be more accurate. Chord, Kelips, and Tapestry are evaluated and compared according to this framework. Parameters of the churn model are calculated by the functions fitting simulation result curves.

Mahmood Fathy et al. [29] analyzed the impact of movement model on performance of P2P overlays such as Gnutella and Chord over MENET. The result shows that various movement models influence the same overlay quite differently. Structured overlays are less adaptable to mobility than unstructured overlays, because the performance of structured overlays is much more dependent on the stability of links between peers than unstructured overlays.

In [31], EpiChord[30] is evaluated for comparing the performance under the different conditions, including workloads, churn, and internal parameters. Churn is presented by the average lifespan of each node in the network. No other protocols are compared with EpiChod in this paper.

3 The three-dimension evaluation framework

Inspired by the evaluation model in [28], we propose a three-dimension evaluation framework specifically designed for mobile P2P networks under churn. The first dimension of the framework includes direct factors arousing churn of mobile P2P overlays. The direct factors refer to a variety of churn models which are based on session time distributions, such as exponential, KAD, and so on,

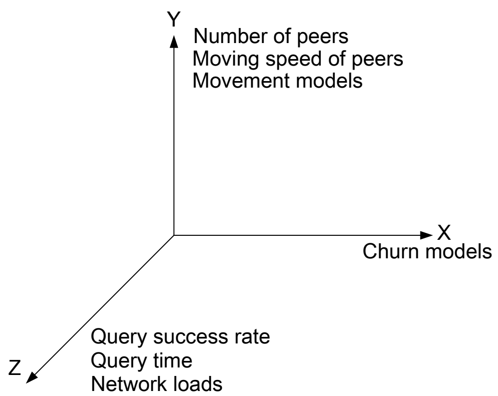

Fig. 1 Evaluation framework for MP2P networks under churn.

or based on frequency measurement. Parameters of different session time distributions are different. The second dimension includes indirect factors arousing churn of mobile P2P overlays, such as the number of peers, the moving speed of peers, and the movement models. The last dimension mainly includes performance evaluation merits, such as query success rate, average query time and network loads. Figure 1 illuminates the above evaluation framework by drawing the first dimension as X axis, the second dimension as Y axis, and the last dimension as Z axis.

The factors of each dimension contained in Fig.1 are shown in Tab. 1. The churn models can be divided into two types. One is based on time metric, which means churn is mainly described by the probability distribution of some length, one of the most frequently used is average session length. The other one is based on the frequency of events such as peer joining, leaving and crashing to characterize the churn of networks. The numbers of peers, the average moving speed of peers, and the movement models affect churn of overlays indirectly. In general, the larger the number of network peers is, the higher the churn is. While the average moving speed of peers is faster, churn in mobile P2P overlays would be higher. The movement pattern of peers has complex impact on the churn so that there is no linear relationship between them. The performance merits under churn mainly mean the average query success rate, average query delay and network loads. Network loads can be evaluated by the average number of delivered data packets in unit time.

Table I. Main factors of the evaluation framework for mobile P2P overlays under churn

Direct factors affecting the churn	Indirect factors affecting the churn	Performance merits under churn
Churn model	Number of peers	Query success rate
	Average moving speed	Query time
	Movement model	Network loads

4 Simulation results

In this section, we conduct several experiments to evaluate the performance of three overlays: GIA, M-GIA and KCCO. We use different churn models to simulate different churn situations. Our results show that KCCO outperforms the other two networks under churn.

4.1 Simulation set-up

Peerfactsim [32] simulator, developed by KOM (Multimedia Communications Lab) of Technische University in Germany, is selected in our experiments. The bottom network is set as mobile ad hot network, which is deployed in a 1000×1000 m area. The wireless transmission distance of every node is set to 240 m and channel capacity is set to 2M bit/s. The RandomWaypoint model is selected as the movement model of nodes and the moving speed of nodes varies from 1 m/s to 10 m/s.

