International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:3, No:11, 2009

An Improved Greedy Routing Algorithm for Grid using Pheromone-Based Landmarks

Lada-On Lertsuwanakul and Herwig Unger

***Abstract*—**This paper objects to extend Jon Kleinberg's research. He introduced the structure of small-world in a grid and shows with a greedy algorithm using only local information able to find route between source and target in delivery time $O(\log^2 n)$. His fundamental model for distributed system uses a two-dimensional grid with long-range random links added between any two node u and v with a probability proportional to distance $d(u,v)^{-2}$.

We propose with an additional information of the long link nearby, we can find the shorter path. We apply the ant colony system as a messenger distributed their pheromone, the long-link details, in surrounding area. The subsequence forwarding decision has more option to move to, select among local neighbors or send to node has long link closer to its target. Our experiment results sustain our approach, the average routing time by Color Pheromone faster than greedy method.

***Keywords*—**Routing algorithm, Small-World network, Ant Colony Optimization, and Peer-to-peer System.

I. Introduction

A peer-to-peer (P2P) system is a network organized as virtual community overlay of the Internet. All peers attach to the network for sharing resources and cooperating with each other. The P2P overlay structure is primarily created for various specific features such as robust routing architecture, redundant storage, efficient searching and routing, load-balancing, and distributed implementation of trust and authentication. P2P overlay approaches can be divided into structured and unstructured networks [5]. First, the P2P structured overlay network that uses the Distributed Hash Table (DHT) to identify a relationship among nodes and files for searching and routing control. Well-known examples of structured types are CAN, Chord, and Pastry. Second, the unstructured P2P overlay networks, ad-hoc systems, organize peers in a random graph or hierarchical, and use flooding or random search on the graph to find the desired content. Each peer then queries its own content locally so it supports complex searching queries. Examples of unstructured types are Freenet and Gnutella. By above functions, the main key performances of P2P are the effectively route and search in any required resources.

We are interested in the overlay structured on P2P is grid-like form according to small-world network of Kleinberg's works [8]. He introduced the small-world network (SWN), a grid structure with long-range link (or shortcut) and proofed that on such architecture the delivery time of any two nodes with greedy algorithm, only local knowledge, is limited to $O(\log^2 n)$. Besides, Berg et al. [2] has shown that the Cartesian coordinate system is possible to generate in grid on top of the large-scale decentralized network.

From above motivation, this paper proposes a novel approach for routing in small-world network which is better than using greedy algorithm. Moreover, we apply the Ant Colony Optimization (ACO) for broadcasting shortcut existence in surrounding area. We designed a small group of ant walks around in order to drop the pheromone until they die. Our artificial ant has special substance, Color Pheromone which the color adapts rely on long-range link characteristic; direction and length of shortcut.

This paper is organized as follows: Sec. II discusses more details on Small-World Network and application from Ants Colony System. Sec. III introduces our approach using color pheromone for notifying additional shortcut in environment. Sec. IV shows experimental setup, results and discussions to evaluate our method. Finally, Sec. V concludes the paper and gives an outlook for future research.

II. Related Work

A. Small-World Network

The small-world phenomenon, or six degrees of separation, was discovered by Stanley Milgram in 1967. He introduced the short chain of acquaintances through social network of the United States with the average number of steps was six. In 2000, Jon Kleinberg [8] introduced a family of small-world network model building on the model of Watts and Strogatz [3], and proofed that one model of the families is a decentralized algorithm which able to find short path within finite steps. Kleinberg's model bases on two-dimensional grid ($n \times n$) with undirected local links connect to its neighbors and a directed long link is randomly generated as in Fig. 1 that obtained from [8]. The shortcut is constructed from nodes u to random endpoint v with a probability proportional to $d(u,v)^{-2}$, the inverse square of the lattice distance of u and v. Links have a non-uniform distribution that prefer closer node than distant ones, according to power-laws. In such structure Kleinberg shows that with a greedy algorithm, only local information, able to find the route of any two nodes in $O(\log^2 n)$.

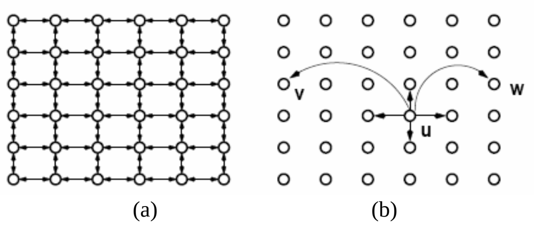


Fig. 1 (a) A two-dimensional grid network with n = 6.
(b) The contacts of a node u with v and w as the shortcut.

There have also been several recent literatures that analyzed and extended Kleinberg's model, not only on routing algorithm but also in model construction process. Martel and Nguyen [1] expanded small-world to k-dimensional model based on the diameter of random graphs focused on uniformly distributed arcs. They introduced short path with expected length $O(\log^{3/2} n)$ in 2-dimension model and $O(\log^{1+1/k} n)$ in the general k-dimensional model ($k \geq 1$) by adding global knowledge of random links. Naor and Wieder [11] presented better delivery time with greedy algorithm by selecting the neighbors of its neighbors instead. And Zou et al. [6] claimed that Kleinberg's model needed to use the global information to form the structure, then they proposed not to fix long link by using cached replacing strategy to reform the shortcut when received new query request.

B. Ants Colony Optimization

For decades that the Ants Colony Optimization (ACO) was introduced by Dorigo et al. [10] that copied biological ant's behaviors transformed into useful optimization techniques in networking and telecommunication area. A colony of ants performs fantastic tasks; finding shortest path between their nest and food, and sharing information to other ants by pheromone. The scientists transform such behavior into optimization algorithms. The ants algorithms are suited for peer-to-peer networks because the global knowledge about network is not required. Sim and Sun [9] survey and presented some example that apply Ant Colony Optimization for routing and load balancing in network such as Ant-based control (ABC) system, AntNet and some extension, and ants with genetic algorithm compare to traditional routing algorithm.

The outstanding ant algorithm for routing is AntNet presented by Caro and Dorigo in [7], the two ant groups, the forward and backward ants, collaborate in building routing tables that adapt to the up-to-date traffic intends to optimize the performance of the whole network. The SemNet presented by Michlmayr [4] is an example of AntNet's extension. She adopted AntNet strategy for searching content in distributed system. The ants system also is able to apply for self-organized and self-adaptive routing as Rojas et al. introduced in [12]. They applied Ant system to find alternative routes under congestion situations using Hue-based color pheromone. The color space described in three features: Hue presents the alternative route under congestion circumstances, Saturation indicates amount of messages passed or level of congestion, and Intensity use for avoiding infinite loop.

III. Color Pheromone Algorithm

The color pheromone algorithm uses greedy algorithm likes Kleinberg's model, in addition, when the long-range link was found and used by packet then we apply ant colony system to introduce possible shorter path to surrounding peers as shown in Fig. 2. The ants work as the messenger to broadcast long-range link to environment object to inform incoming packet in an area about long link which possibly is shorter route. The color pheromone represents long link details. The ants are spread randomly around jumper node and walk until they died.

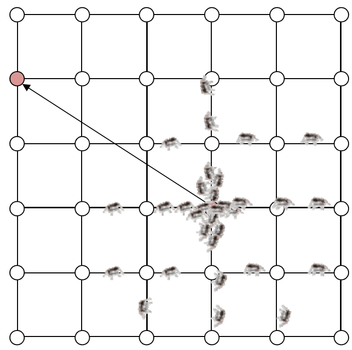


Fig. 2 The color ants spread around when long-link has been used.

The pheromone amount is dropped increasing as cumulative exponentially by hop count, and pheromone is decayed exponentially by time in case none of ants visited. The information of each node by greedy algorithm, they keep only their own local neighbors and its shortcut. Furthermore by color pheromone, they keep the pheromone data from the ants had passed see in Fig. 3. The pheromone table consists of color, amount and neighbor who have sent the ants.