In order to evaluate the performance of mobile P2P overlays under churn, we choose three kinds of P2P overlays for comparison. The first one is GIA, using the satisfaction level parameter in order to improve the scalability of the Gnutella. Nodes which have higher abilities could accept more neighbor nodes and query requests, so as to realize the load balance and improve the searching efficiency. M-GIA is an improved GIA model designed specifically for mobile network. It changes the rules of constructing ID and increases the information of node location. It uses the node ID to calculate the network distance between two nodes. Each node in the M-GIA decides whether to accept a new neighbor node according to the satisfaction level and the requesting node distance.

The last one is KCCO, designed for mobile networks in our previous work. It is based on k-clique community structure. Each node in KCCO only belongs to one k-clique. In order to improve the anti-churn ability, every node in each k-clique shares resource lists with each other. At the same time, KCCO handles nodes' joining, leaving and crashing through the dynamic node algorithm and topology control algorithm, adjusting the topology of the overlay continuously during the dynamic evolution. There are three kinds of nodes in KCCO: the central nodes, the contact nodes and the normal nodes. The central nodes are the original nodes in the construction process of one k-clique. Contact nodes are the nodes whose neighbor nodes belong to more than one k-clique. All the nodes other than central nodes and contact nodes are the normal nodes.

Table II. Common parameters of three overlays for simulation

Name of parameter	Value
The maximal number of neighbor nodes	50
The minimal number of neighbor nodes	5
Query TTL	20
Message discard interval	180s
Query timeout	20s

All the above mentioned three overlays are unstructured P2P networks so that there are some common parameters for them. Table 2 shows these parameters in detail. Besides, the weights of α and β are set to 0.5 and 0.5 respectively in M-GIA. In KCCO, the value of k in every k-clique is 3 for simplicity.

4.2 The exponential churn model

We choose the exponential churn model as the churn model for performance evaluation of the three overlays. The default mean session length is 30 minutes, the default nodes number is 500, and the default moving speed of nodes is 5 m/s. We change one of the above three parameters to evaluate the performance of the three overlays while the other three parameters are set to the default value.

At first, we set the average session length to 30 minutes, set the average node speed to 5m/s, and increase the node number from 200 to 1000 to simulate respectively. From figure 2 and 3 we can see that KCCO takes the shortest average query delay when the number of nodes is not 600. When the number of the nodes is larger than 200, KCCO gets much higher query success rate than other two overlays. When the nodes are less than 600, M-GIA get higher query success rate than GIA. All the three overlays take more query delay and gain lower query success rate while the number of nodes grows.

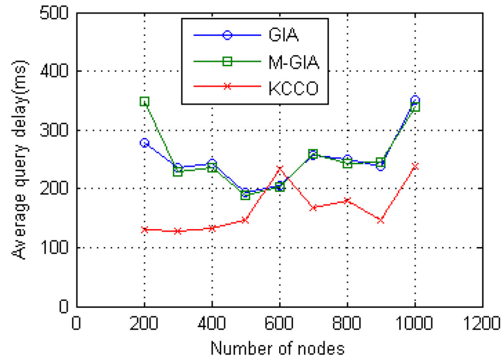

Fig. 2 Average query delay with different numbers of nodes.

Secondly, the average session length is set to 30, the node number is set to 500, the average node speed increases from 1m/s to 10m/s. From figure 4 and 5 we can see that unlike the number of nodes, the moving speed of nodes does not influence the performance of three overlays obviously. KCCO is the best one no matter for average query delay or for query success rate all the time. For average query delay GIA is better than M-GIA when the moving speed is slow, but turns to be worse as the speed is medium. M-GIA gets higher query success rate than GIA in most cases.

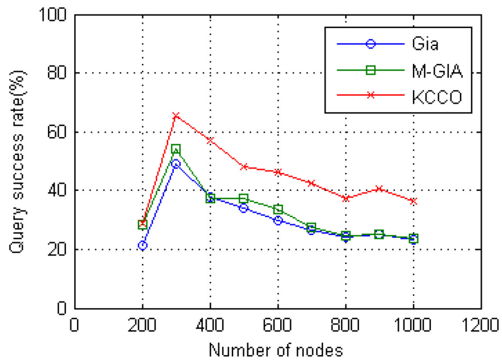

Fig. 3 Query success rate with different numbers of nodes.