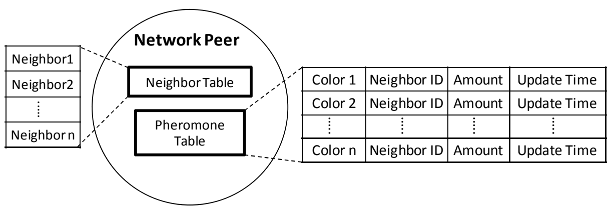
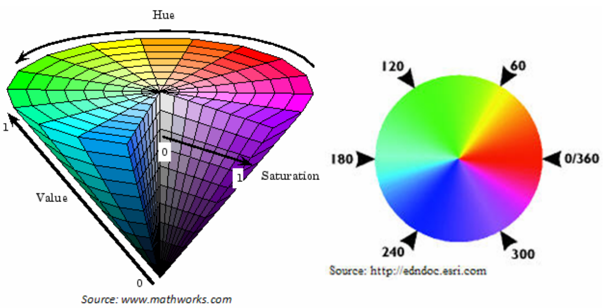


Fig. 3 The color pheromone peer structure.

The color of pheromone in this paper is set up according to HSV (Hue, Saturation and Value) color model [13]. HSV model, also known as the hex-cone color model, presents a type of color space as Fig. 4 (a). The model has three components: hue, saturation and value. *Hue* is the actual color that measured in angular degrees counter-clockwise around the cone starting and ending at red = 0 or 360 (such as yellow = 60, green = 120, etc.) as in Fig. 4 (b). *Saturation* describes grey scale of the color, identified by value between 0 and 1. When value is "0", the color is grey and when value is "1", the color is primary color. *Value* is the brightness of the color and varies with color saturation. It ranges from 0 to 1. When the value is '0' the color space will be totally black. With the increase in the value, the color space brightness up and shows various colors.



(a) (b)

Fig. 4 (a) HSV color model diagram
(b) Hue color wheel

We apply HSV color model for identifying pheromone color; Hue keeps direction of remote node compare with jumper node in 360 degree. Saturation keep length of long-range link calculated in lattice distance. And Value is default one. In the small-world model, color pheromone is able to spread overlapping due to lots of shortcut were setup.

At any hold packet node, the next node to forward packet to, is decided by the shortest distance to message's target. It is able to choose a node among its neighbors (its local neighbors and its long links) and remote node of long-link nearby which search from its pheromone table.

In the following sub sections, the above scheme is explained and a more detailed of the algorithm is given.

A. Algorithm Characteristics

The process of algorithm is described as follows:

1) At a simulation time *t*, a packet is generated randomly toward a destination node *d* at source node *s* by the constant probability.
2) While travelling toward their destination nodes, the packet memorizes their source, target, and travelling paths.
3) At each node *k*, each packet headed to its destination *d* selects the next node *n* to move to
   i) Consider the closest neighbors (n_1) to its targets and not the previous sender that measured by lattice distance.
   ii) Consider the pheromone table, compare destination location *d* with nearby long-link, as defined in color pheromone, and select best neighbor (n_2)
   iii) Compare n_1 and n_2 then choose a closer neighbor to target.
4) At each node *k*, if the shortcut has been used the color pheromone algorithm starts
   i) Additional definition, node *k* which has long link that founded by packet at *t* is called *jumper node*. The opposite side of shortcut is called *remote node*.
   ii) A group of ants is generated at jumper node *k*. Number of ants in group and the ant ages are predefined as global constants. The starting age of ant t_{ant} is zero when they are born.
   iii) System calculates pheromone color following the HSV color model bases on direction of remote node compare to jumper node and link distance.
5) At each simulation time step, data packet and ants are forwarded with different methods and different priority. The ant has higher priority than data packet due to it is small and object to drop pheromone only.
6) The ants characteristics:
   i) They walk around jumper node non-uniform random due to they are not allowed to return to its sender or jumper direction.
   ii) The color pheromone (φ) is dropped at every node they passed in each time unit until they died; t_{ant} is reached the ant age.
   iii) The dropped amount of pheromone is increase according to the distance away from jumper node or ant age, as in (1).

$$\varphi_{new} = \varphi_{old} \cdot [1 - \exp^{(-\lambda \cdot t_{amt})}] \tag{1}$$

7) The new ants is updated pheromone value when they found the peers already have pheromone information (keys are color and neighbor ID)
8) When there is not ants visited at peer, the pheromone is decayed exponentially by ant-free time $t_{ant\text{-}free}$ as (2)

$$\varphi_{new} = \begin{cases} \varphi_{old} \cdot \exp^{(-\lambda \cdot t_{ant-free})} & , \varphi_{old} \geq 0.0001 \\ 0 & , \varphi_{old} < 0.0001 \end{cases} \tag{2}$$

B. Pseudo-code

The color pheromone algorithm shows in pseudo-code as Fig. 5. In each simulation time, peers over the network execute method *doSim* concurrently.

```
public void doSim (long simTime) {
    while (isReceiveMessageNotEmpty) {
        if (isAnt) {
            UpdateColorPheromoneTable();
            if (!=AntExpired) {
                SelectNextNodeForAnt();
                ForwardAnt();
            } else
                AntDie();
        else if (isPacket) {
                PushInPeerBuffer ();
            } // end receive data packet
        } // end receive ant
  } // end while receive message

    while (isPeerBufferNotEmpty) {
        SelectNextReceiver();
        ForwardPacket();
        if (useLongLink) {
            SetColorPheromone();
            LaunchColorAnt();
        }
    } // end while stack not empty

    PheromoneEvaporate();
} // end doSim function
```

Fig. 5 The color pheromone algorithm's pseudo-code

IV. Experiments

In order to evaluate the performance of the proposed algorithm, this section we made the experiments to show the performance of the routing algorithm by the average delivery time comparing between color pheromone algorithm and greedy method.

A. Simulation Setup

We simulated the experiments using P2PNetSim, the network simulation environment. This tool allows simulating large distributed networks. The peers can be configured collectively and individually using XML file. The peer behavior is implemented by Java programming language.

We generated a small-world network; two-dimensional grid sized 10,000 nodes (100x100). The long-range links were random added between any two nodes with a probability proportion to lattice distance: $d(u,v)^{-2}$. All the links are bidirectional graphs, noted that this point is different from Kleinberg's model. There are ten percentages of source nodes that uniform-randomly distribution in network which aim to generate a message send to their target in every simulation time with a constant probability value. This network is used in all following experiments. All simulations were generated 50,000 data messages and run until all packets reached their targets. The system handles the data packet in First-In-First-Out manner. Each packet overhead contains only source ID, target ID, and path that passed. Each data message has 500 time-to-life time units. The color pheromone parameter setting for exponential functions as mentioned in (1) and (2), the lamda (λ) value for calculating volume of pheromone drop and amount of pheromone evaporation were set to one in all experiments.

The simulation has taken into account the two scenarios. First case aims to analyze the influence of number of ants per group and time-to-life of color ants. The jumper node spread groups of 10, 15, and 20 ants at each time, and TTL of ants were 3, 4, and 5 time unit. The probability of packet generate in each time unit was 0.3 for all source peers. Second scenario intends to take the congestion into account then we defined the probability of packet generate to 0.3, 0.5 and 0.7. The jumper node spread two types of ants; ten three-aged-ants and fifteen four-aged-ants.

B. Simulation Results

In the first scenario in Fig. 6, compare routing performance by the average routing time (Z axis) between greedy algorithm and color pheromone algorithm. The parameters of color pheromone are set. Three different numbers of ants per group (Y axis) are 10, 15, and 20 and three different values of ant age or TTL (X axis) are 3, 4, and 5. From graph, the average routing time of greedy algorithm is 7.23 time unit, showed in small net. It is only one value due to its routing time dependent from color pheromone parameters. The second net, big one presents the average routing time of color pheromone form nine combination cases. The best result of color pheromone method, the average routing time is 7.20 when ant age is three and numbers of ant per group are ten and twenty which is better than greedy one

In contrast, some two peaks in the graph show higher routing time than greedy approach; the values are 7.28 and 7.26 time unit, when ant age is five. This result came up because pheromone amount is not up-to-date. The pheromone trails decayed exponentially when time that none of ants pass the nodes. In case the packets decided to follow pheromone but the pheromone is evaporated while moving to the jumper node. The packets can decide to select local neighbors instead of going to jumper node although previous few steps finding the jumper station if pheromone is not enough. Such that situation makes delivery time longer than usual. This situation is more explicit when we use small group of ants. Number of ants is not enough to spread through the area and not enough to maintain the pheromone until next packet need. Then it makes time higher according to the influence of color pheromone.