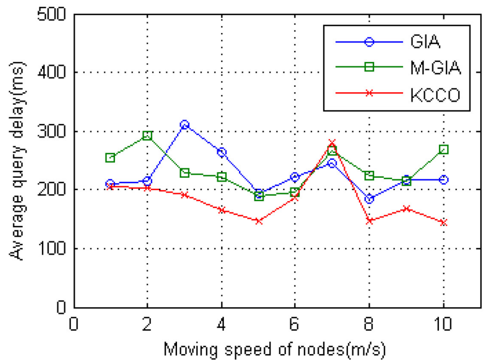

Fig. 4 Average query delay with different moving speeds of nodes.

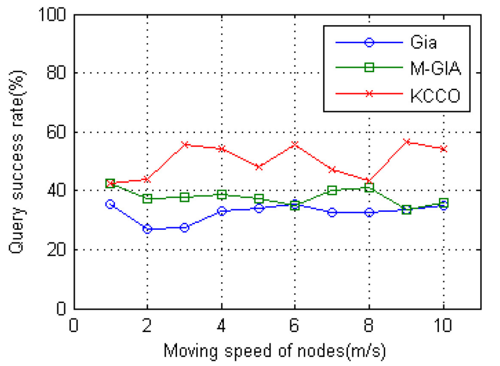

Fig. 5 Query success rate with different moving speeds of nodes.

Finally, the node number is set to 500, the node speed is set to 5m/s, the average session length increases from 6 minutes to 60 minutes. Figure 6 and 7 show that with the medium mean session length, KCCO takes less time to get query results than other two overlays. The query success ratio of KCCO increases with the growth of longer mean session length while other two networks nearly keep the same ratio.

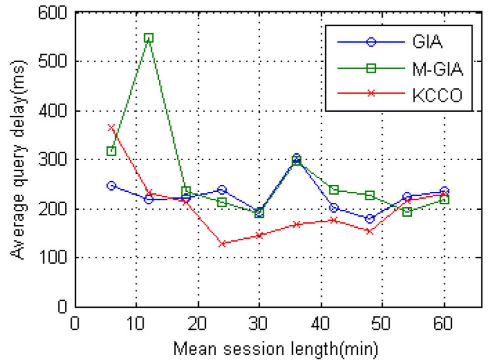

Fig. 6 Average query delay with different mean session lengths of nodes.

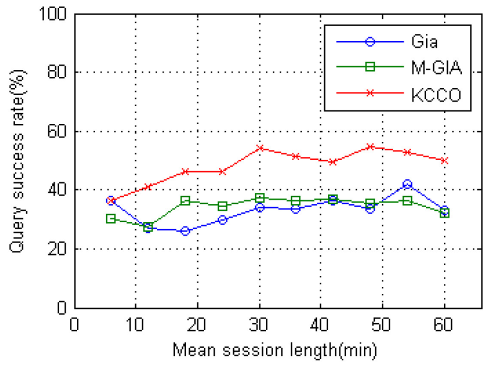

Fig. 7 Query success rate with different mean session lengths of nodes.

4.3 The KAD churn model

The KAD churn model is derived from the real application environment whose network protocol is Kademlia. In this model, both the session time and the inter-session time vary with the Weibull distribution. There are no parameters in this model.

Firstly, when the average moving speed of nodes is set to 6m/s, the number of nodes increases from 200 to 1000. The simulation results are shown in figure 8 and 9. Under this model the fluctuation of the query success rate of the three overlays is more severe than that of them under exponential churn model when the number of nodes changes. The average query delay of KCCO is better than the other two kinds of overlays in most cases. While the number of nodes increases, the query success rate of M-GIA goes up rapidly at first and then declines sharply. Meanwhile, the other two kinds of overlays decline rapidly. In most cases, GIA gets slightly higher query success rate than M-GIA.