The life time of ants implies to circle of pheromone spread area. The number of ant per group implies to opportunity to visit every node around within area. The short life ants present better performance than long-life one. And big ant group in cooperation are better than small group. Of course, big group leads to more processing time and resource consumption than small one, then the optimal point should be considered depend on network size and resources.

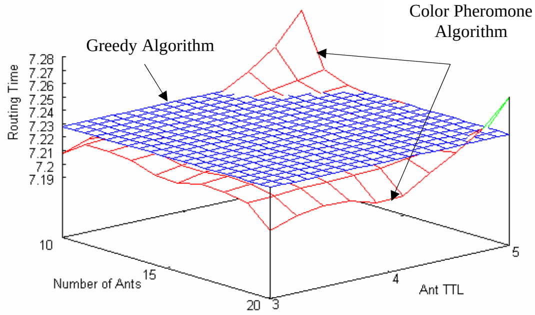


Fig. 6 The average routing time compares greedy algorithm with color pheromone algorithm when number of ants per group are 10, 15, and 20, and ant age are 3, 4, and 5. The probability to generate packet is fixed at 0.3.

The second scenario in Fig. 7 and Fig. 8, this test intend to analyze influence of congestion effect to color pheromone. Fig. 7, we tested with two color pheromone parameter sets, ten ants per group with three steps of age and fifteen ants per group with four steps of age compare to three probability values for generating message per time unit; 0.3, 05, and 0.7. And, of course, compare average routing time to greedy algorithm as presented in small net diagram. All results of color pheromone present better performance than greedy algorithm in these cases. The best result of color pheromone (big net) comes from probability value is 0.7 and set ten three-aged-ants per group that shows average routing time 7.18 time unit. So the average routing time increase when probability to generate packet decrease. Also longer-life ants lead to longer routing time.

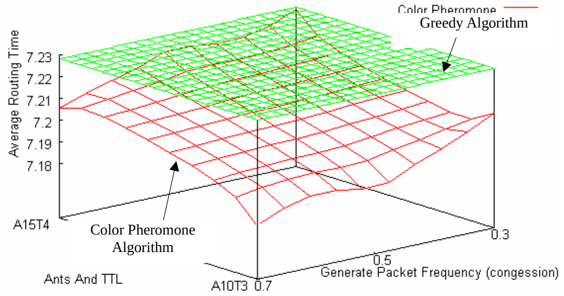


Fig. 7 The average routing time compares greedy algorithm with color pheromone algorithm when the probability to generate packet are 0.3, 0.5 and 0.7. Compare with two set of ants; ten of three-aged-ants and fifteen of four-aged-ants.

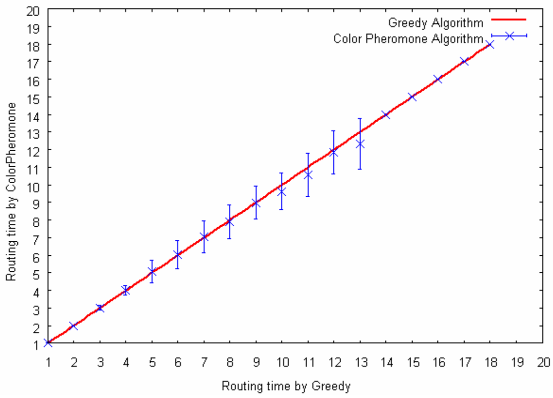


Fig. 8 The average routing time compare greedy algorithm (Straight line) with color pheromone algorithm ('X' marks with lines) of ten three-aged-ant group. This graph observed packets that have same source and target peers.

Fig. 8 also shows routing performance of color pheromone (data of ten three-aged-ants) compare with greedy algorithm. But this graph demonstrates the results of greedy and color pheromone routing methods comparing of messages that generated from same source send to same target. The straight line is actual routing time by greedy method. And blue 'X' mark is the mean of routing time by color pheromone with standard deviation line. Graph shows there are some messages by color pheromone using longer route than greedy, however, more messages are forwarded faster.

V. Conclusion and Future Work

This paper we introduced a novel approach for routing in small-world network. We showed that with an additional information, the existence of shortcut in surrounding area, is able to find the shorter path than using greedy algorithm. The experiments ran with efficient network simulation tools, P2PNetSim. The test results sustain that color pheromone approach work more effective than the greedy.

In the performance evaluation above, the small-world network structure is setup in the early stage. Next step, we want to improve the performance of algorithm in a dynamic way in which long link is added and changed according to current distribution of network, or the algorithm is able immediately react to network conditions. In these cases, it is necessary to adapt algorithm parameter to reflect these changes, or tune algorithm parameter according to the traffic.

The vision of the research is to build multi-criteria consideration algorithm for routing in peer-to-peer network. In addition, it can adapt itself to any network changes.

References

[1] C. Martel and V. Nguyen, "*Analyzing Kleinberg's (and other) Small-world models*", Proc. 23rd ACM symposium on Principles of distributed computing, St. John's, Newfoundland, Canada, pp. 179-188, 2004.

[2] D. Berg, P. Sukjit, and H. Unger, "*Grid Generation in Decentralized Systems*", Proceeding of IDNS Conference, Klagenfurt, Austria, 2009.

[3] D. Watts and S. Strogatz, "*Collective dynamics of small-world networks*", Nature 393, pp.440-442, 1998.

[4] E. Michlmayr, "*Ant Algorithms for Search in Unstructured Peer-to-Peer Networks*", 22nd International Conference on Data Engineering Workshops (ICDEW'06), pp. x142, 2006.

[5] E.K. Lua, J. Crowcroft, M. Pias, R. Scharma, and S. Lim, "*A Survey and Comparison of Peer-to-Peer Overlay Network Schemes*", IEEE Communications Survey and Tutorial, March, 2004.

[6] F. Zou, Y. Li, L. Zhang, F. Ma, and M. Li, "*A Novel Approach for Constructing Small World in Structured P2P Systems*" , LNCS, Vol. 3251, pp. 807-810, 2004.

[7] G. Di Caro and M. Dorigo, "*AntNet: Distributed Stigmergetic Control for Communications Networks*", Journal of Artificial Intelligence Research, Vol. 9, pp. 317-365, 1998.

[8] J.Kleinberg, "*The small-world phenomenon: an algorithm perspective*", Proceeding of the Thirty-Second Annual ACM Symposium on theory of Computing (STOC'00), New York, pp.163-170, 2000.

[9] K.M. Sim and W.H. Sun, "*Ant colony optimization for routing and load-balancing: survey and new directions*", IEEE Transactions on Systems, Man and Cybernetics, Part A, Vol. 33, No. 5., pp. 560-572, 2003.

[10] M. Dorigo, V. Maniezzo, and A. Colorni, "*Ant System: Optimization by a Colony of Cooperating Agents",* IEEE Transactions on Systems, Man, and Cybernetics - Part B, 26(1):29-41, 1996.

[11] M. Naor and U. Wieder, "*Know the Neighbor's Neighbor: Better Routing for Skip-Graphs and Small Worlds*", LNCS, Vol. 3279, pp. 269-277, 2005.

[12] M. Rojas, H. Unger, and H. Coltzau, "*Self-Balanced and Self-Adaptive Routes in Unstructured P2P Networks*", 2nd International Conference on Systems (ICONS'07), IEEE Computer Society, France, 2007.

[13] The Tech FAQ, "*What is HSV?*", Retrieved September 10, 2009, from http://www.tech-faq.com/hsv.shtml

Lada-On Lertsuwanakul finished the Master of Science in Information Technology at Kasetsart University, Bangkok, Thailand in 2002 and the Bachelor of Science in Computer Science at Rangsit University, Pathum Thani, Thailand in 1997. She had worked in IT area in Ajinomoto (Thailand) Co., Ltd. and The Siam Gypsum Industry (Saraburi) Co., Ltd. Her last position is IT Project Manager. Since 2008, she has worked as a PhD Student at FernUniversität in Hagen, Germany. Her research interests are in adaptive, self organized, routing and searching algorithm in peer-to-peer network.

Prof. Dr.-Ing. habil. Herwig Unger got his PhD with a work on Petri Net transformation in 1991 from the Technical University of Ilmenau and his habilitation with a work on large distributed systems from the University of Rostock in 2000. Since 2006 he is a full professor at the FernUniversitaet in Hagen and the head of the Chair of Communication Networks. His research interests are in self-organization, adaptive and learning systems, Internet algorithms and simulation.