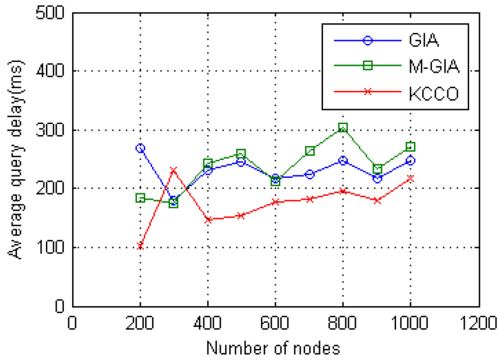

Fig. 8 Average query delay with different numbers of nodes.

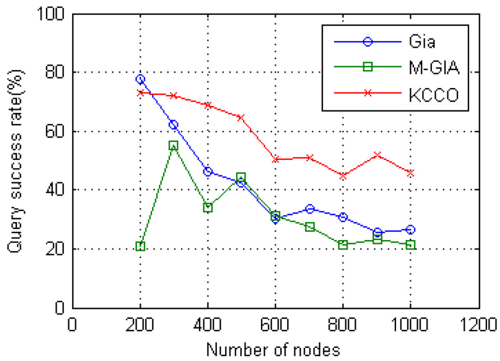

Fig. 9 Query success rate with different numbers of nodes.

Secondly, when the number of nodes is set to 500, the average moving speed of nodes increases from 1m/s to 10m/s. Figure 10 and 11 show that the average query delay of KCCO is shorter than that of the other two overlays when the average moving speed of nodes varies. M-GIA is better than GIA when the moving speed of nodes is fast. Query success rate of GIA and M-GIA fluctuates, while KCCO remains almost the same. M-GIA gets higher query success rate than GIA In some cases.

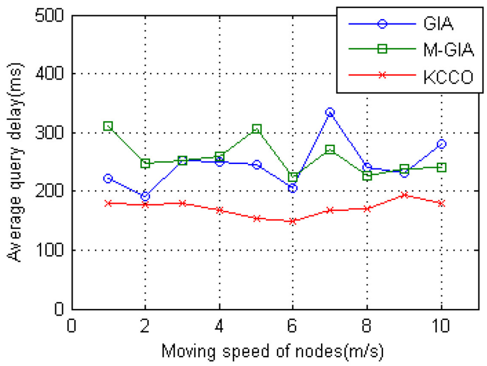

Fig. 10 Average query delay with different moving speeds of nodes.

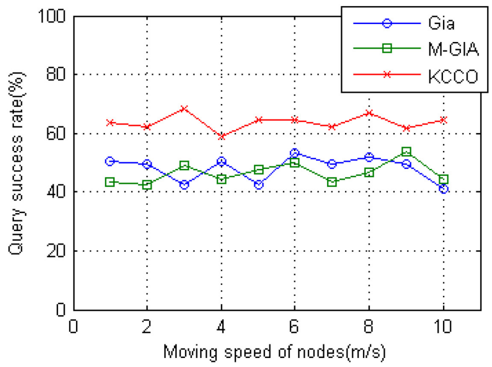

Fig. 11 Query success rate with different moving speeds of nodes.

4.4 Performance comparison and analysis

Through two groups of experiments the performance of the three peer-to-peer overlays under the exponential churn model and the KAD churn model is simulated and compared respectively. The results of the experiments indicate that the performance of the three kinds of overlays under different churn model does differ, under some conditions there is a big difference in performance, but in most cases the performance is similar and shows the same trends. For different churn factors, the impact on the performance of the three overlays is also different.

4.4.1 Average query delay

Average query delay of the three peer-to-peer overlays under different churn model and different parameters show each have advantages and disadvantages. With the dynamic changes of the parameters, the three kinds of overlays gain average query latency fluctuating wildly. Because of the instability due to the mobile network links and access randomness, average query latency of the three overlays also show obvious instability. Unstructured networks, due to their queries are generally based on the Flooding or Random Walk, would get more average query delay than structured networks. Through improving the query algorithms and strengthening the improvement of the resource list caching mechanism, average query latency can be further reduced. Table 3, 4, 5, and 6 show average query delay comparison of three overlays with different parameters and different parameter's influence on average query delay of the three overlays.

From table 3 and 4 we can see that performance of KCCO under both of the churn models are the best, and the M-GIA's performance under the exponential churn model is the worst. Under the KAD churn model M-GIA still gets larger average query delay than that of GIA.

Table 5 and 6 show that average query delay of KCCO is extremely sensitive to the change of parameters, and the effects of parameter changes on the GIA are the lowest. The extent of performance changes of M-GIA cause by the parameters changes is medium.

TABLE III. Average query delay comparison of the three overlays with different parameters changing under exponential churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	High	High	Low
Average moving speed of nodes	High	High	Low
Average session length	High	High	Low

TABLE IV. Average query delay comparison of the three overlays with different parameters changing under KAD churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	High	High	Low
Average moving speed of nodes	High	High	Low

TABLE V. Different parameter's influence on average query delay of three overlays under exponential churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	High	High	High
Average moving speed of nodes	Low	Low	High
Average session length	Low	High	High

TABLE VI. Different parameter's influence on average query delay of three overlays under KAD churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	High	High	High
Average moving speed of nodes	High	Low	Low

4.4.2 Query success rate

Query success rates of KCCO under the different churn models and parameters are significantly higher than the other two kinds of overlays, but they show larger fluctuations with the change of parameters. Overall, query success rate of unstructured network limited by its topology is relatively low, but the adaptability of churn is good. Given in table 7, 8, 9, and 10, query success rates of the three peer-to-peer overlays under different parameters and the influence of various parameters are respectively compared.

Table 7 and 8 show that query success rates of KCCO under two kinds of churn models are much higher than the other two kinds of network, and query success rates of M-GIA are higher than that of GIA under the exponential churn model, but lower than that of GIA under KAD churn model. Query success rates of GIA and M-GIA under the condition of all the parameters don't differ very much.

Table 9 and 10 show that query success rate of KCCO is extremely sensitive to the change of parameters, and the effects of parameter changes on the M-GIA are the lowest. In all parameters, the change in the number of nodes has the biggest influence on query success rate of three overlays.

To sum up, the performance of KCCO is the best of three peer-to-peer overlays, but also the most unstable. GIA's performance is slightly affected by the parameter change, and the its query success rate in some cases is less than M-GIA. The performance of M-GIA under mobile networks has improved compared to GIA, but not great.

The abovementioned experiment did not test the network load of each overlay network under churn, nor evaluate the overlay network performance under multiple node mobility models. In addition, further experiments are still needed to be carried out to evaluate the performance when the network size is larger than 1000 nodes.

TABLE VII. Query success rate comparison of the three overlays with different parameters changing under exponential churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	Low	Low	High
Average moving speed of nodes	Low	Low	High
Average session length	Low	Low	High

TABLE VIII. Query success rate comparison of the three overlays with different parameters changing under KAD churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	Low	Low	High
Average moving speed of nodes	Low	Low	High

TABLE IX. Different parameter's influence on query success rate of three overlays under exponential churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	High	High	High
Average moving speed of nodes	Low	Low	High
Average session length	Low	Low	High

TABLE X. Different parameter's influence on query success rate of three overlays under KAD churn model

Parameters	GIA	M-GIA	KCCO
Number of nodes	High	High	High
Average moving speed of nodes	Low	Low	Low

5 Conclusion

By analyzing the characteristics of mobile P2P networks, this paper proposes a three-dimensional evaluation framework of mobile P2P overlays under churn. The framework includes churn models, network characteristics, performance merit and so on. This paper evaluates the performance of the three kinds of mobile peer-to-peer overlays under churn. Whether under the exponential churn model or the KAD churn model, KCCO has higher query success rate than the other two kinds of overlays. For the average query delay, the performance of KCCO is better than other P2P overlays in most cases. GIA and M-GIA achieve similar average query time. The average query delay of M-GIA is worse than GIA under exponential churn model, but it is better under the KAD churn model than GIA. In some cases, M-GIA can get higher query success rate than GIA.

In the future, we shall further improve the proposed performance evaluation framework and add more performance evaluation factors, e.g. the energy consumption of nodes. In addition, we shall perform the simulation on overlay network with more nodes as well as the load test under more node mobility models and churn models.

Acknowledgement

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